Radoslav Ponechal - Daniela Staffenova*

INSULATION THICKNESS VERSUS DYNAMIC THERMAL PARAMETERS OF EXTERNAL WALLS WITH REGARD TO THE THERMAL STABILITY

It appears that the walls, insulated according to the new requirements for thermal resistance, can contribute to thermal stability. This is advantageous not only for the thermal comfort during the summer but in the cases of the intermittent heating, or overheating, as well. This article evaluates some alternatives of insulated and uninsulated external walls. The phase time shift of the indoor surface temperature with respect to the outdoor surface, together with the periodic penetration depth of indoor surface temperature, are considered in this analysis. Analyzing subsurface temperature courses we evaluate the ability of construction to accumulate heat gains, which can arise during the day.

Keywords: *Penetration depth, thermal damping factor, phase time shift, thermal accumulation.*

1. Introduction

The criterion of thermal resistance is undoubtedly the important criterion in the process of the building material selection. However, if the values of thermal resistance are approximately at the same level, the builders would come to a number of other criteria, such as the construction technology or internal environment, created by these construction products.

The thermal comfort is one of the main components in forming the internal environment. For its fulfillment, some form of thermal stability of the internal environment is required. The wide temperature fluctuation that can be visible inside residential buildings is mainly due to the increase of heat sources. During the summer, overheating, specifically due to solar gains and ventilation with warm air, can occur. According to Durica et al. [1], the risk of overheating from the point of view of frequency (with a temperature over 25 °C) can occur in different kinds of passive house constructions. All of the exterior envelope structures evaluated in this study reach the same thermal transmittance. The lowest percentage of overheating occurrence (0.58 %) was reached by the version with walls made of the lime-sand block covered with expanded polystyrene and ceiling made of reinforced concrete. The highest incidence (2.6 %) was found in the version with walls and ceilings made of wooden frame construction filled with sheep wool insulation. Nemecek solved similar problems in the passive house [2]. In his contribution based on simulation calculations of summer overheating, he ranks an energy storage capacity of construction in the 4th place, according to the importance, behind heat gains from solar radiation, internal heat gains and ventilation regime. The difference between air temperatures by light-weight or heavy-weight construction is about 1-1.5 K.

During the winter, overheating may be caused by too much power used for heating in combination with not optimal thermal control of the heating system. Overheating problems associated with the use of wood stoves are documented in Ponechal [3]. Results from the temperature recorder installed in family house showed relatively large temperature fluctuations during the day from 22 up to 27 °C. High temperatures are reached at night, which are opposite to an ideal state when the night-time temperatures should fall in terms of healthy and good sleeping. The short-term overheating can also be used in a positive way, particularly by the intermittent heating, blackouts, etc. Stock of the heat accumulated in building construction during the period of overheating (ideally when the space is not being occupied) can be used to maintain the thermal stability during the cooler part of the day, as suggested by Wolisz [4]. It is a shame that it was realized on the building with relatively large heat losses, which reduced the general benefit of this idea.

By increasing of thermal inertia of the building, the influence of internal structures is usually evaluated. Figure 1 [5] documents the contribution of reinforced concrete ceiling on the thermal inertia. Houses with higher levels of thermal protection cool down slower.

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* **Radoslav Ponechal, Daniela Staffenova**
Department of Building Engineering and Urban Planning, Faculty of Civil Engineering, University of Zilina, Slovakia
E-mail: daniela.staffenova@fstav.uniza.sk

