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Thermal Comfort Measurement for Wet Floor Cooling System

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Abstract : The trend of constant increase in energy prices can be observed especially on the increased demands on the thermal insulation properties of building structures of buildings. According to European Directive 2010/31 / EU, since 2019 only buildings that meet the energy standards of near zero buildings have to be designed. In practice, the design of the building takes into account, in particular, the shape of the building, its cladding, but also the method and technology for heating, cooling and hot water production. In the case of a family house is considered a specific annual consumption of heat for heating up to 20 kW.h.m^{-2} floor area. A popular way to achieve low heat consumption is to select an efficient heat source - a heat pump. It is best to combine a heat pump with a heating system with a low temperature gradient. The combination of heat pump and radiant floor heating is very popular. Modern heat pumps also come with the possibility of reversible operation and serve as a source of cold. The following article will therefore address floor radiant cooling and its effect on thermal comfort.

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1 Introduction

From 2010 to 2019, the increase in heat prices is more than 45% [4]. This forces users to look for economical heating and cooling systems. At the same time, legislation prescribes the design of buildings with minimum heat losses and thermal loads. European Directive 2010/31 / EU makes it impossible to issue a building permit for buildings that do not fall into categories A1 and better. One of the ways in which a building can meet these conditions is to choose the appropriate method and technology for heating, cooling and hot water production. Many new buildings use the heat pump as the heat source. In combination with radiant underfloor heating, it seems to be the most advantageous solution from fully-automated heating systems in terms of operating costs. A considerable disadvantage is the higher purchase costs. However, this disadvantage can be compensated by the versatility of the heat pump and the possibility of use not only as a heat source but also as a source of cold, where the cooling system can also be an existing floor heating distribution.

2 Cooling using a radiant floor system

The cost of the heat pump is significantly higher than that of a gas condensing boiler. However, if one source is used for both heat and cold production, the total purchase price is consequently lower than for one specific heat source and a separate cold source. Most heat pumps can also operate in reversible mode and can produce cold. A simple circuit diagram of the heat pump so that it can serve as a heat source in winter but also as a source of cold in summer and can also produce hot water is shown in Fig. 1.

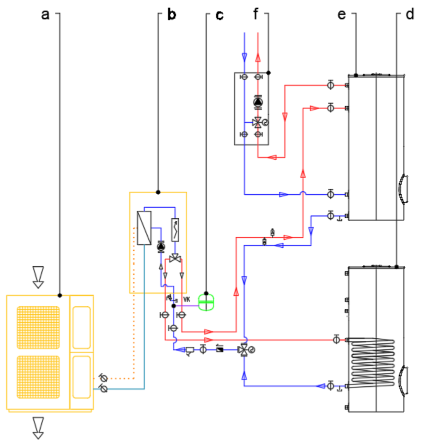

Figure 1 Heat pump wiring diagram for heating and cooling - a) External heat pump unit, b) Internal heat pump unit, c) Expansion vessel, d) Domestic hot water tank, e) Buffer vessel, f) Pump group.

This system is able to replace cooling systems with minimal investment costs in the summer months. However, the performance of a cooling device is limited by several factors that limit its use. When used in combination with a floor radiant system, a suitable temperature gradient should be considered because of the risk of condensation of water vapor on the cooled surface of the structure. An unfavorable factor is also the elimination of the influence of natural convection and accumulation of cold air above the floor. These facts can have a major impact on thermal comfort and comfort in a cold room [6].

3 Thermal comfort for floor cooling

The most important environmental component, the thermal-moisture microclimate, is used to assess the appropriate thermal condition of interiors - thermal comfort. Its disruption affects homoiothermia. A person with his / her mental and physical state is able to adapt to a certain microclimate. There is a range (neutral zone) in which the adaptation requirements are minimal and the person feels best there. In this state, one does not feel cold or resp. excessive heat. The state of thermal comfort can be expressed as a function of six independent variables (thermal comfort factors) [1,2,5].

$$f(q_q, R_{cl}, \theta_i, p_i, v_i, \theta_u) = 0 \tag{1}$$

q_q - total density of heat flow from the human body ($q_q = q_m \pm q_w$) [W.m^{-2}]
R_{cl} - thermal resistance of clothing [m^2.K.W^{-1}] ([CLO])
θ_i - indoor air temperature [°C]
p_i - partial pressure of the water vapor of the internal air [Pa]
v_i - Indoor air flow rate [m.s^{-1}]
θ_u - Average radiant temperature [°C]

The first two parameters characterizing the state of thermal comfort and thus qq and Rcl are subjective. These parameters vary from user to user. The other four parameters are objective and physical-measurable quantities determining the state of the environment [1].

