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KERGRID: A Low-Carbon Footprint Building in Western France*

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Abstract. MORBIHAN ENERGIES carried out an experimental project in designing a building that produces for the electricity grid for its new head office in Vannes, Brittany. It is capable of varying its consumption electric power -- especially in times of high demand -- and can also store or reinject the renewable energy it produces. This project gave birth to the KERGRID building, featuring an area of 3,300 m², in compliance with the low carbon building and PassivHauss labels. A two-storey building made of wood and concrete, it has solar panels spread over the 850 m² of roof space and two micro wind turbines that provide electricity production for the area. EDF R&D (Research and Development) is supporting Morbihan Energies in optimising the operation of its building. In 2017, all-purpose final consumption amounted to 71 kWhfe/m² while solar production amounted to 110 MWh, 63% of which was self-used. All-direct emissions of greenhouse gases amounted to 4.3 kgeqCO_2/m².year (14 TeqCO_2/year). These figures confirm the high performance of this building.

1 Context

Brittany remains one of the most electrically weakened regions in France today because of its shape. During peak times, the peninsula, which produces less than 10% of the electricity it consumes, remains exposed to high risks of cutting.

The region is therefore committed to the Pacte Electrique Breton (Brittany Electric Agreement), which aims to control the demand for electricity, to encourage the massive deployment of renewable energies and even to strengthen the power grid.

Fig. 1. Overview (MORBIHAN ENERGIES).

MORBIHAN ENERGIES carried out an experimental project in designing a building that produces for the electricity grid for its new head office in Vannes, Brittany (Fig 1 and Fig 2).

It is capable of varying its consumption electric power -- especially in times of high demand -- and can also store or reinject the renewable energy it produces It can decrease its electric power, especially in times of high demand, but also store or reinject the renewable energy it produced. This project gave birth to the KERGRID building.

Fig. 2. South access (MORBIHAN ENERGIES).

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2 Description of the building

With an area of 3,300m² and mixed wood and concrete construction, the KERGRID building meets the requirements of the PassivHauss label.

A set of 524 LDK photovoltaic modules of 240Wc each amounting to a total of 850 m² is located on the roof (i.e. 125 kwp), helped by 2 micro wind turbines. Some of the local electricity production can be stored with a Saft battery with a capacity of 56 kWh. Associated with inverters and automation, this battery is managed by a Schneider Power Management System (PMS), which can manage a partial erasure of loads over several hours or supply the building for thirty minutes in case of a blackout on the grid. Several vehicles can be recharged thanks to semi-fast (7 kVA) and fast (18 kVA DC and 20 KVA AC) terminals. These terminals are also managed by the PMS to ensure a suitable recharging. Recently, Morbihan énergies acquired a 35 MPa hydrogen recharging station by electrolysis.

The heating is provided by two CIAT water/water heat pumps producing 80 kW of thermal power each (Fig 3). Associated with an exchanger, the geothermal energy also guarantees cooling by geo-cooling. Additionally, a SWEGON air handling unit also free-cools in the summer.

Fig. 3. Technical room (MORBIHAN ENERGIES).

3 Results

3.1 A building with low energy requirements

In 2017, all-purpose final consumption amounted to 71 kWhfe/m². The heating air conditioning unit represents less than a third of the final consumption with 23 kWhfe/m² (Fig 4).

The heating air conditioning unit represents less than a third of the final consumption with 23 kWhfe/m². The remaining two thirds are for other uses including sockets (30 kWhfe/m²), lighting (6 kWhfe/m²), electric vehicles (6 kWhfe/m²), server computing and outdoor lighting.

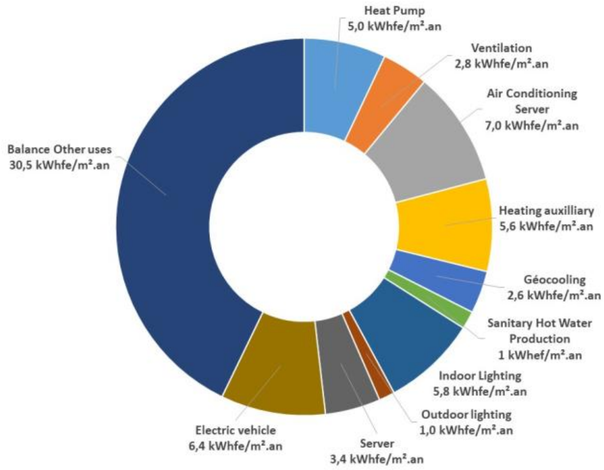

Fig. 4. Distribution of annual consumption per use over the year 2017 in kWhfe/m² (EDF R&D).

The need for heating the building is minimal, with 21 kWh/m² of useful energy; that is to say less than 9 Wh/m²/HDD (Heating Degree Days). These figures decreased by 28% over 2016 [1]. The improvement was possible thanks to sound management of the heating and an anticipation of the heating stoppages in springtime.

Moreover, the heat pump functioned well with a performance rate (COP) of 4.1. Auxiliary consumption also decreased by 16% compared to 2016 because of the shutdown of all circulators early in spring and the restart late in autumn.
Nevertheless, consumption remains significant (6 kWhfe/m²/year) and could still stand to be reduced in stopping the circulators while the heat pump is not working (Fig 5).

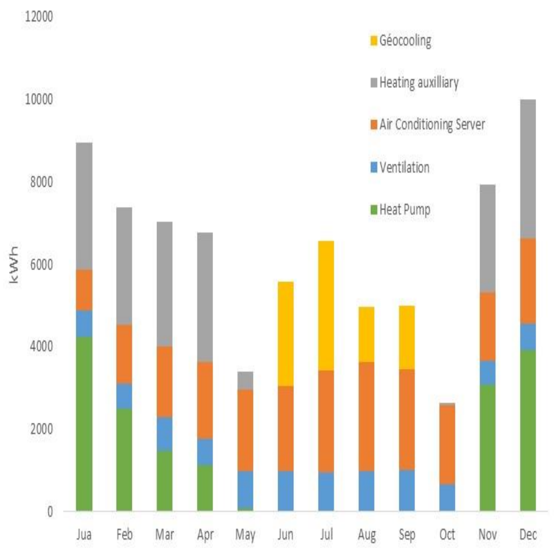

Fig. 5. Evolution of consumption in HVAC over the year 2017 (EDF R&D).

3.2 A building that fits into the National Low-Carbon Strategy

Of the five uses -- heating, ventilation, cooling, hot water production and lighting --, this building gets an ‘A’ grade regarding direct greenhouse gas emissions with only 2.7 kg CO_2/m²/year (Table 1). A boiler gas solution and a chiller unit (with a performance of 95% Higher Calorific Value) would get a B grade. In this case, the geothermal solution reduces greenhouse gas emissions by more than 60% and fully adheres to the national low carbon strategy

Table 1. Distribution of annual green house emissions per use over the year 2017 in kg CO_2/m² (EDF R&D).

Electric uses	**kg CO_2/m²**
Heat Pump and Auxiliary	1.918
Ventilation	0.113
Air Conditioning Server and geocooling	0.385
Sanitary Hot Water Production	0.043
Indoor Lighting	0.230
Total 5 uses	**2.691**

3.3 A building consuming and producing renewable energy

Concerning renewable energy, it is possible to recognise the local production of photovoltaic panels and wind turbine from the energy extracted from the ground for the operation of the heat pump.

Geothermal energy allows for three-quarters of the heating requirements of the building and all the needs of cooling in the summer thanks to geo-cooling.

As for the local production of electricity, it ensures nearly one-third of the electricity requirements necessary for the operation of the building.

Over 2017, photovoltaic production was 110 MWh, or 873 kWh/kWpeak. The volume instantly consumed by the building reached 69 MWh, i.e. 63% of the production, while the remaining 37% (41 MWh) were reinjected into the grid (Fig 6).

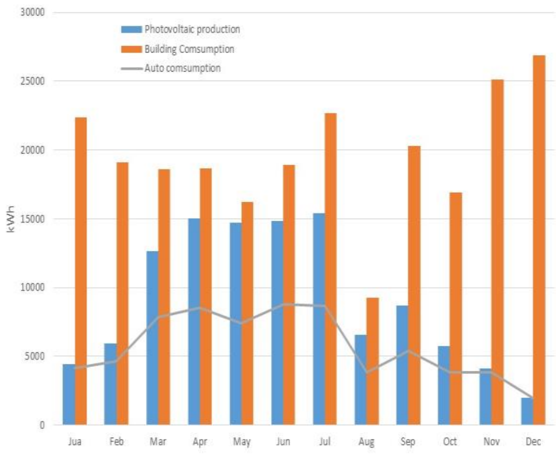

Fig. 6. Building consumption, Photovoltaic production and self consumption in 2017 (EDF R&D).

3.4 A building with low operating and investment costs

In investment, the cost of construction of this building is about €2000/m² excluding VAT. The cost of heating and ventilation systems represents 9% of the total cost, while that of the photovoltaic, wind and storage production system amounts to 15% (Table 2).

Table 2. Allocation of investment costs (estimate Front End Engineering Design – 2010).

Investment	**Cost (€ HT)**
Earthwork	1 069 000
Framing/Roofing/Siding	1 383 450
Woodwork	781 600
Internal arrangment	680 530
HVAC	616 250
Electricity	452 500
Photovoltaic/Wind turbin/storage	1 052 300
Green spaces	831 000

In operation: The production cost of heating MWh amounts to €41/MWh and corresponds to the cost of the electric MWh divided by the rate of the heat pump (COP). These costs include supply, subscription, and local taxes, and are given in euros excluding VAT. To compare, the production cost for a gas boiler solution (with a performance of 90% Higher Calorific Value) would be €51/MWh. Under these conditions, the cost of the energy is €9.60/m² per year and the HVAC represents only €3.12/m² per year.

4 Conclusion

This building fits into the national low Carbon Strategy thanks to its low thermal requirements in the range of 21 KWh/m² of useful energy, its local production which covers 30% of the building's electricity requirements and its low greenhouse gas heating and cooling solutions.

Recently, Morbihan Energies has embarked on an ISO 50001 certification approach aiming to optimise the consumption of its building fleet.

Based on the experimentation carried out on this building which was one of the first in auto consumption, Morbihan Energies has already begun to share its auto consumption with its neighbouring buildings, including a gymnasium and a few residential homes.

Morbihan Energies also looks at the possibilities offered by the Vehicle-to-grid (V2G), in which plug-in electric vehicles, such as battery electric vehicles (BEV) and hydrogen fuel cell electric vehicles (FCEV), communicate with the power grid to sell demand-response services by either returning electricity to the grid or by throttling their charging rate.

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Replacing the existing thermo-frigo-pump (with pistons compressors) by a new thermo-frigo-pump with variable-speed screw resulted in a 50% saving of energy use!

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Abstract. Since 1998, EDF R & D provides energy monitoring of an office building (S = 16633m2) in Lyon and is heating and cooling by a thermo frigo pumps on groundwater. In 2014, it was decided to renovate the production of hot and cold and replace:
-The Existing thermo frigo pumps (with piston compressors) by new machines with variable speed compressors.
-All the water pumps with new variable speed pumps
The measures realized average 2015-2017(variable speed compressors), compare to average 1999-2013 (pistons compressors), have shown that
-The building consumption was reduced by 37%
-The consumption of water pumps 47%
-The consumption of thermo frigo pumps lowered by more than 50% and the COP heating + cooling (*) factor improved by 70%!.
-The CO2 emissions are also reduced by 50% compared to older the heat pumps. Compared to a gas boiler and chiller solution, the heat pumps with the new machines reduces the CO2 emissions of 83%.
- All of these improvements led to a reduction in CO2 emissions of 37% (of the building).
This is the only site in France that has measures (before and after replacement) and certainly the only site in Europe.

1 Introduction

Since 1998, EDF R & D realizes monitoring of energy use of an office building located in Lyon (area of 16 663m²), which includes offices (627), meeting rooms, and a conference room.

The peculiarity of this building is to be heated and cooled by a thermo-frigo-pump on groundwater that provides:

-The heating in winter

-The air conditioning of the computer room all year and offices, meeting rooms and amphitheatre in the summer.

The thermo-frigo-pump realizes the energy transfer between the hot and cold needs by the building which results in excellent performance of the installation, hot or cold surpluses are evacuated by the ground water. It is an ideal solution in terms of energy and costs for buildings which have both cooling and heating needs.

2 Technical site characteristics

In October 2013, the building owner decided to improve the energy performance of the building, this one, well maintained, does not justify energy renovation of facades. As regards the PACs, equipped with piston compressors, with over 130 000 hours of operation without major problems, it could be interesting to study their replacement (in advance) by new machines with latest generation screw compressors operating variable speed.

A study by the consultancy ARTELIA (Lyon agency) has highlighted the interest of upgrading the production of hot and cold by thermo-frigo-pump, namely PACs, pumps, regulation, and metrology.

The installation comprises two water/water heat pumps which feed a network of 4-pipe fan coils (630) and Air Handling (5) Units with energy recovery to limit energy use.

The hydraulic systems are fitted with variable speed pumps. The well comprises two variable speed-boring pumps with a maximum flow rate per unit of 100 m³/hr.

Groundwater is at a depth of 5m, drilling units (1 pumping and 1 injection) are at a depth of 20m, and they 316L stainless steel 800 mm diameter.

The two new heat pumps are with screw compressors operating variable speed manufactured by CARRIER type 30XWHV580 (Eurovent Certified), they replace two heat pump with piston compressors (CARRIER 30HG280).

The main characteristics of new heat pumps (data sheet of CARRIER)

Heating mode
-Heating capacity (45/50 °C) = 2 *633.4 kW Hot
-Power consumption = 2 * 155.2 kW,
-COP in Heating mode= 4.08

Cooling mode
- Cooling capacity (7/12 °C) = 2 * 618.8kW Cold
- Power consumption = 2 *96.2kW
- EER= 6.43, EESER = 7.80

Operating conditions:

–Chilled water is 7-12°C in summer and 10-12°C in winter.

–Hot water is 35°C when it is above 20°C outside and 45°C when it is 0°C outside. The whole installation is managed by a BMS (Building Management System).

Control

This is based on a fundamental principle: "always satisfy the highest demand." The BMS must continuously measure the differences in temperature between the two systems (hot and cold). Depending on which system has a higher demand, it determines the operating conditions for the thermo-frigo-pump by prioritising hot or cold operation.

All of the installations are run by a Metaproductique-brand engineering management system.

How a thermo-frigo-pump works

A thermo frigo pump has five different modes, including:

Heating mode. This mode is used during cold spells. To achieve thermal equilibrium, all the cold produced by the units is discharged into the well.

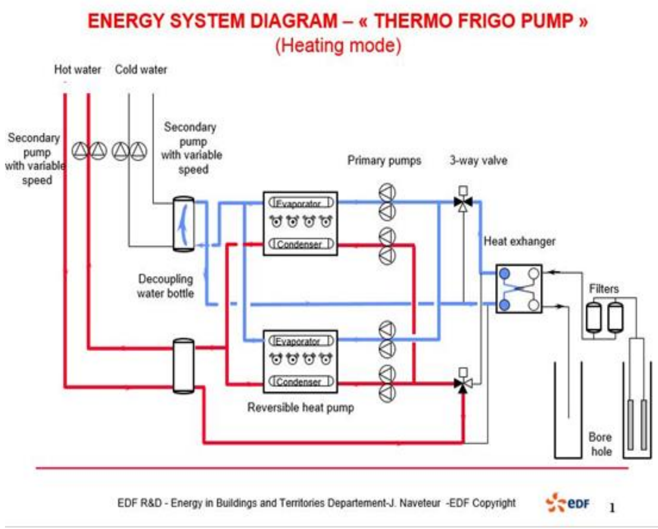


Fig 1: Thermo-frigo-pump in heating mode

Majority heat and minority cold. The building consumes more heat than cold (mid-season and start of winter). Surplus cold is discharged into the well.

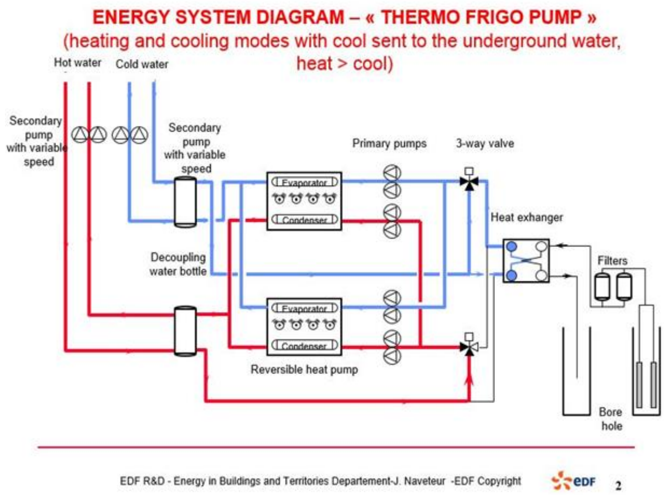


Fig 2: Thermo-frigo-pump with heat > cool

Heat equal to cold. This mode is used when the building consumes all the cold and heat produced. The COP is at its maximum and no energy is discharged into the well.

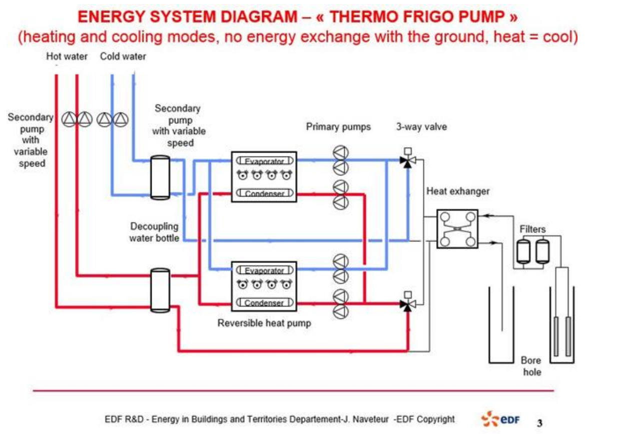


Fig 3: Thermo-frigo-pump with heat = cool

Majority cold and minority heat. The building consumes more cold than heat (mid-season and end of winter). Surplus heat is discharged into the well.

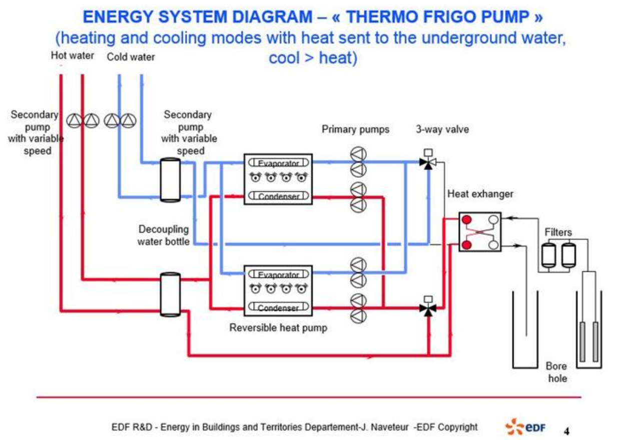


Fig 4: Thermo-frigo-pump with cool > heat

Cooling mode. This mode is used during summer. To achieve thermal equilibrium, all the heat produced by the units is discharged into the well.

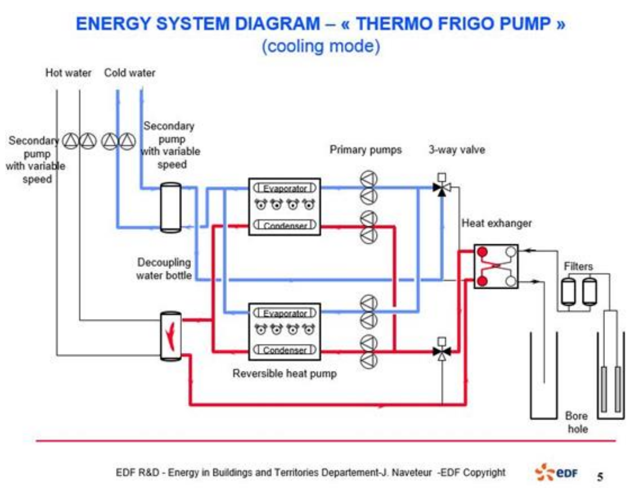


Fig 5: Thermo-frigo-pump cooling mode

3 Measurement results average 2015-2017 compare at average 1998-2013

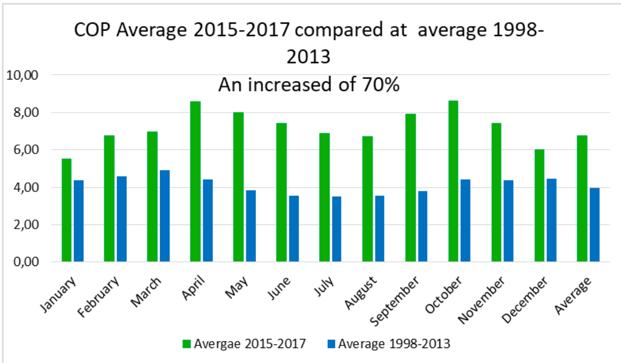
The site has been monitored for energy performance since 1998 with monitoring installation carried out by EDF R&D using 9 electricity meters (6 of which having remote reading capabilities), 1 heating meter, 1 cooling meter and 1 BMS remote investigation and monitoring system.
This is the only site in France that has measures (before and after replacement) and certainly the only site in Europe.

The building energy use decreased **by 37%,** and for the heat pumps by nearly **50%**. It should be noted that all energy uses are reduced which demonstrates the result of good operational management of the site.

Table 1. Average 1998-2013 compare with average 2015-2017 (EDF R&D).

Area 16 633m2	Average 1998 2013	Average 2015-2017 compared with the average 1998 to 2013	Average 2015-2017
Total consumption	157kWh/m²	-37,18%	**99kWh/m2**
Consumption of Heat pumps	37kWh/m²	-50,02%	18kWh/m2
Consumption of water Pumps	18kWh/m²	-47,11%	10kWh/m2
Consumption of Air Handling Units	12kWh/m²	-30,23%	8kWh/m2
Consumption of other uses	90kWh/m²	-30,80%	62kWh/m2
Heating Degree Days	2187	-4,15%	2096
kWh heating/Degree Days (DD)comsumption by the building	515kWh/DD	-11,69%	455kWh/DD
Heating consumption	68kWh Heating/m²	-15,47%	57kWh Heating/m²
Cooling consumption	81kWh Cooling/m²	-5,34%	77kWh Cooling/m²

The COP in heating +cooling increased by 70%!



*COP = Hot and cold energy use by the building / Electrical energy consumed by the heat pumps + the drilling pumps.

-The cost of total energy use has decreased by **4.63 € HT(Nb) /m², and by 1.49 € HT/m²** for the heat pumps and by 0.70 € HT / m² for the all the pumps.

-The average cost of producing the MWh's of heating/cooling is **€13/MWh** and decreased by 42%

-The CO_2 emissions are also reduced by **50%** compared to older the heat pumps. Compared to a gas boiler and chiller solution, the heat pumps with the new machines reduces the CO_2 emissions of 83%.

- All of these improvements led to a reduction in CO_2 emissions of 37% (of the building).

-The cost of renovation of the heat pump (Heat pumps, pumps, management system,) is 349k € HT or 25 € HT / m². **The payback time (IRR) is 11.5 years!**

(Nb) HT indicates: All cost in this article exclude taxes

4 Know-how transfer

Given the experience gained during this monitoring, we then carried out other onsite monitoring at other buildings equipped with geothermal heat pumps such as a shopping center (1), a town hall (2), a museum (3), a swimming pool and an auditorium which is equipped with a heat pump pile foundations.
We have written many articles (4, 5) and conference contributions (6) reporting the results of these facilities and we participated in drafting technical guide (7).
We also work in courses organized by the National Agency for Energy Management and universities where we train interns and students to achieve this type of facility.
EDF R&D is recognized as one of the actors of this type of installation in France

5 Conclusion

This Replacing heat pump has resulted to:
-Reduced 50% of energy use.
-Reduced 50% of CO_2 emissions.
-Reduce by 42% of the cost of MWh's of cold/heat production.
The time of return on investment of 11.5 years is considered satisfactory.

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   Member (since 2003) of the drafting committee of the revue heating, ventilation and air conditioning. This is the revue of AICVF (French association of engineers in heating and air conditioning).

   Member (since 2015) of Board of Directors of AICVF (French association of engineers in heating and air conditioning) - REHVA members

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Certification Systems for Green Buildings in Romania – LEED, BREEAM, Green Homes & the importance of BIM interdisciplinary collaboration in order to achieve energy-efficient projects

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Abstract. The presentation at this conference will focus on the description of mandatory and optional criteria for obtaining LEED and BREEAM international certifications for green buildings. At the same time, recent research will be presented in the field of green building evaluation and market trends, the benefits of these certifications for the beneficiary, investor and developer, occupancy rates, land value for green buildings and the costs and risks of including a building within sustainable initiatives. A breakdown of legislative requirements and incentives for sustainable construction by the Government will be presented. Subsequently, relevant case studies from Romania in the residential and office buildings that are certified or under certification will be detailed in order to present the constructive details used to obtain this recognition on the market.

We are living in a world of fast technological advances that create a dichotomy of effects. On one hand, they enhance the quality of life through innovation, performance and effectiveness and at the same time their significant impact alters the natural surrounding we live in through a high demand of energy consumption. Over the years, several studies have been developed by scholars and professionals who thought of transforming the urban conglomerates into self-sustainable low emission green hubs that intend to benefit the planet on the long term, as well as to protect the natural resources and the way people conduct their daily lives.

Sustainability defines a way of life and work, not just a mere concept of energy efficient architectural features. We need to think of new ways of adapting to the new and emerging ways of working both collectively and from more of an individualistic approach through the use of technology. The visions for the emerging utopian cities of the future must address sustainability. These design strategies will manage to mitigate the toxic by-products of our consumption habits, while maximizing our use of sustainable energy sources. Meeting these challenges means more deeply integrating green technologies like wind and solar power, natural climate controls and space-age materials into the building processes.

Past and current and most up-to-date technologies and strategies are meant to improve the way people design spaces in order to be more eco-friendly, to ultimately improve the users' quality of life, as well as the natural habitats. The research can be extended in order to provide further solutions which could be incorporated into all types of construction, at no high costs.

Integrative approach of design is one aspect of sustainability that has the possibility of diluting the boundaries between clear delineations of professions within the construction world and creating a common language which ultimately has the scope of altering and improving the human condition and the quality of life. These aspects are interconnected and it is up to us to create the bounding vocabulary.

The digital technology is adapting to the permanently diversification and specialization, characteristics of the present environment, and it is not hard to understand that the specialist knows "more and more about less and less". Multidisciplinary approach comes with subspecialties, and may conduct to fragmentation effects or overlap and duplication of information. There is a limitation of information that can be assimilated and constructively processed in traditional informatics systems in design. How could it be checked and controlled such an information system? The current encounters are the efficient and effective coordination, correlation and synergy between the different fields of all multidisciplinary factors involved, integrating categories and methods taken from different disciplines such as: engineering of constructions, installations, legislation, urbanism, related standards, etc.

A hubbub of the information may lead to disruption effects and requires an integrative approach for counteract. Building Information Modelling (BIM)

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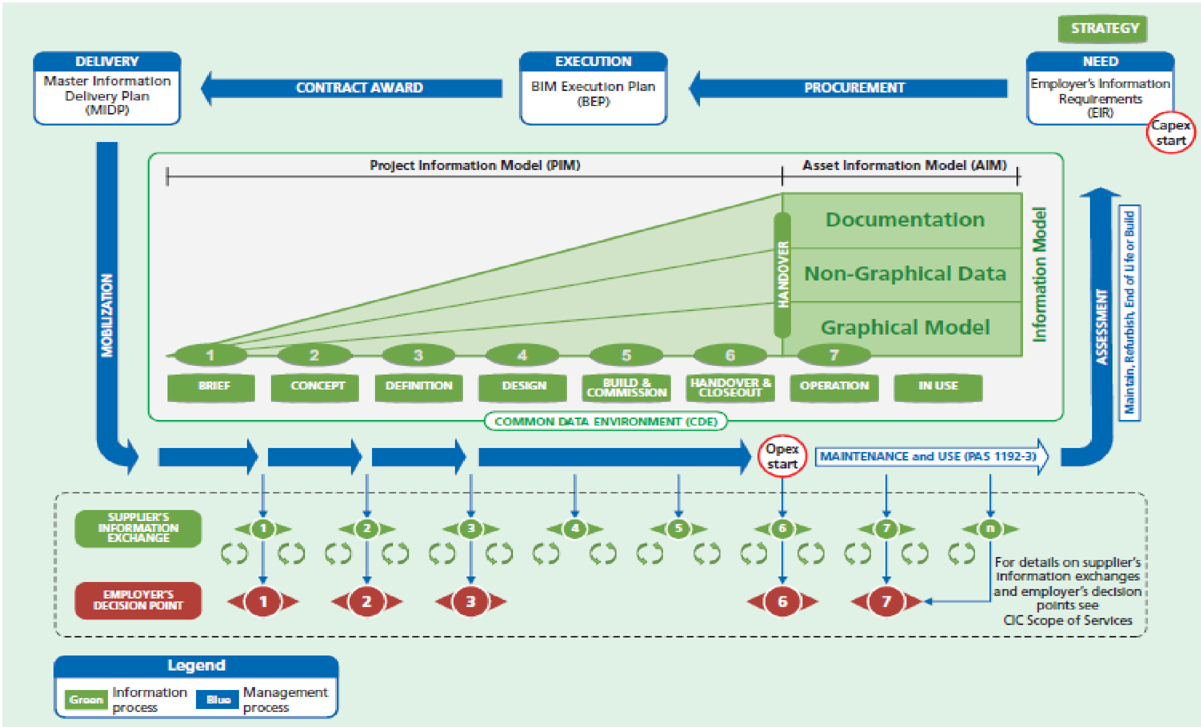
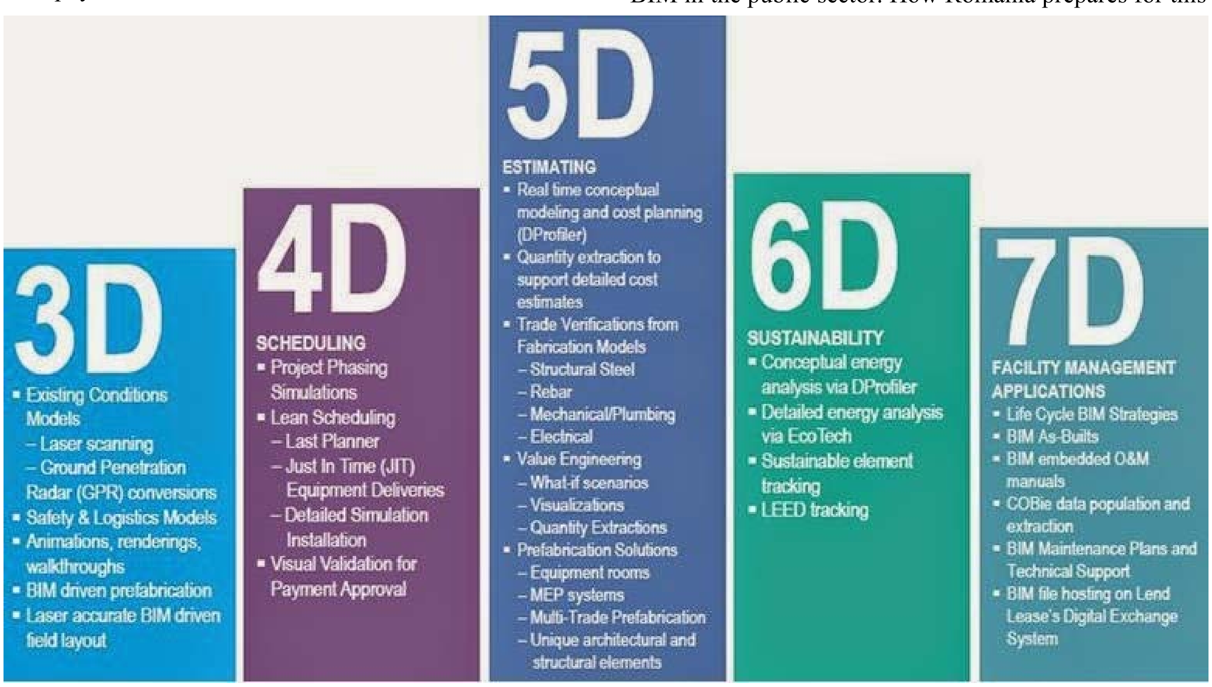
technology may represent the turning point on the path to digitization.

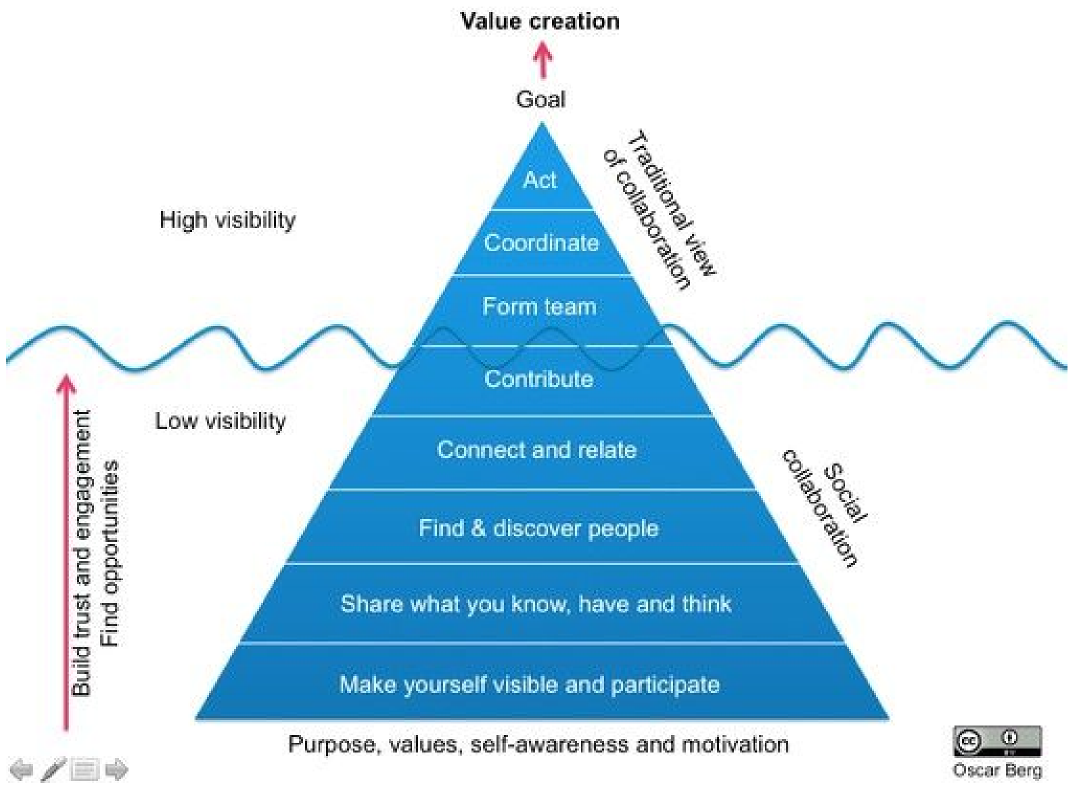
It's important to remark that BIM offers a greater freedom in the manipulation of the content than its predecessor, CAD, computer-aided design, used since the early 1960s. With BIM, users can generate 3D views instantly, create digital representations of physical places and objects and share those designs for collaboration. The project information is accessible throughout the entire construction lifecycle to more effectively plan and build physical infrastructure and more control of it.



The control comes with the effective multi-D management. Assessing BIM's potential, from the perspective of impact on building materials, contractors, building operations and facility management is dealing with BIM adoption and furthermore the different levels of adoption with great impact on people and training needs, on standards and standard object dictionary. Roland Berger believes BIM could be the most disruptive digital instrument in the industry.

Some countries have already announced or plan to announce government mandates for obligatory use of BIM in the public sector. How Romania prepares for this



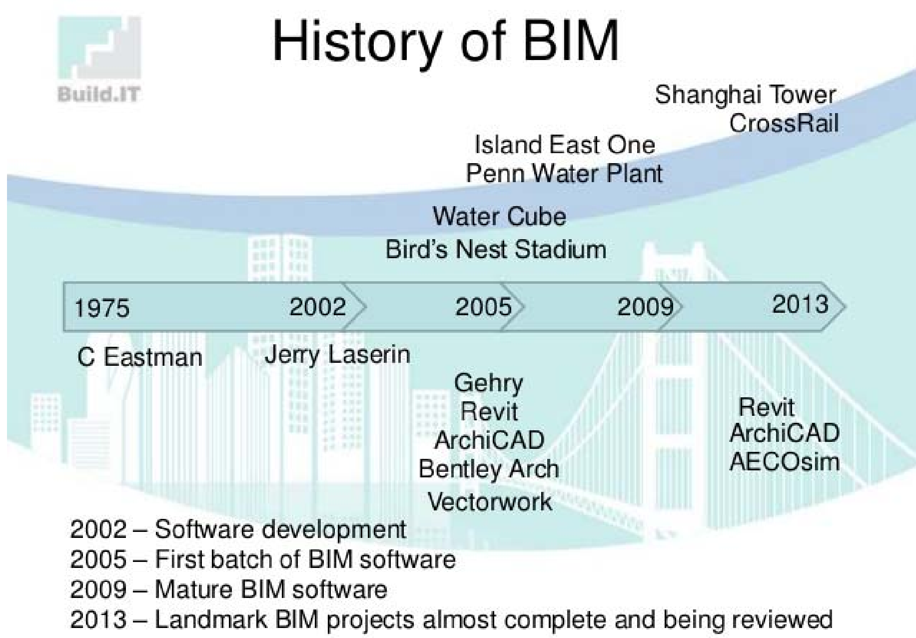


change is a topical issue in debate.

Because the times lead us here, being aware of the context of digitized technologies and diversification.

And since this goal would have been reached, the information held could be further used by operators, customers, and valued. A plus of value that can generate opportunities by use.

The concept of BIM has existed since the 1970s. (Eastman, Charles; Fisher, David; Lafue, Gilles; Lividini, Joseph; Stoker, Douglas; Yessios, Christos (September 1974). An Outline of the Building Derscription System. Institute of Physical Planning, Carnegie-Mellon University).



The term 'building model' (in the sense of BIM as used today) was first used in papers in the mid-1980s: in a 1985 paper by Simon Ruffle eventually published in 1986 (Ruffle S. (1986) "Architectural design exposed: from computer-aided-drawing to computer-aided-design" Environments and Planning B: Planning and

Design 1986 March 7 pp 385-389) and later in a 1986 paper by Robert Aish (Aish, R. (1986) "Building Modelling: The Key to Integrated Construction CAD" CIB 5th International Symposium on the Use of Computers for Environmental Engineering related to Building, 7–9 July) - then at GMW Computers LTD, developer of RUCAPS software - referring to the software's use at London's Heathrow Airport (cited by Laiserin, Jerry (2008), Foreword to Eastman, C., et al (2008), op cit, p.xii), (Really Universal Computer Aided Production System was a CAD system for architects, first developed during the 1970s and 1980s, and today credited as a forerunner of BIM. It ran on minicomputers. The term 'Building Information Model' first appeared in a 1992 paper by G.A. van Nederveen and F. P. Tolman (Van Nederveen, G.A.; Tolman, F.P. (1992). "Modelling multiple views on buildings". Automation in Construction. 1 (3): 215–24.) 10 years later it became popularly. In 2002, Autodesk released a white paper entitled "Building Information Modeling," (Autodesk (2002). Building Information Modeling. San Rafael, CA, Autodesk, Inc.) and other software vendors also started to assert their involvement in the field. Bentley Systems and Graphisoft, industry observers, Jerry Laiserin helped popularize and standardize the term as a common name for the digital representation of the building process (Laiserin, J. (2003) "The BIM Page", The Laiserin Letter.). Facilitating exchange and interoperability of information in digital format had previously been offered under differing terminology by Graphisoft as "Virtual Building", Bentley Systems as "Integrated Project Models", and by Autodesk or Vectorworks as "Building Information Modeling".

Laiserin and UK's Royal Academy of Engineering recognize RUCAPS, Sonata and Reflex as pioneers among applications.

As Graphisoft had been developing such solutions for longer than its competitors, Laiserin regarded its ArchiCAD as then "one of the most mature BIM solutions on the market. (Laiserin, J. (2003) "Graphisoft on BIM", The Laiserin Letter, January 20, 2003)" Following its launch in 1987, ArchiCAD became regarded by some as the first implementation of as it was the first CAD product on a personal computer able to create both 2D and 3D geometry, as well as the first commercial BIM product for personal computers.

ArchiCAD has made substantial gains in user base from 2007-2011.

Meantime, by 2000's, "Revit" was written in C++ and utilizing a parametric change engine by Charles River

Software in Cambridge, MA, purchased by Autodesk in 2002.

Revit revolutionized the world of BIM, allowing a 'fourth-dimension' of time to be associated with the building model.

Making a leap in time, there is not hard to notice the tide competition between the developers of softwares for creating BIM platforms, towards a collaborative architecture, influenced by sustainable design, trends in human computer interaction, augmented reality, cloud computing, parametric and generative design, virtual design and construction.

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Development of Industry 4.0 models and their applicability for BIM

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Abstract. Industry 4.0 (I4.0) and Building Information Modeling (BIM) are representative of the concept of digitisation in different industries. Although both concepts pursue the same goals and apply the same methods, there is no exchange or synchronisation. Investigations of a research project show that I4.0 models are suitable for the description of plant components in building technology and can be integrated into BIM solutions. Weaknesses of BIM in operation can be closed by I4.0 models. The development of I4.0 submodels is a central point of current I4.0 developments. A procedure model has been developed that can be used for deriving and assigning submodels of different assets.

1 Introduction

The digital transformation is in full swing and extends to every area of life. More and more devices are connected to the Internet, resulting in an ever-growing amount of data. By 2025, this should lead to an annual data growth rate of 30 percent [1]. By intelligently linking products and processes, this data can be used to optimise the value chains of manufacturers and users. This leads to novel products and services that offer potential for users to optimise their own business processes. Innovative services are based on information that is created and exchanged during the lifecycle of assets. The term asset stands here for each object, which has a value for an organisation [2]. An asset can be both a physical object such as a pump or an intangible object such as the plan of the building in which the pump is used.

While Building Information Modeling (BIM) is synonymous with the digital transformation of the construction industry, Industry 4.0 (I4.0) stands for the digitisation of industry. The definitions of BIM and I4.0 focus on standardised information that is available throughout the lifecycle [3, 4]. This standardised information has to be made available independent of both manufacturer and platform so that it can be used as a basis for innovative applications [4, 5]. Information that is not standardised but based on manufacturer-specific semantics leads to barriers to the development of the performance of new services.

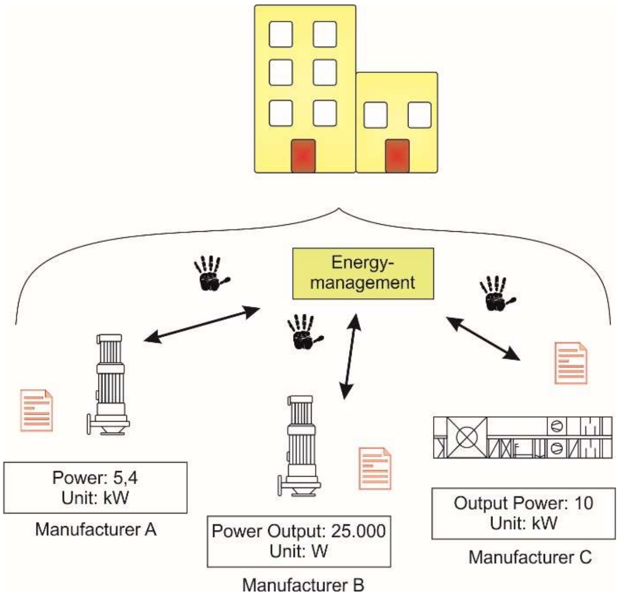

Fig. 1. Different semantics as an obstacle to innovative applications

Figure 1 shows the problem of different semantics. If the information generated by the systems of a building is based on different semantics, this makes it difficult to create innovative applications. The figure shows various components with the property "Power Output". Due to the different semantic characteristics of the performance, it is not possible to automatically record and analyse the performance data of the plants. The manufacturer-specific information requires manual engineering in order to classify the data and make it available to the application. This problem applies to industrial plants as well as to technical building equipment (TBE). Although the concepts BIM and I4.0 pursue the same goals, the same

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problems have to be solved, and components such as pumps are used in both areas, no joint efforts can be discerned at present. Further developments are not interlinked, but run in parallel. Possible combinations of BIM and I4.0 have not yet been published. One aim of this research project is to show what a combination of these two concepts would look like and how it could be developed.

The following sections first give a short overview of the two concepts. Building on this, a possibility is presented of how BIM and I4.0 can be combined. In the last section, a procedure model for the development of I4.0 submodels is presented.

2 State of the art

Information models form the basis of I4.0 and BIM. While the I4.0 component, in particular the administration shell, is a central aspect of I4.0, the data exchange for BIM is based on the Industry Foundation Classes (IFC) standard. The following descriptions focus on the standardisation of properties, since this is the current focus of developments in both concepts.

2.1. Standardisation of properties in Building Information Modeling

The IFC model is described in the international standard ISO 16379 and was converted into a German standard in 2017 [6]. It is maintained by the "buildingSMART" organisation and is intended to enable manufacturer-neutral data exchange of digital building data.

Furthermore, "buildingSMART" is responsible for the standardisation of features in the context of BIM and one of the initiators of "openBIM". The aim of "openBIM" is to enable the manufacturer-neutral exchange of building models [7]. The "buildingSMART Data Dictionary" (bSDD), which is based on ISO 12006-3, is provided for this purpose. This ISO standard defines an information model which is used as a basis for the development of dictionaries. Different objects such as subjects, actors or properties are defined, which can be related to each other [8].

Different properties are defined by "buildingSMART". The properties of the components are assigned to the objects with the help of "Property Set Definitions" (Pset). These collections are explained below using a pump as an example. For pumps, the collections "Pump Type Common", "Pump P History" and "Pump Occurrence" are provided [9]. The Type Common collection includes various pump ratings, such as the maximum and minimum temperature of the fluid being pumped or the rated speed. Properties related to pump operation are summarised in the History collection. Examples are the current speed or the pump efficiency averaged over the life cycle. Three further properties are summarised in the last collection "Occurrence", which deals with the basic functions of pumps [9].

In addition to pump-specific properties, each pump inherits properties from higher classes. In particular, some collections are assigned to the "Element" class. A total of seven collections deal with the aspects warranty, manufacturer information, environmental aspects, service life and condition of an object [10]. The properties of these collections can be useful for the design and operation of pumps as they provide important information during the order process. The inheritance hierarchy of the IFC model and the collections in which the properties are summarised are shown in Figure 2 using the Unified Modeling Language (UML).

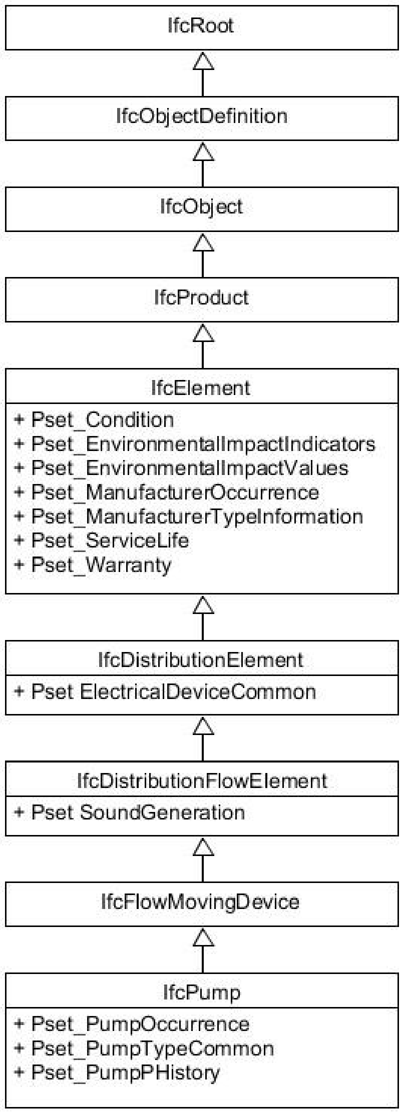

Fig. 2. Possible Pset collections of the pump in connection with the inheritance hierarchy of the IFC model

A total of 93 standardised properties can be assigned to a pump. However, only 16 of these 93 properties are pump-specific [9]. The properties standardised in Pset are all optional. In extreme cases, all 93 properties can be assigned to a pump, or none at all.

2.2 The I4.0 component

The I4.0 component is the core of the I4.0 developments. The I4.0 component consists of an administration shell and an asset. The administration shell represents the I4.0 component in the virtual digital world [11]. The administration shell can be understood as a synonym for the concept of the digital twin. Just like the administration shell, the digital twin is the virtual representation of an asset [12]. Since the term administration shell is preferred in the I4.0 environment, it will be used in the following.

Details regarding the tasks and structure of administration shells are described in various status reports, for example [11, 13]. Among other things, they consist of submodels that describe different aspects of an asset. The development of the submodels and their description by standardised properties with unique identification represents a key task here. In addition to the properties, submodels contain standardised functions, which are summarised as technical functionality [11]. For example, the submodel "operation of heaters" could contain the function "heating".

Current development work deals with the design of administration shells. A working group of the Mechanical Engineering Industry Association (VDMA) and departments "Pumps + Systems" and "Compressors, Compressed Air and Vacuum Technology" is developing submodels for liquid and vacuum pumps. Submodels can be compared with the Pset collections from the IFC model. In both cases, the models, or collections, contain features that describe aspects of an object. Furthermore, there are general models that apply to all components, such as manufacturer information, and models that contain component-specific features [14].

2.3 Industry 4.0 application scenarios in the context of building technology

The working group for "Technology and Application Scenarios" of the "Platform Industry 4.0" examines how digitisation can show new ways and possibilities in the manufacturing industry. Various application scenarios were developed for this purpose [15]. These scenarios were adapted and transferred to the TBE area to show that I4.0 ideas can be transferred to building services engineering. Four of these scenarios and their applicability to building services equipment are described in the following paragraphs.

The first scenario, "Value based services", deals with services that are tailored to needs and uses. This scenario is based on the operating data that is collected and processed. Through an analysis of the data, comparison with target values of planning or manufacturer values, services such as predictive maintenance can be offered. Examples of such recorded data are power consumption of the components or vibration analyses.

Another scenario describes the "Transparency and adaptability of delivered products". The automatic collection of usage-related data from delivered products forms the core of this scenario. Based on this data, status monitoring can be performed and the product properties can be dynamically adjusted in the plant. Furthermore, additional features of the components can be enabled as required. Examples in TBE would be optimisation of the control parameters of individual components to the actual operating conditions, or after-sales services, which are offered to the customer.

In industry, the "Transformable factory" describes a scenario in which production lines are adapted due to short-term changes in production capacities. In TBE, this could be transferred to the replacement of individual components of one manufacturer by those of another. The configuration data is understood by both products so that a manufacturer-independent exchange can be carried out. On the other hand, the idea of "living containers" could be taken up, which could be integrated into different environments through such a "plug and play" scenario.

A fourth scenario, "Continuous and dynamic engineering of plants", describes the engineering of a plant, from the construction and operating phases to disposal. The engineering, operation and service processes interlock and thus extend the original model over its entire life cycle. This principle can be transferred to TBE, since here, too, adjustments are made to plants during operation, which are integrated into the model of the plant or building.

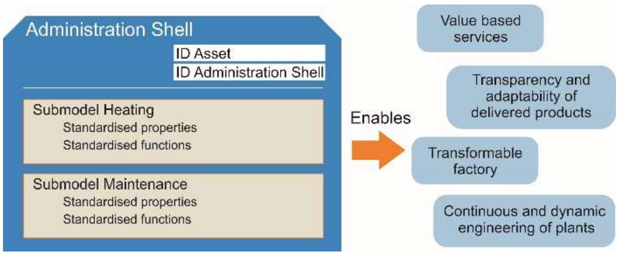

Fig. 3. Administration shell, according to [11], as basis for I4.0 application scenarios

The presented I4.0 scenarios show that these can also be used in TBE. To implement these scenarios, uniform semantic descriptions of the information and standardised functions are required. Without these prerequisites, a high degree of manual engineering would be required to analyse the significance of the information generated. To implement these scenarios, the industry uses the concept of the I4.0 component, shown in Figure 3; in TBE, the BIM method would have to be used. The next section describes whether the concept of BIM is sufficient to cover these scenarios and what a possible combination of I4.0 and BIM might look like.

2.4 Combination of BIM and Industry 4.0

The properties of the "bSDD" for pumps presented in section 2.1 make it clear that the focus of BIM is on planning and the data generated there. Of the 93 possible properties, only six are applicable as current operating data. Accordingly, these data would not be sufficient to cover the operation of plants in their entirety. Discussions that take place around BIM in operation relate to how the models and data generated during planning, for example in Computer Aided Facility Management (CAFM) systems, can be made available. For this purpose, the "openBIM" interface "CAFM-Connect" was developed by various organisations such as "buildingSMART". This is based on the IFC model and provides the planning data in CAFM systems [16]. However, the actual operating data of the plants are essential, especially in TBE. Just as in planning, clear and standardised semantic information is required here in order to be able to automatically evaluate it. In addition, standardised functions are required in order to be able to implement the scenarios from section 2.3. The semantic description of the operational data, however, is currently not the focus of BIM, nor is the development of functions. Therefore, a different concept would have to be used during operation. Therefre, scenarios presented here cannot be implemented with the BIM method alone, since current operating data is required for this.

In contrast to BIM, I4.0 focuses not only on planning but also on operating plants [17]. This becomes clear, for example, in the development of submodels for pumps. In addition to a model for the technical data of the manufacturer and planning, models are developed that describe data from operation and maintenance [14]. These models can close the gap that arises during operation with BIM.

A building in operation is a composition of different assets. All installed objects in the building such as doors, windows, ventilation ducts or pumps can be regarded as assets. Each building has an administration shell (Digital Twin), which in turn is composed of the individual administration shells of the assets. A basic part of the shell is the plan of the building in which the planning data is stored. Further data is added during operation. The presented application scenarios can be implemented on the basis of the manufacturer's, planning and operating data. However, the scenarios can only function automatically if the semantic description of the properties from operation and planning match. If I4.0 models are used in operation, a possibility of combining BIM and I4.0 must be developed. One possibile combination is to use the semantics of the I4.0 models also in planning. This means that the BIM method is still used for the planning of buildings, but the semantic description of the planning and manufacturer data follows the description from I4.0 models. This scenario is shown in Figure 4 below.

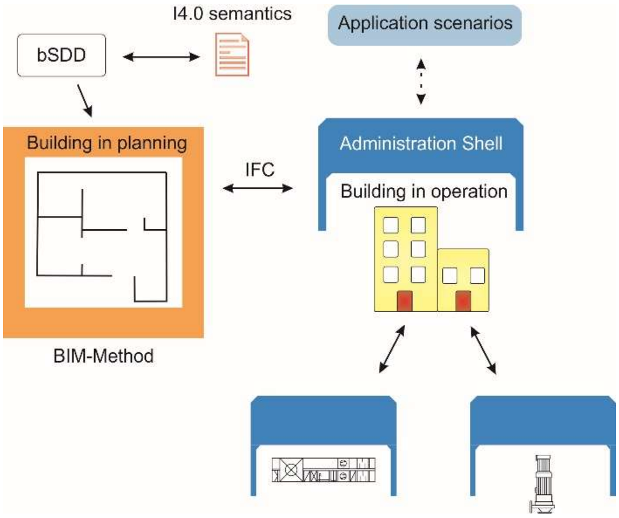

Fig. 4. Combination of BIM and Industry 4.0

One possibility to integrate the semantics of I4.0 into BIM is given by the "bSDD". The "bSDD" is to enable an open exchange of building data. The ISO 12006-3 standard on which the "bSDD" is based enables reference to other classification systems [8]. One example of such integration is the cooperation between "ETIM e.V." and the "buildingSMART" organisation. Since 2017 it has been possible to reference the "ETIM" data model from the "bSDD" [18]. The same mechanism would make it possible to reference relevant I4.0 submodels and integrate their semantics into BIM models. Administration shells used in TBE during operation contain an IFC interface that makes it possible to make the planning data available during operation. This would ensure uniform semantics from planning through operation to the demolition of a building.

The integration of I4.0 submodels in BIM can help to make necessary information about the life cycle of assets available in TBE during operation. A combination of the two concepts would eliminate the need for multiple descriptions and modelling of properties and functions. Plant components would not have to have a BIM conformal description for the planning, as well as an I4.0 conformal description.

The aim is to make the relevant I4.0 submodels of planning available in the "bSDD" or to reference them. The presented method can be used for this. However, the development of I4.0 submodels is currently still in its infancy. As of today, no official submodels have yet been adopted.

3 Proposal for a process model

A prerequisite for a combination of I4.0 and BIM is the development of submodels for components of TBE. A VDMA working group is currently working on submodels for liquid and vacuum pumps. The aim of the working group is the standardisation of an administration shell for pumps. The submodels for liquid pumps will also be used in TBE. Examples of submodels have been presented in various reports [13]. However, there is no model that describes how to proceed with the development of submodels. Figure 1 shows the problems of different semantics. However, this problem can also be extended to submodels. Different terms, like the "performance" shown in the figure, are relevant for different components. Properties that are important for several assets should be defined only once, if possible, and used in the respective submodels of the assets. The VDMA Working Group for Pumps has developed a procedure model that can be used for the derivation and assignment of submodels. The described procedure should be applicable to different assets. The proposal is based on a process and life cycle oriented modelling of asset functions. Furthermore, a classification is suggested, with which assets can be summarised in groups and structured hierarchically. With the help of the procedure model, the development of submodels can be simplified. More manufacturer associations of TBE such as the VDMA professional associations "Refrigeration and Heat Pump Technology" and "Air Conditioning and Ventilation Technology", should be encouraged to develop I4.0 submodels.

3.1 Life cycle phases as the basis for submodels

The first part of the proposal is used to derive submodels. The phases of the life cycle that every asset goes through serve as a basis. In order to achieve a generally valid approach, international standards are used. Starting point for the structuring of the submodels in the life cycle is the reference architecture model 4.0 (RAMI 4.0).

RAMI 4.0 was developed to combine different aspects of I4.0 in one model [19]. A three-dimensional model was designed for this purpose. Since the procedure model is oriented to the life cycle of assets, only the axis of the life cycle is presented. In RAMI 4.0, the life cycle was based on IEC 62890 [20]. The basis of this standard is the distinction between the type and the instance of an asset. The "type phase" extends from the initial idea of a product to the release of series production. The "instance phase" extends from the production of the instance, based on the general type, through its use, to the disposal of the product [21].

Based on this general distinction between type and instance, the process model describes the life cycle of an asset on the basis of basic processes. ISO 15288 was used as the basis for life cycle processes. This standard provides defined processes that describe the life cycles of technical systems [22]. The processes provided in the standard were analysed to determine whether they can be used as a basis for the submodels. The processes that can be used as a basis were included in the model and assigned to the two life cycle phases of RAMI 4.0. Regardless of the procedure model, various use cases were created at the beginning of the working group. This made it possible to define the priorities of the members with regard to the development of the submodels. The different use cases were compiled and examined for overlaps and combined into superordinate use cases. In a next step, these use cases were located in the life cycle model and assigned to the processes.

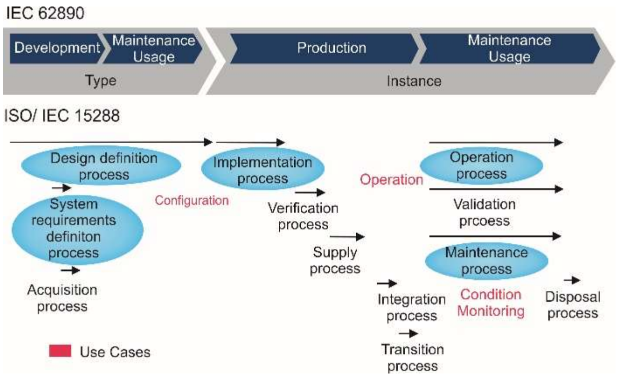

Fig. 5. Assignment of life cycle processes to the RAMI 4.0 life cycle model and location of use cases

The upper part of Figure 5 shows the basic subdivision of the life cycle of a product into the type and instance phase according to IEC 62890. The processes are shown below. These were classified along the life cycle. In addition, the manufacturers' use cases were assigned to the processes. The use case "Configuration" is split to the three processes "Design definition process", "System requirements definition process" and "Implementation process". As a result of this use case, a preconfigured pump is to be delivered that meets the customer's requirements. For example, the correct working points can be set in advance. The use cases "Operation" and "Maintenance" correspond to the two processes "Operation process" and "Maintenance process".

The basic processes form the basis of the submodels. The functions presented are general in nature so that they can be applied to any asset. On the basis of these functions, more specific functions can be modelled that fulfil the characteristic requirements of an asset or an industry. Figure 6 uses UML to illustrate how submodels can be derived from the basic processes "Operation" and "Maintenance".

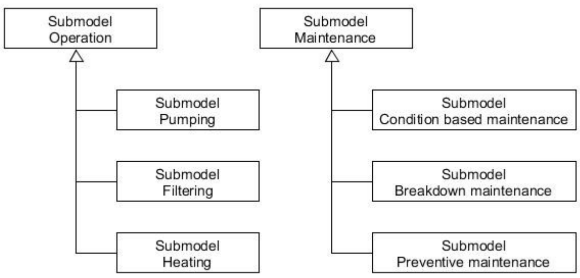

Fig. 6. Submodels derived from general processes

Examples for specific functions of TBE components in the "Operation Process" are the functions "pumping" of the pump, "filtering" of the filter or "heating" of the heater of a ventilation system. For maintenance submodels, DIN

EN 13306 can be used as the basis in which basic terms of maintenance are defined [23].

3.2 Classification of Assets

The second part of the procedure model deals with the classification of assets. The goal is to standardise properties that describe the same thing only once, if possible. This is to prevent properties that are valid for several assets from being defined more than once. A classification is needed to group assets and receive a hierarchical structure as to which assets can be summarised in same groups. The "International Standard Industrial Classification of All Economic Activities" (ISIC), which is used for the classification of economic sectors and branches of industry [24], is suitable for this purpose. The hierarchy of the standard is shown in excerpts in Figure 7, with a focus on the TBE.

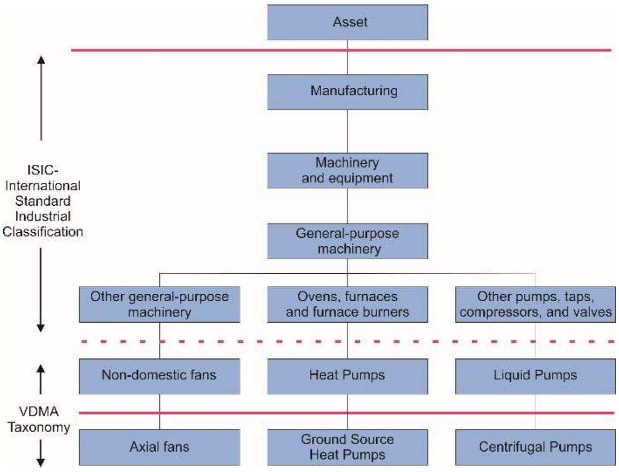

Fig. 7. Classification of Assets

The ISIC classification has been extended upwards and downwards (represented by the red lines). The general class "Asset" was introduced above the main groups. Further classes were introduced below the last subcategory in order to be able to define the hierarchy of the assets more precisely. The main group shown is "manufacturing industry", which is one of the 21 main groups provided by ISIC and is in turn divided into 24 subcategories. These include, for example, the manufacture of textiles, paper and electrical components [24]. A further subcategory is "mechanical engineering", which is included in the figure. Starting from the category "Mechanical engineering", further categories are defined such as the subcategory "Non-industry-specific machinery". The last stage of the ISIC introduces further subcategories. The areas "Pumps, compressors, taps and valves", "Furnaces and burners", as well as "Other non-tool-specific machines" have been included in the figure, as components of TBE are located here. The figure shows that all assets can be mapped with the help of the standard. In the lowest categories of the ISIC, the basic contents of these categories are described, but no further grouping is introduced.

However, these contents described here are not sufficient for guaranteeing an exact classification of the assets. The categories must be further subdivided for this. Figure 8 shows a further subdivision using a pump as an example.

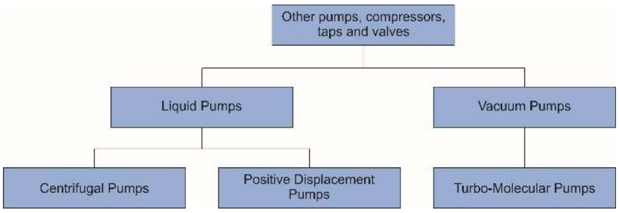

Fig. 8. Finer structuring using a pump as an example

The professional associations of the VDMA distinguish between the two pump types "vacuum pumps" and "liquid pumps". For this reason, this distinction was also taken into account in the development of the submodels. Furthermore, liquid pumps are distinguished between "centrifugal" and "positive displacement" pumps. The "turbomolecular pump" is shown as an example of a vacuum pump. In the further subdivision, the VDMA taxonomy was used. The further subdivision of the individual categories should also be carried out in other areas by the working groups, which want to develop submodels for a certain domain. Here also other taxonomies can be used.

3.3 Combination of basic processes and classification of assets

The following section combines the two parts of the procedure model: the combination of the basic processes and the classification results in the basis for the reusability of properties. This is illustrated in Figure 9.

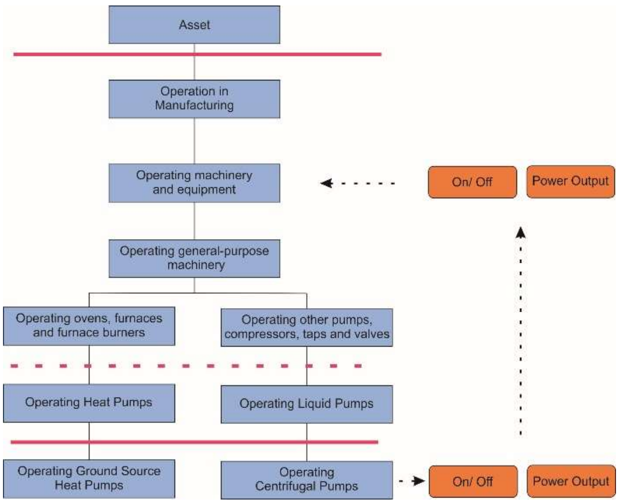

Fig. 9. Reusability of parameters

The submodels for operation are derived from the "Operation" process. At the lowest level, the submodels "Operating ground source heat pumps" and "Operating centrifugal pumps" are derived. When defining the properties, the "bottom-up" principle should be applied. The working group defined the properties for the different pump types (centrifugal pumps, positive displacement pumps, various vacuum pumps). The properties that are valid for all liquid pumps or vacuum pumps were analysed. The next step is to define which of the properties can be used for both liquid and vacuum pumps. With this point, the internal work of the working group is finished, since it was defined, which properties are assigned to the different categories. In a next step, the working group has to define which properties are valid for "Non-industry-specific machines".

The function "On/Off" and the property "Power" are included in the figure. "However, "On/Off" and "Power" are not pump-specific functions or properties, but are valid for all assets that can be switched on and have a drive. These two properties are therefore good examples of features and functions that can be assigned to a higher level of classification and are therefore valid for multiple assets.

