BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iași
Volumul 68 (72), Numărul 2, 2022
Secţia
CONSTRUCŢII. ARHITECTURĂ
DOI: 10.2478/bipca-2022-0018

NUMERICAL ANALYSIS ON THERMAL COMFORT IN ROOMS USING CONVECTIVE HEATING AND RADIANT HEATING TERMINALS

BY

ȘTEFĂNICA-ELIZA VIZITIU*, **ANDREI BURLACU and ROBERT ȘTEFAN VIZITIU**

"Gheorghe Asachi" Technical University of Iasi-Romania, Faculty of Civil Engineering and Building Services, 65 Prof. D. Mangeron Blvd., 700259, Iasi, Romania

Received: April 25, 2022
Accepted for publication: May 21, 2022

Abstract. The concept of energy is closely related to the building sector and the systems used for heating, implicitly energy saving which is a current problem of both old and new buildings. In this paper a series of numerical simulations were made in Autodesk CFD Simulation in order to study the influence of terminal heating systems over the thermal comfort in rooms. Three case solutions were analysed, as follows: heating a room using a steel radiator, heating a room using an aluminium radiator and heating a room using underfloor heating. The values resulted through numerical simulations for the average room temperature were compared with the values for ideal heating. It was observed that underfloor heating is the most efficient source of heating among those analysed. Compared to heating using radiators, the temperatures along the length and height of the room using underfloor heating are constant and close to the ideal heating. The human body feels the most comfortable due to the uniform distribution of temperature from ground level, on height.

Keywords: thermal comfort, heating system, comparative analysis, underfloor heating, temperature distribution.

---

*Corresponding author; *e-mail*: stefanica-eliza.vizitiu@student.tuiasi.ro

1. Introduction

People use to spend about 80% to 90% of their time inside buildings (Klepeis *et al.,* 2001), therefore the enclosed space must ensure the possibility to perform both physical and intellectual work with maximum efficiency and at the same time, the possibility to perform recreational and leisure activities in optimum conditions.

Achieving these conditions depends on a number of factors that mainly influence the feeling of comfort, as well as the work capacity of people.

Buildings are among the largest energy consumers in the whole world, accounting for about 45% of the total energy consumption. Regarding this, heating of buildings has a high impact and therefore, the demand for highly efficient systems and better heat output it has grown more and more in the past few years (Calisir & Baskaya, 2021).

Meeting the challenge of getting carbon dioxide emissions close to zero by 2050 requires a change in the way energy is produced and consumed (IEA, 2021). As highly efficient heat emitters, radiators can produce high levels of thermal comfort in any building, being found in most homes in Europe. The temperature and its distribution in the room is a factor of great importance when it comes to comfort (Putra J.C.P, 2017).

When evaluating the thermal comfort for heating using systems based on convection and radiation, no firm conclusions have yet been reached in the literature regarding the efficiency of the systems. There are still contradictions regarding this subject (Halawa, et al., 2014).

In literature (Catalina, et al., 2009), concluded that radiant heating has generated more thermal comfort votes due to much less air movement in the room. Furthermore, according to research (Kitagawa, et al., 1999) and (Tian & Love, 2008), several votes of dissatisfaction have been reported in rooms heated by radiation systems, due to the fact that they do not feel the movement of air in the room and because of this, people have doubts about its quality.

From Tian and Love's study (Tian & Love, 2008), it was concluded that poor air movement in radiant systems led to more complaints, and more air movement in the room is preferred because air velocity is associated by most occupants with ventilation and air freshness.

2. Analysis through numerical simulations between the heating systems

In this paper, a series of simulations were carried out in Autodesk CFD Simulation Software in order to study the influence of the terminal heating solution on the thermal comfort in a room.

The constructive models were made in Autodesk Inventor 2021 software, with an educational license.

Three case solutions were analyzed as follows:

2.1 Heating system using a steel radiator
2.2 Heating system using an aluminum radiator
2.3 Heating system using underfloor heating coil

A. Constructive model of the room

For this study, a room with the following constructive dimensions was proposed:

- External length: 5,0 m;
- External width: 3.0 m;
- External height: 2.7 m.

