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Temperature Stratification of Underfloor and Ceiling Based Air Heating Distribution System in an Experimental Room

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Abstract

Most of air heating and ventilating systems for passive houses inlet air in floors. It is assumed that a natural motion of air is led upwards, and so the right stratification of temperature in the space is ensured. However, in the case of excellently insulated buildings it is possible to assume that an upper inlet of air is also able to ensure the required layering of temperature. Within the experiment an influence of upper and down air inlet for temperature stratification in the space was followed. Night sensors of indoor air temperature are placed for measurement purposes. Measurements are done in the long term. The results from measurements show that both, vertical and horizontal stratification of temperature in rooms of passive houses are equal regardless of the fact, which system of air inlet is used.

Key words: air heating, distribution, temperature, stratifikation, building

1 Introduction

Recent residential construction of energy efficient/passive buildings has created tighter, energy-saving building envelopes that create a potential for ventilation systems [1-3]. Infiltration rates in these new houses average 3 to 4 times less than rates in existing building stock [4]. As a result, new residential buildings often need provided ventilation systems to meet current ventilation standards. A floor air inlet is a standard solution of air-heating and ventilation by construction of energy efficient/passive buildings in Slovakia. The reason is an assumption that the warm air rises up, and there is enough mixing of air and the optimal temperature stratification is ensured. For buildings with heat energy demand < 20 kWh/(m^2.a) a hypothesis can be said that the ceiling air inlet of heating and ventilation can provide the same quality of indoor conditions as the floor air inlet. If this hypothesis is confirmed, it is possible to use a system with the ceiling air inlet, which is cheaper, less investment, technological, and implementation difficult in comparison with the floor air inlet system.

Some studies devote to the issue of air inlet and they show that the above mentioned hypothesis is true [5-10]. However, this system is necessary to verify also in the weather conditions of Slovakia.

UFAD systems are mechanical ventilation systems that deliver conditioned air through floor diffusers into occupied spaces. UFAD systems are also known to provide enhanced indoor air quality, thermal comfort and energy efficiency as compared to conventional mixing ventilation systems with ceiling supply diffusers [11]. With UFAD systems, the conditioned air is supplied close to occupants and therefore it is apparent that it would have a strong effect on occupants' thermal sensation. In spaces served by UFAD systems, the "cold feet" complaint due to the low supply air temperature and relatively high velocity of the air movement has often been reported by occupants as uncomfortable thermal sensation [12-15]. Supplying the conditioned air in awarmer range is usually recommended as a mean to avoid this uncomfortable sensation [11]. However, by raising the supply air temperature of the UFAD system, the temperature at the breathing zone may become unacceptably warm due to the vertical temperature gradient. In environments with thermal stratification, the "warm head" complaint and preference for cooler environmentwas found mainly due to the vertical temperature stratification and insufficient air movement around head level [16, 17].

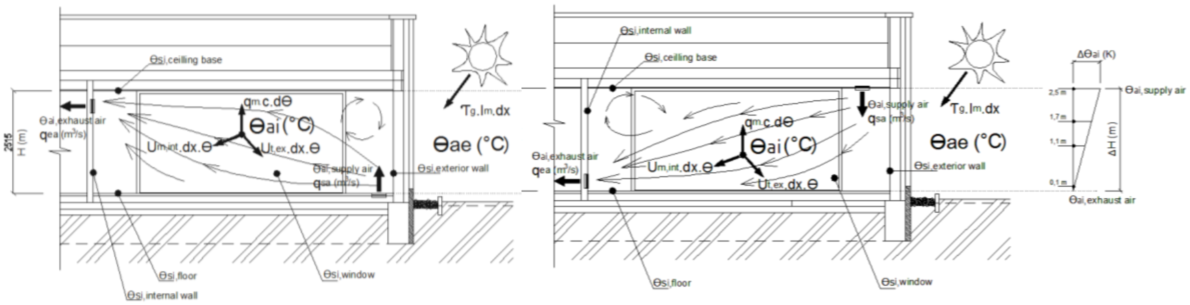


Figure 1: Scheme of temperature stratifikation and airflow of UFAD (left) and CBAD (right) systems

The principle of under floor air distribution (UFAD) and ceiling board air distribution (CBAD) in room shows in Fig. 1. The surface temperature of construction in existing building stock is lower than surface temperature of energy-efficient or passive buildings. Temperature difference changes with high and idealized temperature profile is on Fig. 1 (right).