3.1 Measurement in a thermostatic chamber

For accurate determination of boundary conditions for measuring the thermal comfort of floor cooling, measurements were carried out in a thermostatic chamber for testing and evaluating the performance of heating elements and convectors according to EN 442 part 2. The length of the chamber is 4 ± 0.02 m, width 4 ± 0.02 m height 3 ± 0,02 m. During cooling, cooling water with a flow temperature of 17 ° C flows through the floor system. This temperature is limiting because of local thermal discomfort in the foot area but also because of the risk of water vapor condensation on the floor. Fluorescent lamps are used as the thermal load of the building, which converts 99% of electrical energy into heat. The lamps are evenly distributed over the corners of the room in a total of 12 pieces. The indoor air temperature is controlled by the superior system to maintain the equilibrium conditions and the reference room temperature is in the range of 26 ± 0.5 ° C. With the known fluorescent lamp power, 520 W or the known flow and temperature gradient of the cooling water, we can accurately determine the cooling power during equilibrium in a thermostatic chamber. The parameters of the indoor air temperature-humidity microclimate were measured at five stations according to the following Fig. 2.

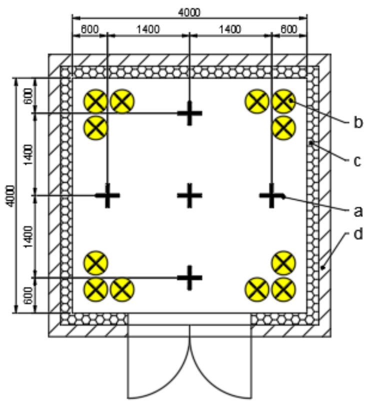

Figure 2 Plan view of thermostatic chamber - a) the position of the measurement of the thermal-humidity microclimate, b) the electric lamp - thermal load, c) the thermal insulation, d) construction of the thermostatic chamber.

3.2 Measuring device

To measure the thermal comfort in the thermostatic chamber, we used the ComfortSense device from Dantec Dynamics. The measuring elements of the device comply with EN 13 182, ISO 7726 and ISO 7730 standards. Overall, the device had five measuring elements. Three measuring elements were used to measure the indoor air temperature and air flow rate. The first, T1, was placed at a height of 0.1 m from the floor and thus at the height of the ankles. The second element, T2, was placed at a height of 1.1 m, the center of gravity of the body. The third element, the T3, was positioned at head level, 1.7 m from the floor. The fourth, OT element, with an ellipsoid shape, is used to measure the operating temperature (function of the effective temperature of the surrounding surfaces). The last element, RH, is used to measure the water vapor partial pressure of the indoor air and assess the relative humidity of the room air. The measuring probes are located on a common tripod of Fig. 3 so that measurements can be made at each station indicated in the thermostatic chamber top view of Fig. 2.

Figure 3 ComfortSense measuring device [3]

3.3 Measured parameters of thermal-humidity microclimate

All objective parameters of the thermo-humidity microclimate was measured during equilibrium in a thermostatic chamber where the average temperature of all sensors was 26 ± 0.5°C. The remaining objective parameters were chosen according to the estimation of the anticipated activity or the value according to the norm was chosen. The selected total heat flux density from the human body was a standing, slightly active user, where production is expected to be 90-100 $W.m^{-2}$. The thermal resistance of the clothing for measuring the thermal comfort of cooling systems is set at 0.5 CLO, or 0.078 $m^2.K.W^{-1}$. Table 1 shows the average values of the measured variables from all the stations, even with the measurement uncertainty.

Table 1 Average parameters of thermal-humidity microclimate for floor cooling

Measuring element	T1	T2	T3	OT	RH
Indoor air flow rate [$m.s^{-1}$]	**0,02 ±0,02**	**0,02 ±0,02**	**0,02 ±0,02**		
Indoor air temperature [°C]	**25,18 ±0,2**	**27,08 ±0,2**	**27,27 ±0,2**		
Operative temperature [°C]				**25,77 ±0,2**	
Relative humidity [%]					**39,51 ±2**

4 Evulation of Thermal comfort in floor cooling

For the assessment of the environment, we can use the seven-stage psychophysical scale by Gage, Stolwijk and Hardy:

-3 - cold, -2 - cool, -1 - slightly cool, 0 - neutral, +1 - slightly warm, +2 - warm, +3 - hot.