The total area of the room resulted $11m^2$, respectively a volume of $26.5m^3$. The thickness of the inner walls is 0.15m, and the thickness of the outer wall is 0.25m. Around the room, a layer of air was considered, with a thickness of 0.5m in relation to each of external surfaces of the room.

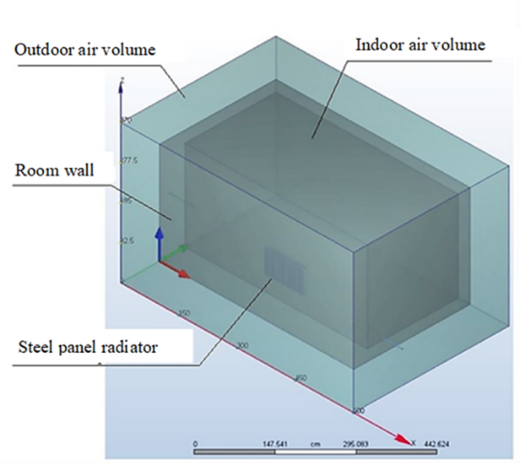


Fig. 1 − 3D model of the studied room using a steel radiator for heating.

For the third case, the room will be heated with a spiral underfloor coil system, due to its ability to heat the room uniformly by radiation. The room has the same constructive dimensions as previously mentioned, and the height from the level of the concrete slab is 13cm in this case, consisting of:

- 3 cm extruded polystyrene;
- 2.3 cm castellated floor panels;
- 1.7 cm underfloor heating pipe 16x2mm;
- 4.5 cm screed (sand, cement, water, additive);
- 1.5 cm parquet.

B. Constructive models of heaters

2.1 Heating system using a steel radiator

For the first scenario, the room will be heated with a panel-type steel radiator, placed on the outer wall of the room, with the following constructive characteristics:

- Length: 1100 mm;
- Height: 600 mm;
- Depth: 104 mm;
- Type: 22;
- Model: panel;
- Material: steel;
- Max. working pressure: 10 bar;
- Test pressure: 13 bar;
- Internal volume: 6.93 l;
- Panel thickness: 1,13 mm;
- Brand: VISION.

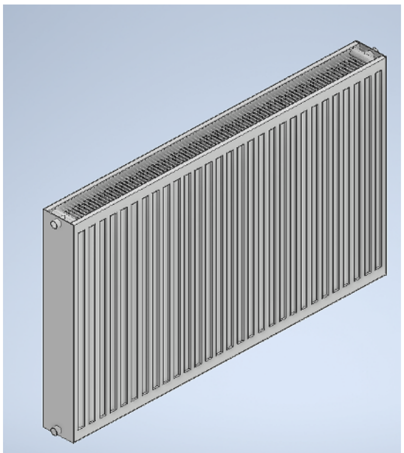


Fig. 2 − 3D geometry made for the steel panel radiator.

2.2 Heating system using an aluminum radiator

For the second scenario, the room is heated with a radiator made of 13 aluminum elements, placed on the outer wall of the room, with following constructive characteristics:

- Length: 1040 mm;
- Height: 657 mm;
- Depth: 97 mm;
- Material: aluminum;

- Type: D3/600;
- No. of elements: 13 pc;
- Internal volume: 0,29 litres/element ;
- Brand: EXCLUSIVO ;
- Max. working pressure: 16 bar;
- Test pressure: 24 bar.

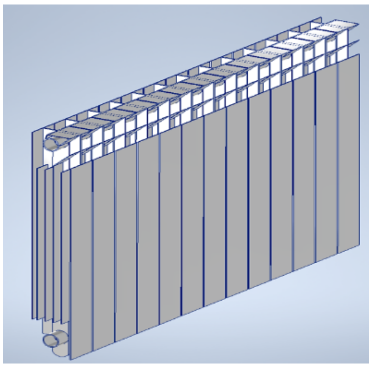


Fig. 3 − 3D geometry made for the aluminum radiator.