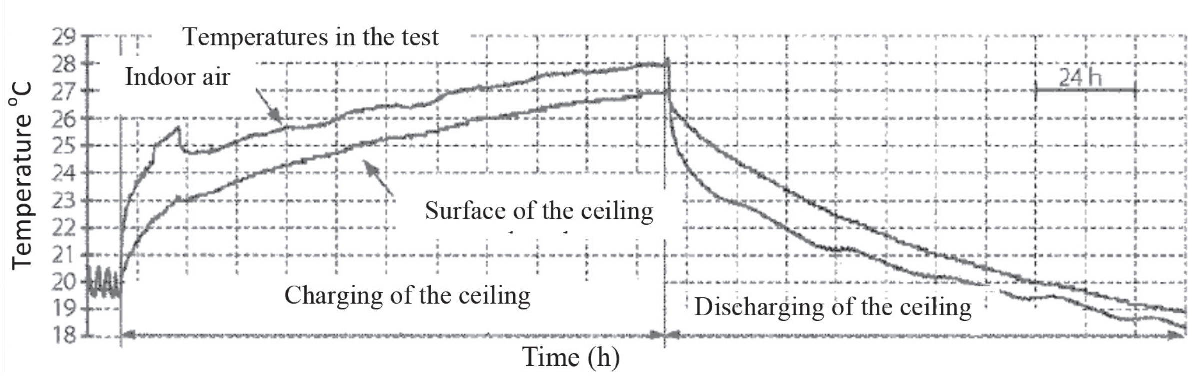


Fig. 1 Experiment of the thermal response. By the absence of residents and switched-off heating and ventilating system, an increase in temperature was reached. This was ensured by the defined heating source in the place of residence, and led to the heating of the reinforced concrete ceiling. After turning off the source, the noticeable thermal inertia is shown, when air in the room is heated by the heat released from the concrete ceiling [5]

Just a temperature discharging process in uninhabited low energy building could be seen in Fig. 2. The presented course of temperature damping is extracted without internal heat gains. With internal heat gains, the temperature damping will be running slower. The effect of internal heat gains is well known and described in details in the literature, e. g. [6].

2. Dynamic thermal properties

Because of the fact that the overheated room temperature is influenced by many factors, it is advisable to look at the comparison of basic dynamic characteristics of building materials separately. The International Standard ISO 13786 [7] describes dynamic thermal parameters of multi-homogeneous-layered walls/roofs based on sinusoidal variations of temperature or the heat flow rate on the one hand and the constant air temperature on the other hand. The parameters relate cyclic heat flow rate to cyclic temperature variations. These parameters are expressed as complex numbers.

Three groups of parameters for the thermal evaluation of building envelope variants in unconditioned buildings are analyzed in this work: thermal damping factor, the phase time shift and the penetration depth of indoor surface temperature. The thermal damping factor (DFs) and phase time shift (LTs) of the indoor surface temperature with respect to the outdoor

