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# Energy Performance Certification and CFD Simulations of Thermal Comfort in Non-Residential Building

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**Abstract:** In 2011, the Republic of Serbia adopted a new legislation on the energy efficiency certification of buildings. This introduced new requirements which demand proof of adequate levels of thermal comfort in buildings by designing and conducting energy efficiency reports. The energy performance certification for new hotel building on Serbian mountain Zlatibor is presented in the paper. The harsh mountain climate conditions were considered together with the building type and usage. The thermal comfort conditions were simulated for three different types of heating system: radiator, under-floor heating and parapet fan coil system. The CFD simulations were performed using software tool PHOENICS FLAIR. One representative hotel apartment was selected and modeled. The results on temperature fields, air velocity distributions, radiant temperature, PMV and PPD indices were obtained, and analyzed for mentioned systems. Using CFD simulations in early stage of the design process enables an appropriate decision making regarding the type of HVAC system which would be the most convenient for specified type of building. The results presented in paper give the overview of the system which provides the most desirable thermal comfort conditions.

**Keywords:** Building energy performance certification, CFD simulation, Thermal comfort, PMV, PPD

## 1. Introduction

During the past ten years, the research concerning thermal comfort has been dramatically increased, with a peak in 2011, when almost 900 documents about thermal comfort were published [1]. There is significant number of papers regarding thermal comfort in buildings, but very limited number of studies about thermal comfort in hotel buildings, which can be noted through the literature review [2-4].

The review of results published so far, regarding thermal comfort in buildings, standards and main approaches is presented in [2]. Different approaches and climate regions can significantly influence the thermal comfort conditions, thus the conclusions about thermal sensations and thermal comfort indices may significantly differ. Zhang et al. [5] were researched the differences in thermal comfort and winter indoor environments among the different regions such as Europe, North America and Asia. The study was done among the ten different cities in these regions. The results showed that Europeans has a sensation of colder environment than predicted, while Chinese felt better than predicted [5]. The thermal comfort in non-residential buildings, which involved educational and office buildings with large number of occupants was researched by Bajc et al. in studies [6-8].

Other authors researched thermal comfort conditions in rooms with respect to the type of heating system and its displacement. Sevilgen and Kilic [9] researched the thermal comfort in room with panel radiators using numerical simulations and concluded that the insulation of thermal envelope significantly impacts on energy consumption reduction and thermal comfort improvement. Chung et al. [10] analyzed the impact of underfloor air distribution system on thermal comfort and suggested that this system has a good control over the local thermal comfort parameters. Lu et al. [11] used the numerical simulations in order to research the airflow and temperature in room with one radiator. The results compared between the simulations and experiments showed good agreement.

All this results were the main impeller for the research regarding different types of heating systems in winter conditions, in hotel building, which is located on Serbian mountain Zlatibor, with harsh climate and extended heating season.

## 2. Building model

The observed building is located on mountain Zlatibor, Serbia. It is a luxury hotel (fig. 1) with total heated area of 777 m$^2$ and total net volume of 2000 m$^3$. It has five floors with apartments and one of them is chosen as a representative one for the CFD analysis of thermal comfort. The analysis was done for three different types of heating system: under-floor heating, radiator and parapet fan coil system. The heat source for the building is an electric water boiler, which fulfill the total building requirements for heating and hot water.

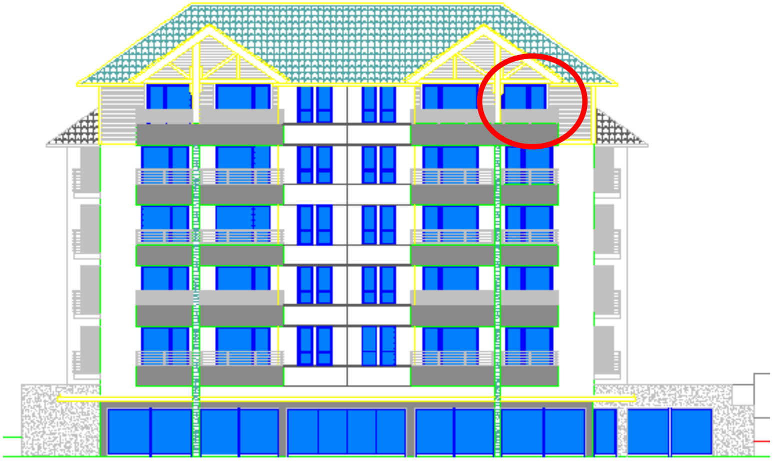

*Figure 1. Building south facade with a position of representative apartment*

## 3. Energy performance certification

The energy performance certification was done in accordance with the Serbian regulation [12,13] for whole heated building area. The energy performance calculation methodology is suggested in Regulations [12,13] and used in this analysis. The building thermal envelope characteristics were calculated according to the prescribed methodology, and the results, compared to the maximal allowed U-values are shown in Table 1.