2.3 Heating system using underfloor heating coil

For the last scenario, the room will be heated with an underfloor heating coil, Herz 16x2mm, with the following characteristics:

- Expansion coefficient: 0.19 mm/mK;
- Thermal conductivity: 0.35 W/mK;
- Maximum operating temperature: 70°C;
- Maximum operating pressure: 6 bar;
- Bending radius: 5x12mm.

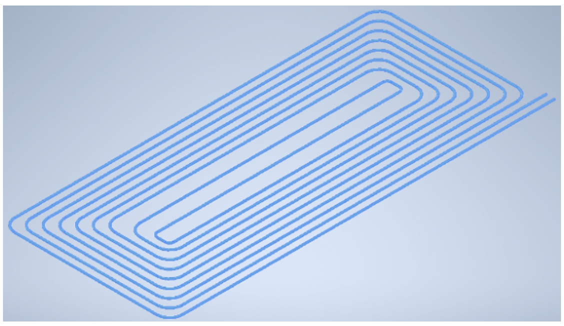


Fig. 4 − 3D geometry made for the spiral underfloor coil at a 10cm pitch.

C. Boundary conditions

The 3D models were imported into Autodesk CFD 2021 simulation software, where the corresponding materials were assigned to each element. A temperature of 1°C was imposed on the outer surface of the outdoor air volume, parallel to the 0.25 m thick wall. On the remaining outer surfaces of the outdoor air volume, a temperature of 15°C was imposed.

The steel and aluminum radiators were required to have a thermal output of 1000W to achieve a temperature of approximately 70°C.

The heating coil was required to have a thermal output of 300W to reach a temperature of approximately 38°C.

D. Meshing

The geometry was discretized into a finite number of elements, a procedure also known as "meshing".

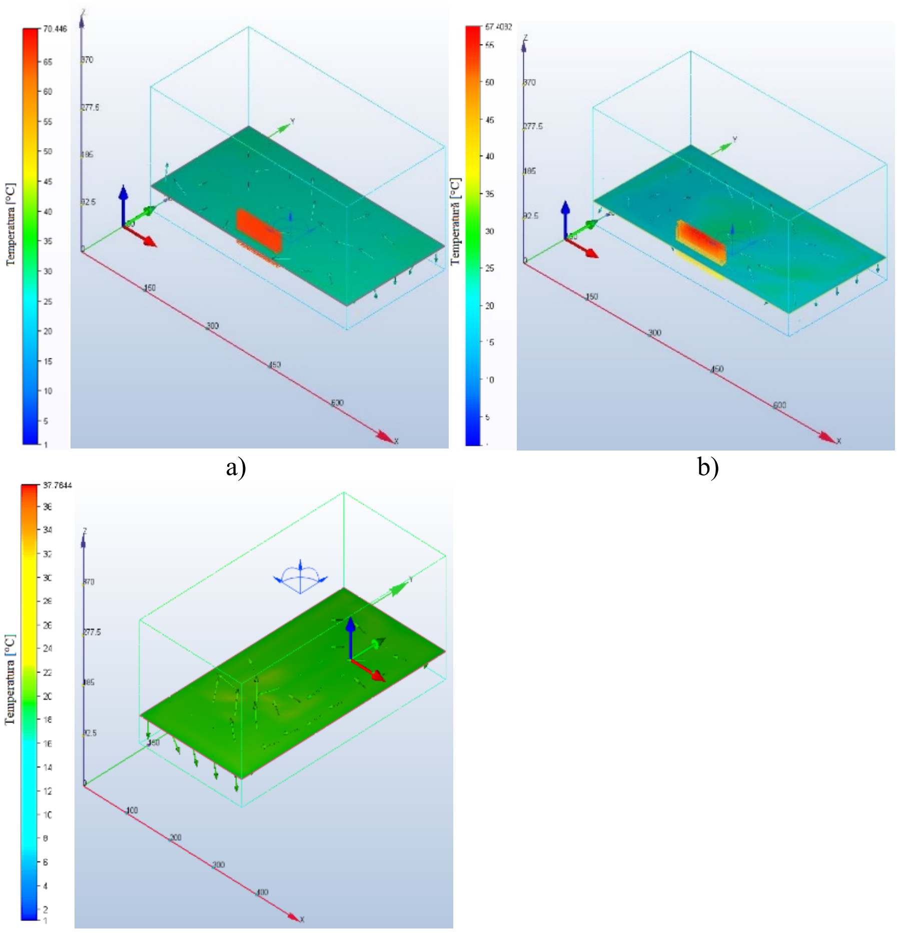
This resulted in approximately 570000 elements for the steel radiator and 2.1 million elements for the aluminum radiator. For the case of using underfloor heating coil, the resulting number of elements is about 510000 elements.

