DOI: http://dx.doi.org/10.24018/ejers.2017.2.5.325 *EJERS, European Journal of Engineering Research and Science*
*Vol. 2, No. 5, May 2017*

# Energy Efficiency Analysis in Buildings using Dynamic Simulations

Elena Eftimie

***Abstract*— This paper proposes an analysis of factors that have a significant impact on energy efficiency in buildings. Thus, as a first objective proposes an analysis of the impact of rehabilitation and modernization of buildings in view of their energy performance improvement. A second followed objective consisted of the study of some production and use thermal energy systems in order to increase the thermal comfort. Based on a case study, this paper provides the opportunity for comparative analyses both among different insulation materials for buildings and among different heating systems. Determination of energy consumption for space heating and of the building comfort parameters was achieved using dynamic simulations by means of TRNSYS program; it was envisaged that the assessment of energy efficiency in buildings, the design stage or before their rehabilitation, is more economical than finding solutions in the use phase of buildings.**

***Index Terms*— Dynamic simulation; Energy efficiency in buildings; Heating system; TRNSYS.**

## I. Introduction

One of the widely adopted measures to reduce heat consumption in buildings - both in Europe and in Romania - targets the enhance of energy performance of buildings and the programs implementation of thermal rehabilitation of buildings. It is envisaged that the share of energy consumed in buildings is very important, this sector offering a huge potential for major reduction of energy consumption [1].

The increase of energy efficiency and the reducing the energy loss in buildings are aimed at the decrease of energy consumption; we refer to fact that one of the biggest consumers of energy is represented by buildings and unquestionably by those from residential sector [1], [2].

In this context, the first stage of this paper aims at highlighting, through a case study, of the influence that different types of insulation systems of buildings have on energy consumption.

Thermal insulation of external walls of a building energy means the energy saving, respectively the costs reducing and protecting the environment. Also, the correct design of the exterior walls structure affects in significantly manner the building interior comfort.

The exterior conventional walls, with a single-layer (homogeneous) are not the appropriate solution, to ensure the current requirements thermal insulation. In the new buildings, it is recommended a multi-layered structure, and in the case of rehabilitation works, the use of an additional system for thermal insulation.

The quality of thermal insulation, in the case of building rehabilitation, has a great significance and the use of high quality materials has a number of advantages, among that is mentioned:

- energy saving for heating, which is reflected in financial savings;
- protecting the interior against overheating;
- protecting the supporting structure by external factors;
- thermal bridges elimination;
- maximizing of the heat conversion - it is envisaged that by a correct insulation of a building, a superior energy class can be achieved;
- high absorption of sound.

Another important objective in the design stage of buildings is represented by the selection of heating system respectively, conventional central heating system, radiant heating system or heating system by ventilation.

The conventional central heating systems consist of the placement of a specific number of radiators in room. The radiators are chosen so that to transfer the air heat from their immediate vicinity; in this way there are created warm air currents circulating through the room.

In case of heating using the radiators, the warm air starts to climb from a distance of one meter above the floor, focusing towards the ceiling; warm air remains in this area until it cools, then it descends turning into a cold air current to the feet level [3].

The disadvantage of these systems is that the top part of the room, under the ceiling, will heat more quickly and to a greater extent than the room. In addition, radiators occupy space and can negatively affect the aesthetics of the room.

Radiant heating systems can be installed either in the floor, wall or ceiling, achieving the direct heating of these areas and thus creating warm surfaces. These systems are comfortable, silent and the thermal comfort felt in case of the floor heating is also far superior to that with radiators [3].

The floor heating system starts from the property of the warm air to climb, this being lighter than the cold air. In this way we obtain a high degree of comfort, with higher temperatures to the feet level and lower temperatures to the head level. Not the least, this system represents an aesthetic solution.

Another heating solution is represented by the heating by ventilation with heat recovery. In this case, the humid and polluted air is evacuated, the fresh air being introduced; this fresh air is preheated using the recovered heat from the exhaust air.

Published on May 2, 2017.
E. Eftimie, is with the Department of Product Design, Mechatronics and Environment, Transilvania University of Brașov, Romania. (e-mail: eftimiem@unitbv.ro).

Most building designers have as objective the expenditure decrease with energy consumption for their heating, the result being a "sealed building," forgetting the fact that the buildings comfort is given also by the indoor air quality; therefore, an important aspect that should be taken into account when designing the heating systems is the quality of indoor air. It should be emphasized that ventilation in rooms is essential for a building. It is envisaged that an improper ventilation or even its absence lead inevitably to a considerable reduction in comfort. Modern buildings are very well insulated, the exterior envelope of the building is sealed and a natural ventilation is practically impossible; in these conditions, the vapors, odors from the kitchens and bathrooms, the cigarette smoke, molds, etc. accumulate and have a deleterious effect on comfort and the building [4]. For this reason, heat loss during ventilation determine largely the energy needs.

Among the advantages of using the heating systems by ventilation there are reminded:

- the increased comfort and a healthy climate; the moist and polluted air is replaced permanently with filtered fresh air;
- the evacuation of odours from kitchens and bathrooms;
- the building protection, because the condensate and moisture are removed permanently, the dampness problem and mould being actively prevented;
- the control of air conditioning by introducing the fresh air during the hot weather or winter.

## II. Materials and Methods Used

### A. Solutions for thermal insulation of buildings

Thermal insulation of buildings can be achieved both with classic and innovative materials as well with eco-friendly materials. At present we have available a large number of insulating building materials and also a series of solutions insulation of exterior walls; in these conditions it is recommended choosing the materials which have a good coefficient of thermal conductivity and that fulfil their function regardless of the season.

The thermal rehabilitation of buildings has an important role in the thermal comfort of dwellings; nonetheless, the extensive use of heat insulation systems based on polystyrene has led to ignoring of the alternative systems of insulation (the most common construction materials used for heat insulating are the expanded and extruded polystyrene).

The heat insulation systems based on polystyrene are preferred primarily because of the low price, but also because there are not know other insulation systems, which can be more efficient and longer lasting. Although the degree of thermal comfort among different insulation systems is similar, it should also be considered the durability of the products used.

Additionally, heat insulation systems must allow a proper ventilation of buildings, ventilation which to allow moisture removal.

Even if insulations based on polystyrene had known significant improvements in the recent years, it should be also considered the alternative solutions that can make the difference over time. Some examples are the heat insulating mineral boards, rigid polyurethane foam, heat insulating metal panels, mineral wool and the new brick types that does not require heat insulation.

*Polystyrene (in accordance with EN 13163 [5] and EN 13163 [6])*

In spite of the existing alternatives, the price of heat insulating systems based on polystyrene make it to be the most used for enveloping the buildings; it is envisaged that expanded polystyrene represents the solution that offers the highest efficiency and the highest rate of investment payback compared to other heat insulating materials.

However, there are aspects that must be considered carefully before deciding the use of systems with polystyrene. One of these aspects relates to the fire resistance; even if the polystyrene is fireproofed from the refinery, if the adhesive applied to system not covering the entire surface of the plate, holes that support combustion can occur and lead to melting of polystyrene.

Also, another aspect is the durability of the material; it is envisaged that ultraviolet rays can cause, in time, the disintegration of substance that acts with role of binder within polystyrene plates; and yet these aspects weigh less in the buying decision.

*Polyurethane foam (in accordance with EN 13165 [7])*

Perhaps the least known system for consumers is based on rigid polyurethane foam. The foam can be applied on the most types of dry constructions: concrete, brick, stone, plaster, wood, plasterboard or metal; the polyurethane foam forms a continuous envelope that separates the inside by the outer environment without thermal bridges.

This system is recommended for buildings with complex architectural shapes that do not allow the insulation with a product of panel type. The disadvantages of this system are obviously the costs by about 20% higher compared with the conventional insulation.

*Mineral wool (in accordance with EN 13162 [8])*

One of the usual materials (probably not as commonly as the expanded polystyrene) used in thermal insulation of exterior walls, mansard and roof is mineral wool.

The thermal insulation with mineral wool works both during the cold season and also during the summer; it is envisaged that this type of thermal insulation has a thermal resistance better during the cold season compared to expanded polystyrene panels.

The cost of insulation systems based on mineral wool is higher than that of systems using polystyrene. But the price difference is given by the resistance of mineral wool throughout the life of the insulated building (the basalt rock does not corrode and it is not corroded, it is not attacked by fungi and microorganisms, it does not represent food for insects and rodents, it does not rot) the high temperature resistance, the resistance to fire / heat, moisture resistance and by the acoustic insulation performance.

