Dynamic Simulation Modeling. (DSM) for Building Energy Performance and HVAC Equipment Selection. A Case Study

Modelare prin simulare dinamică (DSM) pentru performanța energetică a clădirilor și selecția echipamentelor HVAC. Studiu de caz.

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Abstract. *The paper presents a case study in which a dynamic simulation modeling (DSM) calculation was carried out to assess the energy performance of a building in Giroc, a locality adjacent to the city of Timișoara, using the VABI Elements software. The characteristics were determined based on which the HVAC equipment was selected.*

Key words: *VABI Elements, dynamic simulation, DSM, envelope, parameters, buildings, cooling demand, heating demand*

1. General information

1.1. Objectives of the approach

What kind of house do we want?"

Most often, in the endeavor to build a building intended for residential use, a family desires certain functionalities to ensure:

a. *Optimal Comfort achieved through*:

- Thermal Comfort: Ensuring a pleasant temperature in all seasons, through efficient heating and cooling systems, as well as quality insulation.

- Acoustic Comfort: Sound insulation to reduce noise from outside and other parts of the house.
- Air Quality: Ventilation and air purification systems to maintain a healthy and fresh indoor environment.
- Lighting: Maximizing natural lighting and ensuring well-designed artificial lighting for visual comfort.
- Ergonomics: Interior design that facilitates movement and reduces discomfort, with furniture and equipment adapted to the needs of the residents.

b. *Enhanced Safety achieved through***:**

- Structural Security: The construction must comply with building safety standards, be resistant to natural factors (earthquakes, floods) and use high-quality materials.
- Security against Intrusions: Security systems such as alarms, surveillance cameras, motion sensors, and sturdy locks. An alarm system, surveillance cameras, and high-security locks can provide peace of mind and protection.
- Fire Prevention: Smoke detectors, fire extinguishers, and a clear evacuation plan in case of fire.
- Health Safety: Non-toxic materials, prevention of mold, and ensuring proper hygiene.

c.*Energy Efficiency* achieved by providing quality Insulation, double-glazed windows, and energy-efficient heating and cooling systems which can reduce costs and environmental impact.

d. *Green Spaces and Sustainability*: Gardens, outdoor recreation areas, and possibly solar panels or rainwater collection systems for sustainability and savings.

e. *Smart Home Technology*: Automated control systems for lighting, temperature, security, and other aspects of the home for comfort and efficiency.

f. *Ergonomic Design*: Ergonomically designed living spaces to maximize comfort and functionality - for example, kitchens with well-thought-out workspaces, spacious bathrooms, etc.

g. *Intelligent Zoning*: Creating separate areas for different activities (work, relaxation, sleep) can help maintain a healthy balance in the home.

h. *Air Guality*: Ventilation, treatment, and air purification systems to ensure a healthy and fresh indoor environment.

i. *Accessibility*: Design that allows access and comfort for people of all ages and abilities.

j. *Natural and Artificial Lighting*: Maximizing natural light and providing adequate artificial lighting for visual comfort.

k**.** *Durable and Quality Materials*: Using durable and high-quality materials that ensure a longer lifespan of the building and reduce the need for frequent maintenance.

To address the functionalities mentioned above in a unified manner, the current specialized literature recommends the use of Dynamic Simulation Modeling.

2. Dynamic Simulation Modeling

2.1. (DSM) - a tool in the design and construction of a residential building.

Dynamic Simulation Modeling is a powerful tool in the architect's and engineer's toolkit, enabling data-driven decisions to create buildings that are comfortable, energy-efficient, and sustainable.[3]. To facilitate this resolution, recent literature [1] and practice resort to dynamic simulation modeling (DSM), which can be an extremely valuable tool in designing and constructing a residential building that meets the above requirements through the following:

