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INTERNATIONAL HVAC&R CONGRESS AND EXHIBITION

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Društvo za klimatizaciju, grejanje i hlađenje Srbije održalo je 50. Međunarodni kongres i izložbu o KGH, uz podršku najvećih naučnih i stručnih institucija iz sveta i učešće istaknutih predstavnika nauke i struke KGH, ali i sa univerziteta širom sveta i iz mnogih grana industrije.

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Beograd, oktobar 2020.
Prof. dr Branislav Todorović

FOREWORD

The Sebian society for heating ventilation and air-conditiong organized the 50th International HVAC&R Congress and Exhibition with endorsement of the most important scientific and professional organizations from all over the world, and with participation of respectable scientist and professionals in the field of HVAC&R, as well as from universities and various industry branches.

The Proceedings contains more than 60 papers writen by more than 150 authors and coauthors from all over the world.

The International scientific committee proposed a number of papers to be published in "Energy and Buildings" noting that they were presented at our Congress. Papers waiting for peer review in that journal are presented in this Proceedings with abstract only.

The Proceedings is another valuable contribution to the rich collection of papers presented during half a century of International HVAC&R Congress.

Belgrade, October 2020.
Prof. Branislav Todorović, Ph. D.

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UTICAJ PROMENE TEMPERATURE IZVORA KOD ELEKTRIČNIH PODNIH PANELA

THE INFLUCENCE OF SOURCE TEMPERATURE ON ELECTRIC FLOOR HEATING PANELS

Dragan CVETKOVIĆ*, **Aleksandar NEŠOVIĆ, Jasmina SKERLIĆ, Danijela NIKOLIĆ,**
University of Kragujevac, Faculty of Engineering, Kragujevac, Serbia

Primena niskotemperaturnih električnih podnih grejača (NTEPG) ograničena je higijenslim zahtevima, pa maskimalna temperatura slobodne površine poda treba biti jednolika i u određenim granicama. U prvom delu rada, metodom konačnih zapremina (MKZ) u softveru ANSYS Workbench 14.5, ispitano je polje primene električnih grejnih kablova (EGK) u konstrukciji podnih panelnih grejača (PPG), uzimajući u obzir njihovo međusobno osno rastojanje i temperaturni režim. U drugom delu rada, ponašanje NTEPG-a eksperimentalno je istraženo na fizički izgrađenom modelu testne komore praćenjem unutrašnje temperature vazduha (UTV) u zavisnosti od spoljašnjih uslova.

Ključne reči: *NTEPG; ANSYS Workbench; testna komora; temperature slobodne površine poda; toplotni fluks; UTV*

The application of low-temperature electric floor heating panels (LTEFHP) is limited to hygienic requirements, therefore the maximum surface temperature of the floor should be uniform and within certain limits. In the first part of the paper, using the finite volume method (FVM) in software ANSYS Workbench 14.5, the field of application of electric heating cables (EHC) in the construction of floor heating panels (FHP) was examined, taking into account their axial spacing and temperature regime. In the second part of the paper, the behavior of LTEFHP was experimentally investigated on a physically constructed model of the test chamber by monitoring the internal air temperature (IAT) depending on the external conditions.

Key words: *LTEFHP; ANSYS Workbench; test chamber; floor surface temperature; heat flux; IAT*

1. Introduction

In Serbia is increasingly using of panel heating systems. Besides the commonly used hydronic panels there is an option to use the electric panels for the heating. The low temperature radiant systems are very complex because they involve different mechanisms of heat transfer: heat conduction through the walls, heat convection between the heating panel and the indoor air, heat radiation between the heating panel and the surrounding areas, and the heat conduction between the floor and the ground. The main essence of the low-temperature air systems is to provide adequate thermal comfort at significantly lower temperatures. Heat energy to the panel heater is introduced in two ways: indirectly or directly. In the first case, heating pipes are built into the heater, through which the working fluid flows (hot water), while in the second case the EHC is applied. Panel heating systems have many advantages compared to other heating systems. The heating bodies are not visible, which provides greater interior decoration possibilities. In rooms up to 2.7 m height, floor and ceiling heating provide the most direct distribution of air temperature in the height of the room [1]. Heat emission by people is less. Installation of panel systems is simple, and the same goes for control. From the aspect of final energy consumption, thermal comfort, thermal performance, panel systems were examined in a large number of papers [2-12], numerically and experimentally. In the same papers, the application of panels in cooling systems was also analyzed. The possibility of using panel heating systems (wall and ceiling) in large volume rooms, such as sports, was considered in [13, 14]. Mi Su Shin et al.