The metal panels, mainly used in the construction of office buildings, are another system based on mineral wool that can be used in insulation of a building. The panels fixed on an adjustable metal structure, that is assembled on masonry, provides a ventilation space between panel and wall which leads to a thermal insulation superior to other solutions on the market.

It is mentioned the fact that several manufacturers in insulation industry include the mineral wool into the category of organic materials because it does not pollute the environment and is not harmful to health.

*Cellular Glass (in accordance with EN 13167 [9])*

The cellular glass (as well as the mineral wool) works on the principle of air capture in holes to reduce the thermal conductivity from one surface to another. This can be easily mounted on the surface of walls representing a cost-effective insulating solution on the market. The insulating properties of the cellular glass, results from its achievement technology, by embedding a large volume of air among the continuous material fibers, air that is prevented from moving freely. The cellular glass is ideal, for example, to insulate attics.

Besides those mentioned above, another important aspect is that the cellular glass has the advantage of blocking the outside noises and is non-combustible.

In addition, compared to other building materials, the mineral wool products have a very low thermal conductivity, resistance to moisture accumulation or condensation, a stable structure in time and aging resistance. Also, they ensure a good ventilation, do not retain water and do not favor the growth of microorganisms.

*Ecological insulating materials*

To have a house in which the temperature to be ideal both summer and winter, without dampness or mold, it must be properly insulated. Intention to build environmentally friendly has led to the use of different materials of natural origin.

Among these there are mentioned: the straws, reed, clay, wool etc., materials that can be found generally easy and that does not involve industrial processing. Further there will be done a brief description of two of organic materials, namely the cork and the wood wool.

*Cork (in accordance with EN 13170 [10])*

The thermal insulation systems based on cork are used for exterior and interior walls, unheated rooms, sloped or flat roofs, floors, ceilings, ventilation ducts etc. It is envisaged that cork can accumulate ten times more heat than the insulation materials based on mineral fiber; also cork is durable and has great elasticity.

*Wood wool (in accordance with EN 13168 [11])*

Wooden boards have a reduced insulating capacity, reason why these are most often used as a support for plaster over other insulation materials. Although slabs insulating material have a relatively low thermal conductivity, these present a good capacity of heat storage, thus acting as a compensator against the temperature oscillations.

### B. Aspects regarding indoor comfort in buildings

One of the main objectives of the current research in the constructions area, is to reduce energy consumption in buildings, but with a constant attention directed on satisfying the comfort conditions. Refer to the objective and subjective requirements related to human vital functions concerning:

- the possibility of performing with maximum efficiency both the physical and intellectual work;
- the possibility of making some recreational activities, rest and sleep in best conditions.

Ensuring the comfort in buildings is a complex issue, the notion of technical comfort comprising all the parameters achieved and monitored with equipment, that directly influence the human disposal and they act on its senses, such as: thermal comfort, acoustic, olfactory and visual.

Regarding the subject of this work, further there will refer only to the aspects of thermal comfort.

The thermal comfort is a notion difficult to quantify in figures, this depending both on objective parameters, as well as subjective parameters related to each individual person.

The most important factors that contribute to thermal comfort (air temperature, mean radiant temperature, relative humidity, air velocity, barometric pressure) must be correlated with the recommendations concerning the limits of thermal comfort indicators, PMV and PPD, contained in ISO 7730: 2006 [12]. The standard SR EN ISO 7730: 2006 quantify the thermal comfort with the following associated terms:

- PMV (Predicted Mean Vote) represents the thermal sensations expected from individuals, for indoor environment;
- PPD (Predicted Percentage Dissatisfied) represents a percentage value allowable by individuals dissatisfied with a state of the indoor comfort parameters.

PMV factor has values between -3 and 3, where negative values represent the cold sensation and the positive values the heat sensation; the value of 0 represents the sensation of comfort, of thermal equilibrium with the environment.

The relationship between PMV and PPD can be expressed such: the thermal conditions are considered comfortable when the percentage of people who feel comfortable is over 90% and the percentage of people who feel uncomfortable is below 10%. Therefore, in accordance with EN ISO 7730: 2006, the percentage of dissatisfaction for a certain thermal environment, PPD, should be less than 10% and the predicted mean vote, $-0.5 < PMV < 0.5$ [13].

## III. Results and Discussions

### A. Case study

As a computing variant it is proposed an office building of the Transilvania University of Brasov, building presented in [14]. In the study presented by the mentioned paper, the variant of insulation system, most convenient in economic terms, is represented by the insulation of the external walls with polyurethane foam and the use of triple-pane insulation glass windows ($u=0.4$ W/(m$^2$K); $g=0.408$).

The present work will start from this variant and proposes a brief comparative analysis of the building's heating demand depending on the different materials used to insulate the exterior walls. Besides the classic insulation materials, the most common in exterior walls insulation (extruded and expanded polystyrene), the proposed comparative analysis will consider also the thermal insulation systems with mineral wool, cork, wood and cellular glass.

For all analyzed insulation materials, a thickness of 15cm was considered.

The building subjected to the analysis consists of five zones, two of them - the biggest main areas – being designed to offices. The building is conceived on two levels; each office being located on one floor.

The calculation of energy needs for space heating was accomplished considering for the heating regime a temperature of 21°C for the two zones representing the offices (therefore, there were considered only two heated zones).

The evaluation of the energy consumption structure for the analyzed building, was achieved using modelling and simulations with TRNSYS software.

All the proposed TRNSYS simulations were performed for the climatic conditions of the urban area of Brasov (Romania) [14]. It is mentioned that the weather data implemented in the TRNSYS subroutines contain the monitored data from a local Weather Station (Delta T) placed near the building subjected to review; Brasov area is characterized by a temperate continental climate profile and it is geographically situated at 23.1°E longitude and 45.5°N latitude.

In the first stage of the simulations, for the building subject to analysis, it was accomplished the calculation of its energy consumption. The use of computer modelling and simulation techniques specific to the TRNSYS software has enabled additional verifications of energy behavior of building, using different types of materials for thermal insulation of exterior walls.

The second stage of simulating the energy consumption of the building was accomplished to investigate the design problems of the heating systems.

Taking into account that simulation software are tools of the most accurate calculation, that allow dynamic simulation at short intervals, all energy consumption simulations were performed at intervals of 10min.

### *B. Energetic simulation of building - Space heating demand*

The first phase of the energy simulations consisted of the determination of space heating demand using different materials for thermal insulation of exterior walls, namely: extruded polystyrene (XPS), expanded polystyrene (EPS), polyurethane foam (PUR), mineral wool (MW), cork (ICB), wood wool (WW) and cellular glass (CG).

The results obtained from the performed simulations are presented as comparative diagrams, respectively, the monthly consumption for heating space demand is shown in Fig. 1, and the annual values of the heating space demand and the percentage differences between these are shown in Fig. 2 (these percentages were calculated compared to the variant with polyurethane foam insulation system).

Most effective material, in terms of the least value of the space heating demand, is represented by polyurethane foam (12045kWh / year).

However, it should be mentioned that among the different insulating materials - less in terms of wood wool - there are no significant differences in terms of energy consumption for heating. Using thermal insulation materials such as extruded polystyrene, expanded polystyrene, mineral wool, cork, cellular glass (without taking into account the wood wool) the annual percentage increase in consumption for heating versus polyurethane foam, ranges between 2.36% and 6.01% (Fig. 2).

It is also remarked that thermal insulation with mineral wool has an energy performance higher than that of expanded polystyrene and very close to that of extruded polystyrene.

In addition, if there are taken into consideration the better durability of the thermal insulation system with mineral wool, there can be concluded that, this is superior to the thermal insulation with polystyrene.

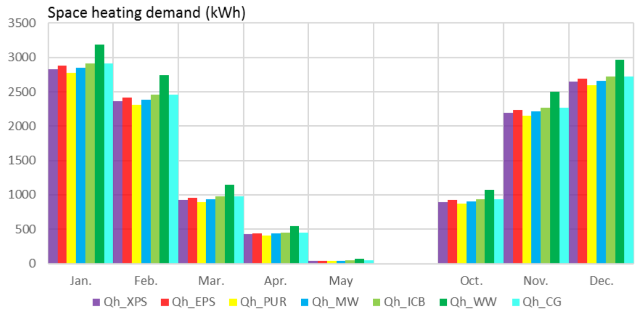



Fig. 1. Monthly values of space heating demand.