3.4 Standardised properties as a basis for interoperability

The model presented should provide guidance on how to proceed with the definition of submodels. The derivation of the submodels of basic processes and the classification enable a uniform structure of the models and reusability of the parameters. The problem of manufacturer-internal standards was described in figure 1. This problem can be solved by uniform submodels and standardised properties. This is represented in figure 10.

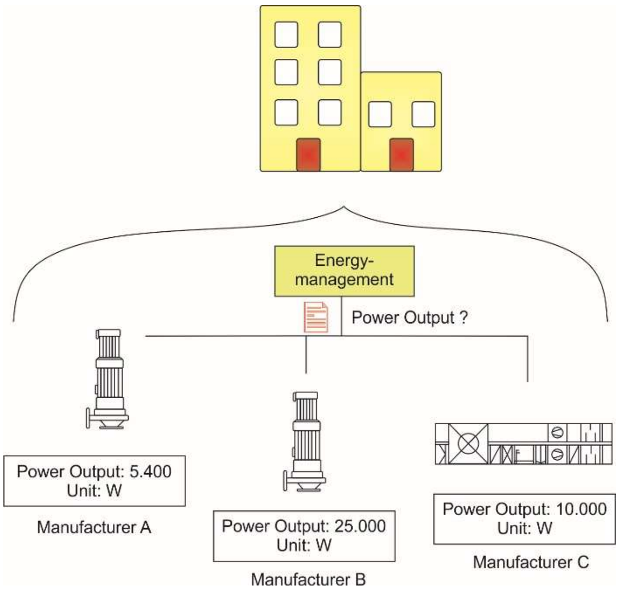

Fig. 10. Uniform standards as a basis for interoperability

The two pumps shown, from two different manufacturers, are based on the same submodels. The uniform structure of the pumps makes it easier for energy management applications to access the pump data. Since performance is not only valid for pumps, it has been assigned to a higher level in the classification and is also valid for other components. This allows the performance property not only to be the same for all pumps, but also to be used by other components of this characteristic. This allows applications to query the performance data of components and use it for analysis purposes without a great deal of manual engineering.

4 Conclusion

BIM and I4.0 stand for digital transformation in different industries. The definitions and developments in the last few years show that both pursue the same goals. With manufacturer-independent standards, an unrestricted exchange of the information can be made possible over the entire life cycle of an asset. Essential for this are open standards, which define the semantics, with which the properties of the assets are described. Although both concepts pursue the same goals and the same methods are applied, digitisation activities currently run separately in both concepts. The current focus of BIM is on building design. There is no concept on how to capture operational data. This gap can be closed by I4.0 submodels, since these cover the operation. In order to achieve uniform semantics over the entire life cycle and thus avoid information breaks, I4.0 submodels must be integrated into the BIM method. This integration is provided by the "bSDD", since this allows the reference to external classifications. Thus, the semantics of the submodels can be integrated into BIM models, enabling uniform and consistent availability of the information over the entire life cycle.

However, the development of I4.0 submodels is still in its infancy. A VDMA working group is currently developing I4.0 submodels for liquid and vacuum pumps. In the course of the group's work, a proposal for a procedure model for the creation of submodels was developed. The aim is to create a uniform basis for the derivation of submodels and to prevent the multiple definition of properties that apply to several assets. The proposal consists of two aspects. On the one hand, basic asset functions were modelled on the basis of a life cycle model, which forms the basis for the submodels. The functions are of a general nature, so that models can be developed for each asset on the basis of these functions. On the other hand, a classification was presented in which each asset can be located. The classification is based on the international standard "ISIC". However, the standard is extended downwards by further categories, which allows a finer division of the assets. With the help of this model, submodels can be derived and the assets classified.

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Synthesis of knowledge on utilization of adsorption filters for healthy indoor environments

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Abstract. Building occupants are exposed to many different kinds of pollutants in indoor environments. A healthy and comfortable indoor environment is an essential need for humans. Air pollution is related to many deadly diseases such as cancer, respiratory and cardiac diseases. As a result, control of hazardous gases in the indoor air is crucial. The utilization of sorbent filters is a promising technology in reducing the level of pollutants from indoor air. This study presents a comprehensive review of adsorption filtering technology. The article discusses factors that influence filter performance, recent technological developments, advantages, limitations and challenges.

1. Introduction

People spend most of their time inside buildings. As a result, problems related to indoor air quality are more crucial than ever. Human beings are in need of fresh air supply continuously. Free access to air and water of acceptable quality is a fundamental human right [1]. There are different types of air pollutants, and air pollutants in the indoor environment must be kept under control, and concentration levels of the air pollutants should not exceed threshold values that are addressed in the related standards. If the sources of the air pollutants are not controlled, indoor air quality problems may occur, even if the ventilation and air conditioning system works correctly. Among the air pollutants, volatile organic compounds (VOCs) have been classified as an important indoor air pollutant type in buildings [2]. In the outdoor environments, industrial and vehicular emissions are major sources of VOCs, and in the indoor environment, inner building materials, furniture, perfumes, paints are the most common sources of VOCs [3]. In Table 1, the health effects of some of the major VOCs are presented.

Control of VOC levels inside the building environments is crucial as exposure to VOC emissions might cause severe health problems on humans. They cause acute symptoms such as irritations of the nose, throat and eyes, headaches, nausea, dizziness and also damage the internal organs such as kidneys and liver [4]. Exposure to some of the VOCs such as benzene can even lead several diseases such as leukemia, immune system abnormalities, neurological disorders, respiratory illnesses, etc. [5]. In addition to being harmful to human health, VOCs are also major contributors to stratospheric ozone depletion [6]. For these reasons, it is vital to develop air filters for the removal of gaseous contaminants. Since the concentration level of VOCs is very low inside the buildings, there are only a few technologies that can be applied for removing VOCs, which are oxidation technique such as photo-catalysis and cold plasma and adsorption systems [7]. In photo-catalysis, VOCs destruction is conducted by using photo-catalysts such as TiO_2 and UV light at ambient temperature [8]. Pollutant molecules come into contact with produced reactive species and break down to lower molecular weight products and eventually to CO_2, water and other by-products [9]. While the adsorption process is a surface phenomenon which involves the transfer of a gas phase material (adsorbate) to the surface of a solid (adsorbent) [10], a photo-catalysis unit would have an installation cost more than ten times greater and annual operation cost seven times greater when compared to sorbent filters [11]. In addition to having lower initial and operation costs, sorbent filters have another advantage of producing no harmful by-products, while oxidation techniques can generate harmful secondary chemicals such as NO_x, O_3, OH* radicals [12], [7]. As a result, most commonly used air purification technique for harmful gases is adsorption.

Table 1. Health effects of some of the significant VOCs [6]

Classification	Representatives	Health effects
Alcohols	Methanol Ethyl alcohol Isopropyl alcohol	Throat irritation Eye irritation Nasal tumors Central nervous system depression
Aldehydes	Formaldehyde Acetaldehyde	
Alkenes	Propylene Ethylene	Carcinogenic effects
Aromatic compounds	Benzene Toluene Ethylbenzene	Carcinogen Produce photochemical smog
Ketones	Acetone Ethyl butyl ketone	Central nervous system depression Carcinogen Headache and nausea

The goal of this study is to provide a review of the critical factors governing VOC adsorption onto adsorbents. In this work, the impact of characteristics of VOCs, adsorbent properties, as well as adsorption conditions on adsorption performance is discussed.

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2. Sorbent Filters

Physical properties of adsorbents and adsorbates and environmental conditions profoundly affect the removal efficiency of sorbent filters. There are many different kinds of adsorbent/filtration media. Among them, activated carbon, activated carbon fiber, silica gel, and zeolite are the most commons [13]. Due to its low cost and large surface area activated carbon is the most extensively used adsorbent media. Activated carbon is developed by thermal decomposition of a carbonaceous material (coal, coconut shell, wood, etc.) and is activated with steam or carbon dioxide at high temperatures (700-1100˚C) [14]. Activated carbon can be found in different forms such as powders, micro-porous, granulated, molecular sieves and carbon fibers [15]. The structure of pores can be classified as macro pores (>50 nm), micro pores (<2nm), meso pores (2-50 nm) and represented in figure 1 [7], [14]. Silica gel and alumina have less surface area than activated carbon, but they are preferred to use for trapping polar compounds such as formaldehyde and sulfur-based contaminants [16].

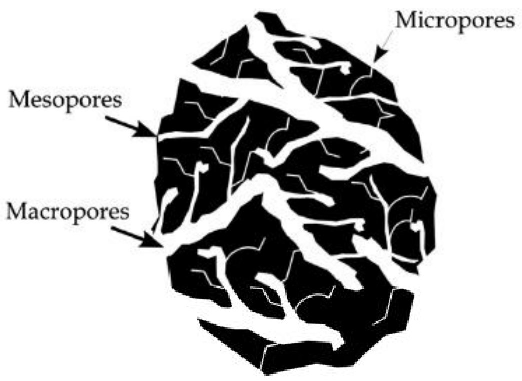

Fig. 1. Schematic representation of adsorbent pore structure [14]

2.1. Mechanism of adsorption

Adsorption is a reversible physical phenomenon that occurs between adsorbent surfaces (solid) and an adsorbate (fluid vapor) driven by cohesive forces [17]. Adsorption process of the contaminant gas occurs mainly within the pores and surface of the solid adsorbent [18]. To maximize the adsorbed amount of the pollutant gas, it is essential to know about adsorption characteristics of the adsorbate-adsorbent pair [19]. Sorbent air filters consist of fixed adsorption beds. VOC removal by the adsorption bed is a dynamic process. The area where adsorption takes place is called mass transfer zone. In the beginning, the bed adsorbs all of the pollutants, however, when the gaseous pollutants saturate bed's first layers, mass transfer zone moves through and finally leaves the bed [10]. The fraction of gas concentration passes the bed unadsorbed is called "breakthrough rate". This parameter is shown in Eq. 1.

$$BT(t)=(C_0(t))/(C_i(t)) \times 100=1-EF(t)(\%) \qquad (1)$$

In this equation, $C_o(t)$ shows the downstream concentration of the contaminant gas, at the end of time t; $C_i(t)$ represents the upstream concentration of the contaminant gas [19]. EF(t) refers to single-pass efficiency of the filter. The time from the beginning of the adsorption process until the filter reaches a specific breakthrough rate is called breakthrough time. The main drawback of sorbent filters is that adsorbent material becomes saturated after a while. Therefore, adsorbent material should be regenerated periodically.

2.2 Related Studies

It is crucial to know which adsorbent material can adsorb most of the target gaseous contaminant for a given time [20]. It will enable potential users to make better decisions taking into account the function of the building. As a result, there are many experimental studies to understand the adsorption performance of different sorbent materials. Owen et al. [21], tested the efficiency of five different sorbent air filters following the ASHRAE 145.2 test standard. In their study, they selected three different VOCs (toluene, sulfur dioxide, ozone) and five different commercial and residential sorbent air cleaner with different media blend. Contaminant air stream was sent to the test air ducts and upstream, downstream concentration of pollutants were measured. As a result, they found out that, adsorption efficiency of the air cleaner varies according to the contaminant gas that is used. It was emphasized that testing with a single pollutant might not give similar results for a mixture containing that particular contaminant. Additionally, it was shown that a sorbent filter may show high efficiency for a particular gaseous contaminant and may show a lower efficiency for another. As a result, it was highlighted that users should select adsorbent material relevant to their gas contaminant removal needs.

Before ASHRAE 145.2 test standard, there was not any standard for measuring the efficiency of sorbent filters. As a result, Lee et al. [22], conducted a study to propose an experimental method for evaluating sorbent filters' efficiency in VOC removal. A closed-loop test system was used to investigate the performance of four different fibrous activated carbon filters (A,B,C,D) in toluene removal. The breakthrough time until 80% breakthrough rate was determined for each filter type. According to the results, 80% breakthrough time was 121.2 minutes for filter A, 61.97 minutes for filter B, 160.6 minutes for filter C and 358.8 minutes for filter D. As a result, compared to the other filters, filter D showed the best performance in toluene removal due to its highest specific surface area.

Often in experimental studies, the concentration of the contaminant gas is much higher (ppm) than in the real indoor air environment conditions (ppb). Since it is complicated and costly to conduct experimental studies with lower concentrations, researchers often prefer to use higher contaminant gas concentrations during their experiments. Since it is difficult and expensive to do experiments under low concentration levels, Pei et al. [23], developed a mathematical model to investigate the performance of the sorbent bed even under relatively low concentration levels.

Table 2. Sum. of experimental conditions of previous studies

Literature	VOC	Concentration	Adsorbent
Lee et al. [22]	Toluene	4.32 µl/min	Fibrous activated carbon types
Owen et al. [21]	Toluene Sulfur Dioxide Ozone	50 ppm 35 ppm 0.5 ppm	Granular activated carbon types
Pei et al. [23]	Toluene Decane Hexane Butanone Iso-butonal Tetrachlorothylene D-limonene	32 ppm 34 ppm 40 ppm 78 ppm 58 ppm 43 ppm 17 ppm	Pellet and granular activated carbon types. Activated alumina with potassium permanganate
Safari [7]	Methyl-ethyl ketone N-hexane	100 ppm 100 ppm	Granular activated carbon
Han et al. [20]	Ozone Nitrogen Dioxide	50ppb-1ppm 55ppb-100 ppm	Virgin AC types Treated AC types Activated alumina Zeolite
Kholafei [10]	Toluene Toluene, p-xylene, n-hexane,2-butanone mixture	10 ppm 5 ppm of each	Granular activated carbon
Haghighat et al. [28]	Toluene	4.32 µl/min	Fibrous activated carbon types Granular activated carbon types
Haghighat et al. [29]	Toluene Cyclohexane Ethyl acetate	50 µl/min 50 µl/min 50 µl/min	Granular activated carbon types

They also validated the proposed model with laboratory test data for toluene, decane, hexane, butanone, iso-butonal, tetracholorothylene and d-limonene. Foster et al. [24], examined the VOC (n-butane, acetone, benzene) adsorption performance of various activated carbon filters with different specific surface areas (900, 1610, 2420 m^2/g) with the aim of optimizing adsorption of VOCs on activated carbon. According to the test results, as the specific surface area of the activated carbon fiber increased, the amount of adsorbed contaminant gas was also increased. In contrast, at low concentrations, activated carbon with smaller pore volume adsorbed the greatest amount of contaminant gas. It was emphasized that micropores rather than the larger macro and mezo pores are preferentially filled at low relative pressures. As a result, micropores are responsible for adsorption low contaminant concentrations. The change in adsorption capacity of the adsorbent with pore size was further demonstrated with Dubinin-Radushkevich equation.

$$W=W_0.\exp[-(A/\beta E_0^2)] \quad (2)$$

$$A=-\Delta G=RT \times \ln(P_0/P) \quad (3)$$

This equation was developed to describe the adsorption characteristics of carbon originated, microporous materials [25]. In equation 2, W is the volume of adsorbed gas for per gram carbon, W_0 is the micropore volume (cm^3/g), β is the similarity coefficient, E_0 defined as characteristic adsorption energy for a standard adsorbate. In Eq. 3, P_0 is the adsorption saturation pressure, P is the desired pressure value, and R is the universal gas constant. Safari [7], investigated the lifetime of a granular activated carbon sorbent filter in her study. An experimental study was conducted in four stages. First, n-hexane was added to the dry air, and the mixture was sent to the sorbent filter. In the second case, methyl-ethyl-ketone and dry air mixture was sent to the sorbent filter, and the adsorption performance was examined. In the third case, both of the contaminant gases were added to the dry air, and the mixture was passed through the sorbent filter. In the last case, the performance of the filter was examined by adding both contaminant gases to the moist air. For those four different cases, the lifetime of the filter was determined both experimentally and with the help of an appropriate mathematical model. According to the results of the study, it was observed that contaminant gases with higher molecular weight (such as n-hexane) were adsorbed more in the filter than the gases with lower molecular weight (such as methyl-ethyl-ketone). The lifetime of the filter calculated with the selected mathematical model is very consistent with the test results for single contaminant gas cases, and the relative error is calculated less than 10%. However, for case 3 and 4, relative error between selected mathematical model and the experimental results is calculated approximately 25%.

Although low cost and high adsorption capability make activated carbon one of the most preferred adsorbent material, micropore structure (<2 nm) of activated carbon may slow the transport velocity of VOC molecules in some cases. Wang et al. [26], investigated VOC adsorption performance (benzene and hexane) of mesoporous activated carbon with larger pore volume and higher specific surface area. They concluded that, since that large pore volume can be used entirely, high adsorption amounts were achieved for different VOCs despite their molecular size differences. They highlighted the superior adsorption capacity of mesoporous adsorbent materials.

Zhang et al. [5] conducted a literature review on the latest technological developments related to VOC adsorption. It was emphasized that VOC adsorption is very complicated and depended on many different factors. According to this study, the most important factors controlling VOC adsorption onto carbon materials are;

- **Structure of the adsorbent material:** Structural factors of the adsorbent material that impact VOC adsorption are the specific surface area, pore size, and bulk density. It was emphasized that the larger specific surface usually means greater adsorption capability. There are also some modification methods for enlargement the surface area of adsorbent materials. However, some of them might destruct surface form and decrease adsorption performance. It was also highlighted that in case of pore size, it is better to conclude as optimal adsorption occurs where pore size fits the adsorbate size; as a result, in some cases, mesopores are more advantageous for VOC adsorption, in others micropores are much better especially for small molecule VOCs.

- **Structure of the adsorbate gas:** The structure of the adsorbate gas is also crucial for adsorption performance. In the article, it was emphasized that contaminant gases with larger molecules have a better adsorption performance with adsorbent materials with larger pore volume. A similar tendency can be observed for VOCs with smaller molecules and adsorbent materials with smaller pore volumes. The boiling point is another critical parameter for adsorbate gases. In the article, it was highlighted that contaminant gases with higher boiling points would be preferentially adsorbed more than those with lower boiling point. Additionally, the molecular weight is another important parameter for adsorbates. Adsorbates with heavier molecular weight are more competitive than adsorbates with lighter ones.

- **Adsorption conditions:** Temperature, relative humidity, the concentration of the contaminant gas and air velocity play crucial roles in adsorption. In general, temperature and adsorption efficiency are inversely proportional, where temperature increases, adsorption capacity decreases. However, this is not always the same. VOC concentration and gas velocity are other important factors. Higher concentration of pollutants may shorten the breakthrough time. Reducing the air velocity increases the breakthrough time, in many cases.

Since there are different VOC removing methods from indoor, it is essential to choose the most suitable one for the application. Henschel [11], conducted a study to make a cost comparison between granule activated carbon (GAC) filter and photocatalytic oxidation (PCO) method. In this study, it was assumed that VOC generation rate inside a building zone is 5 mg/VOC/hr/m^2 floor area, and the air cleaner must reduce indoor pollutant concentration by 85% to 0.3 mg/m^3. First, granular activated carbon unit is designed and equipped, laboring and disposal cost is estimated with the use of related vendor literature and quotes. It was assumed that granular activated carbon should be replaced at every 3.7 months, at 30% breakthrough in order to achieve the target of elimination of 85% of the gaseous pollutant concentration. The increase in fan energy because of the pressure drop across the granular activated filter is also considered. Similarly, with the goal of decreasing indoor gaseous contaminants concentration to 85%, 2-cm thick, TiO_2 coated ceramic foam photo-catalytic oxidation reactors were designed and initial and labour costs were estimated with the use of related literature. According to the results of the article, it was emphasized that the installation and annual cost of the photocatalytic reactor is 10 times and 7 times higher than that of the activated carbon sorbent filter, respectively. In the article, it was emphasized that massive UV power consumption and cooling unit that removes heat from the UV bulb heat from the air stream are significant contributors to initial and annual costs of the PCO and even in most optimistic scenarios, it is impossible PCO reactors to compete with GAC filters.

Since breakthrough time of the adsorbent depends on many parameters such as environmental conditions, air flow rate etc., it is not sufficient enough to decide the most suitable adsorbent material for an application. As a result, Xu et al. [19], developed an approach to select the most suitable adsorbent material to adsorb contaminant gases with considering external diffusion, inner diffusion and inner surface sorption. With the new parameter designated as $V^*_{a,c}$, they defined the volume of purified air divided by the volume of adsorbent material. Sorbent filter with the highest $V^*_{a,c}$ value has the best performance to remove VOCs. Han et al. [20], conducted an experimental study to investigate whether sorbent filters which exhibit good adsorption performance with high contaminant gas concentrations also perform efficiently at low contaminant gas concentrations. They selected ozone and nitrogen dioxide as contaminant gases. They kept the ambient temperature constant at 23+1 ˚C and performed the measurements of 12 air ducts simultaneously. Both low and high concentration contaminant gasses passed through sorbent filters inside the air ducts, and concentration measurements were made inlet and outlet of the air filter with the help of multi-gas monitors. According to the results of the experiments, activated carbon filters adsorbed ozone better than non-carbon filters. Similar results were obtained in experiments with nitrogen dioxide gas. Activated carbon sorbent filters have a much better adsorption capability than non-carbon filters. Based on the results of the experiments, low concentration and high concentration adsorption performance of sorbent filters were consistent. Kabrein et al. [27], investigated the application of a combined filter in office buildings to eliminate both dust and particles and contaminant gases. In their work, they used a combined filter, which consisted of a sorbent filter with activated carbon material for VOC removal and particulate filter for dust removal with the aim of increasing air quality and decreasing energy consumption for ventilation. Experiments were conducted in a space that represents a typical office room. In accordance with ASHRAE 62, the exhaust air taken from the office unit is passed through the combined filter, and sent to the mixing chamber, and mixed with fresh air and then sent back to the indoor environment. With the help of particle measurement device and gas monitor, the contaminant concentrations at the inlet and outlet of the filter were measured, and filter efficiency was determined 3 months and 6 months after the application (Eq. 4).

$$EF=(C_{in}-C_{out})/C_{in} \quad (4)$$

The filter efficiency is calculated as in equation (4), where C_{in} and C_{out} are the contaminant concentrations at the input and the output of the filter respectively. According to the results of the article, filter efficiency of capturing PM_{10} particulates was 90.76%, while 89.25% was found for the $PM_{2.5}$ particulates. It was also emphasized that the measured pressure drops of the combined filters are quite low compared to the conventional air filters. However, in this study, there are not any statements regarding VOC concentration measurements and sorbent filter efficiency.

Haghighat et al. [28], examined the adsorption performance of 12 different, fibrous and granulated activated carbon filters with the help of an experimental setup. Experimental setup was made of galvanized steel and consisted of a closed loop circular air channel of 0.1 diameter, a fan that circulates air flow, sorbent filter bed, an anemometer to measure the air velocity, injector pump for the addition of toluene gas to the air flow, gas sampler and multigas monitor. The experiment continued until the filter reached 80% breakthrough rate. Four different fibrous filters were tested and breakthrough time, in order to reach 80% breakthrough rate, was compared. According to the results, the filter with the largest specific area gave the best performance since the breakthrough time is the longest when compared to the other filter types. Accordingly, it was concluded that sorbent filters with high specific area perform better. In the 3rd stage of the experiment, adsorption performance of the different type of granular activated carbon filters was examined. Results of the experiments showed that 100% activated carbon filters perform best. For the case of activated carbon filters impregnated with potassium hydroxide, as the content of potassium hydroxide increases, toluene gas adsorption performance of the filter decreases.

Haghighat et al. [29], also examined the VOC (toluene, cyclohexane and ethyl acetate) removal performance of various activated carbon filters (three virgins and five impregnated) at different relative humidity values (30%, 50%, 70%) experimentally. Experimental results showed the adsorption performance variation depends on the type of granular activated carbon type, VOC type and different relative humidity levels. For the case of granular activated carbon (GAC) type, test results highlighted that virgin GAC filters have better adsorption performance than impregnated GAC filters. For the case of the effect of type of VOC on adsorption performance, test results showed that filters adsorbed toluene almost 2-3 times more than ethyl acetate and cyclohexane. Moreover, for the last case, it was concluded as adsorption filters perform better at low humidity levels. However, it was also highlighted that increasing humidity levels might result in favorable effects on hydrophilic and adverse effects on hydrophobic volatile organic compounds. As a result, removal efficiency dropped with increasing relative humidity for toluene and cyclohexane, and removal efficiency increased with increasing relative humidity levels for ethyl acetate.

Kholafei [10], examined the performance of activated carbon filters in the granular form. He conducted experiments in two stages. In the first stage, he changed the depth of the adsorbent bed and measured the toluene adsorption performance of the filter. In the second stage of the experiments, he kept the depth of the bed as constant (5 cm) and passed a mixture of contaminant gases, through the filter. The test results showed that gases with higher molecular weight could be easily attached to the adsorbent surface. As a result, it can be concluded that heavier gases can be adsorbed more. The breakthrough time of toluene is much higher in the first set of experiments when compared to the second set. This shows that toluene adsorption performance of the filter is better when a single gas is passed through. When a gas mixture passed through the filter, adsorption performance of toluene worsens. Lastly, he compared the test results with the analytical results he found with the Wheeler-Jonas Model and the results were consistent. Wheener–Jonas model offers the estimation of breakthrough time in a simple correlation.

$$t_b = \frac{M.W_e}{Q.C_{in}} - \frac{W_e.\rho_b}{K_v.C_{in}} In\left(\frac{C_{in}-C_{out}}{C_{out}}\right) \quad (5)$$

In this equation, t_b refers to breakthrough time (minute), M is the weight of the carbon material in the bed (gram), W_e refer to adsorption capacity (g_{voc}/g_{carbon}), $C_{in,out}$ refers to upstream and downstream concentration of the contaminant, Q is the volumetric air flow (cm^3/min), ρ_b is the carbon density (g/cm^3), and K_v is the adsorption rate constant (min^{-1}), respectively.

3. General Evaluation and further research directions

In order to fully understand the performance of sorbent filters, conducting field testing is inevitable. However, most studies in the literature were conducted for a single contaminant gas. Since there are numerous VOCs can be found in indoor air, further researches should be conducted to investigate the performance of sorbent filters on capturing VOC mixtures. In addition, there are not enough studies regarding magnitude of pressure drop occurred in the system after applying sorbent filters. Further researches should be conducted on the subjects as follow:

- Since there is more than one pollutant in the air, more field testing should be conducted for gas mixtures.
- More experiments should be conducted regarding real indoor concentration (ppb) levels.
- New carbon materials should be developed for better adsorption capacities.
- More studies should be focused on decreasing the pressure drop through the filters and decreasing the initial cost of the sorbent materials.

4. Conclusions

VOCs exist everywhere especially in the indoor environment and they are extremely hazardous and directly affect the health of building occupants. Exposure to various VOCs may cause eye, nose, throat irritation, leukemia, immune system abnormalities, neurological disorders, respiratory illnesses etc. As a result, air purification systems are getting more attention every day. Between all VOC removal technologies, sorbent filters are the most popular and common ones. In this study, the most critical factors that effects sorbent filters' efficiency are discussed. The results of this article are summarized below:

- Between all adsorbent materials, carbon originated adsorbent materials are the most effective ones due to their larger specific surface area. As a result, activated carbon filters adsorb better than non-carbon filters.
- At low concentration experiments, adsorbent media with micropore structure have better adsorption capacity whereas, at high concentration experiments, adsorbent media with mezo porous or macroporous structure have better adsorption efficiency.
- A sorbent filter may show high adsorption efficiency for a particular contaminant and may show a lower efficiency for another. Adsorption efficiency depends on many different parameters.
- Testing for a single contaminant would not give the same results as a mixture of gases also containing that particular contaminant.
- Contaminants with higher molecular weight are adsorbed more in the filters. Also, they are more competitive than gases with lower molecular weight.
- With the existing mathematical models, it is easy to estimate efficiency or breakthrough time of a single contaminant. However, gas mixtures are more complicated, and in most studies, mathematical modeling results and experimental results of the gas mixtures are not very consistent.
- Adsorbates with high boiling points are more competitive than adsorbates with low boiling points.
- With increasing relative humidity levels, adsorption efficiency of hydrophilic VOCs also increases, while adsorption efficiency of hydrophobic VOCs decreases.

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Some aspects of historical monument buildings central heating

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Abstract. The monument buildings are special buildings which were not originally designed to be heated to the required parameters nowadays. Old solutions for central heating of such buildings were based on the use of low pressure steam as a heat, with natural return of condensate and use of cast iron heating radiators, or natural running hot air. In the performance halls, the warm air was introduced at the base of the seats and was discharged at the top thereof, or was introduced through the channels stipulated in masonry. Churches, most of the time, they were not equipped with heating systems. This work intends to analyze the main modern solutions for heating historic monument buildings, that does not affect their character, examples applied to some buildings in Romania, the Transilvania County, to which the authors have had important contributions .

1 Introduction

Most of the historic monument buildings were either unheated (eg churches), or equipped with local or central heating systems without meeting the comfort requirements we are accustomed to today.
When it is desired to rehabilitate historical monument buildings, attempts are made to obtain indoor thermal comfort parameters as close as possible to current requirements, taking into account the existing constraints on such buildings.
The present paper aims to analyze the solutions adopted for the heating of 4 historical monument buildings built in the 19th century, related to the rehabilitation projects, to which the author contributed.

Banffy Castle in Sancrai, Alba County

2. Technical solutions

The technical solutions for the heating of the four buildings will be presented..

2.1 Banffy Castle in Sancrai, Alba County

The construction of Sancrai Castle began in the early 19th century, in the Renaissance style, but the subsequent expansions brought baroque and neoclassical elements. The historical documents indicate the completion of the works in 1805. It was successively owned by the noble families Kemeny and Banffy in Transylvania.
The building has been undergoing changes over time, and in the period 1947-2005, it has been designated as a center for social assistance for children with disabilities.

From 1997 until 2011, when the restoration work began, the building was abandoned. The construction has a built area of 781 square meters.
The basement of the building is made of natural brick, dating from the first stage of the castle's construction.
The space has a kitchen, hallways, bathrooms, exhibition spaces, warehouses.
Ground floor includes conference rooms, halls, warehouses, sanitary groups.
The attic, which was newly created, in the attic space, with the rehabilitation, includes a generous conference room, office, sanitary groups.
The existing heating system before rehabilitation was physically degraded, with a long life span, not working.
A new heating system was constructed, with cross-linked polyethylene pipes, buried, in a basement protection tube

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and for aesthetic reasons, from copper to the rest of the rooms.
The boiler house includes 2 gas-fired condensing boilers
In the rooms, the heating is done in the following way: on the ground floor, static, cast iron-like buildings, suitable for this building, which meet the aesthetic requirements of the building, on the underfloor are trench heating, and in the attic and in less aesthetically demanding areas are steel radiators.

2.2 George Cosbuc Municipal Cultural Center Bistrita

The building is located in the city of Bistrita, Albert Berger street, no. 10.

The building was built in 1893, following a project by Viennese architect Peter Paul Brang. It includes a large showroom, and 3 smaller halls, offices and spaces for various group activities. It is built on 3 levels

George Cosbuc Municipal Cultural Center Bistrita

The building is on the Historic Monuments List and is part of the protected city complex. Exact dates from the beginning of the construction of this cultural institution can not be specifically stated, because documents that would prove this are hardly to find.
The building spans three levels (S + P + 1) on a compact rectangular plane
The initial ventilation and heating solution provided a system through which the air was captured through the tunnels located under the basement of the building, through the rooms where it was heated by means of some heat registers of the pipes. By heating the air, the difference in pressure required by the thermosiphon effect is achieved. For the handling of treated air and recirculated air, masonry tubes were used.
Following the subsequent work on the building, this facility was demolished, the air treatment rooms were demolished, and the wall ducts and fresh air capture tunnels were dismantled.
Due to the specific problems imposed on this building with the last rehabilitation, the existing ventilation system used the existing ductwork and, where these are not sufficient, or by the initial modifications to the objective, the tubes disappeared to fit the additional ductwork and were used masking panels.
Existing ventilation ducts and tunnels were released from debris, the formed structures that obstructed their section were refurbished by cleaning, disinfection and protection works.
With the new technical solution, in the showroom, the air that passes through a treatment plant is filled with existing rooms under the stage and gradings, rooms that function as overpressure chambers.
The air preparation is provided by the air-handling units that have been installed in their spaces and the circulation of the fresh air from the outside, the recirculated air and the treated air is done through the rectangular-shaped tubing of the same size as the connections to the objects existing fan coils or tubes).
The calculations resulted in a fresh air volume of 11000 mc / h, and for cooling a thermal output of 137.5 kW.
For air conditioning, the heating medium is warm water, and the cooling medium is cooled water prepared in the cooling unit.

2.3 Lucian Blaga National Theater Cluj-Napoca

The project deals with the works for the heating installations at the "Construction and installation capital repair at the Lucian Blaga National Theater in Cluj-Napoca". The technical documentation was drafted in 2002 and was revised in 2007. Unfortunately, the execution of the works has not been done until today.
The building has a height regime of S + P + 2E. Rehabilitation of indoor installations is necessary because the construction is old and they are physically and morally wasteful.
At the moment, ventilation and thermal comfort are provided in the showroom with hot air distributed through a pressure chamber located below the showroom, with the discharge holes located under the seats in the hall. The extract air is discharged through a discharge hole located in the ceiling of the showroom, which is provided with a butterfly-type circular valve, with a mechanical manipulator.
The internal heating system with cast iron radiators used low-pressure steam produced in boilers. Entrance halls and adjoining showrooms, as well as other spaces where spectators have access, are fitted with cast iron radiators. They are under-dimensioned in relation to the heat losses of the respective spaces, as a result of which there is a feeling of cold in the cold season. The heating of

actors, rehearsal rooms, offices and administrative rooms is also done with cast iron heaters. Many of these heaters have an advanced degree of wear, some of which are even out of use, and various improvisations have been made instead. Under these conditions, the distribution system is unbalanced and can no longer operate at full capacity. Warming up of warehouses is currently taking place in heating registers, physically and morally outdated.
The Euphorion Hall, located at the basement of the building and arranged as a showroom, is heated by two Split Air Conditioners, which, because of their empirical choice, can not cover the room's heat demand and due to overloading they lead to high electric energy consumption.
The existing boilers produced low-pressure steam for both heating and hot water preparation. Steam for heating was produced in the two existing boilers running on gas, with a capacity of 460 kW each, which were in good condition. Steam for the preparation of hot water was produced in a boiler with an advanced degree of physical and moral wear. The hot water supply was made in a horizontal coil with a coil which no longer provided safety due to the high degree of wear.
Meanwhile, the thermal plant has been rehabilitated and moved to another place, so as not to be located under crowded spaces. Steam was quenched as heat, at this time hot water is used.
Although the building rehabilitation project was completed in 2007, the execution of the works has stalled, rehabilitating only the exterior of the building.

2.4 Union Hall Alba Iulia

The Union Hall building has the height regime S + P + E and it is situated in the locality Alba-Iulia str. Mihai Viteazu nr. 12, Alba County. The construction was originally built between 1898 and 1900 as a military casino (Casino) for the local military garrison ceremonies. It had from the beginning a monumental character marked by the romantic style of the end of the century and the Western-European influences. Between 1919 and 1922, after the Great Union of 1918, the building received modifications that amplify the building's sparkling character by increasing its size, attaching a huge portal to the entrance, interior decoration with gold leaf and monumental frescoes (portrait of King Ferdinand and Queen Mary), oak leaves, etc., reasons to remember the great event of the National Union. Between 1967 and 1968, the building is redecorated and refunctionalized, being part of the exhibition circuit for the 50th anniversary of the Great Union, inaugurated on November 28, 1968. Redevelopment has destroyed the original frescoes, replacing them with others that had to glorify the existing regime at that time. Still structural modifications were made in concrete to body A. Currently, the building is intended for the museum circuit that is unfolding on the ground floor, and partially on the basement basement. The latter also owns the majority of museum stores.

The side wings are intended for the southern conservation, restoration of museum objects, books, offices, archives and archaeological sites, and the northern side to the educational spaces, but also to the archaeological institute.

The heating of the studied building was ensured by the existing boilers in the "thermal power plant" destination of the National Union Museum, a building separate from the studied building. The boiler was equipped with 3 boilers, each with a thermal output of 270 kW using gas. From there through the pipes installed in the ground, the heating of the Unirii Hall and of the other rooms was ensured, the Unirii Hall Building not having its own boilers. Also, the capacity of the thermal power plant is under-dimensioned, not insuring the thermal agent demand. the 2 buildings, the Union Museum and the Union Hall. The existing heating system before rehabilitation shows a high degree of wear and tear, the operation was faulty, therefore the required thermal comfort parameters were not guaranteed, and from aesthetic point of view it was totally inadequate. The heating system was totally redeveloped.

The thermal plant in the National Museum of the Union was equipped with a boiler to serve only the building of the Union Hall.

The heating pipes between the central heating system of the Union National Museum and the Union Hall building have been replaced with new preinsulated pipelines, mounted directly into the ground. At the entrance to the studied building was installed a fully equipped distributor with collectors. In order to ensure a better circulation of the heating medium and necessary comfort conditions, pumps have been installed on the newly designed heating circuits.
All heating radiators have been replaced with new steel and cast iron radiators. In the Unirii Hall were fitted skirting heating, covered with grills and adjacent to the cast-iron radiator windows. In the rooms with the destination "exhibition" were placed cast iron heating radiators. Inside the hall there were also retro-cast iron radiators in order to be in tune with the building's destination and for a pleasant visual impact.
The heating system was made of copper pipes.
Static radiators have hot water as heating medium.

3. Conclusions

The heating of monument buildings can not always provide thermal parameters similar to a typical building, due to the limitations of their specificity. Most of the time, the tire of these buildings can not be provided with thermal insulation, so heat loss can not be greatly reduced. Also, the aesthetics of these buildings can not be changed by inappropriate technical solutions. Therefore, when choosing heating solutions, the existing constraints must be taken into account.

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Framework for a transient energy-related occupant behaviour agent-based model.

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Abstract. Simulation of occupant behaviour (OB) is a topic considered to be crucial for further advancement in building performance simulation (BPS). Previous (statistical and stochastic) approaches in attempting to re-create in-building human activities were not sufficient to capture subtle activity changes with significant influence on building energy performance. Development of an occupant behaviour agent-based model seems to be a promising direction because such an approach allows deploying a time-dependent, reactive model. The main purpose of the agent will be its presence in the simulated thermal environment and its ability to react once the thermal conditions are outside its established thermal comfort zone. Herein, the agent model has to provide a personification of its thermal comfort condition. To introduce such features for OB simulations in BPS, a new model framework was introduced. It will enable probing of the simulated state of thermal conditions and the "sensing" of it. If conditions are inside the required limits of thermal comfort, the agent will not react. Otherwise, if the state of the agent's thermal comfort crosses its threshold values, it will try to adjust its thermal conditions using local adjustment possibilities, e.g. simulated adjustment of the set-point. The fundamental input data for this agent model can be obtained by use of the depth registration camera for direct observation of occupants. Continued monitoring of occupant reactions in various thermal conditions will be a foundation for the development of the occupants' thermal profiles. Storage and compilation of such information will contribute to the detection of the parameters that are mandatory for the development of the transient energy-related occupant behaviour agent-based model.

1 Introduction

According to the newest International Energy Agency annual report, thirty per cent of the globally produced energy is consumed in buildings [1]. A vast portion of this resource is explicitly consumed to match up with the expectation of its users. For the past forty years, researchers have investigated demand and the way the users exhaust energy. During that time, the topic has become mature enough to be considered a separate branch of scientific field related to the understanding of building energy performance. One of the milestones in the field of occupant behaviour studies was a work presented by Fanger [2]. His work on the presented ideas and application proposition initialised the process of describing human interactions with the indoor environment. Still, due to the multidisciplinary nature of energy-related occupant behaviour studies, it is difficult to develop a model that could apply to any and all conditions. Similar obstacles appear when it comes to a simulation of the different types of buildings. Lack of accuracy in existing models was noticed and pointed out in the work of Turner et al. [3]. In this, a comparison was made of the energy consumption results from building energy performance simulation and consumption during operation time (after it was built). Comparison have shown that only 30% of investigated buildings consume a similar amount of energy. It is possible to conclude that one of the reasons for such a mismatch is caused by underrating occupant influence on building energy consumption. It seems that the current resolution of monitoring occupant activity is not sufficient to capture energy-meaningful phenomena. The basic description of the occupant as a system user has to be more comprehensive, and it should allow the inclusion of a broader spectrum of occupant/building interaction. Such a conclusion can be made after reviewing Yan et al. [4]. As put forward by Hong et al., ontology is the classification of occupants regarding their energy-related behaviours [5-6]. The approach they present segregates a particular occupant's actions with regard to common behaviours that have influence on building energy performance. Among these are switching on/off the lighting or adjusting windows blinds. Such studies are a step towards transient agent-based modelling wherein a single agent represents the behaviour of one person. However. to gain access to the more comprehensive overview of occupant's actions, it is a necessity to understand their demands and needs. As Wagner et al. notes, this can be done by way of statistical analysis of the group or occupancy state coupled with multi-sensing techniques [7]. Additionally, occupant-related studies should be supported by survey and interviews that allow a description of the personal preference of the particular person. The previously conducted work of Dziedzic et al. shows promising results regarding developing precision in indoor occupant profiling via depth registration camera [8]. A good example of the broad spectrum of data collections was shown in Jamrozik et al. [9]. Herein, collected observations of the human reactions to the thermal environment were enriched by inclusion of occupant socio-psychological data. With such a multidisciplinary approach, it is possible to track occupant motivation for chosen action. A precise socio-psychological description allows compilers to gather, cluster and detect trends among occupant personality. Hence, capturing data holistically regarding energy-related drivers can be used as an additional asset in the development of an action-driven model of occupant behaviour.

Gaetani et al. provide a selection of models that are "fit-to-purpose" in order to show the current developmental level of occupant behaviour modelling [10]. Based on the provided [10], it is possible to notice that most of the developed occupant behaviour models are focused on one or only a few particular issues regarding occupant behaviour. What is also notable is the lack of communication among the model developers and that this has brought about overlaps and absence of cross-modal communication. The idea of "fit-to-purpose" propagates understanding that each application has its optimum workflow resolution, and in the present, there is no solution for scalable applications regarding occupant behaviour modelling. Similar conclusions were drawn in a work of Bing et al. [11]. The main challenge related to occupant behaviour modelling, in general, is operational resolution. Occupant activity that could be considered as significant regarding energy use can be triggered by an event lasting only a few seconds, for example, a draft caused by the sudden opening of a closed door. Yet, exposure to a particular "incident" may have long-term implications, like adjustment of the thermostat. Capturing such phenomena requires a high observational resolution of occupant behaviour. Previously developed models were not capable of portraying such events, because their initial resolution was beyond the ability to capture such an event.

The main disadvantage of any available OB simulators is that all of the spectra of actions are driven by probability or stochastic process. This means that particular occupant activity has no relation to the particular order of performance. Thus, there is a possibility to develop a "story-driven" or "action-reaction" understanding of simulated actions. This has come about by the input data for which previous models were compiled. The origins of limitations within previously developed models were engendered by the resolution of the data that they developed. Current models are capable of performing well on simulations that involve a group of occupants, such as shared lunch, or general occupancy of a room. Unfortunately, trying to identify a reason, meaning or driver of connected actions at the individual scale is impossible from such simulation results. Therefore, the actions triggers are also unknown. To fulfil all of this uncertainties, it is necessary to re-develop occupant behaviour models so that it is possible to explore the reasoning for a particular action. To reach all of the expectation regarding model features, the need is to develop an agent-based model. Here, the simulated agent represents an occupant and it is equipped with an embedded complex behavioural engine capable of simulating reactions to the various conditions of the indoor environment.

The main aim of this paper is to highlight the core milestones of the model development process. Due to the complex structure of the proposed, developed solution, it is necessary to highlight potential outcomes and to open dialogue with the broader scientific community. The proposed framework of the model does not aim at the promotion of particular software or application. This work aims only to introduce to the wider audience, the possible structure for simulation of indoor occupant behaviours.

2 Framework

With regard to heating and cooling, to reach the collective expected requirement that allows generating a contextual response to the simulated actions, the simulated agent has to experience similar thermal conditions. In bringing this about, it is necessary to probe data drawn from the constantly changing physical properties of the indoor environment. This means that the model has to operate on transient indoor environment proprieties. This data can be acquired from a computational fluid dynamics (CFD) simulation or through a multi-zonal model. Because both of the simulation methods consume a significant amount of computational time (at least for now), it is recommended to perform a series of parametrical studies beforehand. As the simulated occupant behaviour relays on reaction to the on-going environment condition, if environmental and physical properties are pre-simulated and the transition between states kept in order, such properties will not have influence upon the occupant behaviour simulator. This implies that while the environmental conditions will influence the occupant behaviour simulator, the simulated agent will not have influence upon the environment and the conducted actions by the agent will do so. Because this approach is based upon assumed model features, this approach is referred to as the 'building occupant transient agenda-based model' (BOT-ABM). The purpose of the model is to simulate more realistically the usage of the various energy resources. The agent (i.e. the simulated occupant) is brought into being by a collection of modules that re-create the routine activity of the building users. Herein, each individual module is responsible for the simulation of one specific behavioural feature. Moreover, all of the used modules operate in the same temporal resolution, and the general model architecture is designed in a parallel structure. As the solving of one particular time step will require the calculation of each activated module, this will increase the calculation time of each

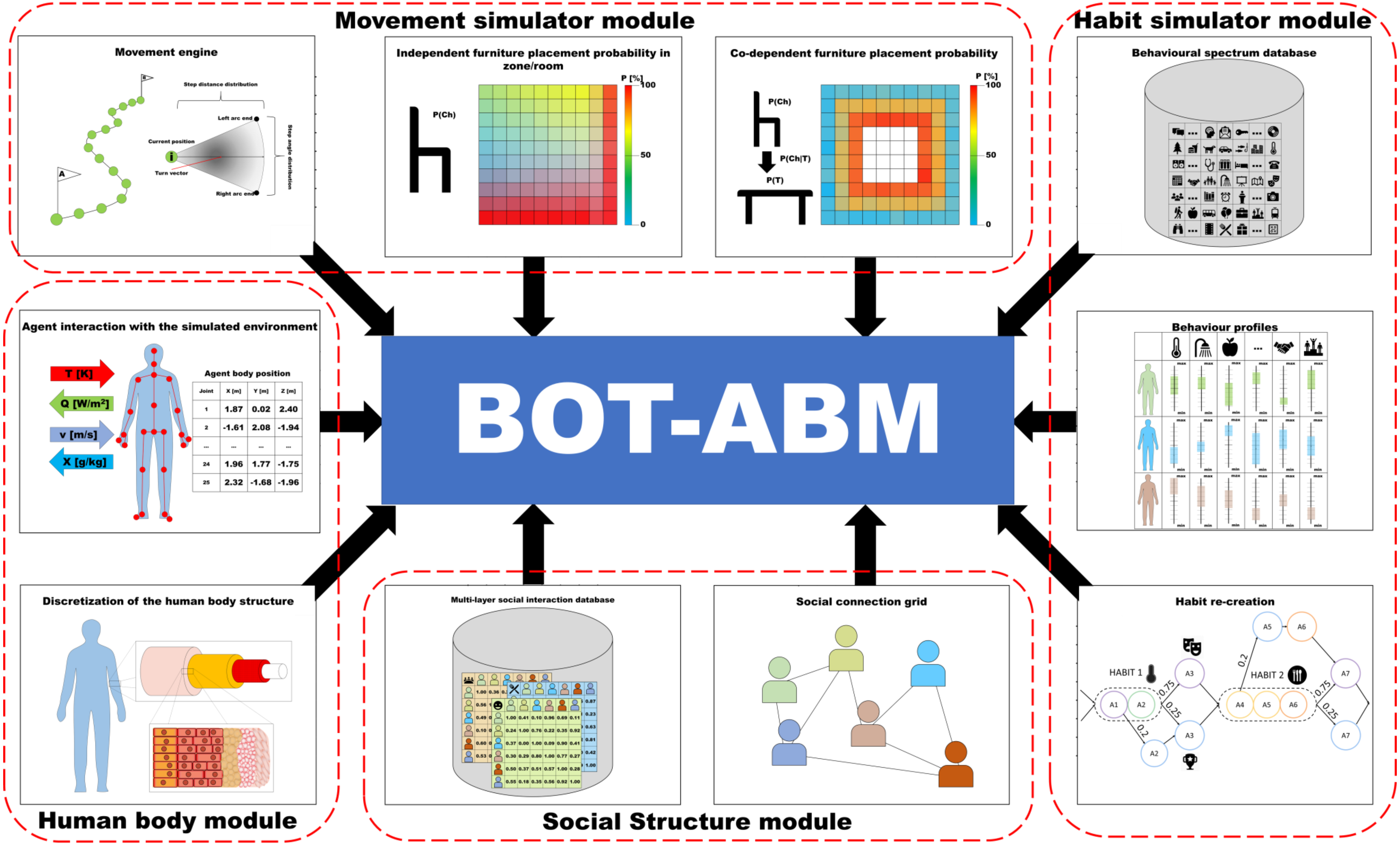

Fig. 1. Building occupant transient agent-based model

time step, but it will allow cross-communication between each of modules. Such a structure enables the development of co-depended scenarios where one particular phenomenon, such as spontaneous exposure to a cold draft, might generate a variety of BOT-ABM reactions. The general structure of this in the form of an information flow chart is presented in Figure 1. Individual module functionality will be briefly explained

3 Modules

3.1 Movement simulator module

One essential feature of occupant activity is the ability to move around. Nevertheless, this occupant behaviour feature is not explored enough with regard to applicability in building performance simulations. In doing so, however, the simulation of direct movement will require a radical incrementation of the time resolution, which, subsequently, will increase required computational power need.

In contrast, simulation of all the transitions allows a precisely described occupant exposure to the indoor environment. It green lights the gathering of data about the occupant position in time; therefore it allows implementing the module that simulates interaction with an indoor environment. The full probing of environmental data will be brought about through the collective response of individual models. This part of the model provides for discretised positioning and transition of the human body, in time.

The Movement engine module itself is solely responsible for simulating the natural transition between point A and B. It will operate through any defined polygon, but to re-create realistic usage of the building, it has to operate within a furnished layout. Once the floor layout is fully designed, the simulated agent actions will be relayed to general placement. Herein, the furniture setting will be used as a coordinate system for the agent movement. The agent will then perform the intended performance task, and will operate and interact with appliance in the same manner as would the building occupants. Data from such appliance usage could be collected via analyses of the plug load or through various Application Programming Interfaces (API). If the layout simulator is available, it will be possible to simulate the layout scenarios, to test various scenarios and to investigate which is producing the most energy efficient or most comfortable settings. Furthermore, it may allow testing how floor layout operational changes (like adding an extra, internal wall) may influence indoor air conditions.

Development of the layout generator has to be paired with the development of an extensive library of appliances and furniture designed for this purpose. This dataset has to hold information about appliance dimensions, heat map localisation (probability of the placement on a floor layout), potential activities that it may be used for and the zone wherein it is possible to interact within. All of these features are important for precise simulation of the building occupant activity. Appliance dimensions (Length, Height, Depth) and heat map localisation will be used for appliance placement in a simulated layout, and for development of the geometry for final operational air volume. If the study is aiming at a parametrical analysis, the heat map localisation feature will not be used. The list of potential occupant activities will be employed to enable a description of the appliance/furniture purpose, as well as to support the habit simulator and the physical environment sensing module. If the agent has to initialise an action, for example: prepare a meal, there are only a few appliance s that can support the execution of this task. The agent will be instructed to select one of the given options and fulfil the given “task/need”. Once the procedure of appliance selection is done, the agent will find a pathway from its current position to the aimed goal which is the space/area where is possible to for interact to occur.

3.2 Habit simulator module

The purpose of the habit simulator module is to trigger activity. This module will cover most of the essential description of agent personalities and their way of utilizing the space. Description of agent habits will cover a wide range of activities connected with maintaining a portrait of occupant routine and of related activities. Additionally, it will try to include a possible spectrum of irregular activities that are non-explainable or could be considerate as unreasonable. This module will be designed to operate within three separate layers: Behavioural Spectrum, Behaviour Profiles and Habit Re-creation.

The first layer (Behavioural spectrum database) will be used as general database source-set of potential activities. This database will deliver operational space for a selection of various behaviours. Thus, it serves as a pool of possible outcomes that can be triggered by any given condition at a particular moment. The spectrum and source of triggers may vary. These depend on the given situation – whether a sudden change of conditions or scheduled activity or simulated “loss of interest”. The more extensive that this library of activities is, the greater the potential exists to simulate more sophisticated activity. This can be analysed later on so as to improve performance. Every time a simulated action is triggered, it is recorded on a simulation timeline. This activity allows for developing an understanding of the context of each conducted activity. Therefore, it will be possible to analyse simulated occupant behaviour by way of a story-driven method. Such an approach will allow investigating building design that includes sensibility analysis of the potential group of building users, and, hence, an estimate of the potential energy demand that the group may require.

Second layer (Behaviour profiles) will focus on an individualization of the activity, by generating an individual behaviour profile description. Each particular activity has to be described by the following features: the conditions that triggers it, the spectrum object or tool that it has too interact with, the time that is consumed in conducting it, the mechanisms that must be operated, and the gain achieved. All activities have to be segregated into two sub-categories, cumulative sum-based or threshold-based. The functionality of the activities that are cumulative sum-based rely on the fulfilment of the task. Each utilized time unit of the selected task performance increases the cumulative sum. In contrast, threshold-based activities are triggered if the threshold of acceptance of the simulated conditions is crossed. Both of this actions trigger engines that control agent performance. Attributes can be defined by the selected trigger engine and described by its operation values. For example, the simulation may test appropriate occupant reaction on a spectrum of indoor air thermal conditions. If the simulated occupant is "sensing" that the indoor environment is beyond its thermal acceptance level, it will react. Its action will aim at a return to the "comfort" state. To do so, it will have a spectrum of potential actions that will provide a return to the acceptance level of a given condition. To avoid infinite feedback loop, each conducted activity will have a "death band" functionality. Therefore, the simulated agent will be described with a certain acceptance reaction latency.

The simulated behaviour of the agents will require behavioural specification. Each agent has to be described by the constraining values of their "personal" preference with regard to the global "character" description. This part of agent description will be held by the behavioural profile layer (second layer). Here, selection of the "basic" human needs and desires can be transferred from the field of anthropology, wherein the study of human behaviour modelling is a scientific pursuit. Through accessing this branch of natural science, it will be possible to define the fundamental features of occupant needs. The most applicable model that fits into the proposed model structure is that suggested by A.H. Maslow [12]. Pyramidal structure describing Hierarchy of Needs can be used as a template and be explored in terms of its applicability in building performance simulations. The selection of appropriate behavioural (anthropological) model and its modification, however, will not be elaborated upon in this paper. Whatever the anthropological model selected/modified for BOT-ABM performance purposes, all of the features included in the description of occupant profile must be transferred to the Behavioural Spectrum layer of the habit simulator. This procedure will allow for direct communication between all of the layers included in this module.

The third layer (Habit re-creation) of this module will be responsible for a re-creation of occupant habit and daily routine. By way of applying this part of the module, it is possible to simulate a task that can be considered as mandatory, such as going to work or school. Proper usage of this layer will allow to control agent health maintenance and the strategies that are triggered by occupant activities related to hygiene and healthcare. It must be noted that each individual has a routine – a daily rhythm and way of organizing daily activity. The order of the actions taken depends on various conditions like lifestyle, personality or employment. No matter what kind of routine each person follows, the day timeframe limits the amount of actions that person conducts per day. This means that pinpointing this on a timeline and limiting its duration can describe daily activity.

Additionally, as habits are desires expressed through a series of actions, each conducted activity can be considered as being a derivative of habit and routine. The module that is responsible for the re-creation of occupant habit, can be looked upon as a binder for a series of actions. Additionally, as the order in which particular activities are followed plays an important role, this part of the module will hold "recipe" information about each habit. However, BOT-ABM will be designed to follow habit protocols as long as its basic demands, described in the previous layer (Behaviour Profile), are balanced. This layer of the module will keep the agent following a daily routine without pointless wondering in uploaded space, zone or floor layout. It will also allow for tracking the overall understanding of the agent's action purpose.

In attempting habit and routine simulation, there is a vast range of activities that cannot be considered routine or habit. Because their nature is unpredictable, as pointed out by Strengers, there are specific actions that cannot be directly explained [13]. Irregular occupant behaviour is defined as an act wherein the occupant consciously or unconsciously performs an action that does not fit in order or/and timeline of any routine. That is why the core description of conducted actions order cannot be completely fixed - it has to hold space for potential irregularity. To do so, all of the daily routines have to be described via a probability factor. This function is responsible for the scoring of the action inside one routine, regarding holding its order and timeline coherency. The higher the value of this probability factor, the larger the probability of habit re-creation inside the simulation.

3.3 Social Structure module

To re-create building occupant behaviour, it is necessary to include their interaction with other occupants. No matter what kind of building is being simulated, the existence of the social grid inside it cannot be by-passed. Indeed, its magnitude can be only forgotten if the designed space of investigation concerns one individual. In the other cases, the way occupants interact with each other has to be included in the simulation. This module will hold information about the social connection between agents, and it will be responsible for assessing the degree of potential collaboration between each in various tasks/routines. Here, selection of assignment has to rely on a hierarchy of relationship structures inside the simulated space. It also has to allow for agent collaboration, as well as following the grading system of simulation. Of note, the simulation of occupant social network also depends on building purpose. If the simulation targets a residential building, the social connection must consider family structure.

The data about the social network in the observation space can be captured by way of the use of mobile telephone data streams. As shown by Ren, Ye. et al., this makes it possible to obtain information that allows for re-creating the social communication structure of the monitored occupants [14]. However, a combination of various measurement methods may allow developing a better general understanding of social connections in different types of buildings. Once such a knowledge base is obtained, it may be used automatically to allocate specific social networks to the appropriate buildings. Until then, this has to be done via the use of pre-defended networks and application of hierarchy.

3.4 Human body module

This module is responsible for the positioning of the human body inside the simulation environment. Here, a general projection of the human body can be used to probe data from a selected body part or point of the body. This feature can be used to calculate the radiant temperature of investigated body limb/area or the general exposition to airflow streams. The limitations of the probing depend upon the used simulation environment and the embedded equations. The higher the resolution of the indoor environment simulation, the more detailed the study. To simulate human body reaction, it is also necessary to investigate the kind of processes that are happening inside the body. An excellent example of a model that could be used for this purposes is that proposed by D. Wölki, wherein the human body is divided into nineteen parts, each part being composed of a few layers of the human tissue structure [15]. This approach shows promising results, but it has to be improved in terms of simulation of the tissue composition. The current state-of-the art is that this model assumes uniform tissue distribution. To simplify modelling, uniform tissue distribution can be considered a good approximation, but for detailed study, such an assumption might be crucial. To provide a proper response to the habit simulator, the delivered input information has to be accurate in order to prevent agent misinterpretation. Hence, the more recent MORPHEUS model must be explored and assessed for simulation competence [15].

Besides sensing the environment, this module will be responsible for delivering information about agent activity level, clothing level and the related. Such information is crucial for the proper simulation of the energy-related occupant behaviour in buildings. Knowledge about activity level will support indoor environmental simulation by delivering data dynamics of energy relesed by the human body to the investigated space. Additionally, it will be a marker for a proper re-creation of the pendular movement of agent body parts. Simulation of the clothing will be embedded in the same way. It will provide an overview of skin exposure to the indoor environment, but it will also be charged by the response system from the habit simulator module.

3.5 Information exchange and modules hierarchy

Access to all of the features that are provided thru each separate module requires an understandable architecture of information flow. Without a specific order of hierarchy, a collaboration between modules might produce a chaotic representation of the actions without meaning. Centralised structure of the BOT-ABM allows for modular applicability of the whole model, but whole information exchange is via its centralised mainframe. It can be considered as a historical database of the particular agent.

In presented BOT-ABM structure, two modules (Movement simulator and Human body) are responsible for direct interaction with a physical environment. Therefore, these modules are not producing a “decision” impulse for conducting a task by the agent. Both of these modules operate on two-way communication with a BOT-ABM mainframe, but each of these modules has a low position in a decision hierarchy.

Other two modules are responsible for taking care of socio-psychological side of the occupant behaviour. The proposed model structure is aiming at a simulation of the individual occupant behaviour. Therefore, Habit simulator module will play a critical role in a decision hierarchy. This modules are not responsible for the probing of the data from the environment. They accumulates the collected information from the other modules, uses it as an input and process it with a defined personal trades. Generated output distributes information of an adequate response to the other modules.

Hierarchical position of the social structure module is hard to pinpoint directly. It might have a significant influence on a Habit and Movement simulator modules. It is also used as an information exchange port with other agents, which allows for a mutual collaboration of numerous agents while keeping their individual trades. Because the main aim of the BOT-ABM is to simulate individual occupant behaviours, Social Structure module has the lowest hierarchical position.

4 Discussion

The presented paper provides a brief overview of the occupant behaviour simulator that potentially can be used in ~~a~~ BPS. The proposed solution operates upon four different modules - each responsible for one facet of human activity. The main aim of this model is to re-create inside building occupant behaviour. Due to the diverse operating resolutions of human beings and building structures, it is difficult to assume what kind of time resolution is optimal for simulation purposes. From the perspective of the building user, a one-minute resolution could be considered too shallow for portraying their behaviour correctly. On the other hand, same resolution can be considered as too detailed if the perspective is set as annual building operation. Therefore, it is difficult to decide what kind of time discretisation should be acceptable to portray events that could be considered as important from the perspective of the building user. Still, no matter what kind of operational resolution will be selected, the proposed structure allows exploring occupant behaviour phenomena through a multi-disciplinary approach.

Social structure can equally influence building user behaviour as does the sensation of thermal comfort. Therefore, the impact of this attribute cannot be ignored, but there are no available tools that allow for a numerical investigation of such. To by-pass, this issue, the proposed framework introduces a modular model structure that allows for non-invasive editing of the general model. This means that selected parts of the module can be modified, and the general compiler of the whole model will still be able to operate and communicate with the rest of the modules. Such model flexibility allows for a parametrical study of the many variables that must be included in any model. For example, it will allow for an investigation of the impact of the various social networks on energy usage inside a simulated zone/building. The same portion of study examples can be drawn via modification of the other modules.

5 Concussions

This paper is an introduction to the core design of the Building Occupant Transient Agent-Based Model (BOT-ABM). The prescribed format of the paper does not, however, allow for an in-depth introduction of each module functionality, but it is crucial for outlining the most critical features of the model within the overall framework. Therefore, development of such vast human behaviour model requires a multi-disciplinary team and proper feedback from future users. Development of a comprehensive model that capture advance functionalities of building users requires a lot of effort and long-term commitment. Therefore, it is necessary to rely on an existing framework. Presented framework is an effect of the extensive review of existing energy-related occupant behaviour modelling methods. Summarised modelling approaches delivered by Dong et al.[11] and Da et al.[4] allowed to highlight missing pieces in OB modelling and address them. Formulation of this framework can be considered as a result of this investigation which is presented in this paper.

Similar efforts in the formulation of building agent-based model could have been conducted in the past, but there are no records in the available literature. Reasons for such absence is unknown, but it might be suspected that it was caused by problem complexity and lack of proper data. No matter what was the reason, publication of framework proposal will open a new platform to scientific communication and discussion which eventually will lead to the new occupant behaviour model.

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A new test room for indoor environmental quality analysis

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Abstract. A new test room for IEQ analysis is under construction at the University of Padova. The CORE-CARE Laboratory (COntrolled Room for building Environment Comfort Assessment and subjective human Response Evaluation) is a test room of about 18 m^2 equipped with radiant systems on the ceiling, on the floor and on all the walls, except for the area of the windows. Each surface is independently controlled, thus enabling to reproduce a room with one or more cold or warm external surfaces and at the same time a heating or cooling surface. The room is also provided with fresh air with controlled flow rate, supply temperature and relative humidity. At first the test room will be used to evaluate, through questionnaires, psychological and productivity tests, the acceptability of defined factors of local thermal discomfort. Not only thermal comfort will be studied, but also perceived air quality, acoustic and lighting aspects will be considered as well. In the present work, the first steps of the set-up of the test room are presented, from the design phase to the building up, along with a brief presentation of the future research activities.

1 Introduction

Indoor Environmental Quality (IEQ) includes different aspects: thermal comfort, indoor air quality, lighting and acoustics [1]. A considerable amount of literature in the last few decades has recognized the significance of IEQ in response to the increasing desire to enhance human well-being [2]. As a consequence, many researchers are facing the challenge to understand how the different IEQ factors affect human perception of the built environment, health and productivity [3,4]. The research activities can be divided in experimental studies and field studies. In the first case the research is carried out in a test chamber or in a space with controlled environmental parameters and the test panel components are recruited to assess their perceptions of the environment, perform tests and measure their physiological parameters. In the second case the research is carried out in real buildings and post occupancy evaluation is used as main approach.

The widest variety of test chambers for the study of thermal comfort of people in buildings can be found at the International Centre for Indoor Environment and Energy, Technical University of Denmark. In 2004 this centre had at its disposal 12 spaces for studying indoor environments and the impact on human comfort, health, productivity at moderate energy demands [5]. The three oldest climate chambers date back to the 70ies and 80ies. In one of these chambers [6] Fanger studied the limits for asymmetric thermal radiation due to a heated ceiling [7], a cooled ceiling, a heated wall and a cooled wall [8]. The temperature of the surfaces of the room could not be controlled; in the first case a suspended light ceiling was used with an electrically heated plastic foil to control its surface temperature, while in the other cases water-based radiant panels were set inside the room. In 2001 three new indoor environmental chambers for tests with subjects were built, along with a laboratory for the study of air movement in spaces and around humans, and five offices were arranged for field experiments under controlled environmental conditions. The three chambers have the same dimensions (5.4 m × 4.2 m × 2.5 m) and resemble real office spaces, also thanks to the presence of three windows (1.0 m × 1.0 m) facing the daylit hall in which they are placed. The temperature of the surfaces of the chambers cannot be controlled, since they are simply made of steel plate elements with a core of polyurethane foam. The air temperature inside the rooms can be controlled from 10 to 40°C. Different ventilation principles are used in the three chambers (mixing, displacement and piston) with a volume flow rate which can be adjusted continuously from 12 to 170 l/s (24 to 340 l/s in one of the room) and with an outdoor air ratio ranging from 0 to 100%. The three climate chambers were designed for research on thermal comfort, air quality, health and productivity and are suitable also for long-term exposures.

Another well-known facility is the test room of the Department of Architecture Building and Planning at Eindhoven University of Technology [9]. The room dimensions (3.6 m × 5.4 m × 2.7 m) are representative of an office. The temperature of each surface can be individually controlled in the range 11-35°C, allowing to study the effects of radiant temperature asymmetries. A modular system composed of extruded anodized aluminum profiles is used for the surfaces, making the response time short. Two ventilation principles can be applied to the test room (mixing ventilation and displacement ventilation), with a flow rate which can be continuously adjusted up to 170 l/s. The temperature range of the inlet air is 9-45°C and the relative humidity

in the room can be controlled from 30 to 80%. The test room was designed to adequately assess thermal comfort under non-uniform and transient environmental conditions both from a global and local point of view, analyzing also the productivity of test subjects and the differences in physiological responses between males and females [10,11].
In 2016 a new climate room was built at the Technical University of Dresden, as part of the Combined Energy Lab 2.0 [12]. The chamber dimensions are 5.0 m × 4.0 m, with a height of 2.5 m. All the surfaces of the room are made of modular elements with the dimensions of 1 m × 2.5 m. The modules are made of a water-based capillary system placed on a metal plate and the external side is insulated with a polyurethane foam. Temperature sensors are placed on the metal plate to measure the surface temperature. Each of the 18 modules of the walls is made of 3 segments which can be independently controlled in temperature, while the 16 modules of the ceiling and of the floor are made of one segment. Thanks to this kind of modules, the system has a very low response time and a great flexibility. The supply water temperature of each capillary segment is controlled by a three-way valve, which mixes the hot and cold water mass flows provided by the hot and cold distribution networks. The surface temperatures of each segment can be regulated in a range from 10°C to 50°C with a heating/cooling rate up to 4 K/min. The climate room is connected to a ventilation and air conditioning systems with a maximum flow rate of 600 m³/h, which corresponds to an air change of 12 h^{-1}. The air temperature can be regulated in a range from 10°C to 35°C and the air humidity from 20% up to 90%. The air supply and extraction are provided through 4 grids placed in 2 opposite walls of the room. A detailed description of the chamber and the first investigations can be found in [13].
The increased interest which has been paid in IEQ and especially in thermal comfort moved the group BETA-Lab of the Department of Industrial Engineering of the University of Padova to decide to build up a test room to make future analyses on well-being of people, perception of the indoor environment and productivity together with the Department of Psychology. In the present work, the first steps of the set-up of the new test room are presented, from the design phase to the building up, along with a brief presentation of the future research activities.

