Computer modeling and simulation - tool for design of buildings and its systems

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Abstract. This paper presents a real example of optimizing the design of buildings and the systems they serve, through computer modeling and simulation. It highlights the capabilities of the DesignBuilder simulation software used as a design tool for buildings and systems for heating, ventilation and air conditioning. The paper also includes discussions and conclusions about how simulation results can provide important information for building design. The building for which the research presented here were done is the Transilvana University of Brasov Development Research Institute (Romania).

1. Introduction
Reducing energy consumption for the operation of buildings, of any kind, is a wish of today's modern economy, both nationally and globally. That is why solving, as accurately as possible, the problems of heat transfer and fluid flow is of major importance in the various applications in the field of civil engineering [1].

It is well known that currently one of the best techniques available for prediction, in the design phase of the actual thermal behavior and energy consumption of a building, is computer modeling and simulation. [2]. This technique, initially used mainly in research, has become increasingly used in current design practice.

With this technique a building is treated and optimized in its entirety, not as a sum of components and systems optimized separately. Also, the simulation has the advantage that in addition to the structure itself of the building, it can also include the interior and exterior environment (of the building), and can also deal with problems related to the classical energy systems of the building, or those of renewable energy [2]. At the same time, with this technique, several solutions regarding the geometry of the building, the construction of the tire or of the heating/cooling (air conditioning) systems can be analyzed in detail and compared with each other.

However results are highly dependent on the knowledge of the person setting up the model and interpreting the results. This is a problem in extending the use of CFD in building design, because CFD software becomes easier to use by people with little understanding of the mathematical model underlying it [3].
In the present research, we used the DesignBuilder software tool. This is a unique software tool for creating and evaluating building projects. It provides a wealth of data on environmental performance, such as: maximum summer temperatures, comfort conditions, energy consumption, carbon emissions, as well as dimensions of HVAC components. DesignBuilder uses the latest EnergyPlus simulation engine to calculate building performance and is suitable for use by architects, energy consultants and construction service engineers. Among the typical uses of this software can be mentioned [4]:

- Calculation of temperature and pressure distribution in and around buildings, using CFD;
- Evaluating a wide range of options for the facade, for the effect on overheating, energy consumption and visual appearance;
- HVAC design, including sizing of heating and cooling equipment;
- Thermal simulation of naturally ventilated buildings;
- Viewing the location of the solar shading in situ;
- Verification of optimal use of natural light.

To carry out the simulations, either real time data for the respective site or, in the absence of them, weather data of the reference year climate, for the locality in which the building is located are required. The simulations of the present research were performed on the basis of hourly values for five meteorological variables, provided by a weather station in Brasov.

Also, in choosing the design solution we also considered the studies performed by our colleagues from the marketing department, regarding the life cycle cost analysis in a building design [5].

2. The building for which the research was carried out

The building for which the research presented in this paper was carried out is actually an ensemble of 12 identical buildings (designed as research laboratories), two access and connection spaces between the buildings (called spines) and a centrally located atrium that forms the Transilvania University of Brasov Development Research Institute (ICDT). The way the 12 buildings are located is shown in figure 1 below. The dimensions of this ensemble are: 180 m long, 78 m wide and between 4.20 m and 7.40 m high, the atrium having the height of 10.20 m.

![Figure 1. The access and connection spaces between the 12 buildings and DesignBuilder model of part of the building.](image)

Each of the 12 buildings is composed of basement, ground floor and floor, and has a built area of 1440 m$^2$ each. The strength structure of the building is made of reinforced, longitudinal and transverse reinforced concrete columns and frames. The outer walls are made of BCA GBC 50 with a thickness of 20 cm and they are clad with aluminum panels, which have a polystyrene insulation with a thickness of 10 cm. The horizontal elements of the resistance structure are made of monolithic reinforced concrete slabs of 15 cm thick. The roof is of terrace type and has a mineral wool insulation with a thickness of 40 cm. [6].

The buildings are oriented with the main facades to the south and were designed with two glazed curtain walls: one on the south facade, with an area of about 90 m$^2$ and the other on the west (respectively east), with an area of about 36 m$^2$. The buildings are not sheltered.
The two connecting spaces between the buildings (Spinele) have an area of 480 m², each, the Atrium has an area of 630 m², resulting in a total useful area of the whole built, of 18870 m². The side walls and the roof of the Spines and the Atrium - with the exception of those common with the laboratories - are glazed surfaces.

3. Research results
Here is presented how, through the carried out researches, the optimal solutions were chosen for two of the important problems whose solution depends, to a large extent, the energy consumption of the building assemblies, namely:

- choosing the best solution for glazed surfaces;
- choosing the optimal solution for heating systems.

In addition to solving these specific problems, from the research carried out with the help of simulations, other important conclusions and indications have been drawn regarding: the interior environment of the buildings (in the cold and hot seasons), the maximum heating and cooling tasks, the operation and control of HVAC systems etc.