*Table 1. Calculated and maximal allowed U-values for building thermal envelope*

| Building thermal envelope | $U$ [W/(m$^2$K)] | $U_{max}$ [W/(m$^2$K)] | Fulfilled YES / NO |
|---|---|---|---|
| External walls | 0.22 | 0.3 | YES |
| Ceiling above heated space (unheated attic) | 0.12 | 0.15 | YES |
| Windows, balcony doors | 1.5 | 1.5 | YES |

The building energy performance for winter period was evaluated for whole building. The annual energy need for space heating is presented in Figure 2.

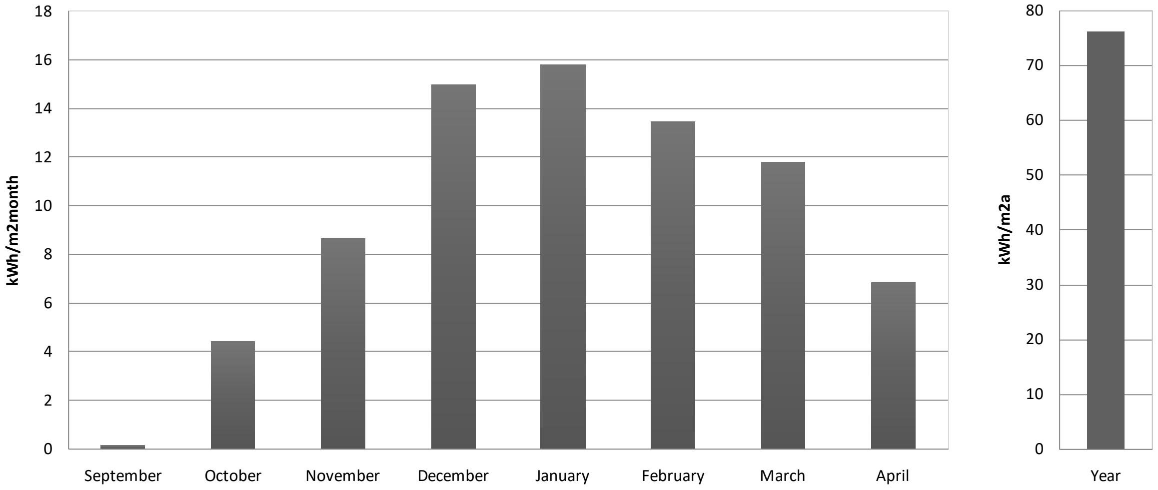

*Figure 2. The building energy needs for space heating monthly (left) yearly (right)*

The total specific calculated annual energy need is 76 kWh/m$^2$a, which corresponds to the "C" class of the building, according to the Rulebook [13]. For new commercial buildings for tourism and catering the maximal allowed amount of annual energy need for space heating is less than or equal to 90 kWh/m$^2$a. The total primary energy need is 316038 kWh/a, including also the primary energy for domestic hot water preparation and auxiliary energy for technical systems during the heating season. Specific emission of carbon-dioxide for observed hotel building with an electric energy source, for winter period is 196 kg/m$^2$a.

## 4. CFD simulations

This part of the analysis had been performed using the Computational Fluid Dynamics (CFD) method in order to obtain the temperatures, velocities, air turbulence and thermal comfort indexes. Numerical simulations are widely used for air distribution prediction in buildings. The first CFD models of a ventilated room were developed in 1970s by Nielsen [14], and these days there are numerous studies on this topic.

### 4.1. Mathematical background

The problems of convection airflow and radiative heat transfer are governed by the conservation equations of mass, momentum in each flow direction and energy, together with the additional mathematical relation for closing the system of equations. In order to solve the system of equations, numerical simulation software tool PHOENICS FLAIR [15] was used. Furthermore, the airflow is considered as predominantly turbulent. The model of the turbulence was formed using a standard $k$-$\varepsilon$ model for natural convection with an additional buoyancy effects, using the model presented in [6, 15].