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[15] conducted a series of numerical and experimental research to develop diagrams that can help engineers and designers to properly dimension the low temperature floor heating panel, taking into account the heat flux, the difference between maximum and minimum temperature the floor area and the maximum surface temperature of the floor. The method for determining the surface temperature of panel systems was investigated in [16] Experimental and numerical investigations of electric floor heating panels were carried out in [17-20].

Due to all this, EHC have been numerically and experimentally investigated in this paper in order to define their application area and to examine their behavior in floor heating systems.

2. Description of the heating system

2.1. Numerical model

2.1.1. Construction of the low-temperature electric floor heating panel

The structure of the low-temperature electric floor heating panel (LTEFHP) from the inside to the outside consists of the following materials (Fig. 1): Granite Plates (1), Cement Screed (2), EHC (3), PVC Foil (4), Styrofoam (5), Reinforced Concrete (6), Gravel Layer (7) and Stone Layer (8).

The characteristics of these materials are enclosed in Tab. 1.

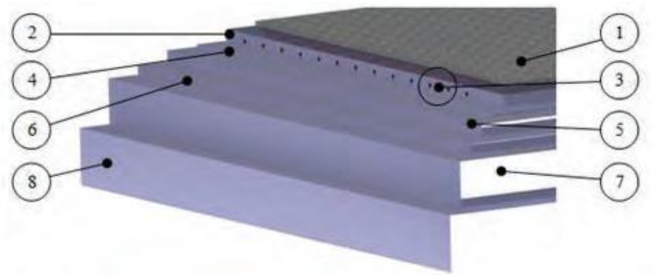

Figure 1. Construction of the LTEFHP

2.1.2. Finite volume method

Finite Volume Method (FVM) is one of the most commonly used methods for considering the problem of fluid transport and the phenomenon of heat transfer. FVM is based on the discretization of the final volume (mathematical model) to a large number of control volumes, with each control volume assigned to the control node.

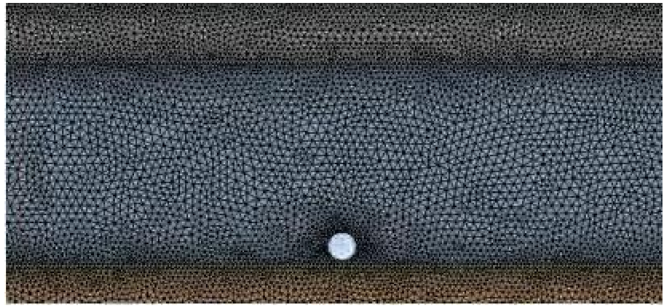

Figure 2. Discretization of the LTEFHP in the heating cable zone

Table 1. Characteristics of materials in the construction of the LTEFHP [21]

Ordinal number	Material	H [m]	ρ [kg/m^3]	c_P [J/kgK]	λ [W/mK]
1	Granite Plates	0.012	2700	920	3.5
2	Cement Screed	0.05	2200	1050	1.4
3	EHC	-			
4	PVC Foil	0.001	1200	960	0.19
5	Styrofoam	0.05	33	1500	0.035
6	Reinforced Concrete	0.04	2400	960	2.04
7	Gravel Layer	0.2	1700	840	0.81
8	Stone Layer	0.25	1750	840	2.035

After discretization, conservation laws are applied to each control volume. The general principle of conservation in differential form [22] can be written as follows (Eq. 1):

$$\frac{\partial(\rho\phi)}{\partial t} + \text{div}\,(\rho\phi\,\text{u}) = \text{div}\,(\Gamma\,\text{grad}\phi) + S_\phi \qquad (1)$$

In the case of only the mechanisms of heat transfer, the members on the left side of the Eq. 1 are ignored, so the Eq. 1 can be written as Eq. 2:

$$\text{div}\,(\Gamma\,\text{grad}\phi) + S_\phi = 0 \qquad (2)$$

where are: S_ϕ = 0 - if only conduction is considered, S_ϕ = - q_{CON} - for conduction and convection, S_ϕ = - q_{RAD} - for conduction and radiation and S_ϕ = - (q_{CON} + q_{RAD}) - if there are all three mechanisms of heat transfer (real problems).

These differential equations are of the integration translate into a system of algebraic equations, which are then solved.

2.1.3. Scenario simulation

The EHC in the LTEFHP was determined on the basis of their mutual axial distance and temperature regime, respectively, based on 70 simulated simulations (Tab. 2).