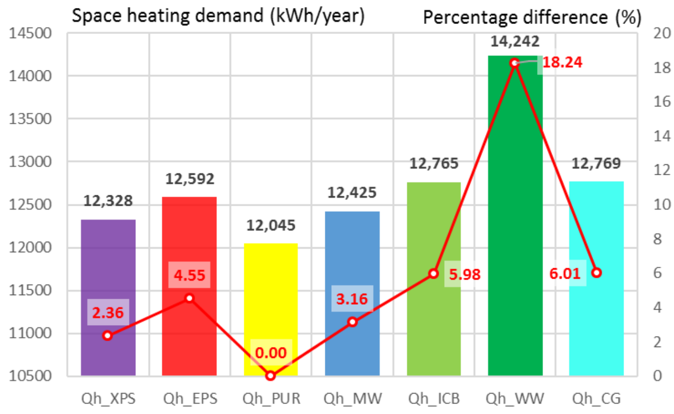



Fig. 2. Annual values of the space heating demand for different thermal insulation materials and the percentage differences between these.

Regarding the ecological materials, it can be said that the energy performances of thermal insulation with cork are close to those of the cellular glass insulation. However, compared with polyurethane foam, the wood wool has the worst energy performance, the annual value of the space heating demand being higher with 18.24%.

### *C. Calculation of energy consumption needed to space heating for various heating installations*

The issue that arises further refers to the fact that between the values of energy demand for space heating - values previously obtained - and the energy consumption of the heating system there are however differences.

These differences are considering the following aspects:

- the values of heating demand of a building are values obtained for imposed temperature and humidity conditions (either at constant values throughout the day or that vary after a program);
- the temperature in the heated areas is not always constant; the room thermostats - no matter how accurate they are - have a temperature gap of 1-1.5 degrees (digital thermostats can reach to temperature gaps of maximum 0.7 degrees but these have the disadvantage of o lower sensitivity) [15];
- another important aspect refers to the area where the thermostat is installed. The use of a thermostat represents a local temperature adjusting method (for that area), but in case when this commands the operation of a gas central heating of a building, the thermostat becomes a method of temperature adjusting for all areas of the building. Therefore, the thermostat will be installed in one of the areas that require heating, and when in this area it is reached the desired temperature, the thermostat

gives the stop command of the heating system.

So, after the selection of the thermal insulation system of exterior walls, another important aspect is the selection of heating system.

Returning to the building subjected to the case study, for the following simulations it has been chosen as variant of rehabilitation for the external walls, the polyurethane foam.

Considering the above mentioned, the first stage proposes an analysis of the energy demand distribution depending on heated areas of the analyzed building. Thus, Fig. 3 highlights major differences between the two heated areas, in terms of the monthly values of the space heating demand; these differences may reach the value of 47.42% during January.

If for this type of building, the designed heating system contains a gas boiler which is controlled only by a thermostat - regardless of the number of areas required to be heated - then an important issue is represented by the choice of placement zone of the thermostat; therefore, because for a heating system with gas boiler there cannot be used more thermostats (for each zone that require heating) not all the areas will have the same conditions of thermal comfort.

In these conditions it must be established the area where the thermostat will be installed so that to not exist high differences of temperature between areas. In these cases, it is obvious that there will be a difference between the values of space heating demand for a building and the energy consumption of the used heating system.

In these situations, the dynamic simulation of the heating system consumption - for different variants of heating system but also for different options of the thermostat placement - allows the selection of its design optimal variant (both in terms of values of space heating demand and of the comfort indicators).

Simulations proposed in this stage were made for the same building configuration (insulation of the external walls with polyurethane foam), considering necessary the operation of the heating system for the periods January 1st to April 20th and October 1st to December 31th, but including a number of successive changes as follows:

- if using a gas boiler, it was considered the thermostat placement in each of the two areas that require heating (office downstairs and office upstairs);
- if using a gas heating installations there have been simulated two embodiments of the heating circuit; for a variant, the heating circuit is continuous – the heat carrier exits the heating circuit of the office downstairs and enter the heating circuit of the office upstairs; in the second variant, the two heating circuits are in a parallel configuration, the heat carrier starting from the boiler to the two heating zones;
- the heating of the two offices is performed using a heating ventilation systems, each heating area having its own thermostat.

*Heating system with gas boiler and thermostat located upstairs*

Fig. 4 shows the building energy simulation when using a heating system with gas boiler and the thermostat is placed upstairs.

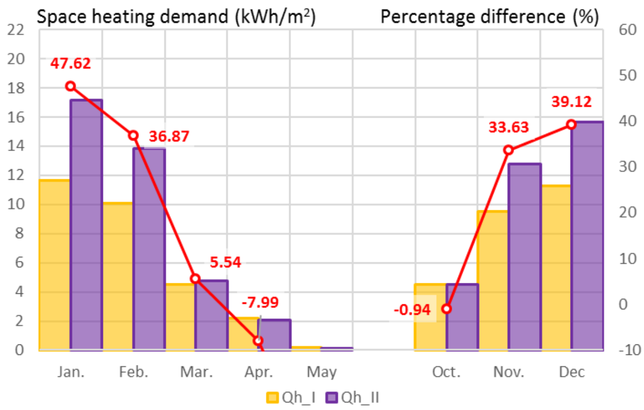
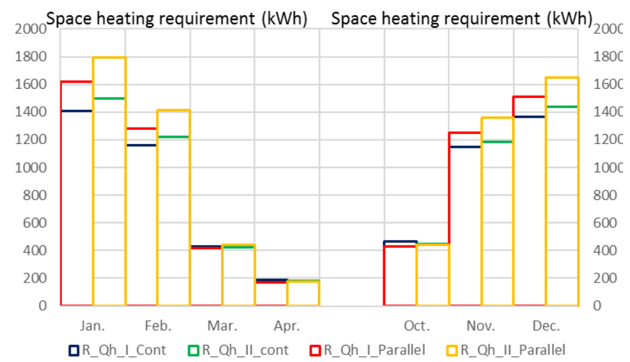
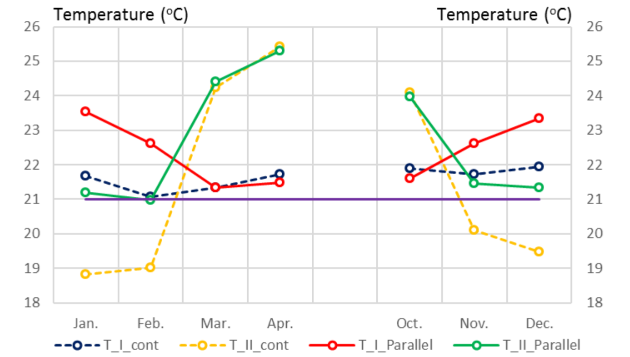



Fig. 3. Monthly values of the space heating demand for the two offices.

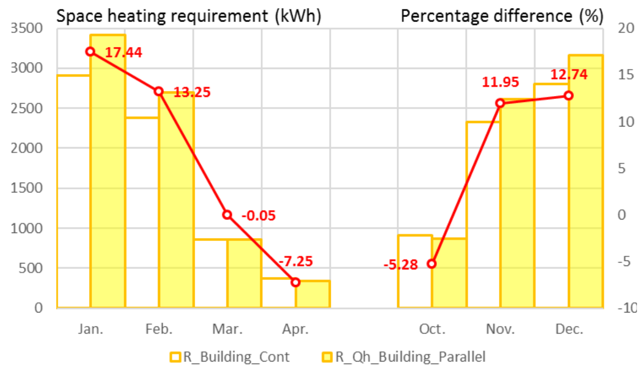
The comparative analysis of the monthly heating requirement (Fig. 4,(a)) highlights a higher consumption when using a parallel circuit of the heating system. This increase is most significant during the cold months, the monthly values of heating requirement for parallel circuit can be up to 17% higher.