E. Results

Following the simulations, cross-sectional and longitudinal planes were made inside the room to observe the temperature stratification in the indoor air volume. An average temperature was calculated for each plane.

Table 1
Average temperature values resulting in transverse plane

Height above floor surface - H [m]	0.25	0.5	1.0	1.5	2.0	2.5
Average temperature [°C] Heating using steel radiator	*26.1*	*27.4*	*28.0*	*28.7*	*29.6*	*28.2*
Average temperature [°C] Heating using aluminium radiator	*19.4*	*21.3*	*22.1*	*23.3*	*24.6*	*24.2*
Average temperature [°C] Heating using underfloor heating coil	*20.6*	*20.3*	*20.6*	*20.8*	*20.8*	*20.3*



a) b)

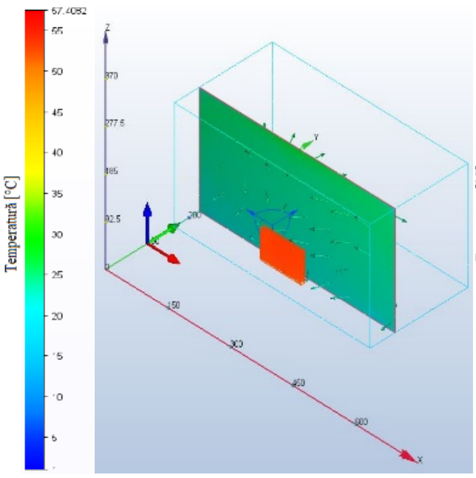
c)

Fig. 5 – Cross-sections at H=0.5m for heating with:
a). steel radiator
b). aluminum radiator
c). underfloor coil.

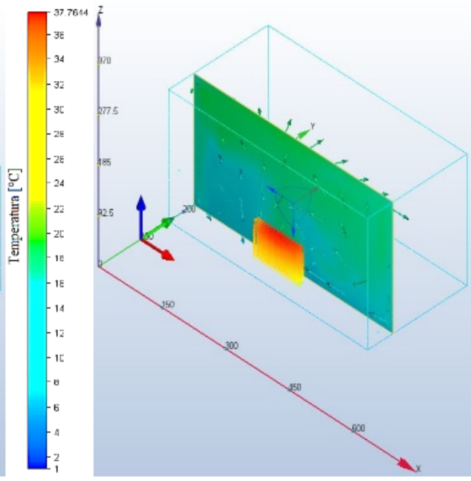
Table 2
Average temperature values resulting in the longitudinal plane

Distance to outside wall - L [m]	0.5	1.0	1.5	2.0	2.5	2.8
Average temperature [°C] Heating using steel radiator	*25.7*	*28.2*	*28.3*	*28.2*	*28.2*	*27.7*

