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Experimental measurements and analysis of the parameters that influence the consumption of electrical energy in HVAC systems.

Măsuratori experimentale și analiza parametriilor care influențează consumul de energie electrică în sisteme HVAC.

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Abstract. *The building sector is one of the largest final consumers of energy, especially for air conditioning, and research has shown that there is a great potential for energy savings in this sector. The performance of a chiller can vary significantly depending on system partial loads and evaporator and condenser operating temperatures. The condensers of water-only chillers take the heat of condensation from the refrigerant only through the sensible heat of the refrigerant, leading to significant water flows. The outside air temperature and the intensity of solar radiation directly influence the consumption of electricity on the chiller. Having available the values for the solar radiation intensity I [W/m²] and the outside air temperature t_e [ºC], with the help of the proposed mathematical model, validated by experimental measurements, the optimal values for the minimum electricity consumption of the system are obtained, under the conditions which the chilled water temperature is 7/12ºC and the indoor air temperature is 27ºC*

Key words: *HVAC, energy efficiency, GWP, chiller, cooling, mechanical ventilation, GES.*

1. Introduction

On 12 December 2015, leaders from 55 countries around the world signed the Paris Climate Agreement, which set out an action plan to limit global warming to "well below" 2°C and work towards limit it to 1.5°C. The European Council approved a binding EU target of reducing net domestic greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels. In 2020, five years after the Paris Agreement signing, the highest temperatures were recorded and 200 gigatons of CO_2 were emitted. Almost 200 countries have agreed for the first time, at the COP28 Dubai climate change summit, to start reducing global consumption of fossil fuels, but without giving up coal, oil and gas for good.

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The need for immediate action to reach the global emissions cap by 2025 at the latest and reduce global greenhouse gas emissions by 43% by 2030 and 60% by 2035. Globally, the main consuming sectors are construction, transport, industry and others, which group minor activities such as agriculture, forestry and fishing. Consumption in each sector increased, while their shares in final consumption remained constant [3].

Although the energy saving potential remains high in all sectors, there is a particular challenge related to transport, as it is responsible for more than 30% of final energy consumption, as well as construction, as 75% of the Union's real estate stock has low energy performance. The 2020 EU reference scenario foresees 864 Mtoe for final energy consumption and 1124 Mtoe for primary energy consumption, values to be reached by 2030. An additional reduction of 11.7% results in 2030, 763 Mtoe and 992.5 Mtoe. Compared to 2005 levels, this means that final energy consumption in the Union should be reduced by around 25% and primary energy consumption should be reduced by around 34% [4].

A classic ventilation and air conditioning (HVAC) system accounts for approximately 40% of the building's total energy consumption [1]. This is an important consideration because energy consumption for cooling, heating and refrigeration has a substantial impact on the total energy consumption of buildings and countries. Depending on how electricity is generated in each country, its efficient use also has a large indirect impact on climate change by reducing CO_2 emissions.

Global warming potential (GWP) is a value that indicates the degree of contribution to global warming of various greenhouse gases (GHGs). (R-410A: 2,090, R-32: 675) [2]. Lifecycle Global Warming Potential measures the GHG emissions associated with the building at different stages throughout its life cycle.

It therefore measures the building's overall contribution to climate change emissions. This is sometimes referred to as 'carbon footprint assessment' or 'life cycle carbon measurement'. It brings together carbon emissions embodied in building materials and direct and indirect carbon emissions from the use stage [4].

2. Presentation of the work

The objective of this study is to illustrate the optimal control of the ventilation/air conditioning system, whereby for a given cooling load, the total electricity consumption of the system is minimized, while maintaining comfort conditions in the building.

The measurements, which were the basis of the electricity consumption analysis, were carried out in an industrial hall (Fig.1), with an area of 2290 m^2 and a height of 12 m, located in the town of Timisoara, having known the values of the air parameters outside for the summer period, from July, t_e=36,4°C, relative humidity of the outside air, θ_e=25%, according to SR 6648-2 / 2014 and I5-2022.