2 Experiment

2.1 Building and HVAC

It is a single-storey, detached family house with a flat roof. The main entrance is oriented toward the north. The family house is suitable for housing of a single family (2-3 persons). The space arrangement is shown in the Figure 3. The built up area is 110 m^2. The floor area of the house is 82.8 m^2. The building volume for HVAC systems calculations is 211 m^3. The building has a cubic body, which is complemented by wooden shading elements over the outside terraces. Protection against summer overheating was solved solely with the using of the external shading for which a proposal was prepared in relation to the critical summer day - 21st July [17]. Architectural design is determined by the energy concept of the building - two liter house. Large transparent surfaces serve to ensure sufficient heat gains from solar radiation and to achieve the adequate level of daylight (Fig.2).

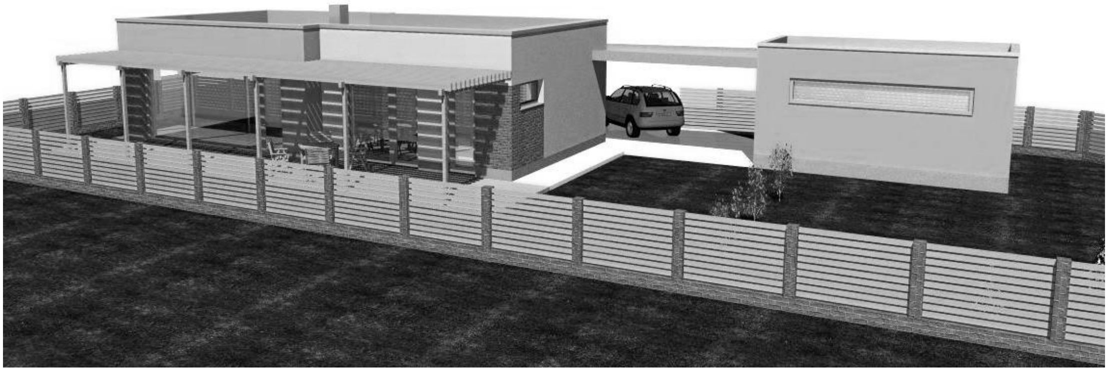


Figure 2: Building model

External walls are made of porous concrete blocks thickness of 250 mm. The insulation system consists of thermal insulation with thickness of 240 mm. Insulation of the foundations and parts of the outer walls at the ground level are proposed by XPS with the width of 120 mm. The roof structure is designed as a single-layer flat roof. The roof insulation is designed with the thickness of 320 mm. The ground floor insulation of thickness 200 mm is placed above the concrete slab. The selected thermo-technical properties of the structures are listed in the Table 1. Typical cross section in the experimental building is in the Fig. 3.

Table 1: Overview of basic thermal properties of the building structures

STRUCTURE	U ($W/(m^2.K)$)	Solar factor g (-)
Envelope	0.125	-
Roof	0.098	-
Floor	0.120	-
Frame systems	0.85	-
Glazing - north	0.44	0.368
Glazing - south	0.51	0.604

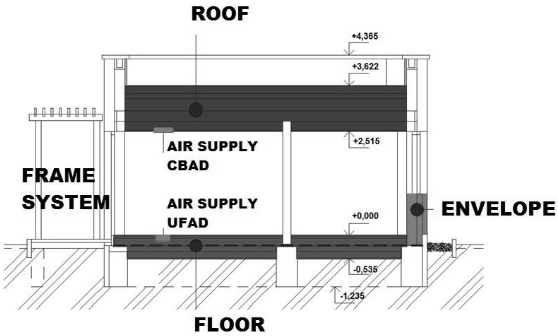


Figure 3: Typical cross section and description of structures in the experimental building

Frames for transparent constructions (windows, glass walls) are made of composite profiles with U_f=0.85 W/(m^2.K). Glazing parts for windows and glazed walls are proposed with triple glazing (4-12-4-12-4) filled with krypton. Different types of glazing are proposed for transparent structures oriented to the north and south. The heat transfer coefficient for the entire window is $U_{w,max}$=0.7 W/(m^2.K).