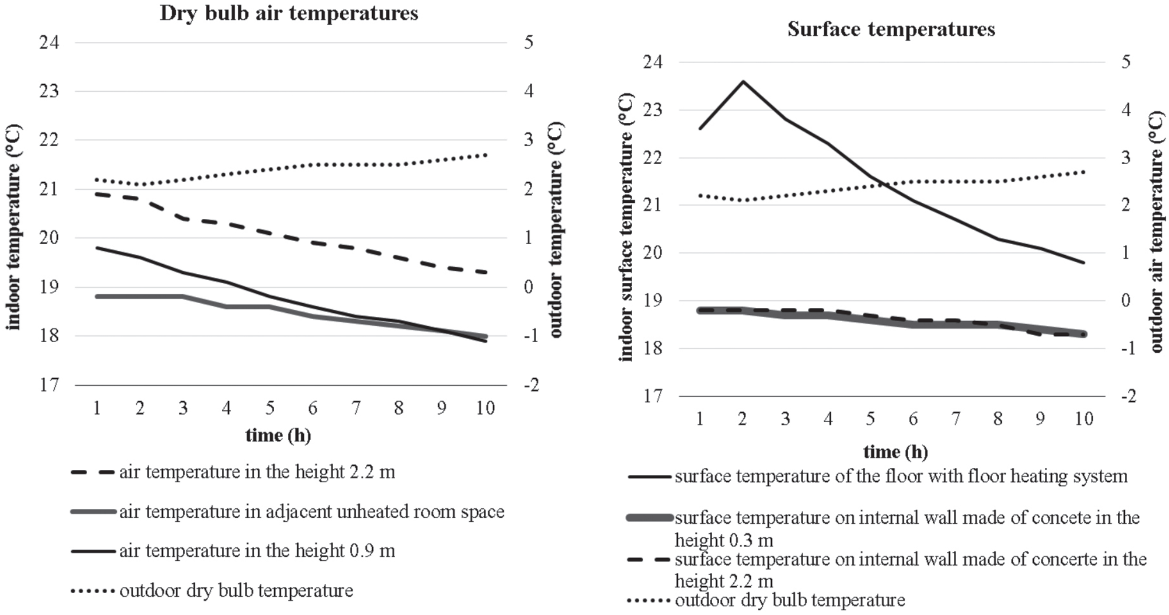


Fig. 2 Experiment of the temperature damping in a low energy family house. The measured building has two floors; the measurement was performed on the 1st floor. The external wall is made of perforated bricks insulated with 200 mm EPS, inner walls are made of 200 mm concrete and partition walls of 115 mm perforated brick. The roof includes 320 mm of mineral wool as the thermal insulation

surface, together with the daily average of the indoor surface temperature θ_{is}, are considered in the analysis. The thermal damping factor is calculated by this formula [8]

$$DFs = \frac{(\theta_{si,\max} - \theta_{si,\min})}{(\theta_{se,\max} - \theta_{se,min})} (\text{-}) \tag{1}$$

where $\theta_{\mathrm{si,max}}$ and $\theta_{\mathrm{si,min}}$ are the maximum and minimum values of the indoor surface temperature during the day, and $\theta_{\mathrm{se,max}}$ and $\theta_{\mathrm{se,min}}$ are the maximum and minimum values of the outdoor surface temperature.

The phase time shift is defined as

$$LTs = t(\theta_{si,\max}) - t(\theta_{se,\max}) \text{ (h), [8]} \tag{2}$$

where $t(\theta_{\mathrm{si,max}})$ and $t(\theta_{\mathrm{se,max}})$ are the times, when the indoor surface and outdoor surface temperatures reach their maxima, respectively.

3. Description of the demonstrational constructions

The three wall configurations with four different insulation thicknesses are studied and presented: perforated brick wall (BR), heavy weight concrete wall (HC), porous concrete wall (PC) with thermal insulation made of expanded polystyrene (EPS) or mineral wool (MW). These three wall variants have very similar U-values, but differ from each other in dimensions, material density and thermal conductivity. Each of the wall compositions (according to Fig. 3) has some selected different insulation thicknesses. The first variant fulfills the requirement for minimal thermal resistance $R_{\min}$, second variant fulfills desired value R_N, third variant fulfills recommended value R_{r1} (considered for the year 2016) and the last variant fulfills the final thermal resistance R_{r2} (considered for the year 2021) by the STN 73 0540 standard [9]. The wall layers compositions are described in Fig. 3.

4. Impact of thermal resistance variations on DFs and LTs

The experiment analyzes several of the above mentioned external wall compositions with the calculation of thermal damping factor and phase time shift of the temperature oscillation, which was conducted based on EN ISO 13786. The results from all calculations are shown in Table 1 and Fig. 4.

Constructions designed for new buildings (with the thermal resistances R_{r1} and R_{r2}) reach significantly higher values of the thermal damping factor than constructions with minimum requirements for thermal resistance. There are strongly significant differences between the porous concrete wall and the other two alternatives. While by the other insulated walls the thermal damping factor is as high as it is meaningless, this is not the case of the porous concrete wall. Comparing differences by phase time shift, it is necessary to take into account the values of temperature setback, too.