1. *Energy efficiency optimization*: DSM can simulate the thermal performance of the building, aiding in optimizing insulation, building orientation, windows, and heating/cooling systems for maximum energy efficiency.
2. *Thermal and acoustic comfort analysis*: Through DSM, various space usage scenarios and their impact on thermal and acoustic comfort can be assessed, allowing adjustments in the design phase.
3. *Study of natural and artificial lighting*: Simulations can help optimize the use of natural light and design artificial lighting systems to maximize visual comfort and energy efficiency.
4. *Indoor air quality assessment*: DSM allows for the simulation of ventilation and air circulation, important for maintaining good indoor air quality.
5. *Structural safety analysis*: Simulations can test the structural strength of the building in different conditions, such as earthquakes or strong winds.
6. *Security systems evaluation*: Simulations can assist in the optimal placement of surveillance cameras, motion sensors, and other security elements.
7. *Sustainability and environmental impact*: DSM can assess the building's impact on the environment, aiding in the design of a sustainable building.
8. *Flexibility and adaptability*: DSM can anticipate the future needs of occupants, allowing the design of a flexible and adaptable space.

Dynamic Simulation Modeling (DSM) is a sophisticated computational technique used in the field of building design and energy analysis. It involves creating a detailed computer model of a building that simulates its performance under various conditions over time.

2.2. Followed procedure

Given the specialization, among all the above dynamic simulations and considering there are multiple mathematical relationships and basic concepts to be taken into account, in the analyzed case, we chose to use Dynamic Simulation Modeling (DSM) with the objective of evaluating the energy performance of a building with a parallelepiped configuration and the thermal comfort inside, and later having the possibility to choose equipment for HVAC. The mathematical relationships and models that form the basis for a DSM simulation must be optimized, adjusted, and calibrated for the considered building, so as to encompass all its unique features, such as geometry, orientation, type and characteristics of construction materials, desired or existing HVAC systems, and the functions of the spaces in the building. To perform a simulation of the energy performance and thermal comfort of a building in the design stage located in Timișoara, Romania, using the information and mathematical relationships we have, the following input data about the building are necessary:

a. *Building Dimensions and Configuration*: Building plans including length, width, height, and number of floors. Also, the internal configuration (e.g., position and size of partition walls, position of windows and doors).

b. *Building Material Properties*: Information about materials used for walls, windows, roof, and floors, including their thermal transfer coefficients (U-value) and thermal capacity.

c. *Building Orientation and Positioning*: The direction the building faces, as this affects sun exposure and prevailing wind directions.

d. *Building Insulation*: Details regarding thermal insulation of walls, roof, windows, and floors.

e. *Heating, Cooling, and Ventilation Systems*: Type and efficiency of heating, cooling, and ventilation systems, including any heat recovery systems.

f. *Building Usage*: Information on how the building is used, including the number of occupants, types of electrical and electronic equipment, lighting, and any processes or activities generating heat.

g. *Local Climate Conditions*: Meteorological data for Timișoara, such as average monthly temperatures, humidity, wind speed, and solar radiation intensity.

h. *Operational Time Schedule*: The building's usage schedule, including variations throughout the day or year.

i. *Thermal Comfort Objectives*: Desired parameters for thermal comfort, such as specific indoor temperatures.

3. The mathematical relationships and models that form the basis for a DSM

Dynamic Simulation Modeling (DSM) for building energy performance and HVAC (Heating, Ventilation, and Air Conditioning) equipment selection involves a complex process that uses mathematical models and simulation software to assess a building's energy performance and to optimize the selection and sizing of HVAC equipment[8]. Below are some of the relevant equations and principles used in this context:

3.1 Thermal Balance for a Room or Building

The thermal balance is fundamental in modeling the energy performance of buildings and can be expressed as:

$$Q_{total}=Q_{internal}+Q_{solar}+Q_{transmission}+Q_{infiltration}-Q_{ventilation}-QHVA_{CQtotal} \quad (1)$$
$$Q_{total}=Q_{internal}+Q_{solar}+Q_{transmission}+Q_{infiltration}-Q_{ventilation}-Q_{HVAC}$$

where:

- Q_{total} is the net thermal load on the space (positive for heating, negative for cooling);
- $Q_{internal}$ is the heat generated internally by occupants, equipment, etc;
- Q_{solar} is the heat gain through windows from solar radiation;
- $Q_{transmission}$ is the heat transferred through walls, roofs, and other elements of the building envelope;
- $Q_{infiltration}$ is the heat lost or gained through uncontrolled air leakage;
- $Q_{ventilation}$ is the heat lost or gained through controlled ventilation;
- Q_{HVAC} is the thermal load removed or added by the HVAC system.