2 Design of the test room

2.1. General description

The CORE-CARE Laboratory (COntrolled Room for building Environment Comfort Assessment and subjective human Response Evaluation) is currently under construction and should start operating in the first months of 2019. The basic idea behind the test room is to investigate different combinations of indoor parameters to check their influence on the perception of the environment by panels of users. For doing this, it has been decided to keep the environment as much neutral as possible so that it looks like a real office rather than a test facility.
The spaces available for the laboratory were two rooms at the 3rd floor of the Headquarter V of the Department of Industrial Engineering at the University of Padova (Figure 1). The external wall of the test room is East-Southeast oriented. There is no building in front of the test room which can shade the building or can inhibit the external view.

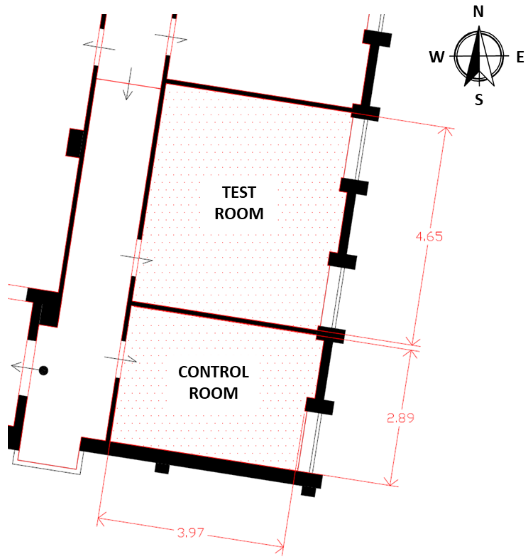

Fig. 1. Planimetry of the test room and the adjoining control room.

The test room, of about 18 m² and 3 m height, is equipped with radiant systems on all its surfaces. Dry radiant systems have been chosen for the ceiling and the walls (excluded the area of the windows), while for the floor a radiant system with quartzite and resin screed has been preferred, in order to have a finished surface without the need of a covering. The supply water temperature of each surface is independently controlled thus enabling to reproduce a real room with one or more cold or warm external surfaces and at the same time a heating or cooling surface. The room is also provided with fresh air with controlled flow rate; air can be controlled in temperature in winter time and in temperature and relative humidity in summer time.
The other room (named control room) is used to house the technical equipment, which consists mainly in:

- 2 primary loops, one for heating and one for cooling;
- 6 secondary loops (one for each surface) with 6 mixing and pumping units;
- 3 inertial tanks (heating loop, cooling loop and chiller loop);
- 1 air handling unit and related air ducts;
- pumps and valves for each circuit;
- control system.

The water of the heating loop is heated in the tank by electrical resistances, while cooling is provided by a chiller placed on the roof of the building. Glycol antifreeze is used in the chiller loop, which is separated

from the cooling loop by means of a plate heat exchanger.
The test room is equipped with windows; therefore the tests will be performed in heating or cooling conditions according to the outdoor environment, i.e. tests will be performed with systems in heating operating conditions in winter and in cooling conditions in summer. New windows have been installed on the external dry-wall to avoid problems during the tests, since the pre-existing windows presented low thermal and acoustical performances. The old windows remained on the external side of the wall and the new ones have been installed on the internal side. Between the two windows new Venetian blinds will be installed, ready to be electrically driven and eventually controlled on the basis of the light illuminance inside the room.

2.2 Radiant surfaces

The design of the radiant surfaces has been be the most critical and challenging phase of the entire project. Dry systems were chosen (except for the floor), and in the case of the external wall the presence of the windows made particularly difficult to find in the market panels with a size which fits the available space. Moreover, it was not possible to choose the same manufacturer for the modules of all the walls since the material was donated. This implicated to deal with 6 different systems which had different pipe diameters (the pipes inside this kind of panels are not standardized), different connectors, different dimensions of the panels, different layout of the structure behind the panels and different laying rules. In this section the layout of the panels and of the hydronic connections of each surface of the room is presented.
As regards the floor, a radiant system with quartzite and resin screed has been chosen. The distinctive trait of this system is the very low thickness of the screed above the clew, which is only 3 mm. Since the dry walls must be installed after the floor, a reduced available surface has been considered for the position of the pipes. The resulting thermally active surface is 17.2 m^2 with 5 loops. The manifold has been placed in the control room because in the test room there was no space available on the walls. The layout of the floor radiant system can be seen in Figure 2.
As regards the ceiling, a system made of plasterboard panels coupled with insulation and aluminum plate diffusers has been chosen. The panels are to be screwed on a structure of metal profiles hang to the ceiling and can be drilled in some marked position for placing spot lights with a diameter of maximum 10 cm. The position of the panels has been studied to allow the positioning of 2 linear slot diffusers near the North wall. The thermally active surface is about 13 m^2, i.e. the 75% of the surface of the ceiling (considering the surface of the new room). The panels are supplied by two loops and the related manifold is placed on the ceiling of the control room. The layout of the ceiling radiant system can be seen in Figure 3.

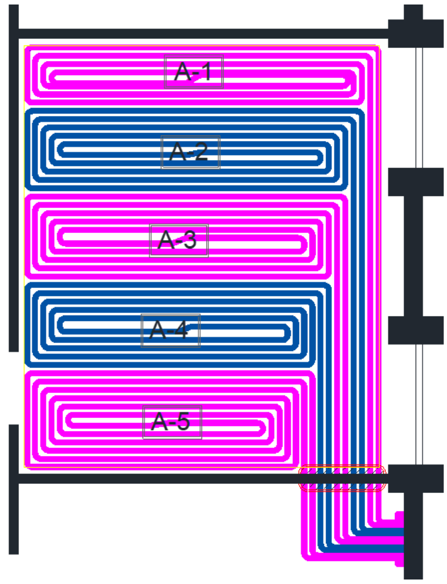

Fig. 2. Layout of the radiant floor system.

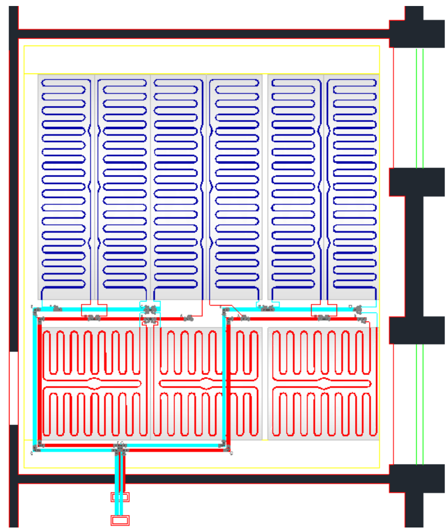

Fig. 3. Layout of the radiant ceiling system.

Dry radiant panels have been used also for the walls of the test room. The dimensions of the panels and the resulting active surfaces are shown in Table 1.

Tab. 1. Active surface of the walls.

Surface	Panel dimensions [mm]	Number of panels	Active surface [m^2]
North wall	1200 x 2000	3	7.20
East wall	600 x 2000 1000 x 1200	3 2	6.00
South wall	625 x 2000	6	7.50
West wall	625 x 2000	4	5.00

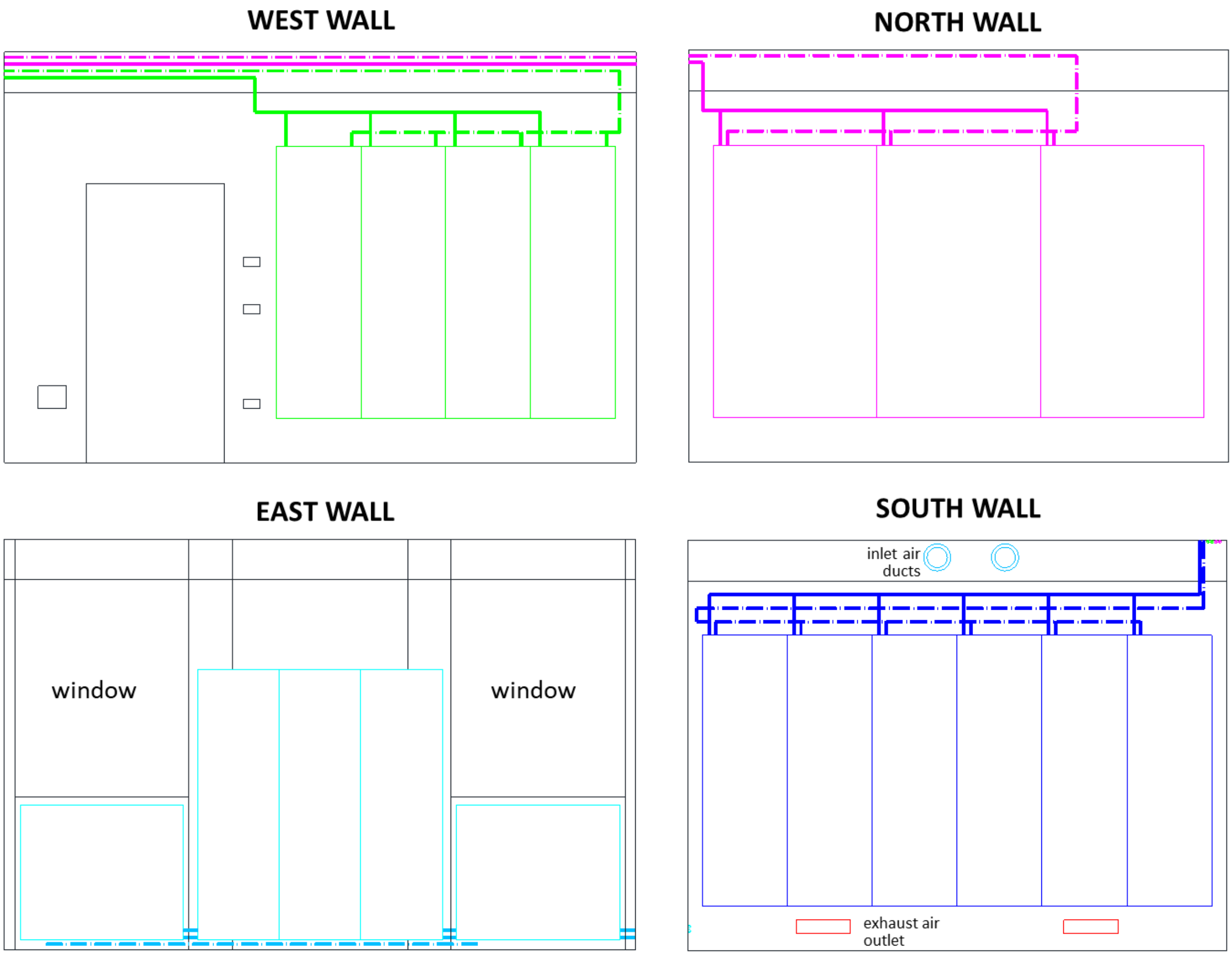

Fig. 4. Layout and hydronic connections of the radiant panels on the walls.

The positions of the panels on each wall, which can be seen in Figure 4, has been defined taking into account the space needed by the exhaust air grilles and by the new electrical system (light switches, wall sockets, data network access points, etc). The layout of the hydronic connections is also shown: for each wall an independent circuit has been realized using pipes with an external diameter of 20 mm which connect the radiant panels according to the Tichelmann system. The connections have been realized from the upper side of the modules, except for the modules of the external wall, which have been connected from the lower side, with the pipes placed in the recess behind the dry wall.
The panels of the South and West walls are not pre-insulated, thus mineral wool insulation (5 cm thick) has been placed behind them. Mineral wool has been also used to fill the recess behind the external dry wall, between the vapor barrier on the rear part of the radiant panels and the vapor barrier placed on the internal side of the concrete wall.
Usual design conditions of the radiant systems cannot be defined in a test room like this, since there is no heating or cooling load to be supplied. As a matter of fact, many combinations of temperature for the radiant surfaces are possible, with some of the surfaces heated and some cooled at the same time and other surfaces at neutral temperature. Hence the boundary conditions have to be set for checking all possible tests which can be performed for heating and cooling, looking at minimum and maximum allowable temperature which in case can be exceeded. For winter investigations, a maximum surface temperature of 40°C has been considered, except the floor surface which was considered at 29°C. For summer investigations, a minimum surface temperature of 16°C has been considered.

2.3 Hydronic system

The radiant panels of the 6 surfaces of the test room are supplied by means of 6 secondary loops, each equipped with its own mixing and pumping unit. Upstream 4 ball valves allow to manually commute between heating and cooling. The 2 primary loops are provided with modular manifolds made of reinforced polyamide and equipped with micrometric flow regulator and flow-rate meter for each circuit. Not only the radiant panels, but also the air handling unit is supplied by the manifolds.
The heating loop has a tank of 200 litres with 3.6 kW of electric heaters. The electrical resistance has been chosen to allow a short time of pre-heating before the start of the tests.
The cooling loop has a tank of 100 litres and is de-coupled from the chiller loop by means of a plate heat exchanger. The chiller loop is 80 m long and has an inertial tank of 50 litres, for a total volume of 90 litres. This loop is treated with a dosage of 30% of an inhibited

antifreeze, formulated to help control corrosion and to provide frost protection down to -15°C.
The primary and secondary circuits, included the hot and the cold tanks, have a volume of 375 litres and must be treated with a dosage of 1% of inhibitor, which provides protection against limescale and corrosion, and a dosage of 0.3% of sanitizer and biocide, which prevents the development of bacteria and fungi and their associated problems.
Expansion vessels, safety valves, air purge valves and filters complete the system. About 20 cockpits for thermometer probes (Pt500 will be used) will be installed for properly monitoring the water temperatures of the radiant circuits and in other important points of the hydronic system.

2.4 Aeraulic system

The test room is provided with fresh air with controlled flow rate, supply temperature and relative humidity. The following operation modalities are possible for the chosen air handling unit:

- fresh air ventilation;
- winter integration;
- dehumidification and/or summer integration;
- free cooling or free heating.

The AHU uses the outside air only, it is equipped with a high-efficiency counter-current heat exchanger (about 90%) for heat recovery from exhaust air and with a by-pass connection for free-cooling, controlled by an NTC probe placed in the outdoor air intake duct. It ensures summer dehumidification and can also integrate heating and cooling, operating as a heat pump. It consists of three separate modules, two fan units and one recovery/handling unit, which can be installed close together or in different positions, depending on the space availability.
The selected air handling unit can provide an air flow rate from 80 to 200 m^3/h to the test room, ensuring an air change from 1.7 h^{-1} to 4.2 h^{-1}. It is independently controlled by a TH controller user terminal but can also be controlled by an external device.
Silencers are installed between the AHU and the test room to reduce noise transmission. The distribution of air is done through flexible insulated air ducts with diameters of 160 mm and 125 mm and distribution boxes. Two linear slot diffusers (800x100 mm) equipped with air shutters and placed on the ceiling are used for supply air, while two grilles (400x400 mm) are placed on the lower part of the opposite wall for exhaust air extraction. The dimensions of the diffusers and the grilles ensure low air velocity near the inlet and extraction areas in the test room.

3 Building up of the test room

A view of the room before starting the works can be seen in Figure 5. After the clear out of the room, the first work to do was the radiant floor system, followed by the radiant walls and finally the radiant ceiling. Particular attention was given to the external wall, since the hydronic connections were placed behind the panels because the space under the windows was limited. A vapor barrier was placed on the external existing concrete wall, then all the space behind the dry wall was filled with mineral wool insulation and another vapor barrier was placed immediately behind the radiant panels. The space behind the radiant panels installed on the internal walls was also filled with mineral wool insulation, except the panels of the North wall which were pre-insulated.
A view of the test room and of the control room during the works are shown in Figure 6 and Figure 7 respectively. The works will be completed in April 2019.

Fig. 5. View of the room before starting the works.

Fig. 6. View of the test room during the works.

Fig. 7. View of the control room during the works.

4 Future research activities

The first activity which will be carried out will be the starting up of the system and the evaluation of the time needed to reach steady-state conditions as well as how these are maintained over the time. Measurements by infrared camera will be taken with many combinations of surface temperatures in order to check how the different surface temperatures affect indoor operative temperature.

The set-up of the room will include measurements of air velocity, temperature and turbulence under different flow rates in order to avoid draft risk problems in the rooms.
At the same time a correlation between supply temperature of the water and surface temperature will be carried out. A suitable number of thermocouples will be installed in active and passive surfaces of each wall, as well as inner surface of windows. The view factor model presented in [14] will be considered to calculate the view factors between the human body and the different surfaces in various positions inside the room. The measured mean radiant temperature with and without occupants will be compared to the one calculated through the measured surface temperature and the calculated view factors.
At the same time a model for the hydronic circuit will be developed in order to find the best strategies to control the temperatures of the warm and cold water in the two tanks, as well as the proper mixing temperatures to supply the water in all the circuits. Also the AHU operation will be tested and tuned as a function of the different external conditions (temperature and relative humidity).
Once tuned the control of the room, the work including panels of occupants will start. At first the test room will be used to evaluate, by means of questionnaires, psychological and productivity tests, the acceptability of defined factors of local thermal discomfort and their influence on human productivity. As regards thermal comfort, an argument which needs in-depth investigations is surely the radiant temperature asymmetry. In particular the analysis on comfort and productivity of people under heated ceiling deserves a prominent attention.
The idea is to study the radiant asymmetry of a room with warm ceiling and one or more cold walls or cold floor, along with the acceptability for people of a possible discomfort. For this purpose, a working space with 2-4 people should be reproduced in the test room. Many combinations of surface temperature can be studied, considering also the possibility to control the supply air of the ventilation system. The experimental investigations with test subjects will be performed considering realistic combination of the surface temperatures of a typical room in a building during the winter, e.g. two cold walls or the cold floor and one cold wall. The possibility to plan the activities as complementary studies to the ones carried out in other research centres will be considered.
In the future other works are planned looking at integrated methods for multi-parameter analysis of global comfort & IEQ in office buildings. As a matter of fact, the studies of the characterizing parameters and of the control methods for the optimization of comfort in building environments are currently mainly focused on the aspects related to thermal comfort and IEQ. Many other aspects and potential correlations, though not neglected, are not yet fully investigated and can be hence currently the subject of in-depth studies. It is the case of the acoustic and lighting environment, yet both are directly dependent on the energy management strategies of buildings. The noise level generated inside a building environment is mainly due to the operation and characteristics of the service equipment, mainly HVAC and mechanical ventilation systems. Natural and artificial lighting are increasingly connected to the managing the contribution of solar radiation through the transparent components of the building envelope. The purpose of the research program is to deepen the interactions between different parameters on global comfort, especially for offices and commercial buildings. To do this, the development of specific methods for analysing the subjective response is expected from the current standardised procedures used for the analysis of comfort in thermally controlled environments. These methods will be developed taking into account the most recent advancements in dialogic psychology, for the analysis of the subjective response of users, and the assessment of productivity related to the daily variation of comfort indicators, following the implementation of energy saving strategies.

5 Conclusions

Indoor environmental quality has gained an increasing interest in response to the increasing desire to enhance human well-being. Thus more investigations employing test subjects should be carried out in spaces with controlled environmental parameters.
After a brief presentation of the most important characteristics of some existing test chambers, the first steps of the set-up of a novel test room are presented in detail, from the design phase to the building up. The most important feature of this new test room is the possibility to independently control the temperature of each surface (floor, ceiling and walls); this enables to reproduce a room with one or more cold or warm external surfaces and at the same time a heating or cooling surface. Moreover, the test room is located in an office building, it is provided with windows and it has been kept as much neutral as possible, so that it looks like a real office rather than a test facility.
Not only thermal aspects will be investigated in the new test room, but also the illuminance level and the acoustics in the indoor environment will be taken into account. The ultimate challenge of the future research activities is to understand how the different IEQ parameters and their interactions affect human perception of the built environment and productivity.

The project of the test room has been realized thanks to the collaboration with 18 companies which donated most of the materials needed for the construction. Among the companies, the Consortium Q-Rad (Italian consortium of radiant systems producers) played an important role. The project is in part financed by TWINNING, a funding program supplied by the Department of Industrial Engineering.

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A Supermarket Eco-Efficientization

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Abstract This article proposes to design and analyse from an energy and ecological efficiency point of view a refrigeration application in the commercial area, related to the cooling consumers in a supermarket.
The fields of use of the cooling agent are various, from commercial refrigeration equipment up to naval refrigeration equipment, etc.
The present paper aims at dimensioning a refrigeration plant with mechanical vapour compression in one step and choosing the optimal solution from an ecological point of view (GWP-TEWI) and energy efficiency COP.
The selected refrigerant is R448 because of its higher C.O.P., lower electricity consumption and lower GWP being in line with EU legislation. Compared to other refrigerants (R404a, R449a) it has the lowest GWP and the highest COP. The composition of R448 is a mixture of ecological halogenated freons R134a, R125, R32a, R1234ze and R1234yf. To simulate and compare refrigerants thermodynamic proprieties The National Institute of Standards and Technology (NIST) - Refprop version 8.0, 2007 was used.
In the project, modern design methods were applied using specialized softwares.
The refrigerant recommended in the Commercial Cooling System is R448 a. This agent was chosen because it is part of the ecological refrigerant category, being recommended on average for cooling and for low energy consumption. The composition of this agent is a mixture of ecological halogenated freons R134a, R125, R32a, R1234ze and R1234yf.

1 Introduction

This refrigerant is a halogenated derivate from saturated hydrocarbons, methane, ethane blended with different contend of flour, olefyne and hydrogen. These components do not burn, do not constitute explosive mixtures if they enter in reaction with the air, they are not poisonous and do not have any smell, if they do not exceed 20%.

This work is also a study case of the new legislative Regulation UE 517/2014 implementation. Concerning this, ecological alternatives cooling agents with low global warming potential (GWP) must be found in the following years, at an international level.

The fields of use of the cooling agent are various, from commercial refrigeration equipment up to naval refrigeration equipment.

The refrigerant recommended in the Commercial Cooling System is R448 a. This agent was chosen because it is part of the ecological refrigerant category, being recommended on average for cooling and for low energy consumption. From the point of view of compression, this agent is a mixture of ecological halogenated freons R134a, R125, R32a, R1234ze and R1234yf.

2 Refrigerants analysis

Three refrigerants are proposed for analysis: R404a, R448a and R449a as can be seen in Table 1 and Table 2 for both freezing (and refrigeration [1,2,3].

Cooling capacities (Φ) and parameter conditions are:

Φ refrigeration = 35.36 kW

Θ_0/ Θ_c -10/36°C ;

Φ freezing = 16.3 kW

Θ_0/ Θ_c -20/36°C (where : Θ_0/ Θ_c is evaporation temperature/condensing temperature).

2.1 R404a Refrigerant

It is an azeotrope mixture of halogenated refrigerants having R143a, R125 and R134a composition with concentrations (44/52/4)%. It has a GWP of 3940, ODP = 0. In terms of physic-chemical characteristics, the following are mentioned:

- boiling temperature: -47°C
- critical temperature: 73°C
- critical pressure: 37.4 bar
- condensing temperature at 26 bar: 55°C
- cooling capacity: 99% (in operating mode -35/+40°C)
- COP = 98% (in operating mode -35/+40°C)
- liquid density at 30°C : 1.091 kg/dm3

From the point of view of the R404a safety prescriptions, they fall into class A1 (non-flammable refrigerants that are not substantially harmful) - SR EN-378

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2.2 R448A Refrigerant

It is a zeotropic blend, designed to replace R22 and R404a in new systems and to retrofit existing installations. It has component R32, R125, R134a, R1234ze and R1234yf with concentrations of (26/26/21/7/20)%. It has a GWP = 1270 and ODP = 0.

In terms of physic-chemical characteristics it mentions:

- boiling temperature: -45.9°C
- critical temperature: 83.7°C
- critical pressure: 46.6 bar
- liquid density at 25°C: 1092.3 kg/m^3
- glide : 5K

From the point of view of the safety instructions, it is part of the A1 flammability class.

2.3 R449A Refrigerant

It is a low GWP hydrofluoroolefin 1282 designed to replace R404a, R507 and R407a, has an energy efficiency of 8-12% better than R404a and R507.

It has component R32, R125, R134a and R1234yf in concentrations of (24.3 / 24.7 / 25.7 / 25.3)%.

Physico-chemical characteristics:

- boiling temperature: -46°C
- critical pressure: 44.47 bar
- critical temperature: 81.5 °C
- liquid density at 21.1°C: 1113.3 kg/m^3
- glide 5K.

Also R449a is part of the A1 flammability class

Fig. 1. R449A

Fig. 2. Glide chart

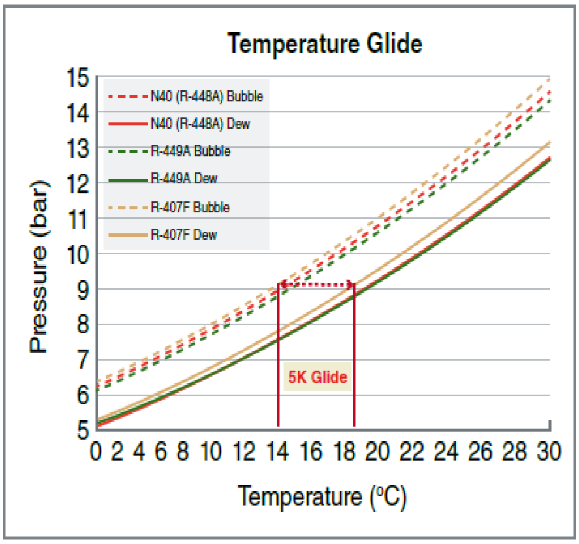

Table 1. Comparative table refrig-- chilled conditions

Parameter	Refrigerant type		
	R 404a	R 448a	R 449a
P_0 [bar]	3,90	3,50	3.22
P_c [bar]	16,06	13,70	17,30
$\prod[Pc/P0]$	4,11	3,91	5.37
Θ_0[0°C]	-10	-10	-10
Θ_c[0°C]	36	36	36
m[kg/s]	0,298	0,224	0.23
P_k[kW]	9,53	9,72	10.30
COP	3,77	3.70	3.50
ODP	0	0	0
GWP	3940	1273	1282

Table 2. Comparative table freezing conditions

Parameter	Refrigerant type		
	R 404a	R 448	R 449
P_0 [bar]	1,45	2,4	2.25
P_c [bar]	16,065	13,7	17,3
$\prod[P_c/P_0]$	11,048	5,71	7,68

Θ_0[0°C]	-20	-20	-20
Θ_c[0°C]	36	36	36
mm[kg/s]	0,16	0,105	0.116
P_k[kW]	8,16	4,83	6,48
COP	2,083	3,5	2,63
ODP	0	0	0
GWP	3940	1273	1282

Following the analysis of the thermodynamic parameters (tables 1 and 2), the R-448a refrigerant was chosen due to the higher COP, the lower energy consumption and the greening of a smaller GWP [4,5,6].

3 TEWI calculation

TEWI Total equivalent warming impact (TEWI), is a way of assessing global warming by combining the direct contribution of refrigerant emissions to the atmosphere with an indirect contribution of carbon dioxide emissions resulting from the need to consume energy for the refrigeration system.

TEWI is designed to calculate the total contribution to the global warming of the refrigerated process as shown in Table 3 below.

It measures both the direct effect of global warming of the refrigerant (its emissions) and the indirect contribution of the power required for the normal operation of the refrigerant system. It is valid only for comparison of alternative systems or refrigerant options for application in a location [9,10,11,12].

The TEWI factor was determinated taking account of the Standard SR EN 378-1:

$$TEWI= [GWP \times L \times n] + [GWP \times m (1-\alpha_{rec})] + [n \times E_{an} \times \beta] \quad (1)$$

Where:
GWP – the global warming potential, CO_2 related
L – Leakage in kilogrammes per year
n – System operating time in years,
m – Refrigerant charge in kilogrammes
α rec - recovery/recycling factor from 0 to 1
E an – energy consumption in kilowatt-hour per year
β - CO2 emission in kilogrammes per kilowatt-hour kg/kWh
GWP x m (1-αrec) - Impact of recovery losses
GWP x L x n - Impact of leakage losses
n x E annual x β - Impact of energy consumption

Table 3. TEWI calculation

Values for	R404A	R448A	R449A
GWP	3784	1273	1282
L	2,304	2,408	2,416
n	15	15	15
m	35.3	30,1	30,2
a	0,75	0,75	0,75
β	0,287	0,287	0,287
GWP*L*n	130775,04	45980,76	46459,68
GWP*M(1-a)	27244,8	9579,325	9679,1
E annual*n*β	296980,425	296980,425	296980,425
TEWI [tones of CO_2]	455,00	352,54	353,12

4 Conclusions

The present paper aimed at dimensioning a refrigeration plant with mechanical vapour compression in one step and choosing the optimal solution from an ecological point of view (GWP-TEWI) and energy efficiency COP.

To implement the International Legislation, in the future it is necessary to retrofit HFC refrigerant with an ecological refrigerant.

The ecological energy efficiency and thermo-physical properties are the main disadvantages of R 404A .

The refrigerant we have chosen was R448 because it has a higher C.O.P. (for refrig-chilled conditions), lower electricity consumption and lower GWP being in line with EU legislation. Compared to other refrigerants (R404a, R449a) it has the lowest GWP.

In the project, modern design methods were applied using the D - COOLSELECTOR and B software [13,14,15,16,17].

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LISCOOL – Smart air-conditioning with cold storage as flexibility provider for automated demand response and virtual power plant supported by cloud based system

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Abstract. This paper describes the main progresses of the LISCOOL – Lisbon Cool energy project. It aims to implement and demonstrate the technical and economic feasibility of air conditioning systems as flexibility providers to different operators on the electricity markets. It promotes consumers as active participants on energy trading and network management, by taking advantage of the flexible load of the AC Systems, providing a suitable solution for large scale deployment of renewable energy sources (RES).

1 Introduction

Lisbon Cool energy project (LISCOOL) is a demonstration project, fully sponsored by New Energy and Industrial Technology Development Organization (NEDO) – a Japanese governmental agency – through a partnership with Portuguese public institutions, namely Câmara Municipal de Lisboa (Lisbon City Council) and LNEG - Laboratório Nacional de Energia e Geologia (National Laboratory for Energy and Geology), a public R&D institution, belonging to the Ministry of Economy and Employment.

This project is being carried out in the city of Lisbon, Portugal between November 2016 until December 2019, to which NEDO has entrusted Daikin Industries, Ltd.. In turn, Daikin has partnered with several European companies to advance with its implementation. Through the installation and aggregation of commercial size air conditioning systems, with an under-development cold storage tank unit, the goal is to assess the technical and economic feasibility of providing energy-related services to electricity grid operators and of empowering end-user by participating on the electric grid management markets.

Within this scope, the project was divided into two phases:

- Phase 1: Installation, system implementation and preliminary operation;
- Phase 2: System improvement, full-scale operation and business feasibility assessment.

This paper focus on the analysis of the operational data retrieved from the Phase 1 operation. After a brief overview on the project and its background, the implemented system is described in a detailed fashion. Lastly, the operational results are analysed, retrieving conclusions on the technical feasibility of the system and future improvements.

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2 Project Background and Objective

In recent years, as strong policy has been put in place regarding decarbonisation and renewable energy resources, the latter's share in the energy mix has been steadily increasing. Ergo, due its inherently intermittent production characteristics, energy supply amount becomes unstable, which affects the reliability of the electrical grid. [1]

Moreover, increasing awareness of climate change and economic attractiveness of Distributed Energy Resources (DER) among consumers such as Electric Vehicles (EVs) and energy microgeneration units (e.g. PV solar panels) has led to its fast deployment on distribution network, as the majority of the consumers is present at the low voltage level [2]. This poses another challenge to efficient and safe operations of networks, i.e., within the technical limits, such as control voltage rise and keeping power flows within lines capacity. [2,3]

Even though the supply-side management has been mainly used as strategy for ensuring stability of electrical power systems and can, potentially, solve systemic stability problems as the balancing between supply and demand, it is not efficient in solving local problems, such as voltage rise and reverse power flows at the level of distribution networks, where DER is being installed in a large-scale. [4,5]

There is a growing consensus among policy makers and market participants that demand side flexibility, empowered through Automated Demand Response (ADR), is one critical resource for achieving low carbon, efficient electricity system.

Demand Response, in its basic form, is a change in the power consumption of end-users in response to financial incentives based on the operation requirements of the electrical grid. It can be provided by any industrial, commercial or residential consumers. [4, 6-8]

With the rise of interconnectivity and smart devices, Demand Response programs are progressively moving towards automation and the industry itself closer to the Smart Grid paradigm. The advances on integrating information and communication technologies (ICT) allow the system operator to interact and effectively coordinate a substantial number of distributed resources in an automated fashion in real time. [6,8]

Demand Response can unblock an immense value not only to grid operators by providing balancing services and thus diverting large investments on infrastructure and capacity resources, but also it can support an efficient operation on local grids, mitigating drawbacks posed by the increasing penetration of DER at low voltage level. [1,4,9]

In parallel, a recent strategy that follows the growing trend of exploring demand side flexibility is a Virtual Power Plant (VPP). The core basis of a VPP is the aggregation and integration of numerous types of producing and/or consuming units, creating a diversified portfolio of independent resources. With such portfolio, the overall load/generation not only becomes more reliable with less intermittency, but also it can be optimized based on the assets' available flexibility and market prices. The aggregation of diverse resources allows a VPP to react quickly to changing conditions, and deliver great values to customers by optimizing supply and demand profiles. [10-12]

In conclusion, the transformation on the electric system and development on ICT devices is creating a conductive environment towards the ADR and VPP systems. In order to be able to enter these growing markets at an early stage, LISCOOL project goal is to implement and demonstrate the technical and economic feasibility of Air Conditioning (AC) Systems as flexibility providers for both ADR and VPP systems.

Also, being Portugal one of the leading European countries in renewable energy deployment [13], the project intends to investigate the technical and non-technical benefits associated with ADR and VPP systems in an urban environment, including the smooth integration of renewable energy sources and in resolving problems at the local grid level.

3 Project overview

LISCOOL project aims to evaluate the effectiveness of AC Systems in ensuring a stable supply of renewable energy by providing the required flexibility to balance the grid. Specifically, the electricity consumption of air conditioning systems is automatically controlled to optimize the renewable energy usage throughout the summer season. In addition, LISCOOL targets the investigation of potential revenue streams and business models availing the AC Systems' power shifting capacity to provide energy related services to market agents, such as retailers or VPP operators.

The project encompasses four office buildings as demonstration sites in the city of Lisbon, where multi-split air conditioning systems were installed. In total, 34 Variable Refrigerant Flow (VRF) systems with a combined power of about 330HP replaced the previous installed air conditioning systems.

In order to enhance the power shifting flexibility of the AC systems, part of those are coupled with cold storage tank units, currently under development. These allow the demand to be adjusted during the AC operation, either increase or decrease in consumption, while mitigating the impact on the end-user comfort. In total, 30 units were installed among the four demonstration sites.

Lastly, as a source of intermittent production on each site, photovoltaic panels were installed as well with a combined peak power of $155kW_p$.

The locations of office buildings in Lisbon, the number of AC Systems and cold storage tank units, and PV power are depicted in Figure 1.

Figure 1. Installation of AC and PV systems in four buildings in the city of Lisbon, Portugal

For demonstration purposes, two distinct use cases were established:

- **Use Case 1:** Automated Demand Response:
- **Use Case 2:** Virtual Power Plant

In the first use case, the system operator will forward Demand Response requests based on weather forecasts, renewables production and power grid status; whereas the latter will optimize the AC consumption based on the spot market price and PV production forecasts. A detailed description on each use case is done in the following sections.

In parallel, Daikin has developed and implemented a cloud-based system ("*AC Aggregating System*"), which is responsible for collecting the operational information from AC systems and managing the units upon receiving signals from either the ADR or VPP system. The overall system architecture is depicted in Figure 2.

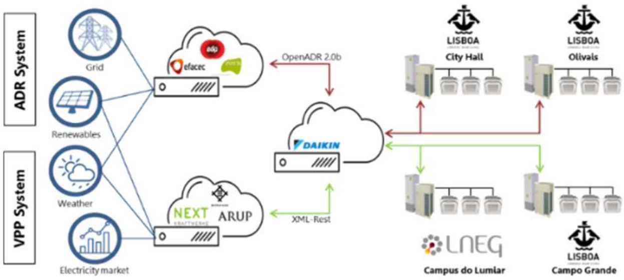

Figure 2. System overview

One of the essential points considered during the project scope definition was the collection (metering) and transmission of performance data from the local sites to server systems. On one hand, operation data and electric consumption data from different components of AC systems, along with weather forecasts, are fundamental to predict the day-ahead load pattern and flexibility on AC systems. On the other hand, from the ADR and VPP operator's standpoint, it is required to have live data with a very high reliability in order to verify the system's compliance with the Demand Response events. On top of it, this data is also valuable for each operator to proceed with its own forecasts, such as PV production. Taking this into consideration, smart meters were installed on each site, which are separately measuring the consumptions of AC system and whole building and PV panels' production.

After an initial design and implementation stage of the system and equipment installation, the system went into operation in May 2018 until the end of October 2018. Throughout this period, signal exchanges between servers and Demand Response events were tested on the four buildings, ensuring an error free operation. The comprehensive system deployment and fully automated operation is scheduled for summer, 2019.

The obtained results during the operation phases of the system will be used to do a comparative evaluation of the performance, energy efficiency and suitability of AC systems to different DR Programs. Also, the value of these platforms for different market players, such as the end-users, retailer or grid operators in resolving issues at the local grid level, will be analysed.

It is anticipated to determine a scalable business model, taking into account each European electricity market specifications in line with the above mentioned project objectives.

3.1. Use Case 1: Automated Demand Response

To implement the use case 1, a partnership was established between Daikin and the Portuguese companies, EDP Inovação S.A. (a Portuguese utility), Efacec S.A. (electric solutions) and Everis Portugal S.A. (IT consulting and service company).

This use case was designed to validate the AC units' flexibility as a viable solution to two major issues associated to the operation of the electrical grid.

In the first case, "*Distributed Energy Resources (DER)*" program's objective function is to maximize renewables auto-consumption on a micro-grid level by shifting AC consumption, thus contributing to the control of voltage and keeping power flows within lines capacity, problems often associated with high penetration of renewables at low voltage level.

Secondly, a "*Direct Load Control (DLC)*" program focuses on the power grid system balancing between supply and demand. It uses the aggregated flexibility of AC systems to solve unforeseen restrictions or emergencies on the electrical grid ensuring its stability.

Since the scope of each DR program is different, they are coordinated in order not to overlap the controls execution. Considering the critical character of DLC events, the DER program is operated continuously, until there is a notice regarding a DLC program event. The latter overrules any previous DER events.

A detailed description of each program is done in the following subsections.

3.1.1 Distributed Energy Resources (DER) Program

The *Distributed Energy Resources* is a program running continuously during the operation phases of the demonstration project with a cyclical communication between both servers – AC Aggregating system and ADR system – concerning the planning and execution of the Demand Response signals.

Daikin, on a daily basis, provides the forecast of AC System's power consumption and flexibility through a day-ahead schedule divided into 30-min periods.

The ADR system gathers information on weather forecasts and power consumption/production on each site, using it to produce the respective forecasts for PV generation. After processing both forecasts, the ADR System sends an optimized consumption schedule.

The AC Aggregating system processes each Demand Response request with Opt-in or Opt-out responses for each event.

Notwithstanding, the AC Aggregating system is also capable, when required, of sending an updated report on the above mentioned forecasts during an intraday operation mode. This allows the ADR System to compute a more granular optimization as there might be significant differences between forecasts and real operation conditions. Considering this, event signals are divided into Slow DR (day-ahead signal) and Fast DR (intra-day signal).

3.1.2 Direct Load Control (DLC) Program

As mentioned above, DLC Program aims at providing support to the network operators on grid management by leading consumers to change their consumptions in response to an emergency event.

This type of Demand Response events is typically generated until 15 minutes before the start time as it is used to tackle operation problems that were not predicted, and thus require fast action controls. For this reason, it implies a direct coordination between the network operator and the available aggregators / assets to participate in these events.

In this specific project case, the role of the network operator and its emergencies are simulated. The ADR operator sends an event based on the latest flexibility forecast provided by the AC Aggregating system.

3.2. Use Case 2: Virtual Power Plant

To carry out a Virtual Power Plant use case, a partnership between Daikin and Mitsui & Co. (a Japanese trading and investment company), Arup (engineering and business consultation) and Next

Kraftwerke GmbH (a German VPP operator) was put in place.

In this case, the main proposition is using AC systems to provide flexibility to the VPP allowing it to optimize its supply and demand profiles, and to improve the trading position on the spot market.

AC Aggregating system computes, on a day-ahead basis, the consumption forecast and available flexibility of the AC systems for each building. Upon receiving that information from Daikin, Next Kraftwerke calculates its own forecasts (spot market price, PV production, etc.) and proposes an optimized AC schedule, in which each use of flexibility is complemented by a priority number. This allows the AC Aggregating system to try to achieve the most optimized schedule possible, based on operational restrictions.

Similar to the previous use case, intra-day mechanisms were also put in place to allow a refined optimization, which takes into account changes in real operation conditions or variations on the market prices.

4 AC System

Undeniably, conventional AC systems already have an intrinsic capability of providing flexibility to the electrical grid, namely through temperature set point variation or load factor control.

Generally speaking, these strategies during Demand Response events may cause an impact on the end-user comfort. In order to mitigate this issue, complementary energy shift strategies, such as pre-cooling, are often necessary. [14,15]

The introduction of cold storage in conventional AC systems, usually in the form of ice, was used to level the daily power load in order to reduce the peak power demand and activate the heat pumps to produce ice at suitable times, e.g., when the electricity price is cheaper. [16]

However, in a future characterized by intermittent electricity production, greater flexibility will be needed either downwards (during demand surplus period) or upwards (during over-supply periods) to respond to quick changes in the electricity supply. [6,17]

The introduction of cold storage tank units that are coupled to the VRF systems enhances its flexibility to respond to changes in the supply by enabling to shift power consumption, either decreasing ("*negawatt*") or increasing ("*posiwatt*") while operating the AC System.

The installed tank unit enable a smooth consumption shift, less curtailment on AC operation (i.e. set-point variation, load control) and reduces possibility of interrupting air-conditioning during Demand Response events, which will therefore result in contributing to a more flexible resource when compared with conventional AC systems.

4.1 Control Optimization

The VRF system installed with the tank units operates in four different modes as shown in Figure 3. The first mode corresponds to the normal AC operation without utilizing the cold storage units. Mode 2 and Mode 3 refer to producing cold storage, whilst Mode 4 is related to the use (consume) of cold storage during AC operation.

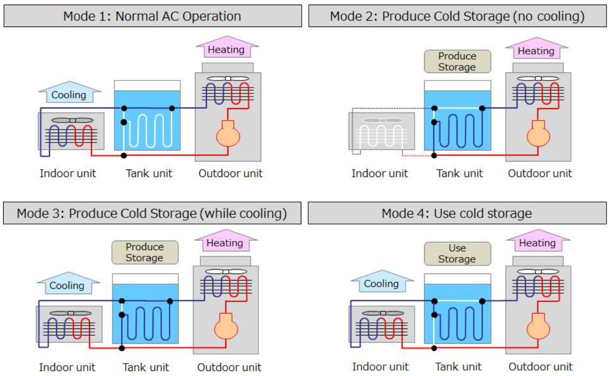

Figure 3. Cold storage operation modes

The main difference between Mode 2 and Mode 3 is that the former activates the heap pump to solely produce the cold storage while there are no cooling requirements in the building (e.g. during the night-time), whereas the latter produces cold storage during the normal operation of the AC system.

The AC system operation and the correspondent refrigerant cycle will be altered to accommodate the introduction of the cold storage – producing or using it – hence varying the power consumption as follows:

Negawatt: During the normal operation of the AC unit, the use of cold storage reduces the required power input in the refrigerant cycle, which decreases the power consumption of the system. In this case, the operation mode resembles the conventional ice storage one. The use of cold storage can be complemented with conventional measures, such as increasing the temperature setpoint, in order to enhance the power shifting capacity of the AC system.

Posiwatt: The power consumption is increased by producing cold storage, either when the system is cooling the rooms or not, which distinguish these units from the ice storage ones. In theory it is always possible to increase power consumption, except when the outdoor unit is operating on its maximum capacity or cold storage is already fully charged.

5 Cloud Server & Communication

More than a cold storage tank unit coupled to VRF systems, the project also encompasses the development of an aggregation system ("*AC Aggregating system*") on cloud-based software architecture. The central server is responsible for managing the power consumption of its assets upon receiving signals (i.e. power consumption targets) from the ADR or VPP systems.

As abovementioned, AC Aggregating system sends the day-ahead and intraday power consumption forecasts and available flexibility to the ADR and VPP systems and receives an optimized schedule proposal or ADR events in return for the AC operation.

For these server to server communications, different protocols were implemented. In use case 1, one of standard Demand Response protocols was used, and in use case 2 a REST-like protocol was adapted to the project specifications. Each type of communication is described in more detail in the following subsections.

5.1 Use Case 1: Automated Demand Response

For the ADR system, the chosen communication protocol was OpenADR 2.0b, as this is specifically developed to facilitate communications related to Automated Demand Response programs. The intention of this protocol is to allow grid operators or utilities to interact with aggregators and control systems that are preprogramed to automatically take action upon receiving DR signals with no manual intervention.

According to the OpenADR 2.0b specifications [18], a hierarchical relation is established between central system and end devices. As a result of this relation, two main actors are identified under the protocol:

- Virtual Top Node (VTN): transmits OpenADR signals to end devices or other intermediate servers
- Virtual End Node (VEN): represents an end device that accepts the OpenADR signal from the VTN.

Consequently, this use case has been design to follow a top down approach, where the ADR system is the VTN and the AC Aggregating system behaves simultaneously as the VEN to the ADR system and as the VTN to the AC Units.

As a starting process, it is required to register the VEN into the VTN. The VEN ID and reporting capabilities are sent to VTN, allowing it to recognize the type of signals to be expected. Only upon completion of the registration phase, a VEN can be eligible for participating in DR programs/events.

During the daily communication between the ADR and AC Aggregating system, two main interactions as defined on OpenADR 2.0b specifications are used: oadrReport and oadrDistributeEvent. Firstly, oadrReport allow a VEN to send updated information (e.g. forecasts) to a VTN. The type of reports is specified during the registration phase. Secondly, oadrDistributeEvent is used by a VTN to send out DR events to the VEN(s). VEN, in this specific case, AC Aggregating system has freedom to accept (opt in) or reject (opt out) each request.

5.2 Use Case 2: Virtual Power Plant

Taking into account the established partnership with an existing VPP operator, the server communication specifications are already well-defined as part of a business as usual stance for Next Kraftwerke. Notwithstanding, some adaptations were required, namely the forecasts and the introduction of priority concept on DR events.

The used format for data interchange is a REST-like XML-API, of which all the required information for automated data exchanges was kindly made available by Next Kraftwerke.

Whereas OpenADR 2.0b was designed to become a *de facto* standard for ADR communications, REST protocol, as a general web service, is easy to implement and it has many architectural properties suitable for such business model as scalability, security, reliability and extensibility. It is therefore a viable and practical option on a business oriented solution.

6 Results

As previously stated, throughout the summer of 2018, the preliminary operation of the overall system proceeded as scheduled. Throughout this phase, signal exchanges between servers and actual Demand Response events were tested. It was primarily focused on identifying and correcting errors in order to smoothly transition from manual to automated operation.

After the necessary adjustments and adaptations to the logic and processes, all schedule exchanges and optimizations worked reliably and operational data was retrieved. On the following subsections an example for each use is analysed in more detail.

6.1 Use Case 1: Automated Demand Response

On the ADR system, both “Distributed Energy Resources” and “Direct Load Control” programs were tested.

Regarding DER program, an optimized daily schedule is sent to the AC Aggregating system, which is responsible for accepting or refusing the DR events. On Figure 4, the daily consumption on October 19th 2018 for Lisbon City Hall is represented. In total, throughout this day, eight DR events were received and accepted.

Additionally, the forecast and the existing flexibility issued on a day-ahead from AC Aggregating system are also plotted in Figure 4. Due to lack of operational data, the forecasting algorithm it is still not accurate as desirable, which greatly impacts the optimized schedule.

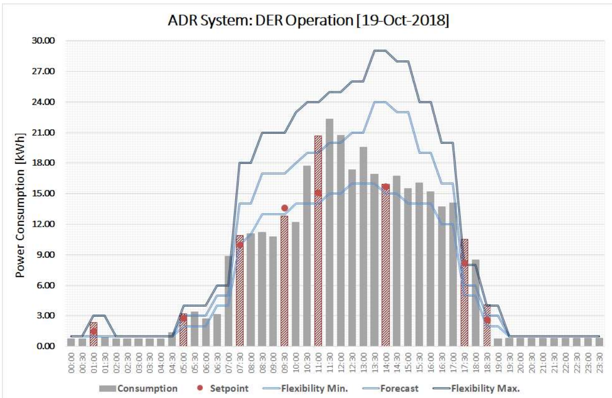

Figure 4. ADR operation: DER Program (19/10/2018)

Nevertheless, focusing on the events received and consequent response, the AC system showed a good compliance, as the deviation from the target was less than 1kWh for most of the events. However, in one case, the AC System did not comply as expected and the actual consumption surpassed the setpoint in about 5,5kWh. The information related to each DR event is presented on Table 1.

Table 1. DER program events (19/10/2018)

Time [UTC]	Setpoint [kWh]	Real [kWh]	Deviation [kWh]	Abs. Error
01:00 – 01:30	1,50	2.35	0,85	56,7%
05:00 – 05:30	2,80	3,23	0,43	15,3%
07:30 – 08:00	10,02	10,87	0,85	8,5%
09:30 – 10:00	13,62	12,80	-0,82	6,0%
11:00 – 11:30	15,12	20,65	5,53	36,6%
14:00 – 14:30	15,70	15,92	0,22	1,4%
17:30 – 18:00	8,25	10,50	2,25	27,2%
18:30 – 19:00	2,60	4,16	1,56	60,1%

On an earlier stage of the operation, the DLC program was also tested. The results on August 16th 2018 for Olivais building are presented on Figure 5. In total 4 *negawatt* events – half of which had 1h duration - and 1 *posiwatt* event were received by the AC Aggregating system.

Contrary to the DER program, in which the optimization process is highly dependent on the accuracy of the forecasts, the DLC case relies solely on the available flexibility at the moment of the grid emergency. For this reason, there is a clear difference between the baseload and the consumption in the course of a DR event.

Moreover, based on the Table 2 values, the AC System displays a great accuracy achieving the consumption target, with deviations below 1kWh for all events (the maximum absolute error is 13,4%).

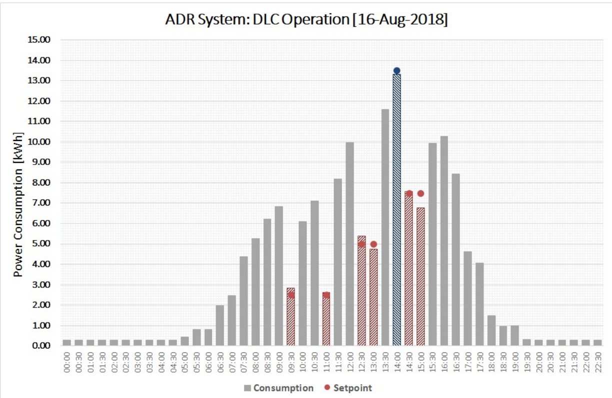

Figure 5. ADR operation: DLC program (16/8/2018)

Table 2. DLC program events (16/08/2018)

Time [UTC]	Setpoint [kWh]	Real [kWh]	Deviation [kWh]	Abs. Error
09:00 – 09:30	2,50	2.84	0,34	13,4%
11:00 – 11:30	2,50	2,62	0,12	4,7%
12:30 – 13:00	5,00	5,38	0,38	7,6%
13:00 – 13:30	5,00	4,74	-0,76	5,1%
14:00 – 14:30	13,50	13,33	-0,17	1,3
14:30 – 15:00	7,50	7,57	0,07	0,9%
15:00 – 15:30	7,50	6,77	-0,83	9,8%

6.2 Use Case 2: Virtual Power Plant

In the VPP use case, the operator, Next Kraftwerke, issues an optimized schedule based on the AC consumption forecast and spot market prices. To each flexibility request, a priority value is assigned in order the AC Aggregating System can determine which events to accept and refuse based on operational restrictions.

On Figure 6, the AC consumption on October 19th 2018 for LNEG building is plotted. During the day-ahead negotiation, the AC Aggregating system accepted five requests to reduce consumption.

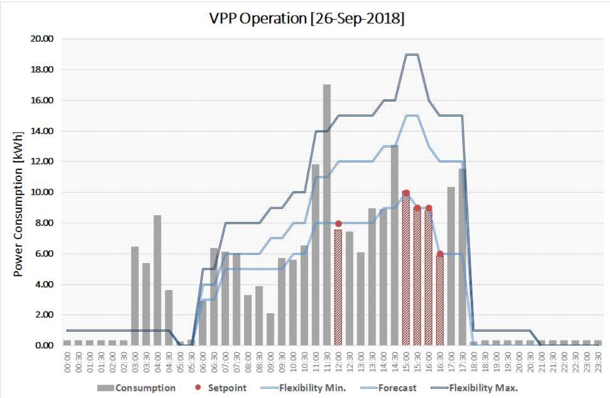

Figure 6. VPP operation example (26/9/2018)

Similar to the previous DER case, the forecast has a negative impact on the optimization as the error between the predicted and actual vales is significant. As mentioned above, it’s worth noticing that this data refers to the preliminary phase of operation.

On Table 3, the details on each event are described. During this day, it is noteworthy the accuracy of the AC System in achieving the defined target. The absolute deviation in all events was lower than 0,50kWh (maximum error was 6,0%).

Table 3. VPP operation results (26/9/2018)

Time [UTC]	Setpoint [kWh]	Real [kWh]	Deviation [kWh]	Abs. Error
12:00 – 12:30	8,00	7,54	-0,46	6,0%
15:00 – 15:30	10,00	10,10	0,10	1,0%
15:30 – 16:00	9,00	9,04	0,04	0,4%
16:00 – 16:30	9,00	8,81	-0,19	2,2%
16:30 – 17:00	6,00	5,85	-0,15	2,5%

As the optimization is based on the spot market price, it is also relevant to take into consideration the financial impact. The VPP performance for the month of September at LNEG is stated on Table 4.

Based on the original forecast and the real consumption, there was a reduction of 7.3% and 8.5%, respectively in terms of supply contract with the retailer and spot market price.

Table 4. VPP Performance at LNEG for September 2018

	Amount [kWh]	Price Supply Contract	Price Spot Market
Original forecast	3,6353	€ 195.38	€ 138.64
Opt. schedule (theoretical)	1,910	€ 151.84	€ 105.61
Opt. schedule (real)	1,858	€ 181.15	€ 129.63
Rel. change (Ori - The.)	-6.07%	-22.29%	-23.82%
Rel. change (Ori - Real)	-8.60%	-7.29%	-8.45%

However, at this moment, such analysis is still inconclusive as there has been a very limited scope for price optimisation and the schedule forecast requires an improvement. So far, the basic principle of achieving a lower price by schedule optimisation was successful, but it will require more data to positively determine the added value for the end-user and VPP operator.

6.3 Results overview

The shifting potential and controllability of the AC systems, coupled with cold storage, were confirmed based on the obtained results. A high accuracy on reaching the consumption target for each event was achieved.

However, it is not possible yet to infer about the increase or reduction of consumption with respect to a baseline. In the current situation, there are significant differences between AC system's forecast and actual consumption due to lack of operational data.

Moreover, this difference has also an effect on both the ADR and VPP logic counteracting each optimization and, consequently, it impacts also the financial analysis and business model assessment. Nonetheless, it is expected to improve forecast accuracy as more data is retrieved until the start of the fully automated operation.

A comprehensive analysis on the technical and non-technical benefits of AC systems providing services to ADR and VPP systems is expected by the end of the demonstration project.

7 Future Works

The results discussed in the previous section were obtained during the preliminary operation of the ADR and VPP systems.

As a preparation for the full system deployment, during the summer of 2019, the partners will focus on improving the reliability of exchanged signal values between different parties (i.e. forecasts, optimized schedules, among others) and on enhancing the robustness of ADR and VPP platforms for precise control and measurements.

Regarding the flexibles loads, further investigation and evaluation on the operational performance of AC system with cold storage tank units (e.g. efficiency improvement, controllability) will be required.

From a business feasibility perspective, assessments on the economical values of AC system's flexibility and the required specifications and functions are necessary in order to integrate such systems in existing energy or balancing markets. Notwithstanding, before considering transferring the concept of flexibility from commercial air conditioning to electricity markets, an analysis of the regulatory situation in the individual target markets is compulsory. Requirements about Demand Response, e.g. metering standards or allowed deviations from the consumption target can have an impact on the rollout of such system.

7 Conclusions

In conclusion, LISCOOL project entails an aggregating platform promoting consumers as active participants on electricity markets by taking advantage of the flexible load of the AC systems.

On top of it, distinct methods are being tested through two operational scenarios in this demonstration project. The goal is to unlock the value of demand response for different players along the value chain. The first is based on network management providing a service to the grid operator (ADR system), while the second is based on energy trading and optimization of supply and demand profiles (VPP system).

The effective and optimized operation of the VRF systems, integrated with cold storage tank units, through either ADR or VPP systems enables a smooth integration of renewable energy sources in the power grid. It increases the electrical power quality and indirectly contributes to reduce greenhouse gas emissions. From an end-user perspective, it can bring lower electricity costs and new revenue streams.

Lastly, the system was considered and designed to have high scalability and versatility. On one hand, it allows the aggregation, integration and control of numerous AC systems on a local, regional or national scale. On the other hand, the AC Aggregating system can connect and provide Demand Response related services to different entities, such as retailers, grid or VPP operators as it is able to communicate through different protocols.

The LISCOOL project is supported by New Energy and Industrial Technology Development Organization (NEDO). We also gratefully thank to Câmara Municipal de Lisboa (Lisboa City Council) and Laboratório Nacional de Energia e Geologia (LNEG) for providing the demonstration sites of this project and for all the support throughout the installation works. We also would like to wish special thanks to our partners who jointly implemented the system and provided insight and expertise that greatly assisted the LISCOOL project.

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The influence of external air supply to air-conditioning systems with fan coil units on the design set-points and the energy consumption

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Abstract. Air-conditioning systems with fan coil units are used in multi-room buildings to adjust air parameters in many rooms with different thermal loads and various uses. These systems are commonly used to set the internal conditions in hotel rooms, offices, small retail stores in shopping centres and others. In fan coil units, the circulating air is treated to ensure that the design set-points are adjusted to the instantaneous heat loads in individual rooms. This treatment is individually controlled by temperature signals from individual rooms. As a result, at a given instance, the circulating air may be heated in some rooms, whilst cooled in the remaining. In this case, the central air treatment affects the overall energy demand for HVAC system. Additionally, the method of external air supply to air-conditioned rooms (direct or through fan coil units) affects both the treated external air set-point and the design parameters of fan coil units. In the paper, we discuss the methods of supplying the external air to air-conditioned rooms. We emphasise how each method influences the design set-points of the centrally-treated air, the size and duty points of fan coil units and the overall energy demand for the HVAC system under investigation.

1 Introduction

Reducing energy consumption in multi-space commercial buildings is ever more pressing these days, due to strict energy policies imposed in recent years. Simulations of HVAC operation have become thus crucial even during early design stages [1]. Also, diagnostic methods for HVAC subsystems, i.e. fan coil units, have been developed to enable fault detection and to improve accuracy of these simulations [2]. While these steps appear to contribute to some energy savings, there are still technological inefficiencies in the current designs of HVAC systems in multi-space buildings. In this paper, we focus on addressing the inefficiencies on the supply air side of the air conditioning systems with two-stage air treatment

Air conditioning systems with two-stage air treatment are commonly used to adjust thermal conditions in rooms with different purposes and usage [8]. Each system consists of a central supply-extract air handling unit (AHU) for the external air treatment/ transport and many individual devices (fan coil units, FCUs) for the circulating air treatment/transport [3]. Central and individual units are designed to operate both independently (e.g. in the periods of non-use) and closely together. While the air treatment tasks in these units are distinct, the overall outcome corresponds to reaching the design set-points in all the air-conditioned rooms. In the central AHU, the external air is treated to the assumed parameters, common for all the air-conditioned rooms, regardless of the individual instantaneous heat loads.

The advantages of systems with FCUs make them particularly suitable for applications to multi-room buildings, where individual rooms have relatively small areas and different thermal loads [9]. In these applications, it is possible to maintain individual temperature set-points in different rooms. The second stage treatment gives individual users flexibility to control and adjust temperature set-points locally, so that user-defined thermal comfort conditions are achieved.

The system restrictions are caused by limited capacity to control air humidity locally in individual rooms. In basic design solutions, air humidity in an individual room results from the AHU setting, properties of the air flow supplied, the FCU settings and individual moisture gains within a room.

Different aspects of improving performance of air-conditioning systems with two-stage air treatment with FCUs have been investigated. For instance, [5-6] discuss the necessity to account for the preparation of heating medium and refrigerant when assessing the system's energy consumption. Subsequently, [7] show that systems with variable water flow appear to improve energy performance of spaces, particularly under variable heat loads. [9] show that improving the system's

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control can lead to maximising energy savings. As a follow-up, [3] form a set of guidelines to design an intelligent control system for ventilation systems with fan coils.

We are, however, not aware of any studies on the impact of the method of supplying external air to the rooms on the energy demand for air treatment and transport. This issue seems to be interesting considering the widespread use of these systems and the large number of FCUs used in buildings.

2 Materials and method

In the context of the discussed systems, two airflows enter air-conditioned rooms, namely the external airflow and the circulating airflow sucked in by FCU. Although both airflows cooperate to adjust the conditions within the room (e. g. thermodynamic parameters of the air, air quality, flow speed in the occupied zone), these can be supplied independently. Both airflows can be supplied to the room through either common or separate diffusers. Fig. 1. shows schematically possible connections of external and circulating airflows supplied into the room. Fig. 1.a shows separate supplies of external and circulating air. Fig. 1.b-c show common supplies of external and circulating air, when connecting external air to FCU on the fan discharge (b) and suction (c) sides, respectively.

When supplying through common diffusers, it is a mixture of external and circulating airflows. In this case, external air, usually thermally-treated, can be fed into either the suction or discharge of the FCU. The room air-conditioning flow is the sum of the external and circulating airflows, therefore

$$V = V_e + V_i \tag{1}$$

With separate supplies of external and circulating air, Fig.1.a, set-points of both the thermally-treated external and circulating airflows should ensure thermal comfort within the occupied zone. Also, their direct impact on people should not cause discomfort, especially in areas with permanent work stations. A careful design of external air supply path is needed to ensure good air quality throughout the room. The desired outcome corresponds to the external air supply evenly dissolving throughout the room and ensuring the required hygienic conditions at all work stations. The external air is treated in a central AHU and distributed to individual rooms via ducts. The circulating air is sucked in by the FCU from the room and after purification and thermodynamic treatment, supplied back into the room. The circulating airflow is equal to the airflow forced through the FCU, hence

$$V_v = V_i \tag{2}$$

Temperature and humidity of the external and circulating air supplies usually vary. Typically, temperature of the thermally-treated external air depends on the outside air temperature. For a given outdoor air temperature, the external air temperature set-point after passing through AHU is thus, regardless of external and internal disturbances, constant. The temperature of the circulating air, on the other hand, varies from the minimum, when a cooling coil operates in the FCU, to the maximum, when a heating coil is in operation. As a result, at any given time, thermally-treated external air of equivalent parameters is supplied to all rooms, whereas the temperature set-point of the circulating air, treated in the FCU, can vary significantly in individual rooms to meet the occupant's local requirements.

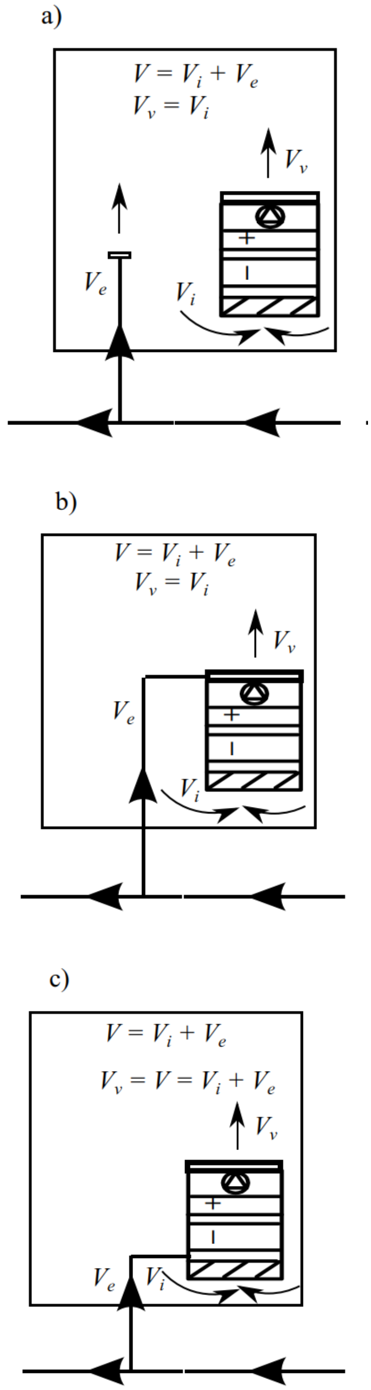

Fig. 1. Schematics of possible entries of external air into air-conditioned space through system with FCUs.

The common supply of external and circulating air occurs when both airflows are mixed prior to reaching supply diffusers (Fig. 1.b-c). The concept of design solution in Fig. 1.b is based on the supply of a mixture of separately-treated external and circulating airflows. The ventilating airflow can be determined from eq. (1). The circulating airflow is equal to the flow drawn by the FCU.

Fig. 1.c presents the concept of design solution in which the entire supply airflow goes through the FCU. The external air mixes with the circulating air. The mixture flows through the FCU, where the entire airflow is purified and thermally-treated (heated or cooled). The supply airflow is, thus, equal to the flow through the FCU, i.e.

$$V_v = V \tag{3}$$

When the mixture of external and circulating airflows is supplied, the supply temperature set-point depends on the thermodynamic changes in the exchangers of individual FCUs and may vary for individual FCUs. At a given time, the external air of corresponding parameters is supplied to all rooms and the circulating air, thermally-treated in FCU, sets the room air temperature.

We perform static modelling to compare the three supply methods under winter and summer design conditions. Our results are based on the following assumptions:

- the maximum supply air temperature increase is set at $\Delta t_s = t_i - t_s = 7$K, where t_i and t_s are room and supply air temperatures,
- the external airflow constitutes 25% of the air-conditioning airflow,
- room air temperature is 20ºC (winter design conditions) and 25ºC (summer),
- room air humidity ranges from 40 to 55%,
- increase of moisture content in the external air supplied corresponds to 1.5 g/kgda in winter and 2.3 g/kgda in summer (grams per kilogram of dry air),
- FCU max air heating by 10ºC.