### 4.2. Creation of geometry

PHOENICS FLAIR is commercial software for HVAC systems and building simulations which can provide information of thermal comfort, IEQ, productivity loss, contamination, smoke movement and fire risk and many other possibilities for airflow analysis.

The created geometries for all three characteristic heating systems are shown in Figure 3.

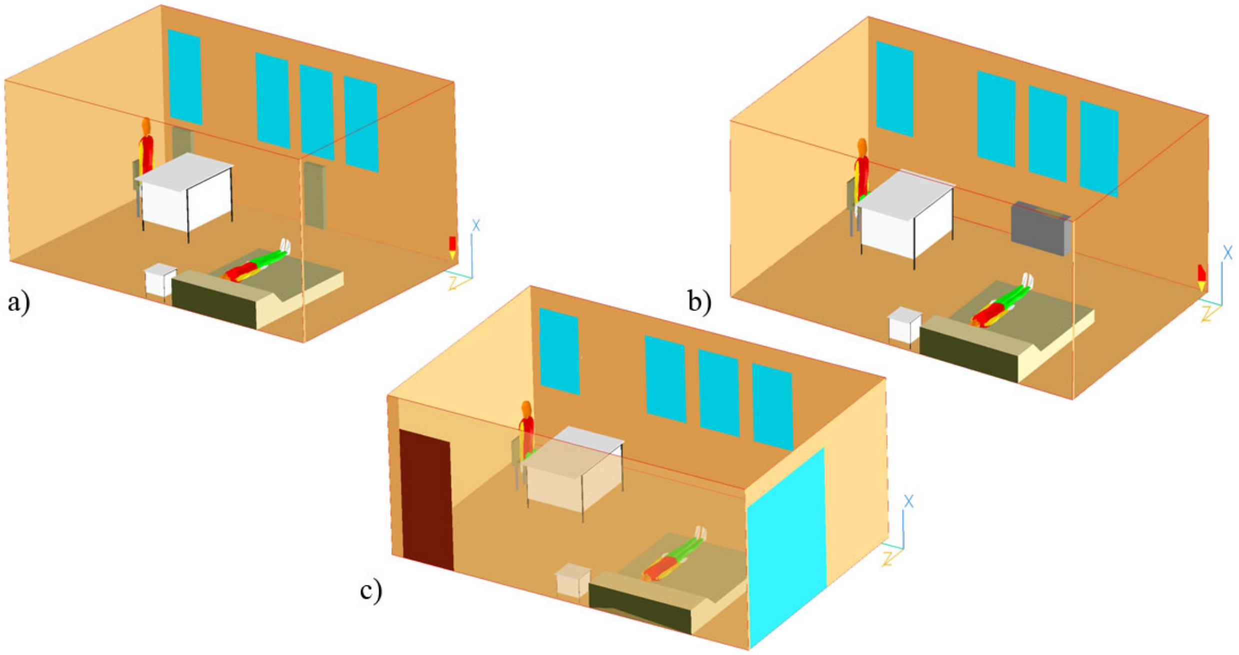

*Figure 3. Geometry created for three heating systems: a) radiator b) fan-coil c) underfloor*

The observed apartment has a total heated area of 25.75 m$^2$ and the total net volume of 64.4 m$^3$. It is South-east oriented, with two external walls. The apartment is located at the fourth floor of the hotel, as it is shown in Figure 1. The East oriented external wall has four windows. Each window has a total area of 0.89 m$^2$ and the parapet below the windows is 1 m in height. The South oriented wall has a balcony door with a total area of 5.07 m$^2$. The other two walls are internal and oriented towards the heated spaces.

## 4.3. Simulation results

The boundary conditions for simulations were calculated for design conditions, for mountain Zlatibor. The inner surface temperatures of the external walls and windows were calculated for the outside design temperature and used as the boundary conditions. The heating systems were dimensioned in order to compensate the heat losses of 1720 W for design conditions, which were calculated in accordance with SRPS EN 12831:2012 [16]. Three different heating systems were compared: underfloor heating, radiator and parapet fan coil system.

### 4.3.1. Underfloor heating system

The design temperature regime for underfloor heating was 35/30°C. The design air temperature in room was 20°C. The average PPD value at heights 0.6m above floor level was about 9% (Figure 4.).