3.2 Calculation of the Heat Transfer Coefficient (U-ValConvective and radiative heat transfer equation):

$$\dot{Q}=U\cdot A\cdot(T_{int}-T_{ext})\dot{Q}=U\cdot A\cdot(T_{int}-T_{ext}) \quad (2)$$

where:

- $\dot{Q}$ represents the rate of heat transfer;
- U is the overall heat transfer coefficient;
- A is the heat transfer area;
- T_{int} and T_{ext} are the indoor and outdoor temperatures, respectively.

$$U=11hext+\sum(diki)+1hintU=hext1+\sum(kidi)+hint11 \quad (3)$$

where:

- U is the heat transfer coefficient of a building element (W/m²K);
- h_{ext} and h_{int} are the external and internal heat transfer coefficients, respectively (W/m²K);
- di and ki are the thickness and thermal conductivity of each layer of the building element.

4. Simulation of HVAC System Performance

Simulating HVAC systems involves calculating thermal loads and the response of the HVAC system to these loads. A simplified model for an HVAC system can be expressed through its efficiency and response capacity:

$$QHVAC=COP\times E_{input}QHVAC=COP\times E_{input} \quad (4)$$

where:

- QHVAC is the heat removed or added by the HVAC system (W).
- COPCOP is the Coefficient of Performance of the system (a measure of system efficiency).
- E_{input} is the electrical or thermal energy consumed by the system (W).

4. Dynamic Modeling

Dynamic modeling involves using differential equations to represent the temporal variations of temperature and other relevant variables within the building. A simplified example could be:

$$CdTdt=Q_{total}-QHVACCdtdT=Qtotal-QHVAC \quad (5)$$

where:

- CC is the thermal capacity of the space (J/K).
- dTdtdtdT is the rate of change of temperature over time.
- TT is the temperature inside the space.

These equations are just a starting point. Detailed DSM models for buildings will include many other aspects, such as detailed modeling of airflows, complex interactions between different spaces and systems in the building, as well as integration with renewable energy sources and energy storage systems. Specialized software, such as EnergyPlus, TRNSYS, or IESVE and VABI are often used to perform such detailed simulations.With this information, mathematical relationships can be used to dynamically model heat transfer, energy consumption, the impact of insulation, and the efficiency of HVAC systems. Also, estimates can be made for heat gains and losses, as well as for thermal comfort inside the building. In the case study, the VABI ELEMENTS SOFTWARE was used[8]. There are also other simulation software such as EnergyPlus or DesignBuilder that can be used to perform these types of complex simulations.

4. Information about vabi elements software

With the help of VABI Elements software, a fairly accurate 3D model of a building can be quickly created for dynamic simulation modeling (DSM) to evaluate a building's energy performance and indoor thermal comfort. This calculation takes into account detailed information about the building's structure and installations, as well as specific details regarding occupancy levels and schedules.

The software provides a simulated environment which, for the buildings to be analyzed, can be calibrated based on available measured and recorded consumption data. It can then be used to test various scenarios either at the whole building level or at the level of a zone or a room, to identify potential energy consumption issues and improvements that can be made to both the building and its installations.

For the building analyzed in our study, to simulate the building's performance over a flexible time period, the calculation uses hourly climate data files corresponding to the Timișoara area. It analyzes periods from the warm season, with peak maximum temperatures, and the cold season, with peak low temperatures.

Dynamic simulation modeling helped us understand how the chosen building for the study works from the perspective of consumption, energy management, and comfort, relative to its potential. Usually, residential buildings, institutions, cultural and sports buildings can have poor energy and comfort performance if there is no active management of the building and its related installations, including their regular maintenance. Significant energy savings can be achieved through modeling existing equipment, their control settings or from BMS - Building Management System, and by assessing the effect of changes on possible control methods. Also, many buildings have reference values for their heating and cooling that lead to waste both for energy used in heating and that used in cooling under conditions of simultaneity.