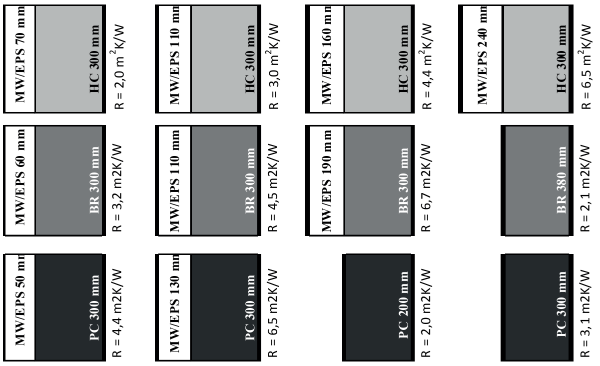


Fig. 3 Evaluated variants of external wall

Results of thermal performance variables reached for evaluated wall variants

Table 1

	Construction	R	DFs	LTs
1	HC 300 + MW 70	2.032	160.8	11.7
2	HC 300 + EPS 70	2.032	156.1	10.5
3	BR 380	2.111	261.4	18.4
4	PC 200	2.083	28.2	8.1
5	HC 300 + MW 110	3.085	294.8	13.4
6	HC 300 + EPS 110	3.085	255	11.5
7	BR 300 + MW 60	3.246	333.3	17.2
8	BR 300 + EPS 60	3.246	314.9	16.1
9	PC 300	3.125	87	12.2
10	HC 300 + MW 160	4.401	575.1	15.6
11	HC 300 + EPS 160	4.401	417.8	12.9
12	BR 300 + MW 110	4.562	726.3	19.3
13	BR 300 + EPS 110	4.562	597.3	17.5
14	PC 300 + MW 50	4.441	119.3	14.4
15	PC 300 + EPS 50	4.441	95	13.5
16	HC 300 + MW 240	6.506	1555	19.1
17	HC 300 + EPS 240	6.506	827.6	15.0
18	BR 300 + MW 190	6.667	2071.6	22.8
19	BR 300 + EPS 190	6.667	1277.4	19.6
20	PC 300 + MW 130	6.546	413.1	17.9
21	PC 300 + EPS 130	6.546	262.6	15.7

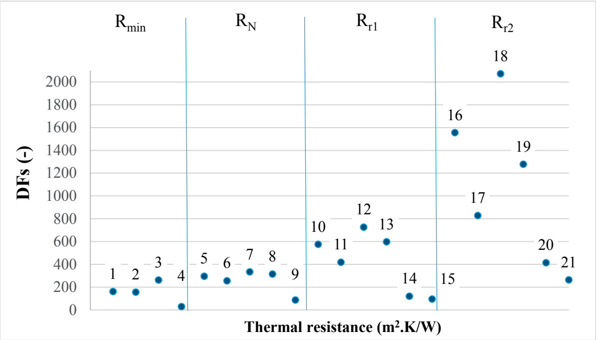
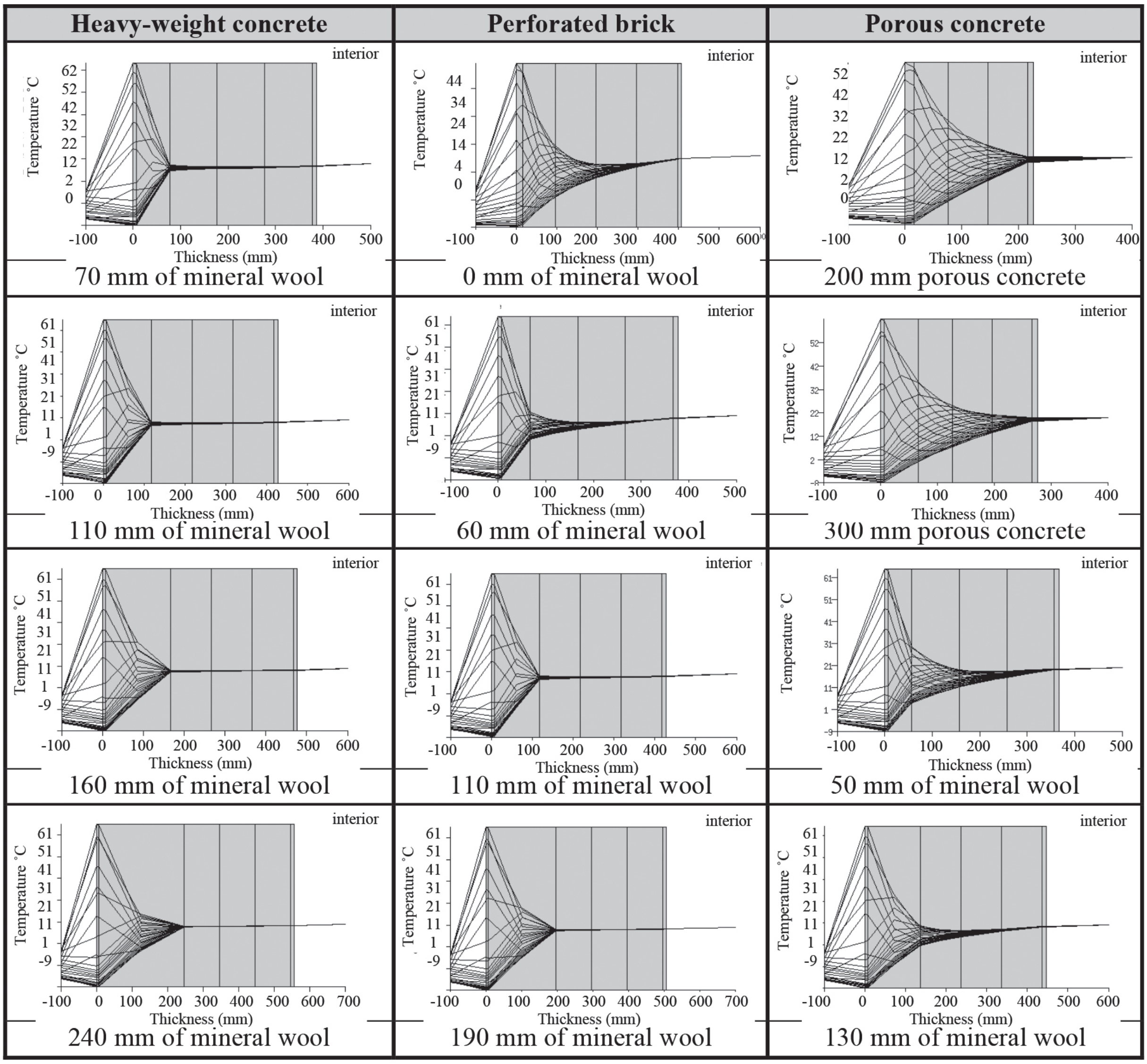