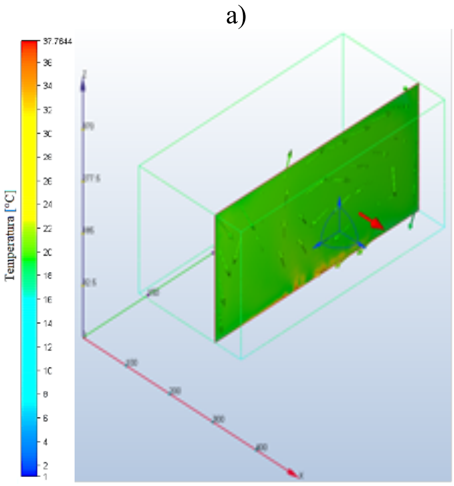
Average temperature [°C] Heating using aluminium radiator	*22.6*	*22.5*	*23.0*	*23.0*	*22.9*	*20.9*
Average temperature [°C] Heating using underfloor heating coil	*18.7*	*20.8*	*20.7*	*20.8*	*20.8*	*19.7*



a)



b)



c)

Fig. 6 – Longitudinal plane sections at L=1.0 m, for heating with:
a). steel radiator
b). aluminum radiator
c). underfloor coil.

3. Conclusions

After performing the three numerical simulations, we can compare the results obtained for the average room temperature in the case of heating with radiators and the one with a serpentine underfloor heating with the average temperature values for the ideal situation.

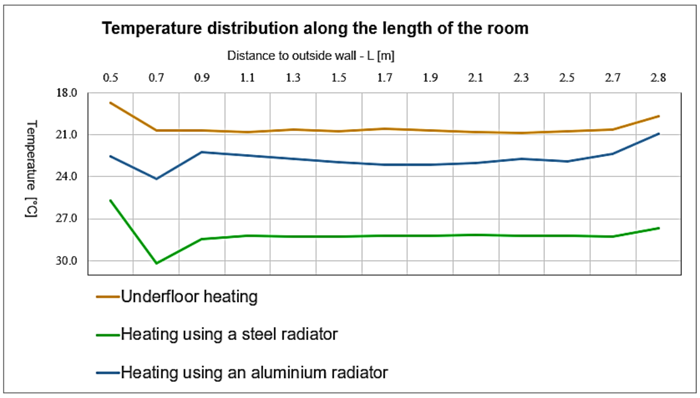


Fig.7 – Temperature distribution graph along the length of the room using a steel radiator for heating, aluminum radiator and underfloor coil.

Comparing the results obtained by numerical simulations for the three cases, we can see that the temperatures along the length of the room are much more constant in the case of underfloor heating rather than in the case of heating with radiators.

In this case, the average temperature remains constant at 20.7 - 20.8 °C, without major variations that could affect the thermal comfort in the room. The maximum temperature reached is 20.9 °C at a distance of 2.3 m from the wall considered outside, and the minimum temperature is at the surface of the wall surrounded by the colder air volume, at a value of 18.7 °C.

Temperatures resulting from heating the room with the aluminum radiator are close to those resulting from underfloor coil heating. The resulting temperature curves are similar in both cases, and the thermal comfort achieved in the room is optimal. In the case of steel radiator heating, however, the maximum temperature reached is 30.2 °C in the proximity of the radiator, as expected, and the lowest temperatures resulted at the extremities.

The resulting high temperatures throughout the room affect thermal comfort and are therefore less efficient than underfloor heating in this regard.

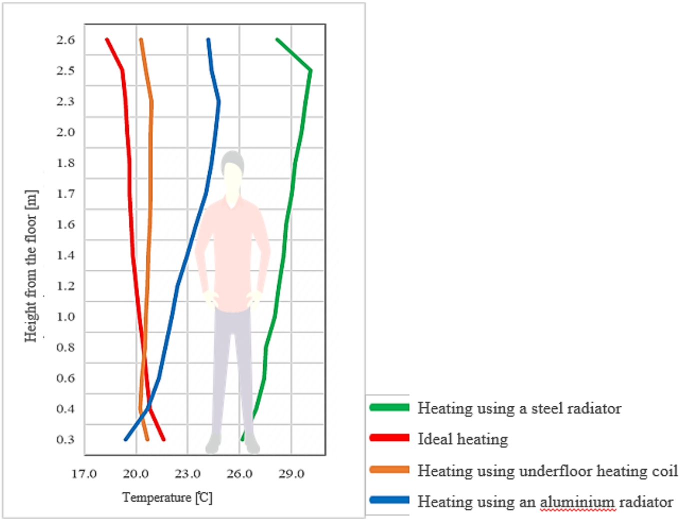


Fig. 8 – Temperature distribution graph by room height between heating using a steel radiator, an aluminum radiator, underfloor heating coil and ideal heating.