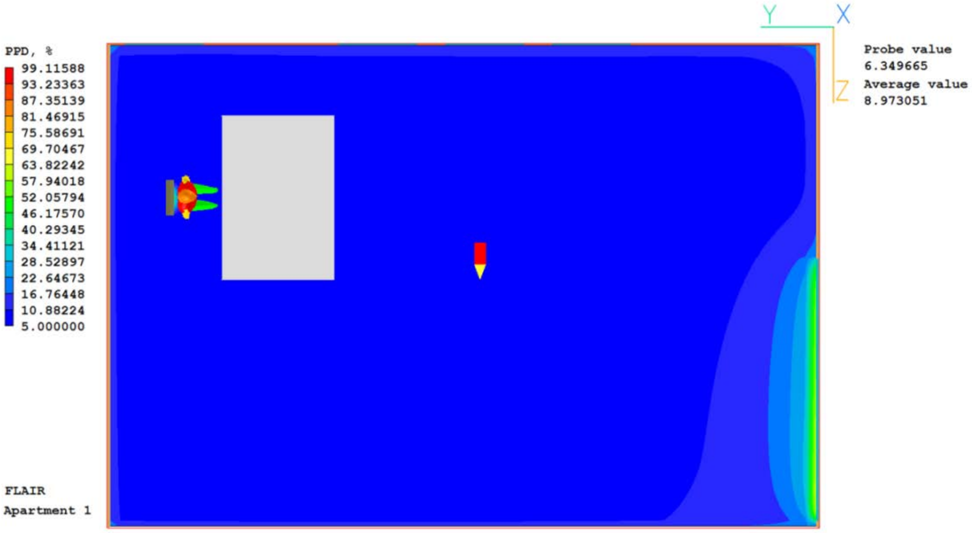

*Figure 4. PPD index for apartment with the underfloor heating system*

### 4.3.2. Radiator heating system

The installed capacity of radiators in observed apartment was dimensioned according to the heating needs for design conditions. The total installed capacity was 1810 W for heating regime 80/60/20°C. Two radiators “Global Vox 800” with five sections each were installed under the windows, as it is shown in Figure 3. a. The CFD simulations of physical parameters and thermal comfort indexes were done also for this case, and an example of results is presented in Figure 5. concerning PPD index for apartment with radiator heating system.

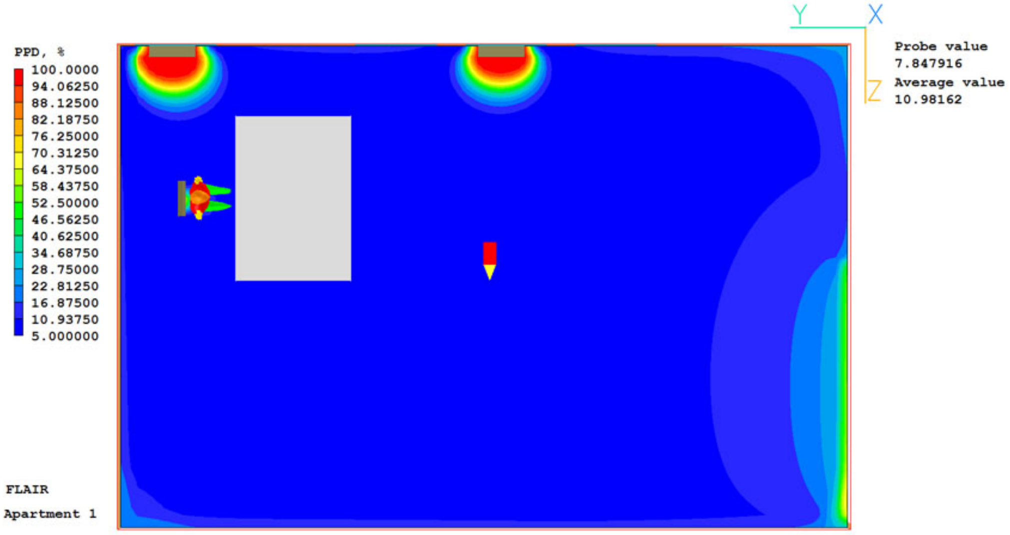

*Figure 5. PPD index for apartment with radiator heating system at heights 0.6 m*

The average PPD value at heights 0.6m above floor level was about 11% (Figure 5.).

