Agronomy Research **14**(S1), 1222–1231, 2016

Thermal properties and reduction of energy consumption of buildings

Týbl, J.[*] and P. Kic

Czech University of Life Sciences Prague, Faculty of Engineering, Kamycka 129, 16521, Prague 6, Czech Republic; [*]Correspondence: tybljiri@seznam.cz

Abstract. The aim of this paper is to summarize and present all relations, which are essential in determination of winter heat balance of the buildings, and that enable a reduction of energy consumption or heating costs. These questions should be realized and taken into account already in the proposal of building design. This paper shows the methods of calculation of winter heat balance and results of measurements which verify theoretical conclusions in real conditions. These factors are applied on two existing buildings. There are due to their different shapes and constructions proposed different solutions of improvement. Two different buildings were selected for this research work: a large ground floor building and a high hall. In the case of the first building (the large ground floor building) it appears to be a major problem not sufficient thermal properties of the envelope constructions. The enormous heat losses caused high heating costs. The existing heating method of the second building (the high hall), is not suitable. The temperature distribution in the interior is undesirable, which results in very high energy consumption. The use of radiant ceiling panels could enable to achieve favourable conditions in the working area and considerable energy savings.

Key words: heat balance, high building, radiant heating, thermal insulation.

INTRODUCTION

Energy consumption is in the interest and attention of all owners of family houses as well apartment buildings. Rather big attention is also paid to the heating problems of various buildings for community facilities (Visockis et al., 2011). There are many standards and recommendations for the reduction of energy consumption in these houses. The question of energy savings in large warehouses and industrial buildings is not so often solved in the literature. Heating of large buildings represents together with ventilation or air conditioning very important issue, which significantly affects the operation of these facilities.

Nevertheless there is not paid sufficient attention to solve the energetic and heating problems in this type of industrial and agricultural buildings in Czech Republic. It can be assumed that a similar situation and problems exist also in other European countries. The situation in many non-European countries is even worse.

This article is aimed at those buildings used in industry, agriculture or in other branches. These buildings are used year-round and must be maintained for the required air temperature, corresponding to the requirements of workers or technological processes. These buildings are characterized by a large surface area, different shape, in some cases high height, and the overall large volume. This creates a need for substantial inputs for heating, which together with the high cost of energy can manifest itself quite significantly in the efficiency of production, or in satisfaction and functional reliability of these buildings.

There are different information from the literature about the heating and ventilation of these buildings. Recommendations of several authors are focused on the radiant heating by different type of heating systems and panels (Cihelka, 1961; Kotrbaty & Kovarova, 2002; Basta, 2010; Vio, 2011; Kic, 2013; Zajicek & Kic, 2014; Kic, 2015), nevertheless this type of heating, especially with ceiling radiant panels, is still not so common in the practice.

Although currently the considerable attention is paid to energy savings for heating, many buildings are still not designed conceptually from the viewpoint of energy savings, usually only layer of thermal insulation is increased. In some cases it is possible to achieve energy savings in heating by choosing appropriate shape of the building and by the solution of adequate heating method which respects the shape of the building.

The following article briefly summarizes some of these ideas, calculation procedures and results of measurements in several options for achieving reductions in energy consumption, or a reduction of heating costs, including factors that have a direct effect on the heat balance. These facts are in this work applied on two existing buildings; and with regard to their different conception there were also chosen different solutions. The results of this applied research can be therefore considered as a good new approach also for the future scientific work which can bring not only theoretical background in scientific literature but also a useful progress in practise.

MATERIALS AND METHODS

Two different industrial buildings were chosen for this research work: a large ground floor building and a high hall. Both buildings do not meet modern ideas about the thermal properties of buildings. There are identified their main weaknesses, which for each of them have different character. Both buildings were examined initially by quasistationary calculation method for determination of annual heat balance with an interval of one heating season. On this basis, there were proposed methods for improvement.

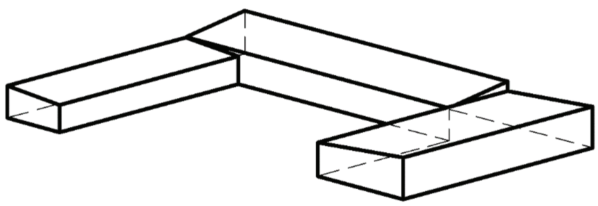

Figure 1. Building A, a large ground floor building.