(a)



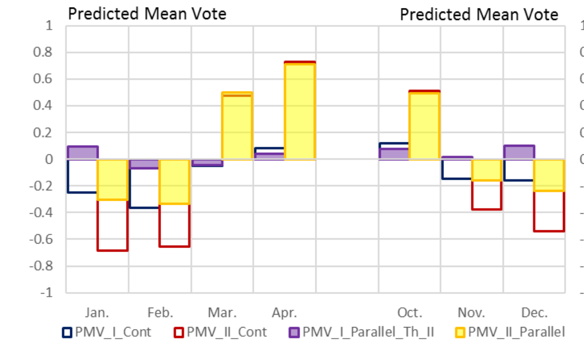

(b)



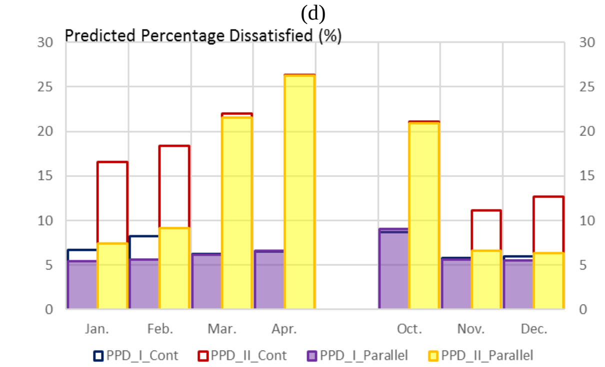

(c)

DOI: http://dx.doi.org/10.24018/ejers.2017.2.5.325



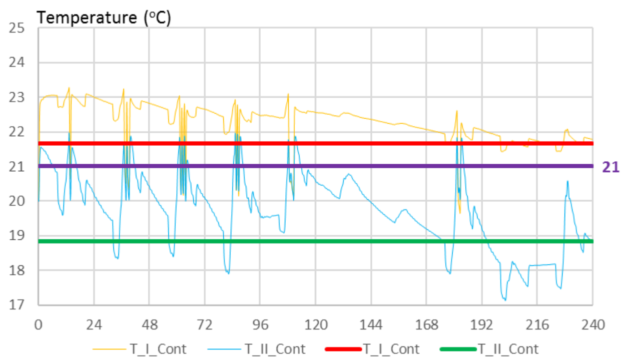



(d)

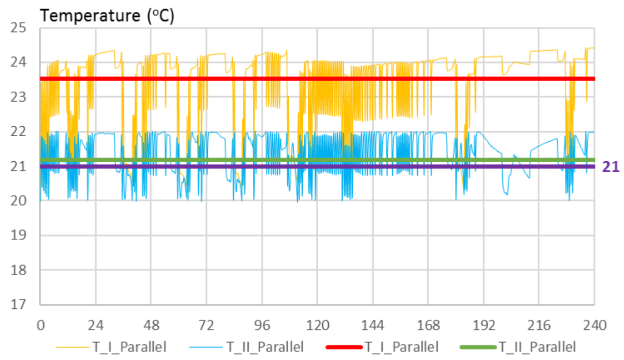



(e)

Fig. 4. Heating system with gas boiler and thermostat placed upstairs: (a) monthly rate of heat transfer for the office zones; (b) monthly mean values of temperature for the offices; (c) monthly values of heat transfer rates for the entire building; (d) monthly mean values of the PMV; (e) monthly mean values of the PPD factor.




(a)




(b)

Fig. 5. Temperature variation for office areas during the first ten days of January: (a) heating system with gas boiler, continuous heating circuit and thermostat placed upstairs; (b) heating system with gas boiler, parallel heating circuit and thermostat placed upstairs.

Although in the case of the continuous circuit, the heating requirements values are lower, the temperature analysis in the two areas (Fig. 4,(b)) highlights the fact that although in the office downstairs, the values of monthly average temperature (T_I_Cont, T_I_Parallel) are between 21°C and 22°C, the monthly average temperature in the office upstairs - during the cold months, January, February, November and December - ranges between 18.8°C and 20.11°C (T_I_Cont, T_I_Parallel).

During periods of spring, autumn, the temperature of the upstairs office increases long enough, but this increase is due mainly to the building configuration that has the walls of upstairs mostly made up of windows [14].

When using a parallel heating circuit, the average values of temperature for the upstairs office (T_II_Parallel) during the periods of January, February, November and December are between 20.9°C - 21.3°C.

But as it was expected - given that the thermostat is located upstairs - the average values of temperature for the office downstairs increase well beyond the desired range (the periods January, February, November, December) namely these fall between 22.6°C and 23.5°C.

Temperature variation analysis of two the office areas during the first ten days of January indicate but significant temperature variations during the day when using an installation with continuous circuit (Fig. 5).

The comparative analysis of the monthly values of comfort factors (Fig. 4,(d) and Fig. 4(e)) indicate lower values of these, when using a parallel circuit, particularly for the periods January – February and November – December. So, in terms of the monthly values of the factors of comfort, PMV and PPD, one can notice that, it is recommended the use of a heating system with parallel circuit, variant for which the comfort indicators are falling within the values corresponding to a neutral sensation, slightly cold, during the winter (Fig. 4).

*Heating system with gas boiler and thermostat placed downstairs*

Placing the thermostat in the office downstairs does not lead to significant differences in terms of monthly values of heating requirements of the installation (Fig. 6,(a)).

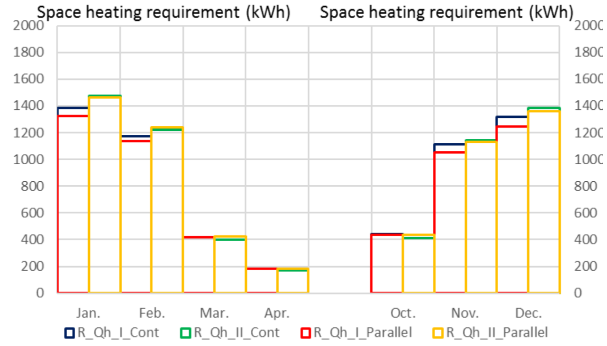
This is because the use of a continuous heating circuit leads to temperature values for the office downstairs, slightly higher (higher values than those imposed by thermostat 21°C); during the periods of January, February, November and December, the average temperatures for the office downstairs, vary between 21.2°C and 21.5°C (Fig. 6,(b)). Concerning the average values of temperature for office upstairs, it can be seen that there are not significant differences between the two chosen circuit variants.

Comparative analysis of the comfort factors, PMV and PPD - in terms of both circuits - show that these have lower values when using a continuous circuit, but the differences are not significant (Fig. 6,(d) and Fig. 6,(e)).

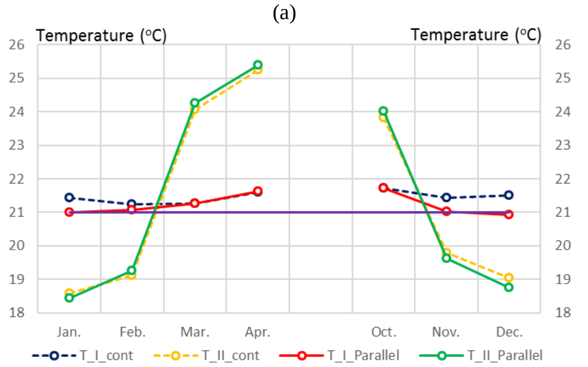
When using a parallel heating circuit, the temperature analysis for the two office areas (Fig. 7) indicate a significant variation of this throughout a day for the office upstairs.

Fig. 8 proposes the comparing the comfort factors for the two parallel heating circuits (with the thermostat placed in the area upstairs, Th_II, and downstairs, Th_I).

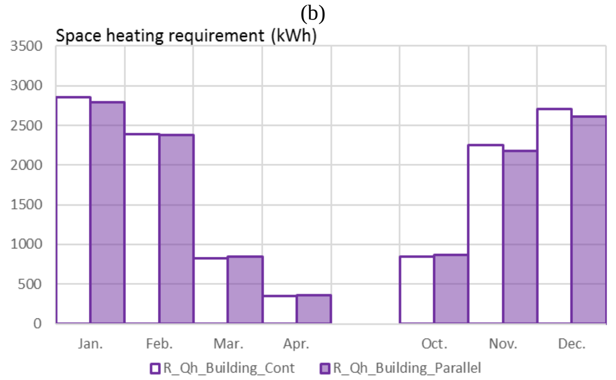
Analysis of the monthly values of comfort factors indicate that thermostat placement in the office upstairs has beneficial effects on comfort conditions, especially during the cold period, leading to the framing the comfort conditions - on the largest period - in the neutral zone.