The whole building is ventilated and heated by a hot air system with output of 3 kW. The heating and ventilation unit (HWU) is designed for heating and circulating hot air simultaneously with ventilation and heat recovery. The HWU works according to the season or momentary needs in five basic modes: Equal-pressure heated mode: full year (n=0,15 to 0,5 1/h); Circulating heating mode: heating season (n=0,15 to 0,5 1/h); Circulating heating mode: the heating period without ventilation (n=0 1/h); Ventilation mode - depressurized: summer and the ventilation period (n=0,15 to 0,5 1/h); Ventilation mode - pressurized: summer period (n=1,0 to 1,8 1/h). The recovery unit works with mean efficiency of 85%. The source of heat for the whole building is warm water. Water is kept in a storage hot water tank (HWT) with the capacity of 615 liters. The HWT is fitted with electric pads and is connected to solar heating panels with surface of 6.5 m^2.

2.2 Methodology of Measurments

Within the research study not only the underfloor air distribution system (UFAD) was installed in an experimental building (house), also the ceiling based air distribution system (CBAD). Schematic descriptions of air distributions for both systems are in the Fig. 4.

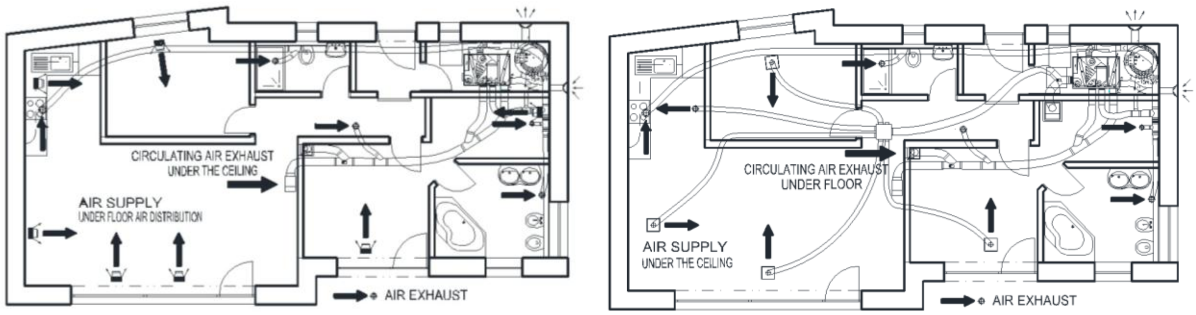
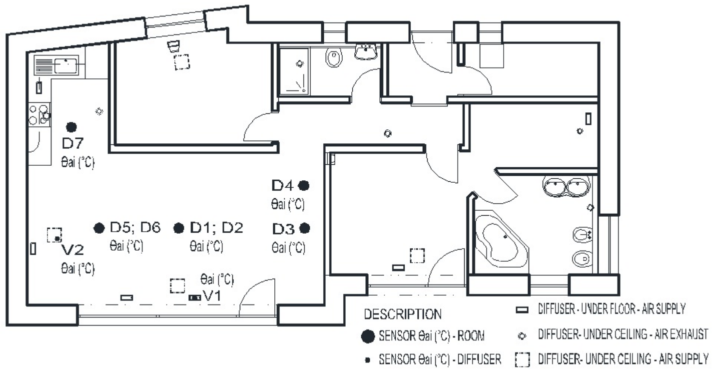