The VABI model allows an assessment of the impact of changes through simulation before the beneficiary commits to investments for improving efficiency as well as for determining the characteristics of HVAC equipment. The effects of changes in building use (such as a reorganization of internal occupancy patterns) can also be evaluated before implementation.Starting in 2008, the issue of potential health risks due to Bisphenol A (BPA) - a chemical found in plastic materials, was raised. BPA is a chemical that has been used to harden plastics over the last 40 years in the production of medical devices, CDs, water bottles, food and beverage packaging, and many other products found in building materials.VABI Elements can also take into account BPA in the evaluation of building performance. BPA can be incorporated into the ESOS - Energy Savings Opportunity Scheme process and offers possibilities for analysis and classification of the building within the provisions of ISO 50001 - Energy Management Standard.

5.Case study

5.1. Information about the analyzed building and the chosen solutions

The study conducted was used for the 'design' phase of the heating and internal sanitary installations, titled 'Construction of a ground-floor house, car and pedestrian access, carport', located in Giroc, Timis County.

The project was designed to comply with the requirements of Romanian or European standards, and where different regulations exist, the most stringent ones will be followed in principle. The design of the indoor sanitary installations is based on the architectural plans of the building, with the positioning of the sanitary groups and sanitary objects. The preparation of hot water is achieved with the help of a vertical boiler with a volume of 300 liters, equipped with two coils and an electric resistance of 3 kW. The primary coil is supplied with heat using an air-to-water heat pump with a power of 14 kW. The secondary coil is supplied with thermal agent from completely automated vacuum tube solar panels. Energy consumption for hot water preparation is reduced by setting economical delivery temperatures for the consumable water. The prescribed value for locally or centrally prepared hot water using conventional sources is 60 ºC. The temperature of the water in the boiler can be automatically raised to 60 ºC once every 2 days for 2 hours during the night to eliminate the possibility of Legionella contamination; otherwise, the temperature can be maintained at 50 ºC. Hot water for the pool is prepared through a tubular heat exchanger made of titanium, supplied with thermal agent from a fully automated solar panel kit.

Parameters considered for winter calculation: Exterior • Design exterior temperature: Te = -15°C • Relative humidity: φ= 90% Interior • Design interior temperature: Bedroom: Ti =20°C, Bathroom: Ti =24°C, Living room: Ti =20°C, Kitchen: Ti =20°C • Relative humidity: φ= 35 - 60%.

The calculation of the heat demand of the rooms was carried out according to the Romanian standard SR-1907/1,2-2014. All the installed power of the circuits was distributed from the heat pump located in the technical space on the ground floor.