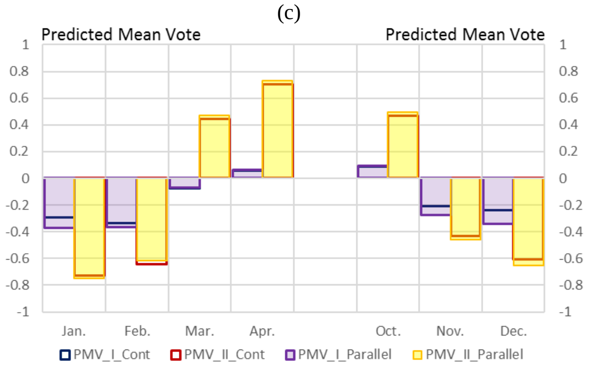

(a)



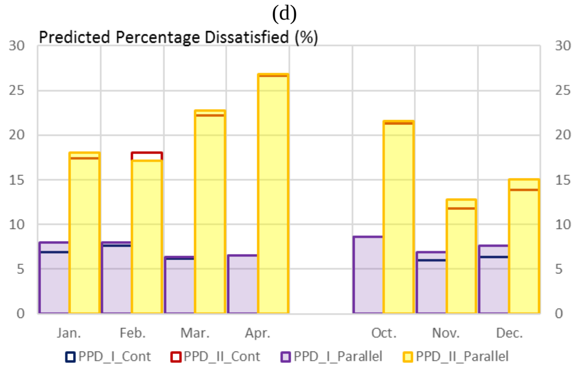

(b)




(c)

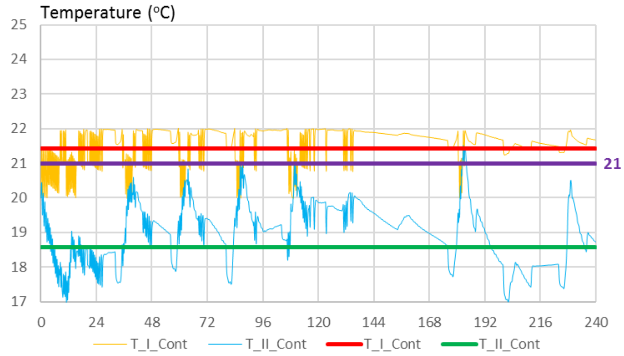



(d)

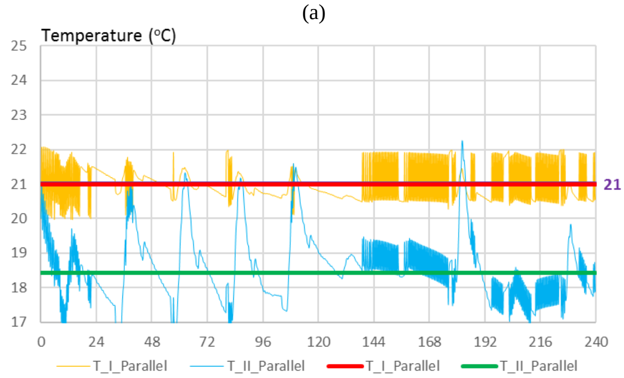



(e)

Fig. 6. Heating system with gas boiler and thermostat placed downstairs: (a) monthly rate of heat transfer for the office zones; (b) monthly mean values of temperature for the offices; (c) monthly values of heat transfer rates for the entire building; (d) monthly mean values of the PMV factor; (e) monthly mean values of the PPD factor.

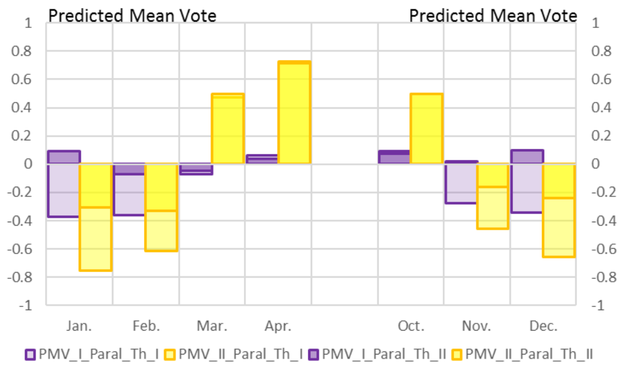



(a)

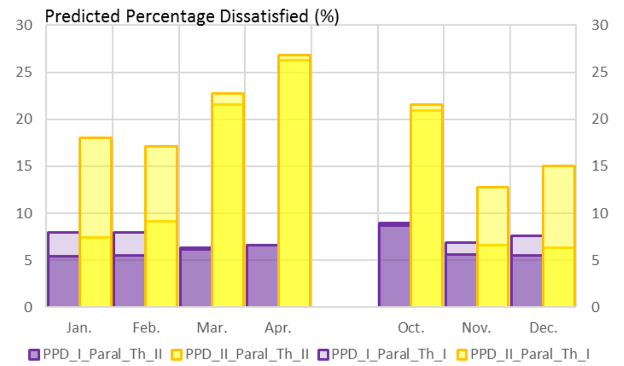



(b)

Fig. 7. Temperature variation during the first ten days of January: (a) continuous heating circuit and thermostat placed downstairs; (b) parallel heating circuit and thermostat placed downstairs.




(a)




(b)

Fig. 8. Heating system with gas boiler and parallel heating circuit: (a) monthly mean values of the PMV factor; (b) monthly mean values of the PPD factor.

### *Ventilation heating system*

Analysis of energy consumption and comfort parameters for the ventilation system will be made by comparison with the heating system with gas boiler, with thermostat placed upstairs (Th_II) and parallel heating circuit.

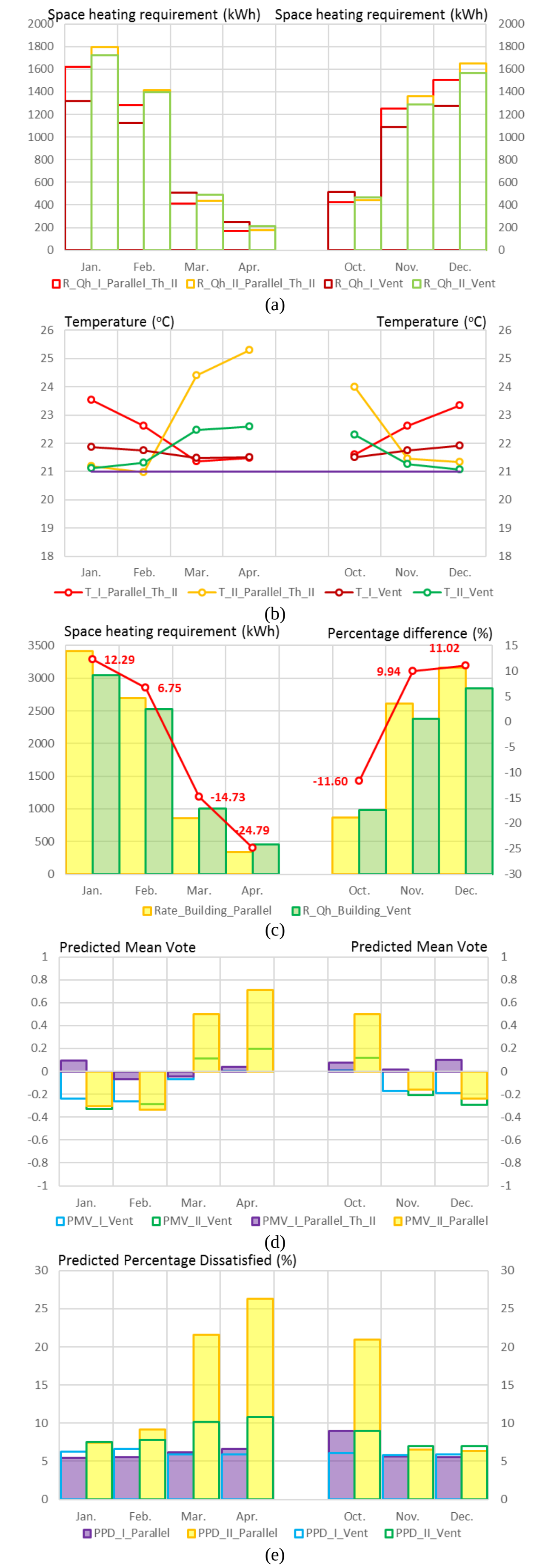



Fig. 9. Heating system with gas boiler and thermostat placed upstairs and heating system by ventilation: (a) monthly values of required heating; (b) monthly mean values of temperature for the offices; (c) monthly values of heat transfer rates for the entire building; (d) monthly mean values of the PMV factor; (e) monthly mean values of the PPD factor.