Table 2. Simulation scenario

t_{IN} [°C]	30	35	40	45	50
L [mm]	70; 80; 90; 100; 110; 120; 130; 140; 150; 160; 170; 180; 190; 200				

The whole numerical problem is considered as a 2D stationary case (the temperature of the heating cable does not change in length), with the following boundary conditions being adopted (Fig. 3): t_{GRO} = 18°C - ground temperature, h = 6 W/m^{2}K - heat transfer coefficient from the LTEFHP to air, ε = 0.45 - Granite Plates emission coefficient [23], H_1 = 603 mm - LTEFHP total thickness, H_2 = 57.5 mm - EHC distance from the free surface, t_{AIR} = 20°C - ambient air temperature.

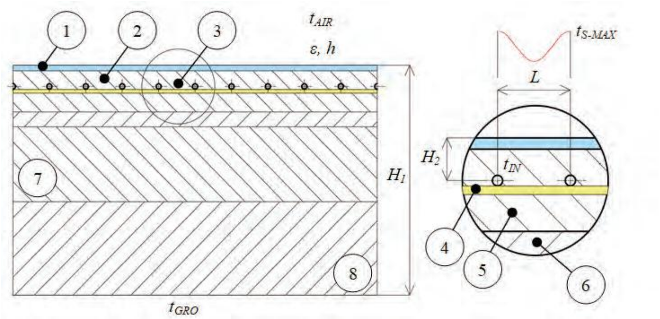

Figure 3. Initial boundary conditions before simulation of LTEFHP

2.2. Experimental model

2.2.1. The test chamber

Experimental study of the characteristics of panel heating systems (PHS) was performed at the Faculty of Engineering Sciences in Kragujevac, partly in the Laboratory of Thermodynamics and Thermal Engineering, and partly in the Laboratory of Motor Vehicles. The experimental installation includes a test chamber, the test model of the house, measuring and control equipment for data collection.

The dimensions of the test chamber were 1500x1500x1800 mm and it placed inside the room dimensions 3500x5500x3800 mm. Test chamber works on the cooling chamber principle which contains two evaporators associated with air chillier. Chiller on the condenser side uses air from the room located within the test chambers. The test chamber has the ability to cool until -15°C however, due to the work of the chiller inside the building in which the chamber was located and due to the low rate of air change in the room leads to overheating of the air and it is not advisable go to temperatures below -5°C.

The temperature of the test chamber was controlled by PID controller type XMTF-308 product Yuyao Gongyi Meter Co. Ltd., which is connected to the PT100 probe (Fig. 4). The humidity and temperature inside the test chamber was measured by the sensor of temperature and humidity type TSN-TH70E product "AREXX Engineering" Netherlands. This sensor used "wireless" connection to communicate with the computer.

The test model was consisted of two stairs that are placed one above the other so that each represents one room which was heated. Dimensions of the test model were 1000x800x650 mm where the room height was 650 mm. In addition, each stair has one opening on the side which glazed with Plexiglas dimensions 300x250 mm. This opening has the function of the window and also has the function of an inspection opening.

Figure 4. The interior of the test model – show the position of the PT100 probe

2.2.2. Construction of the modify low-temperature electric floor heating panel

The modify LTEFHP are made of Polystyrene (5) thickness of 50 mm, unrefined Plywood Slab (1) thickness of 18 mm, PVC Mats (2), EHC (3), Cement Mortar (4) thickness of 5mm and (Fig. 5).

Test model in a constructive sense was entirely made by Plywood, through which by staples attached PVC Mesh with the have the role of laying of the EHC with Raster Laying of 50 mm (Fig. 6). Over the EHC the thin layer of Cement Mortar with thickness 5 mm was applied, which contributes to a homogeneous temperature distribution along the LTEFHP.

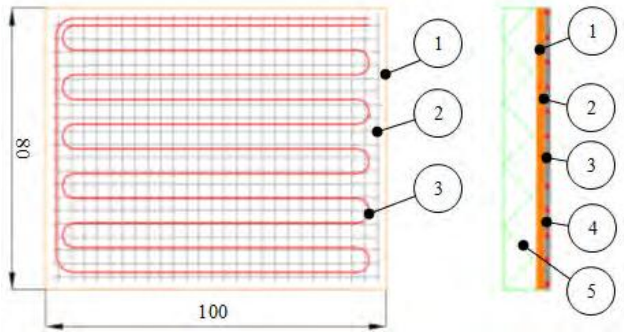

Figure 5. Modify LTEFHP

Figure 6. Detail of installation of the modify LTEFHP

3. Results and discussion

3.1. Numerical investigation

Depending on the LTEFHP application, the maximum floor temperature limit values (t_{S-MAX}) are limited and given in Tab. 3.