We show the results on the Mollier Diagram (i-x). The results can be readily used to compare each method through the design set-points of AHUs, the size and duty points of FCUs and the overall energy demand for the HVAC system.

3 Results

Fig. 2. - Fig. 5. show the air treatment processes under winter and summer design conditions for the above-mentioned supply methods.

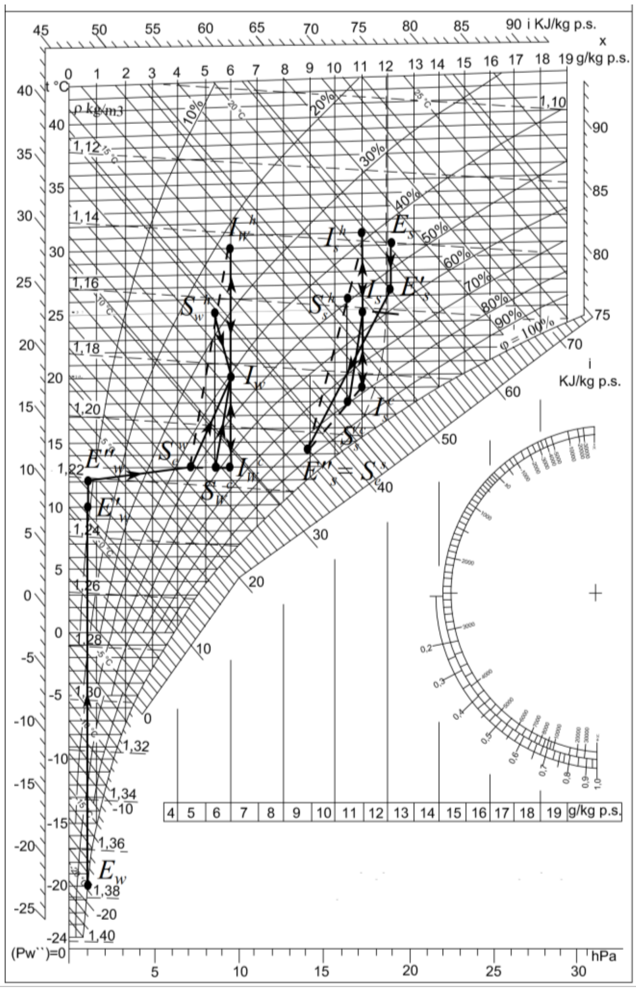

Fig. 2. Processes of air-conditioning airflow treatment and air transitions within a room under summer and winter design conditions for system with external air supplied to FCU discharge side (see p.5 for full list of symbols).

When adjusting air parameters in the FCUs, the aim is to reduce or even eliminate air dehumidification. It is achievable when, in the summer period, the moisture released in a room is assimilated by the thermally-treated external air and the thermodynamic changes of the circulating air are carried out without changing the moisture content.

Keeping the relative air humidity set-point in rooms is possible with proper dehumidification of the external air. This is achieved by cooling the external air down to approximately 14°C. The airflow at such a low temperature, in the summer period, should, however, not be supplied into rooms. With the joint supply of external and circulating airflows (Fig. 2 and Fig. 3), a mixture of a higher temperature, as discussed in the paragraph on assumptions, is supplied into rooms.

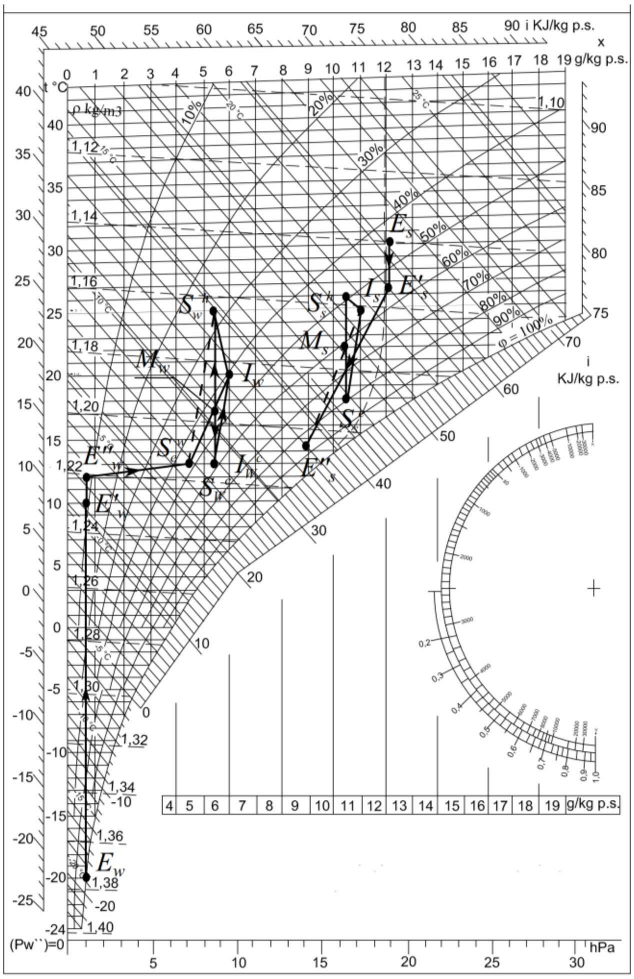

Fig. 3. Processes of air-conditioning airflow treatment and air transitions within a room under summer and winter design conditions for system with external air supplied to FCU suction side (see p.5 for full list of symbols).

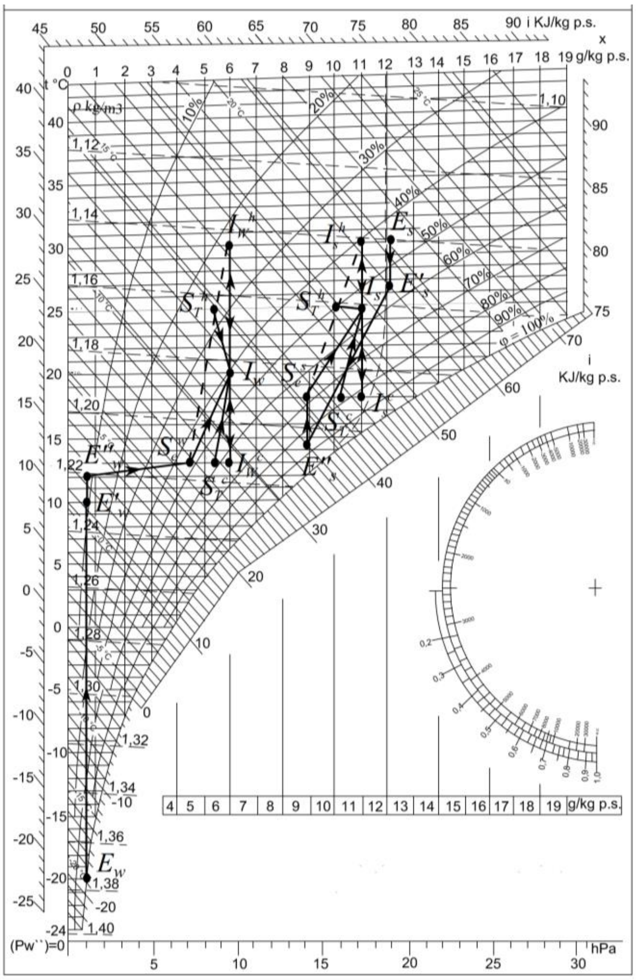

Fig. 4. Processes of air-conditioning airflow treatment and air transitions within a room under summer and winter design conditions for system with direct external air supply to room and cooling without dehumidification (see p.5 for full list of symbols).

However, in the case of direct air supply, the external air should be heated to a higher temperature after cooling and dehumidification (Fig. 4). The alternative solution corresponds to restricting the external air cooling, thus limiting air dehumidification and relying on FCU to dehumidify the circulating air (Fig. 5).

The method of supplying the thermally-treated external air into the room determines the efficiency of the FCUs. With the direct supply of external air (Fig. 1.a, Fig. 4 and Fig. 5) or the joint supply with external air connected to FCU on discharge side (Fig. 1.b and Fig. 2), the airflows of treated air transported through the FCUs correspond to the circulating air flows. On the other hand, when the external airflows are connected to FCUs on the suction side (Fig. 3), the airflows transported by FCUs are equal to the sum of the circulating and external airflows. Also, the external airflow which is thermally-treated in the central AHU is subjected to thermodynamic re-treatment in the FCU.

The external air supply method to air-conditioned rooms affects the energy demand for treatment and transport of air-conditioning, external and recirculating air. To compare this demand, for the presented design solutions, we assume the air-conditioning airflow of 10 m^3/s, of which 2.5 m^3/s corresponds to the external airflow and 7.5 m^3/s to the circulating airflow.

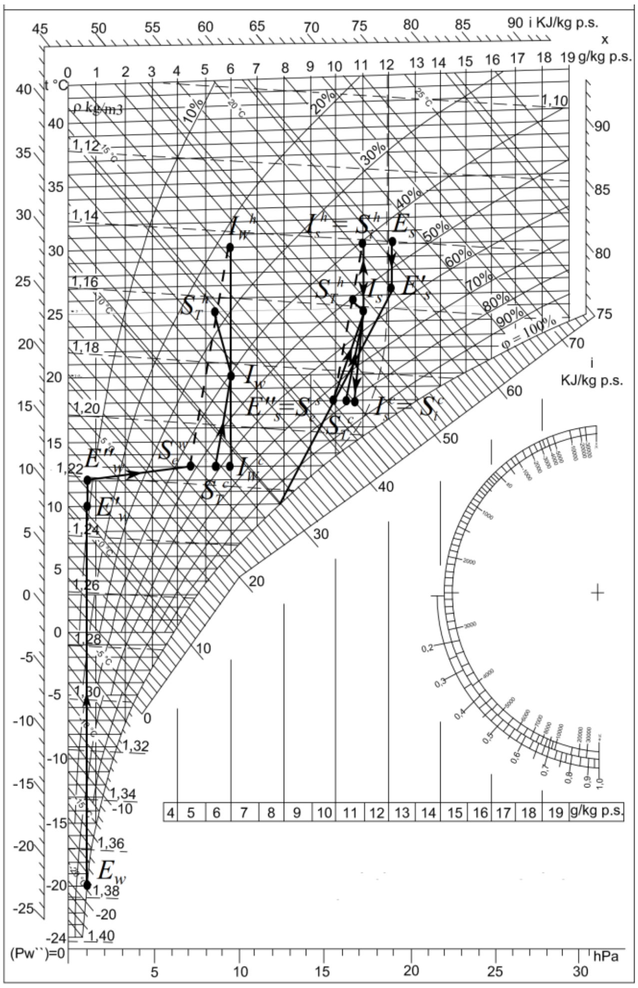

Fig. 5. Processes of air-conditioning airflow treatment and air transitions within a room under summer and winter design conditions for system with direct external air supply to room and cooling with dehumidification (see below for full list of symbols).

4 Conclusions

Air-conditioning systems with FCUs, for individual air treatment of circulating air, are commonly used to set air parameters in multi-space buildings. While systems under investigation are relatively well-known, these are hardly ever discussed in the context of reducing energy demand in the annual cycle of operation. This paper addresses this gap and investigates the impact of external air connection into the treated room on the energy consumption. This paper outlines four design solutions for thermal treatment of airflow in the system consisting of central AHU (for fresh air preparation) and FCUs (for individual treatment of circulating airflow). Two design solutions are based on the separate treatment and separate supplies of fresh air and circulating air (cases 1, 2). The latter two solutions are based on the common supply (cases 3, 4). Our simulations are based on the ventilating airflow of 10 m^3/s. Fig. 6 provides an overview of each case through comparisons of design parameters.

In the case of separate supplies, the energy demand for cooling under summer design conditions corresponds to:

- 126 kW, when circulating air is not dehumidified and external airflow (dehumidified) is heated in the heating coil of 12 kW duty or
- 115.5 kW, when both airflows are dehumidified.

In both cases, 45 FCUs are used to provide individual treatment of circulating air. These correspond to power drive exceeding 4 kW.

The common supply is achieved either by mixing both airflows in the suction or discharge side of FCU. In both cases, the cooling load required to treat 10 m^3/s of air-conditioned air corresponds to 113-114kW. For treatment of the circulating air, for mixing in the discharge side, 45 FCUs are to be charged by over 4 kW drive power. When mixing occurs in the suction side of FCU, air transport requirement is fulfilled by either 60 FCUs of 600 m^3/h duty or 45 FCUs of 800 m^3/h duty. Drive power for these solutions corresponds to 5.5kW.

In order to compare design solutions under consideration, we use identical parameters and design set-points (i.e. airflows, temperature set-points, temperature increments, etc). The most energy-efficient design solutions are based on separate supply of the fresh and circulating air with partial air dehumidification in FCU or mixing the airflows on the discharge side. The connection of the external air (common vs separate) is shown to be another governing parameter, which influences the energy consumption in the annual cycle of operation.

Symbols

V – air- conditioning airflow,
V_e – thermally-treated external airflow,
V_i - circulating airflow,
V_v – airflow on FCU discharge,
E_s – summer design parameters of external airflow,
E_s' - summer design parameters of external airflow after passing through the heat recovery exchanger,
E_s''- summer design parameters of external airflow after passing through the heat recovery exchanger and cooling coil,
E_w – winter design parameters of external air,
E_w' - winter design parameters of external air after passing through the heat recovery exchanger,
E_w'' - winter design parameters of external air after passing through the heat recovery exchanger and heating coil,
I_s – summer design parameters of room airflow,
I_s^c - summer design parameters of recirculating air after cooling,
I_s^h – summer design parameters of recirculating air after heating,
I_w – winter design parameters of room air,
I_w^c – winter design parameters of recirculating air after cooling,
I_w^h – winter design parameters of recirculating air after heating,
S_e^s - set-point of thermally-treated external air supplied into the room under summer design conditions,
S_e^w – set-point of thermally-treated external air supplied into the room under winter design conditions,

S_T^c - theoretical supply air set-point when the circulating air is cooled,
S_T^h - theoretical supply air set-point when the circulating air is heated,
S_s^c - supply air set-point when the circulating air is cooled under summer design conditions,
S_s^h - supply air set-point when heating the circulating air under summer design conditions,
S_w^c - supply air set-point when the circulating air is cooled under winter design conditions,
S_w^h - supply air set-point when the circulating air is heated under winter design conditions,
M_s – set-point of the mixture of thermally-treated external air and circulating air under summer design conditions,
M_w – set-point of the mixture of thermally-treated external air and circulating air under winter design conditions,

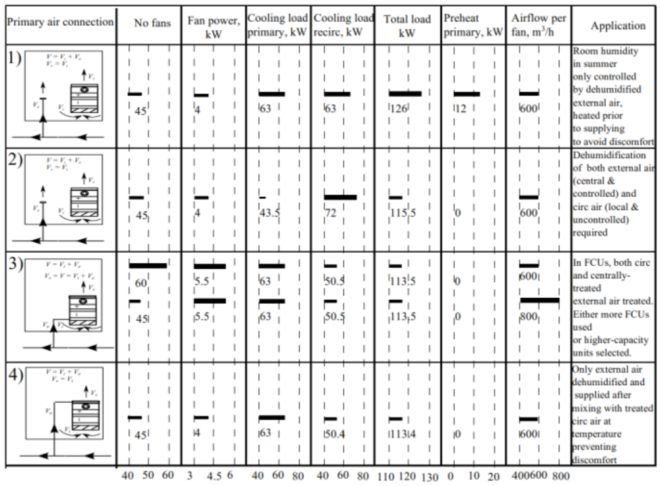

Fig.6. Governing parameters: number of fans, fan power, primary cooling load, circ cooling load, total load, preheat primary, airflow per fan for four cases under investigation.

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Energy-efficient hybrid dual-duct dual-fan systems

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Abstract. Reduction of energy demand for air treatment in dual-duct systems proves particularly challenging, due to simultaneous thermal treatment of two airflows with significantly varying temperature set-points. In pursuit of substantial energy savings for HVAC, we propose new hybrid dual-duct systems, which combine advantages of both extract air recirculation and heat recovery from exhaust air. To ensure energy-efficient performance of our hybrid systems, we propose appropriate technological design solutions for thermal treatment and automatic control. We also resolve problems caused by simultaneous use of heat recovery and air recirculation. The paper presents our technological solution for the hybrid dual-duct dual-fan system with a two-stage reduction of energy demand and our dedicated strategy for the system automatic control. Finally, we perform dynamic simulations of the proposed hybrid system under two-shift occupancy of ventilated rooms to quantify expected annual energy savings.

1 INTRODUCTION

In general dual-duct ventilation systems are designed to deliver temperature set-points in many rooms with different instantaneous thermal loads [7]. In these systems, two streams of supply air are centrally treated, namely a hot airflow and a cold airflow [10-11]. These airflows are subsequently distributed within the building and supplied to individual rooms. Prior to supplying to individual rooms, hot air is mixed with cold air in mixing boxes, in portions that ensure the required instantaneous temperature set-points. Portions of hot and cold air supplied to mixing boxes can vary significantly and be subject to ongoing adjustments during the use of individual rooms. These individual adjustments may be caused by changes in either external conditions (e.g. temperature, solar radiation) or internal room conditions (e.g. variable heat loads, variable air temperature set-points). Energy consumption of dual-duct systems can be relatively high due to simultaneous thermal treatment of two airflows with significantly varying temperature set-points [8]. A standard approach to reducing energy demand in HVAC involves modifying systems by adding either air recirculation or heat recovery [7].

2 REDUCTION OF ENERGY DEMAND FOR THERMAL TREATMENT

The simplest way to reduce the energy demand for air treatment is to use recirculated extract air for supply air. A common practice is to design recirculation with different portions of external air, such that the minimum external air supply requirement, under design conditions, is fulfilled. Different set-point conditions and variable portions of external airflow are used under transient conditions. The purpose of using variable external airflows in ventilation systems is to minimise the energy demand for thermal treatment of the ventilating airflow.
When using heat recovery from exhaust air, it is prudent to use the maximum heat recovery under both summer and winter design conditions. Under transient conditions, it is beneficial to adjust the efficiency of heat recovery to instantaneous requirements and periodically disable heat recovery. Changing the efficiency of heat recovery during transients should also minimise the energy demand for thermal air treatment.

Technological procedures, associated with both recirculation and heat recovery, are well-developed and thoroughly investigated for single-duct ventilation systems [10]. These procedures are, however, not straightforward for dual-duct systems.

The use of recirculation in dual-duct ventilation and air-conditioning systems is presented in many papers [1-14]. However, only few [6-8] include annual analysis of the variable portion of external air in the ventilating air and its impact on the primary energy demand for the treatment of supply air.

The reduction of the primary energy demand through heat recovery in dual-duct ventilation and air-conditioning systems and the efficiency of heat recovery in the annual cycle are only discussed in [7].

We are not aware of any solutions in the literature showing the simultaneous use of extract air recirculation and heat recovery from exhaust air to minimise the primary energy demand for air treatment in dual-duct systems.

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Fig. 1. - Fig. 3. show schematics of technological design solutions, where the above-mentioned possibilities to limit the energy demand for air treatment are applied to dual-duct systems with two supply fans.

Fig. 1. shows a schematic of a dual-duct system with extract air recirculation, in which recirculation is individually controlled for the cold and hot air subsystems, respectively. This technological design solution allows the use of different external air portions in each subsystem, thus ensuring the reduction of energy consumption for air treatment processes in a yearly cycle.

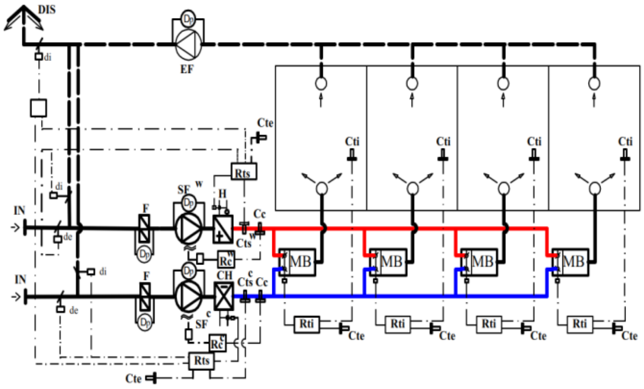

Fig. 1. Schematic of a dual-duct dual-fan ventilation system with individual extract air recirculation for cold and hot air subsystems.
Key: IN – air intake, d – damper, F – filter, Dp – pressure control, SF – supply air fan, c – cold air, w – hot air, H – heating coil, CH – cooling coil, EF – extract air fan, MB – mixing box, DIS – air discharge, Ct – temperature sensor, e – external air, i – room air, s – supply air, r – air mixture, R – regulator, Rc – pressure regulator, Rt – temperature regulator, Cc – pressure sensor.

Fig. 2. shows a schematic of a dual-duct system with heat recovery from exhaust air, in which the efficiency of heat recovery from exhaust air is individually controlled to heat the external airflows distributed into the cold and hot air subsystems, respectively. The diversity of the efficiency of heat recovery is obtained by using the bypass of the heat recovery exchanger through which periodically a portion of the external air is distributed. This technological design solution allows obtaining different temperatures of pre-treated external air in both supply airflows. As a result, the overall energy consumption in the annual cycle for the final air treatment processes is minimised, particularly in the case of cold air subsystem. This design solution, involving the diversified preheat of external air, allows for the maximum use of heat recovery from the exhaust air to heat the external air distributed into the hot air subsystem. Simultaneously, the external air parameters in the winter and transitional periods can be used to set the temperature of the treated cold air.

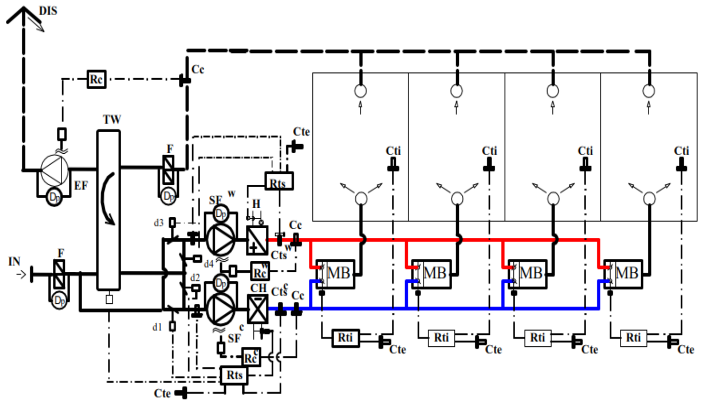

Fig. 2. Schematic of a dual-duct dual-fan ventilation system with individual setting of exhaust air heat recovery for pre-treatment of external air supplied to cold and hot air subsystems.
Key: IN – air intake, d – damper, F – filter, Dp – pressure control, SF – supply air fan, c – cold air, w – hot air, H – heating coil, CH – cooling coil, EF – extract air fan, MB – mixing box, DIS – air discharge, Ct – temperature sensor, e – external air, i – room air, s – supply air, r – air mixture, R – regulator, Rc – pressure regulator, Rt – temperature regulator, Cc – pressure sensor.

Fig. 3. shows a schematic of a new hybrid dual-duct system with extract air recirculation and exhaust air heat recovery. In this technological design solution, the extract air recirculation is individually controlled for the cold and hot air subsystems. Also, energy from exhaust air is used to pre-treat external air distributed into both cold and hot air subsystems. The idea of such a technological solution is to maximise simultaneous usage of both external and exhaust air parameters (temperatures) to set the temperature of hot and cold air, thus minimising primary energy demand for heating and cooling.

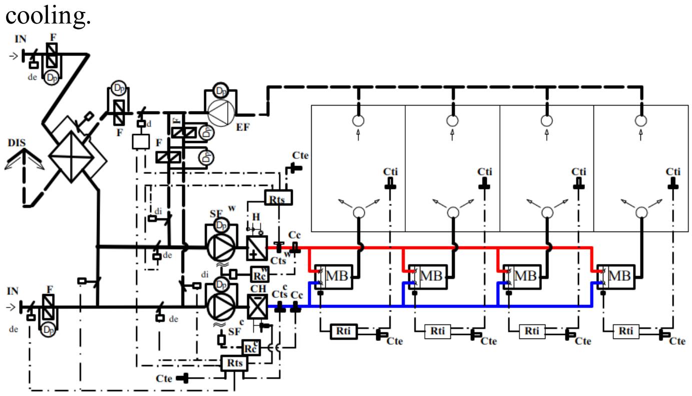

Fig. 3. Schematic of a hybrid dual-duct dual-fan ventilation system with extract air recirculation and heat recovery from exhaust air.
Key: IN – air intake, d – damper, F – filter, Dp – pressure control, SF – supply air fan, c – cold air, w – hot air, H – heating coil, CH – cooling coil, EF – extract air fan, MB – mixing box, DIS – air discharge, Ct – temperature sensor, e – external air, i – room air, s – supply air, r – air mixture, R – regulator, Rc – pressure regulator, Rt – temperature regulator, Cc – pressure sensor.

To illustrate the achievable effects of reducing the energy demand for supply air treatment, we present the results of the full-range dynamic simulation of changes in external air temperature in a yearly cycle of operation of above-described dual-duct systems. Our simulations are carried out at given design conditions and for a summation of thermal loads for all rooms. We present the change of thermal loads as a function of the external air temperature.

3 REDUCTION OF ENERGY DEMAND FOR THERMAL TREATMENT

The t-t_e graphs of the treated air temperature, as a function of the external air temperature, are shown herein to determine the effects of reducing the energy demand for air treatment, as a result of the proposed design solutions of dual-duct ventilation systems. These graphs are based on the following assumptions:
- the constant ventilating airflow;
- the maximum increase in the supply air temperature of 7 K in the room;
- omission of the treated air temperature increase upon passing through a fan;
- changes in the relative heat load of all the rooms, as a function of the external air temperature, as shown in Fig. 4. (a).

Relative heat load q for all the rooms, serviced by a single dual-duct system, is described by eq. (1):

$$q = \Sigma Q_{ci} / \Sigma Q^{max}{}_i \qquad (1)$$

where: Q_{ci} denotes the instantaneous heat gains in the i-room (kW) and Q^{maxi} denotes the maximum heat gains in the i-room (kW).

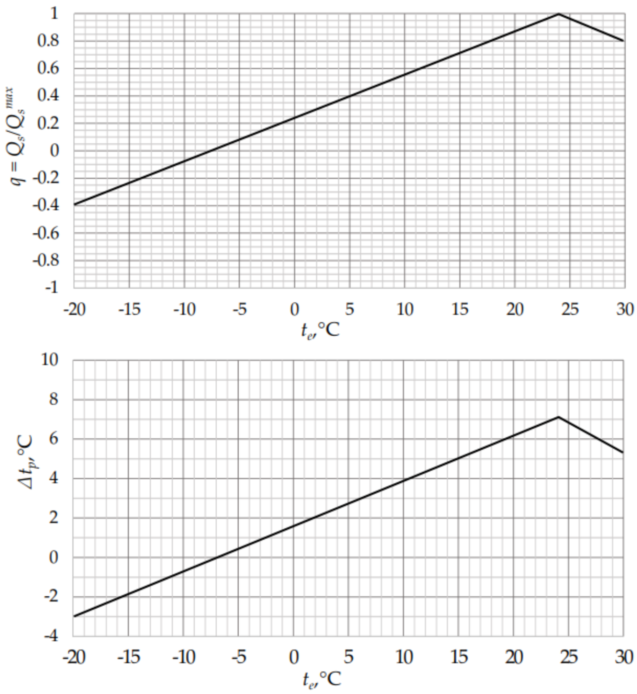

Fig. 4. Functions of external air temperature t_e: relative heat load q of all rooms serviced by dual-duct system; average increment of supply air temperature Δt_p in rooms serviced by dual-duct ventilation system.

Fig. 4. (b) shows the average increase in temperature of the supply air to all the rooms, as a function of the external air temperature, which corresponds to the relative heat load q.

The relationships, presented in Fig. 4.a-b, form the basis for the development of t-t_e graphs showing the variation in the hot and cold air temperature, as a function of the external air temperature. Upon preparing these t-t_e graphs, the room air temperature ensuring thermal comfort is assumed. In the summer period, this corresponds to the room air temperature as a follow-up function of the external air temperature.

4 RESULTS

For relative heat load given in Fig. 4, we have simulated the annual operation of ventilation systems (for schematics of three cases used in simulations, see Fig. 1 - Fig. 3). The results of the dynamic simulations of the annual operation of these systems are presented in Fig. 5. -Fig. 8, respectively. The variations in the following parameters, in the function of external temperature, are shown:
- temperatures of hot and cold airflows,
- internal room air temperatures t_i,
- average supply air temperature t_s,
- temperatures of the mixture of external and recirculating air t_m (in the cold $t^m{}_{e,c}$ and hot air subsystems $t^m{}_{e,w}$),
- temperatures of centrally-treated air in the heat recovery exchanger $t^{\eta}{}_e$, distributed into the cold $t^{\eta}{}_{e,c}$ and hot $t^{\eta}{}_{e,w}$, air subsystems,
- portions of the hot and cold air in the ventilating airflow,
- portions of the external air in the treated cold $a_e{}^c$, hot air $a_e{}^w$ and portions of external air through the bypass of the heat recovery exchanger to the cold air subsystem $a^{\eta}{}_{e,c}$,
- efficiency of heat recovery from extract air for treatment of hot air $\eta_t{}^w$ and cold $\eta_t{}^c$ and efficiency of an additional exchanger for heat recovery η_t,
- hot air temperature increase Δt_w in the heating coil and cold air temperature drop Δt_c in the cooling coil.

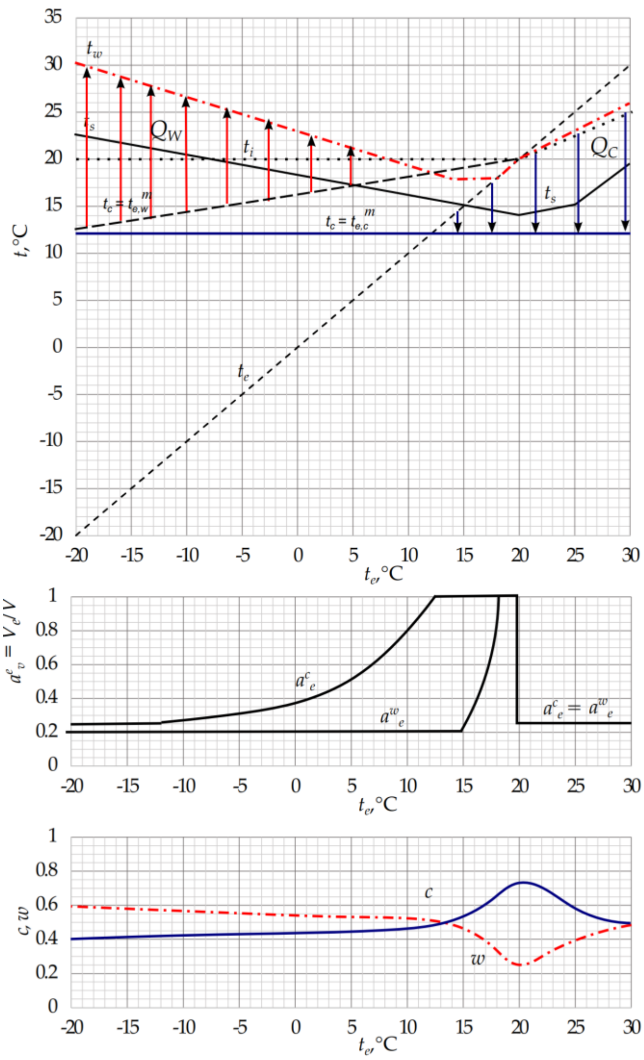

Fig. 5. Results of dynamic simulation of dual-duct system operation, in configuration as shown in Fig. 1, with the minimum potion of external air in the ventilating air $a_e^v = 0.2$ and the relative thermal load of rooms shown in Fig. 4. Functions of external air temperature t_e: variations in temperatures of: hot air t_w and cold air t_c, room air t_i, averaged supply air t_s, mixture of external air and extract air tr; variations in portion of external air in ventilating (a_v^e); variations in portions of hot w and cold c air.

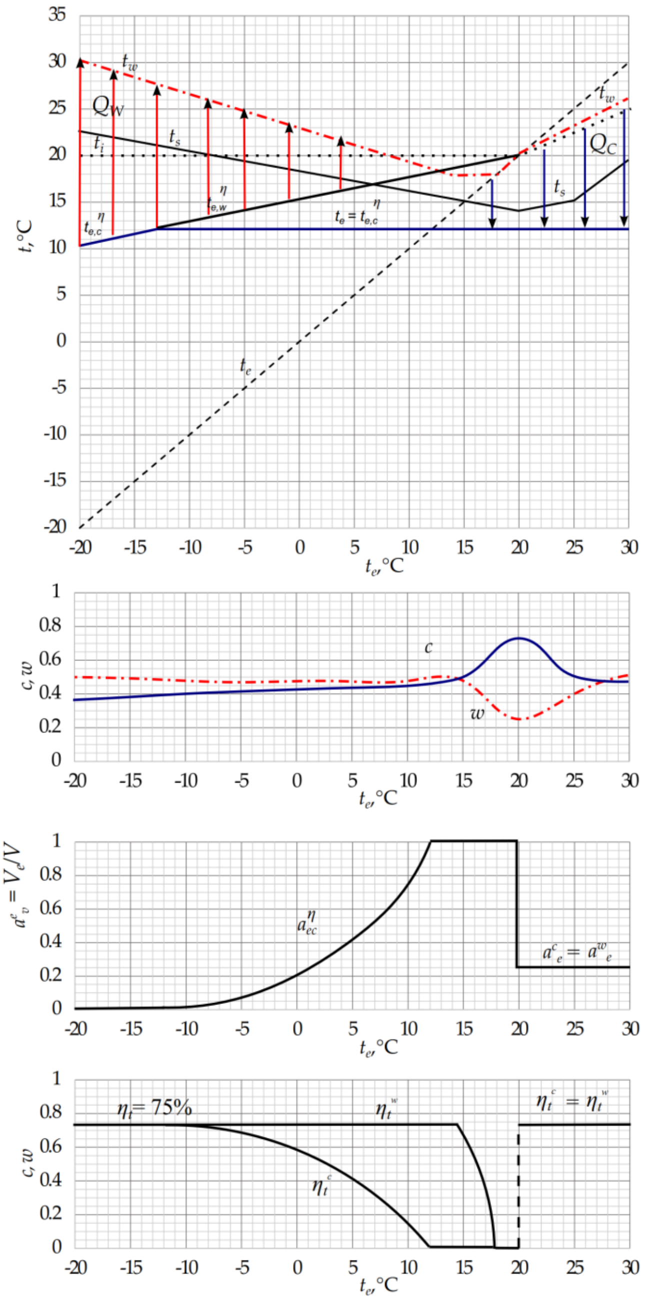

Fig. 6. Results of dynamic simulation of dual-duct system operation, in configuration as shown in Fig. 2, with the maximum thermal efficiency of recovery $\eta_t = 0.75$ and the relative thermal load of rooms shown in Fig. 4. Functions of external air temperature t_e: variations in temperatures of: hot air t_w and cold air t_c, room air t_i, averaged supply air t_s, mixture of external air and extract air tr; variations in portion of external air in ventilating (a_v^e); variations in portions of hot w and cold c air.

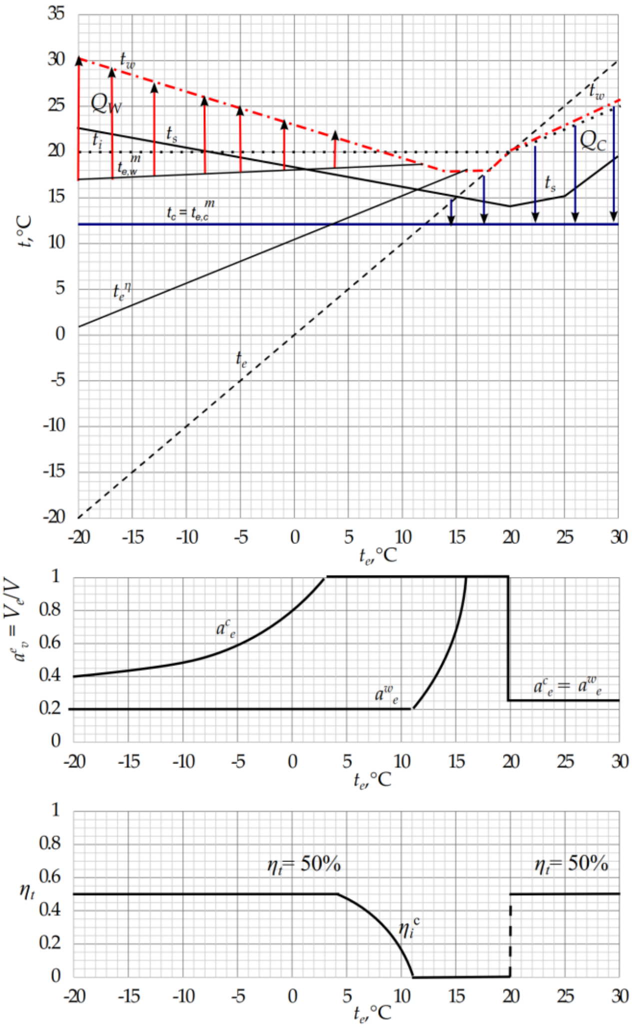

Fig. 7. Results of dynamic simulation of dual-duct system operation, in configuration as shown in Fig. 3, with the minimum potion of external air in the ventilating air $a_e^v = 0.2$, the maximum thermal efficiency of recovery $\eta_t = 0.5$ and the relative thermal load of rooms shown in Fig. 4. Functions of external air temperature t_e: variations in temperatures of: hot air t_w and cold air t_c, room air t_i, averaged supply air t_s, mixture of external air and extract air tr; variations in portion of external air in ventilating (a_v^e); variations in portions of hot *w* and cold *c* air.

Fig. 5. - Fig. 7. show variations in temperatures of treated airflows, in the function of external air temperature. Airflows under consideration include: external air (t_e), or mixture of external air (t_e) and circulating water (t_i) Temperature variations occur during thermal treatment processes prior to reaching the cold air ($t^\eta_{e,c}$, $t^m_{e,c}$) and the warm air temperature set-points ($t^\eta_{e,w}$, $t^m_{e,w}$), respectively. We design thermal treatment processes to use both the energy recovered from the exhaust and external airflows and the primary heating and cooling energy. Fields hatched in Fig. 5. - Fig. 7. indicate temperature variations triggered by the primary energy. The temperature increase Δt_w indicates heating of the portion of the ventilating air (namely hot airflow V_w) in the heating coil installed in the hot air system, whereas the temperature decrease Δt_c represents cooling of the portion of the ventilating air (namely cold airflow V_c) in the cooling coil installed in the cold air system.

In addition, Fig. 5. - Fig. 7. show, in the function of external air temperature, portions of the hot and cold air in the ventilating airflow, thermal efficiency of heat recovery in the hot η_t^w and cold air system η_t^c, portions of external air in the hot a_e^w and cold a_e^c airflow, thermal efficiency of heat recovery in additional exchanger η_t and portion of external airflow through the bypass of the heat recovery exchanger (cold air system).

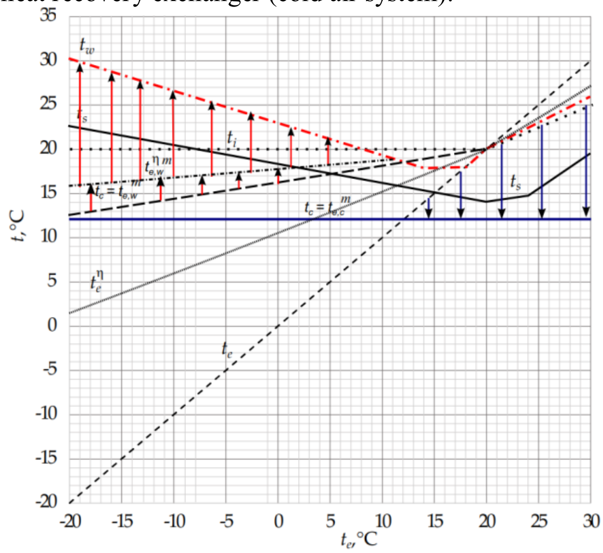

Fig. 8. Results of dynamic simulation of dual-duct system operation, in configuration as shown in Fig. 3, with the minimum potion of external air in the ventilating air $a_e^v = 0.2$, the maximum thermal efficiency of recovery $\eta_t = 0.5$ and the relative thermal load of rooms shown in Fig. 4. Additionally marked is the temperature of pre-treated hot air prior to passing through heating coil ($t^m_{e,w}$).

Fig. 8. shows a graph of the change in the temperature of air treated in the ventilation system shown schematically in Fig. 3. with additionally marked temperature of pre-treated hot air before the heating coil ($t^m_{e,w}$). The hatched field between lines ($t^m_{e,w}$) and ($t^\eta_{e,w}$), represents a decrease in the hot air temperature rise in the heating coil, i.e. reduction of the primary energy demand. This effect is achieved in a dual-duct system with recirculation by adding a heat recovery exchanger to extract energy from the exhaust air. In the summer period, primary energy savings for cooling cold airflow are also achieved and the temperature of the hot air is also lower.

5 CONCLUSIONS

Dual-duct systems have been introduced decades ago to ensure design conditions in multi-room spaces with varying temperature set points and/or different heat loads. The first dual-duct systems were particularly energy-intensive due to technological limitations, control inaccuracies and a limited understanding of annual cycles of operation. However, with the current control and regulation capabilities, the energy demand for air treatment and transport in dual-duct systems can be decreased significantly. The possibility of direct control and regulation of air treatment processes in setting the temperature of hot and cold air, depending on the instantaneous thermal loads in rooms and external air parameters, may lead to: rational use of energy recovered from the exhaust air to adjust the temperature set-points of both hot and cold air and equalization of hot and cold air flows at the inlet to the distribution systems. In advanced and extensive control systems, air treatment in dual-duct systems can also eliminate the processes of simultaneous hot air heating and cold air cooling. In addition, the parallel flow of treated hot and cold air through the heating and cooling coils, rather than in series, reduces the fan static pressure and thus the energy demand for air transport. Also, dual-duct systems allow for individual adjustments of the supply air temperature without local secondary air treatment in each room and additional distribution of heating and cooling medium within the ventilated building. The latter is particularly significant in context of recent controversies regarding refrigerants.

In the paper, we present the fundamental technological design solutions aimed at further reductions of the primary energy demand for the treatment of ventilating air in dual-duct dual-supply-fan ventilation systems. Apart from established design solutions, i.e. extract air recirculation and heat recovery from exhaust air, we propose the new hybrid solution. Our new hybrid system is based on the simultaneous use of extract air recirculation and additional heat recovery from exhaust air.

We used identical thermal loads and operating conditions to simulate the annual operation of dual-duct dual-supply-fan systems under consideration. We present our results in graphs as functions of the external air temperature. Our results include variations: in the temperature of the treated airflow, portions of the hot and cold air in the ventilating airflow, portions of external air in the treated hot and cold air, thermal efficiency of heat recovery from hot and cold airflow.

Our hybrid technological solution results in a significant reduction of the primary energy demand for heating the ventilating airflow. This reduction of primary energy demand may even exceed 30% in the annual cycle of operation.

The simultaneous use of extract air recirculation and heat recovery from the exhaust air ensures the quality improvement of the supplied cold airflow compared to the recirculation only systems. Interestingly, the portion of external air in cold airflow in winter period is higher than the minimum required.

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Comparative study on the electrical power consumption versus monitoring for an outdoor ice rink

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Abstract.

Our paper refers to the analysis of the variation in electricity consumption made by a removable, seasonally ice rink installed outside of a commercial building. The electricity consumption of the ice-skating installation was monitored for about six months between 2016 and 2017, during November and March period of skating season. It is described the ice rink refrigeration plant which is one with indirect mechanical compression in one step using a R134a refrigerant agent and a 30% ethylene glycol solution as a secondary agent. It is compared and analyzed the current electricity consumption with the one obtained by simulating the operation of the refrigeration plant in ideal conditions using R134a refrigerants. A comparison of the electricity consumption is made between simulating the operation of the refrigeration plant using refrigerant R134a or R410a or R507a.

Keywords: monitoring, skating rink temperature, energy performances, outdoor skating rink, analysis

1 Introduction

In this article we analyze the current real electricity consumption against the theoretic one resulted from the installation design of a seasonal ice rink with a surface of 600m^2 mounted on the land next to a commercial building, monitored for its energy consumption.
It will be performed a comparative study between the real electricity consumption and the theoretical electricity consumption by using the Pack Calculation Pro software for the designed installation using R134a as freon refrigerant agent. Supplementary, it will be compared with the similar theoretical electricity consumptions when using R410a and R507a as refrigerant agents.
The operational period of this installation is ranged from November to March, and in the off-season period, the land is used for the terraces for various commercial activities.

2. Description of the installation

The ice rink installation [1] is a mechanical compression system with indirect vaporization in a stage using freon refrigerant R134a and as secondary agent 30% ethylene glycol solution with a refrigerant power of 180kW. This is designed to create and maintain the ice layer of runway up to an outside temperature of 18°C.

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The ice layer thickness should be between 2.5cm and 3.5cm [2], [8], [11], the ratio of the ice quality and ice consumption to maintain the ice is optimal at a thickness of 3 cm. Given that the ice-skating rink is discovered (thus is subject to the wind and precipitations), the ice making activities should be carried out more often.
The temperature of the ice layer varies between - 4 °C and - 8 °C depending on the exterior temperature, the number of the skaters and the opening hours when the ice skating is working.
In figure 1 is represented the ice rink assembly.

Fig. 1. The ice rink assembly

To make these conditions it is recommendable that the ethylene glycol solution temperature which is circulating through the rink pipes to be:

- between - 9°C and -7°C at an exterior temperature between -10°C and 0°C;
- -10°C at an exterior temperature between +5°C and +15°C;
- lower than -10°C at an exterior temperature over +15°C.

When the exterior air temperature falls below -12°C and 15°C, the ice formation and its maintenance will be achieved naturally, without the use of the refrigeration system, it is mounted in a technical room (figure 2) and consists of the following equipment:

a) chiller type York JCI - model YLCS 0620 HA (*CH*) [3] with refrigerant agent freon R134a, having a capacity of 314W, power P_{abs} =131.8kW, with an evaporator for the 30%, flow solution Q_{gl} = 27.5 l/s, condenser cooled with water t_{water} =30^{0}C/35^{0}C, flow water Q_{water} = 21 l/s, with two screw compressors;

b) glycol tank with V = 1000 liters;

c) double pump Willo (*PG*) [4] for the ethylene glycol solution for the ice-skating - model DL 80/220-4/4, with an engine in operation and another engine as reserve, with flow Q = 60.4m^3/h, pumping height of H =14.2 m, NPSH 1.97 m;

d) expansion tank (*VE)* with volume V = 250 liters, pressure p_{max} =10 bars.

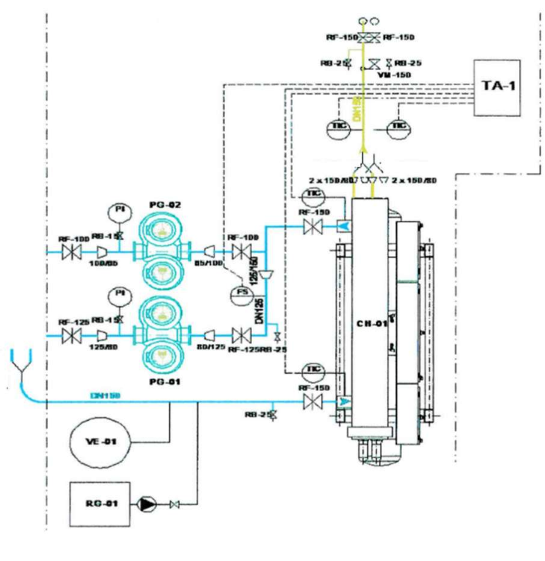

Fig. 2. The refrigeration technical room

The rink has a schedule to operate between 10.00 a.m. and 11.00 p.m. from Monday to Sunday and during the legal holiday's days and at the request of the landlord between 10.00 a.m. and 10.00 p.m.

In the table 1 and figure 3 there are presented the outdoor air parameters and the electricity consumption resulted from the monitoring of the electricity consumption from the refrigerant installations during the period of November 2016 and March 2017, consumptions related to the outdoor air parameters and skaters' number.

Table 1. Outdoor air parameters and electricity consumption for refrigeration system and lighting

Month	Outdoor air parameters		Electricity consumption (kWh)
	Temperature T_M /T_m /T_{med} (° C)	Humidity M / m/ med (%)	
November 2016	19/-3/6	100/35/84	22785
December 2016	12/-1/0	100/34/79	25382
January 2017	6/-17/-5	100/46/85	22205
February 2017	18/-10/2	100/32/80	12094
March 2017	22/-1/9	100/16/72	545

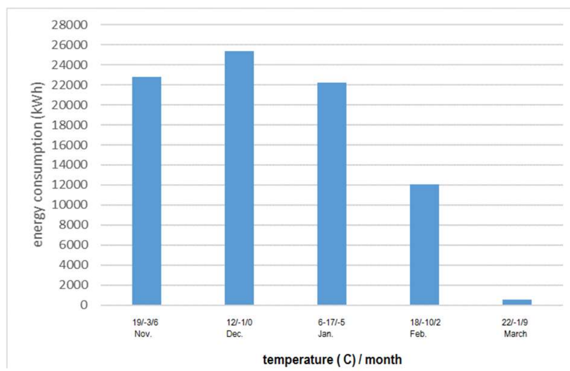

Fig. 3. Variation of the real energy consumption depending on the exterior temperatures

3. Energy consumptions analysis

Pack Calculation Pro is a software used for simulation to calculate and to compare the annual energy consumption of refrigeration systems [9].

The Pack Calculation Pro software contains a wide range of meteorological data, technical characteristics of the various equipment and refrigerants used, which allows studies on energy consumption, efficiency and environmental impact of the analyzed installation.

Using the Pack Calculation Pro software, a comparative analysis was carried out between the current consumption of the refrigerant installation using the R134a freon refrigerant agent and the theoretical consumption of the installation using as refrigerant agents such as R134a, R410a and R 507a.

R134a has the following characteristics:

a) good thermo-dynamic properties used in refrigerant installations having medium power values;

b) chemically stable;

c) hardly inflammable;

d) does not chemically react with metals used in the refrigerant installations;

e) insoluble with mineral and synthetic oils, which causes the use of special oils on the compressor;

f) water solubility is low.
R410A has the following characteristics:
a) transfer of higher heat;
b) low vaporization temperature;
c) high volume refrigeration power;
d) high compressed steam superheat temperature;
e) high adiabatic compression index.
R507A has the following characteristics:
a) stable in normal environmental conditions;
b) having good thermo-dynamic properties in normal environmental conditions;
c) inflammability,
d) miscibility with mineral oils.

For theoretical model of the refrigerant installation of the ice rink, there are used, during the simulation with Pack Calculation software, the Bitzer compressors types such as:
a) CSH7573 – 70 Y for R 134a freon refrigerant agent;
b) OSK 7441 for R 410a freon refrigerant agent;
c) 6 FE – 44Y for R 507a freon refrigerant agent.

In table 2 there are presented the real and theoretical electricity consumptions for the refrigerant installations of the ice rink using the R134a refrigerant agent.

Table 2. Electricity consumption for refrigeration system use R134a

Month	Electricity consumption	
	Refrigeration system real (kWh)	Refrigeration system theoretic (kWh)
November 2016	22,681	22,662.8
December 2016	25,187	23,401.2
January 2017	21,989	23,344.4
February 2017	11,878	21,129,3
March 2017	531	23,458
Total	82,266	113,995.8

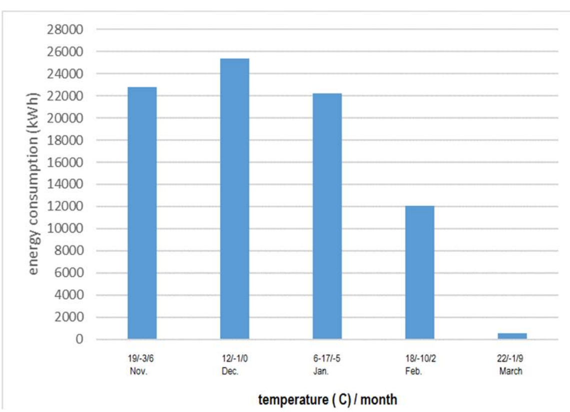

Fig. 4. Real / Theoretical energy consumption for system use R 134a

As it can be observed in the table 2 and the figure 4 the real consumptions are closed to the theoretical ones, exception is seen in the values for the month of February when the consumption is reduced due to the low number of the skaters, so that the refrigerant installation worked more to maintain the ice level and not to remake the ice. Also, in the month of March is seen when the ice rink installation is closed in the first week due to the lowest number of the skaters and to the high exterior temperatures.

The consumption differences are influenced by the parameters of the exterior air temperature, humidity and direction of the wind.

It is noted that the peak of the energy consumption is in December and January because of the higher number of the skaters during the holidays period and of the winter holiday for children.

In the table 3 and the figure 5 there are presented the theoretical electrical energy for the refrigerant installation of the ice rink using as refrigerant agents R 134a, R 410a and R507a during the period of November 2016 – March 2017.

Table 3. Energy consumption for refrigeration system use R134a, R 410a and R 507a

	R 134a theoretic	R 410a theoretic	R 507a theoretic
November	22,662.8	23,302.8	23,605.1
December	23,401.2	24,062.1	24,374.2
January	23,344.4	24,003.7	24,315.0
February	21,129.3	21,725.9	22,007.7
March	23,458.0	24,120.5	24,433.3
Total consumption	113,995.8	117,215.0	118,735.3
Medium consumption	9,499.6	9,767.9	9,984.6

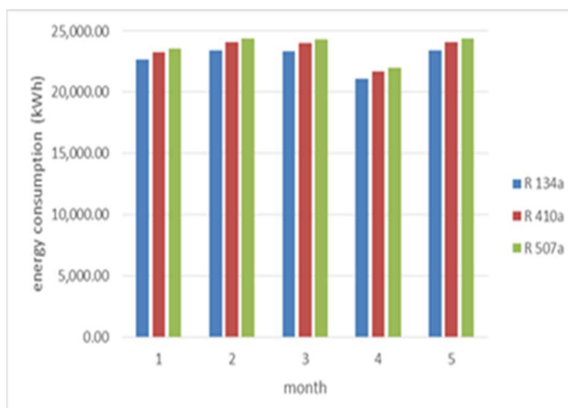

Fig. 5. Energy consumption for refrigeration system use R 134a, R 410a and R 507a

From the table 3 and figure 5 results that the refrigerant installation, which is using R134a freon as refrigerant agent, has the lowest theoretical electricity consumption.

COP for the refrigeration plant is defined as the ratio between the refrigerant output produced during the operating season and the energy consumed by the compressor, condenser, and circulation pumps for the brine.

$$COP = \frac{Q_{refrig}}{W_k + W_{pumps}} \quad (1)$$

Where:

COP – performance coefficient,
Q_{refrig} – refrigerant power (kW),
W_k – energy consumed by the compressor (kW)
W_{pumps} – energy consumed by the pumps for the brine (kW)

In the Table 4 and Figure 6 there is shown the performance coefficient (C.O.P) of the refrigerant installation of the ice rink using the three types of refrigerant agents used and studied. It results that, R 134a has the highest C.O.P. against the others refrigerant agents used.

Table 4. The performance coefficient (C.O.P.) for R134a, R 410a and R 507a refrigerant agents

	R134a theoretic	R 410a theoretic	R 507a theoretic
C.O.P.	2.79	2.71	2.68

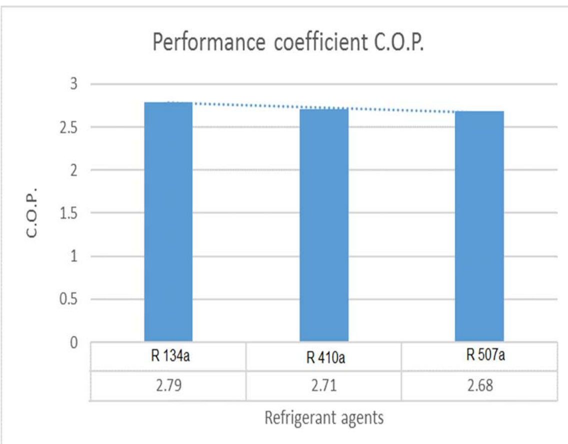

Fig. 6. The performance coefficient (C.O.P.) for R134a, R 410a and R 507a refrigerant agents

As it can be observed, in the table 5 and Figure 7, there are presented the CO_2 emissions obtained in case of the use of the three types of refrigerant agents. Thus, it results that the by using the refrigerant agent R 134a freon, it is obtained the lowest CO2 emission value for the installation.

Table 5. CO_2 emissions for the refrigerant installations of the ice rink using R134a, R 410a and R 507a refrigerant agents

	R 134a	R 410a	R 507a
Emissions Kg the eel (CO_2)	604,178	621,239	629,297

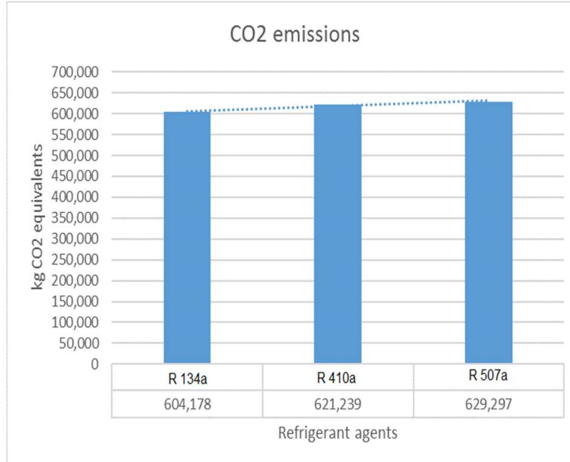

Fig. 7. CO_2 emissions for the refrigerant installations of the ice rink using R134a, R 410a and R 507a refrigerant agents

In the picture 8 there is presented a comparison between the exploitation costs for a duration of 10 years of the refrigerant installation of the ice rink plant. As it can be shown in this picture, the installation using R134a freon refrigerant agent has a higher cost in the first three years and afterwards the exploitation costs are lower versus the ones used by the installation with R410a or R507a during period of ten years in operation.

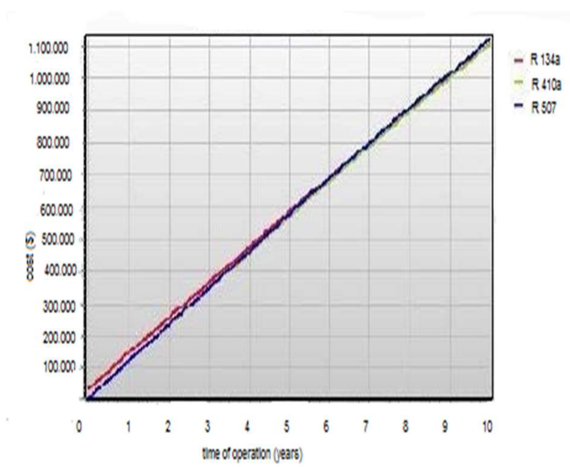

Fig. 8. Exploitation costs (energy consumptions, maintenance)

The cost of the ice rink equipment and their installation is $ 375,000, the maintenance cost per season is $ 7100 for a 10-year life span.
In Figure 9 is presented the evolution of the life cycle cost including the cost of the investment, the cost of maintenance and the cost of the energy electricity consumed.
Figure 10 shows the structure of the life cycle cost. Considering these charts, one can study what measures are indicated for the quicker depreciation of the investment.

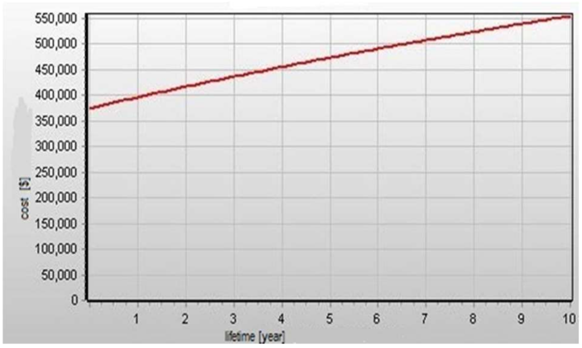

Fig. 9. The evolution of the life cycle cost of the ice rink

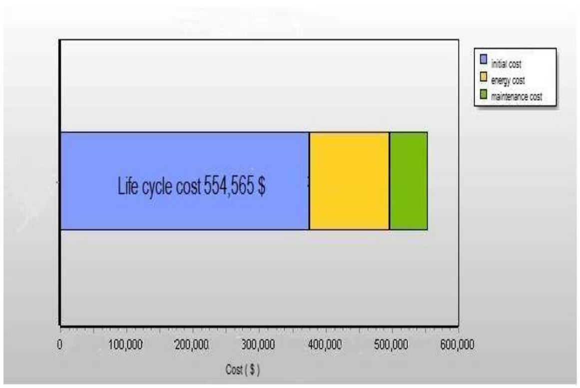

Fig. 10. Life cycle cost diagram

4. Conclusions

Analyzing the results, it is noticed that the solution adopted by the beneficiary by using the refrigerant agent R134a freon is optimal to the use of other refrigerants R410a and R507a, due to the lower energy consumption and higher COP. The refrigerant units using R134a freon are more advantageous than the reliability point.

The R134a freon has a lower purchase price than the other refrigerants studied, therefore the CO_2 emissions are less polluting.

R134a freon refrigerant agent versus R507a freon is not flammable, which is recommended when to be used in cold shops. According to the European Commission regulation 517/2014 as of 2018, it is intended to reduce and eliminate agent R507a in 2020. Between real and theoretical electricity consumption for the refrigerator of the ice rink using the freon R134a, there are small differences which determine that the installation was correctly designed and not oversized.

To produce the energy consumption during the operation of the ice skating it is required:

a) to adopt a dry cooler solution to the refrigeration installation and to lead to 65% electricity consumption savings [5];

b) to equip the electric engines of the frequency inverter equipment for different operating modes such as forming, maintaining ice, recovering ice, leads to 20% reduction of the electricity consumption [2];

c) to plant trees in the wind direction or mounting billboards [2]; the predominant direction of the winds is North-East to South West;

d) to adjust the temperature of the sole according to the outside temperature by fitting external temperature sensors which, depending on its variation and the return temperature of the sole, controls the flow temperature of the sole in the track of the skating rink;

e) to cover the night skating rink with thermal foil.

To establish the budget of the operating the ice-skating installation [6], [7], it is important to consider the monthly costs such as:

a) utility costs;

b) operating monthly fees;

c) charges for insurance policies;

d) salaries with the staff.

The ice rink installation requires permanent supervision, involving the hiring of trained personnel to monitor and maintain the installation permanently and serve the skaters on the track. Limiting the operation of the refrigeration plant to save money can result in lower quality ice, which can lead to less customers over time resulting in higher financial losses by closing the ice rink. Failure to review [6] on time and with proper parts may result in damage to the plant, and its repair is much more expensive.

The costs of opening an ice skating rink are high, they can be amortized by adopting technical solutions to allow for subsequent energy savings. In the first years of operation the percentage of investment recovery is small, the role of the skating rink being specially to attract customers to the commercial building. The owner of the ice rink installation must consider when determining the costs of recovering the investment of the tendency to limit and eliminate from the market refrigerants based on hydrofluorocarbons according to European Commission Regulation 517/2014 if the equipment using this freon is more cost-effective to be repaired or replaced, taking into account its evolution on the market.

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Evaluation of the building envelope to achieve comfort standards in an office building in Izmir

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Abstract. The rapid increase in the world energy use causes the depletion of various resources and has severe environmental impacts such as global warming and climate change. In this context, one of the measures taken throughout Europe is “nearly zero energy building”. The purpose of this study is to examine the effect of a passive design strategy, the design of the building envelope in reaching the comfort standards of an office building in Izmir. The analysis method is to investigate selected variables in a hypothetical office building within the context of reaching a nearly zero energy building via building energy simulation. Four scenarios were modeled included changing the wall-window ratios of façades, changing the window glass type, adding insulation material to opaque building components, and adding shading elements to the facades respectively. Finally, the scenarios are discussed through yearly analyses of heating and cooling loads. The results show that the passive strategies that aim to decrease the cooling loads cause higher reductions in the energy demand of the building in Izmir. Consequently reaching a nearly zero energy office building is not feasible with the evaluated passive design strategies; however they can play a significant role in decreasing the total energy consumption of the building.

1 Introduction

The rapid increase in world energy use leads to the depletion of energy resources and has caused severe environmental impacts such as global warming, ozone depletion and climate change. While buildings account for about 70% of sulfur oxides and 50% of carbon dioxide (CO_2) emissions, they consume about 40% of the world's energy consumption, 16% of the world's fresh water and 25% of the forest timber [1]. Energy use in the built environment is estimated to increase by 34% over the next 20 years. Also in 2030, the consumption attributed to houses and non-domestic sectors is expected to increase to 67% and 33%, respectively [2].

The concept of zero energy building (ZEB) is now perceived as a realistic solution to reduce CO_2 emissions and / or energy use in the construction sector, and not as a distant future concept. An increasing number of ZEB projects and research in this area highlight the increasing international interest in ZEBs. The objectives for the implementation of ZEBs are discussed European level within the recast of the Directive on Energy Performance of Buildings (EPBD) adopted in May 2010 [3]. As of 2018, the EPBD has set out to be a "nearly zero energy building" as a building target for all public buildings or public administration buildings of the public authorities and for all new buildings after 2020. In the studies carried out to date, the concept of ZEB has been defined with a wide variety of expressions, and different approaches to ZEB definitions can be distinguished. The lack of a generally accepted definition of ZEB is currently debated at international level [4].

The facade affects the building's energy budget and comfort more than other systems in most buildings. In the design process of high-performance building facades, directives specific to climate principles must be taken into account. The basic methods for designing high-performance building facades are: Arranging building orientation according to the position of the sun; Using natural ventilation to improve air quality and reduce cooling loads; Minimizing the energy use of mechanical heating / cooling by optimizing the opaque components of the building shell with insulated material; Increasing the use of daylight to minimize the use of artificial lighting and mechanical heating/cooling use by optimizing transparent components of the building variables such as window / wall ratio (WWR), visible light transmission of glazing (VLT), U-value and solar heat gain coefficient (SHGC); Shading to control cooling loads and increase thermal comfort [5].

There are many studies on the optimization of building energy consumption through simulation programs in the literature. Boyanoa A, Hernandez P and Wolf O [6] investigated the effect of different improvement scenarios on the energy consumption and economic performance of the building. Two scenarios with different lighting control systems, two scenarios for the improvement of glass and wall insulations, and two different building orientation variables were calculated for three places representing three climatic regions of Europe. Yıldız et al. [7], investigated the effect of window-wall area ratio on the building energy performance of an educational building in Izmir. Accordingly, they calculated that the eastern and western facades are the most effective and the northern facade has the least effect in terms of total energy consumption. When using low-e coated glass instead of double glazing (base case), they found that the same effects is obtained according to directions. Altan et al. [8], presented thermal balance and daylight level analysis of residential areas. In this context, four different hypothetical spaces with different windows has been modelled. The thickness of the extruded polystyrene (XPS) as the thermal insulation layer of the outer wall and the double glazed and triple glazed features of the windows are the parameters for evaluation. The simulation outputs provided information about optimal facade design for energy efficiency and favorable daylight in buildings with temperate climates.