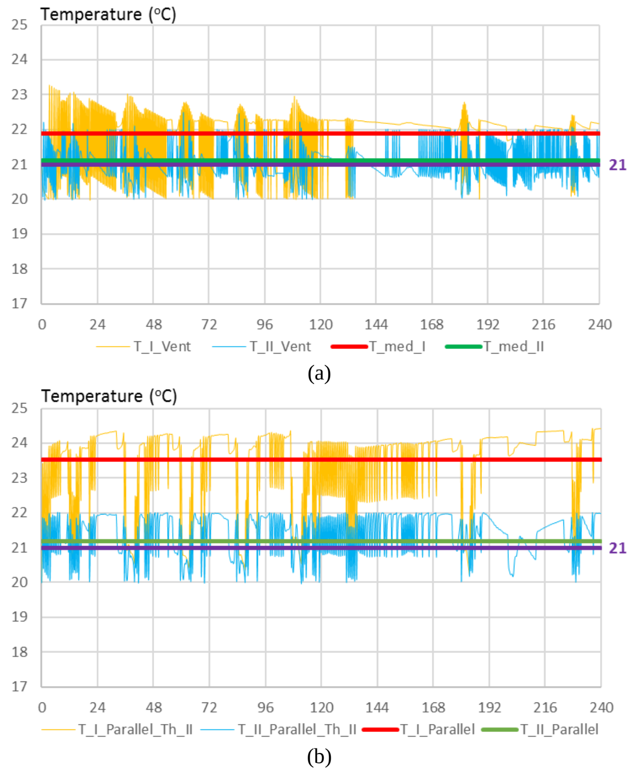



Fig. 10. Temperature variation for office areas during the first ten days of January: (a) heating system by ventilation; (b) heating system with gas boiler, parallel heating circuit and thermostat placed upstairs.

This comparison variant was selected because from all system variants with gas boiler, for this were obtained values of comfort parameters closest to conditions corresponding to the neutral sensation. Also, as previously discussed, this is the only option for which, during the cold months (January, February, November, December) there were obtained, for the office upstairs, monthly mean values of temperatures close to temperature imposed 21°C.

Simulations analysis for a ventilation heating system indicate a decrease in the monthly demand for heating during the cold period (January, February, November, December); monthly values of heating demand may decrease, depending on the month, with values between 6.7% and 12.3% (Fig. 9). It be also noticed, an approximation of the temperature values of the two zones, to the desired value of 21°C. However, in terms of comfort conditions (parameters PMV and PPD) it is recommended the use of the heating system with gas boiler, parallel heating circuit and thermostat located upstairs.

Worth noting that for the warmer periods (March, April, October) the energy consumption for a ventilation system, increase; these monthly increases have values between 110kWh/month (April, October) and 147kWh/month (March). However, the annual energy consumption for a ventilation system is lower.

The use of a ventilation heating system leads to obtaining of some mean monthly temperatures – for the two areas that require heating - closer to the desired value of 21°C, but this objective is achieved with frequent variations in temperature during the day (Fig. 10).

*Comparative analysis of the proposed heating systems*

The comparative analysis of the proposed heating systems, in terms of annual heating requirements for the entire building, highlights the fact that the lowest value of this is recorded when using a heating system with gas boiler, thermostat placed downstairs and the designing of a parallel circuit (Fig. 11 Qh_I_Par). However, in the case of adoption of this solution, it can be seen (Fig. 6) that for the office upstairs, during the cold period, temperatures are around 19°C (the range between 18.4°C and 19.6°C).

But, the most times, in reality - whether it is a building that requires rehabilitation or whether it is a building in the design stage - there is an "imbalance" in terms of heating requirements for the different areas of it. Ensuring the comfort conditions for all areas, in the case of such building, is difficult and the possibility of building energy simulation (and analysis of as many possible variants) may be welcome in taking some decisions about choosing solutions for rehabilitation or of the heating system.

The example of building subjected to the case study was chosen in this respect, in order to highlight situations where there is a significant difference between the heating requirements for the two office areas.

In the case of the considered building, the zone upstairs has a large proportion of the surface of exterior walls made up of windows [14]. In the case of such a type of building, a series of "contradictory" situations can arise, depending on the time of year:

- in circumstances where it is necessary to provide thermal comfort conditions, during the cold period, for the area upstairs, it will be required a heating demand higher than that for the area downstairs (as it can be seen, Fig. 3, differences can overcome 40%);
- for the periods of spring (March, April) and autumn (October) the glazing area of the upstairs leads to a temperature increase of this area and the differences between the heating requirements for the two areas decrease (Fig. 4, Fig. 6 and Fig. 9);

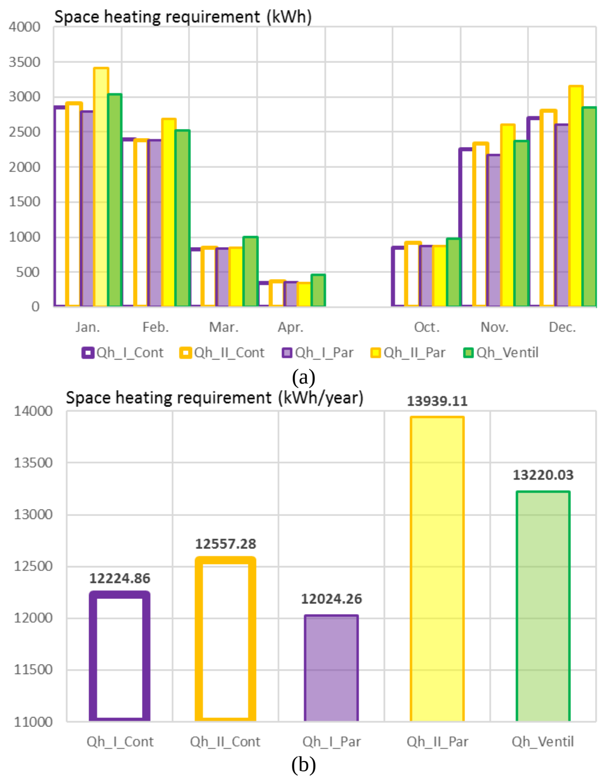



Fig. 11. Monthly and annual heating requirement for the entire building: (a) monthly heating requirement; (b) annual heating requirement.

- during the warm period of summer, the temperatures to the building upstairs are much higher than those downstairs and the requirements for cooling the area upstairs, substantially increase ([14]).

In these situations, the simulation of the heating consumption and of the comfort parameters of the building, has beneficial effects in taking decisions about the adopting of the heating system.

For the considered building, Fig. 12 proposes – for the January – variation of the comfort parameters, PMV and PPD; the values of the two parameters were calculated for the two office areas and for all considered variants of the heating system.

The month of January was chosen for analysis of comfort parameters, because as it can be seen from the diagrams above, this is the month for which there were obtained the highest value of the space heating. In addition, also for the month of January, it was found the biggest difference between the values of heating demand for the two office areas.

It should be noted that, for building subject to the case study, the comfort factors, PMV and PPD, were calculated considering that the metabolic activity is on average of 1.2met and the operative temperature, ideal to winter (clothing factor 1) is between 18°C and 24°C [16].

A first conclusion that may be worded after analyzing the Fig. 12, it refers to the fact that all values of the PMV factor, are mostly negative, regardless of the area that needs heating.

For the office downstairs, the values of PMV factor indicate, from the comfort conditions point of view, a sensation of neutral, slightly cold (-0.8 <PMV <0.3).