Fig. 4 Thermal damping factor (DFs) vs. thermal resistance of the wall variations. Characteristics: perforated brick (BR) λ = 0.18 W/(m.K), ρ = 930 kg/m^3, porous concrete (PC) λ = 0.096 W/(m.K), ρ = 300 kg/m^3, heavy-weight concrete (HC) λ = 1.58 W/(m.K), ρ = 2400 kg/m^3

If the value of temperature damping is high (e.g. 200 and more), the phase time shift does not play such a role and the inner surface temperature will increase up to 0.5 degree only. It is not so crucial according to the fact at what time this occurs.

Some uncertainty in the results may be caused by the moisture content. Weather and other boundary conditions and circumstances can produce humidity that can act on the building structure, e.g., by changing its heat capacity, heat transfer coefficient and other factors [10]. It is therefore necessary to measure the sorption behaviours of the construction materials [11].

Calculations of DF and LT are meaningful only in terms of heat transfer in fragments of building envelope constructions (walls, roofs, etc.). The complete image of the building or a room in the building, in terms of summer overheating, will be given



Heavy-weight concrete | **Perforated brick** | **Porous concrete**

70 mm of mineral wool | 0 mm of mineral wool | 200 mm porous concrete

110 mm of mineral wool | 60 mm of mineral wool | 300 mm porous concrete

160 mm of mineral wool | 110 mm of mineral wool | 50 mm of mineral wool

240 mm of mineral wool | 190 mm of mineral wool | 130 mm of mineral wool

Fig. 5 External surface temperature penetration depth on a typical winter sunny day for the southward oriented facade only by complex calculations of the thermal stability or computer simulations.