In the case of the first building A, i.e. the large building, it appears to be a major problem not sufficient thermal properties of the envelope constructions. The first building A is a large ground floor building, which consists of three parts. Scheme of hall A is shown in Fig. 1. All parts are interconnected and together have a floor area of

404 m^2. Heating is provided by a central boiler on natural gas and heat is distributed by pipeline heating system with heating radiators throughout the building. The building is currently used as a warehouse for office supplies, dry goods and some durable food.

The second building B is a large-capacity compact ground floor brick building, which is not particularly spatially divided. The total floor area is about 418 m^2, the building has a gabled roof, the ridge of which has a height of almost 8 m. Heating is provided by a central boiler on natural gas heat is distributed by pipeline heating system with radiators throughout the building. Now the building serves as a carpentry workshop.

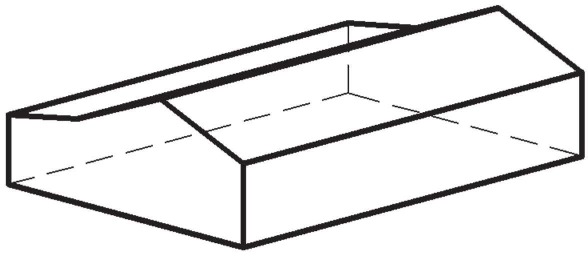

Figure 2. Building B, a large compact building with a height 8 m.

Air temperatures were measured by thermocouples NiCr-Ni type K with the thermometer THERM 2253-2 with temperature operative range -100 to 1,370 °C with accuracy ± 0.1 K. This thermometer was used also for the measurement of the temperature profile in the high building B. The surface temperatures of the walls, ceiling and floor were measured by Pyrometer Amir 7811 with temperature operative range -32 to 600 °C with accuracy ± 0.1 K.

The obtained results of dust measurements were processed by Excel software and verified by statistical software Statistica 12 *(ANOVA* and *TUKEY HSD Test*). Different superscript letters (a, b, c, d, e, f) in common are significantly different from each other in the rows of the tables *(ANOVA; Tukey HSD Test; $P \leq 0.05$)*, e.g. if there are the same superscript letters in all the rows it means the differences between the values are not statistically significant at the significance level of *0.05*.

RESULTS AND DISCUSSION

Results of temperature measurement in the buildings

As a part this research is to perform basic measurements of indoor temperatures and compare obtained results as a background for the improvement proposal. There were measured the surface temperature of floor, air temperature in level 1 m above the floor, and surface temperature of the wall and ceilings. The results are summarised in the Table 1.

Measurements were carried out at the building A and B at outdoor temperature from 1.7 °C to 3.5 °C when the heating of rooms was reduced. In the working area the desired temperature not reached of 12 °C, but only 7 °C. The difference between the outside temperature and the temperature in the working area was therefore very small. Nevertheless, the measurement confirmed not suitable temperature distribution in the interiors. It can be assumed that with a larger temperature difference could also increase the negative impacts of these phenomena.

Table 1. Average surface temperature of floor, air temperature in level 1 m above the floor, and surface temperature of the wall and ceilings. Different superscript letters (a, b, c, d, e, f) are the sign of high significant difference (*ANOVA; Tukey HSD Test*; $P \leq 0.05$)

Building	A	B
Measured part	Temperature, °C ± SD	Temperature, °C ± SD
Floor	7.8 ± 0.86^{a}	7.8 ± 0.94^{a}
Air in 1 m	7.2 ± 0.88^{b}	7.2 ± 0.92^{b}
Walls	7.4 ± 0.92^{c}	8.9 ± 0.76^{d}
Ceiling	7.1 ± 1.27^{e}	6.0 ± 1.25^{f}

SD – Standard deviation

The air temperatures in the height of 1 m above the floor do not indicate high dispersion nor is there apparent dependency on other circumstances. A small scattering is also in the case of internal surface temperatures of external walls, but there is noticeable and a slight increase of temperatures with increasing height.

More interesting is the situation in the building B at the surface temperature of the inside of the ceiling. The temperature difference in the ridge and in the lower foothills of the roof structure is up to 4.2 °C. There was observed dependence of temperature increase towards the ridge, where it holds the hottest air.

Measurements confirmed that the current thermal conditions in both buildings are unfavourable. The appropriate solution of this problem seems to be an improvement of thermal properties of envelope constructions of building A and a change of heating system in the building B.