### 4.3.3. Fan-coil heating system

Third type of heating system that was concerned was parapet fan-coil system, with total installed capacity of 1700 W (medium speed). The designed model was “Aermec FCX-32”. The fan-coil was positioned under the window, as it is shown in Figure 3. b. The results for PPD index for this case are shown in Figure 6.

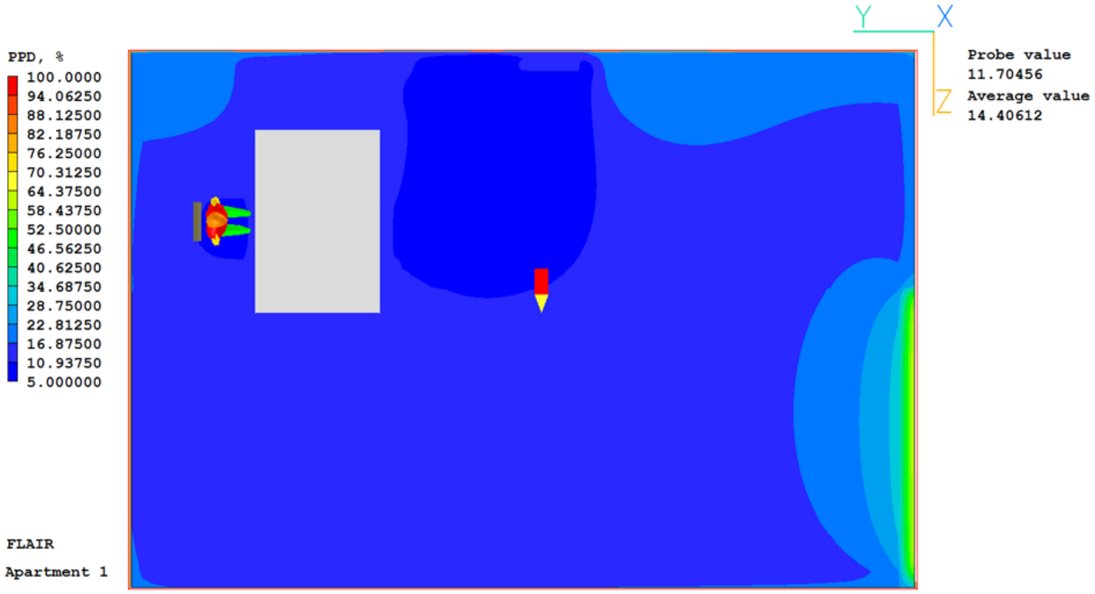

*Figure 6. PPD index for apartment with parapet fan-coil heating system at heights 0.6 m*

## 5. Discussion

Comparing the supply water temperature regime for observed cases (Figure 7.) it can be seen that the highest supply temperature is necessary for radiator heating system, which corresponds to the highest energy consumption for the water preparation and the highest exploitation costs.

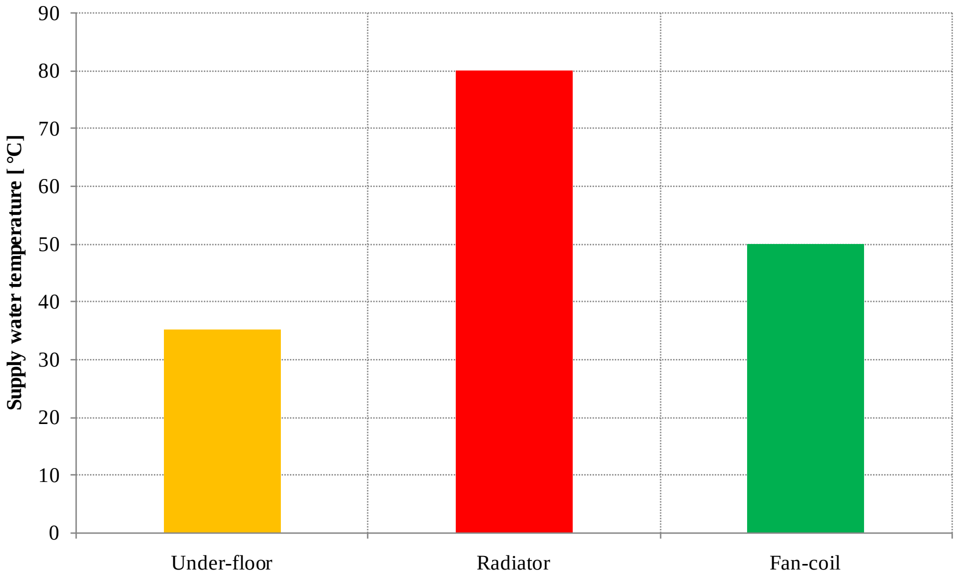

*Figure 7. Supply water temperature for different heating systems*

The results of numerical simulations showed that the indoor air temperature in room was similar in all cases (from 22 to 23°C), but the crucial parameter for comparison was the radiant temperature (Figure 8.).