3.1. Choosing the best solution for glazed surfaces
Whereas:

- large portions of the external walls are designed as glazed;
- in Romania, the solar thermal inputs during the summer, through a triple glazed surface are about 6.5 MJ/m² - for the south orientation and 5.5 MJ/m² - for the west orientation (which significantly influences the overall energy of the building and its performances, the first part of the study aimed at choosing the best solution for glazed surfaces [6].

As the architectural design mode and the degree of glazing differ from one type of building to another, the study was carried out for each type of building separately:

- laboratories;
- spines;
- atrium.

Thus, for each type of building the annual energy consumption for heating (and cooling) was compared for four variants (double glazing surface, triple glazing surface and two different types of glass). The results of this part of the study are shown in figure 2, below.

![Figure 2. Annual energy consumption for heating depending on the type of glazing.](image)

Following the study, for all the glazed facades and all the windows, a very high performance triple glazing system was chosen, whose specific characteristics are: low solar energy transmittance (32.4%), low overall heat gain factor (32.8%) and high visible transmittance (58.2%).
3.2. Choosing the optimal solution for heating systems

Whereas:

- the way of architectural conception differs from one type of building to another;
- the destination, occupancy and interior comfort parameters are different, also, the study was performed for each type of building separately: laboratories, spines and atrium.

Regarding the laboratories (in which the indoor temperature in the cold season must be 20°C) we considered the following:

- the structure of the strength structure with concrete pillars and frames, with horizontal elements consisting of monolithic reinforced concrete slabs, which constitutes a structure with an important thermal mass;
- the fact that the laboratories do not have a high degree of occupancy, which means that they do not need major fresh air exchanges;
- the fact that although they are important, the solar thermal inputs during the hot season are not as great as in the case of the spines and the atrium, which means that we can achieve the indoor climate and without having an air conditioning system, which would be a great energy consumer.

Therefore, we chose to analyze two solutions for the heating system:

- Thermoactive building systems (TABS);
- heating system with static radiators.

Regarding the spines and the atrium (in which the indoor temperature in the cold season must be 18°C) we considered the following:

- the fact that the solar thermal inputs during the hot season are very high, which means that a cooling system is needed;
- the fact that these spaces do not have a high occupancy, which means that they do not need major fresh air exchanges;
- the fact that they do not need to be cooled during the cold season.

Therefore, we chose to analyze two solutions for the heating system:

- TABS;
- heating system with hot air, with which to carry out the cooling in the hot season. The results of this part of the study are shown in figure 3, below.

![Figure 3. Annual energy consumption for heating depending on the heating system.](image)

The primary purpose of this project was to ensure that the buildings as a whole have the least energy consumption for heating (and cooling). According to this objective, and based on the results of the study carried out (presented in the figure above), we have chosen the best solutions for the heating (and cooling) systems of the whole building. As for the laboratories, we opted for heating with a TABS,
whose energy consumption is lower due to the use of the important thermal mass of the building. Regarding the cooling, given the relatively low temperatures (the location is located in a mountainous area) of the outside air in the hot season, we opted for natural ventilation and night cooling, with the help of operable windows. Regarding the spines and the atrium, an heating system with air would respond better to the indoor climate, both in the hot and cold season, but would involve a high energy consumption. Considering:

- that they are not continuously occupied spaces, but only connection spaces between the buildings, and that in the cold season we must ensure a lower indoor air temperature (18°C);
- that in the atrium it is necessary to realize the comfort conditions, in the cold season, only for an area occupied with the height of (2.50-3.00) m;
- the relatively low temperatures of the outside air during the hot season, which favors the cooling by natural ventilation and a very good night cooling, we opted, for the spines and the atrium, also for heating with a TABS.

Obviously, energy saving was an important factor in choosing this solution. In addition, the owner's intention was also taken into account in the future to develop a system of ground/water heat pumps (with wells drilled to a depth of 100 meters), which would provide the full amount of thermal agent needed to heat the institute's buildings. We considered that in this situation, during the hot season, with the help of the TABS, a passive cooling with cooled water is carried out in the drilling holes of the heat pump system. Opting for this solution I accepted that, both in the cold and hot season, short periods of time can occur when the thermal comfort could suffer.

4. Conclusions

Today, an important trend in the design of buildings and the systems that serve them, is that it starts from the requirements of integration of the latest technologies in the field of construction, and less from the primary need to design, through modeling and simulation, energy-efficient buildings.

Even so, there are many design teams in the field of heating, ventilation and air conditioning (HVAC), who are aware of the benefits, in terms of energy performance and environmental protection, of this design technique, and therefore use it. We believe that, in the near future, by introducing design standards based on energy performance, construction design will increasingly use the technique of building design through computer modeling and simulation. In the present paper, a real application related to the optimization of the design of the buildings and the systems that serve them was presented, through computer modeling and simulation. The DesignBuilder software, which we have used here, has the ability to provide all the data related to the thermal behavior of the building being designed, the conditions of its interior environment, to help the designers in adopting the most efficient solutions. Of course, it is not easy to do design using this technique. This requires a thorough knowledge of the software, a certain experience in its use and in the interpretation and validation of the data it provides. It also takes more time, which makes this technique somewhat costly.

References

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