The use of Building Performance Simulation (BPS) tools at the beginning of the design process is indispensable for assessing the challenges of energy efficient building design. Decisions taken at the early design stage affect 80% of all design decisions [9]. Although there are similar scenarios in the literature, there is a lack of studies which use simulation programs as a decision support tool and aim to optimize environmental comfort, in terms of office buildings in the Mediterranean climate regions. Therefore, the aim of this study is to evaluate the effect of building envelope in an office building to reach the comfort standards in the city of Izmir, Turkey. In this context, the basic methods for designing high performance building facades, which are mentioned above will be examined comparatively.

2 Methodology

The methodology of the investigation is modelling a hypothetical nearly zero energy office building, to calculate the heating and cooling designs of the selected variables and the base case, and to compare the total energy loads calculated by building energy simulation.

Selected simulation engine for this study is EnergyPlus, a 3rd generation dynamic building energy simulation engine developed by the US Department of Energy to model building, heating, cooling, lighting, ventilation and other energy flows. DesignBuilder 5.0.3.007 [10], which is a graphical interface of EnergyPlus simulation engine, is used in this study.

2.1 Building Description and Building System

The hypothetical office building examined is supposed to be completed in 2019. The location of the building is 38°27'3.93" North; 27°10'52.42" East with 2m altitude. The building will comprise of 8-stories and each floor will have the same open-plan office.

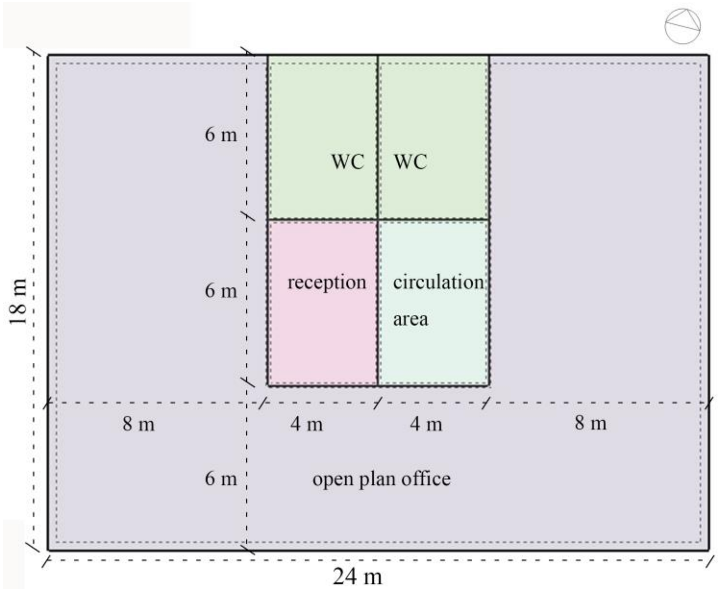

Fig. 1. Floor plan of the building.

The floor plan of the building is a rectangle with a north-south façade of 24 m and an east-west facade of 18 m (Figure 1). Its floor height is 3.5 m. It has a 30° gable roof with 50 cm eaves. The plan is divided into 7 thermal zones: the reception, the core, two WCs and an open-office space oriented towards three different directions, with no separators in between. Table 1 summarizes the general characteristics of the building.

Table 1. General characteristics of the building.

Location of the building	38°27'3,93" North; 27°10'52,42" East
Altitude	2 m
Year of construction	2019
Orientation	North-South
Number of floors	8
Floor height	3.5 m
Floor area	432 m² (18x24 m)
Building total area of use	3456 m² (18x24x8 m)
Building total volume	96768 m³ (3456x8x3.5)
Heating system	Fan coil (natural gas)
Cooling system	Split airconditioner

The opaque parts of the building envelope consists of layers defined as in Table 2 and their thermal conductivity values are also given there. In addition the recommended U-values (thermal conductivity) in the thermal insulation standards for buildings in Turkey TS825 are indicated [11].

The properties of the transparent envelope elements of the building include both the geometric data (the window wall ratio) as well as the thermophysical properties of the windows. In this context, the window-wall ratio of the north, south, east and west facades of the building is 20%, 30%, 40%, 40% respectively. The thermophysical properties of the windows are given in Table 3. The parapet wall of the window is 80 cm and height of the windows are 150 cm.

The office is used between 07.00-19.00 hours except weekend and holidays. HVAC elements do not work except for working hours. Table 4 summarizes the HVAC data that determine the energy loads of the building. The target illumination for the office area, corridors and auxiliary spaces of the building is 500 lux. This value is the minimum value for the office areas specified in EN 12464-1.2009 [12]. The heating / cooling energy of the building is met by a natural gas-powered 4-pipe Fan Coil Unit with an air-cooled chiller. The heating performance coefficient (COP value) of the air conditioning system is 0.85 and the cooling performance coefficient is 1.8. The climate data of the city of Izmir, which has a Mediterranean climate, is taken from the database of US Department of Energy generated for use in EnergyPlus.

Table 2. Parameters of the opaque envelope elements.

Building Envelope Component	Layers	Thickness (m)	Thermal conductivity (W/m²K)	U-value (W/m²K)	U-value recommended in TS825 (W/m²K)
Roof	Tile roofing Air space Waterproofing Screed R.Concrete slab Ceiling plaster	0.015 0.05 0.006 0.04 0.12 0.02	1 - 0.25 0.88 2.5 0.4	1.878	0.45
Wall	Exterior plaster Hollow brick Interior plaster	0.03 0.19 0.02	0.42 0.72 0.4	1.801	0.7
Floor	Laminate flooring Particleboard Mounting Elements Correction screed R.concrete foundation Waterproofing Lean concretev	0.01 0.05 0.04 0.4 0.006 0.15	0.14 0.15 0.41 0.16 0.25 1.13	0.297	0.7

Table 3. Parameters of transparent building components in base case and in Scenario 2.

Glass Type	U-value (W/m²K)	Visible light transmission (VLT)	Solar heat gain coefficient (SHGC)	Thickness (mm)	Joinery type
Double glass (base case)	2.725	0.801	0.742	4mm clear glass + 12 mm air + 4mm clear glass	Aluminium joinery with thermal break
Low-e coated double glass	1.931	0.721	0.634	4mm Low-e glass + 12 mm air + 6mm Low-e glass	Aluminium joinery with thermal break

Table 4. Building's main operating conditions.

Occupancy hours	7-19 h	Hours Monday to Friday
Density of occupation	0.11	person/m²
Metabolic rate	120	W/person
Set point cooling	24	°C
Set point heating	22	°C
Hot water	0.2	l/m² day
Ventilation	10	l/person second
Equipment	12	W/m²
Target iluminance	500	lux

3 Optimisation of building energy consumption

The possible contribution of 4 different scenarios in reducing building energy consumption was evaluated. In order to compare the measures taken, each scenario will be implemented individually. The scenarios and changing parameters are as follows:

Scenario 1: Changing facade transparency ratios; The WWR of southern facade was increased to 40%, the eastern and western facades were reduced to 30% and the northern facade was left as 20%.

Scenario 2: Improving the parameters of transparent building components by changing the glass type to low-e coated double glass (Table 3).

Scenario 3: Adding 5cm XPS extruded polystryne to opaque building components; The U-values of the roof, wall and floor became 0.499, 0.494, 0.207 W / m²K respectively, with the addition of a material with of 0.034 W / m²K U-value.

Scenario 4: Adding shading elements to facades; 50 cm aluminum overhangs on south side and 50 cm aluminum vertical sidefins on east and west facades.

4 Results and conclusion

In this study, it is aimed to compare the heating and cooling loads of the building in different scenarios through a hypothetical office building. Four different improvement scenarios and base case were modelled in DesignBuilder. These scenarios are changing the window-wall ratios, changing the parameters of the transparent building components by changing the glass type, adding 5cm extruded polystyrene to opaque building components and using overhangs to the south and sidefins to the west and the east facade.

Heating and cooling loads of five scenarios, including the original version of the building, is calculated. In this section, firstly the results of heating design and cooling design, then yearly analyses will be evaluated.

The heating design of the building, which is calculated according to the winter design day, is based on the steady-state method [13]. Figure 2 shows the steady-state heat losses in each scenario. The heating boiler of the building is selected by this value obtained by multiplying a design margin (taken as 1.25 in this study). According to the graph, the maximum heat loss is experienced in scenario 1 where the WWR of the southern front was increased and the eastern and western facades were reduced. This is followed by scenario 4 in which the outer shading devices are added, base case and scenario 2 where the glass type is changed respectively. However, there are no significant differences between these 4 scenarios with average 6kW. In scenario 3, where insulation is added to the opaque building components, has minimal heat loss and has 43 kW less heat loss from scenario 2 and 58 kW less from scenario 1. The result is that the most important effect on the heating design is obtained by adding insulation to the opaque building components. Increasing the transparency in the south facade increases the solar heat gain although the heat loss from inside to outside is more. Due to the fact that the shading elements are constant, the heating design has a negative impact on the winter days when solar heat is needed.

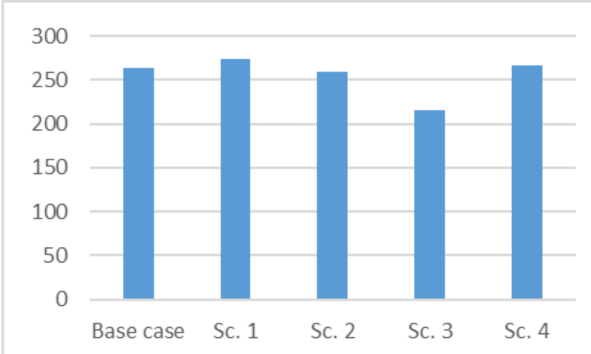

Fig. 2. Comparison of steady state heat loss values [kW].

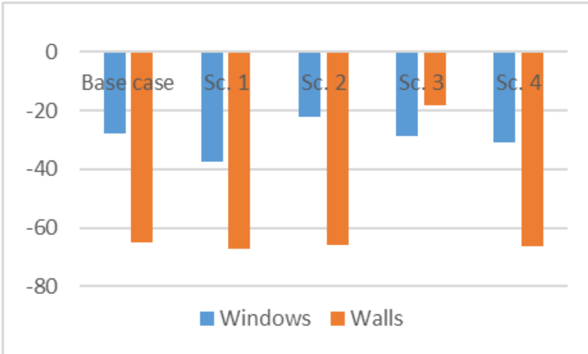

Fig. 3. Comparison of heat loss values of windows and walls [kW].

Heat losses from windows and walls are compared in Figure 3. As can be seen from the chart, the losses in the walls in scenario 3 are critically reduced. The losses in other scenarios are very close. The losses in the windows are the lowest in scenario 2 where low-e coated glass is used. These are followed by base case and scenarios 3, 4 and 1. As a result, the scenario in which the losses are the highest is the situation in which the window / wall ratio in the south direction is increased and those in the east and west direction are reduced.

The cooling design of the building is done according to the characteristics of the summer design day of July 15 with dynamic design [13]. Total cooling loads are given in Figure 4. Accordingly, the lowest cooling load is in scenario 3 where insulation is added to opaque building components. This is followed by scenario 2 with low-e coated glass. There is almost no difference between the scenario of the shading element and the base case. The scenario with the highest cooling load is scenario 1, in which the WWR changed. It is interesting that improving the opaque building components results better than improving the transparent building components. The addition of a shading element is found to be negligible, while it is thought to reduce the cooling load. It is an expected result that increasing the transparency in the south will increase the cooling load due to the increase of solar heat in Izmir climate conditions.

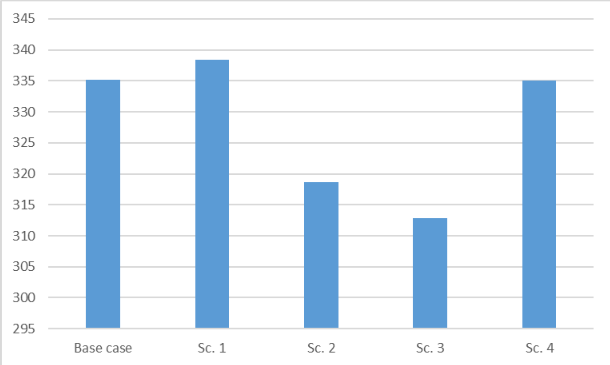

Fig. 4. Comparison of cooling load values at summer design day [kW].

Heating and cooling desig has been carried out to determine the capacity of the heating and cooling system, which needs the coldest and hottest weather conditions of the building. As for the capacity of the heating and cooling system requirements will vary according to the passive climatization measures, the heating and cooling design data are compared above. However, in order to obtain more meaningful data about energy efficiency, the annual total heating - cooling - lighting loads of the building must be compared as shown in Table 9. The heating data for the scenarios in the table are compared in Figure 5, while the cooling data are compared in Figure 6 and the lighting data in Figure 7.

As a result of comparing the annual total heating loads in Figure 5, it is seen that the addition of insulation to the opaque building components in scenario 3 has the greatest positive effect. While the use of low-e coated glass is more positive than base case, adding shading devices in scenario 4 and changing WWR in scenario 1 has resulted with more heating energy consumption than the base case. However, since the heating energy requirement is very low compared to the cooling and illumination, the changes in heating energy did not show much effect on the total energy loads.

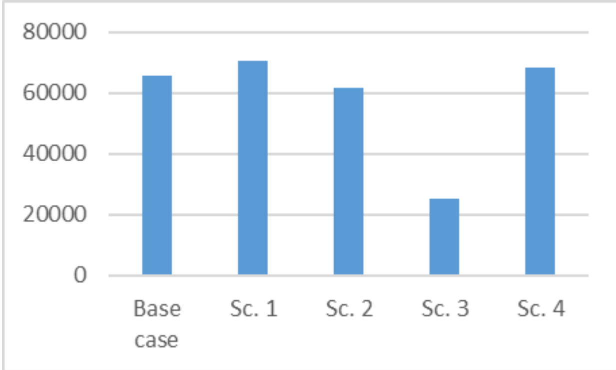

Fig. 5. Comparison of annual total heating loads [kWh] for all scenarios.

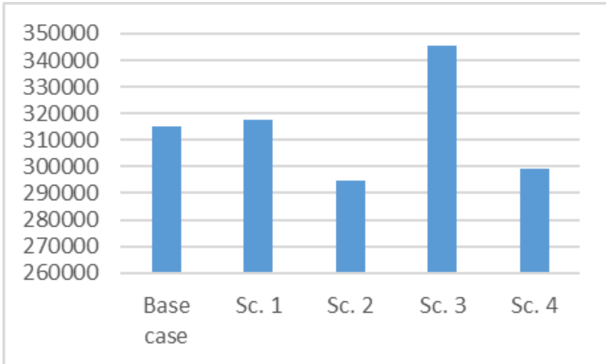

Fig. 6. Comparison of annual total cooling loads [kWh] for all scenarios.

As a result of the comparison of the annual total cooling loads in Figure 6, the use of Low-e coated glass in scenario 2 has the greatest positive effect. Adding external shading devices (scenario 4) has a higher energy load scenario 2 with little difference. Changing WWR in Scenario 1 is closer to the base case and requires more cooling energy than the base case. Addition of insulation to opaque building components has significantly increased cooling loads. The largest energy load is due to the need for cooling energy in general situation.

Annual total indoor lighting loads are compared in Figure 7. Accordingly, the addition of insulation to opaque building components made the most positive effect. Adding exterior shading devices and changing the WWR of the facades are similar. Besides, there is no significant difference between the electricity consumption of the scenarios.

Table 9. Annual total heating-cooling-interior lighting loads [kWh].

	Base case	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Heating	65944.65	70842.49	61635.67	25097.07	68536.81
Cooling	315313.01	317623.76	294671.93	345232.87	299409.23
Interior Lighting	150877.09	149628.14	150877.09	149351.15	149628.14
Total	532134.75	538094.39	507184.69	519618.09	517574.18

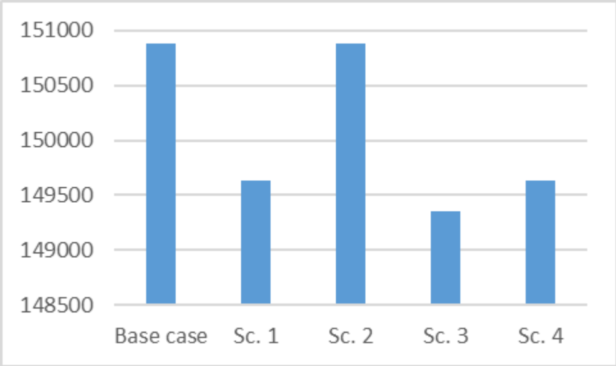

Fig. 7. Comparison of annual total interior lighting loads [kWh] for all scenarios.

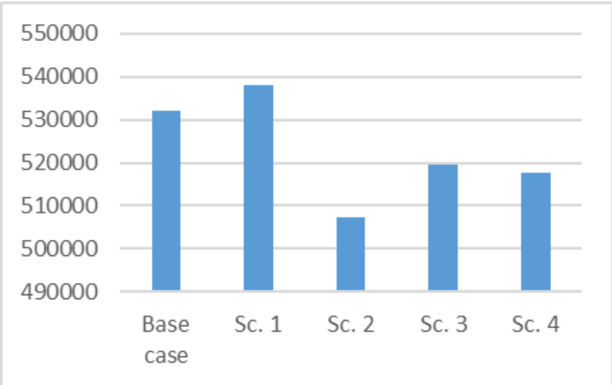

Fig. 8. Comparison of annual total energy loads [kWh] for all scenarios.

Finally, Figure 8 compares the total energy load of all scenarios. According to the chart, the most positive result was obtained by using Low-e coated glass. Adding insulation material to the opaque building components and inserting the exterior shading devices has very close values and is the scenarios that require the least energy use after the use of Low-e coated glass. It was comprehended that the increase in the transparency in the southern front and the reduction of the eastern and western facades caused more energy needs than the base case. In general terms, it is seen that strategies intended to reduce cooling loads have more positive results for decreasing the energy needs of the building in İzmir city.

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Eliminating the Design-Operation Energy Gap: A Case Study on Developing a University Level Course

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Abstract. The global community has reached a consensus on the need to address global warming through the ratification of the Paris Accord (2015). Achieving the goals set forth in the Paris Accord will necessitate a worldwide initiative to design, construct, operate and maintain Net Zero Energy (NZE) Buildings. Creating a new generation of NZE buildings will require the elimination of the historical "energy gap" between a building's design and its operation. This paper describes the development of a new college-level course at the Milwaukee School of Engineering (MSOE) that applies ASHRAE's Building Energy Quotient certification program to eliminate the energy gap by identifying, quantifying and accounting for the energy gap. The course is a critical step in training the next generation of industry leaders, in a multi-disciplinary environment, if NZE Buildings are to be a viable option for our industry.

1 Introduction

1.1 The Paris Agreement

In 2015, the parties to the United Nations Framework Convention on Climate Change (UNFCCC) reached a consensus on combatting climate change through the ratification of the Paris Agreement. This landmark agreement specifies a unified approach to climate change by setting a goal to limit the increase in global temperature to 2°C or less above pre-industrial levels to reduce the risk and impact of climate change. Moreover, the Paris Agreement envisions additional efforts to further limit the increase to 1.5°C.

The Paris Agreement is set to start in 2020 and calls for a mobilization of financial resources, a new technology framework and an enhanced capacity-building to be put in place. The agreement also calls for expanded support for developing countries to assist them in meeting the ambitious goals set forth in the agreement.

1.2 Complying with the Paris Agreement

Approximately 55% of the world's electric demand is used to light, power, heat, air-condition and ventilate buildings (IEA, 2017). Additionally, approximately 40% of the world's electricity comes from coal-burning plants. Coal, in turn, contributes 70% of the world's Carbon Dioxide (CO_2) emissions, a primary Green House Gas (GHG) driving climate change.

Due to the significant GHG contributions made by buildings it stands to reason that the process used to reach the goals of the Paris Agreement will, in large part, flow through the design, construction, operation and maintenance of buildings. The need to produce the most efficient, sustainable and resilient buildings is manifest. Fortunately, a number of organizations worldwide have recognized the need for a new generation of high-performance buildings and have worked steadfastly to produce a design, construction, operation and maintenance protocol to produce buildings with the lowest possible energy use. The ultimate design for such buildings is a Net Zero Energy building.

1.3 The Role of Net Zero Energy (NZE) Buildings

The relatively recent emergence of NZE buildings, along with the traditional protection of boundaries, has prevented a consensus on the definition of an NZE building. Two of the more common definitions have been develop by the European Union and the United States. The definition used by European Union (EU) states (EPBD, 2010):

".... a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent from renewable sources, including sources produced on-site or nearby."

The United States Department of Energy has a slightly different definition of an NZE building (DOE, 2015).

"an energy efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy."

Arising out of these different definitions of an NZE, it is not surprising that there is also a lack of consensus on how to best create an NZE building. In its simplest form, an NZE follows the following steps, in the order listed:

1. An analysis of user demand and behaviour that fully meets user expectations

2. Reducing the energy loads to the lowest possible level
3. Selecting an optimal mechanical and electrical system
4. Harvesting and storing energy from energy streams to and from the building
5. Selecting an optimal renewable energy strategy that covers the difference between the energy required and the energy harvested
6. Eliminate the "energy gap" between design (as designed) and operation (in operation)

Other protocols that have been proposed, but most contain at least the elements found on the list above.

2 The Role of ASHRAE's Building Energy Quotient Rating System

In order to produce an NZE, it is necessary to eliminate the "energy gap", the difference between the energy the building is designed to use and the energy that the building actually uses. The three-step process typically used to eliminate the energy gap consists of:

- Identify the gap
- Quantify the gap
- Account for the gap

ASHRAE's Building Energy Quotient (bEQ) is a rating program for buildings based upon energy that was specifically designed to identify and quantify the energy gap. There are two scales to an bEQ rating; In Operation and As Designed. The 'In Operation' rating compares actual building energy use based upon metered energy use. A minimum of 12-months of energy invoices is required. The 'As Designed' rating compares potential energy use based upon the building's physical characteristics (HVAC system, envelope, etc.) with standardized energy use simulation. The use of standardized criteria in the simulation ensures an equitable comparison between buildings that is independent of operational and occupancy variables. Both the 'In Operation' and the 'As Designed' ratings compare similar buildings in similar climate zones thereby producing an equitable comparison.

The bEQ scale is based on calculating the Energy Use Intensity (EUI) based on source energy. The rating is calculated by dividing the EUI of the building by the EUI for a baseline building and multiplying by 100 $(EUI_{Building}/EUI_{Baseline})/100$ The mid-point of the scale (100) then represents the average of all buildings of a similar type in a similar climate zone. The scale improves to a value of zero for excellent buildings, which also constitutes an NZE. Although the label lists an inefficient building as 200, it is possible for a building to receive a rating higher than 200.

The difference between 'In Operation' and 'As Designed' for a specific building identifies and quantifies the energy gap. Accordingly, bEQ is a critically important tool for design and construction professionals in their quest to produce NZEs.

2.2 Accounting for the Energy Gap

The first two steps in eliminating the energy gap are straightforward and are outside the scope of this discussion. Accounting for the gap is the critical step in the process and the one step that has caused the most frustration in our industry.

Accounting for the energy gap is a significant conundrum for most design and construction professionals, as it is a widely held believe that designers and constructors cannot control how an owner operates and maintains a building once the construction process has concluded. On the other hand, identification and quantification are comparatively easy steps and use tools that we are familiar with and apply every day. Controlling, or even influencing, owner behaviour is a different matter altogether, particularly on a topic as complex as building operation and maintenance.

The bEQ process does include a reporting process that identifies "low-cost, no-cost" Energy Efficiency Measures (EEM) to help lower the energy gap in a cost-effective manner. The larger issue is ensuring that the owner operates and maintains the building over its service life in a manner consistent with the high-performance design and construction practices that produced the building in the first place. High-performance design and construction techniques have little meaning if the building isn't similarly operated and maintained to those same high-performance standards. This is the source of the frustration felt by design and construction professionals.

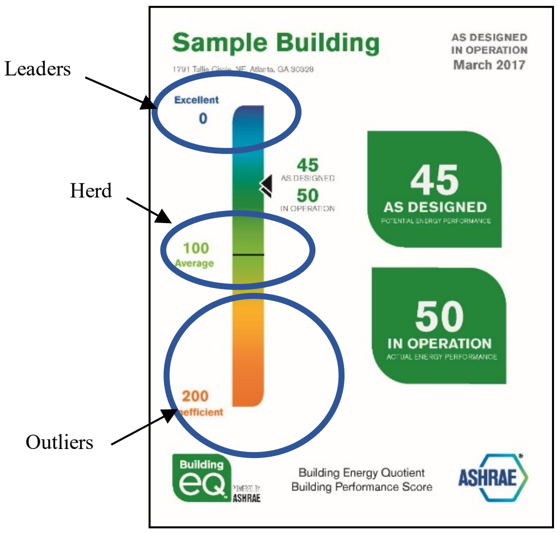
2.3 Shaping Human Behaviour through bEQ

Recent research indicates that shaping or influencing human behaviour may provide 10 to 20% energy savings in the operation of a building (Chen, 2016). One of the hidden strengths of the ASHRAE bEQ program is its ability to shape human behaviour.

Human beings have lived in groups or tribes since pre-historic times. We essentially are pre-wired to operate in a "herd", which not only increases our comfort level, it also shapes our behavior. At least in some respect our behavior has been historically shaped to follow the herd.

Evidence of our herding tendency is ubiquitous. Everything from corporate polo shirts to how we buy cars demonstrates our tendency to herd. One example of how our tendency to follow the herd impacts our behavior is found in research done on tip jars. Using a transparent tip jar and then "seeding" the tip jar with coins and paper currency will increase tip revenue (Heath and Heath, 2010). Why? Because of herding, often referred to as behavior herding (Ariely, 2009). People can see the money in the tip jar, and they assume it was inserted by other people (in point of fact, it may be money seeded by the proprietor). There is a natural urge to follow the herd and insert more money of the type that can be seen in the tip jar.

ASHRAE's bEQ program shapes behaviour through a form of behavioural herding by visually depicting a "herd" at the midpoint representing average performance (Figure 1). Under this strategy ASHRAE's bEQ program quickly and visually "triggers" or shapes behaviour by letting the viewer know if they are a part of the herd or not. Owners not a part of the herd will be strongly influenced to change their behaviour to at least join the herd. If the client has as its goal creating an NZE or nearly NZE building, this visual process will not only identify the distance the client must cover to get to its stated goal, it will also serve as a motivator to move the client towards taking a leadership role.



ASHRAE bEQ Label – Courtesy ASHRAE

3 Case Study

The Milwaukee School of Engineering (MSOE) is a private university located in Milwaukee, Wisconsin, USA. The Bachelor of Science degree program in Architectural Engineering (BSAE) focuses on the design of building systems, with specialties in Building Mechanical Systems, Building Electrical Systems, and Building Structural Systems. MSOE also offers a Master of Science degree program in Architectural Engineering, with specialties in Mechanical-Electrical-Plumbing Systems, or in Structural Systems. The course developed for this case study is housed in MSOE's master program and can be taken as a technical elective in the undergraduate program.

One of the Program Educational Objectives of the BSAE program is that "graduates of the BSAE program are expected to have demonstrated an appreciation for sustainable design by having included aspects of sustainability in their completed projects" (MSOE Undergraduate Catalog, 2019). Conversely in the MSAE program one of the Student Outcomes is that students will be able to "use advanced design techniques to design complex building systems, related to their specialty, made of many components in accordance with building codes, regulations, and/or specifications under realistic constraints such as practice, costs and sustainability" (MSOE Graduate Catalog, 2019). With these outcomes and objectives in mind, the faculty developed a course to address the energy gap in a building using the ASHRAE bEQ rating system.

The course developed for this purpose is titled AE6412 – Building Energy Simulations. The course focuses on the study of building energy assessment principles and protocols for new and existing commercial buildings, as well as a focus on energy modelling to inform and guide the design of a new commercial building. MSOE utilizes a quarter system for course delivery; which means each class consists of ten weeks of instruction followed by a finals week. The AE6412 course is a three-credit course with three lecture hours per week without a separate laboratory for the course. This results in 30-hours of instruction in the course to cover the topics. The students are required to work on a current building project on the campus of MSOE for their semester project and submit the documentation for an ASHRAE bEQ rating.

The course learning outcomes were developed with the ASHRAE standards in mind as well as making a link back to the Program Educational Objectives and Outcomes. The learning outcomes developed are that by the end of the course students should be: 1.) Knowledgeable on building benchmarking and rating systems, 2.) Knowledgeable in the ASHRAE Standards that relate to energy efficiency, 3.) Proficient in utilizing computer energy modelling software to inform design decisions, 4.) Proficient in oral and written communications, and 5.) Knowledgeable of the professional responsibility required of the architectural engineer related to building energy efficiency.

The course begins with an overview of the ASHRAE bEQ rating system and its use. Students then discuss the principles of a Preliminary Energy Use Analysis (PEA) including review of a buildings energy billing data and energy billing rate structures. As part of the PEA the students also review ASHRAE Standard 100 and develop appropriate energy targets for the building. As the final part of the PEA the students conduct the preliminary water and energy use analysis and complete the appropriate ASHRAE bEQ form.

The next component of the course is the ASHRAE Level-1 Walk Thru Analysis. Students were required to develop a questionnaire and perform a Walk-Through Survey on the project as well as review the construction documents for the project. Students were required to document their observations in written form as well as with photographs.

The class then reviews Energy Efficiency Measures (EEM). Students review ASHRAE Standard 100 for EEMs to consider and develop a checklist of likely EEMs for the project. As part of this analysis students review HVAC systems, building automation and controls, lighting systems, and the ventilation/pressurization strategies of the design. Students are then required to conduct an Indoor Air Quality (IAQ) survey. A review of the systems of the building comfort control and indoor air quality are completed using a checklist of likely IAQ issues.

The students then review the requirements for an ASHRAE Level-1 Energy Audit. The financial analysis of the building systems is conducted as well as completing the ASHRAE bEQ in Operation Form 4. As part of the final project students are required to collaborate to submit the ASHRAE bEQ in Operation rating application on behalf of the University.

The final portion of the class is the presentation of the ASHRAE bEQ submission to the administration of the University. Students developed a 45-minute presentation showing the results of their review of the project, comparing the in-operation rating to the as-designed system for the building, identifying the energy gap. Suggested strategies to increase the energy performance of the facility are also presented. This presentation was given to the instructor of record, the Vice-President of Operations, as well as the Owner's Representative for the University.

The University has stated in its strategic plan that sustainability for their campus is a focus for improvement, as stated in Strategy 3 under the Commitment to Being Extraordinary – implement visionary and comprehensive plans for campus buildings, instructional technologies, and information systems (MSOE Strategic Plan, 2018). As part of this strategy the university needs to identify the baseline of their physical plant in terms of energy usage and efficiency, since no such evaluation had been done in the past. In keeping with the experiential-based learning that is the hallmark of MSOE, as well as also being part of the strategic plan as listed in Strategy 3 under the Commitment to Learning and Discovery – ensure that all students use real-world projects and initiatives in their field of study or extracurricular interest to benefit society and the communities where we live and work, it is vital to provide Architectural Engineering with buildings to work on in order to study its energy use. With this in mind, the University asked to have the evaluation of the energy use and energy gap for buildings on campus to be done by students as part of a class, and the AE6412-Building Energy Simulations course was developed specifically to help with this endeavour.

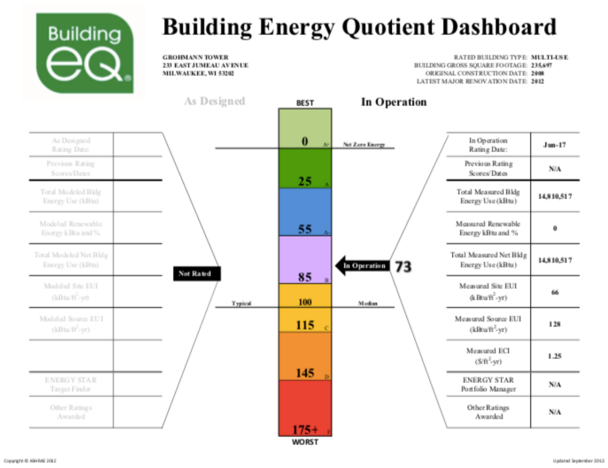
The project used for this course in the last academic year was the Grohmann Tower Apartments building. This is the first building on MSOE's campus to be evaluated for the ASHRAE bEQ rating system, it is also the first building on MSOE's campus to be evaluated for any type of energy or sustainability rating. The building is a 14-story mixed-use high-rise student housing facility located in downtown Milwaukee, Wisconsin. The 2^{nd} and 3^{rd} floor of the building are a parking structure while the 4^{th} thru the 14^{th} floor are the living units. There is also a larger conference room on the 14^{th} floor. The first floor of the building has two separate commercial restaurants as well as a lobby area entrance for the residents of the building. The building has 150 living units in a variety of sizes ranging from 525 square foot (53 square meter) studio units up to 2300 square foot (250 square meter) 2-bedroom units. The project was completed in 2015 and utilizes a water-source heat pump HVAC system and a Johnson Controls Metasys Building Automation System.

Grohmann Tower Apartments

The facility has a gross floor area of 235,697 square feet (23,570 square meter) and a gross conditioned floor area of 225,213 square feet (22,521 square meter). Since the building is located in Milwaukee, Wisconsin, it resides in DOE Climate Zone 6A. The energy data used for the evaluation was from January 1^{st}, 2016 thru December 31^{st}, 2017. The data collected showed that the facility used 7,858,917 kBtu of electricity and 6,951,600 kBtu of natural gas for a total building use of 14,810,517 kBtu.

The students entered this data into the ASHRAE bEQ workbook and verified the results. The students then entered the relevant data into the ASHRAE bEQ Dashboard to evaluate their results, showing that the building in operation has a rating score of 85, earning a rating of B for the project.

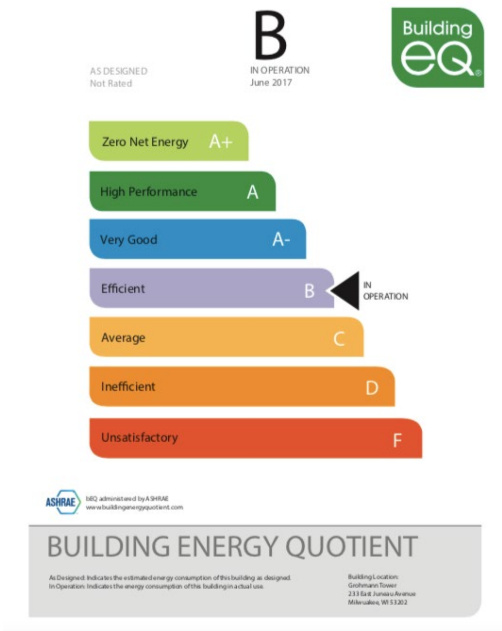
Since the pilot course was run, ASHRAE has completely revamped the bEQ program to include a new bEQ portal where the necessary data is now uploaded online. This eliminates the requirement for downloading and uploading spreadsheets, greatly simplifies the process and increases the response time thus giving the designer timely feedback and enables better design decisions.



ASHRAE bEQ Dashboard – Grohmann Tower Apartments

The AE6412 course was offered for the first time in 2017 and consisted of 6 students. All students worked collectively on both the ASHRAE Level-1 Energy Audit as well as the ASHRAE bEQ In-Operation rating application. The submission was accepted and reviewed, and the Grohmann Tower Apartments project was awarded a rating of B, or "Efficient" for 2017.

The students presented their findings to the leadership team of the University, including the Vice President of Operations. The conclusion of the students was in order to improve the energy performance of the building and help close the energy gap, the primary strategy the University should implement is the use of occupancy sensors for the lighting in all of the common areas of the building (e.g. hallways, elevator rooms, 4th floor common spaces). The students ran an energy model implementing this technology and it was determined the building would achieve an A rating if this was done. The University is currently researching the possibility of adding these occupancy sensors to the building and will be soliciting bids from contractors in 2019 assuming funding is approved.



ASHRAE bEQ Label – Grohmann Tower Apartments

Students were invited to a ceremony to hang the ASHRAE bEQ rating plaque at the Grohmann Tower Apartments. The University will continue to utilize this class to evaluate the energy usage for other facilities on campus. The University is currently constructing a new facility, the Dwight and Dian Diercks Science Hall, a 64,000 square foot (6,400 square meter) facility to house the Computational Science and Software Engineering programs. The building also features a new Nvidia Supercomputer and data centre. The students for the current AE6412 course will be completing an ASHRAE bEQ As-Designed rating, with the following years class doing the In-Operation rating. This provides a unique opportunity for students to do both rating systems and compare the results.

4 Conclusion

The need for buildings to become more energy efficient in order to lower the demand for coal is clear. In turn, this will help combat the global warming crisis and help comply with the Paris Agreement. The push for buildings to strive for NZE will continue to grow in the immediate future.

Many building owners are concerned with the energy usage of their facilities, and universities in the United States have significant expenses in this regard for their campuses. Students entering into the Architectural Engineering industry will need to be aware of these concerns in their designs and should be knowledgeable in how to conduct an ASHRAE bEQ rating for a project.

This course showed the tangible benefits of having a college class dedicated to energy analysis and identifying the energy gap thru the ASHRAE bEQ rating system. The University helped make progress towards its strategic goal of obtaining a more energy efficient campus by establishing a baseline of energy usage on the Grohmann Tower Apartments. The University also obtained several strategies from the student presentations on methods to lower energy usage in the building for the future.

The course was successful in instructing students on how to complete an ASHRAE bEQ In Operation rating for a building. The course also met all of its stated learning outcomes as verified thru exam scores as well as by the rubric used to grade the final project submission. Further validating this was the acceptance of the ASHRAE bEQ submission and the project receiving a rating.

The course also helped the students achieve the specific MSAE program outcome to be able to use advanced design techniques to design complex building systems, related to their specialty, made of many components in accordance with building codes, regulations and/or specifications under realistic constraints such as practice, costs and sustainability by evaluating a real-world project thru an ASHRAE Level-1 Energy Audit and then presenting strategies to improve the energy performance of the building. By incorporating these types of projects into the curriculum it is hoped that graduates will then meet the Program Educational Objective to demonstrate an appreciation for sustainable design by having included aspects of sustainability in their completed projects.

It is clear that building owners will continue to seek systems and strategies that lower the energy use of the building. In order to do this, engineers must be trained to perform design analysis of various options to achieve NZE status. It is imperative that college curricula reflect this need and implement courses that address this need. This case study serves as an example that not only will the course help train the future engineering professionals about these strategies, but also that the University can gain tangible benefits from having the students use campus buildings as class projects.

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Relating forms and materials of traditional and contemporary building types to indoor and outdoor air temperatures for sustainable development in Okigwe, Nigeria

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Abstract. This paper relates forms and materials of traditional and contemporary building types to indoor and outdoor air temperatures in Okigwe, Nigeria, with a view to developing design criteria for minimum consumption of energy for maximum comfort. Data on indoor air temperature were collected from nine purposively sampled buildings monitored simultaneously on hourly basis for a year (1 Nov 2015 - 31 Oct 2016), using Tinytag Explorer Data Loggers. The mean annual indoor air temperature value of traditional building types was 28.2^{0}C, contemporary building types 28.7^{0}C and mean annual outdoor air temperature value was 29.0^{0}C.The mean daily values of indoor air temperature of both building types were significantly different ($z = 1.74$, $p = 0.04$). Contrastingly, there were no significant differences between the outdoor and indoor temperature values of traditional building types [$t(20) = 1.25$, $p = 0.22$], and contemporary building types [$t(20) = 0.53$, $p = 0.60$]. The forms and materials of traditional building types ensure reduction in energy and consumption pattern and provide acceptable indoor thermal environment. The adaptation of its forms and materials will aid in the conceptualisation of design criteria for sustainable development strategies in Nigeria and other developing nations.

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1. Introduction

The urban milieu is stressed by the rate at which humankind exploit its resources. Buildings as part of the urban environment enable humans perform greater part of their activities within them; they also contribute to the generation of greenhouse gases, thereby making attempts at understanding their thermal characteristics a major plank in the discursive field of sustainability. Although much have been done on the need for shift in energy demand, building design and internal temperature control to reduce the rapid global warming and climate change which have been adduced to be devastating and exhaustive, very little efforts are yet to be made in knowing the thermal climate and its integration into conceptions of sustainability and urban development in Nigeria and other developing nations [1, 2, 3]. More so, according to [2], developing nations are at advantage in that much of their urbanisation has not taken place and as such it's planning and management can be construed in ways amenable to the dictates of the risks associated with climate changes.

The challenges connected with unsustainable consumption patterns have continued to undercut society's sustainability goals. Issues of air quality due to carbon and greenhouse gas emissions remain predominant and bothersome. The evolution of industrialisation and transfer of technology in the guise of global enterprise coupled with growing costs of energy, scarcer and more expensive, and more extreme changes in the global climate, have confronted the environmental designers and stakeholders to design buildings and articulate policies that are not only going to provide thermally acceptable but secure, accessible, healthy and productive while reducing its effects on the environment [4, 5].

The rate at which the human race reshape the environment has raised concern to the global community, hence, the World Commission on Environment and Development in 1987 agreed that development should be sustainable by meeting the needs of the present without compromising the ability of future generations to meet their own needs. Sustainable development was further devolved to incorporate economic, social and environmental key dimensions. According to [5] economic sustainability is a method of production that satisfies present consumption rates without affecting future needs. Social sustainability has to do with the ideas of equity, empowerment, accessibility, participation, sharing and cultural identity [6]. Whereas environmental sustainability conforms to consumption of natural resources by humans at a rate where they are able to replenish themselves, and maintaining ecological integrity of all earth's environmental systems.

Forms and materials of composition of traditional and contemporary building types differ in the approaches toward providing suitable and sustainable strategies in ensuring users' satisfaction, reduction of energy consumption and provision of acceptable indoor thermal environment. The forms and materials for buildings constitute the interface between the external and internal environments and as such control energy efficiency, indoor environment and functional performance of buildings. They are described as 'climate moderators' and first lines of defence against impact of external climate on indoor environment [7]. In the attempt to attain desired thermal comfort levels, different forms and materials are manipulated and they reflect the relationship between climate, architecture and people [5].

Different climates, cultures and traditions akin to different regions all over the world are not endowed with same building materials and techniques either in type or quantity [8]. Consequently, forms and types of shelter vary [9]. Each culture, tradition and regions developed her architecture based on the availability of these materials and her ability to handle them within the ambit of their knowledge prowess. With the independence of Nigeria from her British colonialists in 1960, mud (known as *aja ulo* in Igbo Language, one of the major tribes in Nigeria), timber (*osisi*), bamboo (*achara*), palm midribs (*ogugu*), thatch (*akilika*), and rope (*udo*) were the component materials used in the forms and materials composition of traditional building types. Similarly, sandcrete walls, cement, metal roofing sheets, asbestos ceiling sheets and other materials such as steel, glass, plastics, and plywood gave rise to the systems of composition adopted in contemporary building types. Also, the development of new materials, technology and increase in the number of indigenous architects and practices aided in the blossoming of contemporary architecture. However, use of electro-mechanical devices for comfort in the contemporary building types which are variance with the passive design strategies associated with traditional building types adversely led to mismanagement of energy resources [10]

Numerous studies have identified air temperature, relative humidity, mean radiant temperature, air velocity, metabolic rate and clothing insulation as the factors that define thermal comfort and also established indices for their measurements, however, air temperature has been singled out as the main design parameter since it determines the sensation of occupants within spaces [11, 12, 13]. The design challenge in warm-humid climate like Okigwe, Nigeria, revolves around mitigation of adverse effects of elevated temperatures and humidity. Despite global worries mitigating and adapting buildings for sustainable development, there is dearth of literatures on the thermal performance of forms and materials and methods of composition of different types of buildings in Nigeria. The few existing studies concentrated on thermal performance of residential buildings and its occupants' responses to thermal environment without investigating the effects of outdoor on indoor environmental variable of air temperature on forms and materials of traditional and contemporary building types [14].

Therefore, the thrust of this paper, is to relate forms and materials of traditional and contemporary building types to indoor and outdoor air temperatures for sustainable development in Okigwe, Nigeria, with a view of providing design criteria for minimum consumption of energy for maximum comfort. The hypotheses formulated for the study test the significant differences between indoor air temperature values of traditional and contemporary building types, and compared each of the types to the outdoor temperature of the study area – Okigwe, Nigeria.

2. Research Methodology

2.1 Study area

Okigwe, a semi-urban city in the warm-humid climate of Nigeria lies between Latitudes 5^0 30' and 5^0 57' North of the Equator and Longitudes 7^0 04' and 7^0 26' East of the Greenwich Meridian. It is one of the 27 Local Government Areas (L.G.A.) and has a land area of about 1,824 km^2. It is bounded in the north and east by Abia and Anambra States; Ideato North and Onuimo L.G.As of Imo State share the western boundary whereas, Ehime Mbano and Ihite-Uboma L.G.As are on the southern fringe of Okigwe. The tropical rainforest climate designated by the Koppen climate classification as 'AF' characterizes the south-eastern part of Nigeria including Okigwe. It experiences dry and rainy (wet) seasons. The mean annual temperature is 26.4^0C with 27.6^0C, 25.0^0C and 2.6^0C as maximum, minimum and range respectively. The annual precipitation is over 2000mm.

The relative humidity is high in the mornings and during rainy seasons. It ranges from 80% to 100% while in the afternoons and during the dry seasons, it hovers between 60% and 80%. This semi-urban city experiences the conventional type of rainfall due to its proximity to the equatorial belt. Rainfall is heaviest during the months of June and July. It is situated approximately 62 km north-east of Owerri, Imo State capital; 87 km south of Enugu, the regional headquarters of south-east Nigeria. It is also about 549 km east of Lagos – commercial nerve centre of Nigeria and about 525 km, south-east of Abuja – the Federal Capital Territory (F.C.T) of Nigeria. Generally, the people are predominantly farmers.

2.2 Research design

To gain an in-depth understanding of the phenomenon of indoor and outdoor air temperature, the case study research design approach was adopted with multiple case study variant used to collect data from nine purposively sampled case buildings. The sampled buildings possess forms and materials reminiscent of traditional and contemporary building types and practices. Two of the buildings belonged to the traditional types, whereas the other seven were of the contemporary types.

Buildings whose walls and roofs fabrics were made of mud and thatches constitute traditional building types whereas contemporary building types comprise those with sandcrete block and corrugated iron and aluminium roofing sheets. Walls and roofs as elements of buildings possess inherent qualities that modify the internal environment of buildings [3].

2.3 Data collection

Indoor environmental variable of air temperature for the nine sampled buildings was monitored simultaneously on hourly basis from 1 November 2015 to 31^{st} October 2016 using Tinytag Explorer Data Loggers. They were mounted at 1200mm above the finished floor level. The secondary data comprise outdoor temperature values obtained from the nearest Meteorological Station at the Imo (Sam Mbakwe) International Cargo Airport, Owerri, Nigeria.

3. Results

Data on indoor and outdoor environmental variable of air temperature were obtained from traditional and contemporary building types. Also, secondary data were got for outdoor temperature in the study area.

3.1 Indoor air temperature values in traditional building types

As in Table 1, the mean annual indoor air temperature value obtained for traditional building types was 28.2^0C. The maximum and minimum values of 30.6^0C and 26.3^0C were recorded in February 2016 and August 2016 respectively. As stated earlier, there are two major seasons in the study area: rainy (wet) and dry seasons. Rainy season starts from April to October whereas; dry season is from November to March. A difference of 1.1^0C exists between the mean rainy season indoor air temperature value of 27.7^0C and 28.8^0C for the dry season. The standard deviation was 1.4^0C and range 4.3^0C.

3.2 Indoor air temperature values in contemporary building types

As indicated in Table 1, the mean annual indoor air temperature value obtained for contemporary building types was 28.7^0C. The maximum and minimum values of 30.9^0C and 26.8^0C were similarly recorded in February 2016 and August 2016 respectively. The mean indoor air temperature value of 28.1^0C was obtained for rainy season and 29.4^0C for the dry season; with a difference of 1.3^0C. The standard deviation was 1.36^0C and range 4.1^0C.

3.3 Outdoor air temperature values in Okigwe, Nigeria

Further Table 1 showed that the mean annual outdoor air temperature value obtained for the Nigeria was 29.0^{0}C. The maximum and minimum values of 30.7^{0}C and 28.4^{0}C were recorded in January 2016 and September 2016 respectively. The mean indoor air temperature value of 28.2^{0}C was obtained for rainy season and 30.2^{0}C for the dry season; with a difference of 2.0^{0}C. The standard deviation was 1.97^{0}C and range 2.3^{0}C.

study area from the nearest Meteorological Station at the Imo (Sam Mbakwe) International Cargo Airport, Owerri,

3.4 Relationship between indoor and outdoor air temperature values of traditional and contemporary building types in Okigwe, Nigeria

Table 1 and Figure 1 depict the relationship between indoor and outdoor environmental variable of air temperature with respect to traditional and contemporary building types in Okigwe, Nigeria.

Table1: Statistical results for indoor and outdoor air temperature values of traditional and contemporary building types in Okigwe, Nigeria from Nov 2015 – Oct 2016.

Period	TBT	CBT	O/DOOR
November 2015	28.5	29.0	29.0
December 2015	27.1	27.9	28.5
January 2016	28.1	28.8	31.9
February 2016	30.6	30.9	29.8
March 2016	29.7	30.2	31.6
April 2016	29.4	29.9	30.0
May 2016	28.8	29.4	31.1
June 2016	27.6	28.1	27.6
July 2016	26.6	27.1	27.0
August 2016	26.3	26.8	27.7
September 2016	26.8	27.2	26.2
October 2016	28.5	28.5	27.6
Annual Min	*26.3*	*26.8*	*26.2*
Annual Max	*30.6*	*30.9*	*31.9*
Annual Mean	*28.2*	*28.7*	*29.0*
Standard Deviation	*1.40*	*1.36*	*1.97*

TBT = Traditional building type, CBT = Contemporary building type and O/DOOR = Outdoor
Source: Fieldwork 2016

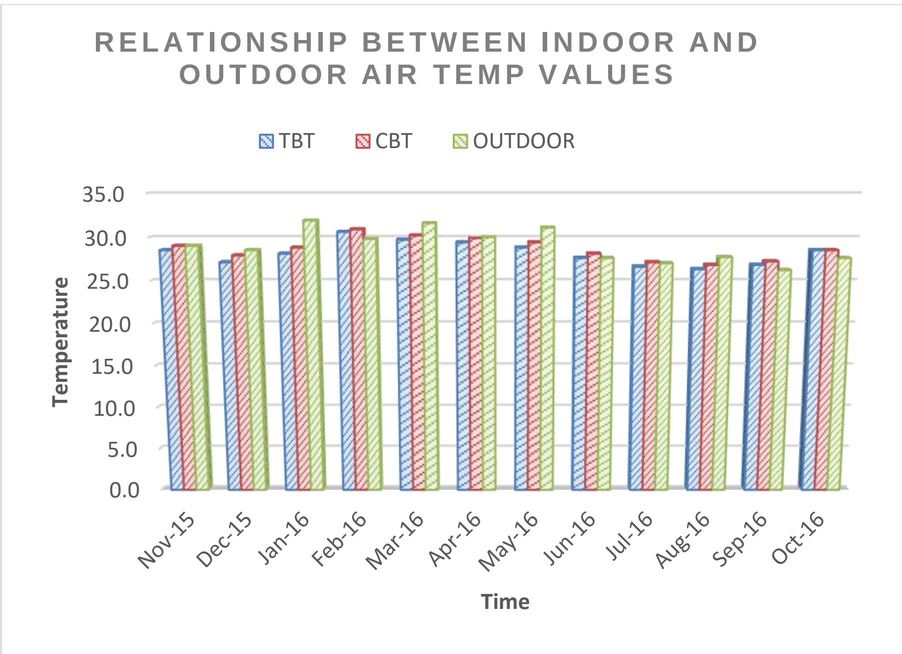

Figure 1: Variations between indoor and outdoor monthly mean air temperature of traditional and contemporary building types

4. Findings and Discussion

Data were exported to MS Excel computer program for analyses. A z-test was conducted to test whether there was a significant difference between the mean daily values on indoor air temperature of traditional and contemporary building types. The findings revealed that a significant difference existed between both building types (z = 1.74, p =0.04). Another test was carried out to ascertain if there was a significant difference between outdoor and indoor air temperature values of traditional building types using t-test statistical analytical tool. The result showed that there was no significant difference between indoor and outdoor air temperature values of traditional building types [t (20) = 1.25, p = 0.22]. Similarly, there was no significant difference between indoor and outdoor air temperature values of contemporary building types [t (20) = 0.53, p = 0.60].

However, the mean annual indoor air temperature value obtained from traditional building types (28.2^{0}C) was lower than the value for contemporary building types (28.7^{0}C) by 0.5^{0}C. Furthermore, it was found that the mean annual indoor air temperature values of both building types were lower than that of the outdoor temperature (29.0^{0}C) by 0.8^{0}C and 0.3^{0}C respectively. Comparing the seasonal results, traditional building types equally had lower indoor air temperature values both in the dry and rainy seasons than contemporary building types. They also had lower values than contemporary when related to outdoor values.

Invariably, the forms and materials adopted in the composition of traditional building types were instrumental to the lower values of indoor air temperature obtained throughout the year. It would be recalled that traditional building types were made from locally sourced materials such as mud (*known as aja ulo in Igbo Language, one of the major tribes in Nigeria*), timber (*osisi*), bamboo (*achara*), palm midribs (*ogugu*), thatch (*akilika*), and rope (*udo*). Contemporary building types had much of the influence of new materials, and technology from steel, glass, plastics, and plywood. They relied heavily on the use of electro-mechanical devices for comfort whereas, passive design strategies played much greater roles in the composition of traditional building types.

The significance of these results obtained from the statistical analysis confirmed that differences exist in the thermal qualities of traditional and contemporary building types in Okigwe, Nigeria. Thus aligning with opinions expressed by [15], and [16]. Therefore, the architect and other environmental designers and stakeholders are tasked to produce building designs and policies that would lead to reduced adverse environmental effects in the conception of sustainable development in Nigeria, for thermally comfortable, healthy, secure and productive living spaces.

5. Conclusion

The paper has through the indoor and outdoor air temperature values shown the differences in the thermal qualities of traditional and contemporary building types. The forms and materials enabled traditional building types to modify the external environment better than contemporary building types. In other words, the building practices and types handed over to us by our forebears provide suitable and better sustainable strategies. They ensured reduction of energy consumption and provision of acceptable indoor thermal environment. The adaptation of its forms, materials and techniques will aid in the conceptualisation of design criteria for sustainable development strategies in Nigeria and other developing nations.

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Air-Water Heat-Pump with Low GWP Refrigerant

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Abstract. As a result of the new legislative regulation on an international level regarding the refrigerants, new ecological alternatives which comply with the Global Warming Potential (GWP) guidelines must be found in the following years. This paper is a study case focused on the ecological and energy – efficiency aspects of a water-air heat pump. In this study, comparisons between R134a, MV3T and R1234yf were made. The theoretical study analyzes a one stage refrigeration system that currently works with R 134a. The comparative study of these facilities followed the coefficient of performance of a plant and also the TEWI factor (Total Equivalent Warming Impact – in respect with EN 378-1). Energy efficiency is directly related to global warming and greenhouse gases emissions has focused on water-air heat pump ecological and energy - efficiency study case.

1 Introduction

The theoretical study analyses a one stage refrigeration system that currently works with R 134a. The comparative study of this facility followed the coefficient of performance (COP/EER) and also the TEWI factor (Total Equivalent Warming Impact) – in respect with EN 378-1 [1,2].

Energy efficiency is directly related to global warming and greenhouse gases emissions.

Thermodynamic properties of these simulations were done using software RefProp and Clima Check (CC).

This work is also a study case of the new legislative Regulation UE 517/2014 implementation. Concerning this, ecological alternatives cooling agents with low global warming potential (GWP) must be found in the following years, at an international level. Table 1 presents the properties of the refrigerants.

Table 1. Properties of refrigerant retrofit.

Refrigerant	R134a	MV3T	R1234yf
Critical temperature	101,06	98.06	94.7
Group safety	A1	A1	A2L
Molar mass [kg/kmol]	102	108	114.04
Critical density, kg/m3	511.9	493.06	475.55
GWP	1430	717	4

Similarly to R134a, MV3T is a medium pressure refrigerant with a lower critical temperature and density.

Some of the properties of the refrigerants R1234yf and MV3T in comparison to R134a are listed in Table 1.

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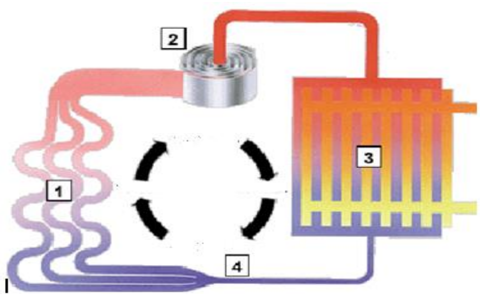

Fig. 1. The circuit of function of PC (1 – Evaporator, 2 – Compressor, 3 – Condenser,4 –Expansion Valve).

2 Ecological Analysis

HFO R1234yf has a GWP of just 4, providing substantially lower direct greenhouse gas emissions than R134a systems. It thus significantly reduces the CO_2 emissions of refrigeration systems [3,4].

The study case has a refrigeration capacity of 1.6kW. The temperature of evaporation for the refrigeration system is 2 °C and condensation temperature is 46.8 °C.

The TEWI factor was determinated taking account of the Standard SR EN 378-1:

$$TEWI = [GWP \times L \times n] + [GWP \times m\,(1-\alpha_{rec})] + [n \times E_{an} \times \beta]$$

Where:
GWP – the global warming potential, CO_2 related
L – Leakage in kilogrammes per year
n – System operating time in years,
m – Refrigerant charge in kilogrammes
α rec - recovery/recycling factor from 0 to 1
E an – energy consumption in kilowatt-hour per year
β - CO2 emission in kilogrammes per kilowatt-hour kg/kWh
GWP x m (1-αrec) - Impact of recovery losses
GWP x L x n - Impact of leakage losses
n x E annual x β - Impact of energy consumption

To calculate TEWI (Table 2) factor were following assumptions: mass for alternative (R1234yf - 0,72kg, MV3T – 0,75 kg and 0,78 kg) for R134a.
The recovery factor was 0.75.

Operating time of the system was 15 years, and CO2 emission was 0.28 kg / kWh.

Table 2. Calculation for factor TEWI for retrofit.

	R134a	MV3T	R1234YF
GWP	1430	717	4
L	0.062	0.06	0.057
n	15	15	15
m	0.780	0.750	0.720
ALFA	0.75	0.75	0.75
beta	0.28	0.28	0.28
TEWI [tons of CO2]	8.57	7.73	6.95

3 Energy efficiency analyses

The next part of this article shows some characteristics of the heat-pump (Fig.2)[5].

The advanced technology of the water heater / heat pump (1).

The two-stage radial fan (2) permits the air to be routed through a pipe of up to 10 m in length and 200 mm in diameter. The thermostatic expansion valve and safety devices ensure the possible circulation.

The compressors with oil coolers and waste heat utilisation by cooling the exhaust gases (3).

The evaporator unit has a large surface area giving a cleaning effect (4).

Heat insulation of the storage tank: high insulating value, made of CFC free polystyrene (5). The air connectors permit connection of air inlet/exhaust on site.

Quality 270 litre double enamelled hot water tank (6).

Anode gives increased safety (7).

Helical tube condenser in the double casing ensures efficient heat transfer and the possible safety (8).

Internal plain tube heat exchanger (enamelled) for connecting solar collectors or boilers (9).

Electrical immersion heater (10).

The COP and EER (coefficients of performances) for the HP (air conditioning and refrigeration) systems was calculated with CC and EES software simulations.

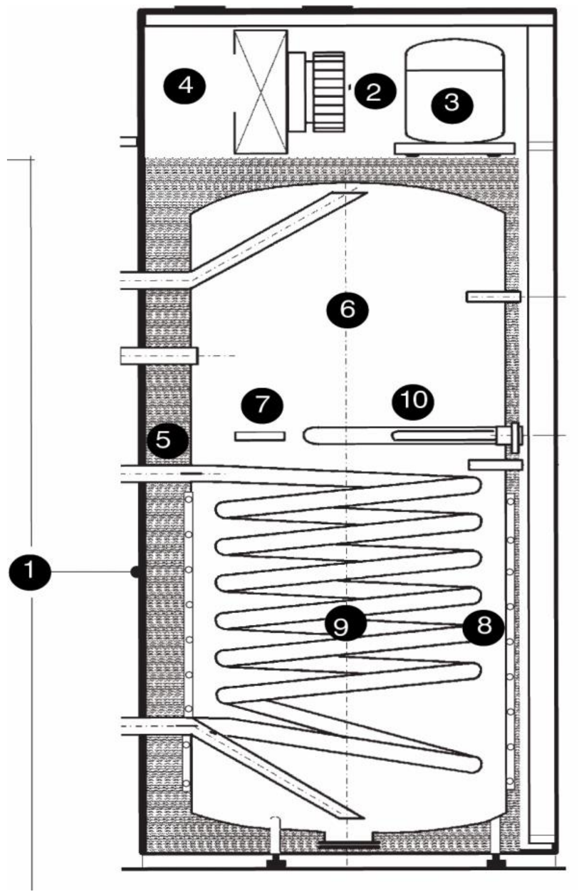

Fig. 2 . Heat pump air-water

Table 3. Efficiency Analysis of refrigerant retrofit**.**

Refrigerant	R134a	MV3T	R1234yf
COP	4.56	4.04	3.95
EER	3.63	3.11	2.93

4 Conclusions

In order to implement the International Legislation, in the future it is necessary to retrofit HFC refrigerant with an ecological refrigerant.

The ecological energy efficiency and thermo-physical properties are the main disadvantages of R 404A.

From an environmental perspective (factor TEWI - Table 2) MV3T [6] and R 1234yf have the advantage of a lower global warming potential (GWP) than R134a [7].

Regarding energy efficiency and yearly consumptions (Table 3) the MV3T has a higher EER and COP than R 1234yf.

Regarding F-Gas Regulation, the optimum alternative for this application is MV3T.

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Heat recovery in ventilation systems - waste heat use or renewable energy

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For as long as discussions about renewable energies have been ongoing, definitions and chargeability have been discussed in various technical standards and legal regulations. Practically each document defines something differently and there is no uniform procedure especially in the area of air conditioning and ventilation technologies. This paper shows differences between heat recovery and waste heat use and defines the renewable share of heat and cold recovery in ventilation units. A definition of renewable energies based on a primary energy approach would allow a fully technology neutral calculation of renewable shares and give a clarity to the political direction of travel.

1 Legal framework

The main legal bases for renewable energies in Europe are:

- DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the promotion of the use of energy from renewable sources
- Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency.

Definition in 2018/2001/EU:
(1) ‘energy from renewable sources’ or ‘renewable energy’ means energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas;
(2) ‘ambient energy’ means naturally occurring thermal energy and energy accumulated in the environment with constrained boundaries, which can be stored in the ambient air, excluding in exhaust air, or in surface or sewage water;
(9) ‘waste heat and cold’ means unavoidable heat or cold generated as by-product in industrial or power generation installations, or in the tertiary sector, which would be dissipated unused in air or water without access to a district heating or cooling system, where a cogeneration process has been used or will be used or where cogeneration is not feasible;

The limitation to ambient air in (2) is not understandable, because ambient air immediately becomes outdoor air when leaving the building or machinery. The definition of waste heat and cold in (9) is also difficult to understand and has no physical base.

We can summarise, that the definition of these items is at any time a question which boundary conditions are selected.

This regulation is amended and supported by national regulations for the promotion of renewable energies in the Member States.
For example in Germany:

- Act on the Promotion of Renewable Energies in the Heat Sector (Renewable Energies Heat Act - EEWärmeG)
- Regional laws such as EWärmeG in Baden-Württemberg

There is no common definition of renewable energy and especially the heat recovery of ventilation system is treated and considered in different ways:

- Excluded
- treated as waste heat use and not counted in statistics
- treated as waste heat use depending on application (residential, tertiary, commercial, process, etc.).

This article and the proposals are limited to building related energies (heating, cooling, ventilation). The regulation itself gives guidance for some technologies but is not following consequently.
The amount of aerothermal, geothermal or hydrothermal energy captured by heat pumps is to be considered as energy from renewable sources for the purposes of Directive [1] shall be calculated according Annex VII.

$$E_{RES} = Q_{usable} * (1 - \frac{1}{SPF}) \qquad (1)$$

Q_{usable}: The estimated total usable heat delivered by heat pumps. Only heat pumps for which SPF > 1.15 * 1/η shall be taken into account,

SPF: The estimated average seasonal performance factor for those heat pumps (in this article mainly used as COP),

η_{is}: The ratio between total gross production of electricity and the primary energy consumption for electricity production. (in this article mainly uses as $1/f_{pr}$)

According guidance [3] the power system efficiency for electrical heat pumps is η_{is}= 0.45 and for thermal heat pumps is η_{is}= 1.0. The minimum SPF for electrical systems is 2.55 and for thermal systems 1.15.

The equation (1) can be used for a fully technology open specification of renewable energy and additionally in heat recovery of ventilation units. This means, if the coefficient of performance based on primary energy is bigger than 1.15, the contribution to renewable energies can be counted (2).

$$SPF * \eta = \frac{SPF}{f_{pri}} = COP_{pri} = SPF_{pri} > 1.15 \qquad (2)$$

It is nothing more than saying: Renewable energy is considered, if the usable energy of the machine is bigger than the primary energy input plus a threshold of 15%.

2 Heat recovery vs. waste heat use

2.1 General

Heat recovery, if at all creditable, is usually treated as waste heat recovery. It should be noted that there are physical differences between waste heat recovery and heat recovery in ventilation systems. The following examples are intended to illustrate this:

2.2 Waste heat use

If the building is heated with a fuel boiler (Fig. 1) then, for example only 75% for the heating is available, 25% passes outwards via the exhaust gas flow. In this example, a waste heat utilisation recovers 80% of the waste gas flow, i.e. 20% of the input, and accordingly only 5% of the waste gas passes outside.
This is a classic waste heat utilisation from a combustion process for a building. The waste heat can be used only one time exactly as the energy of the fuel.

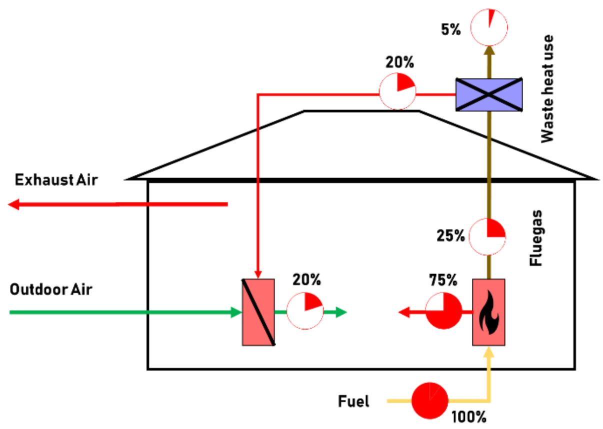

Fig. 1 : Example waste heat use with a boiler

2.3 Heat recovery in a ventilation system

If we now simplify the heat generation and only consider the ventilation system without heat recovery, the entire heat of the heating (including waste heat utilisation if necessary) is lost by the exhaust air (Fig. 2).

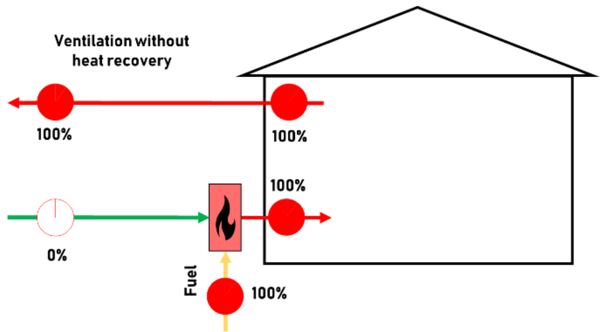

Fig. 2 : Example ventilation unit without heat recovery

With heat recovery in a ventilation system, the recovered heat is now returned to the circuit and is available again for heat recovery.
The installation of a heat recovery system (in our example 50%, Fig. 3) also reduces the heat requirement by 50%. This means that 0.5 kWh is recovered from 1 kWh of input in the first step.