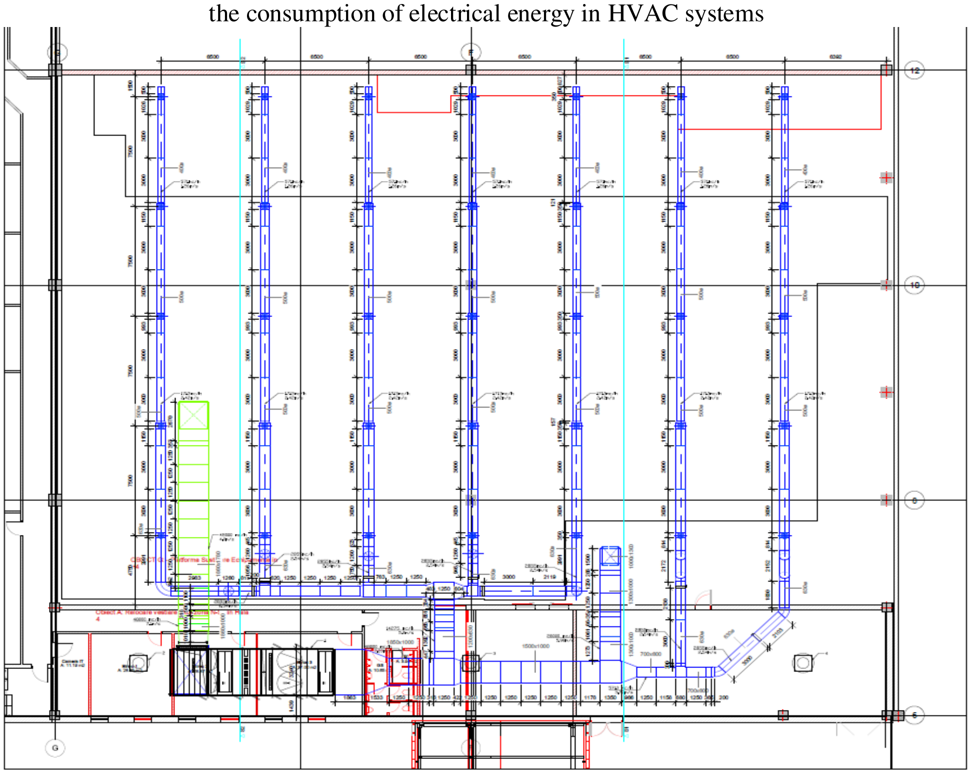

Fig. 1. Industrial hall plan.

The resulting values for the cooling and heating thermal loads are as follows, ΔQ_{Summer}=312 kW and ΔQ_{Winter}=210 kW.

The air conditioning ventilation system consists of a chiller, a cooling tower and an air treatment plant.

For this ventilation/air conditioning system, two controllable parameters were defined (indoor air temperature and chilled water temperature) which were determined so that the electricity consumption was minimal. Controllable parameters were defined as depending on other uncontrollable parameters, such as the outside air temperature and the intensity of solar radiation. The electricity consumption of the ventilation/air conditioning system is the sum of the electricity consumption of the chiller, cooling tower, exhaust and air intake fans from the air treatment plant and heat agent circulation pumps.

3. Description of the ventilation/air conditioning system

The ventilation / air conditioning system that ensures thermal comfort and olfactory comfort parameters for the industrial hall is made up of the following components:

- air treatment plant with fresh air intake, with a flow rate of 48,000 m^3/h;
- water-cooled chiller, net cooling power 337.1 kW, chilled water 7ºC /12ºC, freon 410A;
- open cooling tower, with radial fan, water flow 48m^3/h, electric power 4.3kW;
- 3 air exhaust fans, flow rate 16000 m^3/h;

- water treatment station.

