Effect of heat accumulation of buildings for control precision heating system

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Abstract: - It is still a lingering practice to classify energy demands of buildings on the basis of thermal insulation properties of the building envelope, although, more aspects, which cannot be ignored, enter to the evaluation. Calculation of the impact the each aspect is necessary to perform on the basis of the thermal response of the room, which varies primarily by the thermal storage properties of construction materials. This article deals with the analysis of the possibility of regulating heating systems depending on heat accumulation properties of the building. Knowledge of these relationships creates appropriate premises for rational determination of the required thermal conditions for the internal environment under which is carries out the dimensioning the heating systems, heat sources, methods of regulation and optimization of the total heat consumption.

Key-Words: - energy demand, heat accumulation, heating system, external temperature running mean, operating temperature, regulation accuracy

1 Introduction

The calculation of heating and cooling performance is very important part of the design the heating and air conditioning systems in buildings. It allows to predict the requirements that will be placed on the energy system. Designing technological systems governing the internal microclimate has to consider appropriate solutions associated with a time-varying process of temperatures and heat flows in walls, rooms, and the entire building. Today is the preferred parameter of sufficient thermal insulation, which often does not solve the thermal storage capability. Problematic are mainly buildings constructed from lightweight materials, where temperature variations may cause inconsiderable temperature variations of inner wall surfaces, which for users causes discomfort. [3] Solving this problem concerns the control algorithm of regulation device. The temperature variations are caused by numerous factors, not only the composition of the walls. Especially it is external air temperature and intensity of solar radiation corresponding to the geographical location and season, absorption of solar radiation, the tilt and orientation of the walls and other factors. [2] Actually under the selected continental weather conditions the energy performance is evenly influenced by the winter and the summer behavior while often one of the two seasons largely dominates the annual energy demand. [1]

Heat accumulation of heated area of the building is one of the most important parameters for the design of the regulation device. This paper deals with the analysis of the effect of thermal mass to the more accurate control of heating systems. Desired output is a prediction of the heat demand, taking into account the historical course of the outside temperature and dynamics thermal properties of structures. For construction material were chosen three different walls that have the same thermal transmittance (U-value), but different dynamics properties.

2 Parameters of regulation of the heating system

Energy consumption of heating systems in the building depends on several parameters, such as external climatic parameters, thermal insulation and storage properties of the building, the degree of utilization of internal and external gains and observance of optimum microclimatic conditions [3]. Levels of microclimate conditions described in a detailed standard EN 15251 divides the internal

environment according to the level of expectations of comfort on 4 categories:
I. – High level of expectation and it is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons.
II. – Normal level of expectation and it should be used for new buildings and renovations.
III. – An acceptable, moderate level of expectation and it may be used for existing buildings.
IV. – Values outside the criteria for the categories mentioned above. This category should only be accepted for limited part of the year.

The proposed parameters of the temperature range for a normal level of expectations is mentioned in Table 1.

Table 1 proposed parameters range of operational temperatures in winter seasons for heating (Cat. II.) [11]

Type of building or premises	**Range of operating temperature for heating, θ_0 [°C]**
Residential buildings, residential rooms (bedrooms, living rooms, etc.) Sitting activity (~ 1.2 met)	20.0 – 25.0
Residential buildings, other rooms (kitchen, etc.) Standing activity (~ 1.5 met)	16.0 – 25.0
Offices and premises with similar activities (classrooms, restaurants, etc.) Seated activity (~ 1.2 met)	20.0 – 24.0

Assumed clothing insulation ~ 1.0 clo

3 Methods used for determination of dynamic thermal properties

For determination of dynamic thermal characteristics of structures that are loaded with variable boundary conditions, was chosen admittance method. Application of this method is explained in international standard EN ISO 13786. The admittance method describes the non-stationary heat conduction of outer wall and applications of matrix solution of a composite wall. The factors used in this method are based on the assumption that the change of boundary conditions is close to the harmonic waveform. That means that at any location in the component, the temperature variations can be modeled by

$$\theta_n(x,t) = \bar{\theta}(x) + \frac{\hat{\theta}_{+n}(x)e^{j\omega t} + \hat{\theta}_{-n}(x)e^{-jwt}}{2} \qquad (1)$$

and the variations of the density of heat low rate are

$$q_n(x,t) = \bar{q}(x) + \frac{\hat{q}_{+n}(x)e^{j\omega t} + \hat{q}_{-n}(x)e^{-jwt}}{2} \qquad (2)$$