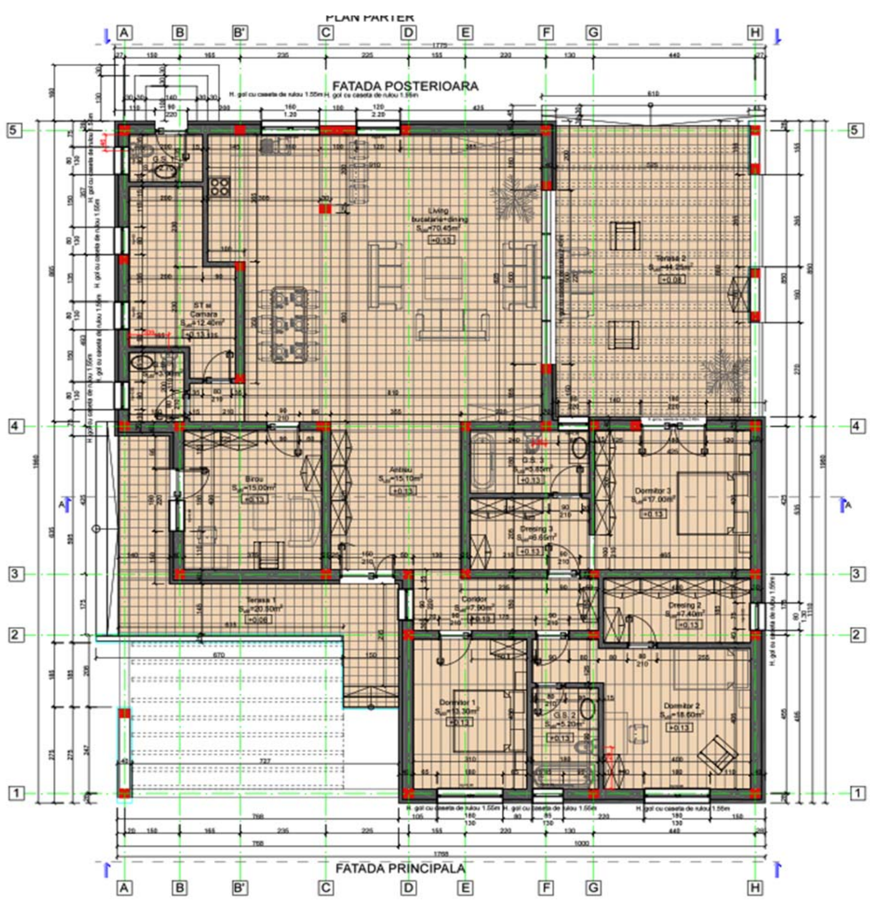

Fig. 1. The interior characteristics of the rooms in the studied building

The installed system is intended to compensate for heat losses through the external construction elements until achieving the calculated interior temperatures, both during cold months and seasonally. The technical room is equipped with an air-to-water heat pump with a power of 14 kW. Additionally, the heat pump will produce domestic hot water through the boiler with two coils and a single-phase electric resistance of 3 kW. For the optimal operation of the system, a variable temperature automation has been proposed for the underfloor heating circuit, with adjustment possible through the local thermomechanical automation system of the underfloor heating. For cooling purposes, a ceiling cooling system of Uponor Renovis type has been provided, following the calculations obtained according to SR 6648-1:2014 " Ventilation and air conditioning installations. Calculation of heat inputs from the outside and of the (sensible) cooling thermal load for the calculation of the rooms of an air-conditioned building. Basic prescriptions" and SR 6648-2:2014 " Ventilation and air conditioning installations. External climatic parameters" . The Uponor Renovis system for the ceiling consists of a 15 mm gypsum board panel in which the high-quality Uponor PE-Xa pipe is already factory-integrated. The elements can be installed as dry-mounted panels on almost any type of ceiling using a 27/60 CD profile substructure available on the market. After filling and sanding the joints, the Uponor Renovis system elements can be immediately installed. For building ventilation, i.e., the supply of fresh air and heat recovery, circular heat recovery units mounted in the wall have been provided, with 3 speed stages and a copper heat exchanger. A minimum of 50 m^3/h of fresh air flow is ensured. The energy efficiency of the recovery is 95%.

The characteristics of the building envelope elements were also defined based on the details from the architectural project, resulting in the thermal transfer resistances presented in Table 1. The exterior walls of the building are made of brick masonry with cavities and thermal insulation with a thickness of 10 cm. For the terrace-type roof, the use of a 20 cm thick layer of mineral wool insulation was proposed. The ground floor slab was also thermally insulated with a 5 cm thick layer of extruded polystyrene placed beneath the reinforced concrete slab.

The calculation was performed at the level of each room, according to the thermal zoning presented in Figure 1. Thus, for each room, parameters such as: winter design indoor temperature, summer design indoor temperature, air changes per hour, installed lighting power were defined. The aforementioned parameters are presented in Table 1. As the number of building occupants, 4 permanent occupants were considered.

Table 1

Thermal resistances of the building envelope elements

Designation of Envelope Element	Thermal Resistance R [m^2K/W]
Exterior Walls	3.05
Flat Roof	5.58
Slab in Contact with the Ground	4.66
Exterior Joinery	0.77

The calculation was performed at the level of each room, according to the thermal zoning presented in Figure 2. Thus, for each room, parameters such as: winter design indoor temperature, summer design indoor temperature, air changes per hour, installed lighting power were defined. The aforementioned parameters are presented in Table 1. As the number of building occupants, 4 permanent occupants were considered. Upon running the analysis in the calculation program, several useful data have been obtained. Figure 3 shows the heat losses through transmission corresponding to each envelope element of the building. The most significant heat losses occur at the level of the exterior walls and the terrace-type roof.