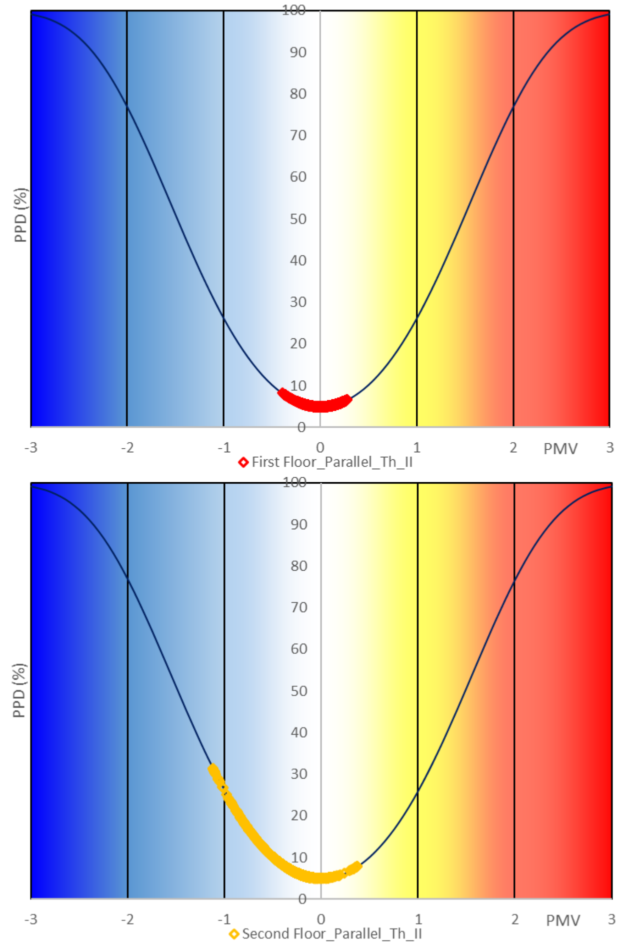
But, for the office area upstairs, the lowest values (absolute values) of PMV factor were obtained when using a heating system with continuous circuit (regardless of the location of the thermostat); in this situation, the values of PMV factor fall within the range -1.7 to 0.3 (these values are corresponding to the neutral comfort zone, slightly cold).

If using a gas heating systems with parallel circuit, it can be seen that PMV values lead to the classification of comfort conditions as follows:

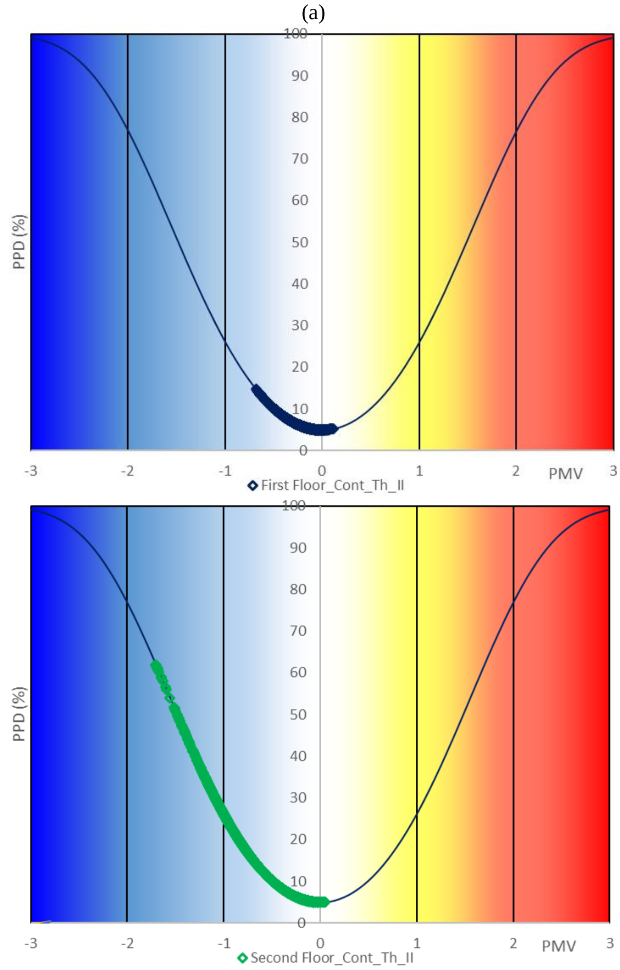
- predominantly in the neutral zone for the office downstairs (for thermostat placed downstairs, -0.542<PMV<-0.107, for thermostat placed upstairs, -0.394<PMV<0.279);
- the neutral zone, slightly cold for the office upstairs (for thermostat placed downstairs, -1.42<PMV<0.351, for thermostat placed upstairs, -1.2<PMV<0.37).

The use of a heating system by ventilation leads to the obtaining of some comfort conditions that fall into the neutral zone, slightly cold both for office area downstairs (-0.8<PMV<0.06) and for the office upstairs (-0.65<PMV<0.415).

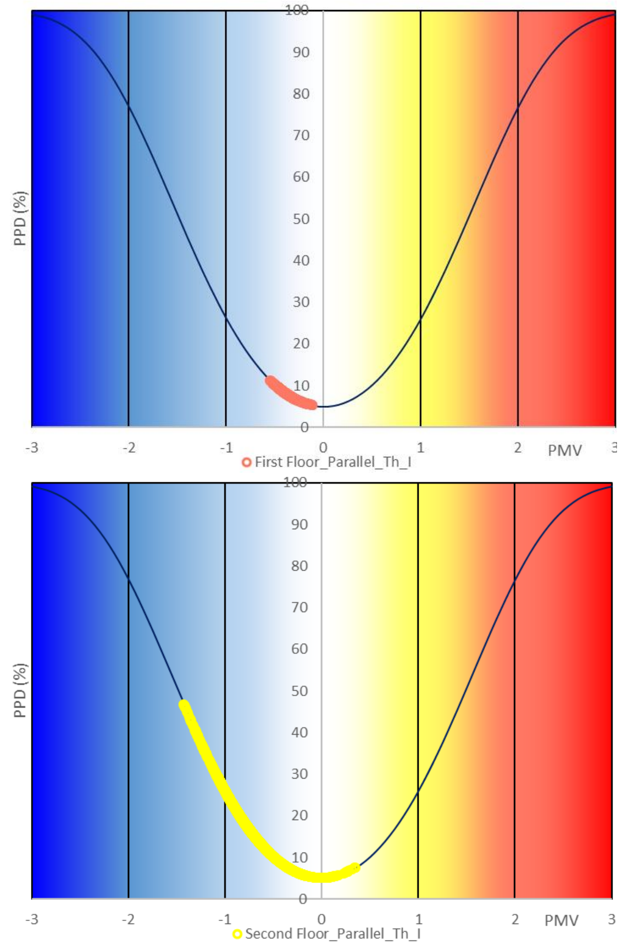
Therefore, analyzing the values of comfort factors result that, the best comfort conditions for the office downstairs are obtained when using a gas heating system, parallel circuit and thermostat placed upstairs; but analyzing the comfort conditions for the office upstairs, the best option is that of heating by ventilation (in these conditions, it remains to the designer discretion to choose the heating system variant).


PPD (%)
PMV
First Floor_Parallel_Th_II
Second Floor_Parallel_Th_II

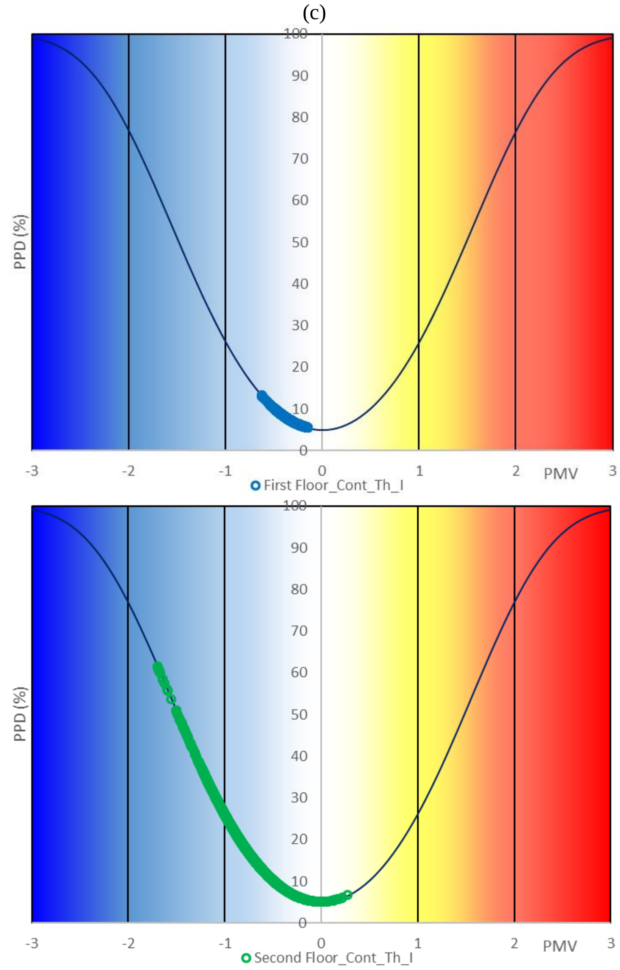
(a)