Figure 4: The scheme of air distribution from the floor air inlet UFAD (left) and the ceiling air inlet CBAD (right) in the experimental building

The air heating, ventilating and air conditioning unit (HVAC) is installed in a technical room. Suction of fresh air and exhaust of waste air is located on the building's facade. The inlet of fresh air and circulating heating air are solved by a lower and upper branching system. Behind the HVAC unit the pipes are divided to the lower and upper (under-ceiling) distribution. It is possible to automatically switch these two systems. UFAD consists of thermally insulated flat air distribution ducts beginning in the distribution chamber. The ducts are separately led into each room and to the individual inlet diffusers. CBAD are made from thermo-acoustic ducts above the ceilings. The inlet diffusers are located in the ceilings (CBAD), or close to the windows (UFAD) (Fig. 5).

Figure 5: Exhaust diffusers for CBAD (left) and UFAD (center), and a grid for air circulation in a door (right)



Mark	Height above the floor
D1	2,5
D2	0,1
D3	1,1
D4	0,1
D5	0,1
D6	1,7
D7	2,0
V1	Floor diffuser
V2	Ceiling diffuser

Figure 6: Floor plan – positions of the internal air temperature sensors in the experimental room

The target of the experiment was to monitor the stratification of indoor air temperature in the space, and during the time of the operation of the two distribution systems. The measurements were carried out in a living room. The room was equipped with nine temperature sensors (Fig. 6). Measurements were made with PMICRO TX devices, the temperature range: from -30 to 60 °C, the temperature resolution: 0.065 °C, the maximum uncertainty of: 0.5 °C, the measurement interval: from 1 to 255 minutes, communication via RS232.

3 Results

The analysis of results was done in the years 2011 and 2012. The occupant predominantly uses UFAD. However, CBAD was chosen during the selected period in 2011 (January 1st- February 7th), and in 2012 (February 6th- February 12th). The average difference of measured indoor air temperatures between sensor D3 and D4 was $\Delta\theta_{ai,a}$ = 0.85 K during the operation period for CBAD (February 1st- February 7th). The maximum difference was reached $\Delta\theta_{ai,max}$ = 1.4 K. The limit value $\Delta\theta_{ai}$ = 2 K was not exceeded in any case. The course of the temperature differences for D3 and D4 sensors, and for two days of this period is shown in the Fig. 7a. The average difference of the measured indoor air temperatures for D3 and D4 sensor was $\Delta\theta_{ai,a}$ = 1.09 K during the whole period of CBAD operation in 2012 (February 6th- February 12th). The limit value $\Delta\theta_{ai}$ = 2 K was exceeded in 17 cases. The course of the temperature differences for D3 and D4 sensors during two days from this period is shown in the Fig. 7b.

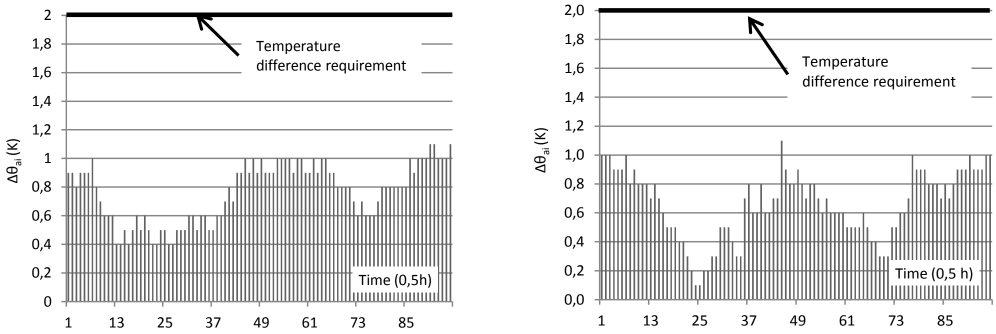


Figure 7: Δθai (K) CBAD, sensors D3 and D4 two days of 2011 (a); two days of 2012 (b)