In open cooling towers, the water coming from the cooling system is distributed directly on the spray surface and comes into contact with the air blown through the tower, thus ensuring its cooling by evaporating a certain amount of water. This type of cooling is the most advantageous in terms of efficiency, dimensions, cost and energy consumption. Regarding the risks related to water quality, the volume of water to be managed (water from the cooling tower and that from the cooling network) and the diversity of materials with which it comes into contact must be taken into account. In these systems, the water has high temperatures, which favors microbial proliferation, and the hot spots of the system are favorable areas for stone deposits and corrosion production. The functional diagram for the cooling system is shown in Fig. 2.

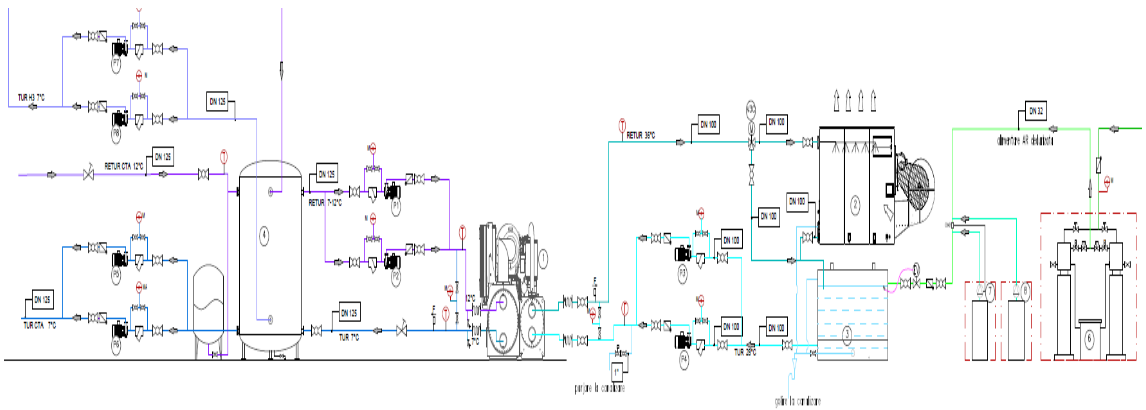

Fig. 2. Cooling system functional diagram.

For ventilation and air conditioning in the industrial hall, an air treatment plant with fresh air intake is used, with an input air flow rate of 48000m³/h. The air treatment unit, for indoor installation, will consist of the following modules:

- multifunctional mixing chamber, with the following connections provided with motorized dampers with proportional actuators (0-10V control), powered by 24 V alternating current:
- fresh air connection (for free cooling from 0 to 100% air flow);
- recirculated air connection in winter (from 0 to 100% air flow);
- recirculated air connection in summer (from 0 to 100% air flow);
- 2 bar steam heating battery, power 225 kW, including steam solenoid valve;
- water cooling coil 7/12ºC, power 349.7 kW, including three-way valve with proportional servo motor (0-10V command), powered by 24 V alternating current;
- G4 filters on the fresh air intake side and F7 final filter;
- noise attenuators on air suction and discharge;
- 2 fresh air intake fans, with a total flow rate of 48,000 m³/h, equipped with frequency converters, with a static pressure of 450Pa.

The air evacuation will be done by means of three roof ventilators, equipped with a basic plinth and anti-return valve, mounted in the area of the air treatment plant. The flow rate of air circulated by each fan will be 16000 m^3/h, but these fans will only work when the air treatment plant introduces fresh air (free-cooling mode).

4. Monitoring and analysis of the parameters that influence the consumption of electricity on the chiller

The indoor air temperature was set to the comfort value of 27°C, and the measurements were performed at 15-minute intervals every day from July 2023 in (Fig.3).