The factors that express the relationship of the harmonic function representing the calculation condition and the resulting harmonic function affected by the effect of accumulation. The relationship of harmonic functions can be described by changing the amplitude and time shift. Admittance method is the analytical solution of heat conduction with a harmonious boundary condition.[5] Relationship between variables on the inner and outer surface of the structure are expressed by matrix form

$$\begin{bmatrix} \hat{\theta}_2 \\ \hat{q}_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \cdot \begin{bmatrix} \hat{\theta}_1 \\ \hat{q}_1 \end{bmatrix} \qquad (3)$$

where

$\hat{\theta}$ is the phase of harmonic temperature change,
$\hat{q}$ the phase of harmonic heat flow change,
Z_{mn} complex elements of the transfer matrix.

The result of the matrix calculation is two complex values, thermal admittance Y_{nn} and thermal transmittance Y_{mn}, which can be expressed by amplitude and phase. Indices *m* and *n* indicates the type of environment, *m* means an internal environment and *n* means an external environment. These values allow to calculate important parameters to compare the thermal inertia of the structure, which describes [5]. It is the decrement factor *f* and corresponding time shift Δt_f.

4 Comparing the thermal inertia of structures

The purpose of the computational analysis was to evaluate three different structures, whose thermal insulating properties meet the legislative requirements on newly exposed homes. With the current trends in building industry in the Czech Republic, were designed structures of various surface weight. Sandwich type construction typical for timber (C1), the wall of bricks porotherm insulated from the outside (C2) and the wall of reinforced concrete with thermal insulation (C3). All construction are characterized by the same thermal transmittance (U=0,21W/m^{2}K). This, however, resulted in a total wall thickness, which varies. Three model buildings were made from these walls, which are dimensionally identical. As a source of reference climatic data was used weather station, located at University in Zlin.

Dynamic thermal properties of the walls were evaluated by the aforementioned admittance method. The accumulation of the non-stationary heat conduction can at heavy walls achieved substantial delay and it is, therefore, necessary to assess the heat accumulation in a time interval longer than 24 hours. [2] The evaluation covers the entire wall thickness.

Table 2 dynamic thermal characteristics of structures

Wall	**Surface weight *m* [kg/m^2]**	**Thermal transmittance $Y_{12} - \Delta t_f$ [h]**	**Decrement factor *f* [-]**
Time period: 24 h			
C1	116,80	11,34	0,237
C2	263,10	11,68	0,142
C3	810,80	10,36	0,059
Time period: 48 h			
C1	116,80	14,78	0,552
C2	263,10	16,50	0,332
C3	810,80	19,08	0,155

The values in Table II contain the parameters needed to evaluate the thermal inertia of structures. Decrement factor describes absorbing of thermal waves generated during the passage from the exterior to interior. A lower number means higher thermal inertia. Thermal admittance indicates how the structure responds to change of heat density of heat flux. [5]

According to the above values can be concluded that the highest thermal inertia has a wall C3. The main criterion is the decrement factor *f*, which is more than twice lower than the wall C2 and almost four times lower than the wall C1. Another interesting value is the time shift Δt_f that's the time for which structure respond to sudden changes outside temperature or solar radiation. This value is for all structures greater than 10 hrs. The lowest time shift shows wall C3. The wall with the greatest surface weight and probably the greatest thermal inertia. It is probably because the structure achieves a considerable delay. In case of evaluation with a time period 48 hours and more, the wall C3 shows the biggest response time to sudden changes outside temperature (Fig. 1). The resulting values may be affected by a certain degree of inaccuracy. According to [6] can be larger relative error expected with heavy walls in comparison with walls of light.