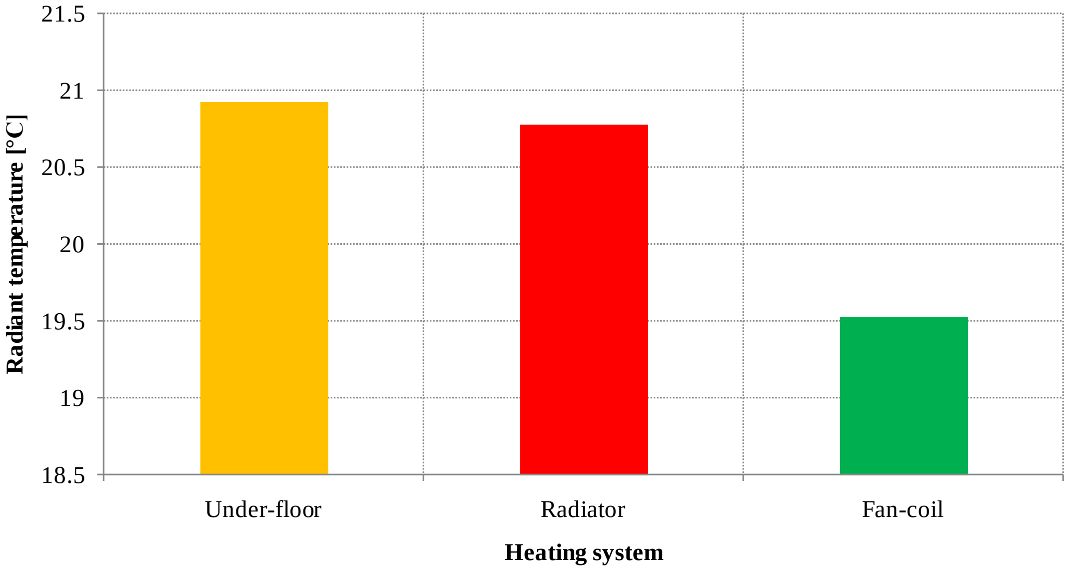

*Figure 8. Radiant temperature for different heating systems*

According to the results, the lowest radiant temperature in apartment was noticed in case of the fan-coil system, which is the consequence of a convective heat transfer mechanism. The radiator heating systems include both the convective and radiant heat transfer mechanism, which is also more comfortable for the occupants and is also reflected through the PPD index compared in Figures 4 to 6. The lowest number of people dissatisfied was noticed in case with under-floor heating system, about 9%, where the radiant temperature was the highest, about 21°C. The indoor air temperature for this case was about 22.6°C.

The results of CFD simulations showed that the biggest occupants' discomfort was caused by the unpleasant cold window surfaces, which influenced on radiant asymmetry, known as one of the most dominant causes of local thermal discomfort, according to ASHRAE Standard 55: 2013 [17] and ISO 7730: 2005 [18].

## 6. Conclusions

According to the simulation results and the analysis of most influential thermal comfort parameters, it is shown that the impact of the radiant asymmetry and unpleasant radiation caused by significant areas with low surface temperature is one of the dominant factors for occupants' dissatisfaction. It is also shown that the heating systems, with both the convective and radiant heat transfer mechanism, provide more favorable thermal comfort conditions, comparing to the heating systems with only convective heat transfer mechanism. Fan-coil systems with forced convection could also provoke a discomfort when air velocities in occupants' zone are higher than prescribed values.

The under-floor heating system was marked as a system with the lowest PPD index, and also with the lowest supply water temperature, which further implies with the lowest exploitation costs in comparison with the radiator and fan-coil system. The impact of radiant asymmetry caused by huge cold window surfaces is minimized in this case and reduced only on the boundary layers near the windows.

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