5. Impact of variation in wall construction on external surface temperature penetration depth

Insulated wall can resist temperatures from the inside and from the outside with a difference. Although the greater insulation thickness features very high DF values (200 and more and thus the amplitude of temperature on the inner surface is very small), we can see the difference between the external surface temperature penetration depths. An overview of the daily temperature operation on a sunny winter day in each type of wall can be seen in Fig. 5. The simulation model was calibrated by comparison to real measurements in a research laboratory [12]. The temperature measurements were made for the lightweight wall construction, which consists of three different material solutions and three different color solutions of external coating. The ESP-r software [13] was used to perform the thermal simulation. The facade is oriented southward with a rotation of 17 degrees from the west. Indoor air temperature was set as ideal to 20 °C for the whole duration of the experiment. For simulation the test reference year from IWEC database for Ostrava was used.

The amplitude of the external surface temperature is very large in all evaluated alternatives of simulation. In majority of cases, it expires at the position between the thermal insulation and bearing wall. This statement does not go for the wall without insulation or with a very small insulation thickness.

6. Impact of the wall material variation on internal surface temperature penetration depth

The periodic penetration depth δ is a depth at which the amplitude of the temperature variations is 2.71 times reduced in a homogeneous material of infinite thickness subjected to sinusoidal temperature variations on its surface. Another representation of the concept is:

$$\delta = \sqrt{\frac{\lambda T}{\pi.\rho.c}} \ \text{(m)} \qquad (3)$$

When we look at the course in Fig. 6, we can see that the difference in the depth of penetration of thermal waves is negligible in the first hours. The significant difference between the concrete wall and the others occurs when the temperature wave operates longer than T = 12 hours. Penetration depth 100 mm (which is currently under consideration in the calculation of heat accumulation in structures) is achieved by use of new bricks in 24 hours or more. This has practically nothing to do with diurnal variations in temperature.

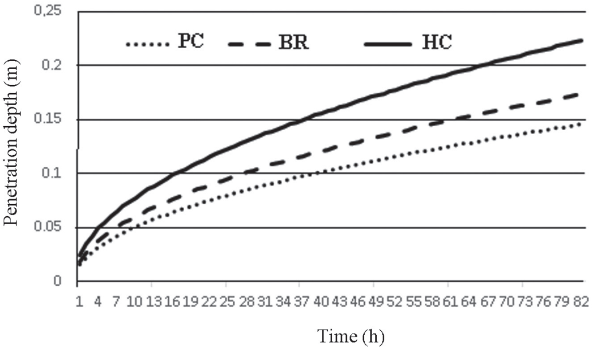


Fig. 6 Dependence of penetration depth vs time, perforated brick (BR), porous concrete (PC), heavy-weight concrete (HC)

7. Impact of variation in wall construction on subsurface temperature

Impact of the wall variation on temperature at the position of 50 mm under the inner wall surface was studied at the above described simulation model. The 50 mm is the penetration depth in case of the 4 - 10 hour time interval. The evaluation was made in an extreme summer week when several hot sunny days followed each other. To simplify, the internal air temperature was set as constant with the value of 22 °C. The resulting behavior of subsurface temperatures is shown in Fig. 7. Thermal insulation of the walls significantly reduces the rise of inside subsurface temperature, particularly by the brick wall. When comparing a brick wall to a porous concrete wall, the brick wall has the lower subsurface temperature by the identical thermal resistance. The 300 mm perforated brick wall with 110 mm of mineral wool reached the maximum temperature of 22.8 °C, while the porous concrete wall 300 mm thick with mineral wool of thickness 50 mm reached the temperature of 24.2 °C (Fig. 8). The brick wall has a surface thermal capacity of 79 680 kJ/K, while the porous concrete wall has only 30 000 kJ/K. If we consider that the internal air temperature at a given time is 26 °C, we get an accumulation potential of 254 976 kJ for the brick wall and 54 000 kJ for the porous concrete, which is five times less.