Specific overall heat transfer through the buildings envelope

Due to the considerable amount of data there are given only general formulas (1) to (4) for calculation of the heat transfer and specific heat loss; the results of numerical calculation of the buildings A and B are presented in the Tables 2 and 3.

$$R_n = \frac{d_n}{\lambda_n} \tag{1}$$

where: R_n – thermal resistance of the n-th layer, $m^2\ K\ W^{-1}$; d_n – thickness of the n-th layer in the structure, m; λ_n – thermal conductivity of the n-th layer, $W\ m^{-1}\ K^{-1}$.

$$R_{Tj} = R_{si} + R_j + R_{se} \tag{2}$$

where: R_{Tj} – resistance to heat transmission j-th component of the envelope, $m^2\ K\ W^{-1}$; R_{si} – internal resistance to heat transfer, $m^2\ K\ W^{-1}$; R_j – thermal resistance of j-th component layer of the envelope, $m^2\ K\ W^{-1}$; R_{se} – external resistance to heat transfer, $m^2\ K\ W^{-1}$.

$$U_j = \frac{1}{R_{Tj}} \tag{3}$$

where: U_j – heat transfer coefficient for the j-th component of the envelope, $W\ m^{-2}\ K^{-1}$.

$$H_{Tp} = \sum_{j=1}^{n} A_j \cdot U_j \tag{4}$$

where: H_{Tp} – specific heat loss by the heat transfer through the structure envelope, W K^{-1}; A – external surface area of j-part of surrounding structure envelope, m^2; n – data-set extent.

For a comparison of buildings in terms of energy efficiency serves its inclusion in the appropriate class, so called House Energy Rating, according to the European Union energy label. As a basic indicator of the energy performance of a building are used a weighted average of heat transfer coefficients of sub-components of the surrounding structure. It is used for comparison with a weighted average of standard heat transfer coefficients of so-called reference building. The reference building is actually the same as a compared building; just each surrounding component of the envelope has a standard overall heat transfer coefficient.

Table 2. Properties of structure for calculation of the heat transfer and specific heat loss of the large ground floor building A in its original state

Structure component	A_j, m^2	R_{tj}, m^2 K W^{-1}	U_j, W m^{-2} K^{-1}	H_{Tp}, W K^{-1}
Bricks 30	33.87	0.564	1.774	60.09
Bricks 45	232.91	0.744	1.343	312.90
Bricks 60	44.00	0.925	1.081	47.56
Concrete 20	117.15	0.342	2.923	342.49
Ytong	10.10	1.356	0.737	7.45
Windows and doors	54.97	0.5373	1.861	102.31
Roof	477.33	0.2694	3.711	1,771.50
Total				2,644.30

Table 3. Properties of structure for calculation of the heat transfer and specific heat loss of the compact high building B in its original state

Structure component	A_j, m^2	R_{tj}, m^2 K W^{-1}	U_j, W m^{-2} K^{-1}	H_{Tp}, W K^{-1}
Bricks 30	64.97	0.564	1.774	115.26
Bricks 45	133.70	0.744	1.343	179.61
Windows and doors	119.04	0.22	4.54	540.0
Roof	454.26	0.27	3.69	1,675.50
Total				2,510.36

According to (Bernardinová & Mareš, 2013) the average overall heat transfer coefficient U is determined by the equations (5) and (6). The values in the Table 4 are calculated according to these equations:

$$U = \frac{\sum_{j=1}^{n} U_j \cdot A_j}{\sum_{j=1}^{n} A_j} \tag{5}$$

where: U – average overall heat transfer coefficient, W m^{-2} K^{-1}; U_j – overall heat transfer coefficient of j-surrounding wall, W m^{-2} K^{-1}; A_j – surface area of j-surrounding wall, m^2; n – data-set extent.

The reference overall heat transfer coefficient U_R is determined by the following equation:

$$U_R = \frac{\sum_{j=1}^{n} U_j \cdot A_j}{\sum_{j=1}^{n} A_j} \tag{6}$$

where: U_R – reference overall heat transfer coefficient, W m^{-2} K^{-1}; U_N – standard overall heat transfer coefficient of j-surrounding wall, W m^{-2} K^{-1}; A_j – surface area of j-surrounding wall, m^{-2}; n – data-set extent.

As the required internal temperature sufficient for both buildings is only 12 °C, required fundamental value of the reference overall heat transfer coefficient U_R is changed to value U_{R12}. Nevertheless, the average overall heat transfer coefficient U is three and half times higher than overall heat transfer coefficient U_{R12} of the reference building.