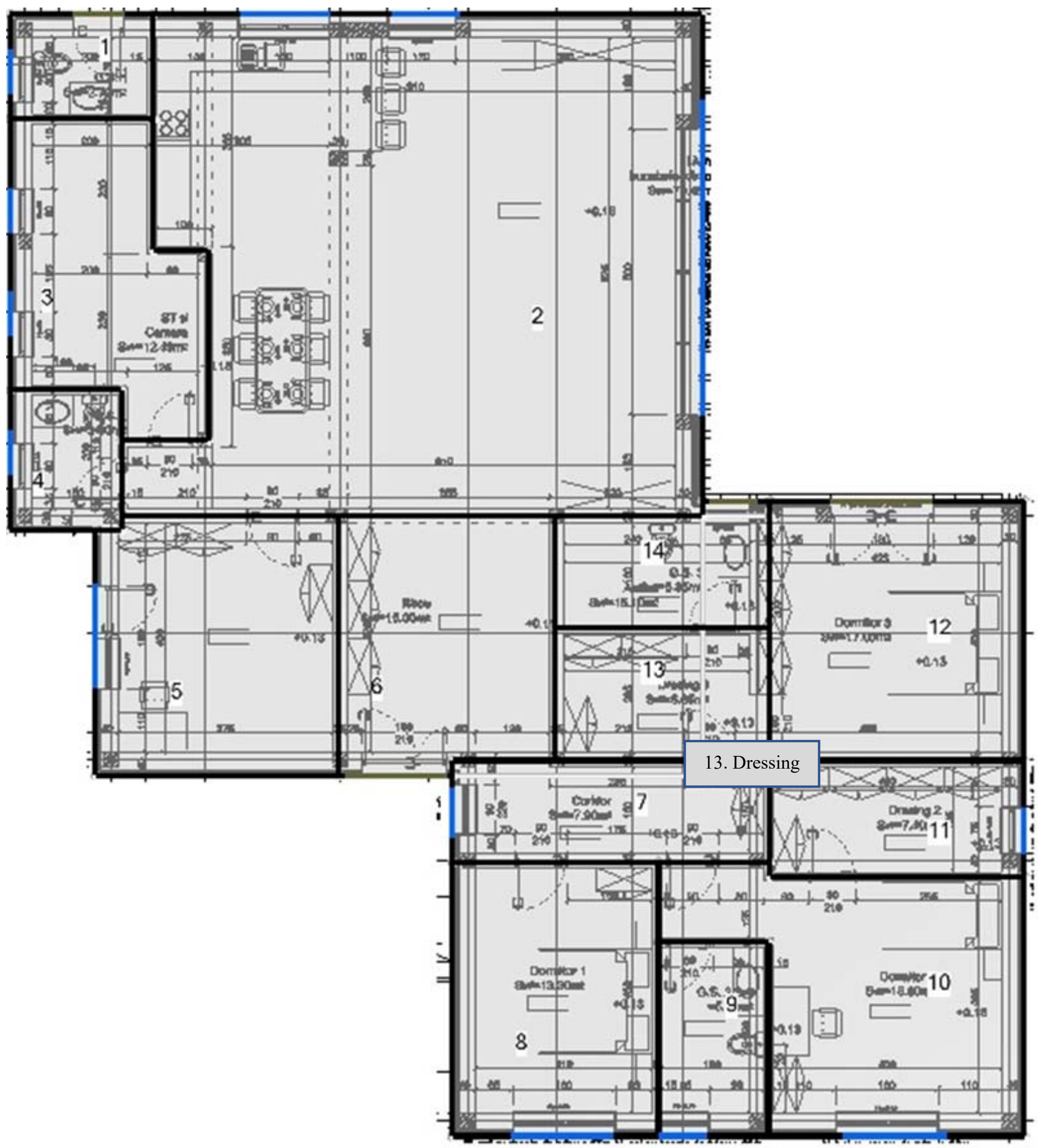

Fig. 2. The thermal zoning of the building

Table 2

Parameters related to the rooms in the building

No.	Denumire incapere/Room name	Temperatura interioara de calcul iarna/Interior deisgn temperature for winter [°C]	Temperatura interioara de calcul vara/Interior deisgn temperature for summer [°C]	Putere instalata iluminat/ Installed lighting power [W/m^2]	Numarul de schimburi orare de aer/Number of air changes per hour [h^{-1}]
1	G.S	24	-	10	10
2	Bucatarie si dining/kitchen and dining	22	26		
3	ST-tehnical space/pantry	22	-		
4	G.S	24	-		
5	Birou/Office	22	26		
6	Antreu/Hallway	22	26		
7	Corridor	22	26		
8	Dormitor/Bedroom1	22	26		
9	G.S 2	24	-		
10	Dormitor/bedroom2	22	26		
11	Dressing 2	22	-		
12	Dormitor/bedroom3	22	26		
13	Dressing 3	22	-		
14	G.S 3	24	-		

Additionally, as a result of the simulation, the values of the cooling and heating requirements for each room were obtained, as centralized in Table 2. The total heating requirement of the building is 11.40 kW, and the total cooling requirement is 10.56 kW. These values were the starting point for sizing the equipment at the level of each room and the heat pump.