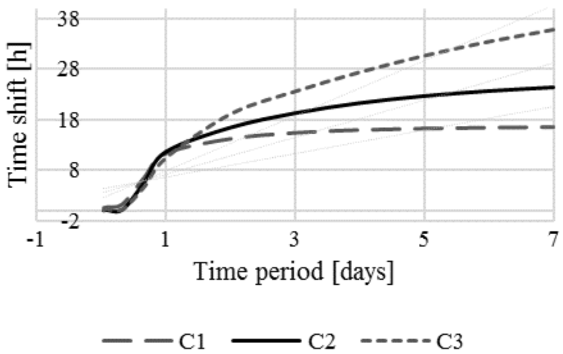

Fig. 1 time response to sudden changes outside temperature

Heat accumulation due to the non-stationary heat transfer of wall can be divided into two parts. The accumulation of absorbed radiation falling on the inner wall surfaces and the accumulation in the outer wall caused by changes of outdoor temperature and solar radiation. [4]

For a more realistic result, the building model was the interior space separated by walls from the same material as the evaluated peripheral wall. The inner wall surfaces are exposed to solar radiation passing through the transparent building elements and also solar radiation reflected from the other internal surfaces. To obtain a cyclic boundary condition was calculated to the average temperature of outside air for 24 hours cycle. Subsequently, the temperature variation was calculated. The analysis was carried out for one day with consideration of heat accumulation from previous days. To evaluation was included the effect of thermal inertia which an identical amount of heat transfer surfaces, sunlight intensity and ventilation. As a valuation day was selected Jan. 7, 2015, when the previous three days had a similar temperature curve. The average daily temperature was 3.26°C and during the day temperature dropped about 7°C. Inner temperature was assumed 21°C. Solar radiation values were set at hourly intervals by normative recommendations.

On a noticeable decrease indoor air temperature the construction responded with some delay. At the model building with walls C1 was reduced internal operating temperature below the limit of a normal level of expectation of comfort for 5 hours, wall C2 for 6.5 hours and for the wall with the largest thermal inertia during 15 hours did not decrease below this limit.

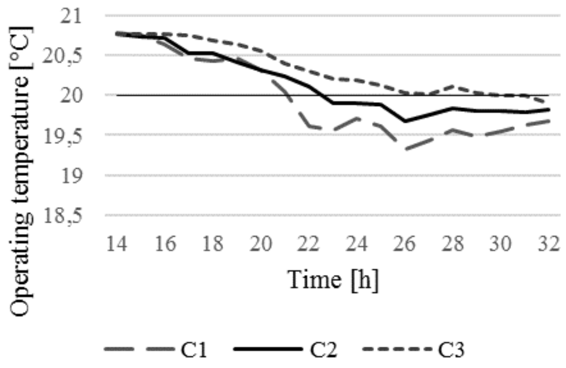

Fig. 2 the effect of thermal inertia on the course of operating temperature

The resulting values had to be adjusted, before evaluated day, to be able to compare the course of the internal temperatures under the same conditions. The problem was that the model house from the wall C3 resulted from the biggest response time and has not been able to accumulate a sufficient amount of heat. This fact verifies the assertion that the buildings with high heat accumulation have extended heating season, although characterized by lower energy requirements. [2] Fig. 2 shows that the evaluated day it will be necessary to deliver the most energy to model building consisting of lightweight construction like C1. In these buildings, there is a greater risk of overheating, especially in summer. In perennial balance can the consumption of cold exceed consumption of heat. However, this depends on the climatic zones according to the fluctuation frequency of outdoor temperature and solar radiation. For optimum energy consumption for heating is necessary to choose the type of heating system, a heating course in terms of the size of flood heat flow and the effect of the heat transfer coefficient is proportional to the thermal storage properties of the building. [2]

5 Control options based on knowledge of thermal storage properties

The above findings of the impact of heat accumulation are very important for proper and precise control. Without this knowledge cannot be correctly predicted heat demand during the day. Only sophisticated regulation systems take into account, excepting the inner air temperature also the historical course of outside temperatures and storage properties of the building. [3] Therefore it is appropriate to carry out the regulation of heat supply on external temperature running mean, which includes the above parameters and interprets them as a single number. The purpose of the regulation device, operating according to the outside temperature, is to save the energy by the followings functions:

1) Regulation of production and distribution of the heat in order to maintain the desired internal temperature, to ensure an acceptable thermal comfort and simultaneously in terms of energy demands, when the heat demand is determined by the external temperature and thermal storage of building. [9]
2) Regulation of the heat amount is carried out according to the schedule which takes into an account the occupancy of premises.