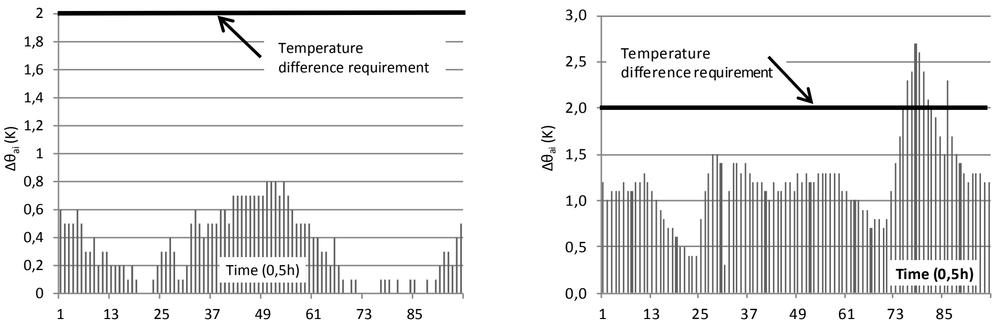


Figure 8: Δθai (K) UFAD, sensors D3 and D4, two days of 2011(a); two days of 2012 (b)

The average difference of the measured indoor air temperatures for UFAD, and for D3 and D4 sensors was Δθai,a = 0.68 K during whole January 2011. The limit value Δθai = 2 K was exceeded in many cases. However, the value Δθai = 2.5 K was not exceeded in any case. The course of the temperature differences for D3 and D4 sensors, and during two days of this period is shown in the Fig. 8a. The average difference of the measured indoor air temperatures for D3 and D4 sensor was Δθai,a = 0.97 K during the UFAD operation in 2012 (January 30th-February 5th). The limit value Δθai = 2 K was exceeded in 7 cases. The course of the temperature differences for D3 and D4 sensors and during two days of this period is shown in the Fig. 8b. The Fig. 9a presents the temperature stratification for D3 and D4 sensors, during use of UFAD system 31.01.-05.02.2012. The Figure 9b presents the temperature stratification for D3 and D4 sensors, during use of CBAD 06.02.-12.02.2012.

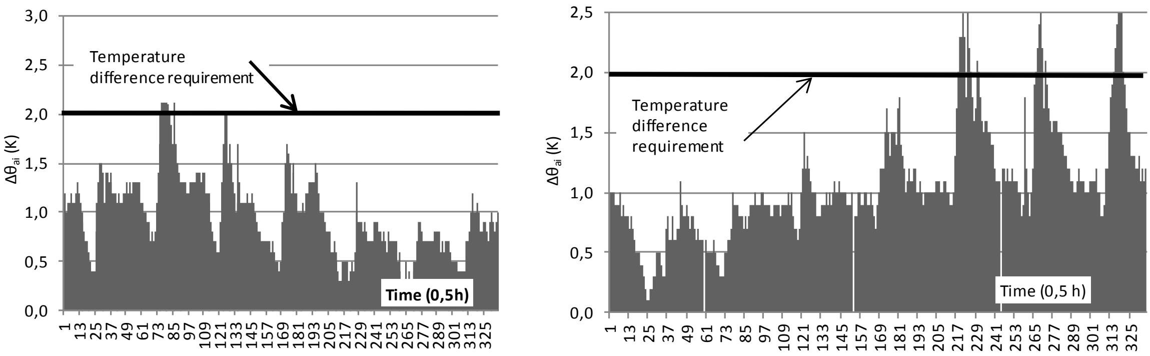


Figure 9: Δθai (K), sensors D3 and D4 UFAD 31.01.-05.02.2012 (a) and CBAD 06.02.-12.02.2012 (b)

The Fig. 10a presents the temperature stratification in a horizontal level (h = 0.1 m; D1 and D4 sensors). The average value for the measurement interval was $\Delta\theta_{ai}$ = 0.29 K. The Figure 10b presents the temperature stratification along a vertical level of the room (h = 2.5 m; D1 and D2 sensors). The average value for the measurement interval is $\Delta\theta_{ai}$ = 1.96 K. If $\Delta\theta_{ai} > 3$ K, it is the effect of the occupant's activity or climatic factors. For the more detailed analysis of the internal air temperatures were chosen the days, when the lowest (February 2nd, 2011) and the highest (February 6th, 2011) external air temperatures were recorded. The courses of the indoor air temperature differences for the selected sensors are shown in the Fig. 11a and 11b. It is clear from the results that the temperature stratification is natural. The differences between temperatures arise because of the different sensors positioning, or due to an impact of external factors as solar radiation or the occupant's activity.