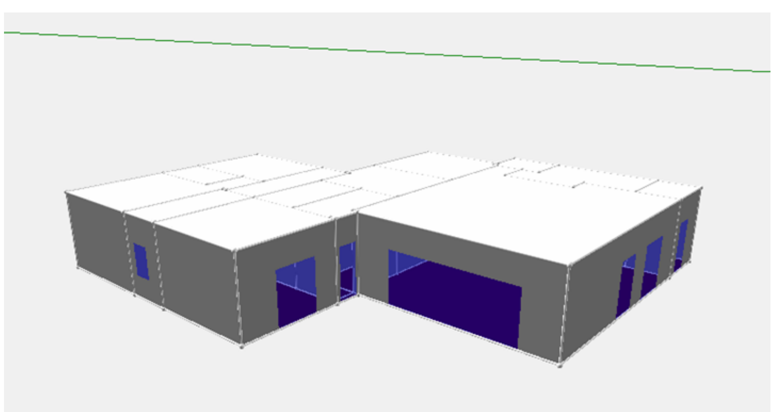

Fig. 3. D calculation model in VABI software

5.2. Calculations performed with VABI software

Table 3

Maximum cooling load per room

No. Room	Room type	Temp [°C]	Sensible cooling load [W]	Latent cooling load[W]	Total cooling load[W]	[W/m^2]	[W/m^2]	Month max	Time max
Living-Kitchen and dining	VG	26	3400	183	3583	49	17	August	11
St-tehnical space/pantry	TR	26	484	0	484	41	15	June	20
Office	VG	26	978	14	992	63	22	June	19
Antreu/hallway	VKR	26	172	0	172	13	5	July	20
Corridor	VKR	26	420	0	420	59	22	June	19
Dormitor/bedroom 1	VG	26	756	14	770	56	20	August	19
Dormitor/bedroom 2	VG	26	743	14	757	41	15	August	19
Dressing2	VG	26	408	20	428	67	24	August	10
Dormitor/bedroom 3	VG	26	305	20	325	20	7	July	8
Dressing3	VG	26	201	20	221	34	12	Ju;y	8

Table 4

Monthly cooling load for building

Time Period	May	June	July	August	September	Max
8	4872	5142	5284	4887	3311	July
9	5020	5344	5439	5337	3849	July
10	5483	5771	5904	5834	4678	July
11	5155	5441	5547	5478	4477	July
12	5328	5505	5606	5626	4857	August
13	5475	5596	5699	5765	5104	August
14	5536	5634	5763	5828	5150	August
15	5399	5536	5656	5709	5009	August
16	4945	5203	5297	5227	4425	July
17	4927	5214	5328	5179	4303	July