PPD (%)
PMV
First Floor_Cont_Th_II
Second Floor_Cont_Th_II

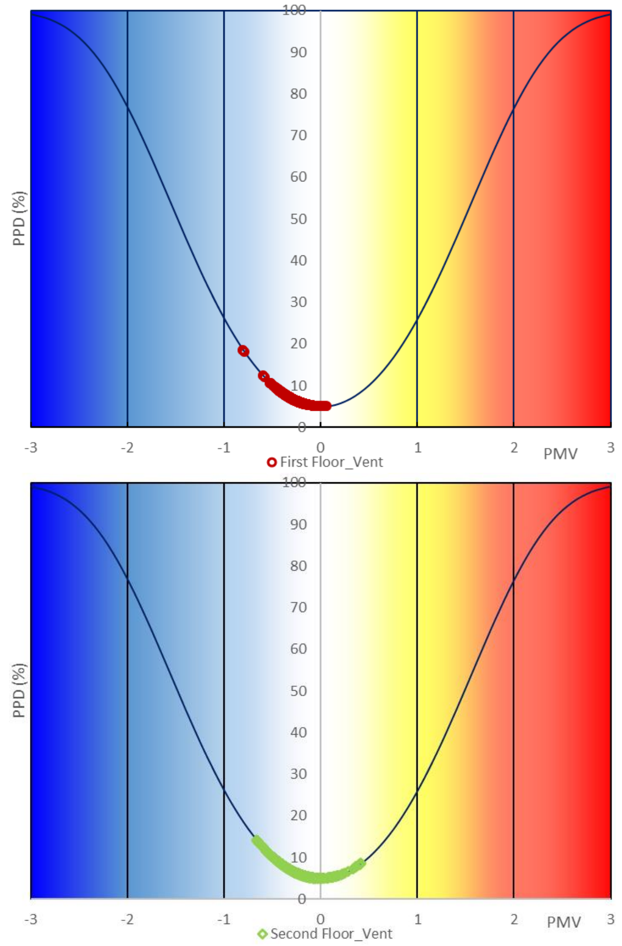
(b)


PPD (%)
PMV
First Floor_Parallel_Th_I
Second Floor_Parallel_Th_I

(c)


PPD (%)
PMV
First Floor_Cont_Th_I
Second Floor_Cont_Th_I

(d)




(e)

Fig. 12. The relationship between the comfort factors, PMV and PPD, during January: (a) heating system with gas boiler and thermostat placed upstairs, parallel heating circuit; (b) heating system with gas boiler and thermostat placed upstairs, continuous heating circuit; (c) heating system with gas boiler and thermostat placed downstairs, parallel heating circuit; (d) heating system with gas boiler and thermostat placed downstairs, continuous heating circuit; (e) heating system by ventilation.

## IV. Conclusions

The greatest losses of a building are found in thermic energy area, which is why there are imposed a number of additional measures to avoid them. Of these, there are mentioned only those that represented the objective of this work:

- the building's thermal envelope must be very efficient, so this to provide the comfortable climate from indoor with low energy consumption, regardless of season, both in the warm and in the cold one;
- ensuring a high level of airtightness in order to reduce air leaks; the building's thermal envelope must be doubled by a sealing envelope usually achieved by finishing works;
- the ensuring a proper ventilation, with continuous duty of air supply; thus it is recommended to perform ventilation in controlled system, with energy recovery (air-to-air energy recovery systems); the energy recovery can be done both for thermal discharge of exhaust air and for the use of recovered energy for heating or cooling (as the case) of the introduced fresh air.

Dynamic analysis of the buildings energy behavior is a useful tool for a better understanding of this. An energy analysis can help designers to develop a series of strategies for efficient design of building.

For the case study was elected an office building for which there are large differences among the values of heating requirements of the main heated areas; it might be said that it has been chosen the variant of a "disadvantageous solution" of building, but for which, it is still desired to provide the best possible conditions of indoor comfort. It was chosen this type of building to highlight the importance of dynamic simulations of buildings:

- whether it be by existing old buildings, requiring rehabilitation and a decision is needed in terms of thermal insulation
- whether it be about a new building, in design stage and the choice of some design decisions relate to both the building structure aspects and to issues concerning the type of heating systems.

Therefore, for the building subject to the proposed case study, the dynamic simulation allowed the evaluation of different options for energy savings both in terms of the building envelope as well in terms of the heating system.

Given the analysis proposed by this paper, the author's recommendation is for choosing a ventilation heating systems. This recommendation takes into account besides the diagrams shown in the previous chapter also a number of issues regarding the negative effect it may have the condensation on a building.

In many new buildings, there use sophisticated heating systems and the doors and window frames are provided with sealing gaskets to stop the air flow; in this situations, warmer areas and apparently more comfortable are created, but the high condensation incidence is ignored.

These modern aids for comfort increase have created rooms that are warmer but that often have less ventilation and less air circulation. The result is that the water vapor produced by everyday normal activities can no longer evaporate through the chimney or through doors' frame, through the window joints or other outlet openings.

Therefore, in certain circumstances, all these aids for comfort increase are combining, leading to the creation of ideal conditions for the condensate production [4].

In conclusion, it is mentioned the fact that there are a high number of factors with great influence on energy efficiency in buildings. In this sense, the future studies will aim to the study of solutions that can be adopted for increasing the energy efficiency of the heating systems.

## References

[1] *Net Zero Energy Solar Buildings: International Projects of Carbon Neutrality in Buildings*, International Energy Agency. SHC Task 40, 2011.

[2] *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings*. Official Journal of the European Union, 2010.

[3] I. Sarbu and C. Sebarchievici, “Performance evaluation of radiator and radiant floor heating systems for an office room connected to a ground-coupled heat pump,” *Energies*, vol. 9, no. 4, pp. 228-247, April 2016.

[4] F. Allard and C. Ghiaus, “Natural Ventilation in the Urban Environment. Assessment and Design,” 2005, Earthscan UK.

[5] *Thermal insulation products for buildings - Factory made products of expanded polystyrene (EPS) - Specification*, EN 13163, November 2008.

[6] *Thermal insulation products for buildings - Factory made products of extruded polystyrene foam (XPS) - Specification*, EN 13164, November 2008.

[7] *Thermal insulation products for buildings - Factory made rigid polyurethane foam (PUR) products - Specification*, EN 13165, November 2008.
[8] *Thermal insulation products for buildings - Factory made mineral wool (MW) products - Specification*, EN 13162, 2015.
[9] Thermal insulation products for buildings - Factory made cellular glass (CG) products – Specification, EN 13167, 2012+A1:2015.
[10] Thermal insulation products for buildings - Factory made products of expanded cork (ICB) – Specification, EN 13170, 2012+A1:2015.
[11] *Thermal insulation products for buildings - Factory made wood wool (WW) products – Specification*, EN 13168, 2008.
[12] *Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*, ISO 7730, 2006.
[13] W. Linden van der, M. G. L. C. Loomans and J. L. M. Hensen, "Adaptive thermal comfort explained by PMV," in *Proc. of the 11th International Conference on Indoor Air Quality and Climate*, 2008, Copenhagen. Available: purl.tue.nl/712648209539104.pdf
[14] E. Eftimie E, "Costing energy efficiency improvements in buildings. Case study: Brasov, Romania, *International Journal of Energy and Environment*, vol. 6, no. 1, pp. 47-60, January 2015.
[15] B. G. Liptak, *Instrument Engineers' Handbook, Fourth Edition*, vol. 1: Process Measurements and Analysis. 2003, CRC Press.
[16] A. Ioannou and L. C. C Itard, "Thermal comfort in residential buidings: Sensitivity to building parameters and occupancy," in *Proc. of the Fifth German-Austrian IBPSA Conference RWTH*, Aachen University, BauSIM, 2014. Available: http://www.ibpsa.org/proceedings/bausimPapers/2014/p1116_final.pdf

**Elena Eftimie** was born in Brașov, Romania, in 1969. She is a full Professor at Transilvania University of Brașov, Faculty of Product Design and Environment, Department of Product Design, Mechatronics and Environment, Romania. She has a Ph.D. in Mechanical Engineering from Transilvania University of Brașov (2000). She supervises MSc and PhD students.

Her main research interests are in information technology and renewable energy especially solar radiation estimation, building energy simulation.

Prof. Dr. Eng. Eftimie is member of Romanian Association for the Science of Mechanisms and Machines and Romanian Association of Mechanical Transmissions.