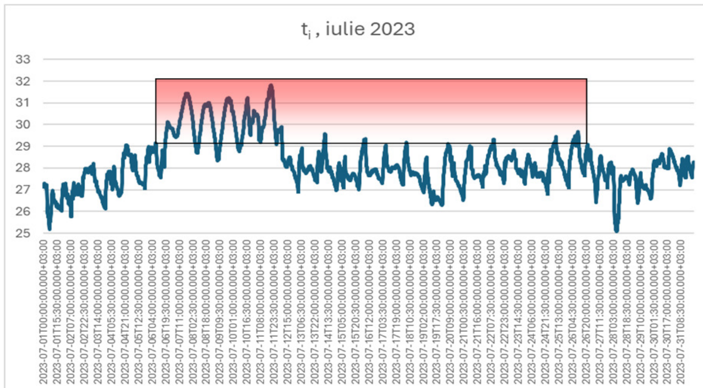

Fig. 3. Variation of indoor air temperature over time

It is noted that between July 6 and July 12, the value of the set indoor air temperature is exceeded by more than 2ºC. This situation is not due to the high values recorded for the outside air temperature or the intensity of the solar radiation, but is caused by the improper operation of the chiller during that period as can be seen from the graphs that follow.

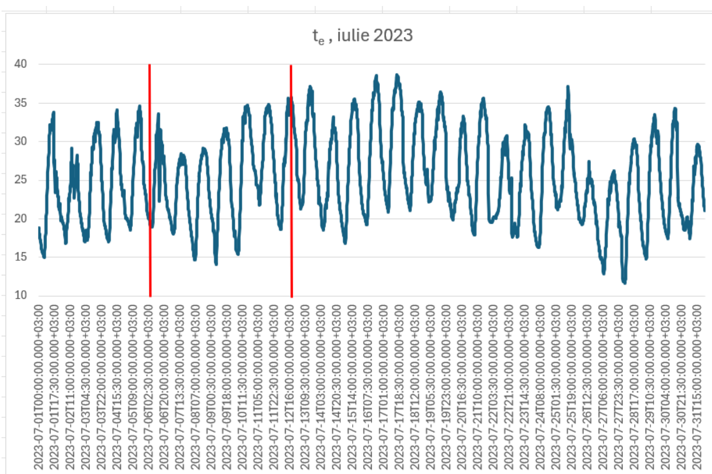

Fig. 4. Variation of outside air temperature over time

For the period July 6 - July 12, the value of the outdoor air temperature is between the minimum values of 14ºC and the maximum of 35ºC (Fig.4). These values are normal for the period of July and do not exceed the values taken into account during the design phase, when choosing the ventilation / air conditioning equipment.

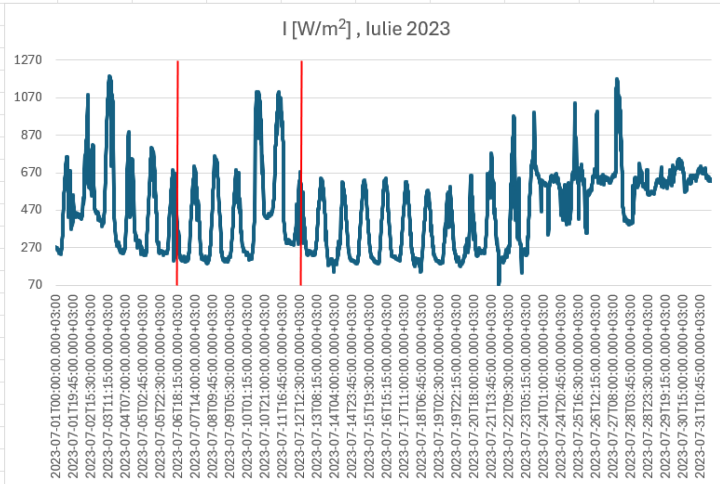

Fig. 5. Variation of solar radiation intensity over time

In the graph in Fig. 5 shows the solar radiation intensity values for the month of July with normal values between 200 W/m^2 and 1100 W/m^2, these values complying with the values of the external calculation parameters from SR 6648-2 /2014.