Table 5

Daily output Month July

Temp Outside[°C]	Max temp inside cooling [°C]	Internal cooling load [W]	External cooling load [W]	Building Temp variation[W]	Total sensible cooling load[W]	Total latent cooling load[W]	Total cooling load[W]
21.5	26	2141	2845	0	4986	297	5284
23.4	26	1687	3456	0	5142	297	5439
25.7	26	1663	3944	0	5607	297	5904
27.1	26	1024	4226	0	5250	297	5547
28.1	26	1000	4308	0	5309	297	5606
28.9	26	995	4407	0	5402	297	5699
29.6	26	976	4490	0	5466	297	5763
30.4	26	949	4410	0	5359	297	5656
31.0	26	1104	3996	0	5100	197	5297
31.5	26	1148	3983	0	5131	197	5328
31.4	26	1164	4095	0	5260	197	5457
31.0	26	1888	4140	0	6027	267	6295
30.3	26	1922	3932	0	5854	267	6121

Table 6

The maximum cooling load occurs in July at 19

No.Room	Sensible[W]	Latent[W]	Cooling load [W]
Living-bucatarie and dining	1927	183	2110
St-tehnical space and pantry	471	0	471
Office	965	14	979
Antreu/hallway	172	0	172
Corridor	411	0	411
Dormitor/bedroom1	722	14	736
Dormitor/bedroom2	712	14	726
Dressing 2	238	14	252
Dormitor/bedroom3	241	14	255
Dressing 3	168	14	182
Total	6027	14	6295

Table 7

Calculation heat loss residential building ground floor

No.	Room Name	ISSO	Temp [°C]	Transmission [W]	Ventialtion [W]	Reheat [W]	Total[2] [W]	Total [W/m^2]	Total [W/m^3]
1	G.S	51	24	370	63	0	433	150	53
2	Living-Bucatatarie /kitchen	51	22	2245	1471	0	3716	51	18
3	ST pantry /hallway	51	22	423	237	0	660	56	20
4	G.S	51	22	361	67	0	428	139	50
5	Birou/ office	51	22	677	313	0	991	63	22
6	Antreu/ hallway	51	22	254	266	0	520	39	14
7	Corridor	51	22	236	137	0	373	53	19
8	Dormitor/ bedroom1	51	22	583	277	0	860	62	22
9	G.S2	51	22	378	97	0	475	108	18
10	Dormitor/ bedroom2	51	22	664	368	0	1033	56	20
11	Dressing 2	51	22	215	128	0	343	53	19
12	Dormitor/ bedroom3	51	22	556	331	0	886	54	19
13	Dressing3	51	22	82	126	0	208	32	12
14	G.S 3	51	24	357	117	0	473	83	32
Total				7400	3999	0	11399	57	20

5.3. Selection of equipment for installations following calculations with VABI software

Equipment selected following the calculations of dynamic simulation modeling (Dynamic Simulation Modeling - DSM) with VABI Elements software for the studied house:

- Vitosol 200-TM vacuum tube collector. TheVitosol 200-TM vacuum tube collector was specially designed for horizontal installation in large systems on flat roofs and for apartment buildings. The absorbers can be rotated at 45 degrees to best reflect the sun's trajectory without increasing shading.
- Mitsubishi Electric PUHZ-SHW140YHA heat pump This outdoor heat pump unit features Zubadan technology, which allows it to maintain its nominal heating power down to -15°C and continue operating down to -28°C.
- Coated domestic hot water calorifier with 2 fixed heat exchangers.

Data have been calculated on following basis: primary circuit at T1 and proper energy source; production of DHW in continue way from 10 °C at t2, DHW that can be taken in the first 10’ and in the first hour from storage at 60°C, input 10°C and output 45°C, sanitary water according to UNI CTI 8065.

6. Conclusions

This paper presents the method of determining theheating and cooling requirements for a residential building, using the VABI Elements automatic calculation program. For the case study building, the heating and cooling needs were determined, for each room and for the building as a whole. Modeling the building in the VABI program allowed for quick and organized results, even in the case of minor architectural changes that occurred during the project development.[5]#The use of the VABI calculation program represents a useful tool in the calculations of heating and cooling needs, as it offers an optimal perspective through the 3D visualization of the analyzed building and the possibility of analyzing multiple scenarios [8].

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