From Table 1 above is evident that the range of operating temperature, which should comply the normal level of expectations, is relatively wide. At this time, the accuracy of regulation enters to the rate of energy efficiency fundamentally, which directly indicates the possibility of decrease of the desired internal temperature in the premises of the building and also, it ensures an acceptable thermal comfort. Accuracy should be assessed at multiple points because the regulation also affects other dynamic components of the sensor, controller and other components of the heating system, which directly affects the results of the regulation. [13] Some influence on the energy efficiency of buildings also carries the ability to predict system of variable start/stop switches times for example between switching modes according to the time schedule of occupancy in the building.

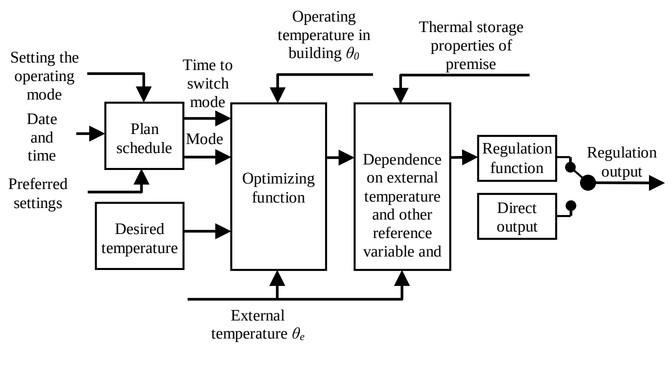

Fig. 3 block scheme of the regulation device [4]

6 Evaluation of the impact of regulation accuracy on total energy consumption

It was created a room model for obtaining the desired outputs. This model is graphically depicted in Fig. 4. The model of the heating system consists of a heat source, heat distribution, and equipment for heat transfer. Heat transfer is represented by the model of the radiator. Heat generation is simulated simply, that the output of the source of the heat is a maximum supply temperature of heating water. Dynamic behavior of the system is determined by a returnable temperature of heating water. The model also includes a mixing valve and circulating pump. The position of the valve is dependent on the output signal from the controller, which is in precisely defined time steps readjusted for regulating the heat output variables. The accuracy of the regulation of this model does not depend only on the effectiveness of the internal algorithm for changes the parameters of the controller, but it also depends on the flow characteristics of the mixing valve (K_{VS} value). In the case of using a regulation fitting with a micro strangling system, it can minimize the rate of regulation deviation, which allows us to heat the premise on operating temperature in a range from 20.0 to 20.5 °C.

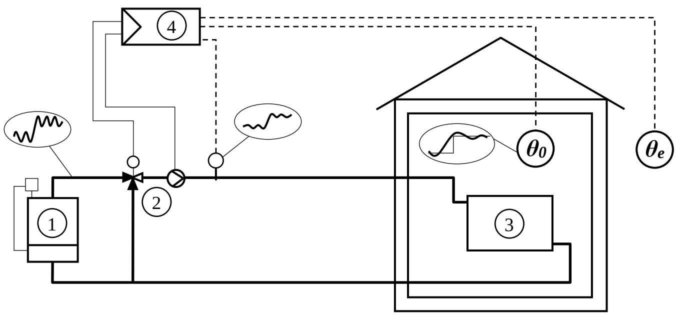

Fig. 4 model of heating system [4]
1 – Heat source, 2 – Heat distribution, 3 – Heat transfer, 4 – Controller, θ_0 – Operating temperature, θe – External temperature

Evaluation of the impact, mentioned the way of regulation, on an energy efficiency of buildings can be carried out in several ways. In the case of sufficient knowledge of the managing and regulation system of heating, it can be used a detailed method, which includes the fact that controlled room and the control system interact with each other. Calculation of the impact on different aspects of regulation is necessary to perform on the basis of the thermal response of the room. Calculation relationship is based on the knowledge of energy needs for heating over a defined time period. A convenient way to determine the energy required for heating is to use the model of simple hourly methods according to EN 13790, which ensures a sufficient level of accuracy in areas, where the dynamic behavior has a significant impact on the calculated energy consumption. The standard EN 15232 shows the calculation of the energy required by the following formula

$$E = L \cdot \left[\left(\theta_{sp} + \Delta\theta_c \right) - \theta_e \right] \cdot t \quad (4)$$

where

E is energy consumption for a defined time period [Wh],

L a transfer coefficient [W/K],

θ_{sp} the set point which shall be maintained by the control system [K],

$\Delta\theta_c$ a characteristic parameter represents the impact of actual control system [-],

θ_e a reference temperature (outdoor temperature) [K],

t the duration of the time period [h].