Table 3. The maximum floor temperature limit values depending on the LTEFHP application [1]

Room category	Type of room	t_{S-MAX} [°C]
I	In working rooms where a longer period of time is mostly standing	25
II	In residential and office spaces	28
III	In exhibition and similar halls	30
IV	In the bathrooms and swimming pools	32
V	In rooms where short stays, or through which only passes	35

Fig. 5 shows the maximum surface temperature (t_{S-MAX}) depending on the mutual axial distance (L) EHC in the case of the operating temperature t_{IN} = 30-50°C. The same picture shows the functional dependence between the mentioned variables, which is very close to the straight line for all tested cases, so using linear regression equations can be formed in order to simplify the method of determining t_{S-MAX}, and therefore the field of application of EHC in LTEFHP (Eq. 3-7):

$$t_{S-MAX}(t_{IN} = 30°C) = -0.009 \times L + 27.96 \quad (3)$$

$$t_{S-MAX}(t_{IN} = 35°C) = -0.015 \times L + 31.72 \quad (4)$$

$$t_{S-MAX}(t_{IN} = 40°C) = -0.021 \times L + 35.41 \quad (5)$$

$$t_{S-MAX}(t_{IN} = 45°C) = -0.027 \times L + 39.04 \quad (6)$$

$$t_{S-MAX}(t_{IN} = 50°C) = -0.038 \times L + 43.18 \quad (7)$$

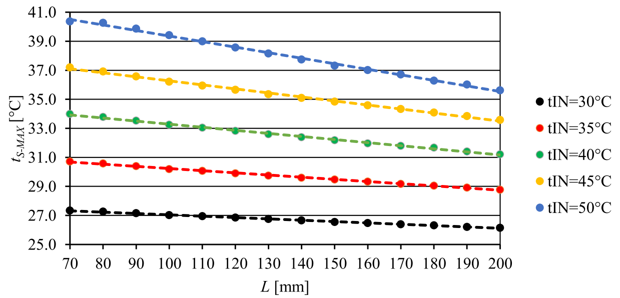

Figure 5. The maximum surface temperature of the LTEFHP depending on the operating temperature and the axial distance of the EHC

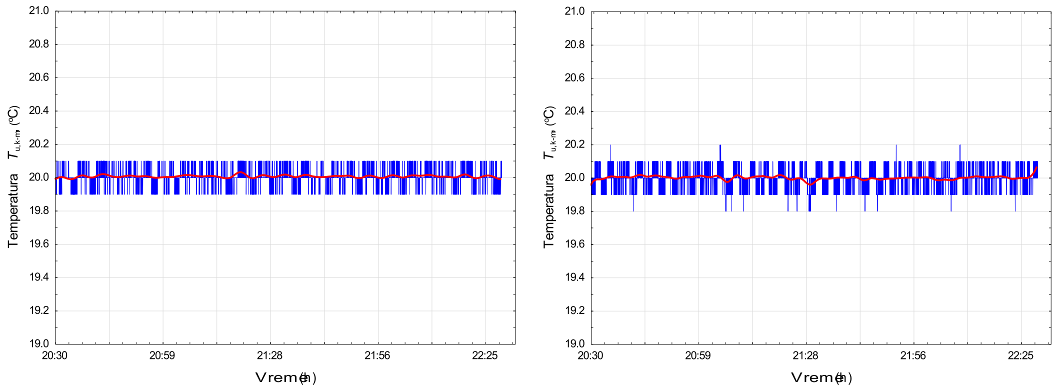

Figure 6. Indoor temperature for t_{OUT} = -5°C upper floor (left) and lower floor (right)

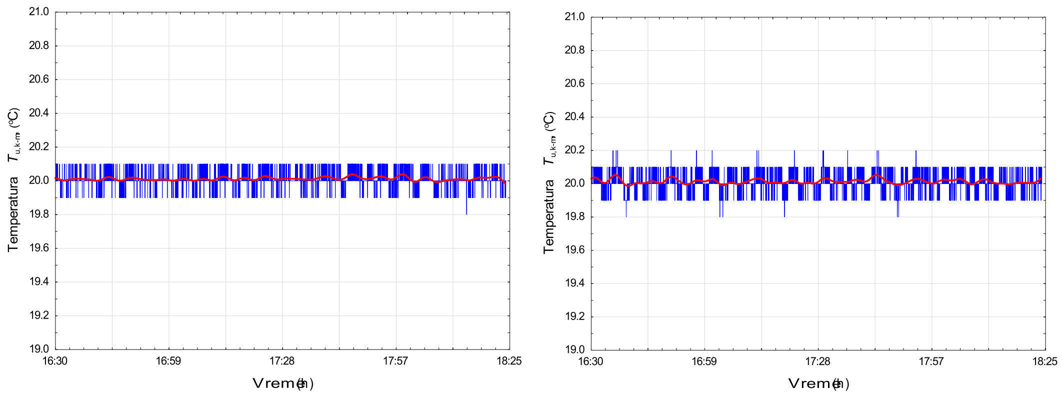

Figure 7. Indoor temperature for t_{OUT} = 0°C upper floor (left) and lower floor (right)