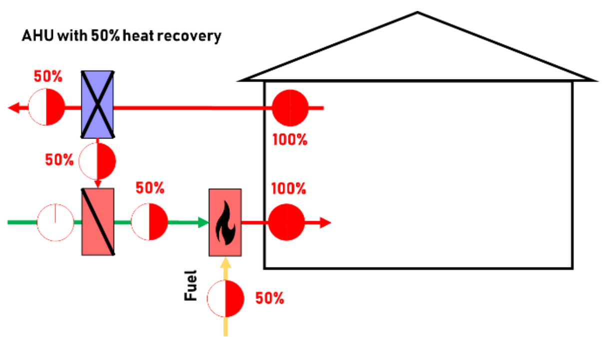

Fig. 3 : Example ventilation unit with 50% heat recovery

In the case of heat recovery in a ventilation system, the recovered heat is now back in the cycle and is again available for heat recovery.

A part of recovered energy thus regenerates again and again (Fig. 4). By definition this share is renewable energy.

If we would have a heat recovery with 100% efficiency, all energy will be recovered and recovered again (**renewing itself**). By definition renewable energy.

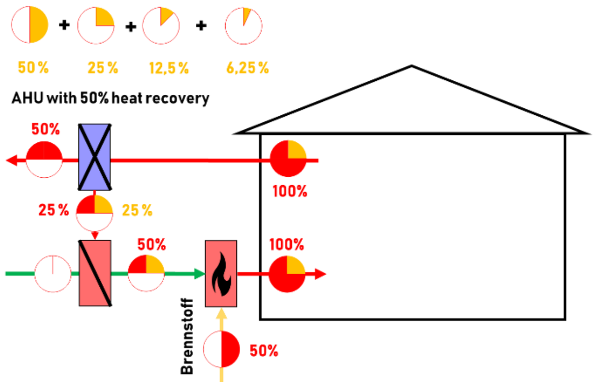

Fig. 4 : Example ventilation unit with 50% heat recovery

This process can be represented by an infinite series (3):

$$Q_{\text{useable}} = Q_{\text{end}} + Q_{\text{end}} \times \left(\frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \cdots\right) \tag{3}$$

2.4 Calculation of renewable share in ventilation heat recovery system

Based on the specifications made in chapter 1 in analogy for the heat pump and using the general equation for a converging geometric series n and the temperature ratio of heat recovery η_t [0..100%]:

$$S_n = \sum_{k=1}^{n} a \times q^{k-1} = a + a \times q + a \times q^2 + \cdots + a \times q^{n-1} = a \times \frac{(1-q^n)}{(1-q)} \tag{4}$$

We get the usable energy for the heat recovery:

$$Q_{usable} = Q_{end} \times \frac{(1-{\eta_t}^n)}{(1-\eta_t)} \tag{5}$$

Or in analogy for a heat pump and furthermore, ventilation is a continuous process and if we consider a non-stop operation, we have an endless period and:

$$COP = \lim_{n \to \infty} \left(\frac{(1-{\eta_t}^n)}{(1-\eta_t)}\right) = \left(\frac{1}{(1-\eta_t)}\right) \tag{6}$$

Typically, a heating (including heat recovery) in ventilation systems is designed to cover ventilation loss. Space heating systems are designed to cover the transmission plus infiltration plus ventilation losses not covered by heat recovery. This means, we can isolate the ventilation and the heating system.

So, for a non-continuous operation (for example ventilation stops during night time) there is no ventilation loss in the stop period (only infiltration and transmission losses). When ventilation starts again, it starts exactly at the same situation where it stoped. Generally speaking, ventilation can be seen as a continuous process and equation (6) is valid in any case.

Using the approach of equation (1) we get:

$$Q_{usable} = Q_{end} + Q_{RES} \tag{7}$$

Or for the renewable energy of the heat recovery

$$Q_{RES} = Q_{usable} - Q_{end} \tag{8}$$

Using (5)

$$Q_{RES,HR} = Q_{usable,WRG} * (1 - \frac{1}{COP}) \tag{9}$$

And using (6):

$$Q_{RES,HR} = Q_{usable,HR} * \eta_t \tag{10}$$

What does is this equation (10) want to tell us? In technical heat recovery systems there is always a part which is waste heat use from the heating device.

$$Q_{Waste,HR} = Q_{usable,HR} * (1 - \eta_t) \tag{11}$$

All the calculations do not consider, that there might be other renewable heat sources in the ventilated building like passive solar gains, human beings or even renewable heating systems which will improve the renewable performance of the heat recovery, by recovering also these sources again.

2.5 Cold recovery

The cold recovery follows exactly the same principle and can be used in the same way. For humidification and dehumidification the same approach can be used based on humidity and enthalpy recovery performance data.

2.6 Examples

The specifications made in chapter 2.4 are valid for a heat recovery based only on thermal energy and not considering the transport energy for the air flow (this will be treated in the following chapter). But this will help to understand the principle.

Using equation (6) for typical heat recovery systems according Ecodesign regulation 1253/2014 (run around coils $\eta_{t,min}$=0.67 and others $\eta_{t,min}$=0.73) or slightly better we find a thermal COP of 3…5, which is in the same range like the electrical performance of a heat pump (Fig. 5).

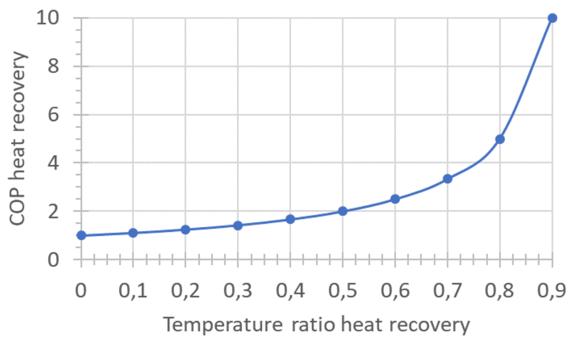

Fig. 5 : Thermal COP of a heat recovery system

3 Primary energy based approach

3.1 General aspects

The approach in chapter 2 calculates the renewable thermal energy of a heat recovery, but does not cover all the energy aspects needed. A real ventilation system with heat recovery needs electrical energy and depending on heat recovery and outdoor conditions additional thermal energy. Thermal and electrical energy cannot simply be added, so we have to shift to a primary energy based approach.
We can specify a COP based on primary energy for our ventilation system with heat recovery:

$$COP_{pri,\mathrm{HR}} = \frac{Q_{usable,\mathrm{HR}}}{Q_{\mathrm{Waste,HR}} * f_{\mathrm{heat}} + Q_{trans} * f_{\mathrm{elec.}}} \qquad (12)$$

$$Q_{useable,\mathrm{HR}} = Q_{Waste,HR} + Q_{RES,HR} \qquad (13)$$

A primary based COP is a helpful indicator to decide if any system is delivering a renewable energy contribution or not. If for example the COP_{pri} >1 says, that the system is generating more useable energy, than it needs primary energy.
Nothing else is the minimum requirement of RED [1] for heat pumps in with a threshold of 15% based on electrical energy in (1).

Using the equations chapter 2 we get:

$$COP_{pri,\mathrm{HR}} = \frac{1}{\eta_t * f_{heat} + \frac{Q_{trans}}{Q_{useable,\mathrm{HR}}} * f_{\mathrm{elec.}}} \qquad (14)$$

Heat recovery systems shall have a thermal control system. This means, depending on the supply air temperatures needed and the climate conditions, the average temperature ratio operation in operation is lower than the design temperature ratio (Fig. 6). For renewable energy share calculation, the average temperature ratio for heat recovery in operation shall be used.

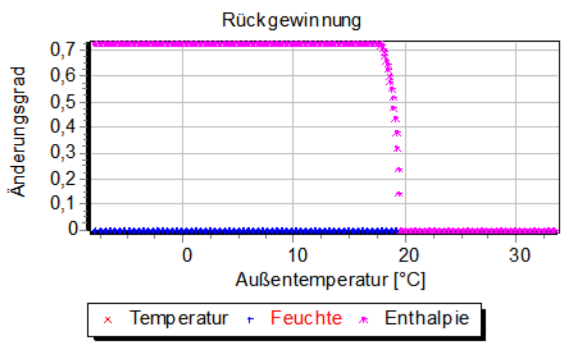

Fig. 6: Hourly temperature ratio of heat recovery supply air temperature 20°C (Frankfurt)

3.2 Examples

The following simplified examples will demonstrate the options of primary energy based approach.

Ventilation unit according EU 1253/2014 Tier 2:

- V=10.800 m^3/h = 3 m^3/s
- fan consumption including filter, heat recovery, casing = 800 W/(m^3/s) * 3 m^3/s = 2.400 W
  SUP fan 1.400 W und EXT Fan 1000 W
- temperature ratio of heat recovery 0,73
- primary energy factor heat $f_{pri,heat}$=1,0 (η=1)
- primary energy factor electricity $f_{pri,elec}$=2,2 (η=0,45)
- supply air temperature and room temperature min 20°C (no cooling)
- 8760 h operation

The hourly simulation (Table 1) for the different parameters and locations shows, that the COP_{pri} of the ventilation system with heat recovery is around 2 in the northern and around 1.5 in the southern European countries (Table 1, column 3-6) . The fan consumption based on ErP 1253/2014 does not include the additional demand for the transportation inside the building. This is exactly the same approach as the heat pumps with borderline SPFH2 according [3].

Even if we consider a further demand for transportation by doubling the fan power, the COP_{pri} still is 1.33.

If we compare for example with a heat pump COP=3.5 and using $f_{pri,elec}$=2,2 (η=0,45) the COP_{pri} is around 1.59 and in the same range.

4 Other renewable technologies

The primary energy approach as a basis for determining the renewable energy contribution can be applied to other known technologies including:

- Cold generation
- Cooling and enthalpy recovery
- Free cooling with cooling towers
- Evaporative cooling
- Solar systems
- And any combination

If we generalise the equation (12) to:

$$COP_{pri} = \frac{\sum Q_{usable}}{\sum(Q_f * f_{pri,f}) + \sum(W_f * f_{w,f})} \quad (15)$$

Q_{usable}: Generator outgoing energy
Q_f: Generator end energy demand
W_f: Generator auxiliaries demand
f: Primary energy factor for each end energy considered

A political steering aspect is fully implemented by the primary energy factors for each energy considered.

If we furthermore introduce for example a renewable share factor r in equation (16), then we get a simple determination of the contribution of renewable energies. If the factor r is positive (COP_{pri}>1), then we have a renewable contribution and if the factor r is negative (COP_{pri}<1), we have no.

$$r = \frac{E_{RES}}{Q_{usable}} = (1 - \frac{1}{COP_{pri}}) \quad (16)$$

The examples in Table 2 show some simplified approaches for different technologies.

As stated in the regulation [1], the primary energy approach works with heat pumps (Table 2 line 1 and 2). It works also for a solar water heater (line 3) and thermal heat pumps as well (line 5). If we look at the boilers, we see REG <0 for fossil heated and REG >0 for biogas and wood pellet. Clearly depending on their primary energy factors. (line 4,6,7).

Looking at the cold generators, we see negative contribution for fossil heated absorption chillers (line 9) and the approach is working for any free cooling system (line 11, 12).

Some experts might challenge, whether an electrical chiller can be a contributor to renewable energy shares depending on the efficiency and the primary energy factors.
Some might also highlight, that a chiller is not "producing" energy as such but shifting energy to another level. But also, this is exactly the same with heat pumps and the cold generated in chillers, is usable energy – no doubt.
With this principle a combined generation of heat and cold in a heat pump can be treated by adding the generated energy and considering the primary energy input.

5 Conclusion

This article has shown, that the current political definitions of renewable energies in buildings are complicated and do not adhere to the principle of technological neutrality.

Heat recovery in ventilation systems is comparable with heat pumps and is providing a significant amount of renewable energy in buildings.
A primary energy based coefficient of performance would allow a fully technology neutral calculation of renewable contribution. Specifying individual and/or national primary energy factors would provide clarity to underpin political decision-making and a improve the transparency of recalculation and reporting.

6 Symbols and abbrevations

Q_{usable}: The usable heat or cold delivered by a generator
Q_{end}: The end-energy used by a generator
Q_{RES}: The renewable energy contribution
Q_{Waste}: The waste energy contribution
$Q_{tansport}$: The transport energy demand (typically fan in ventilation systems)
W_f: Auxiliary energy demand for a generator
COP: The seasonal performance factor of a generator (in [2] SPF
COP_{pri}: The seasonal performance factor of a generator based on primary energy
η_{is}: The ratio between total gross production of electricity and the primary energy consumption for electricity production. (in this article mainly uses as $1/f_{pr}$)
f_{pri}: The primary energy factor for each energy used
η_t: The temperature ratio of a ventilation heat recovery system
HR: Heat recovery
SUP: Supply air
EXT: Extract air

7 References

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Table 1: Example calculation for the renewable contribution of ventilation heat recovery

1	2	3	4	5	6	3a	
Climate zone		Frankfurt	Helsinki	Barcelona	Athens	Frankfurt	
Operation time [h]		8760	8760	8760	8760	8760	
Temperature ratio η		0.73	0.73	0.73	0.73	0.73	
$P_{SFP,ges}$ [W/(m³/s)]		800	800	800	800	**1600**	
average temperture ratio η_{av}	Sim	0.716	0.721	0.705	0.704	0.698	
COP	(6)	3,52	3,58	3,39	3,39	3,31	
$Q_{usable,HR}$ [kWh]	Sim	203,045	331,519	119,818	129,781	206,366	
$Q_{ren,heat}$ [kWh]	(9)	145,380	239,025	84,472	91,366	144,043	
$Q_{not\ ren,heat}$ [kWh]	(12)	57,665	92,494	35,346	38,415	62,323	
Elec. Fans [kWh]	Sim	21,024	21,024	21,024	21,024	**45,550**	
$COP_{pri,WRG,Wärme,reg}$	**(13)**	**1.954**	**2.389**	**1.468**	**1.533**	**1.333**	
REG	(16)	**49%**	**58%**	**32%**	**35%**	**25%**	

Table 2: Simplified example calculation for the renewable contribution of different technologies

		Q_{outg}	Q_f	ζ	$f_{pri,f}$	W	COP / EER	f_w	**COP_{Pri}**	**REG**
	Heat generation									
1	Air to water heat pump	10000			1	2800	3,57	2,2	**1,62**	**38%**
2	Water to water heat pump	10000			1	2500	4,00	2,2	**1,82**	**45%**
3	Solar water heater	3000			1	300		2,2	**4,55**	**78%**
4	Gas boiler (fossil)	10000	11000	0,91	1	200		2,2	**0,87**	**-14%**
5	Thermal heat pump	10000	8000	1,25	1	30		2,2	**1,24**	**19%**
6	Gas boiler (biogas)	10000	11000	0,91	0,5	30		2,2	**1,80**	**44%**
7	Pellet	10000	12000	0,83	0,2	200		2,2	**3,52**	**72%**
	Cold generation									
8	Chiller (electrical)	10000			1	3000	3,33	2,2	**1,52**	**34%**
9	Absorptions chiller (fossil)	10000	15000	0,67	1	500		2,2	**0,62**	**-61%**
10	Absorptions chiller (biogas)	10000	15000	0,67	0,5	500		2,2	**1,16**	**14%**
11	Free geothermal cooling	5000			0	200	25,00	2,2	**11,36**	**91%**
12	Free cooling tower	5000			0	500	10,00	2,2	**4,55**	**78%**

Questionnaire's Elaboration and application to the contribution at knowledge of certificate LEED's application at Brazil with based on case studies.

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Abstract. The sustainable building with LEED Certification search the better thermal comfort adaptation to their users. This research has analysed the impact of LEED certification at first Brazilian enterprises, which receives the seal of sustainable building. It is understandable that, initially, there was restrictions about the use in another reality of the American buildings. The questionnaire developed was distributed in XX national case studies. Note that the labour market must be prepared to the certification; otherwise, it will be difficult to achieve the final goal, which is being a sustainable building. The results obtained to confirm that LEED certification need to move forward in the indoor environment studies to buildings located in regions with tropical altitude climate with abrupt changes of temperature. The final results of questionnaire allows to obtain an evaluation of standard measures of an ideal temperature to the buildings, establishing the limit among comfort zones of human metabolism, proposing comfort model adaptive to a country with a wide latitudinal variation, as in Brazil.

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1 Introduction

This study is an experimental approach of human thermal comfort sensation and real thermal behaviour of the building with complementary evaluation based on thermal comfort methods of questionnaire and Fanger-ISO, Givoni, Humphrey-Nicol and Moraes.
In 2007 several buildings were certified Leed, Moraes, C.M. 2010. It is noteworthy the progress in seeking sustainable certification methodology. However, the sustainability parameters were defined from American concepts whose climatic characteristics and building materials are different from the Brazilian climate. Aware of these aspects, the LEED certification was made, emphasizing that the same buildings should be re-evaluated later because they would present divergences of construction concepts. Later in 2015, researchers from this public body met with researchers from the "Green Building Consul Brasil (GBC Brasil), located in the city of São Paulo, Brazil, with the purpose of carrying out an evaluation of these buildings certified after 2007. Based on the methodology presented by Moraes (2004) to the Congress Plea 2004, which evaluated the real thermal behavior in the classroom with the survey of climatological variables of the external and internal environment of the building located in two different universities in the state of São Paulo in order to contribute to the wellness and productivity. By means of thermal comfort methods (Givoni, 1969) of wrapping environments and their correlation with human thermal sensation (Fanger, 1970) with student participation. To establish thermal comfort limit conditions in the classroom, by verifying abrupt temperature changes in tropical altitude. Objective and subjective physical measurements were adopted. T (° C), RH (%), Var (m / s) and P (atm) were monitored; with the recording of internal data by means of "datalogger" and sensors; by the Meteorological Station, and the thermal perception of the student was evaluated with questionnaires. Therefore, this research presents the results of the questionnaires that were reassessed in 2015 and applied to the buildings which received LEEd certification to evaluate the Brazilian enterprises located in a tropical climate of altitude and to understand the restrictions of use in a reality different from the original reference (North American). Note that the questionnaires presented were answered by the users of buildings with LEED certification, that is, a real environment and reports present a spontaneous language according to the individual understands about the edification, so the comments are spontaneous sentences without rigor. The results presented by these individuals allow us to verify how the construction of the local urban climate influences the thermal behavior of the property and the individual.

2 Thermal comfort methods

A brief description of thermal comfort methods applicability is necessary for people have a good understanding about the profile of the research in development. In the same way, some researcher's models to deal with human comfort sensations are described below:

Fanger - Establishes the thermal heat flux between the person the physical environment through the clothes. Predicted mean votes (PMV) and Predicted Percentage of dissatisfied (PPD), sets a satisfaction degree.

Givoni – Demonstrates how the environmental conditions like: DBT, UBT, RU%, atmospheric pressure and air velocity change the thermal comfort conditions. This study focuses the effects of the environment conditions.

Humprey & Nicol – Demonstrates how factors such as corporeal mass, ethical body characteristics as high-mass, acclimatization factors and origin affect the result on thermal human comfort evaluations. This model also adopts blood flux and corporeal area for modelling the human thermal response. This method is important because shows the adequacy of adopting the local applicability of the thermal satisfaction response.

Moraes - The method of delimiting the rules of thermal comfort of the connection of its system is human and its correction with an idea of edification, being verified like changes of temperature. Adopting objective and subjective measures. Monitoring the climatological variables; with internal data logging for the heat control means and sensors; External for Meteorological Station and the thermal barrier of users of edification was evaluated with questionnaires.

.1 Experimental setting for the building

The experimental scenario chosen for the study was the first buildings to receive LEED certification in Brazil.

3 Building users' thermal comfort

Equations should be centred and should be numbered with the number on the right-hand side.

Use italics for variables (u) and bold (**u**) for vectors. The order for brackets should be {[()]}, except where brackets have special significance.

Q1 Gender

	Company 3	Company 4	Company 5
Male	58,14%	37%	31,03%
Female	41,86%	63%	68,97%

Q2 Age

	Company 3	Company 4	Company 5
Under 25 years old	13,95% -6	25% - 25	6,9% - 8
25 to 35 years old	41,86% -18	50% - 50	49,14% -57
35 to 45 years old	30,28% - 13	19% - 19	24,14% - 28
45 to 55 years old	11,63% - 5	5% - 5	14,66% - 17
55 to 65 years	2,33% - 1	1% - 1	5,17% - 6
Over 65 years old	0,00% - 0	0% - 0	0,00% - 0
Total	23	100	116

Questionnaires were distributed to all employees of commercial buildings, considering the layout of each building and measurements of internal and external climatological variables. Read the article Plea 2004; Moraes, C. M.; et al.

Thermal Comfort Analisys: Modeling evaluation

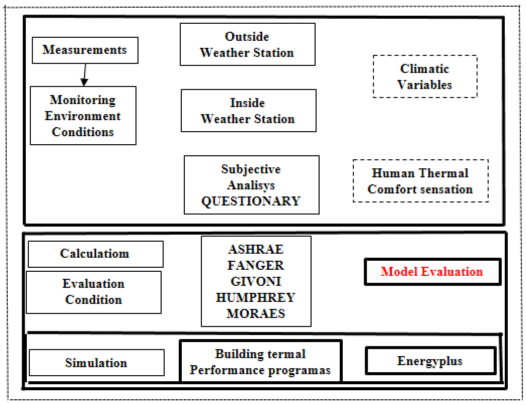

Figura 1: Experimental settings

Q3 Position or Activity

	Company3	Company 4	Company5
Direction	13,95% - 6	4% - 4	0,87% - 1
Manager, Coordinator	32,56% - 14	46% - 46	27,83% - 32
Operational	37,21% - 16	25% - 25	49,57% - 57
Other	16,28% - 7	25% - 25	21,74% - 25

Q4 Location of your workstation. Only answer if you have a fixed work location. You can select more than one option

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	Company3	Company 4	Company5
Next to window (until 2 meters)	60,47% - 26	60% - 6	59,65% -68
Near the wall (until 2 meters)	20,93% - 9	19% - 19	11,40% -13
Near the door (until 2 meters)	13,95% - 6	6% - 6	2,63% - 3
Center in the environment	20,93% - 9	29% - 29	21,05% - 24
Next to restroom (until 2 meters)	0,00% - 0	19% - 19	2,63% - 3
Near to corridor (until 2 meters)	18,60% - 8	19% - 19	24,56% - 28
Near to coffee (until 2 meters)	4,65% - 2	5% - 5	5,26% - 6
Near to printers (until 2 meters)	25,58% - 11	14% - 14	13,16% - 15
Other (specify)	2.33% - 1	0% - 0	2,63% - 3
Interviews	43	100	114

Q5 The role of sustainability Specify your impression of this theme. If any question does not apply to you, do not respond.

Company 3

	Never	Sometimes	Many times	Always	Total
I am interested in sustainability issues.	0,00% 0	23% 23	33% 33	44% 44	100
My employer is concerned about sustainability	1,03% 1	22,68% 22	51,55% 50	24,8% 24	97

Company 4

	Never	Sometimes	Many times	Always	Total
I am interested in sustainability issues.	4,2% 1	8,3% 2	45,8% 11	41,7% 10	24
My employer is concerned about sustainability	4,3% 1	21,7% 5	39,1% 9	34,8% 8	23

Company 5

	Never	Sometimes	Many times	Always	Total
I am interested in sustainability issues.	0,00 % 0	28,45% 33	42,24% 49	29,31% 34	116
My employer is concerned about sustainability	0,88 % 1	15,79% 18	31,84% 42	46,89%5 3	114

Q13 In your opinion, how important are the factors listed for health improvement / conservation in the workplace?

Company 3	not important	Little important	Important	Much important	Total
Air Quality and Ventilation	0,00 % 0	2,44% 1	14,63 % 6	82,93 % 34	41
Thermal comfort	0,00 % 0	4,88% 2	26,83 % 11	68,29 % 28	41
Lighting	0,00 % 0	2,44% 1	26,83 % 11	70,73 % 29	41
Acoustic quality	0,00 % 0	12,20 % 5	34,15 % 14	53,66 % 22	41
Spaces and ergonomics	0,00 % 0	7,32% 3	26,83 % 11	65,85 % 27	41
Green Areas	4,88 % 2	12,20 % 5	36,59 % 15	46,34 % 19	41
Textures and coatings	4,88 % 2	48,78 % 20	29,27 % 12	17,07 % 7	41
Transport	4,88 % 2	7,32% 3	29,27 % 12	58,54 % 24	41

Facilities and Convenience s	2,44 % 1	2,44% 1	48,78 % 20	46,34 % 19	41
Company 4	not important	Little important	Important	Much important	Total
Air Quality and Ventilation	0% 0	0% 0	14,9% 14	85,1% 80	94
Thermal comfort	0% 0	0% 0	17,9% 17	82,1% 78	95
Lighting	0% 0	0% 0	19,2% 18	80,9% 76	94
Acoustic quality	1,06 % 1	2,13% 2	30,9% 29	65,9% 62	94
Spaces and ergonomics	0% 0	1,06% 1	23,4% 22	75,6% 71	94
Green Areas	0% 0	12,63 % 12	49,5% 47	37,9% 36	95
Textures and coatings	5,32 % 5	40,43 % 38	40,5% 38	13,9% 13	94
Transport	0% 0	3,19% 3	35,1% 33	61,7% 58	94
Facilities and Convenience s	0% 0	5,26% 5	34,8% 33	60% 57	99

Company 5	not important	Little important	Important	Much important	Total
Air Quality and Ventilation	0,00 % 0	0,88% 1	20,18 % 23	78,95 % 90	11 4
Thermal comfort	0,00 % 0	0,88% 1	15,79 % 18	83,33 % 95	11 4
Lighting	0,00 % 0	0,88% 1	20,18 % 23	78,95 % 90	11 4
Acoustic quality	0,00 % 0	3,54% 4	30,97 % 35	65,49 % 74	11 3
Spaces and ergonomics	0,00 % 0	1,79% 2	25,89 % 29	72,32 % 81	11 2
Green Areas	0,00 % 0	11,71 % 13	61,26 % 68	27,03 % 30	11 1
Textures and coatings	4,46 % 5	39,29 % 44	45,54 % 51	10,71 % 12	11 2
Transport	2,68 % 3	5,36% 6	38,39 % 43	53,57 % 60	11 2
Facilities and Convenience s	0,88 % 1	5,31% 6	43,36 % 49	50,44 % 57	11 3

Q14 In this space you can write about what can affect to improve or to worsen health in your workspace.

Company 3	
Air conditioning	Noise harmful to health

Company 9	
Thermal comfort	Natural lighting
General Ventilation	Artificial Lighting
Natural ventilation	Bank or ATM 24hrs
Air quality	Cleaning
Noise (sound pollution and air conditioning)	Safety
Check the air temperature of the air conditioner	Removing carpet due to respiratory allergies
Economy time	Include green areas
Ergonomics furniture (chair, desk, leptop position and meeting room)	Install Emergency System
Improve room layout according to the air-conditioning duct	Trash for organic waste

Company 5

Thermal comfort	Natural lighting
General Ventilation	Artificial Lighting
Natural ventilation	Removing carpet due to respiratory allergies
Air quality	Dust
Noise (sound pollution and air conditioning)	Adjusting the curtain
Check the air temperature of the air conditioner	Do not put anyone to sit facing the window.
Ergonomics furniture (chair, desk, leptop position and meeting room)	Water Quality Acoustic quality
Air conditioning and asepsis	Privacy
Breaks, such as work experience	Cleaning
Access to healthy food	Improve lifts with sensors
Bathroom door for people with disabilities is very heavy	Inefficiency of air distribution design by air conditioning
Central Air Conditioning directly affects health, because many of the hours of the daylight, the temperature is very cold and other time is very hot.	The air conditioning regulation system is individualized by room
Best temperature air conditioning in summer (air conditioning better controlled).	Install larger number of plugs
Open office desk does not work in Brazilian culture	

Q15 Air Quality and Ventilation. Specify your impression of this theme. If any question does not apply to you, do not respond.

Company3	**Never**	**Sometimes**	**Many times**	**Always**	**Total**
The office is well ventilated	7,7% 3	12,8% 5	35,9% 14	43,6 % 17	39
The office air is very humid	81,9% 31	13,2% 5	2,6% 1	2,6% 1	38
The office air is very dry	47,4% 18	31,6% 12	18,4% 7	2,6% 1	38
I can control the ventilation of my workplace, either by opening or closing windows or by controlling forced ventilation	56,8% 21	18,9% 7	16,2% 6	8,1% 3	37
The velocity of air circulation impairs because it is too high	76,3% 29	21,1% 8	2,6% 1	0,0% 0	38
I feel discomfort due to air localization	61,6% 24	33,3% 13	0,0% 0	5,2% 2	39
I have the feeling of stale air ("stagnant air") in the environment	66,7% 26	23,1% 9	7,7% 3	2,7% 1	39
The office has a bad smell (unpleasant odors). If so, please describe odors unpleasant	84,7% 33	12,8% 5	2,6% 1	0,0% 0	39

Company 9	**Never**	**Sometimes**	**Many times**	**Always**	**Total**
The office air is very humid	5,56% 5	30,0% 27	51,1% 46	13,3% 12	90
The office air is very dry	64,7% 57	29,5% 26	5,68% 5	0,00% 0	88
I can control the ventilation of my workplace, either by opening or closing windows or by controlling forced ventilation	25,9% 23	41,8% 37	22,5% 20	10,2% 9	89
The velocity of air circulation impairs because it is too high	73,9% 65	15,9% 14	6,9% 6	3,5% 3	88
I feel discomfort due to air localization	62,1% 54	25,3% 22	8,1% 7	4,6% 4	87
I have the feeling of stale air ("stagnant air") in the environment	59,1% 52	26,5% 23	11,4% 10	3,5% 3	88
The office has a bad smell (unpleasant odors). If so, please describe odors unpleasant	34,9% 31	52,9% 47	8,9% 8	3,4% 3	89
The office air is very humid	58, 9% 53	28,9% 26	8,89% 8	3,33% 3	90

Company 5	**Never**	**Sometimes**	**Many times**	**Always**	**Total**
The office air is very humid	15,3% 17	27,0% 30	39,7% 44	18,0% 20	111
The office air is very dry	61,7% 66	30,9% 33	4,7% 5	2,8% 3	107
I can control the ventilation of my workplace, either by opening or closing windows or by controlling forced ventilation	19,7% 21	42,1% 45	27,1% 29	11,2% 12	107
The velocity of air circulation impairs because it is too high	94,6% 105	2,7% 3	0,90% 1	1,80% 2	111
I feel discomfort due to air localization	60,0% 66	29,1% 32	6,4% 7	4,5% 5	110

I have the feeling of stale air ("stagnant air") in the environment	52,8% 58	25,5% 28	12,8% 14	9,1% 10	110
The office has a bad smell (unpleasant nhodors). If so, please describe odors unpleasant	38,6% 42	44,1% 48	8,3% 9	9,2% 10	109
The office air is very humid	36,9% 41	41,5% 46	18,1% 20	3,6% 4	111

Company 3	
Bad odors	Natural ventilation
No ventilation in bathrooms	

Company 9	
Improve Air Conditioning System	General Ventilation
Bad odors	Natural ventilation
Mold	Open the windows
No ventilation in bathrooms	Noise (sound pollution and air conditioning)
Excess humidity in environments	Dust
Removing carpet due to respiratory allergies	Food court in common area
garbage	Sewer

Company 5	
Bad Odors	No ventilation in bathrooms
Sewer	No of ventilation in the garage and cafeteria
Mold	Removing carpet due to respiratory allergies
Improve Air Conditioning System	Excess humidity in environments
Ventilation in general	Improve layout and ventilation of meeting rooms
Natural ventilation	

Q19 Thermal sensation on the desktop Specify your impression of this theme. If any question does not apply to you, do not respond.

Company 3

	The thermal sensation in the summer is	The thermal sensation at 40 winter is
Very Cold	15% 6	10% 4
Cold	10% 4	15% 6
Slightly cold	20% 8	20% 8
Neither cold nor hot	37,5% 15	42,5% 17
Slightly hot	7,5% 3	7,5% 3
Hot	10% 4	5% 2
Very hot	0% 0	0% 0
Total	40	40

Company 9

	The thermal sensation in the summer is	The thermal sensation at 40 winter is
Very Cold	12,79% 11	2,44% 2
Cold	11,63% 10	12,2% 10
Slightly cold	16,28% 14	15,85% 13
Neither cold nor hot	32,56% 28	36,59% 30
Slightly hot	19,77% 17	14,63% 12
Hot	5,81% 5	10,98% 9
Very hot	1,16% 1	7,32% 6
Total	86	82

Company 5

	The thermal sensation in the summer is	The thermal sensation at 40 winter is
Very Cold	23,64% 26	7,41% 8
Cold	22,73% 25	24,07% 26
Slightly cold	20,00% 22	25,00% 27
Neither cold nor hot	22,73% 25	26,85% 29
Slightly hot	6,36% 7	11,11% 12
Hot	2,73% 3	3,70% 4
Very hot	1,82% 2	1,85% 2
Total	110	108

4 Results

3.1. Employees' thermal comfort

The effectiveness of the model of the methods used to verify the sensation of human thermal comfort and the real thermal behaviour of the building reached the objective obtaining the description of the 55 questions asked to the employees of the companies that received the LEED Certification. In this article we focus on the results of the questionnaires about the employee's profile, his workstation, thermal comfort and which aspects that most influence the quality of the building.

The growing number of LEED-certified buildings from 2007 to the present year has shown a strong tendency to opt for sustainable buildings, influencing builders and customers, and building employees are accepting sustainable building solutions that contribute to the environment and, in parallel, reduce building maintenance costs compared to traditional buildings. Obtaining a LEED certification requires a technical rigor on the part of the construction entrepreneur, a series of documentation and proof of compliance with the requested requirements. Another point is the specialized workforce from the project prepared by architects and engineers to the execution of the project and the supply of construction materials by specialized companies for the execution of the service. The certified buildings have emerged from the initiative of private companies using North American concepts for the construction of sustainable buildings. However, the American parameters present climatic and constructive factors different from the Brazilian reality. Such facts are perceptible to the users of the buildings certified and verified through the questionnaires. It is fundamental to adapt the certification to the user of the building and the place where the building is implanted. In this way, the certification must respect the local climatic characteristics, verifying that Brazil is a country where the tropical climate of altitude predominates and a wide latitudinal variation. Introducing the use of natural ventilation as a way to reduce heat and reduce building odors. In this way, the use of passive technology taking advantage of nature's resources to the extreme and then opting for the use of passive technology for the days too much heat would provide thermal comfort to the user of the building. Thus, obtaining an ideal temperature for the buildings, establishing the limit between the zones of comfort of the human metabolism proposing an adaptive model of comfort for Brazil. However, it is not an easy task and requires a process of adaptation to the labor market, making it important to treat the results raised in these works and to evaluate them with scientific technical rigor by companies and universities with the intention of seeking sustainable buildings that receive the support labor market and tax incentives, rebates and leadership by the public sector.

Future work

Application of the questionnaires and the environmental variables of temperature, humidity, air velocity and atmospheric pressure raised in the place in the methods of evaluation of the sensation of the thermal comfort of the human being and the thermal control of the building.

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New method of increasing building efficiency

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Abstract. Increasing the comfort of a residential building depends a lot on how well the structure of resistance is known and the materials it is made of, but also the possible stages of degradation and the causes that led to them. One of the best performing procedures to determine some of the causes of degradation is thermal imaging known as thermography.The thermography results for the residential building are compared with the legal indices and then the conclusions are drawn, followed by establishing the methods and the techniques of approach for its thermal recovery. Thermography has a very long history, although its use has increased with the commercial and industrial applications of the past forty years.

1 Introduction

With buildings responsible for more than 30 percents of global energy consumption and a quarter of $CO2$ emissions, there is a huge, under-tapped opportunity to create more sustainable cities through building efficiency. More efficient buildings can generate economic benefits, reduce environmental impacts and improve people's quality of life. [1]

Much progress has been made on improving building energy efficiency over the past decades by focusing on the efficiency of individual building components and, more recently, the efficiency of the building as a whole. As a middle ground between component and whole-building efficiency, a building systems approach considers the interactions of components within and among building systems, as well as interactions among multiple buildings, and between the building and the electric grid. Adopting a systems perspective will become increasingly necessary to achieve meaningful and cost-effective future energy savings within the built environment .[2]

2 Principles of thermography

The energy emitted by a surface of an object whose temperature is above absolute zero as we already know is infrared radiation. This radiation is function of one thing: temperature of the material.

There are three ways by which the radiant energy striking an object may be dissipated: absorption ,transmission and reflection. In order to describe this phenomena we are using three parameters : spectral reflectance ρ_λ ,spectral absorption α_λ and the spectral transmittance τ_λ. These three parameters are wavelength dependent. The sum of these three parameters must be one at any wavelength, as in the following equation: $\alpha_\lambda + \rho_\lambda + \tau_\lambda = 1$ (1). If we discuss about opaque materials, the above equation becomes more simplified. All of the energy is either absorbed or reflected. $\alpha_\lambda + = 1 - \rho_\lambda$ (2).[13]

3 Case study

The objective of this paper is to review the current state and to identify the future challenges regarding the application of thermography in building heat loss calculation . This paper is a result of a study over two buildings , one residential home situated in Constanta and a bloc of apartments from Bucharest. We carried out those two studies at the request of the inhabitants in order to detect why the thermal comfort is so low. All the tests were done using a professional thermal imaging camera, Testo 885-2 .

In both cases a calculation of the heat loss was made first. A calculation of heat inputs for the summer period was also made to see if the insulation is properly dimensioned. We mention that the two buildings have different years of construction, the block is from 1982 and the house is built in 2012, both having a 10 cm extrusion polystyrene insulation applied 8 years and 5 years ago.

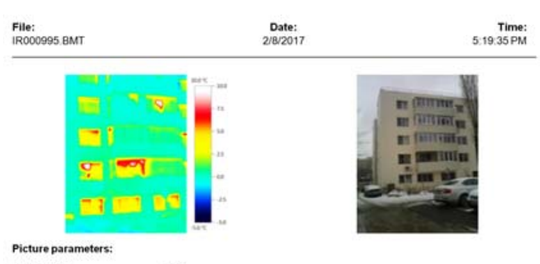

Fig. 1. North side of the building

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As you can see from the pictures, the owner of the house wanted to find out why he has mold and a cold feeling in some parts of the house.

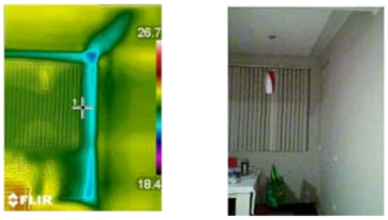

Fig. 2. House – Nord wall

In the following figures, both buildings can be observed from interior and exterior.

In order to be able to present the overall image of the two buildings and to make a fair comparison, I would point out that both buildings are made of BCA and are insulated on the outside with the same type and thickness of polystyrene. The outside temperatures in the two days in which the measurements were made were approximately -4 Celsius

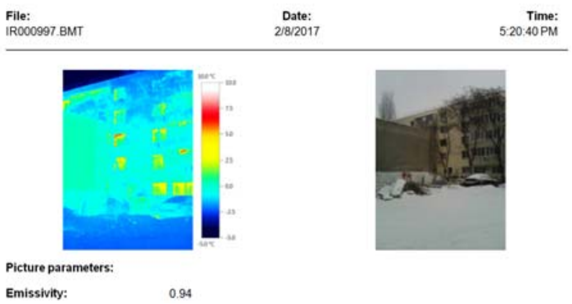

Fig. 3. South side of the building

In both cases, the colour palette of the thermal chamber was set so as to highlight differences of up to 1.5 degrees Celsius. As is shown in figure 3 , the red spots are not thermal bridges but open windows from balconies.

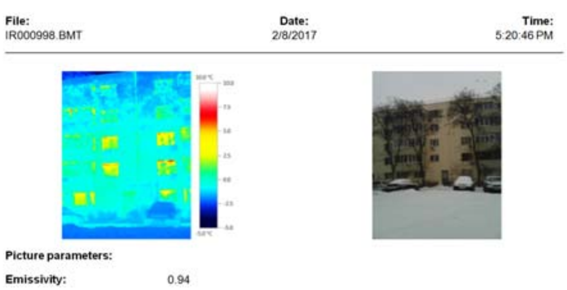

Fig. 4. South side second entrance

Figures 1, 4 and 5 are very conclusive about the way the insulation was made for the apartments bloc. The blue colour from the facades means that the temperature on the exterior surface of the insulation is very close to the exterior temperature leading us to the idea that thickness was well-chosen .

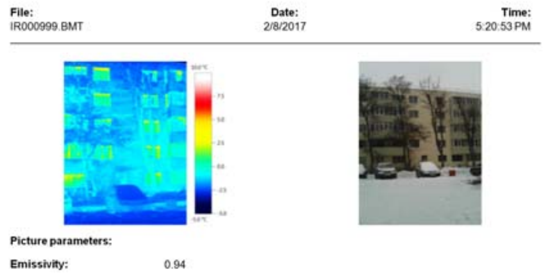

Fig. 5. South side- different angle

At the same time there is no heat loss at the joints of the polystyrene boards, which indicates that the commissioning was done well. One thing notable is the quality of the windows, in both cases studied. These are new generators with at least two sheets of glass. The last image of the building represents the east side of it and we can observe some small differences regarding heat transfer through elements of glass (yellow colour). It is clear that the balconies are not properly heated and the risk of mold to appear at the top of the interior walls high.

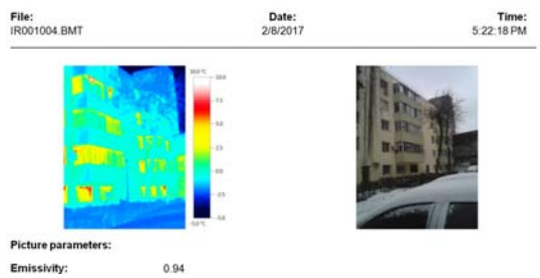

Fig. 6. East side of the building

This method of determining whether there are heat loss issues is non-invasive and has a fairly large scale in recent years. More and more owners want to see the areas with larger losses and also make sure that the insulation works were done properly. This is also the case in Constanta, where the owner has explicitly asked for such a diagnosis, because no matter how much the house was heated, it also had mold in some areas.

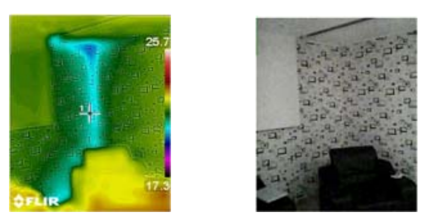

Fig. 7. North corner of the room

From the first thermal camera picture I could notice a fairly high temperature difference between the component elements (walls, beams and poles). It was clear that something had been wrong since the beginning of the construction. In this case, the diagnosis of “sick home” was put in the first moment. I told the owner that the workers did not isolate the pillars and the beams because the house was built on the border

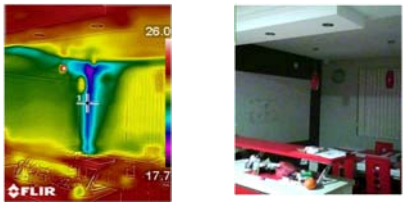

Fig. 8. Ground floor - kitchen

In this case there was no need for a thermography from outside. The solution for stopping the cold sensation was on the first place.

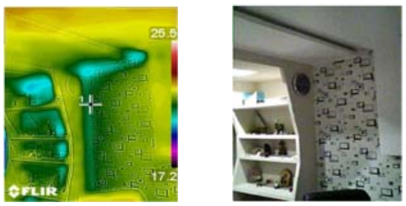

Fig. 9. First floor - bedroom wall

Although this house uses an efficient gas-fired thermal boiler, underfloor heating, and a chiller that serves all the space does not manage to annihilate the discomfort created by cold radiation and mold odor. The picture from figure 9 above shows the wrong way of working, approached by the workers. This not invasive method of thermal vision, corroborated with the calculation of the energy heatloss provides a technical and economical solution, for the problem of thermal discomfort in the building.[3] At the same time, this dynamic method of hot air, but also wet or inadequately insulated parts, can be brought to light.[4]

4 Results

The results of this method are extraordinary from a visual point of view; allowing us to quickly locate the cause of the problem. This diagnosis, made in a relatively short time together with an appropriate heat loss calculation, gives the recipient an overview of the problem. Applied solutions are based on this and can be accomplished much faster. In both cases studied the increase of the thermal efficiency of the respective building was based on this method. The synthesis of the results is presented below :

	Appartment	House
Temp in/ out	20/-4	21/-4
Material	BCA	BCA
Insulation	10 cm	10 cm
Heat loss	89	83
Thermal comfort	ok all the time	ok / cold feeling
Agent provider	Radet	Gas heater

Table 1. Synthesis of the results

Another important result is the difference between anticipated and observed values of temperature.

Anticipeted temperatures values								
Wals			Windows			Ceiling		
21	21.5	22	19	12	12.5	19.5	19.8	20

Observed temperatures values								
Wals			Windows			Ceiling		
17.5	19	21.5	10	10.45	11	14	18	18.5

Table 2. Temperature results

There are three main temperature stages. If the difference between observed and anticipated temperature from calculations is in interval 1-8 degrees than the problem it is considered minor and can be easily solved. If the difference is between 8-12 the problem becomes more urgent and between 12-15 and above it is critical and immediate intervention is required.

Following the application of this method and related thermal calculations, it was decided to apply the following measures to reduce thermal discomfort as follows: Apartment buildings in Bucharest have been recommended to change the windows somewhat of a high quality and to fill insulation hollows where necessary and reduce heat inputs in summer by fitting drapes. The Constanta house received several recommendations, of which the most urgent is the isolation on the outside of all the pillars and beams. They also have been recommended to mechanically or naturally ventilate the entire space for at least 30 minutes daily to remove moisture and odor. All these recommendations were possible in a relatively short time due to this method of thermal imaging, the method that enhances the efficiency of buildings and spaces by visualizing a few elements of risk.

5 Conclusions

The new concept of sustainable development leads to a different approach than the classic one we are used to when building. Currently, the building is considered to be a continuous development, which has to be treated, rehabilitated and modernized in time to meet the requirements set by the user at a certain stage. Highlights are analyses and interventions related to energy saving under conditions of adequate comfort. This aspect has been called the energy efficiency of the building. Alongside reducing energy needs, two important goals of sustainable development, namely the primary resource economy and the reduction of pollutant emissions in the environment, are achieved.[5]

Increasing energy efficiency can be achieved in a number of ways, from educating building users to the energy economy, interventions that are available to many, and carrying out an expertise and energy audit, where experts recommend a range of technical solutions modernization. These solutions depend on the type, age and destination of the buildings and constitute what is called the rehabilitation or modernization of the building.[5]

The thermal rehabilitation / modernization of a building is to improve it in order to keep the heat inside. This involves adding thermal insulation, sealing, improving or even replacing windows and doors, as well as improving the equipment and facilities with which the building is fitted. Thermal rehabilitation also means the implementation of energy efficiency measures in all renovation and repair activities of the building.[5]

Energy efficiency of buildings is a top priority, given the poor quality of most existing buildings, whether old or cheap. On the other hand, the costs related to the thermal rehabilitation of a building are lower than the costs of installing additional heating capacity for heating. In Romania, energy consumption for the population sector is at the level of 40% of the total energy consumption of the country, and this share has been found more or less all over the world.[5]

This method of thermal imaging , is one of the best non-destructive and non-invasive methods, making it useful in the following situations:

- determining areas with heat loss of buildings, identifying deficiencies of thermal insulation;
- identification of excessive air infiltration;
- determining the areas where condensation and mold are likely to occur;
- identifying clogged pipes;
- determining constructive issues [3]

Improved building efficiency can reduce costs, improve productivity and help create jobs for people in cities. Increasing efficiency in buildings is one of the most cost-effective ways to improve cities – every $1 invested saves $2 in new electricity generation and distribution costs. [1]

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THERMAL CONVECTION ANALYSIS OF HEAT PUMP SYSTEMS

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Abstract. Correlated with EU directives, the national energy strategy provides important measures in order to improve energy efficiency in buildings and related facilities, as well as using advanced technologies and materias and by promoting appropriate solutions and equipment in full knowledge of the peculiarities and applicability limits for different categories of requirements, with maximum functional and energy efficiency. Since it is known that in the energy balance the biggest share is in thermal energy, it is appropriate to say that continuous efforts in the optimization of conventional fuel saving solutions and intense promotion of renewable energies is highly justified. Also taking into account the major energy crisis, foreseeable for the global economy, we can say that there is a need for a series of research and development strategies in terms of energy performance, transport and storage. The use of renewable energy forms in the cooling and heating systems, as well as the „waste heat” resulted from different processes is consistent with sustainable development and helps reduce the consumption and emissions of conventional fuels. Plant systems equipped with heat pumps with mechanical vapor compression require the existence of an additional source with a low thermal potential, normally obtained from the natural environment. For example, the additional source can be arranged in line with the utilization of the residual heat from the system in self-compensating regime, when the system is designed to heat the space during the cold season and cool it during summer. In this case, the heat surplus from the cooling operation is gathered in seasonal storage and provides the necessary intake for heating, resulting the autonomy and independence of the system regardless the natural thermal resources. Replacing the usual secondary agent with nanofluids increases heat transfer by significantly increasing the convective transfer coefficient and also the storage of thermal energy in phase-change materials is a method that has experienced significant development in recent years, being attractive in terms of the large amount of thermal energy accumulated by the storage medium per unit volume at constant temperature.

1 Introduction

The major energy crisis, predictable for the global economy, requires R & D strategies to focus primarily on increasing the energy performance of power generation, transmission, transport and storage equipment.

In this respect, one of the major challenges for the European Union is how to ensure the energy security of Member States, taking into account the evolution of climate change and the uncertain future of access to energy resources.

It is a known fact that the highest share, in the energy balance, is represented by thermal energy and so the continuous effort in order to optimize saving solutions for fossil fuels and promotion of renewable energies is well justified.

The use of plant systems for the use of renewable forms of energy as well as waste heat from different processes corresponds to the concept of "sustainable development" and directly contributes to reducing conventional fuel consumption and emissions. [1]

In the category of unconventional forms, shallow geothermal energy - recovered through heat pumps - is a source with great potential for saving primary resources and achieving the goals set for the 2030 and 2050 stages.

Seasonal Thermal Energy Storage (STES) is generically used and refers to technologies for storing “heat” or “cold” for a period of time that may be up to a several months. Available thermal energy can be collected, stored and used when necessary, such as in opposite seasons. For example, residual heat, waste heat from industrial processes or the heat from solar panels can be collected during the summer and used, in a system equipped with a heat pump, to ensure the comfort parameters during winter. The same principle is applied when collecting natural cold, used during the hot season for cooling. [2]

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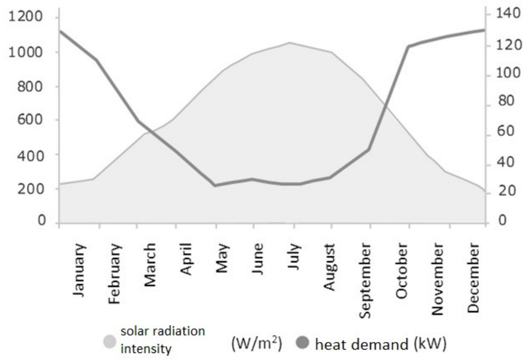

Fig. 1. Solar radiation/heat demand during the year.

In the case of air conditioning units designed for cooling in the warm season and for cold season heating, there is a need for an additional source, which can be appropriately arranged for the recovery of the residual heat energy from the system in a self-extinguishing regime. This creates autonomy of the system independent of natural thermal resources.
Achieving an efficient heat transfer between the working environments of geothermal exchangers is conditional on their thermophysical parameters and the improvement of the overall transfer coefficient through constructive performance solutions.
Also, increasing the heat storage capacity by using controlled materials ensures the efficiency of the system.

2 Components

2.1. Heat exchangers

Heat capture in the soil can be achieved through heat exchangers also known as collectors. They consist of tubes in closed loops through which circulates the working fluid (water, various glycol solutions, nanofluid etc.) and, properly dimensioned, can recover the stored energy soil at a temperature compatible with a suitable heating system (low temperature radiation – floor, radiant walls or ceilings).
Considering that the system chosen for the numerical simulation presented in the paper is **Borehole Thermal Energy Storage (BTES)**, it is made clear that in the volume of earth will be introduced more vertical tubes at equal distances between them. Among the advantages of this solution we mention the fact that the soil is a very good medium for storage of thermal energy because it does not involve costs (it is already in the place where we want to implement the system), it is not harmful to the environment or people and above these drillings can parking facilities, playgrounds, green spaces etc. The volume of water flowing through the heat exchanger is used to load or discharge the system at different time intervals. [2]

2.2 Nanofluids

Nanofluid research began in the 1980s, but the nanofluid concept only appeared in 1995 at the Argon National Laboratory in Chicago by Choi. It described a new fluid in which nanomaterial particle suspensions (<100 nm) are present.
The benefit of using nanofluids is that we can obtain low-temperature heat transfer systems with low production costs but with increased energy efficiency. This is due to the physic-mechanical characteristics that nanoparticles have: high surface / volume ratio, low pulse, increased mobility. [4]

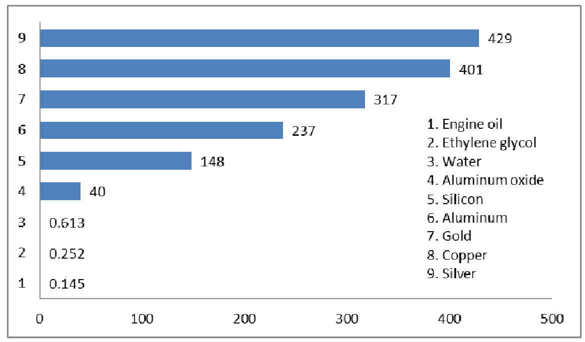

Fig. 2. Thermal conductivity of solid and liquid materials at 300 K

3 Numerical simulation

3.1. Description of geometry

The geometry for the numerical simulation was developed with the help of Autodesk Inventor. The dimensions adopted for the quartz sand "cube" were Lxlxh = 1x1x1 m. The length of the tube used is 1 m and the diameter is 1 ". [2]

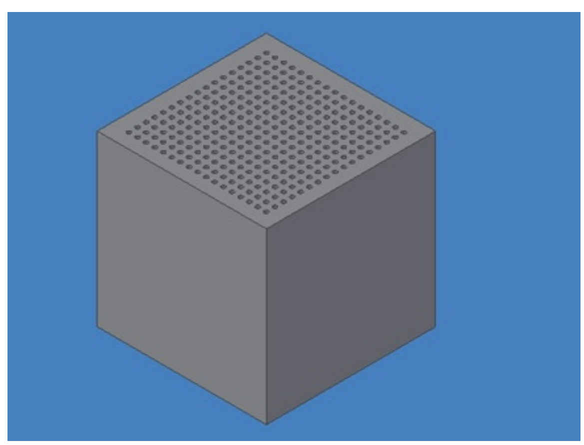

Fig. 3. Quartz sand "cube" (1x1x1 m)

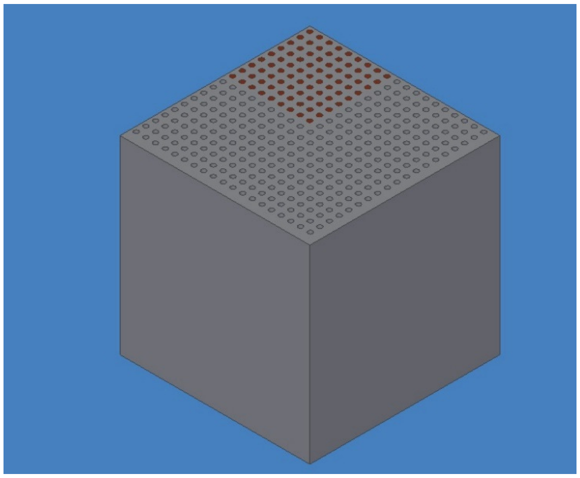

Fig. 4. Inserted copper tubes at equal distances

In order to simplify and reduce the time of simulations, the geometry was reduced to only one tube, as presented in the image below. Further, with the help of similarities, the results obtained for the other tubes can be applied.

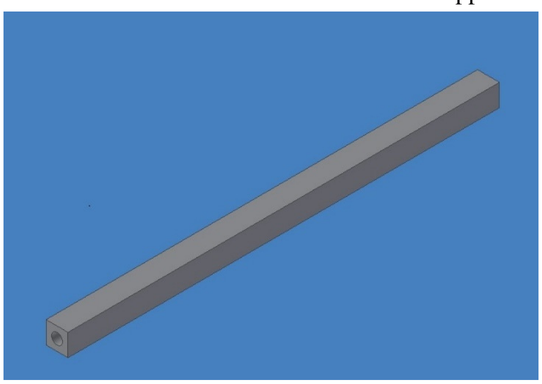

Fig. 5. Simplified case

3.2. Working hypotheses

Simulations of working conditions were done using the **Ansys Fluent** program. [2]

• Nanofluid working temperatures: 50, 60, 70, 80 90℃;
• Flows: 0.5, 0.6, 0.7, 0.8, 0.9 mc / h;
• Nanoparticle concentrations: 0%, 1%, 2%, 3%, 4%.

Water properties:
• ρ = 1000 kg/m^3
• Cp = 4500 J/kg*K
• Λ = 0.9 W/m*K
• μ = 0.0015 kg/m*s

Quartz sand properties:
• ρ = 1600 kg/m^3
• Cp = 795 J/kg*K
• Λ = 0.2 W/m*K

Table 1. Water properties with 1% nanofluid concentration.

Temp. [℃]	ρ [kg/mc]	Cp [J/kg*K]	μ [kg/m*s]	Λ [W/m*K]
50	1036.5	4147.0	0.00059	0.66037
60	1032.0	4159.5	0.00050	0.67103
70	1027.0	4172.8	0.00043	0.68025
80	1021.2	4187.1	0.00038	0.68804
90	1014.8	4202.4	0.00034	0.69445

Table 2. Water properties with 2% nanofluid concentration.

Temp. [℃]	ρ [kg/mc]	Cp [J/kg*K]	μ [kg/m*s]	Λ [W/m*K]
50	1085.2	4113.0	0.00065	0.67917
60	1080.7	4125.3	0.00055	0.69011
70	1075.5	4138.5	0.00048	0.69958
80	1069.7	4152.6	0.00042	0.70758
90	1063.3	4167.7	0.00037	0.71416

Table 3. Water properties with 3% nanofluid concentration.

Temp. [℃]	ρ [kg/mc]	Cp [J/kg*K]	μ [kg/m*s]	Λ [W/m*K]
50	1133.9	4078.9	0.00072	0.69833
60	1129.3	4091.1	0.00062	0.70957
70	1124.1	4104.2	0.00053	0.71928
80	1118.3	4118.1	0.00047	0.72750
90	1111.8	4133.1	0.00041	0.73425

Table 4. Water properties with 4% nanofluid concentration.

Temp. [℃]	ρ [kg/mc]	Cp [J/kg*K]	μ [kg/m*s]	Λ [W/m*K]
50	1182.5	4044.8	0.00081	0.71787
60	1177.9	4056.9	0.00069	0.72940
70	1172.7	4069.8	0.00060	0.73938
80	1166.8	4083.6	0.00052	0.74781
90	1160.2	4098.4	0.00046	0.75474

4 Results

To evaluate the accuracy of measurements, experimental system has been tested with distilled water before measuring the heat transfer characteristics of different volume concentration of Al_2O_3/water.
From the experimental system, the values that have been measured are, the temperatures of the inlet and outlet of the hot water as well as the inlet of the distilled water and the different concentrations of nanofluids at different mass flow rates.
The numerical model, performed by the FLUENT calculation program, allowed the qualitative and quantitative analysis of the influence of the volume concentration of the solid phase on the temperature and velocity spectra, respectively on the main parameters involved in the thermal transfer, namely the convective

transfer coefficient, the global coefficient of thermal transfer and thermal efficiency.

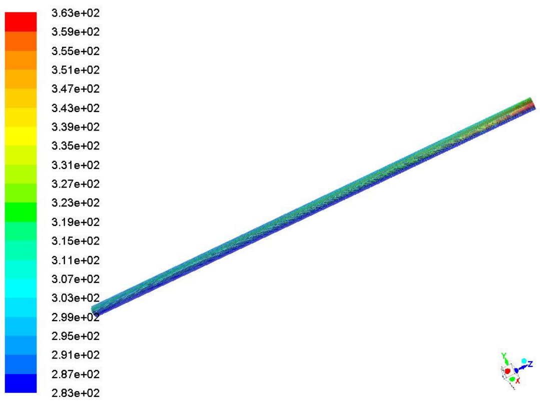

Fig. 7. 0% nano, 90℃, 0,9 m^3/h

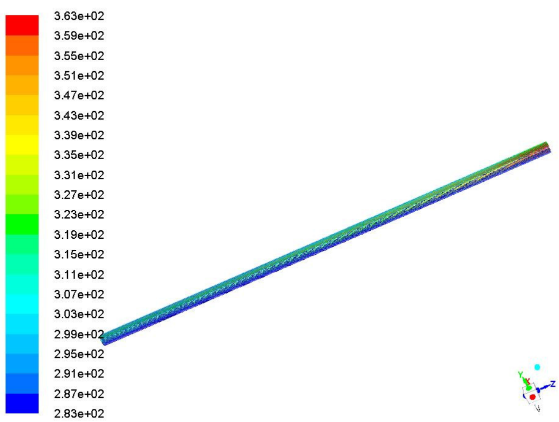

Fig. 8. 1% nano, 90℃, 0,9 m^3/h

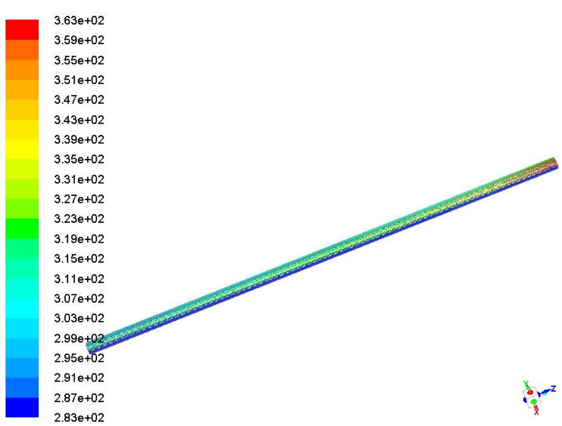

Fig. 9. 2% nano, 90℃, 0,9 m^3/h

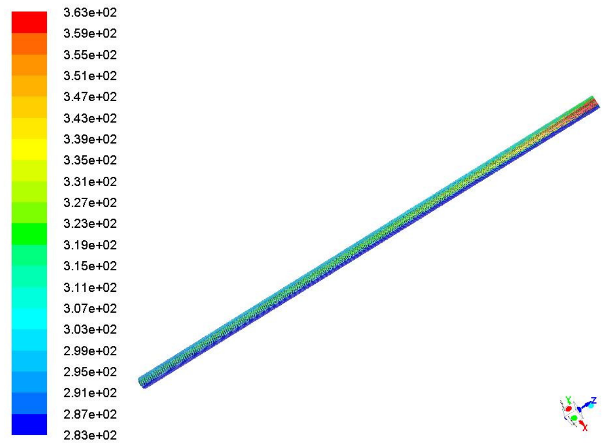

Fig. 10. 3% nano, 90℃, 0,9 m^3/h

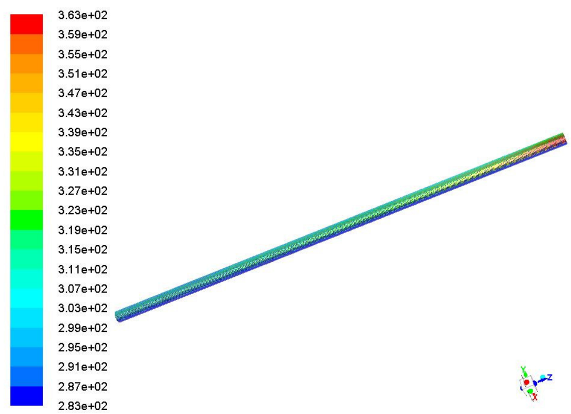

Fig. 11. 4% nano, 90℃, 0,9 m^3/h

The conclusions of the numerical study have highlighted the intensification of heat transfer, when using nanofluids, compared to water. Thus, we can say that of the 4 concentrations proposed in the working hypotheses, the best results we have for the 2% concentration. [5]

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Rehabilitation of the Utility Spaces and Boiler Room - Monnaie Royal Theatre

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Abstract. The building used for workshops and administrative services at the Monnaie Royal Theatre in Brussels was subjected to complete renovation, in an effort to make the work conditions for the administrative and technical staff at the theatre more comfortable, and the building more conform to fire safety regulations and more energy efficient. The objective of energy efficiency was achieved by renovation of the infrastructure of installations : central heating and cooling, water supply, sewage and gas pipes, electrical (power and control of equipment's, fire detection, lighting, and BMS (Building Management System) integration. Two major areas were assigned as utility rooms (in the basement) and the boiler room (on the roof , 4th floor).

1 Introduction

The purpose of this paper is to show the stages of rehabilitation of a heating and cooling system for a monument building, the Royal Theater of Monnaie in Brussels, Belgium, as well as the problems encountered and the solutions found in order to ensure a low-energy efficient system energy. The energy efficiency concept provides a powerful and cost-effective framework for reducing greenhouse gas emissions, fuel consumption, and operating costs.

Control and monitoring are provided by the BMS (Building Management System) system, which intervenes in the modulation and adjustment of four high-volume condensing boilers: three 850 kw heating boilers, a 100 kw ACM boiler, a 300 kw chiller, two 195 kw dry-cooler units, all pumps, and auxiliary control devices.

Water quality is a problem addressed in the paper in light of the requirements of preserving existing installations and protecting newly installed boilers.

The execution work has two stages:

Stage I. - centralized administration of the technical spaces - the distribution of the theater

Stage II. - connection of the second building through a technical and passage tunnel, crossing under a pedestrian street - the connection of the central installations with the terminal equipment inside the theater (13 central air treatment units)

1.1 Data about the building complex

1.1.1 Location

The address is Place de la Monnaie – 1000 Bruxelles, for the theatre building and for the administrative and workshop building it is 23, rue Léopold , and 41 rue Fossé aux Loups (Figure 1, Figure 2, Figure 3).

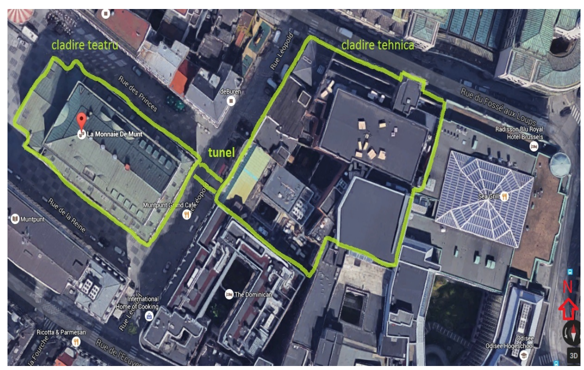

Fig. 1. Location of theatre and technical building

Fig. 2. Technical building façade at 23, rue Léopold

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Fig. 3. Technical building façade at 41 rue Fossé aux Loups

1.1.2 Landmark and Historical Place

The first Grand Theater was opened in 1700. In 1819, it was however demolished and rebuilt at the current location by the french architect Louis-Emmanuel Damesne on the site of the former 'Herberge van Oistervant' mint ('La Monnaie' is the French word for 'coins'). It was considered one of the most beautiful theatres outside Italy. But by January 21, 1855, a serious fire reduced to ashes the entire building. There were only the four exterior walls. Fortunately, the Theatre of the Mint was quickly rebuilt. Joseph Poelaert took up both the design of the new building and the whole of the interior decoration. The new Theatre of the Mint reopened its doors in 1856. The major recent changes date back to 1985 when the stage tower was completely restored and the building, raised an additional volume.