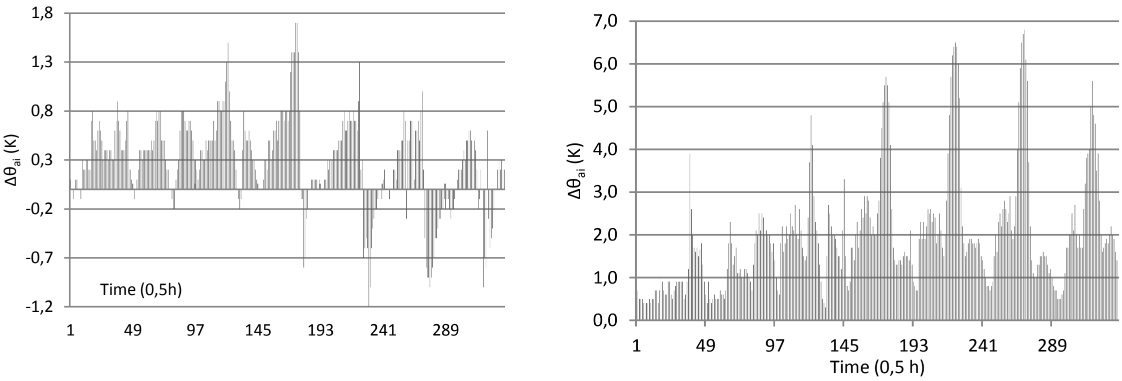


Figure 10: Δθai (K) CBAD, February 6th-12th, 2012 sensors D1-D4 (a); sensors D1-D2 (b)

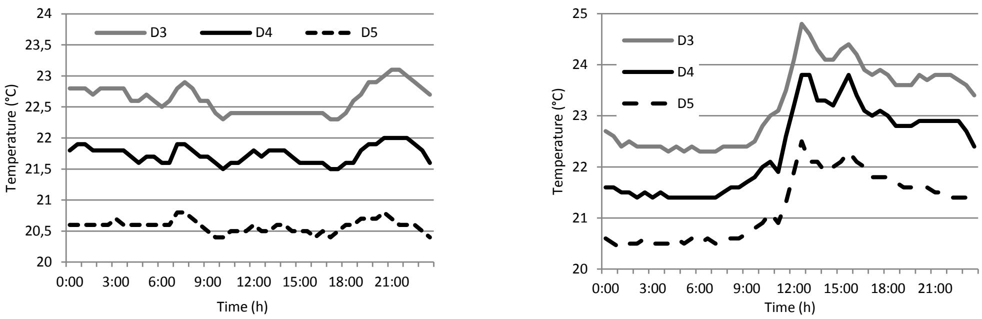


Figure 11: Daily indoor air temperatures - CBAD, 2.2. (a) and 6.2. (b) D3, D4, D5.

4 Conclusion

The matter of buildings design with the energy heat demand < 20 kWh/(m^2.a) is strongly actual. The development of components enables an effective implementation, operation and economy of buildings. For this purpose was proposed, and in this paper examined, the air heating and ventilating system. This system allows to inlet warm/cold air into the room from the floor, or the ceiling. The aim was to verify, whether the air inlet in the ceiling is as effective as the air inlet in the floor from a point of temperature stratification. Based on conducted experiments and obtained results it can be concluded that the air inlet in the ceiling is as effective as the air inlet in the floor. The results of this system can be recommended for a wider usage in a practice.

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