The effectiveness of the regulation system is presented by the parameter $\Delta\theta_c$. When the value of this parameter is 0, it represents the best effectiveness of regulation. [7] Theoretically, it is possible to determine the change of energy consumption when the ambient temperature of the room change assuming that the provided time step of the calculation will be shorter than the period of change of the operating temperature.

7 Calculating the effect of adjusting the internal temperature on energy consumption for heating

The theoretical analysis of the problem preceded the creating of a model room including aground plan and compositions structures. An important consideration was to determine the particularity of the simulation. An essential part was to verify the influence of each parameter on the total energy consumption for heating. Desired output of the simulation was to determine the amount of potential savings by reducing the internal temperature on the marginal value of category II (Table 1).

For calculating the annual heating energy were used the methods and procedures mentioned in the standard EN 13790, in combination with other standards for energy performance. As a source of needed climate data was used the university weather station. To determine the potential energy savings, the internal temperature served as a variable of room model. Other parameters related with the heating system and thermal insulation properties of constructions remained unchanged.

It was possible to obtain a lot of information from the simulation results. Information captured the dynamic behavior of the system and the impact of individual components on the total energy efficiency. The Fig. 5 shows graphically the percentage savings of heating costs. The percentage value is connected with a specific internal temperature and always represents saving compared to an internal temperature of about 1°C higher.

The calculation results show that the impact of the accuracy of regulation not only has a positive effect on the thermal comfort of users of the building but also reduces the unnecessary overheating of the room. Fig. 5 shows that the percentage savings in the range for residential rooms (range 20 – 23 °C) is around 7,5%. In case of high precision of regulation with a deviation about 0,5 °C is possible to reduce the temperature set point on the marginal value from 21,5 to 20,5 °C, which means a saving about 7,3%.

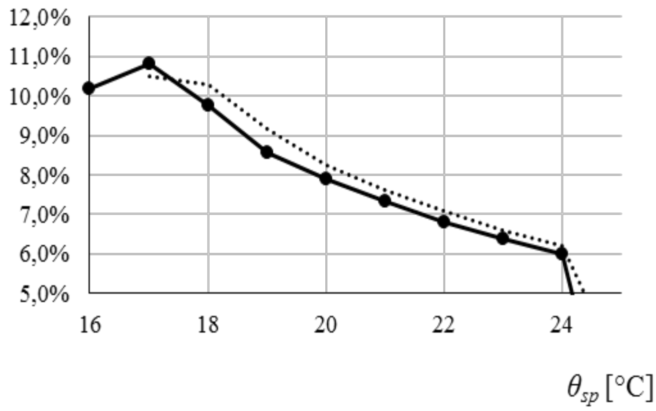

Fig. 5 potential percentage savings due to the adjustment of the internal temperature

8 Conclusion

This paper deals with heat accumulation, which has a major impact on the decision of the regulation system. The basic prerequisite for achieving precise regulation is knowledge of the effect on various aspects for energy needs. It is energy-inefficient to generate and storage energy, I will not able to consume. The paper focuses on the issues of design and control heating systems, but also assumes cooperation with all energy systems in building (power generation from renewable sources, etc.). Current technologies allow a wide range of networking the various elements of technology, including access to the Internet. To obtain input data like weather forecast, etc. Due to utilized predictions of inner temperatures can be found optimal control. This procedure ensures that the desired temperature is reached exerting the least possible amount of energy.

Acknowledgements

This work was supported by the Ministry of Education, Youth and Sports of the Czech Republic within the National Sustainability Programme project No. LO1303 (MSMT-7778/2014).Work was also supported in frame of Internal Grant Agency of Tomas Bata University in Zlin, Faculty of Applied Informatics No. IGA/CEBIATech/2015/041.

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