The resulting thermal status of the measured environment by Petráš (2005) is expressed using the Predicted Mean Vote (PMV), which results in the average value of the thermal sensations of a large group of users. The PMV index reflects the average sense of well-being of a large group of users, but feeling of individual's can move around the resulting value. For this reason, the PPD (Predicted Percentage of Dissatisfied) was used to express the predicted percentage of people dissatisfied with the thermal environment. An environment in which the PPD of 5% to 10% is optimal for the human body [1].

Tab. 2 shows the PMV and PPD values for a wet floor cooling system with a heat load stabilized at 520 W. These values are shown in the graph of PPD and PMV indices in Fig. 4

Table 2 PMV and PPD values for a wet floor cooling system

Measuring element	T1	T2	T3
PMV [-]	**-0,33**	**-0,12**	**-0,11**
PPD [-]	**7,21**	**5,32**	**5,24**

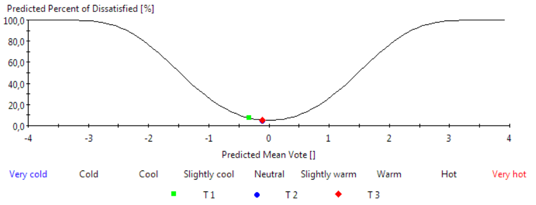

Figure 4 Dependence of PPD and PMV indices for wet floor cooling

A simpler idea of indoor air temperature distribution, as well as vertical and horizontal temperature gradients, is illustrated in Fig. 5. In the figure we can observe the gradual distribution of temperatures in the vertical direction due to the absence of a significant proportion of the convective component in the distribution of cold in the room.

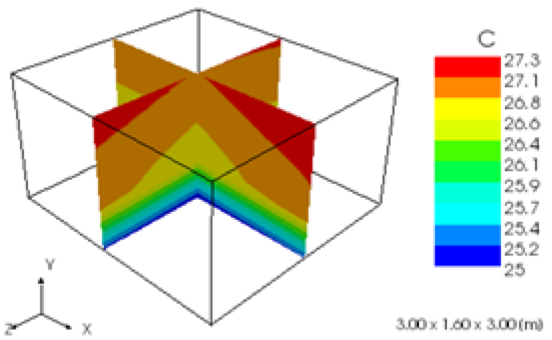

Figure 5 Temperature distribution in the interior for wet floor cooling

4 Conclusions

The return of the heat pump can be significantly reduced in its use as a source of cold. In combination with a wet floor radiant system it forms a frequent and comfortable combination for heating buildings. With a suitable design, it can replace the cooling system with minimal purchase costs. However, the condition of low heat load of the building must be taken into account. The maximum thermal load for an area of 16 m^2 in the thermostatic chamber where the measurement was carried out at equilibrium was 520 W. The floor surface was formed by concrete screed. In normal use, however, the floor surface will be a laminate floor, ceramic tile or other surface material. Thus, it can be determined that under normal conditions the cooling power of the system is at most 30 $W.m^{-2}$. Such outputs are only sufficient for passive houses and houses with low thermal loads. Assessment of the environment and the thermal-moisture microclimate in the thermostatic chamber where the cooling system of the measurements represented a PPD index interval of 〈5.24; 7.21〉, representing a range of nearly 2%. The wet floor cooling system can therefore be evaluated as comfortable and at the same time affordable. However, local thermal comfort factors must also be taken into account, as a long stay on the cold floor can lead to discomfort.

Reference list

[1] PETRAS, D.: *Vykurovanie rodinných a bytových domov*, Bratislava, Jaga group, 2005.

[2] SZÉKYOVÁ, M., FERSTL, K., NOVÝ, R.: *Vetranie a klimatizácia*, Bratislava, Jaga group, 2004.

[3] DANTEC DYNAMICS.: ComfortSense, [Online], Available: https://www.dantecdynamics.com/comfortsense [3 December 2019], 2019.

[4] ZILINSKA TEPLARENSKA.: Ceny tepla, [Online], Available: http://www.teplarenzilina.sk/dokumenty/ceny-tepla# [3 December 2019], 2019.

[5] RESEARCHGATE.: Practical evaluation of the thermal comfort parameters, [Online], Available: https://www.researchgate.net/publication/305755583_Practical_evaluation_of_the_thermal_comfort_parameters [3 December 2019], 2002.

[6] PAPUCIK, S., NOSEK, R., LENHARD, R.: *Vykurovanie*, Žilina, EDIS, 2012.

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