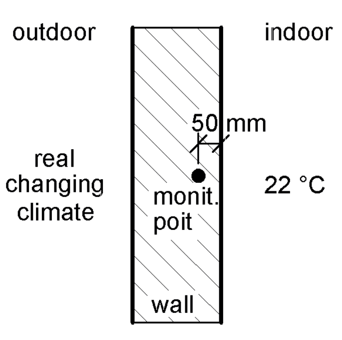


Fig. 7 Position of the subsurface temperature monitoring point

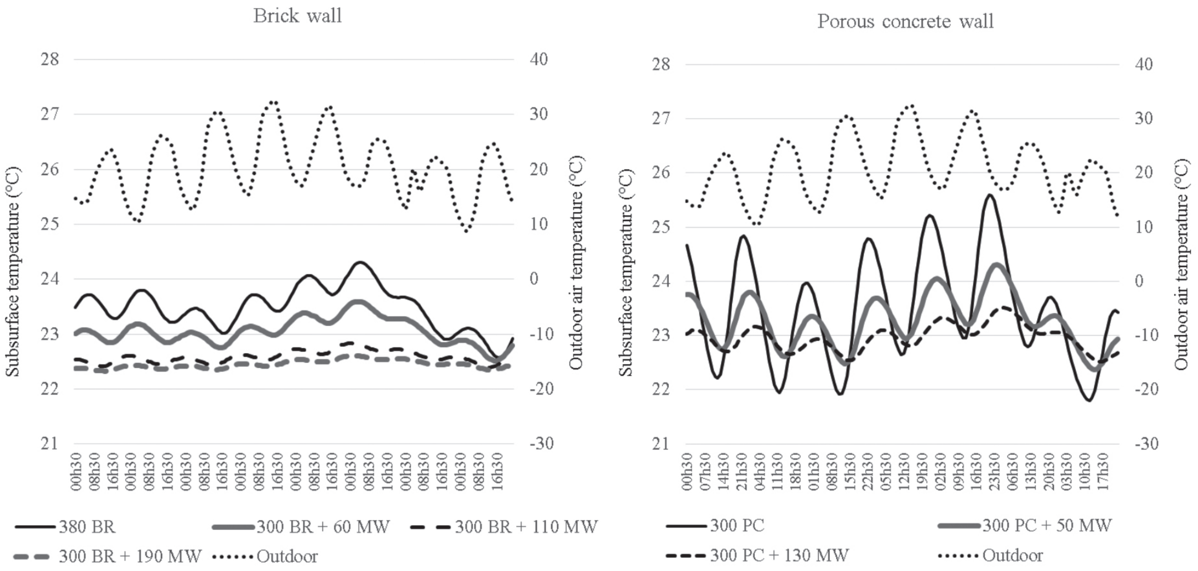


Fig. 8 Subsurface temperature in perforated brick wall and porous concrete wall (50 mm under the interior surface)

8. Conclusion

By use of the thermal stability calculation and possibility of overheating, the internal heat capacity of the floor, ceiling and dividing walls is taken into account, as well as the measure of heat gains from internal sources and solar radiation.

The impact of external wall on overheating could be defined in two ways: as the structure, through which the heat is transferred from the exterior and it warms the interior or (less usual) as the structure, which by its accumulative ability contributes to the thermal stability of interior.

In the first case, the thermal damping factor, which is very high for the walls in new buildings, is an important criteria. The thermal insulation protects the wall from rapid temperature changes. Assessment in terms of the daily cycle of temperature rise and fall is an insignificant phenomenon from this point of view. If we use a simplified assessment, based on the thermal damping factor and phase time shift, the use of any of the examined alternatives for external walls does not represent a significant risk in terms of overheating, except for porous concrete wall with small thickness.

The second method, when the external walls could affect the interior overheating is its accumulative ability. The simplified calculation does not account for external walls thermal capacity. Integrating of simulation approach could eliminate this imperfection. It appears that the walls insulated in compliance with the new requirements for the thermal resistance can contribute to thermal stability of the room. From the point of view of the daily temperature increase only the internal layer is important. Well shielded, insulated and ventilated buildings are able to resist overheating during the several hot days. We think, that in the future it might be interesting to track the ability of building to resist the long-term higher temperatures during the summer or failure of a heat source during the winter. The external wall, which holds more heat, has a higher potential to stabilize the interior temperature.

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