In **1985** The Department of Public Works decided to renovate the building for technical, safety and aesthetic reasons. In **2000** there was the Inauguration of the New Monnaie workshops in the ancient Vanderborght buildings and the neo-classical building at no. 23 Leopold street just behind 'La Monnaie'

There were two more renovation campaigns one between 2003-2007 and the other between 2015 – 2017 to better conform to the new fire safety regulations.

2 Utilities

2.1 Initial heating and cooling facilities

The base station in the basement had 30-year-old equipment, namely 2 boilers with atmospheric burner on gaseous and oil fuel, developing a 2 x 764kW thermal capacity, a 600 liter day tank for oil fuel, a hydraulic separator, two WILO circulation pumps on each boiler, a manifold of DN300 with 10 circuits and 3 expansion vessels of 500 litres each.

There was a secondary station in the basement with 2 boilers of 240 kW each, two expansion vessels (2 x 300 litres), a manifold collector, pumps, three - way valves for workshops and the administrative area. The radiator pipeline distribution was made up of steel joint with copper in an advanced state of decay.

The cooling system for administrative offices si made of direct evaporative cooler units. Domestic hot water preparation is centralized only for administrative area, with tank accumulation, circulation pumps, and a water softening station.

2.2 Design brief and contractual requirements

Design theme [1]:
- Dismantling of existing installations
- Heating for 3 administrative buildings, workshops and theater with 4th floor thermal plant on the roof and two basement substations for workshops and administrative offices
- Replacement of domestic hot water distribution, pumps, valves, inserting two new heat exchangers
- A new split type cooling system: made up of a chiller and two drycooler machines for the theater building
- A BMS for monitoring, control and adjustment
- Power supply and indoor gas distribution

2.3 Heating system

2.3.1 Heating system concept

- 3 x 850 kW HOVAL gas fired condensing boilers, of large water volume, support the overall heating system
- 1 x 100 kW HOVAL condensing boiler for domestic hot water production
- GRUNDFOS variable speed pumps
- PNEUMATEX pressure maintenance systems
- Gas exhaust chimney
- Ventilation intake for combustion process

Two solutions were discussed:

- Version 1 : gas condensing boilers without large water content, constant speed pumps, hydraulic pressure separator (BEP)
- Version 2: gas condensing boilers with large water content so that the minimum water flow required to be as low as zero, and variable speed pumps

The second solution was implemented due to the high energetical efficiency [1, 3-5,7,8].

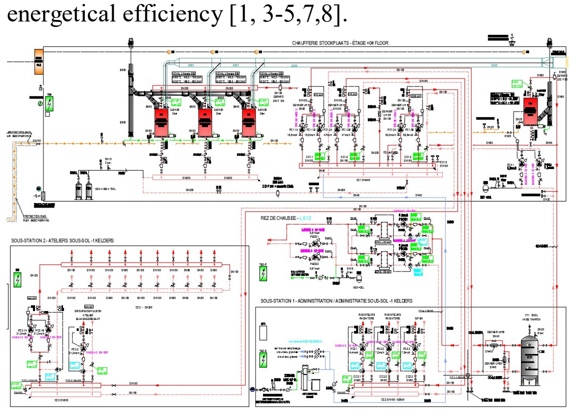

Fig. 4. Heating system general diagram

Fig. 5. Boiler plant new construction on terrace roof 4th floor: structure (left), finished (right)

2.3.2 Boiler room heat source

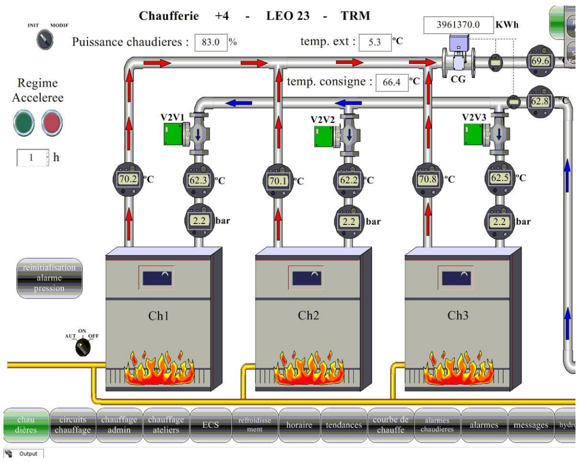

Fig. 5. Heating system diagram - boilers

The three boiler units work together in a "cascade system" because of multiple benefits:
- High turndown capability when only one boiler is required
- Flexibility with footprint allowing installation in irregular spaces
- Increased reliability with heat provided by several boilers
- Service and maintenance is simplified
- Smaller boilers can be maintained by a single engineer on site
- Simple spare part management
- Different rated outputs can be cascaded and control boilers by priority, delivering excellent efficiency; in the example shown in Figure 5 the capacity used is 83%.

From the BMS perspective, if you there is no circulation of water in the pipes , the flow switches on the boiler return pipe change color from black to a red impulse. If the boilers are in authorised mode, they change color from black to green, if one of them is in alarm, it becomes a red impulse.

The prescription of boiler input ratio can be changed by switching off the auto/manual switch and selecting manual input and enter the value in the numeric field.

2.3.3 Boiler room main manifolds

There are four main distribution circuits (Figure 6):

- CC1.1 – Theatre
- CC1.2 – Administrative offices
- CC1.3 – Workshops
- CC1.4 – Domestic hot water production

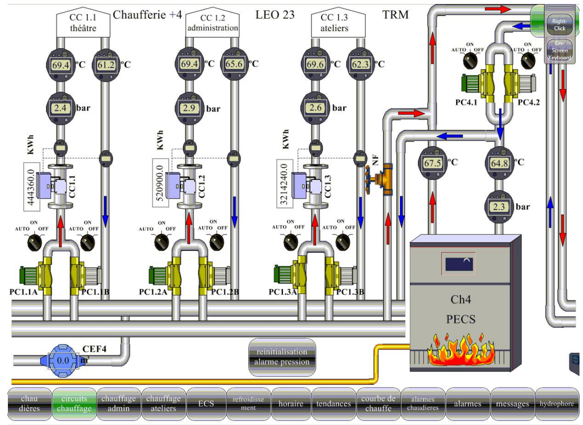

Fig. 6. Heating system diagram – main manifolds

Each circuit is equipped with two centrifugal pumps, a lead and a backup. The operation between the pumps is systematically altered to achieve equal wear using timed alternation - where the lead and backup pumps are switched by an automatic timer controlled by the BMS.

As in the case of the other boilers, for the fourth one can visualise on the BMS display the supply and return temperatures, the return pressure and water flow alarm. If the boiler is authorised, it changes colour from black to green, if there is an alarm, it becomes a red impulse. The prescription of boiler input ratio can be changed by switching off the auto/manual switch and selecting manual input and enter the value in the numeric field.

Every pump can be started / stopped with the aid of a three position selector (Auto – 0 – Manual). In automatic mode, the pumps alternate every 24 hrs. In manual mode, the pump can be stopped if the selector is in "0" position and started if the selector is in "manual" position. When the pump is stopped the BMS displays a black symbol, when the pump is in motion it becomes green, in case of an alarm, it becomes red.

2.3.4 Connection to the theatre building – CC1.1

In order to connect the heat source with the terminals in the theatre building, an underground tunnel was devised to house (Figure 7) :

- 2 heating DN100 distribution pipes (CC1.1),
- 2 cooling water DN125 pipes
- 2 domestic hot water DN65 pipes
- ventilation ducts

The construction of this tunnel was the final stage in the installation project. It was a cumbersome endeavour because the site contained archaeological artefacts and they had to be carefully moved and evalued, street access was closed off. The tunnel between the Monnaie theatre and its workshops measures sixteen metres, under

Leopold street. It is aimed at routing decors to the stage and allowing a direct and discreet access for the artists and the personnel.

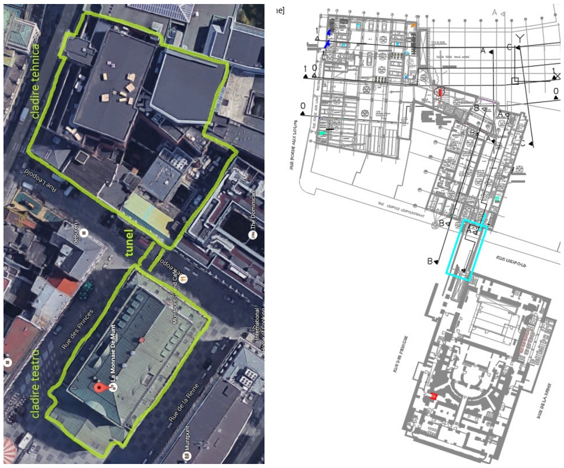

Fig. 7. Underground tunnel for CC1.1

Site works consist of the realization of the tunnel (unearthing, walls, soil and ceiling), and the installation of technical connections (ventilation, heating, electricity, water, Internet) between both buildings and reconstruction of the rail and waterways network after the creation of the tunnel.

2.3.5 Substation 1 – CC1.2

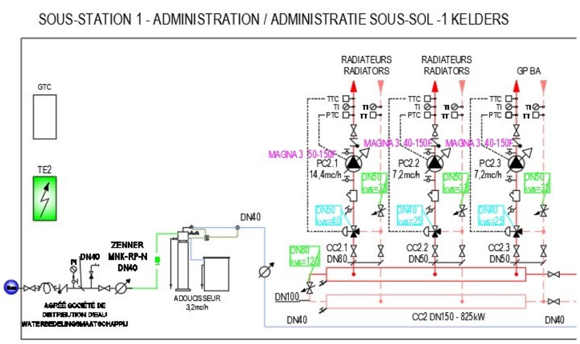

Fig. 8. Heating system diagram – substation 1

Substation 1 (Figure 8) is located in the basement in a separate room, and houses two manifolds supply/return DN 100 for heat circuit distribution to all the office radiators and to an air handling unit heater battery. Every circuit is equipped with a balancing valve, a pump, two temperature sensors placed on the supply and return pipes and a pressure sensor on supply. Every pump can be started / stopped with the aid of a three position selector (Auto - 0 – Manual). In Automatic mode, pumps work to an hourly program. The temperature value can be changed by passing the selector in manual position, and by typing the desired value.

2.3.6 Substation 2 – CC1.3

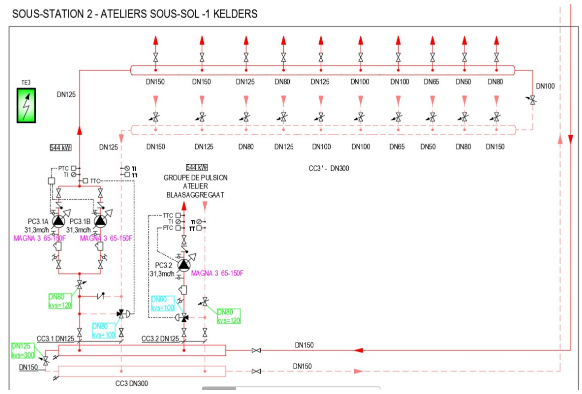

Fig. 9. Heating system diagram – substation 2

Substation 2 (Figure 9) is located in the basement in a separate room, and houses two manifolds supply/return DN 300 for heat circuit distribution to all the workshop radiators and to an air handling unit heater battery. Every circuit is equipped with a balancing valve, a pump, two temperature sensors placed on the supply and return pipes and a pressure sensor on supply. The supply circuit for radiators is equipped with two pumps alternating every 24 hrs. Every pump can be started / stopped with the aid of a three position selector (Auto - 0 – Manual). The temperature value can be changed by passing the selector in manual position, and by typing the desired value.

2.3.7 Hot water production station – CC1.4

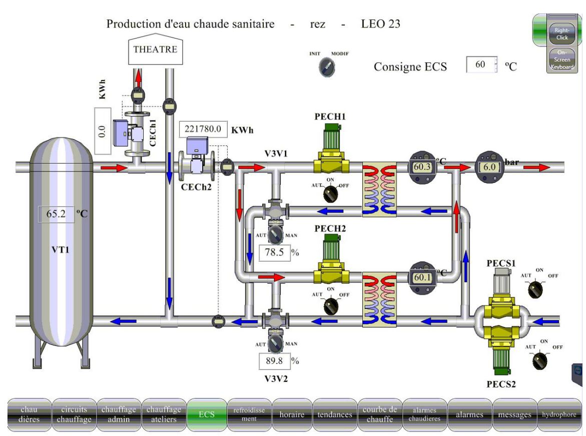

Fig. 10. Heating system diagram – domestic hot water

The reservoir VT1 (Figure 10) with a 1000 litre capacity is connected to the main manifold (the secondary source) and the smaller 100 kW condensing boiler as a primary source of heated water. It is located in the basement where the original reservoir was, so as not to overcrowd the new boiler room on the 4th floor. The temperature in the reservoir must be at least 60 °C. In the example above in fig. 7 it is 65.2 °C. This is important because it inhibits Legionella and other bacteria to develop. Both thermostatic regulating valves on the primary circuit of the heat exchanger ensure a temperature of 45 °C on the secondary side of the exchanger. Between one and three o'clock at night, the “Légionnelle function” is active, and the temperature of water goes up to 65 ºC.

The hot water station composed of 2 plate heat exchangers, 2 primary pumps, 2 recirculating pumps, valves, 3-way thermo static valves, expansion vessels and accesories is located on the ground floor in a separate room, closer to where the offices are. Every pump can be started / stopped with the aid of a three position selector (Auto - 0 – Manual). In Automatic mode, primary pumps work to an hourly program. The secondary recirculating pumps also work on an hourly schedule but alternate every 24 hrs. The temperature value can be changed by passing the selector in manual position, and by typing the desired value.

2.4 The problem of water treatment

In a complex work in which a new distribution system and old terminals must be connected, the is a problem of circulation and treatment of heat-carrying agent.

We have the following premises:
- design requirements: the design theme required the washing of the old heating system with trisodium phosphate (Na_3PO_4) to ensure an anticorrosion protection film as well as pH and hardness and conductivity measurement
- boiler supplier: requires very low conductivity -thus demineralization of water throughout the system, in the new and the old plant in order not to affect the stainless steel / aluminum of internal boiler exchanger

Volume de remplissage maximal basé sur la norme VDI 2035

	Dureté totale de l'eau de remplissage jusqu'à ...							
[mol/m³] [1]	<0,1	0,5	1	1,5	2	2,5	3	>3,0
f°H	<1	5	10	15	20	25	30	>30
d°H	<0,56	2,8	5,6	8,4	11,2	14,0	16,8	>16,8
e°H	<0,71	3,6	7,1	10,7	14,2	17,8	21,3	>21,3
~mg/l	<10	50,0	100,0	150,0	200,0	250,0	300,0	>300
Conductance [2]	<20	100,0	200,0	300,0	400,0	500,0	600,0	>600
Dimension de chaudière individuelle	**volume de remplissage maximal sans démineralisation**							
de 50 à 200 kW	PAS D'EXI		50 l/kW	20 l/kW	20 l/kW	toujours déminéraliser		
de 200 à 600 kW	GEN-	50 l/kW	50 l/kW	20 l/kW				
sur 600 kW	CE							

[1] Somme des alcalis terreux
[2] Si la conductance en µS/cm dépasse la valeur du tableau, une analyse de l'eau s'impose.

Fig. 11. Water hardness in relation to boiler capacity

Thus there is a contradiction between the design requirements to protect the anticorrosion facility with a trisodium phosphate film (Na_3PO_4), i.e. adding salts in water and the supplier's requirements to have a demineralised thermal agent.

In order to evaluate the actual situation as well as possible and 4 samples were collected for analysis from 4 different locations:
- softened water station,
- water from the central heating system
- substation 1- substation 2

Analyses were performed for conductivity, PH and salts:

No.	Analysis	UM	H2O after treatment	H2O Boiler plant	H2O CC1.2	H2O CC1.3
1	Conductivity	µS/cm	801	1030	1038	1077
2	pH	unit. pH	7,65/8,00/8,44	6,78/7,54/7,77	7,50/8,05/8,18	9,38/9,89/9,68
3	Na^+	mg/L	180±5	275±5	265±5	250±5
4	K^+	mg/L	0,5±0,2	1,0±0,2	1,0±0,2	1,0±0,2
5	Ca^{2+}	mg/L	19±1	<0,2	<0,2	<0,2
6	Mg^{2+}	mg/L	2,6±0,2	<0,2	<0,2	<0,2
7	PO_4^{3-}	mg/L	3±5	31±5	31±5	30±5

Observations:

1. Conductivity is determined by the presence of salts, namely the presence of sodium salts, i.e. NaCl (sodium chloride) used to regenerate the ion exchanger (cationite).

2. The softening system does not change the conductivity of the treated water because there is only a substitution of calcium ions with sodium ions on the ion exchanger, therefore the conductivity cannot fall below 800 µS / cm unless another water purification stage, or a reverse osmosis plant, were to be installed after the softening plant. In this case the conductivity may drop below 80 ... 90 µS / cm, and if a two-stage installation is used, the conductivity may drop below 10 µS / cm. This would not be efficient because the water in the new plant would mix with the water in the old plant that could never be brought to the required parameters because all components either pipes or equipment had accumulations of impurities over 30 years. Installation and operating costs would increase considerably and would be repetitive. Adjacent to the above solution, the intercalation of a heat exchanger in the boiler room between the boilers and the main distribution, with additional extra costs, was discussed, but then the efficiency of the condensing system would be lost.

3. The presence of phosphates in the circuit is determined by traces of trisodium phosphate (Na_3PO_4), used in the flushing stage. The presence of phosphate ions is beneficial as it results in the formation of a protective layer of iron phosphates on the inner surface of the pipes and heating elements, this layer having a protective role against corrosion.

Conclusions:

Rehabilitation of monument buildings implies both consolidation, modernization, replacement, but also energy efficiency [9], [10]. All together are a difficult task due to the restrictions resulting from the building typology. This problem is present and as presented in the paper it is a very fine balance between the choice of the technical solution, the equipments, the routes and the connection between the circulation of the thermal agents from different areas of the installation.

2.5 Cooling system

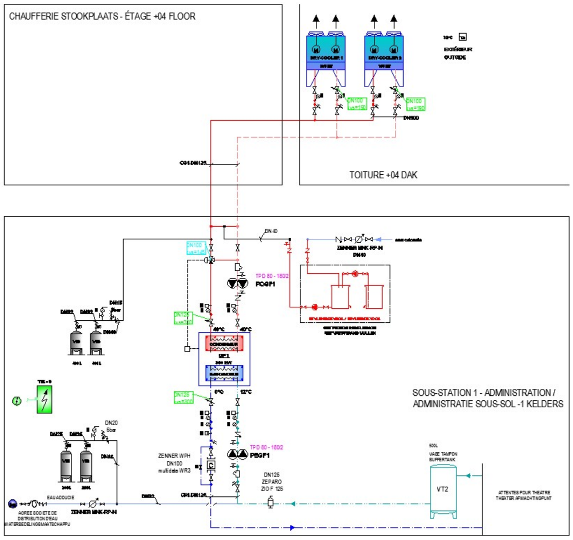

Fig. 12. Cooling system general diagram

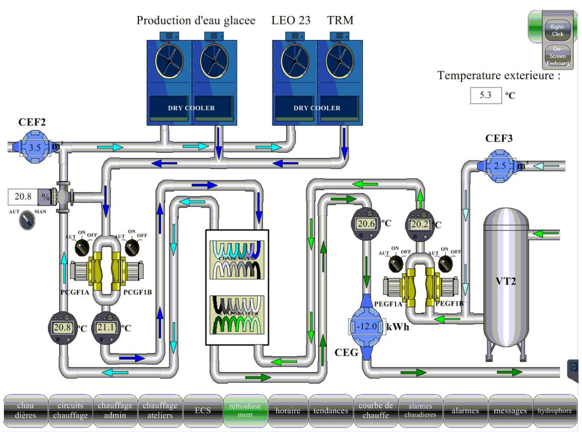

Fig. 13. Cooling system BMS diagram

The cooling system comprises :
- 2 x 195 kW "silent" cooling tower units located on the roof on the 4th floor
- chiller with a cooling capacity of 300kw
- 2 expansion vessels with variable pressure membranes on the distribution to dry coolers
- 2 expansion vessels with variable pressure diaphragm on chiller distribution
- variable speed twin (double) pump
- 500 liter buffer tank

The BMS display controls the pumps of the evaporator and condenser and to see the temperatures of both tower and chiller circuits. The BMS link can also start or close two dry coolers together. A switchflow sets off an alarm if there is no circulation of water in the evaporator circuit and the pumps are working. Every pump can be started / stopped with the aid of a three position selector (Auto - 0 – Manual). The temperature value can be changed by passing the selector in manual position, and by typing the desired value.

2.7 Buiding management system

The automation system controls the heating and cooling systems of 4th floor and basement with four electrical panels TE1, TE2, TE2P e TE3 containing also power and automation circuits and an industrial PC which also serves as operator interface. Automation equipment is modular, with the possibility of extension by adding more modules local or remote.

All panels are equipped with ILC 151 Phoenix Contact control units and modules of inputs / outputs working in stand-alone mode. However all the controllers are connected to a ModBus IP bus that allows the exchange of data between them and / or the industrial PC.

TE1 is located on the 4th floor in the boiler room and manages 3 boilers, heating circuits, the boiler for domestic hot water circuit, 4 groups of double pumps. The 3 large boilers have their own automation panels work in the master-slave system with the first boiler as the master and the other as slave. The capacity of the boiler is controlled by BMS using an analog input 0 - 10V reacting to the outside temperature. The fourth boiler is used for producing hot water and has a temperature of 65 °C limitation in the BMS. TE1 also monitors the gas detection panel: in case of gas alarm, the fire alarm control panel cuts the power to the electrical panel.

TE2 is located in the basement and manages the heating for the administration offices: two circuits for radiators, the circuit for heat batteryof the air handling unit and domestic hot water circuits, and the circuits for drycooler and chiller pump groups.

TE2P is located on the ground floor and manages the hot water service circuits. The two 3-way valves which regulate the water temperature are integrated in the primary circuit of the heat exchanger and the temperature sensors are located in the secondary circuit.

TE3 is located in the basement and manages the radiator heating of the workshops and the ventilation unit heating battery.

All circuits for temperature control use immersion temperature sensors and 3-way valves. The industrial PC communicates on a bus Ethernet with the controllers of the 4 panels and reads the variables which portray the image of the process in real time.

All trials are shown on six pages among which we can navigate using page indicators.

3 Energy consumption

The graph below shows the registered thermal energy consumption related to the heating system during a period of 30 days (from 15.12.2018 – 14.01.2019). Heat meters on general and secondary branches of installation provide valuable data needed for billing and optimisation of the network performance. The flow is measured using bi-directional ultrasound based on the transit time method, with proven long-term stability and accuracy. All circuits for calculating and measuring are collected on a single board, providing a high level of measuring.

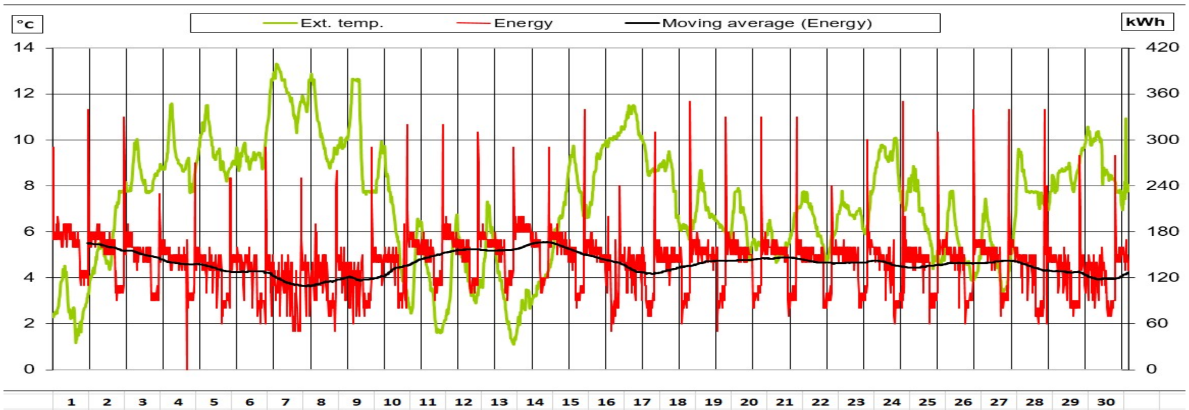

Fig. 14. Thermal energy consumption graph

The green graph is the variation of outside temperature. The red graph is the variation of thermal energy consumption. The high spikes are at the beginning of each day are the energy boosts when the boilers are turned on. Then the graph is pretty stable. The black graph is the calculated moving average for the thirty days.

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Special Engineering Techniques - Ecole Des Trèfles

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Abstract. This paper presents the challenges encountered in designing and planning an educational building complex in order to have a very low energy standard and thus reaching the exemplary building objectives. The case study building is part of the Exemplary Buildings program launched by the Brussels-Capital Region, through which the building sector is encouraged to produce sustainable buildings. This project addresses the sustainability topic in an important building category, as the educational environment is and always will be a central part of everyone's life. The paper aims at showing the technical solutions proposed by the architects and design engineers towards achieving high energy performance, sustainability, good water and waste management and offering at the same time high standard conditions to the building users, architectural quality and economic efficiency.

1 Introduction

Pollution and climate change combat are global priorities nowadays. The European Union has set objectives to gradually reduce the green house gas emissions so as to achieve a 80% to 95% reduction by 2050, compared to 1999 levels [1]. In this context, reducing the energy consumption in the building sector has become a central activity in the European Union environment as it is the sector responsible for approximately 40% of the total energy consumption. A positive example of the EU countries involvement in this direction is the Exemplary Buildings program launched by the Burssells-Capital Region with the purpose of building or refurbishing following passive or low energy standards [2]. This paper presents the case study of a highly energy efficient school building, which is a successfully implemented project part of the Exemplary Buildings programme. The study puts emphasis on the technical aspects of the design and planning of the building, for which all the requirements of the passive standard were used. The Department of Public Works of Anderlecht, Bruxelles had commissioned a new school and gym building complex for 750 students, having a surface of 9100 m^2. The present project won the BATEX 2012 competition and aims to be exemplary in terms of energy performance and sustainable development, but also incorporates the desire to involve children in energy management by teaching them the right reflexes in terms of energy efficiency.

2 Case study building description

2.1 Architectural concept

The case study building is located in Anderlechten, which is one of the 19 municipalities of the Brussels-Capital Region. The architecture of the building is quite innovative, as it can be seen in Figure 1, geometrically speaking, the building is composed of four circles and a rectangle. The circular form inspires and encourages the children to exercise more. The architecture, with the 4 circles, is inspired by a four-leaf clover (Figure 2). Each circle has its own age section and own playground. The circles are interconnected.

Fig. 1. Architectural model

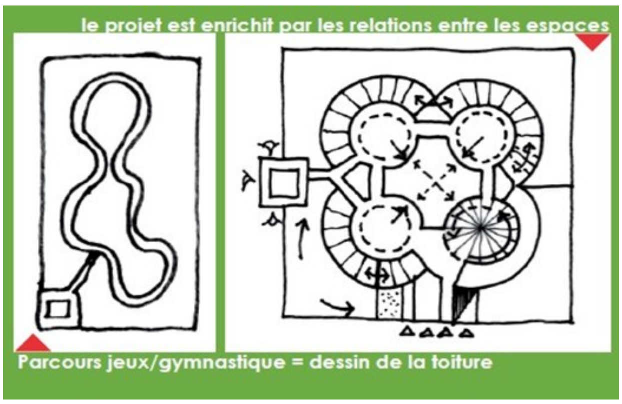

Fig. 2. "Clover Leaf" inspiration for design

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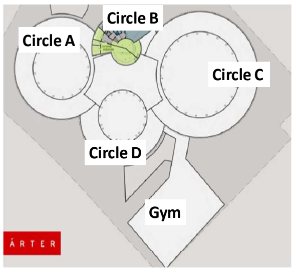
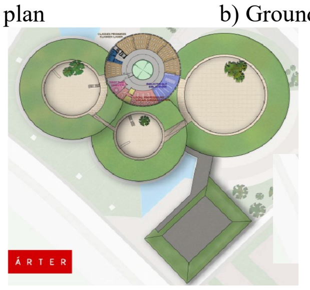
In Figure 4 are presented the horizontal plans of the case study building. The school includes: a basement where the kitchen is functioning, technical rooms, cloakrooms, toilets. The ground floor spaces are distributed in the 4 main circles - circle A includes primary classes; circle B is composed of the entrance hall, cafeteria, concierge; in circle C are the nursery classes and in circle D, the primary classes. The 1st floor is composed of the teacher rooms, the executive offices, the library, primary classes. The gym building includes: The gym, cloakrooms, toilets, storage, technical premises



a) Basement plan

b) Ground floor



c) First floor plan

Fig. 3. Architectural horizontal plans

The *vegetation* is visually important in the project: the surroundings of the school are treated in a landscaped way by proposing a *succession of vegetable spaces, facades and green roofs*, ponds, all contributing to the development of the site's biodiversity, which was one of the exemplary building requirements. Sustainable water management incorporates *rainwater recovery* to avoid over consumption of drinking water.

2.2 Building design requirements

Each assignment was the subject of a specific study leading to appropriate technical choices in terms of energy needs, insulation, ventilation, solar gains, lighting, regulation etc. For each parameter having an influence on the energy performance, an optimisation of the solutions has been made in accordance with the Public Works' and architectural requirements. This optimisation has allowed us to achieve a high energy standard in order to meet the passive construction criteria. As we can see in the charts in Figure 4, the building energy demand is in compliance and well below the passive house standard criteria for primary energy and heating energy demand. The design phase of the building included a series of studies such as: energy feasibility study, the study of passive building certification, the dynamic simulation with TRNSYS software [3], lighting with the ECOTEC software study [4], study PEB, the study of special techniques, recovery and water management.

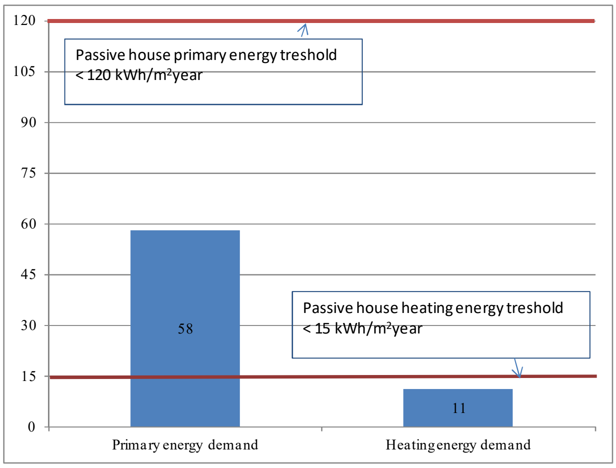


Fig. 4. Design phase energy demand

Features and special items studied are at the level of: ventilation, solar radiation, cooling load, lighting load, domestic hot water and BMS.

2.1.1 Ventilation

The ventilation and heating are independent ensuring adequate thermal comfort in every space regardless of the change of occupation and without interference between spaces.

2.1.2 Solar radiation

The building enclosure is made of precast concrete in order to achieve a high thermal inertia. The windows glass have a high solar factor and overflowing caps for shading during summer, but letting the lower rays of the winter sun heat the building.

2.1.3 Cooling load

The problem of overheating is controlled through passive strategies, so as to ensure indoor comfort during summer without the use of an active cooling system. These strategies are the green intensive roofs and a strategic and automated shielding of solar radiation.

2.1.4 Lighting load

An important goal of the design phase was the optimisation of natural light in order to achieve a factor of daylight in classes over 5% and daylight autonomy in the classes of 80%. Also, high performance lighting equipment was used and a management system of artificial lighting by probes of brightness depending on the natural lighting was implemented. Light output is less than 2 W/m²/100 lux for classes and cafeteria and for the gym is less than 1.5 W/m²/100 lux. The Hall is justified with natural light requiring very little artificial lighting.

2.1.5 Domestic hot water

The production of domestic hot water for the kitchen of the school is using a gas condensing boiler. The production of domestic hot water to the gym is via the boiler room and a cogeneration gas.

2.1.6 BMS

The use of an overall building automation/ management system can be an effective solution to increase comfort and energy efficiency in the operational building phase. Thus, a building management system was implemented: electronic control for all heating and ventilation installations. Cogeneration is also integrated into this regulation to operate primarily from the boilers.

3 Overall design concept

3.1 Building envelope

The quality and comfort of the indoor climate, both guaranteed within the buildings, are paramount to the health of students and teachers. In addition to significantly limiting primary energy requirements through efficient thermal insulation, the planned interventions also include the use of high-efficiency technical facilities and production systems. In the design of the building envelope, two major aspects were considered: daylight optimization and a high performance of thermal insulation. In Figure 5 we can see the design concept of a typical classroom.

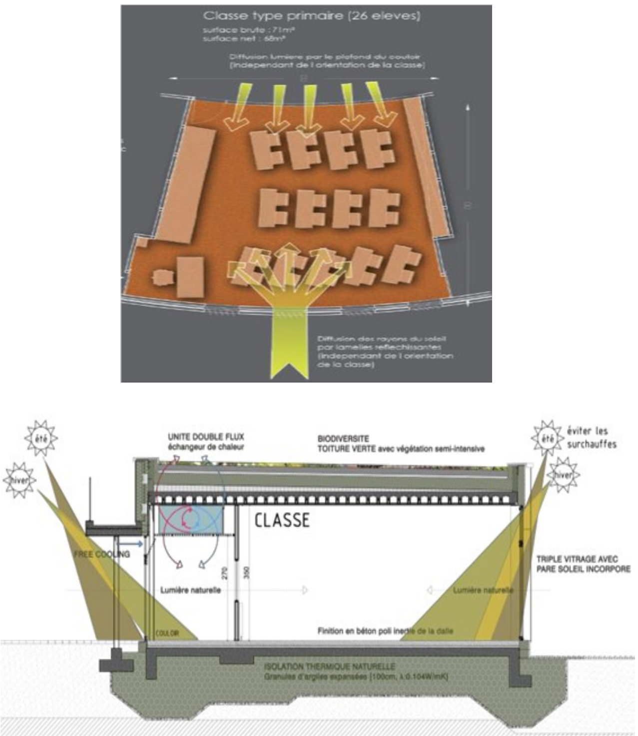


Fig. 5. Typical classroom model

The rooms design was conducted in such a way as to achieve an important contribution of daylight independent from the artificial lighting during the school hours. As mentioned earlier, the target daylight factor in the classrooms must be higher than 5% while the daylight autonomy higher than 80%.

The envelope elements are highly insulated as follows:

- Ground floor: 30 cm of expanded clay granules, achieving a U-value of 0.78 W/m²K;
- Exterior walls: 36 cm of glass wool and the U-value is 0.097 W/m^{2}K;
- Roof: 30 cm of rigid polyurethane, obtaining a U-value of 0.09 W/^{2}K

The exterior fenestration system is composed of highly energy efficient triple glazed window and insulated frames. The windows U-values are: frames U_f=0.8 W/m²K and glass U_g 0.6 W/m²K. The windows and doors were installed in the insulation layer, which is a common technique used in the passive house buildings design and construction, to minimize thermal bridges and improve building airtightness. Figure 6 shows a detail of an exterior wall insulation and window.

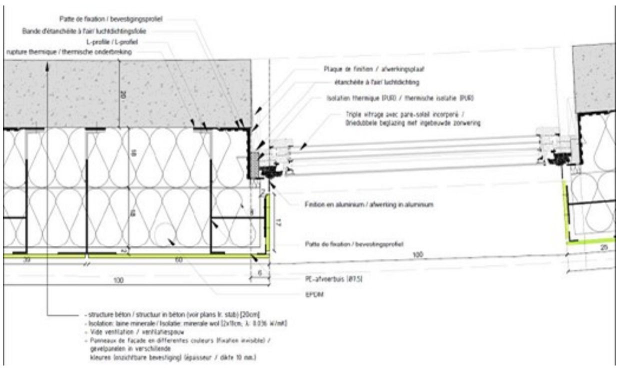


Fig. 6. Wall and window detail

All the constructive details have been detailed and simulated with the help of a program to ensure the perfect continuity of the insulation in order to achieve an airtight building envelope, in accordance with the passive house requirements (number of air changes measured at a 50 Pa pressure to be below 0.60 h^{-1}). The heating energy demand of the building is well below the maximum allowed for a passive building, therefore the building aims at achieving a zero-energy balance.

3.2 Heating system

The design of the heating system was made in accordance to the Belgian standards [4-9]. For the school the primary heat source is gas condensing boilers. Heating independent of ventilation ensures an optimal thermal comfort through the internal and external intake in the classrooms. The rooms heating is made with radiators put in classrooms and other rooms and floor heating in the hallways. The heating plant of the gym consist of a gas condensing boiler – cogeneration. The heating is achieved by means of ventilation system, radiant panels and radiators. At the sports hall level, ***domestic hot water*** is produced from ***cogeneration*** (simultaneous production of electricity and heat) and, in addition, by the heating system. Figure 7 to 9 shows the heating systems schemes of the school, while Figure 10 to 12 show the systems scheme of the gym building.

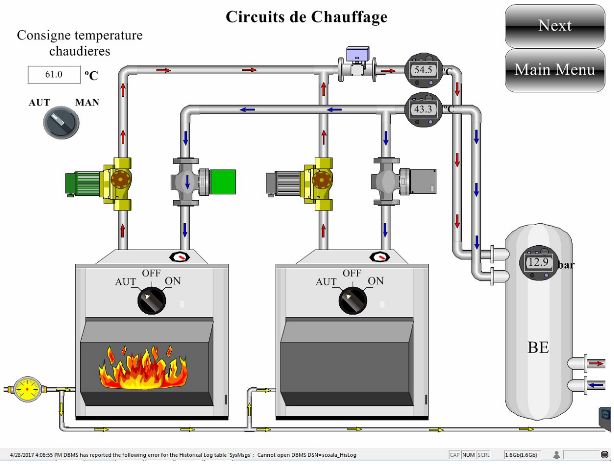


Fig. 7. School boiler plant – heat source

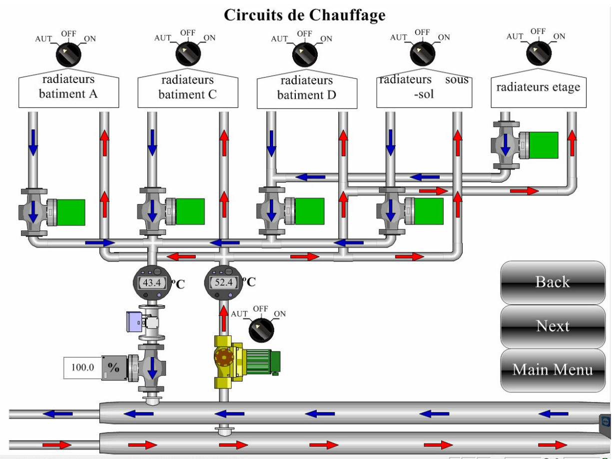


Fig. 8. School boiler plant – radiator manifolds

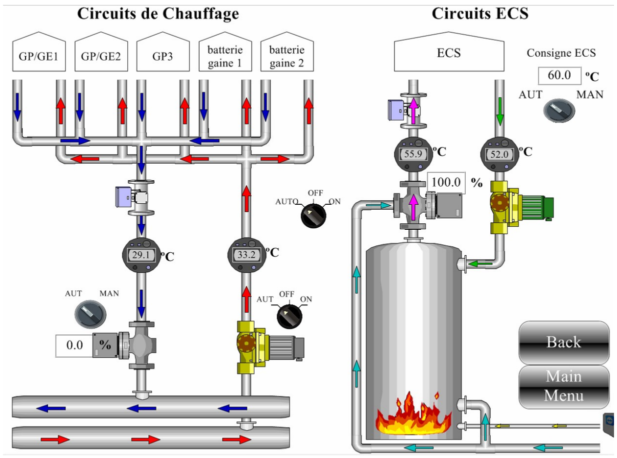


Fig. 9. School boiler plant – air handling unit batteries manifolds; production of domestic hot water

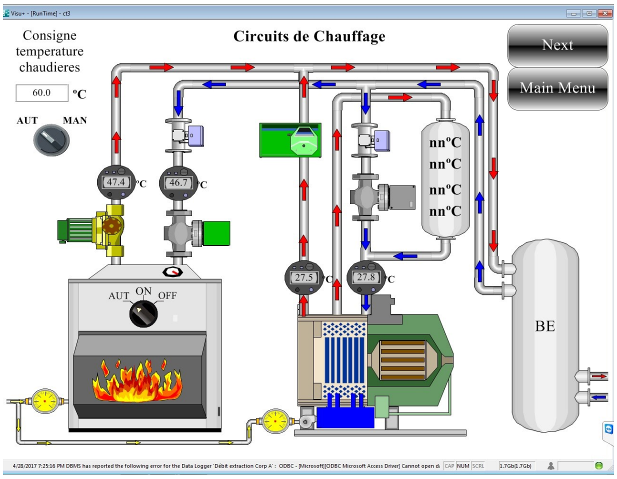


Fig. 10. GYM boiler plant – heat source and cogeneration

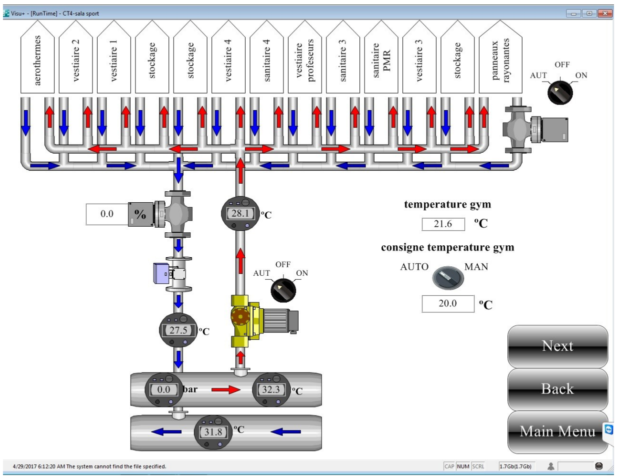


Fig. 11. GYM boiler plant – manifolds for radiators, heater batterie, radiant panels

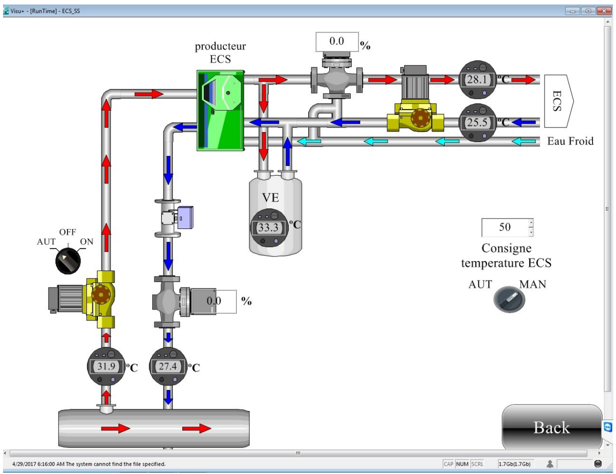


Fig. 12. GYM boiler plant – domestic hot water

3.3 Ventilation system

The ventilation of the school premises is ensured by a very high efficiency double flow unit installed in each class. Thanks to the air quality CO_2 sensors, the flow of the ventilation system is permanently controlled according to the occupancy. The design of the ventilation system was made in accordance to the

Belgian standards [4-9]. Figure 13 displays the building C circle ventilated rooms.

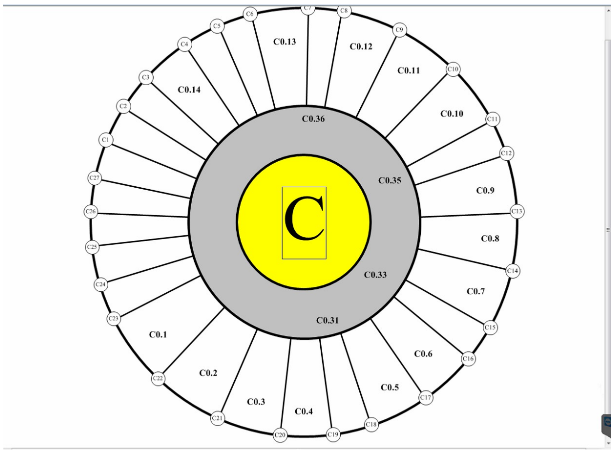


Fig. 13. Ventilation building C – display of rooms

3.3.1 Classroom model

Due to the large amount of natural lighting, the majority of classes will be able to do without artificial lighting during class hours. Triple glazing windows will be combined with a fourth integrated sunshade to prevent overheating in the summer. No active cooling system is needed to control overheating. Figure 14 shows an image from the construction phase of the building in the left, while on the right a classroom model is displayed with the air handling unit piping system. The building heating and ventilation systems parameters are monitored (Fig. 15 and Fig. 16).

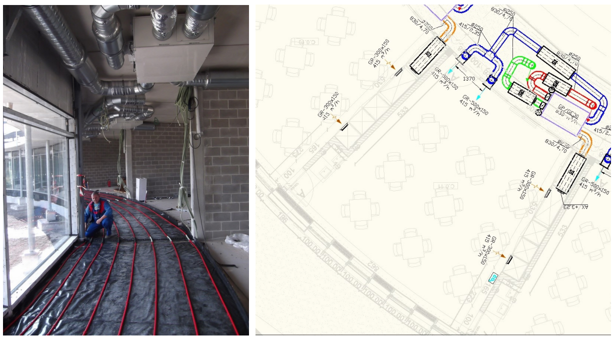


Fig. 14. Example of model classroom (C.0.11) AHU installed

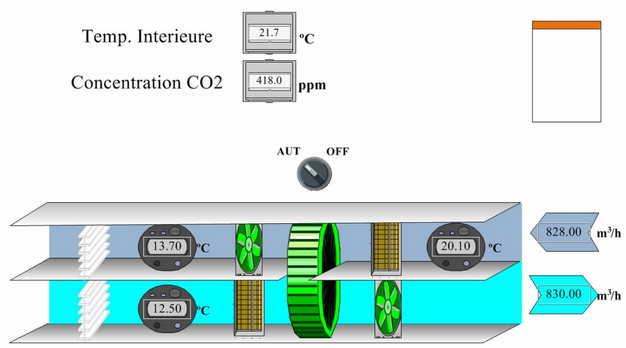


Fig. 15. Model classroom (C.0.11) AHU monitoring

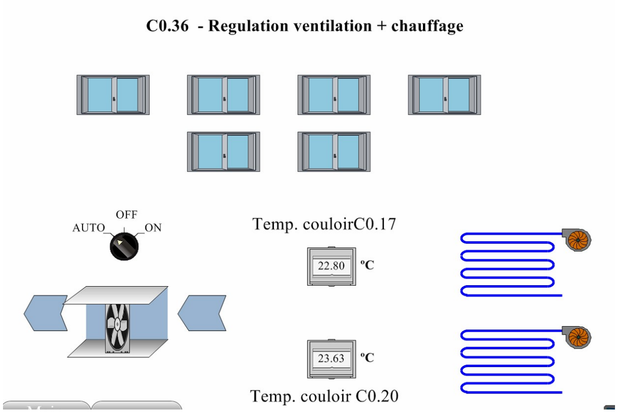


Fig. 16. Monitoring of heating and ventilation

Indeed, a system of free cooling and night cooling via double flow and natural ventilation is integrated into the buildings. In winter, however, solar gains reduce the heat load. Monitoring makes it possible to check and make sure that the building functions according to its original design. These measures make it possible, in addition to the GTC (centralized technical management), to monitor indicators of energy and water consumption, thus avoiding any drift.

4 Building monitoring and management system

The figure above sets the premises with all the consigned: corridor temperature (20 °C), 2 temperature values for corridor free cooling (26 °C and 30 °C), minumum vetilation flow 50% and maximum CO_2 sensor setting, in relation to the outside temperature (13.5 °C).

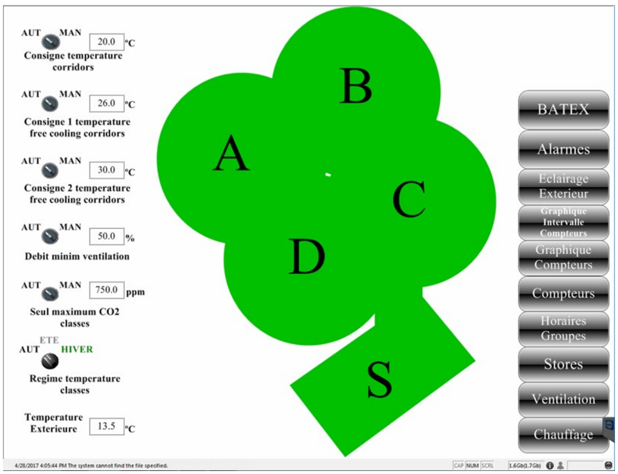


Fig. 17. Heating and ventilation control parameters

The BMS basement integrates via m-bus interface the following energy meters:

- ✓ gas (w01);
- ✓ hot water supplied by boilers (w12);
- ✓ thermal energy meter used by groups of ventilation (w04);

- ✓ meter for thermal energy of central heating radiators (w03);
- ✓ meter hot sanitary school (w05);
- ✓ counter of all switchboard;

4.1 Boiler integration

Every boiler is equipped with a managing controler:
- a control aquastat
- a security thermostat
- a pressure switch
- a flow switch
- the burner
- the temperature sensors
- the pump

The temperature of primary fluid varies between 30 °C - 60 °C influenced by the outside temperature. The automation panel DDC in the basement is responsible for service or boiler shut down. Before the burner starts operating, the gate on / off valve opens and the corresponding pump starts operating. Through lack of pressure in the installation, a pressure switch cuts the functioning of the burner, a red lamp signals this. The circulating pumps have an adaptable time delay via the local regulator.

4.2 Collector

The temperature from circuits is individually regulated by a 2 way gate valve, ordered via DDC basement panel, by an outside sensor (station weather forecast). Circuits can work, either in normal paces, or in decelerated paces, or in speeded up paces. The passage from one to the other is automatically done by a clock with daily and weekly cycle. The heating pumps stop when all conditions are satisfied, with a time delay from 5 to10 minutes.

4.3 Zoning valves

On/off valves are also used for every zone of the building to regulate the installation according to needs. Every valve can be more ordered by an independent hourly program to fit in with BMS and coupled with the optimiser.

4.4 Domestic hot water

The domestic hot water boiler functions autonomously. The basement DDC panel controls the circulator via MosBus and the 3 way regulating valve according to the temperature supply / return sensors.

4.5 Ventilation groups

Cafeteria: the operation of ventilation units is dependent on a schedule. The group works in full fresh air supply. The supply temperature of 20 ° C is kept constant by acting via the local controller on the heating valve and via the flow valve on the supply manifold. The fresh air intake register closes when the group stops. The unit is started by opening the damper. The recovery battery is by-passed if the free cooling conditions allow it. The condition of the air filters is controlled by measuring the pressure loss. The temperature of the supply air is read by both the local controller and the BMS. If the GP / GE-1's heating coil is not enough, 2 post-heater batteries are controlled by the DDC panel by acting on the 2-way valves.

Classrooms, offices, teachers' room: the operation of the ventilation units is dependent on a time program and an integrated control of ventilation groups with ModBus interface to the local building BMS. The group works in all fresh and variable air depending on an air quality sensor and temperature in the room. The local controller reads the temperature sensor and CO2 and controls the analog input of the ventilation unit accordingly. The fresh air intake register closes when the unit is shut down. The start of the group is done by opening the register. The recovery battery is by-passed if the conditions of free cooling or nightcooling allow. In this case, the fan unit operates at a nominal flow rate. The condition of the air filters is also monitored by measuring the pressure loss. The fouling threshold is indicated by a warning light and a report of the status to the BMS.

Terminal control cafeteria the cafeteria management includes for each zone:

· An atmosphere probe.
· A probe of air quality.
· Valve regulation VAV
· A transmitter of air
· A smoke detector

4.6. Regulation Free cooling - Night Cooling

During summer, by free cooling ventilation day and night cooling is done automatically: energy recovery battery is bypassed 100% and the windows of the corridors will open automatically by the SDC and the local controllers. During the night cooling, the point of air flow of ventilation groups, as well as extractors intended for this purpose, is brought to its maximum capacity. For corridors, the principle of free cooling and cooling night is this:

Step 1: If a first threshold temperature is reached, the opening of windows opening is controlled

Step 2: If a second temperature threshold is reached, the Group extraction at the level of the health are provisioned until where the descent below the temperature 1 temperature. Each Corridor has its independent regulation which includes: A temperature ambient. probe For each window opening control modules. In the case of free cooling, the planned extractors will be piloted by probes of temperatures throughout the corridors.

4.7. Store Regulation

Control functions are the following:
•local control by motor or several motors in the same room;
•each service of a floor;
•automatic control order by area depending on the conditions of luminosity (Sun) and wind for 8 or 16 climate zones.
•function 'wind protection' (value and delay) configurable per area. In case the wind exceeds a given value and after the delay of onset of wind, all the blinds in the building will be back in the position required by the light conditions. These blinds will remain blocked until the wind speed will remain above this value or the disappearance of the wind delay will not be completed (ex 12 or 15 min).
•the 'Sun control' function is customizable for each of the planned climate zones. The thresholds of appearance and disappearance as well as timers can be programmed for each of these areas. The Sun function ensures the descent of the blinds and the rise in intermediate positions, defined by a % of descent (e.g. 80% or 100%) and an inclination of the store.
•central control priority to rise based on alarm 'fire' and a lock for 'window cleaner'
•'Weather station': the weather station consists of 4 solar cells, an anemometer and a temperature sensor. The interface allows the management of 8 solar cells, 2 anemometers, to a direction indicator of wind, rain and a temperature probe detector.

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10.

Recovery of waste heat from the sewer system

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Abstract. In the first part of my article I would like to introduce the possibilities of the recovery of waste heat from the sewer system and react to the answer of minimalism of the demand of energy needed for the preparation of domestic hot water. The recovery of waste heat from the sewer system outside of building is possible using a heat pump in combination of heat exchanger located in sewerage and the recovery of waste heat of sewer system inside of building is possible using a heat from waste water through a heat exchanger to direct preheating of cold water.

The second part is dedicated to design of alternative solutions of the recovery of waste heat from the sewer system in the object of multifunction sports facility which include complete project documentation of the sport complex with application of heat exchanger to direct preheating of cold water in shower. The efficiency of regenerative systems and the saving of hot water was determined thanks to the experimental observation executed under laboratory conditions.

The main point of this article is to introduce the possibilities of the recovery of waste heat from sewer system, apply them in the object of multifunction sport complex and review the energy and economic efficiency.

1. Introduction

Nowadays, more and more energy is consumed in dwelling houses - energy is used for preparing hot water, heating and cooling of the building and energy became very valuable. The energy consumption for heating and cooling decreases due to thermal insulation of the building constructions and replacement of the windows of the building to new plastic windows with triple glazing, while the energy consumption for preparing hot water is constantly increasing. How can we reduce the energy needed to heat the drinking water? One option is recuperation. We are able to recover waste heat from the sewer system to preheat domestic hot water using a heat exchangers. Heat from wastewater can be optimally used for heating, cooling and hot water preparation in low-energy houses.

2. Recovery of waste heat from the sewer system outside of the building

Waste water drained from different types of buildings is full of unused thermal energy. When using heat recovery from the sewer system outside of building, systems consist of two main parts: heat exchanger and heat pump. Heat exchanger extract the thermal energy from the sewage and transfers it to the heat pump, which supplies the building with this energy.

Heat exchanger is installed at the bottom of the drain pipe which is a connecting element between the waste water and heat pump (figure 1). Heat pumps use the energy contained in the wastewater as source of energy. Heat energy is taken through the heat exchanger and is transferred to the circulated heat transfer medium called refrigerant – water or a mixture of water and glycol. Heat pumps exploit the physical properties of the refrigerant - it compresses the refrigerant to make it hotter.

The low-pressure liquid refrigerant (waste water with temperature 6-14 °C) enters the heat exchanger - evaporator, in which the fluid (water or mixture of water and glycol) absorbs heat and boils and transfers to a gaseous state. The working fluid, in its gaseous state, is pressurized and circulated through the system by a compressor. On the discharge side of the compressor, the currently hot and highly pressurized vapor is cooled in a heat exchanger - condenser, until it condenses into a high pressure, moderate temperature liquid. The condensed refrigerant then passes through a pressure-lowering device also called a metering device. The refrigerant then returns to the compressor and the cycle is repeated, see the Figure 1. [1].

Factors for the design and application of heat recovery systems are the distance between the consuming system and the place of heat recovery (should be as short as possible); constant temperature of the wastewater, as possible; diameter of sewage pipe (at least 800 mm); flow of wastewater; flow rate of wastewater) should be as high as possible, at least 15 l/s). These conditions are usually met in municipalities of over 10,000 inhabitants or a group of residential buildings, swimming pools, administrative or industrial building are also suitable [1].

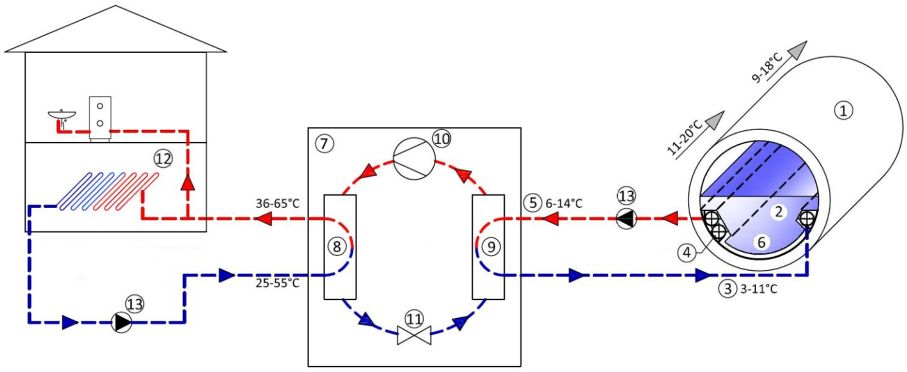

Fig. 1. Circuit layout of heat exchanger embedded in sewage pipe in combination with heat pump [2].

1 - sewage pipeline, 2 – waste water, 3 - cold water supply to the heat exchanger, 4 – pipe for collection of heated water from many heat exchangers if the system Tichelmann is used, 5 - output of the heated water from the heat exchanger, 6 - heat exchanger, 7 - heat pump, 8 - condenser, 9 - evaporator, 10 - compressor, 11 - expansion valve, 12 - heating network in building, 13 - circulating pump

Disposition and design of heat exchangers (Fig. 2) is based on various requirements and the suitability of the sewage network itself.
Heat exchangers (outside the building) are classified according to the structure and location of the:
• heat exchangers embedded in sewage pipe,
• heat exchanger integrated in concrete wall of a sewage pipe,
• sewage pipe with special double jacket

Design of heat exchangers depends on different requirements and on suitability of sewage system itself. Heat exchangers can be installed into existing or new pipelines. It can be used for all kinds of waste water [1].

a)

b)

c)

Fig. 2. Types of heat exchangers for recovery of waste heat from the sewer outside of the building [3,4]

a) stainless steel heat exchanger embedded in the bottom of the sewage pipeline, b) heat exchanger integrated in concrete wall of a sewage pipe, c) sewage pipe with special double jacket

Heat exchangers could be used both in new or in existing pipelines. The advantage of heat exchangers integrated in concrete wall is that the heat exchanger does not detract from the diameter of pipe.

3. Recovery of waste heat from the sewer system inside of the building

Buildings, where is a constant flow rate of waste water and significant amount of it is being drained away, are suitable for heat recovery directly inside them [1]. In this case, it is very convenient to use the heat from the sewage for preheating hot water for immediate consumption. System of the recovery of waste heat from sewage inside of building are based on heat exchangers, which serves to exchange the heat energy between the waste water and the domestic cold water. There is no contact between the water supply and the drain water.

Figure 3 shows the fundamental principle of system of recovery of waste heat from sewage inside of building to direct preheating of domestic hot water. Waste water from the shower with a temperature 38 °C is drained into the sewerage through the heat exchanger. The cold water with the initial temperature 10 °C flows through the heat exchanger, in the opposite direction of the drainage water, and is transported into the thermostatic mixer shower tap via this heat exchanger.

Wastewater transfers the heat through heat exchanger to the cold water to preheat it – cold water can reach a temperature approximately 20 °C. The result is, that we mix a smaller portion of hot water with a larger portion of preheated water for reduce the hot water consumption.

The recovery of waste heat to direct preheat of hot water is recommended for sanitary appliances where the need for hot water exceeds the need for cold water – showers and wash basins. In the case of bath tubs, this principle does not work because the hot water is swallowed at another time as it flows. This type of recuperation is not suitable for kitchen sink because the wastewater contains oils which can settle on the wall of the heat exchanger and thus reduce its effectiveness.

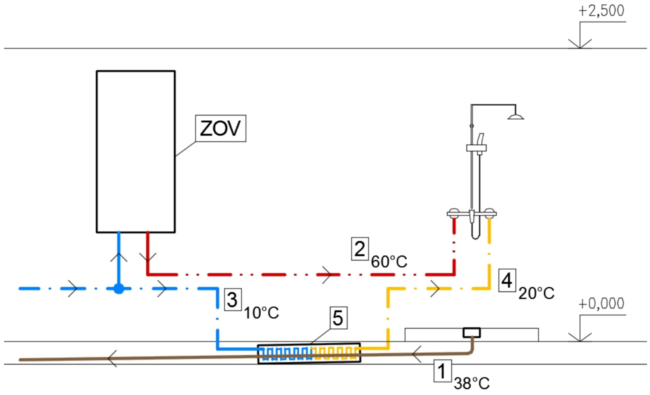

Fig. 3. Cold water preheated for immediate consumption through heat exchanger [5]

1 – waste water drained from the shower (38 °C), 2 – hot water supply from the storage water heater (60 °C), 3 – cold water supply to the heat exchanger (10 °C), 4 – preheated cold water supply to the shower thermostatic mixer tap (20 °C), 5 – heat exchanger, ZOV – storage water heater

Heat exchangers could be installed in a several ways, depending on the type of building, the water requirement in the building or the disposition of the bathroom. The heat exchanger should always be installed as close as possible to the sanitary appliance from which waste heat will be used (shower, washbasin, etc.).

a) direct connection of the heat exchanger to one sanitary appliance (shower):

Figure 4 shows a direct connection of the heat exchanger to one sanitary appliance (shower). Preheated cold water is fed into a thermostatic mixer shower tap, which reduces the hot water consumption. The connection could be comfortably used for showers in flats, family houses, hotels, sanitary equipment of sport facilities, swimming pools, or showers in industrial halls.

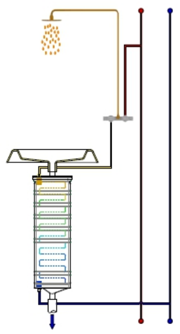

Fig. 4. Direct connection of the heat exchanger to one sanitary appliance (shower) [6]

b) direct connection of the heat exchanger to several sanitary appliances:

Figure 5 shows direct connection of the heat exchanger to several sanitary appliances – one shower and two wash basins. The wastewater drained from the shower and washbasins flows through one common heat exchanger into the sewerage. The preheated water is supplied into the thermostatic mixer tap of the shower and also into the mixer taps of wash basins (Figure 5).

This connection could be used in dwelling houses or apartment flats to direct preheating of the domestic cold water for a sanitary equipment in the bathroom (e.g. a shower and washabsin). Even though this system installation is one of the useful alternatives, for washbasins preheat water to a temperature above 20 °C I do not recommend from the point of view of hygiene of potable water, and the washing times are too low for this system to be effective.

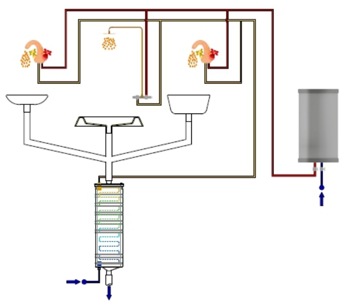

Fig. 5. Direct connection of the heat exchanger to several sanitary appliances (shower and two wash basins) [6]

c) combined connection of the heat exchanger with a storage water heater:

Figure 6 shows a combined connection of the heat exchanger with a storage water heater. The preheated cold water is not only transported into the thermostatic mixture tap but is also transported to the storage water heater which serves to save energy needed for preparation of hot water. This connection could be used in every operation of sanitary equipment where the hot water is prepared locally using a storage water heater.

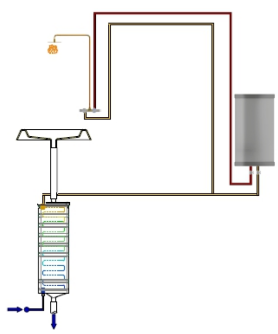

Fig. 6. Combined connection of the heat exchanger with a storage water heater [6]

d) direct parallel connection of the heat exchanger to several sanitary appliances (several showers):

Figure 7 shows a direct parallel connection of the heat exchangers to several sanitary appliances (several showers) which is used in mass showers in objects such as swimming pools, sports facilities, industrial facilities, etc. Sewage from many showers flows into the sewerage through one common sewer pipe into many heat exchangers. With this type of installation, as many heat exchangers are installed as many sanitary appliances there are - heat transfer is more efficient.

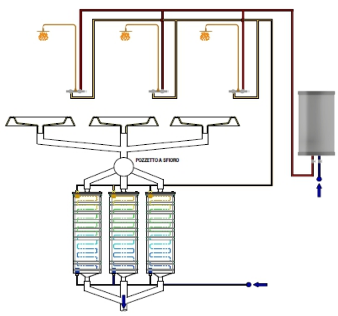

Fig. 7. Direct parallel connection of the heat exchangers to several sanitary appliances – showers [6]

4. Types of heat exchangers for recuperation of waste heat from the internal sewerage system

Several types of heat exchangers for recuperation from the internal sewerage systems are known - special shower trays with integrated heat exchanger [7] (see chapter 4.1), heat exchanger in combination with a shower with floor drain system [9] (see chapter 4.3), wastewater storage tank with integrated heat exchanger, regenerative panels with stainless steel heat exchanger [6] (see chapter 4.4), etc. In the rest of this article I would like to introduce alternative solutions of the recovery of waste heat from the sewer system which I applied in the object of a sport facility.

4.1 Shower tray with integrated heat exchanger

In this case, the recuperation system consists of a special shower tray below which heat exchanger is integrated (Fig. 8). Heat exchanger is placed under a shower tray, normal height of shower tray is maintained. The waste water flows across a spherical copper shell from the centre to the outside, underneath the shell copper pipes are connected to the shell. The fresh water flows through these pipes and is thereby preheated and this preheated cold water is supplied to the water heater or / and the shower mixer tap. There is a trap in the centre of the heat exchanger which prevents smells or vapour entering the bathroom. The heat exchanger has a double wall separation between sewage and potable water. Combining the heat exchanger with copper or multilayer water pipes is recommended. This kind of heat exchangers is recommended to dwelling houses, apartments, hotels, nursing homes, swimming pools, hospitals, industrial applications, gyms, etc.

The energy efficiency depends on the flow of water, and is around 41 %. Efficiency can decrease as a result of dirt accumulating on the inside of the heat exchanger. The surface of the heat exchanger, the dish, can become slightly fouled. It only takes a couple of minutes, once or twice a year to clean the surface using a brush [7].