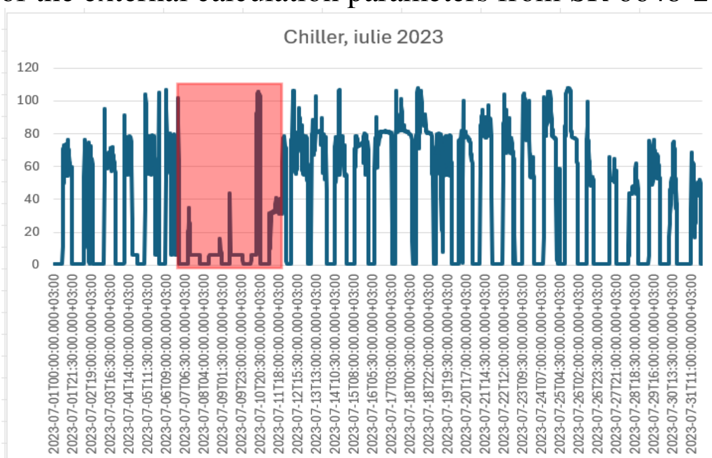

Fig. 6. Variation of electricity consumption on the chiller as a function of time

For the ventilation / air conditioning system used for the industrial hall, analyzing the values recorded for the month of July for the consumption of electricity on the chiller, E_{ch} [kWh] and the values for the outside air temperature, t_e [ºC] (Fig.7.) and the intensity of solar radiation, I [W/m^2] (Fig.8), a strong correlation can be determined between these parameters.

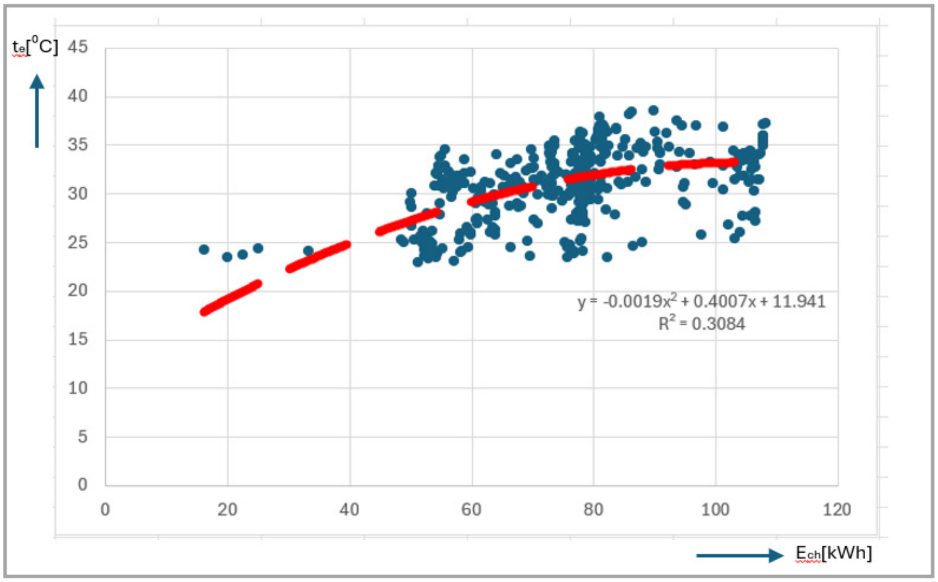

Fig. 7. Variation of electricity consumption on the chiller depending on the outside air temperature

This correlation is valid for chiller operation with chilled water, temperature 7/12ºC and a set indoor air temperature, t_i, of 27ºC ± 2ºC. For the correlation of the outdoor air temperature with the electrical energy consumed by the chiller, a polynomial function of degree 2 resulted and the square of the correlation coefficient being R^2=0.3084.