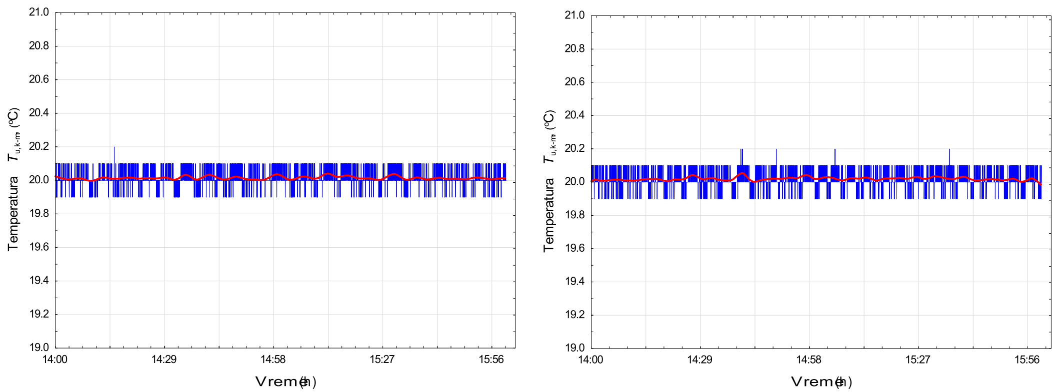

Figure 8. Indoor temperature for t_{OUT} = +4.5°C upper floor (left) and lower floor (right)

Fig. 5 shows that $t_{S\text{-}MAX}$ for all examined cases it ranges between 26-27.5°C, which, according to Tab. 3, would correspond to the premises of the second category, that is, the heating of residential and office space.

If the LTEFHP is operated in the specified mode (t_{IN} = 35°C), for L = 120-200 mm, it can be used (Tab. 3, Eq. 4) for rooms of the third category ($t_{S\text{-}MAX}$ = 28-30°C for L = 115-200 mm) and the rooms of the fourth category ($t_{S\text{-}MAX}$ = 30-32°C, for L = 70-114 mm).

In the case of t_{IN} = 40°C EHC in LTEFHP there is an application for heating the bath and swimming pool area (category IV) if it is L = 163-200 mm, or in short-stayed rooms (category V) for L = 70-162 mm.

Fig. 5 shows that for t_{IN} = 45°C the application of EHC in LTEFHP makes sense only if it is L = 150-200 mm, for heating rooms in which it is short-lived (category V). Because of the $t_{S\text{-}MAX}$ > 35°C (hygienic requirements), LTEFHP do not have the application if it is t_{IN} = 50°C.

3.2. Experimental investigation

The following figures (Fig. 6-8) show the changes in internal temperatures in the test chambers over time for the selected measurement period. Measurements are displayed every second for a total of 2 hours. The change in temperature within the chambers of the test model was measured at constant outdoor temperatures of -5°C, 0°C and +4.5°C. The lower floor temperature of the test chamber was predominantly in the range of 20±0.1°C with a few jumps of ±0.2°C. While the temperature of the upper floor of the test chamber, except for one measuring sample, was exclusively within the limits of 20±0.1°C. This can be attributed to the movement of heat flux from the lower to the upper chamber of the test model.

4. Conclusion

LTEFHP are used in Serbia due to a number of advantages: a uniform temperature distribution in height premises, lower temperature regime, easy installation, long service life, simple control, low electricity price, etc. However, the application of LTEFHP is limited to hygienic requirements, which means that the surface temperature of the floor should be uniform and within certain limits, and what needs to be taken into account at the stage of design and dimensioning of the system.

The results showed that EHC can easily be used to heat residential and office space (category II) if the operating temperature is 30°C in the LTEFHP. If the operating temperature is 35°C, then it can be used to heat the exhibition and sports hall (L = 115-200 mm). Heating rooms IV and V category is possible with an operating temperature of 40°C, but the application limit is quite shifted (L = 163-200 mm for category IV). With an operating temperature of 45°C it is possible to heat only the rooms of the V category, if the distance between EHC is 150-200 mm. Due to hygienic requirements, LTEFHP has no application for the operating temperatures in the panel ≥ 50°C.

5. Acknowledgments

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