Fig. 8. Shower tray with integrated heat exchanger [7]

4.2 Heat exchanger in the form of regenerative panel placed under the shower tray

Recuperative panels are designed to recover energy from waste water from the shower. This panel has a plastic casing and the heat exchanger is made of a copper in the form of a spiral (Fig. 9). The efficiency of these heat exchangers is approximately 30%. The wastewater flows around the heat exchanger. Cold water is supplied to the thermostatic shower mixer through this heat exchanger. The heat extracted from the waste water through the heat exchanger is supplied to the cold water in order to preheat it [8].

Fig. 9. Heat exchanger in the form of regenerative panel placed under the shower tray [8]

The efficiency of this type of heat exchanger depends on the shower flow rate of water – at the flow of 5,8 l/min the efficiency is 36,6 % and at the flow of 12,5 l/min the efficiency is 27,9%.

The design of this water heater allows to minimize Legionella-related risks, as follows:

- The unit has no dead spaces and is subject to high flow rates which prevents water from stagnation.
- Drain water never stays a long time inside of the unit since its construction guarantees that it is fully drained out at the end of the shower.
- After a shower, fresh water cools down below 25°C,
- Copper coil itself contributes to reducing Legionella-related risks.

The maintenance of a heat exchanger is very – this device must be installed with a shower drain filter and trap to prevent the passage of debris. Like any other drain pipe, is strongly recommended a periodically cleaning [8].

4.3 Heat exchanger in combination with a shower with floor drain system

This recuperative panel in combination with the shower with floor drain system (Fig. 10) offers a compact and efficient solution for heat recovery from wastewater inside of building. Waste water passes through a heat exchanger which is a double walled stainless steel heat exchanger in the form of a spiral. The energy efficiency depends on the flow of water The reported efficiency of these heat exchangers depend on the shower flow rate - at the flow of 9 liters/min the efficiency is 38,9 % and at the flow of 11 liters/min the efficiency is 38,6% [9].

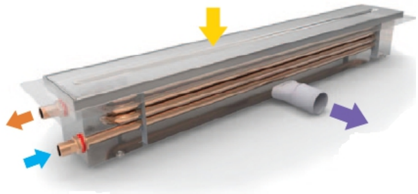

Fig. 10. Waste water heat recovery system for showers with floor drain system [9]

The maintenance required for the heat exchanger is very minimal, however, it is recommended to clean the unit periodically to avoid any reduction in efficiency. This cleaning will remove any build - up of soap and dirt residue on the inside of the copper pipe where the waste water passes [9].

4.4 Regenerative panels with stainless steel heat exchanger

Regenerative panel consists of a plastic waterproof case and a stainless steel heat exchanger (Fig. 11). The heat exchanger is placed as close to sanitary equipment as possible. Through the heat exchanger to sanitary equipment cold water (10 °C) is transported to the thermostatic shower mixer tap. Heat from wastewater is transferred to cold water to preheat it. The regenerative panel is available in two versions –630 mm long version and 1320 mm long version. [6].

Fig. 11. Regenerative panel with stainless steel heat exchanger [6]

The energy efficiency greatly depends on the the temperature of hot water at the output of water heater and the type of installation. If the preheated water out of the heat exchanger is sent both to the mixer and to the water heater, the energy savings are at the maximum. In this case, if the heat exchanger is placed at some distance from the drain point, a certain loss of heat from the pipes must be taken into consideration. If we use direct connection of the heat exchanger to one sanitary appliance, there is the advantage of a very short connection and therefore minimizes any heat losses.

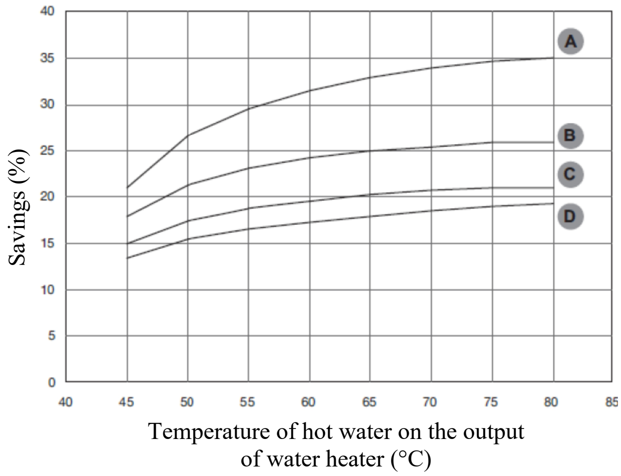

Fig. 12. Saving of energy according to the temperature of hot water at the output of water heater for different flow rates [6]
A – flow rate of hot water in the shower 4 l/min
B – flow rate of hot water in the shower 8 l/min
C – flow rate of hot water in the shower 12 l/min
D – flow rate of hot water in the shower 16 l/min

5. Alternative solutions of recovery of waste heat from sewer system inside of building

In the project documentation of multifunction sports facility I consider the sanitary equipment using recovery of waste heat from sewage from showers. I propose alternative solutions for the use of waste heat from internal sewerage as follows:

<u>**a)** recuperation using a shower trays with an integrated circular heat exchanger</u> through which the waste water flows. The cold water (10 °C) supply into the shower tray from the bottom of the heat exchanger. At the bottom of the heat exchanger there is a drainage of cooled wastewater. Preheated cold water (20 °C) is transported from the shower tray to the wall-mounted thermostatic shower mixer through the heat exchanger. The temperature 20°C of preheated cold water was experimentally observed.

In the Figure 13 we can see a floor plan of the sports facility, where the heat recovery is solved using a shower trays with an integrated circular heat exchanger through which the wastewater flows.

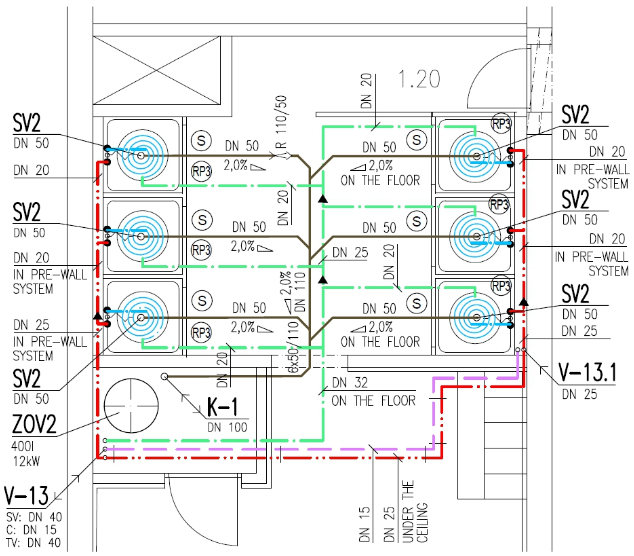

Fig. 13. Floor plan with alternative solution of recovery of waste heat using a shower tray with integrated heat exchanger

V – rising pipe of cold water, hot water and circulation of hot water, K – foul water stack, ZOV – water heater, SV2 – squared shower tray with drain in the middle, RP3 – shower tray with integrated heat exchanger, S – wall-mounted thermostatic shower mixer

b) recuperation using a heat exchanger in the form of regenerative panel placed under the shower trays.

Figure 14 shows a floor plan of the sports facility, where the heat recovery is solved using a heat exchanger in the form of regenerative panel placed under the shower trays, in the floor. The wastewater will be drained from the shower tray through the regenerative panel and the cold water flows through the heat exchanger.

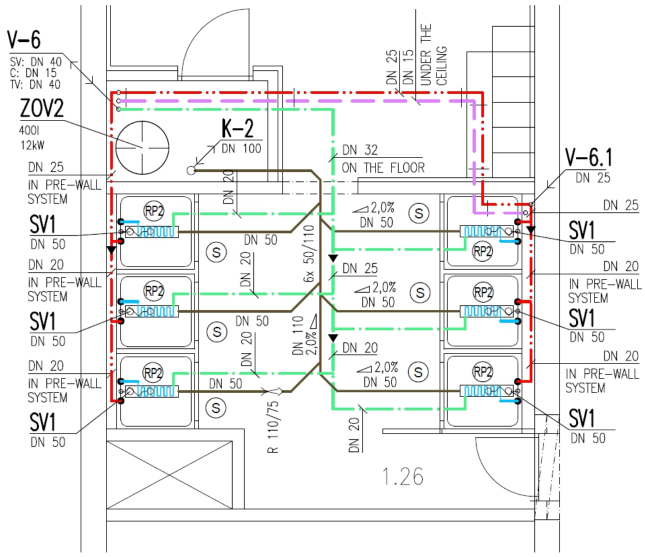

Fig. 14. Floor plan with alternative solution of recovery of waste heat using a heat exchanger placed under the shower tray

V – rising pipe of cold water, hot water and circulation of hot water, K – foul water stack, ZOV – water heater, SV1 – squared shower tray with drain up, in the middle, RP2 – heat exchanger-regenerative panel placed under the shower tray, S – thermostatic shower mixture tap

c) recuperation using the with regenerative panel with stainless steel heat exchanger placed in the floor, close by the shower. I propose to drain the sewage water from the shower tray through the branch pipe situated in the floor via the regenerative panel. The cold water with the initial temperature 10 °C flows through the heat exchanger in the opposite direction of the drainage water and is transported into the thermostatic mixer shower tap as a preheated water with temperature approximately 20 °C. It is recommended that preheated cold water pipe and the regenerative panel are thermally insulated. The temperature 20°C of preheated cold water was experimentally observed.

In the Figure 15 is shown a floor plan of the sports facility, where the heat recovery is solved using the regenerative panel with stainless steel heat exchanger placed in the floor, close by the shower. I propose a direct connection of the heat exchanger with length of 613 mm to one sanitary appliance, shower, and a direct connection of the heat exchanger with a length of 1319 mm to two sanitary appliances – two showers.

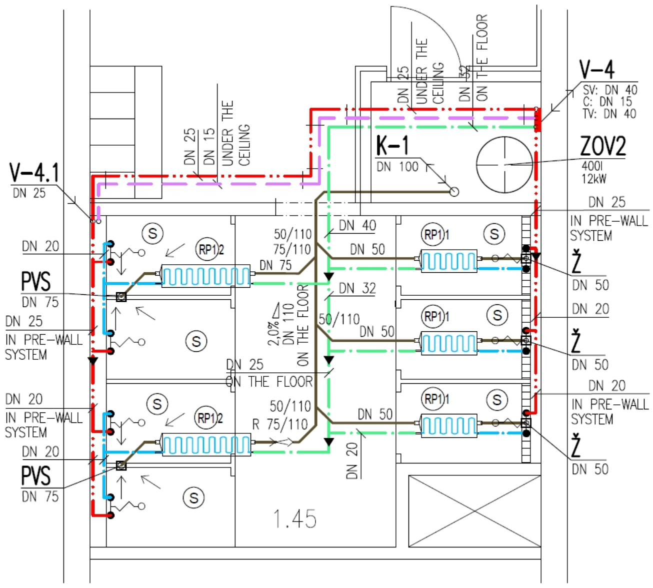

Fig. 15. Floor plan with alternative solution of recovery of waste heat using a panel with stainless steel heat exchanger

V – rising pipe of cold water, hot water and circulation of hot water, K – foul water stack, ZOV – water heater, PVS – shower floor drain, RP1 –regenerative panel with stainless steel heat exchanger: RP1.1 – length of the panel 613 mm, RP1.2 – length of the panel 1319 mm

cold water (10 °C)
preheated cold water (20 °C)*
hot water (50 °C)
foul water (38 °C)
circulation of hot water (55 °C)

*The temperature 20°C of preheated cold water was experimentally observed.

Figure 16 shows the recuperation using regenerative panels with stainless steel heat exchanger with a direct parallel connection of the regenerative panels. Parallel connection I propose for three showers - I propose installing three heat exchangers through which cold water will be supplied for three thermostatic shower mixers and to a water heater.

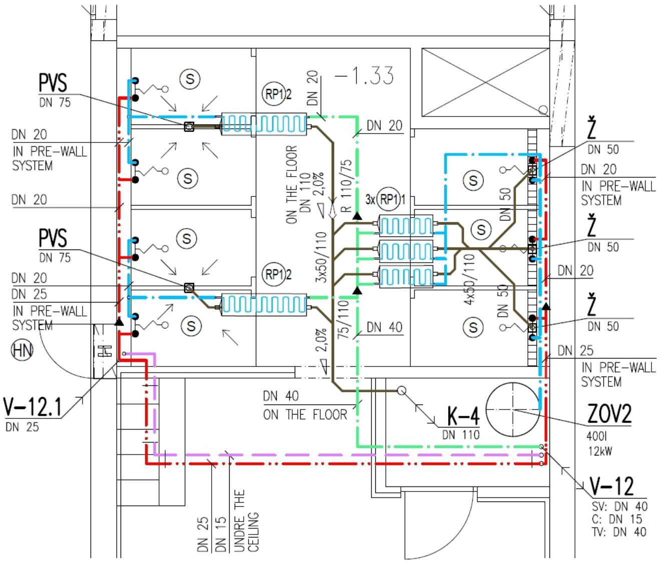

Fig. 16. Floor plan with alternative solution of recovery of waste heat using direct parallel connection of panels

V – rising pipe of cold water, hot water and circulation of hot water, K – foul water stack, ZOV – water heater, PVS – shower floor drain, RP1 –regenerative panel with stainless steel heat exchanger placed in the floor: RP1.1 – length of panel 613 mm, RP1.2 – length of panel 1319 mm

cold water (10 °C)
preheated cold water (20 °C)
hot water (50 °C)
foul water (38 °C)
circulation of hot water (55 °C)

6. Evaluation of the system of recovery of waste heat from the energetic and economic point of view

The last part of my article is dedicated to experimental observation of the system of recovery of waste heat from the sewer system inside of the building.

The energy evaluation of this system is based on the results of the experimental observation carried out in the laboratory of the Department of Building Services in The Faculty of Civil Engineering. The purpose of the experimental observation was to calculate the energy savings and payback period of heat exchanger. In this observation regenerative panel with stainless steel heat exchanger was used [6].

Technical equipment installed in the laboratory:

In the laboratory there was only potable cold water supply installed. For the experimental observation was necessary to provide water heater as a source of heat needed for hot water preparation. Electrical water heater with a capacity of 100 liters was installed in the laboratory.

As the pressure conditions in the system of water supply were insufficient, it was necessary to increase the pressure using water pressurization system – compact electronically controlled home waterworks was installed in order to provide the required pressure.

The measured values were:

- Temperature of hot water
- Temperature of cold water
- Temperature of mixed water
- Temperature of waste water
- Temperature of preheated cold water
- Flow of hot water
- Flow of mixed water

The experimental model was based on a direct connection of the regenerative panel to one shower. Experimental model was installed in order to shower could be started with recovery of waste heat and without recovery, because we wanted to compare measured values of both cases. On the cold water route there are bypasses installed with shut-off valves which allowed measurements to be made for both recovery and non-recovery system (Figure 17).

The hot water consumption was measured during a shower with recovery of waste heat and without a heat recovery, values were compared and the evaluation of system of recovery of waste heat was made.

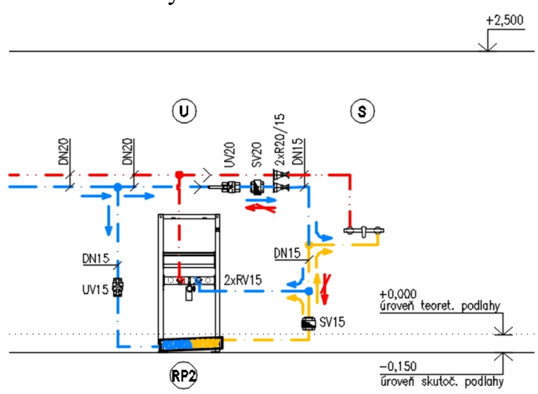

Fig. 17. Detail of connection of heat exchanger with bypass of cold water

S – wall-mounted thermostatic shower mixer, U – wall-mounted thermostatic washbasin mixer, RP2 – heat exchanger in the form of regenerative panel placed in the floor of laboratory, UV – shut-off valve, SV – backflow prevent

cold water (10 °C)
preheated cold water (20 °C)*
hot water (50 °C)

*The temperature 20°C of preheated cold water was experimentally observed.

For the purpose of the evaluation of system of recovery of waste heat I chose the object of a sports facility. The input data for evaluation were as follows:

- operating hours of the object of sports facility: 12 hours per day, 350 days a year
- is considered one shower per hour
- duration of one shower: 5 minutes
- totally 4,200 showers per year on one shower with one heat exchanger

Shower without recovery of waste water:
- hot water flow: 5.71 l/min
- hot water consumed per 5-minute shower: 28.55 liters

Shower with recovery of waste water:
- hot water flow: 4,407 l/min
- hot water consumed per 5-minute shower: 23.70 liters

The total hot water savings were approximately 5 liters per one shower.

With these data obtained in experimental measurement was possible to calculate the cost of shower with and without recuperation - it was considered preparation hot water using electrical water heater and gas water heater. First I calculate the power consumption – energy needed for heating a cold water and I multiply the energy needed for heat by the price of every type of energy (electricity and gas) – I obtained the price of one shower. I consider totally 4,200 showers per year on one shower with one heat exchanger – prices for one year showering with recuperation and without recuperation was determined.

When comparing prices for showering with and without recuperation, we can calculate the annual savings for each type of energy (Fig. 18):

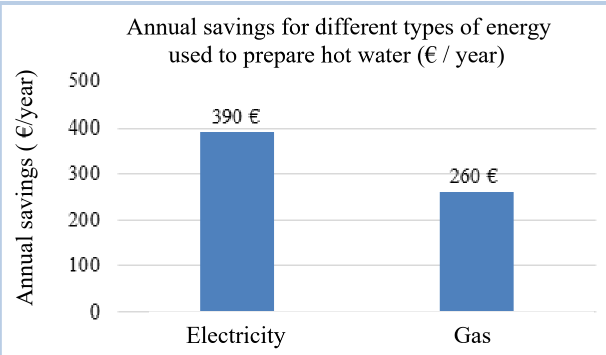

Fig. 18. Annual savings for each type of energy used to prepare hot water

The payback period of installed regenerative panel with stainless steel heat exchanger to one shower is 1.5 years when electricity is used for preparation of hot water and for using gas, the payback period is 2 years and 4 months.

7. Conclusion

The aim of this article was to introduce different possibilities of using heat from external and internal sewerage systems and answer to the question about reducing the need of energy for preparation hot water. Recovery of waste heat from sewer systems outside of building is applied in municipalities over 10,000 inhabitants, in order to ensure sufficient flow. Suitable consumers are building complexes of several buildings near the source of heat.

Heat recovery from sewerage systems inside of the buildings could be applied in dwelling houses and apartment flats, in sports facilities, swimming pools or factories and the advantage of these systems is that, in addition to their simplicity and price, there is no need for electricity to operate them.

In the paper I presented various ways and alternative solutions by using recuperation, the options of recovery of waste heat from sewerage systems are many and these systems can also be applied in our conditions. Sewage water discharged from dwelling houses, residential, administrative, sports or other buildings is full of unused energy and presents a low-potential renewable source of energy that can be used to prepare hot water or heating and cooling the building.

Acknowledgement

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Mapping digital transformation in building performance assessment and management – commercial activities for the operation phase

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Abstract. Having in mind both the possibilities (e.g. automatic analysis of complex data to increase building performance and automation of difficult/dangerous/repetitive traditionally human tasks using machine learning/data mining/artificial intelligence and sensors) and challenges (e.g. regarding: privacy, security, safety), the main aim is developing an approach to structure the various commercial activities, for the time being in a non-comprehensive manner, related to the digital transformation of the built environment and assess the current state of technology in terms of products, services and solutions.

1 Introduction

By the year 2020, an entire generation, Generation C (for “connected”), will have grown up in a primarily digital world. Computers, the internet, mobile phones, social networking — all are second nature to members of this group. The effects of an increasingly digitized world are now reaching into every corner of our lives. [1]

Buildings make no exception. The futuristic perceived concept of smart buildings is already a reality today in many buildings across the globe and is creating new experiences for building operators and occupants alike. The maturity of state-of-the-art hardware and software finally allows researchers and industry to pilot and implement working solutions for real-world and large-scale contexts. The available and rapidly emerging new digital technologies are also enabling to assess in real-time, inter-relate and visualize/ communicate to stakeholders crucial aspects of overall building performance, including indoor environmental quality, performance aspects relating to user satisfaction, and well-being and (where applicable) productivity, resource-efficiency, compliance with specifications and contractual requirements, profitability, certification levels, and – ultimately – market value.

In a natural or forced response the industry landscape [2,3] is reshaping and traditional manufacturers are shifting their businesses. Moreover, technology companies are entering the buildings market as new players and are apparently having a disruptive effect in terms of technology being installed and used in buildings. EU policy is also undergoing a similar response. For example the revised Energy Performance of Buildings Directive (EPBD) [4] introduces provisions on automated Technical Building Systems inspections and a new tool the Smart Readiness Indicator (SRI) [5].

In terms of research there is a lot happening in this field. This point can be easily illustrated just by looking at how Europe’s Horizon 2020 framework programme alone is supporting research, innovation and market uptake of smart buildings, although this frequently used term is ill-defined [6]. The searching and mapping of EU projects was carried out during April and early May 2017. The final results of the research [7] have found 42 relevant Horizon 2020 actions, funded across 28 topics, the majority of which are Research and Innovation Actions (RIA) and Innovation Actions (IA). The total budget costs for these 42 actions add up to 367.9 million Euros, of which the EU grant contribution is 304.1 million Euros.

The authors of this paper identified the need to focus on commercial activities available today on the market owing to the following reasons:

- The diverse plethora of ongoing research activities most often remain disaggregated and thus uncaptured in comprehensive reviews;
- Too often in research activities the touch with reality is lost;
- Actual building performance is experienced by building operators and occupants alike and not the designed building performance.

With the above backdrop and arguments in mind the authors laid down the foundation for the mapping of products, services or solutions available today on the market, that have long passed the research phase and are continuously being improved based on “testing” by users in real life conditions.

2 Methods

In this paper, the terms digitization, digitalization and digital transformation are used as follows:

- Digitization as the process of making information available and accessible in digital format;
- Digitalization as the process of considering how to best apply digitized information to simplify specific operations;
- Digital transformation as the process of devising new business applications that integrate all the digitized data and digitalized applications) [8].

Although, the authors cover mostly digital transformation at times there is an expected overlap with digitalization.

The main scope of this paper is to capture two out of three key functionalities of the Smart Readiness Indicator [9], introduced in the revised EPBD [4], on one hand the readiness to adapt in response to occupant needs and on the other hand the readiness to facilitate maintenance and efficient operation. The third key functionality, the readiness to adapt in response to energy grids, shall be included in future papers. Even though, the SRI is a political instrument and digital transformation in buildings has a much wider scope than EPBD’s technical building systems, the SRI will presumably act as a driver in the market, making it much more than just a political tool, similar to Energy Performance Certificates (EPCs), inspections and nearly Zero Energy Buildings (nZEBs).

In doing so, the authors focus on the operation phase of buildings for the purpose of this non-comprehensive mapping of current commercial activities related to the built environment and linked to the next phase in the digital revolution [10].

For ensuring a simple and easy to understand overview the authors propose a structured approach. The selected products, systems or solutions are displayed in a multidimensional array: aim of product, service or solution ↔ data source ↔ data science discipline. The considered data science disciplines are statistics, visualisations, patter recognition, data mining, machine learning, artificial intelligence (see **Fig. 1**).

All products, services or solutions included in this paper have been collected by the authors via internet research and include only publicly available information. There have been no enquiries of the organisations offering the products, services or solutions.

Although, it is obvious that moving from products and services to solutions implies a shift from features and benefits to value and that solutions integrate different products and services, for the purpose of this paper the three types of business offering remain aggregated. This is largely due to the fact that most often these offerings overlap and setting them apart is a challenging task.

Both non-residential and residential buildings are covered, the former due to their higher degree of complexity and the latter due to their sheer volume. Furthermore, the use cases are very different and most likely this is reflected in the available products, services and solutions.

3 Results

For each product, service or solution the following data has been collected: short name; product, service or solution; organisation; criterion 1 energy; criterion 2 convenience; market entry year; market penetration (no. of buildings); spread (country(ies), EU, global); reference(s). Being an internet research, not all information was available. This can be however further enquired from the organisations offering the products, services or solutions for being included in future updates in case this proposed approach picks up speed.

At this stage of testing this approach 40 products, services or solutions have been mapped in no particular order and without any filtering on the envisaged criteria:

[(short name) product, service or solution / organisation]

- **(BELOK OA)** BELOK Operational Analysis / BELOK;
- **(Indoors a)** Indoors analytics / Indoo.rs;
- **(Indoors p)** Indoors positioning / Indoo.rs;
- **(Indoors m)** Indoors mapping / Indoo.rs;
- **(SMHI FC)** SMHI Forecast Control / SMHI;

- **(JEM)** Johnson Controls Enterprise Management / Johnson Controls International;
- **(Leanheat)** Leanheat / Lenaheat;
- **(Watty)** Watty / Watty;
- **(OptiWatti)** OptiWatti / OptiWatti;
- **(Fourdeg)** Fourdeg / Fourdeg;
- **(Emphatic building)** Emphatic building / Tieto;
- **(My MCS SB)** My MCS Smart Building / Nemetschek;
- **(Axxerion)** Axxerion / Nemetschek;
- **(Locatee)** Locatee / Locatee;
- **(Thingsee)** Thingsee / Haltian;
- **(Yanzi)** Yanzi / Yanzi;
- **(Steerpath)** Steerpath / Steerpath;
- **(Teem)** Teem / TeemWeWork;
- **(Mapiq)** Mapiq / Mapiq;
- **(bGrid)** bGrid built to adapt / bGrid;
- **(BuildingiQ)** BuildingiQ / BuildingiQ;
- **(SE BA)** Building Analytics / Schneider Electric;
- **(Raybased)** Raybased / Raybased;
- **(Comfy)** Comfy / Siemens;
- **(Enlighted)** Enlighted / Siemens;
- **(FIN)** FIN framework / Siemens;
- **(Fibaro)** Fibaro / Nice Group;
- **(Lerta)** Lerta Energy Intelligence / Lerta Energy;
- **(SES)** Smart Energy Solution / S-Labs;
- **(Enerbrain)** Enerbrain / Enerbrain;
- **(Eve)** Evehome / Eve Systems;
- **(Netatmo E)** Netatmo Energy / Legrand;
- **(Netatmo W)** Netatmo Weather / Legrand;
- **(Netatmo A)** Netatmo Air Care / Legrand;
- **(Ambinode)** Ambinode / Leapcraft;
- **(Go IoT)** Go IoT / Go IoT;
- **(Healthbox)** Healthbox 3.0 / Renson;
- **(Tririga BI)** Tririga Building Insights / IBM;
- **(Tado H)** Tado Heating / Tado;
- **(Tado C)** Tado Cooling / Tado;
- **(SkySpark)** SkySpar / SkyFoundry;
- **(Digital TB)** Digital Test Bench / Synavision;
- **(Genesis64)** Genesis64 / Iconics.

The products, services and solutions have been mapped in two multidimensional arrays, one for the readiness to facilitate maintenance and efficient operation and the second for the readiness to adapt in response to occupant needs.

The multidimensional array for the readiness to facilitate maintenance and efficient operation has the following three dimensions (see **Fig. 2**):

- Aim of product, service or solution: continuous technical building systems optimization, boost business / space optimization, continuous heating optimization, continuous ventilation optimization, continuous heating and cooling optimization, improve occupant satisfaction, facility management, Internet of Things (IoT) platform;

- Data source: Building Automation and Control System / Building Management System (BACS / BMS), IoT devices (humans included), weather;

- Data science discipline: statistics, visualizations, pattern recognition, data mining, machine learning, artificial intelligence.

The multidimensional array for the readiness to adapt in response to occupant needs has the following three dimensions (see **Fig. 3**):

- Aim of product, service or solution: increase experience and satisfaction, tenant management, smart living and sustainability, increase well-being, happiness and performance, IoT platform;

- Data source: BACS / BMS, IoT devices (humans included), weather;

- Data science discipline: statistics, visualizations, pattern recognition, data mining, machine learning, artificial intelligence.

For easy visualization the third dimension is represented under the following colour code: **statistics**, **visualizations**, **pattern recognition**, **data mining**, **machine learning**, **artificial intelligence**.

4 Discussion

Some of the 43 selected products, services and solutions are included in both multidimensional arrays while some find themselves only in one of them. The multidimensional array for the readiness to facilitate maintenance and efficient operation includes 38 products, services and solutions while the multidimensional array for the readiness to adapt in response to occupant needs includes 31 products, services and solutions.

The proposed approach enables a simple and easy to understand overview of the selection of products, services or solutions.

Data privacy, security and safety is at the top of the agenda for all the products, services and solutions included in this paper. Some of them even leverages it into their unique value proposition (e.g. fully storing the data locally without cloud uploads). All the products, services and solutions offered in Europe need to comply as of 25 May 2018 with the General Data Protection Regulation (GDPR), which in turn most likely increases the clients' trust.

Many products, services and solutions entered the market around 2010, but mostly immediately after or in recent years. Only a few have been on the market since the early 2000s. Since then the market penetration of the products,

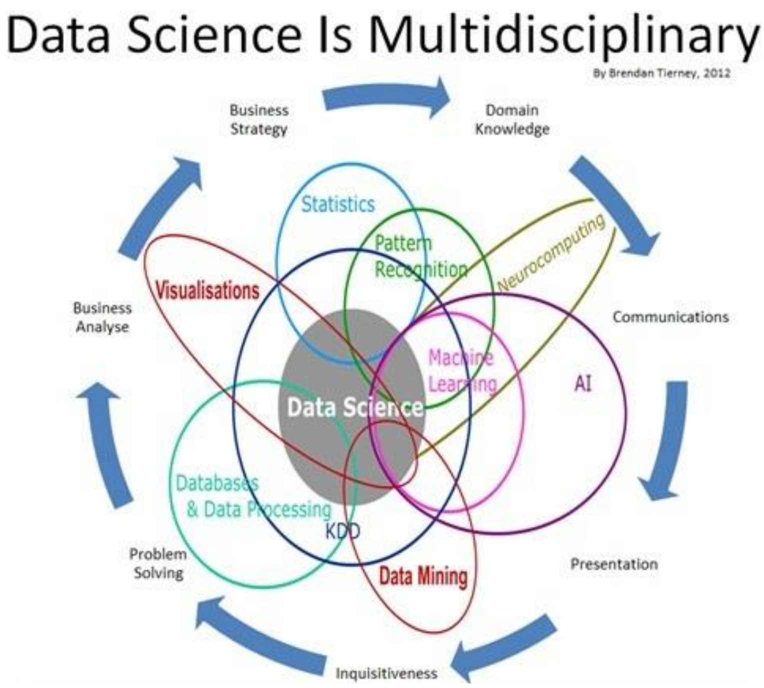

Fig. 1 The multiple disciplines of data science and the key skills of a data scientist (Brendan Tierney, 2012)

Data science discipline →	*Statistics*	*Visualizations*	*Pattern recognition*	*Data mining*	*Machine learning*	*Artificial intelligence*		
Aim of product, service or solution →	*Continuous technical building systems optimization*	*Boost business Space optimization*	*Continuous heating optimization*	*Continuous ventilation optimization*	*Continuous heating and cooling optimization*	*Improve ocupant satisfaction*	*Facilty management*	*IoT platform*
Data source ↓								
BACS / BMS	BELOK OA JEM JEM JEM bGrid bGrid BuildingiQ BuildingiQ BuildingiQ SE BA SE BA Raybased Raybased Tririga BI Tririga BI Tririga BI SkySpark SkySpark SkySpark SkySpark Digital TB Digital TB Digital TB	Mapiq Mapiq					myMCS SB myMCS SB Axxerion Axxerion Comfy Comfy Comfy Genesis64 Genesis64 Genesis64	Mapiq Mapiq Raybased Raybased Comfy Comfy Comfy Enlighted Enlighted FIN FIN Go IoT Go IoT
IoT devices (humans included)	bGrid bGrid BuildingiQ BuildingiQ BuildingiQ Raybased Raybased Enlighted Enlighted Fibaro SES SES Enerbrain Enerbrain Eve Ambinode Ambinode Ambinode Tririga BI Tririga BI Tririga BI	Indoors a Indoors a Locatee Locatee Locatee Steerpath Steerpath Mapiq Mapiq	Leanheat Leanheat Fourdeg Fourdeg Netatmo E Netatmo E	Healthbox Healthbox	OptiWatti OptiWatti Lerta Lerta Tado H Tado H Tado C Tado C	Emphatic building Emphatic building	myMCS SB myMCS SB Locatee Locatee Locatee Comfy Comfy Comfy Fibaro	Thingsee Thingsee Yanzi Yanzi Comfy Comfy Comfy Enlighted Enlighted FIN FIN Go IoT Go IoT
Weather	SkySpark SkySpark SkySpark SkySpark		SMHI FC SMHI FC Leanheat Leanheat Fourdeg Fourdeg Netatmo E Netatmo E	OptiWatti OptiWatti Lerta Lerta	OptiWatti OptiWatti Lerta Lerta			

Fig. 2 Key functionality 1: multidimensional array for the readiness to facilitate maintenance and efficient operation

services and solutions included in this paper are around 3-4 digit for non-residential buildings, and 6-digit for residential buildings. It is safe to assume that summing up all the buildings that have at least one of the selected products, services or solutions reaches the order of magnitude of 7-digit, most likely somewhere between one and two million. Although, it might seem a lot in absolute value, it is almost negligible relative to the hundreds of millions of buildings across the globe.

The organisations offering the products, services and solutions are either incumbent ones from the building automation and facility management industry or new comers from the information and communication technology industry. There are successful partnerships or mergers between incumbents and new comers (good hardware needs good software), incumbents develop own software and enables IoT (on top of the common building automation communication protocol), new comers develop own hardware and integrates legacy hardware (in IoT).

The most noteworthy aspect of the current digital transformation is the intention of several market players, be they incumbent or new comers, to create IoT platforms that can integrate both legacy and new hardware.

Data science discipline →	*Statistics*	*Visualizations*	*Pattern recognition*	*Data mining*	*Machine learning*	*Artificial intelligence*
Aim of product, service or solution →	*Increase experience and satisfaction*	*Tenant management*	*Smart living and sustainability*	*Increase well-being, happiness and performance*	*IoT platform*	...
Data source ↓						
BACS / BMS	JEM MyMCS SB MyMCS SB Mapiq Mapiq bGrid bGrid BuildingiQ Comfy Comfy Comfy	JEM BuildingiQ		Tririga BI Tririga BI Tririga BI	Mapiq Mapiq Comfy Comfy Comfy FIN FIN	
IoT devices (humans included)	Indoors p Indoors m MyMCS SB MyMCS SB Locatee Locatee Locatee Steerpath Teem Mapiq Mapiq bGrid bGrid BuildingiQ Comfy Comfy Comfy	BuildingiQ	Leanheat Leanheat Watty Watty Optiwatti Optiwatti Fourdeg Fourdeg Fibaro Lerta Lerta SES Eve Netatmo E Netatmo E Netatmo W Netatmo A Healthbox Tado H Tado H Tado C Tado C	Emphatic building Emphatic building Comfy Comfy Comfy Ambinode Ambinode Ambinode Tririga BI Tririga BI Tririga BI	Thingsee Thingsee Yanzi Yanzi Mapiq Mapiq Comfy Comfy Comfy FIN FIN	
Weather			Leanheat Leanheat OptiWatti OptiWatti Fourdeg Fourdeg Lerta Lerta			

Fig. 3 Key functionality 2: multidimensional array for the readiness to adapt in response to occupant needs

When analysing the data science disciplines, visualization is ubiquitous in all the selected products, services and solutions. Most products, services and solutions additionally include data mining and several stand out from the rest incorporating a form of pattern recognition, machine learning and artificial intelligence.

The end-users are at the heart of the digital transformation which is attacking carefully and skilfully from different angles both the occupant and the building operator (facility manager). The products, services and solutions aim to make their life and tasks easier and more enjoyable while at the same time boosting business, reducing maintenance and energy costs, optimizing space usage or just enabling smart living. It is interesting to observe the trend of integrating all building services under one single umbrella (an app or a web interface).

Digital transformation is taking the digitalized way of using and operating a building to reach critical mass which will then push all products, services and solutions to reach economies of scale and eventually be cost-effectively incorporated in a few decades in all buildings around the globe.

5 Conclusions

The presented mapping could effortlessly serve as starting point for those interested in the topic of digital transformation of the built environment and provide a wider view for those active in the field. Although, the content is non-comprehensive, the aim was rather to develop an approach fully scalable to incorporate further data sources, aims of products, services and solutions and data science disciplines, which is most needed for these rapidly evolving offerings. The authors strongly believe it's fully feasible to integrate eventually all existing commercial activities available on the market at a given time if enough resources would be made available.

The authors endeavour to attract more colleagues to the process of continuously updating the mapping exercise and widening its reach. The underlying intentions are to establish a community on this topic that would connect the different market players, researchers and policy makers for facilitating further developments in the field of digital transformation in buildings and possibly start with supporting the development [11] and implementation of the SRI in Europe.

There is no doubt that digital transformation is reshaping the way we use and operate buildings, shifting from guess-based to complete evidence-based decisions stemming from the gained ability to bring from the invisible to the visible a breadth of information and furthermore analyse it and obtain actionable (automated) insights. What remains to be seen is if, how and who will be able to completely integrate all hardware and software under a single ecosystem and create full interoperability between all building technology enabling a single user-building interaction interface, mitigating todays cognitive overload.

6 Acknowledgements

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At the same time the authors acknowledge the usefulness of having ease of access over the internet to information about products, services and solutions offered by front-running organisations facilitating the digital transformation of the built environment. A big thank you to all the transparent organisations out there!

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From Sustainable Urban Mobility Plans (SUMPs) to Operational Energy Policies and Measures for the City of Tomorrow

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Abstract. Technology, mobility and the large availability of data have dramatically changed values, expectations, approaches and jobs as well as the ways of understanding, interacting, living and working of individuals and communities. Therefore a more comprehensive perspective and new ways of thinking, designing, planning and managing cities are urgently needed. Confronted with increased exigencies in the conditions of reduced resources and ever growing levels of complexity and instability, public administrations are desperately calling for help. Based on the innovations developed, tested and promoted in the framework of Civitas PROSPERITY European project (focused on enhancing the adoption and efficiency of Sustainable Urban Mobility Plans), the present contribution is extrapolating this experience offering insights on public capacity building and on the sustainable preparation and implementation of various urban policies and measures and especially of the ones regarding energy efficiency. The latter are being regarded from a comprehensive, integrated and inclusive perspective, being considered essential for the wealth of a city and of its inhabitants.

1 Context

Over the past decades, communication and information technologies knew an unprecedented advancement enhancing liberty as well as control, (long distance) transport democratised, life expectancy and population number increased, sharing economy raised, tangible and intangible assets multiplied, while values changed. On the other hand, migrations became more and more significant and frequent, social and cultural conflicts, disparities, hazardous events, insecurity and terrorism sharpened and, above all, consume, waste, pollution and pressures are ever more important (IPCC, 2014; WWF, 2018).

In this profoundly changed context, characterised by amplified instability, uncertainty (due to, among others, global volatility and technological advances, as explained by Lyons and Davidson, 2016), complexity and globalisation; traditional methods and instruments can no longer work properly, so public authorities and societies have to move on towards a new paradigm (Murray et al., 2010; Tosics, 2011; Boonstra and Boelens, 2011).

Rizzo (1989) observed that there is an undeniable relationship between the energetic flows and the way in which a city is designed, built, maintained and managed. He considered that it is when the levels of entropy are too high, that big changes occur, namely the shift to a different energetic model with the development of new economic, social and political institutions. Furthermore he noticed that the ever increased amount of energy needed along the evolution of production activities, was not always accompanied by an equivalent augmentation of the productivity, but rather of a reduction of the work needed. According to Rizzo, a real evolution cannot be limited to the simple substitution of the manpower by advanced technological instruments, but should refer to the invention and application of technological systems that allow using better the same or a larger amount of work. Hence technology should allow advancing from a quantitative progress with elevated entropy to a qualitative one with low entropy, the energy making the difference between harmony and entropy.

Similarly, Alvarez Pereira (2017) noticed that despite our expectations that technology is going to solve all problems, today high levels of development imply large energy footprints, thus through their evolution people tending to destroy the material conditions of their own existence. For sure, nature is no longer an issue in this discussion as it will recover somehow, but it might be in a form no longer favourable to human beings (Rotaru, 2013).

In this context, energy (and especially its management) has always a crucial importance and its production, distribution and consumption are depending of the urban flows and land-use planning (spatial organisation). Therefore, these 3 issues (energy efficiency, urban mobility and land-use) have to be

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considered together, correlated, especially as they are all pursuing the improvement of the quality of life, the increase in efficiency and the reduction of negative externalities. As also noticed by Fresner et al. (2018) “individual sectoral plans dealing with energy, transport and mobility separately have often proved inefficient to provide effective, long-term solutions”. Hence there is a need of “working on those areas which are complementary in order to have the plans working together for the achievement of an overall strategic objective […] and help different departments in local authorities share the same vision, work together and optimize the use of resources”. Moreover, according to the statistics and analysis published by the European Commission (2013c) and by the European Environment Agency (2018) based on Eurostat data, if in some other areas energy consumption could be slightly reduced or kept more or less at the same level, transport is the only sector where it augmented decisively and this trend is expected to continue. Between 1990 and 2016, there was a 34 % net growth in the energy consumption of transport in the EEA-33 (European Environment Agency, 2018). Despite the fact that cars became more energy efficient, the preference for bigger and stronger SUV (sport utility vehicles) is steadily growing. The saved energy due to more energy efficient current cars is compensated by an increase in the power of cars and in their use (faster cars and longer distances). Besides, better performing technology usually needs more energy to produce, operate and disable. In order to address the difficulty to decrease energy consumption in the urban mobility field, Lyons and Davidson (2016) analyse the possibility to limit the need of physical mobility (seen as only one of the means to accessibility) through spatial proximity and digital connectivity. Furthermore, they refer the Triple Access System (associating these 3 elements) as a “framework for policy and investment decisions that can harness flexibility and resilience”, that was used in the process of future mobility scenarios building conducted in New Zeeland in 2014. This hypothesis has also served as one of the starting points for several Horizon2020 European like Civitas PROSPERITY and CREATE.

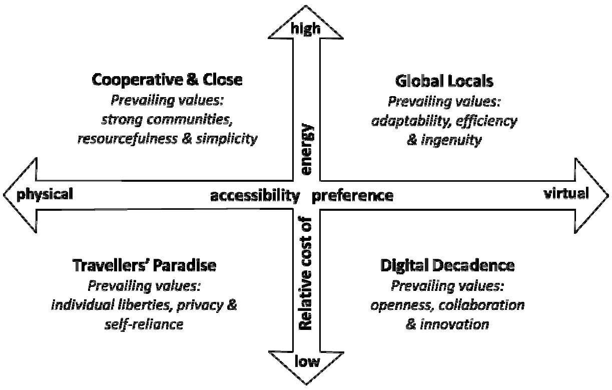

Fig. 1. The Triple Access System framing in 2014 the definition of 4 main scenarios for future mobility and society in New Zeeland in 2042. Reinterpretation after Lyons and Davidson (2016, p. 109)

2 Civitas PROSPERITY - a resourceful experience

Started since September 2016, Civitas PROSPERITY is a 3 years research and innovation project developed in the framework of Horizon 2020 in response to the call “Mobility for Growth” (sub call topic of “Urban Mobility”) corresponding to the societal challenge “Smart, Green and Integrated Transport”. It focused on rendering the Sustainable Urban Mobility Plans (SUMP) an effective operational tool especially in countries, regions and cities where the essence and potential of this instrument were not yet fully understood and capitalised. Based on a comprehensive analysis of the urban mobility situation at national, regional and local levels conducted in the target countries (the results of which were presented in the framework of the European SUMP conference from 2017 and published on the project website), it supported the proposition of customised solutions best answering the various specific issues, but widely informed by the international experience and theoretical and practical advancements in the field.

Civitas PROSPERITY is considered a particularly resourceful experience as it enabled the development of a strategy for the optimisation of the SUMP that can be extrapolated for land-use plans and energy plans for their harmonization with the mobility ones in a first phase, in the preparation of the next steps supposing the integration of the objectives and actions from these 3 fields in an unitary system (plan or, in a later stage, 3D intelligent model). Moreover, if energy might seem something abstract for many, urban mobility is a really concrete daily issue for everybody, therefore analysing theories, decision making and measures in this sector together with their impacts can enable general understanding and orient other urban management areas.

Inspired by the philosophy of the SUMP as promoted at European level (European Commission, 2007; 2013a; 2013b) Civitas PROSPERITY rendered possible the development of a virtuous methodology of collaborative integrated planning possible to adapt to the various specific contexts while following the same core principles. It thus enabled public authorities solve their problems and regain legitimacy and acceptance, by re-establishing the connections with the other levels of governance and capitalizing the national and European exchanges with their peers as well as the genuine intelligence of local communities.

Despite the actual tendency of flattening hierarchies in favour of collaborative systems of governance (Folke et al., 2005; Boyd et al., 2015) that take advantage of a widespread network of subjects (citizens as sensors) in supporting central decision-making processes, there are a lot of missing connections preventing the various public and private initiatives and efforts reach their full potential. City planning and management in particular seem still tributary to traditional models (Rotaru, 2014). In this sense, one of the strongest outputs of PROSPERITY resulted from the fact that the exchanges were not limited to peers from different countries as in the case of most European initiatives, but it got involved the representatives of the Ministries and high level authorities and focused on fostering communication between the ones making the rules (at national level) and the ones that have to interpret and apply them (at regional and local levels), thus facilitating a better adaptation of the dedicated legislation and support measures.

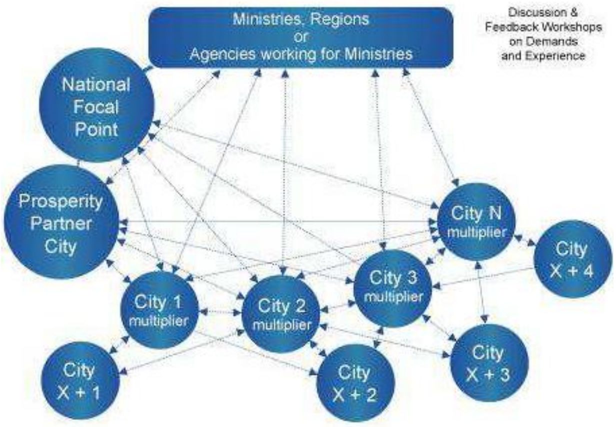

Fig. 2. The organisation of the national regular exchanges in the framework of Civitas PROSPERITY. Source: Civitas PROSPERITY http://sump-network.eu

In order to ensure the durability and the efficacy of those links between the various levels and professionals concerned, SUMP taskforces were created as permanent transverse national structures (formed of people from all the categories of stakeholders, functioning on a voluntary basis and meant to continue even after the end of the project) that gather information from the territory and advise the optimisation of the SUMPs. In their framework there were produced or improved the SUMP national support programmes following a unitary structure advanced and validated in Flanders and in Slovenia (Demšar Mitrovič, 2017).

Like this, Civitas PROSPERITY succeeded to regularly bring together the policy makers and professionals working with those policies (through periodical face-to-face meetings – at least 2 per year and online exchanges: videoconferences and webinars). This enabled changes of attitudes and behaviours, losing the gap between the needs and demands of the local level, and higher administrative institutions supposed to prepare the ground and provide programmes to encourage cities design and implement SUMPs. For example, in Romania, these exchanges brought a better awareness and capitalization of the relevance of functional connections over the urban mobility and development. Presently, at national level (Ministry for Regional Development and Public Administration) there are negotiations for the adaptation of the legislative framework in order to promote functional area SUMP beyond the administrative level ones. In this sense, significant help came from Flanders region which experience on this specific topic has been summarized into a dedicated innovation brief published on the project site in several languages. Additionally, efforts are being made in order to provide specific guidance and requirements for the SUMPs of small and medium sized cities representing the majority in Romania.

The actual challenges (uncertainty, acceleration of the rhythm of change, limitation of resources, abundance of information and huge increase in fashion generated demand responding to an artificially created need) were addressed through the adoption of the project anticipation theory. This resulted in the promotion of the advancement from the regime-compliant “predict and provide” approach to the regime-testing “vision and validate” one, explained by Lyons and Davidson (2016) and also endorsed through the CREATE European project.

The overall support offered to public administrations in target countries was completed through the organisation of tailor-made coaching sessions and national trainings (coordinated by European experts) with a strong operational component. These were given in national languages so that to reduce the barriers of understanding. The selection of themes was made depending on the demands in each country and the training modules were adapted each time to the local realities and involving participants in real case studies inspired by their daily work and challenges. These were complemented by open access webinars on the most demanded themes (http://sump-network.eu/webinars/).

The trainer/coach team was composed each time of both, experts and successful city representatives. The latter were involved because they “speak the language of cities” knowing exactly how public administrations are organised and which are their main challenges and tools. Compared to regular training approaches this has proven to be a new and more successful one.

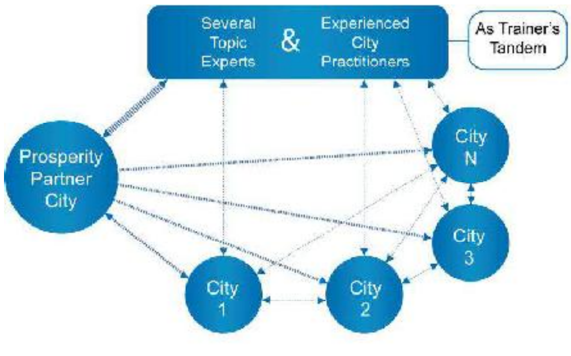

Fig. 3. Civitas PROSPERITY’s training and coaching concept. Source: Civitas PROSPERITY http://sump-network.eu

Moreover, a network of cities was created including champion and follower ones. Selected best performing cities were acknowledged as champion cities and invited to share their experience on the occasion of the national promotion, training and coaching events, serving as reference and inspiration for the follower ones. Among the champion cities, Vitoria Gasteiz provided policy makers having supported and participated in the implementation of the Superblocks scheme at the core of their SUMP who advised their peers from follower cities. A dedicated innovation brief was published on Civitas PROSPERITY website in 7 languages (with more translations in preparation). Furthermore, a project meeting and study visit were organised in Vitoria Gasteiz for local, regional and national level representatives in the project countries.

Partner cities were meant to play the role of innovation labs, while the coaching sessions dedicated to them enabled knowledge transfer and work on specific local issues backed by a broader international perspective.

The different solutions applied in local situations allowed the distinction of promising innovations to be promoted (through the innovation briefs developed in this context). Their selection has chiefly considered the possibility to apply them in more economically developed countries as well as in poorer ones, the team being faithful to the conviction that inspiration can go in both senses. They are all available in English and different project languages on the Civitas PROSPERITY website (http://sump-network.eu/tools-resources/).

The promotion of adaptive flexible solutions and the long term thinking also guiding short and medium term actions resulted in the correlation of the various projects in the same field as well as in their harmonization with the measures in related sectors. For example, the project inspired the update of the SUMP of Făgăraș, the Romanian partner city, reorganised around 3 main interrelated projects aimed to restructure together the entire urban mobility system of the city, but also working individually in relation with the different energy and urban design measures. Those 3 projects were presented for being funded through the Regional Operational Programme and their implementation should start this year.

Additionally, a special topic, SUMP ambassadors, was launched including people who were successful in their urban mobility initiatives and willing to share their experience and possibly act as advisors. This enabled the dissemination of the endeavours of the ones that supported the preparation, promotion and implementation of the best SUMPs. http://sump-network.eu/ambassadors. Authentic role models, the SUMP ambassadors helped build confidence and inspired tailored-made good practices.

Successful urban governance is frequently a matter of communication, shared references and political commitment, issues at the core of this project. The methods and tools developed and tested through PROSPERITY proved effective in enabling national and regional public authorities benefit of input and feedback from all the ones affected by their policies and measures, and empower local authorities by providing them the context to express their needs and opinions and enhancing their capacity to better understand and apply the general guidelines, recommendations and rules (Prosperity, 2019). It thus demonstrated the value and sustainability of network thinking also in terms of governance.

3 Conclusions and ways forward

The principles that were validated through Civitas PROSPERITY for urban mobility management and can be extended to the other urban governance sectors are:

1) Enhanced connectivity / multilevel networks replacing strict hierarchies: horizontal (between peers) and vertical (between governance levels);

2) Comprehensive perspective: multi-time scale correlation (long term perspective guiding short and medium term planning), spatial correlation (building – neighbourhood – city – territory) and broad assessment (of direct and indirect, internal and external costs and impacts)

3) Function prevailing over administrative limits (principle validated through the positive impact of the functional area SUMPs tested in Flanders and Wallonia)

4) Flexible / tailor-made approach: adaptation to the local context, integrating the existing practices and regulatory frameworks

5) Extensive participation (and crowd sourcing): structures enabling people contribute (express and develop ideas together)

6) Role models: champion cities and SUMP ambassadors

7) Production of references: innovation briefs, applied research

8) Experimentation / flexibility of thinking as well as of the infrastructure provided / place for creativity: partner cities as living innovation labs

9) Shared strategic vision: interdisciplinary approach and correlation of the various sectors

10) Inclusive approach: balanced development of all modes of transport, while favouring environment-friendly mobility and giving priority to more vulnerable users (children, seniors, impaired people)

11) Political and inter-departmental buy-in: involvement of the political level and of the different departments directly or indirectly connected to urban mobility

12) Collaboration with similar projects and capitalisation of the best practices: use of the SUMP European guidelines and contribution to their update;

13) anticipative thinking: integration and further advancement of the "vision and validate" approach also promoted through the CREATE project in replacement of the traditional "predict and provide" theory (Jones, 2016a, 2016b).

A novelty of PROSPERITY, the involvement of ministries and high level (national and regional) authorities proved to be very beneficial for the implementation and impact of the project rendering its proposals easier accepted and more proficient. This idea could be adopted in the fields of energy and land-use planning and further by creating a similar multilevel collaboration connecting not only the various authorities in one field, but also the different urban planning sectors (energy efficiency, urban mobility and land-use).

Besides the essential contribution in terms of methodology and process management, distinguishing through the extensive involvement of all governance levels (and especially of the high level authorities) as equal partners in the process of improving the sustainability of the management and functioning of cities, an essential output of PROSPERITY was represented by the innovation briefs. The latter stressed some key elements to be capitalised for advancing towards more liveable cities. Veritable flexible “recipes”, they contain all the necessary elements to be easily adapted and implemented in various contexts. Their content and impact going beyond the urban mobility, they play the role of interdisciplinary references possibly nurturing multiple sectors of city management.

However, in order to attain their full potential, the collaborative structures (like the SUMP national taskforces and the SUMP national programmes) and mechanisms advanced in this context have to be applied at a larger scale (more cities and countries) and refer to all urban planning fields.

As demonstrated through PROSPERITY (Civitas Prosperity, 2019), this integrated approach proposed to connect the various scales (micro - building, meso - neighbourhood and macro - city) and also for some sectors already exercising reciprocal influences one upon another, can reduce the energy needed thanks to a better correlation of efforts that are concomitantly responding to multiple needs and / or lead to the simplification of processes.

In Romania, a first step has been done through the inclusion of the SUMP as a compulsory component of the city land-use and spatial development plan (the so-called General Urban Plan), complemented by efforts to correlate the various time spans of the different urban planning documents. What limited the success of this initiative was the absence of adapted evaluation, approval and monitoring procedures. There are still no specific performance / quality indicators (besides the administrative compliance request) and the commissions are not kept to include urban mobility professionals.

Meanwhile, the Sustainable Energy Action Plans (SEAP) compulsory for all the signatories of the Covenant of the Mayors for Climate and Energy are of a more recent date and less known and connected to the other planning documents, even if following the same principles as the SUMPs and highly influencing cities’ sustainability.

In order to overcome this retard, it would worth further investigating the possible transverse connectors, like for instance the systems allowing fast transmission of information and energy and enabling important economies. Lighting systems for example can play such a role and ensure the link between the different urban planning sectors as they can capture and transmit information (such as traffic data) and energy besides their basic role (networked / connected lighting systems).

Together with circular economy, multi-functionality enables the more efficient use of resources, partially regenerated through creativity, thus contributing to the reduction of energy consumption, waste and entropy. However, this kind of arrangements demand advanced vertical (across management levels) and horizontal (between various sectors) collaboration.

Therefore, for all these connections and processes work properly, efforts are also to be made for the development of the collaboration culture still missing in many contexts and particularly in public administration because of its more rigid nature and elevated inertia (Ritchie, 2014).

The progressive integration of the idea of BIM (Building Information Model) requested more and more often for public projects has opened new perspectives. In the building sector, the correlation between the various disciplines is obtained through the architectural and technical synthesis that consists in the superposition of the different plans (architecture, structure and various networks) in order to define the necessary reservations and identify and solve the eventual conflicts. BIM not only facilitated the significant optimisation of the entire building process, enabling as well important economies over the entire lifetime of an edifice, but also changed the way of working imposing collaboration as an indispensable approach.

A very complex tool following the same principles as an SUMP, BIM radically changes the design and management of systems for which it is used, requiring different levels of cooperation. Similarly to the way BIM gathers and connects the various specialities intervening into the construction (and management) of a building, it could also serve for the integration of the various urban plans and strategies in an unitary system, allowing their real time correlation through fast identification and solving of the various conflicts and thus enabling significant economies (of energy, time, work load etc.). This organisation could then further evolve into a living urban management 3D model integrating and better optimising all the information actually contained in the various city plans and strategies (updated in real time). Besides providing the advantages of an economy of scale, such a model would help adopt a preventive and proactive attitude instead of a reactive one. Through the easier and faster elimination of conflicts before they start having negative consequences, it can simplify procedures, limit the negative impacts and enhance the positive ones in the conditions of reduced consumes of energy. Some very incipient steps in this sense have already been done with the development of the traffic model associated to the SUMP, the use and impact of which is however still very limited.

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Wind energy and environment

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Abstract

For mankind to be able to continue life at a high level of comfort and satisfaction, first of all it is necessary to provide a significant amount of energy. Electrical and mechanical energy as well as thermal energy in the form of heat or domestic hot water over 75% is ensured by combustion of fossil fuels, which generates a large amount of gaseous and solid pollutants.

In the last decades, mankind has searched for new sources of primary energy that, transformed into electricity or heat, do not pollute the environment, under the generic name of renewable energy.

Currently, the most used renewable energy source is wind energy, which has grown, mainly due to the financial support policies adopted in most countries in the world.

Making an onshore / offshore wind turbine involves a series of energy-consuming activities, both in wind turbine components manufacturing and building on a given location. Wind turbines also affect the environment, directly and indirectly throughout their life cycle. In addition, the decommissioning of these colossi with growth tendencies has a number of difficulties, especially for offshore winds, generating enormous quantities of waste.

Depending on the type of turbine and its power, the work involves research, design, manufacturing and experimentation.

These activities, as well as the actual realization of wind turbines in the current technology, are energy consuming and produce a series of waste in fuctoning and especially decommissioning.

In this paper, an assessment of the embodied energy and energy produced by a wind turbine at an onshore site is made.

Chapter. 1 Energy consumption to build a new wind turbine

1.1 General aspects

Given that most of the onshore wind turbines of various companies currently have an installed capacity of 1- 3 MW, a wind turbine of 3 MW will be considered in the analysis. For this analysis, average values of turbine and site specific parameters will be considered.

1.2 Design and experimentation

The design of a new wind turbine involves energy-consuming activities, the evaluation of which is in accordance with Table 1.2.1. For the assessment of the energy encompassed at this stage were considered the specificities and activities specific to the development of the new wind turbine as well as generic data related to experimentation in a Onshore location at a distance of 50km from the existing transport routes.

Table 1.2.1 Embodied energy for a 3 MW onshore wind turbine

No	Activities	Unit	Qty	specific energy (kWh/unit)	Embodied energy (kWh)	Total energy (MWh)
1	Research	Hours / month	240	150	36000	36
2	Experimental prototype – human factor	Hours / month	18	150	2700	39
3	Experimental prototype – design of nacell model	tons	76	15000	1140000	1179
4	Experimental prototype – excavation of access road	km	50	12000	600000	1779
5	Access road – concrete pouring	tons	15000	300	4500000	6279
6	Access road – asphalt pouring	tons	200	420	84000	6363
7	Experimental prototype – design of tower	tons	325	15000	4875000	11238
8	Experimental prototype – design of foundation	tons	7260	35	254089	11492
9	Experimental prototype – concrete foundation	tons	5723	350	2002928	13495
10	Iron rebar for concrete foundation	tons	636	11800	7503030	20998
11	Experimental prototype – assembly	Hours / month	5	150	750	20998
12	Experimental prototype – operation for 1 year	Hours / month	12	120	1440	21000
13	Wind turbine prototype production	energy	45% of energy required to build components			9450
14	Energy used to make the prototype	energy	energy required to build and assemble components			30450
15	Percentage of repartition to mass production	10%	energy transferred to mass production			3045

1.3 Onshore turbines

For assessing the energy involved in building an onshore 3 MW turbine power plant, the data from a wind turbine installed in Constanta County Romania is considered. For this assesment, a distance of 50 km between the existing transport routes and the 3 MW onshore turbine has been taken into consideration.

All dimensions of the components of the onshore wind turbine considered in the assessment are from the 3 MW wind turbine installed in Constanta County Romania.Table 1.3.1 shows the energies embodied in the wind turbine stages considered.

Table 1.3.1 The energy embodied in the construction and operation of a 3 MW onshore wind turbine

No	Activities	Unit	Qty	specific energy (kWh/unit)	Embodied energy (kWh)
1	Excavation of access road	km	10	1200	12
2	Access road – concrete pouring	tons	3000	300	912
3	Access road – asphalt pouring	tons	40	420	929
4	Excavation for turbine foundation	tons	7260	35	1183
5	Foundation – concrete pouring	tons	5723	350	3186
6	Iron rebar for concrete foundation	tons	636	11800	10689
7	Turbine tower production	tons	325	15000	15564
8	Turbine tower assembly	Hours / month	5	70	15564
9	Turbine nacelle production	tons	76	15000	16704
10	Turbine nacelle assembly	Hours / month	2	70	16704
11	Total for turbine production and assembly	Energy	Energy required for components production		81448
12	Final assembly	Energy	30% din energia necesară realizării componentelor		24434
13	Operation, overhauls and repairs at 5 years	Hours / month	10	70	24435
14	Total energy used for turbine production and assembly	Energy	energia necesară realizării și montării comp.		130317
15	Total energy used for turbine production and assembly and operation	Energy	energia necesară realizării si expolatării		130317

Chapter. 2 Annual production of electric energy of one wind turbine

2.1 General aspects

The amount of electricity produced by a wind turbine was estimated on the basis of engineering calculations, taking into account the average wind speed at the turbine site.

2.2 Onshore turbines

The power generation for 3 MW onshore onshore turbine power installed in Constanta County, Romania for one year is 7500 MWh / year

Cap. 3 Consumption versus energy production of a wind turbine

3.1 General aspects

In order to evaluate representatively the efficiency of electricity production, the analysis considers the difference between the spent energy embodied in the

For the decommissioning of wind turbines onshore, the following top-down activities are required:

a. removing the blades by means of a heavy crane;

wind turbine and the delivered electricity production (excluding domestic services).

3.2 Onshore turbines

If the 3 MW wind turbine installed in Constanta, Romania, will operate for 25 years without capital repairs, with minimum operating costs, the annual energy produced by it is of (7500 MWh), which returns to a total energy output of 25 years of 187500 MWh

The energy involved for the construction and operation of the wind turbine onshore for 25 years of operation is 1368o7 MWh. If the energy consumption for turbine decommissioning is taken into account, the energy involved is 147911MWh.

For the wind turbines installed in the Dobrogea region, the recovery period of the energy involved in the turbine is 18.24 years. If the energy spent on the decommissioning of the turbine is considered, the recovery period of the energy involved in the turbine is 19.72 years.

b. dismounting the nacelle;

c. dismantling the nacelle tower sections; the resulting materials are transported for processing and recovery of recyclable materials.

d. decommissioning of the reinforced concrete foundation

For the decommissioning of the concrete foundation, several steps are required for the foundation to be brought to the stage of reusable materials. The necessary activities for decommissioning the foundation are:

d1. performing a truncated excavation around the foundation with a lower radius at least 2 m longer than the foundation radius and an angle of 45 degrees;

d2.the realization of an access corridor from one side with a 5 degree inclination and a width of about 8 m for the access of the machines and the decommissioning machines;

d3. breaking the foundation by dynamics into large pieces;

d4. crushing of reinforced concrete blocks in re-used materials for concrete production;

d5. transportation of materials resulting from crushing the foundation;

d6. filling the resulting dump with the ground and recovering the soil from the surface.

Table 3.1 shows the energies required for decommissioning of the metal part of the onshore wind turbine.

Table 3.1 Embodied energy in required for decommissioning of the metal part of the 3 MW onshore wind turbine

No	**Activities**	**Unit**	**Qty**	**specific energy (kWh/unit)**	**specific energy (kWh/unit)**	**Total energy (MW)**
1	Turbine blade disassembly	Tons	12	1500	18000	18
2	Turbine nacelle disassembly	Tons	64	1500	96000	114
3	Transportation of recyclable materials to processing unit	Tons	76	150	11400	125
4	Tower disassembly	Tons	460	1500	690000	815
5	Transportation of tower to processing unit	tons	460	150	69000	884

Table 3.2 presents the energies required for the decommissioning of the reinforced concrete part of the onshore wind turbine.

Table 3.2 The energy embodied in decommissioning 3 MW of onshore wind turbine concrete

No	Activities	Unit	Qty	specific energy (kWh/unit)	Embodied energy (kWh)	Total energy (MWh)
1	Excavation around turbine foundation	tone	10754	120	1290442	1290
2	Build access around foundation	tone	1461	120	175325	1466
3	Breaking of foundation	tone	5723	30	171680	1637
7	Crushing of foundation blocks	tone	5723	120	686718	2324
8	Recycling of iron rebar integrated in concrete	tone	636	5900	3751515	6076
9	Transport of broken-up foundation blocks	tone	7630	150	1144530	7220
10	Restoring the land to the original state	tone	20000	150	3000000	10220

Chapter.4 Environmental damage caused by wind turbines

The current wind farm exploitation solution is a series of activities and waste that affect the environment as follows.

1. Creation of own access roads to each wind turbine from the national roads leading to the removal of a few hectares from the economic and vegetal circuit;

2. The construction of a wind turbine involves the destruction of soil quality over an area of about 2000 square meters.

3. Very high tangential velocities of blade peaks generate vibrations and high frequency noise that affect turbine neighbors

4. The decommissioning of wind turbines generates a large number of thousands of tons of concrete and metal waste

Chapter. 5 Conclusions

The present paper aims at highlighting the positive and negative aspects related to the realization, exploitation and decommissioning of a medium power onshore wind turbine.

In order to assess the effective efficiency of a wind turbine, the difference between 25-year lifetime energy and wind energy in an onshore wind turbine was considered as a criterion.

In the evaluation, it was considered that 10% of the energy spent for conception, research (including experimentation on a prototype) was added to the energy embedded in the realization of the turbine considered. The energy consumed for the decommissioning of the onshore turbine has also been added to the energy embedded in a turbine.

From the analyzes made and presented in the paper, it results that the wind turbines, as they are currently being realized, have little efficiency compared to the wind potential in the area. Taking into account the efficiency of the current wind turbine type, it is proposed to develop a new generation of wind turbines that do not have parts of external motion and whose efficiency is not influenced by the direction of the air currents.

To increase the efficiency of the wind turbine, it is proposed that they use both the direct action effect of the air and suction currents generated by the leakage of air streams on aerodynamic surfaces.

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