Comparing the room-height temperatures with an ideal heating curve, the results again show that heating using underfloor heating has the values closest to this ideal curve. In this situation, the human body feels most comfortable due to the even distribution of temperature from ground level upwards. At foot level, the temperature reaches 20.6°C, and is constant up to head level. In the case of radiator heating, the resulting temperature at head level is much higher than at foot level, with a difference of 3-5°C. The temperature differences are high because the heating is done punctually, and this creates draughts in the room which also entrain dust particles, and the heat is not evenly distributed in the room.

Underfloor heating distributes heat radiantly from floor level upwards across the entire floor surface, which results in even temperature distribution throughout the room.

By comparison, radiators radiate heat by convection, with the warm air rising above the radiator towards the ceiling and once up, descending to the floor to be heated again. This creates gaps of cold, respectively warm air, with warmer air near the radiator and cooler air in the rest of the room.

It can be seen that underfloor heating is the most efficient heating solution of those studied, having the values closest to the ideal heating curve, with the human body feeling more comfortable due to the uniform distribution of temperature from ground level over height.

REFERENCES

Calisir, T. & Baskaya, S., *The influence of different geometrical dimensions of convectors on the heat transfer from panel radiators*, SN Appl. Sci., 284(3), 2021.

Catalina, T., Virgone, J. & Kuznik, F., *Evaluation of thermal comfort using combined CFD and experimentation study in a test room equipped with a cooling ceiling*, Building Environment, Volume 44, pp. 1740-1750, 2009.

Halawa, E., Hoof, J. & Soebarto, V., *The impacts of the thermal radiation field on thermal comfort, energy consumption and control — A critical overview*, Renewable & Sustainable Energy Reviews, Issue 37, pp. 907-919, 2014.

IEA, *Net Zero by 2050,* Paris: IEA, 2021.

Kitagawa, K., Komada, N., Hayano, H. & Tanabe, S.-i., *Effect of humidity and small air movement on thermal comfort under a*, Energy and Buildings*,* Volume 30, pp. 185-193, 1999.

Putra J.C.P, *A Study of Thermal Comfort and Occupant Satisfaction in Office Room*, Procedia Engineering, Volume 170, pp. 240-247, 2017.

Tian, Z. & Love, J. A., *A field study of occupant thermal comfort and thermal environments with radiant slab cooling*, Energy and Buildings, Volume 43, pp. 1658-1670, 2008.

ANALIZĂ NUMERICĂ ASUPRA CONFORTULUI TERMIC ÎN ÎNCĂPERI CE UTILIZEAZĂ SISTEME DE ÎNCĂLZIRE PRIN CONVECȚIE ȘI RADIAȚIE

Conceptul de energie este în strânsă legătură cu clădirile și sistemele de încălzire utilizate pentru acestea, implicit economisirea de energie, care este o problemă actuală a clădirilor noi, dar mai ales a celor vechi. În cadrul lucrării au fost realizate o serie de simulări în programul Autodesk CFD Simulation, cu scopul de a studia influența soluției terminale de încălzire asupra confortului termic, într-o încăpere.

S-au analizat trei soluții de caz, după cum urmează: încălzirea unei încăperi cu radiator din oțel, încălzirea unei încăperi cu radiator din aluminiu și încălzirea unei încăperi cu pardoseală încălzitoare. Au fost comparate valorile rezultate prin simulări numerice pentru temperaturile medii pe înălțimea încăperii cu valorile pentru încălzirea ideală. S-a observat că încălzirea în pardoseală este cea mai eficientă sursă de încălzire dintre cele analizate, corpul uman simțindu-se mai confortabil datorită repartizării uniforme a temperaturii de la nivelul solului, pe înălțime.