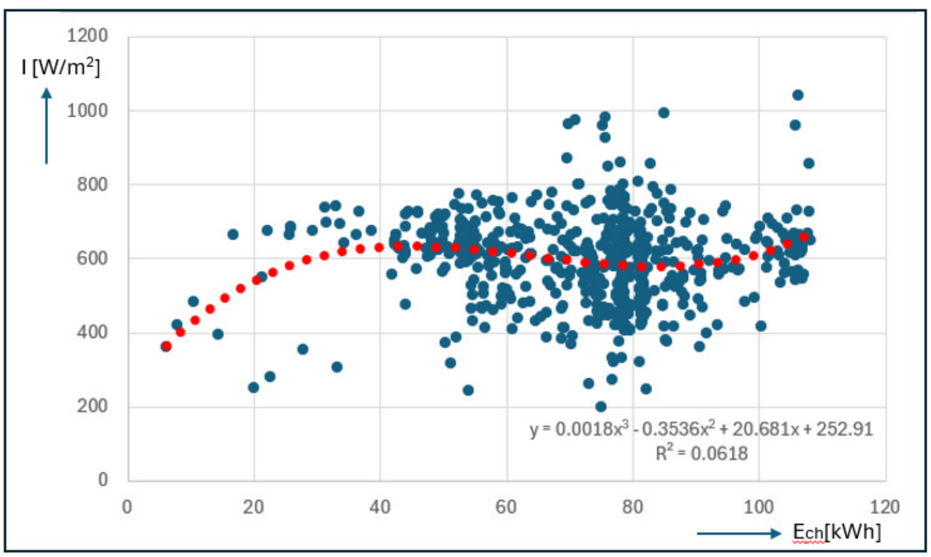

Fig. 8. The variation of electricity consumption on the chiller depending on the intensity of solar radiation

Analyzing the graphs in Fig.7 and Fig.8 shows that the influence of solar radiation is smaller compared to the influence of the outside air temperature on the consumption of electricity on the chiller, for constructive reasons. The industrial hall has a very small glazed area and the building elements with thermal inertia have a high thermal resistance so that heat intakes through insolation are reduced.

Using the two polynomial functions, a minimum value can be determined for the consumption of electricity at the chiller [5] and using the same algorithm, the minimum consumption can be determined for each piece of equipment in the ventilation / air conditioning system.

5. Conclusions

Based on the studies and research carried out, the following main conclusions were drawn:

1) The building sector is one of the largest final consumers of energy, especially for air conditioning, and research has shown that there is a great potential for energy savings in this sector.
2) It is necessary to promote the energy efficiency of buildings, the rational use of energy at the level of buildings, but also the use of renewable energies, with the idea of saving fossil fuels and reducing the level of polluting emissions.
3) The performance of a chiller can vary significantly depending on the partial loads of the system and the operating temperatures of the evaporator and condenser. The condensers of water-only chillers take the heat of condensation from the refrigerant only through the sensible heat of the refrigerant, leading to significant water flows. The outside air temperature and the intensity of solar radiation directly influence the consumption of electricity on the chiller.
4) Having available the values for the solar radiation intensity I [W/m^2] and the outside air temperature t_e [^{o}C], with the help of the proposed mathematical model, validated by experimental measurements, the optimal values for the minimum electricity consumption of the system can be obtained, in the conditions in which the chilled water temperature is 7/12^{o}C and the indoor air temperature is 27^{o}C.
5) In the future, the authors propose an extension of the mathematical model that estimates the electricity consumption of the ventilation/air conditioning system so that it takes into account several controllable variables such as the thermal inertia of the building, the total opaque surface and the total glazed surface

References

[1] HVAC HESS, „HVAC Energy Breakdown”, http://ee.ret.gov.au/, september 2013.
[2] ***, „Daikin’s Policy and Comprehensive Actions on the Environmental Impact of Refrigerants”, Available at: https://www.daikin.com/csr/,Accessed: july 2020.
[3] M. González-Torres, L. Pérez-Lombard, J. F. Coronel, I. R. Maestre, D. Yan, „A review on buildings energy information: Trends, end-uses, fuels and drivers”, Energy Reports, Vol. 8, pp. 626–637, 2022.
[4] ***, “Directiva (UE) 2023/1791 a Parlamentului European și a Consiliului din 13 septembrie 2023 privind eficiența energetică și de modificare a Regulamentului (UE) 2023/955”, Jurnalul Oficial al Uniunii Europene, september 2023.
[5] M. Adam, „Optimizarea instalaţiilor de ventilare/climatizare în regim de răcire în scopul asigurării eficienţei energetice şi a confortului în clădiri de birouri”, Editura Politehnica, 2014.