Table 4. Classification of evaluated objects according to the European Union energy label

Building	U	U_R	U_{R12}	U : U_R	Classification
A – large ground floor building	2.725	0.386	0.772	3.5	G – extremely non-economical
B – compact high building	3.252	0.493	0.986	3.3	G – extremely non-economical

Improvement of the large ground floor building A

On the example of a large ground floor building A it is suitable to demonstrate the impact of geometric characteristics on the total heat losses. It is not expected that it would be a suitable method of improvement of the winter heat balance for existing buildings, as demands to change layout of the existing building is practically equal to construct a new house, but theoretical considerations on this subject is interesting and practical example is very illustrative.

The large building A will be compared with the theoretical compact building of the same floor area and height of construction. The current use of the buildings A does not allow locating a usable area into several floors, so the theoretical building will be also ground floor. To compare thermal properties of both buildings the average heat transfer coefficient of the building cladding is used for the calculation.

Due to the fact that the real and theoretical structures being compared have the same floor space, as well as both are ground floor with the same slope of the roof, the area of roofs is identical. Also the heat losses by ventilation are considered identical. To the average heat transfer coefficient are included windows, doors etc., thus the quality of both vertical claddings is comparable.

The theoretical compact building is a structure of the same floor area, which is 403.9 m^2 but with a square plan, therefore a usable area is 20.1 · 20.1 m, built-up area of 21 · 21 m. The overall height of the building is 3.7 m. Both constructions are shown schematically in the Fig. 3. The calculation of the heat losses by heat transmission through surrounding vertical envelope are based on the equation (4). The resulting values for both compared buildings with the same average heat transfer coefficient are shown in the Table 5.

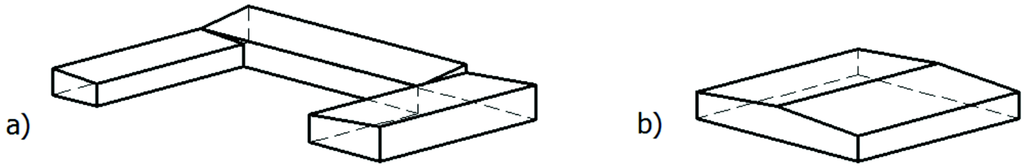

Figure 3. Scheme of: a) the real large ground floor building, b) theoretical compact building.

Table 5. Differences of specific heat losses for both variants of the geometric arrangement of buildings

Specific heat losses	A – large ground floor building	Theoretical compact building	Difference	Savings, %
Surrounding vertical envelope H_{Tp}, W K^{-1}	872.80	550.00	322.80	37.0
Soil, W K^{-1}	253.53	1,77.23	76.30	30.1
Roof and ventilation, W K^{-1}	2,058.60	2,058.6	0.00	0.00
Total, W K^{-1}	3,184.93	2,785.83	399.1	12.5

Practical improvement measures of heat balance in this massive structure will be an additional thermal insulation of claddings, roof and replacing windows and doors. For insulation of surrounding envelope is considered Styrotrade EPS polystyrene foam with a thermal conductivity $\lambda = 0.04$ W m^{-1} K^{-1}. It is assumed that the other parts of the structure after the exchange will exactly achieve the required standard values of the heat transfer coefficient. Relevant parameters of the thickness and the thermal insulation parameters are shown in the Table 6.

Parameters in the Table 6 are: d_x – required thickness of thermal insulation of the j-th component of the envelope, m, U_x – heat transfer coefficient for the j-th component of the envelope after improvement of thermal insulation, W m^{-2} K^{-1}, H_{Tpx} – specific heat loss by the heat transfer through the structure envelope after improvement of thermal insulation, W K^{-1}.

Table 6. Properties of structure specific heat loss of the large ground floor building A after improvement of thermal insulation

Structure component	A_j, m^2	d_x, m	U_x, W m^{-2} K^{-1}	H_{Tpx}, W K^{-1}
Bricks 30	33.87	0.120	0.28	9.46
Bricks 45	232.91	0.100	0.30	69.87
Bricks 60	44.00	0.100	0.29	12.78
Concrete 20	117.15	0.120	0.30	34.88
Ytong	10.10	0.080	0.30	2.99
Doors and windows	54.97	-	1.14	62.79
Roof	477.33	0.16	0.23	111.35
Total, W K^{-1}				304.12

Improvement of the high compact ground floor building B

In the case of a high building B the reduction of energy consumption by improvement of thermal properties of this building would be very expensive, especially because of a large area of glass structures. But inappropriate in this building is mainly the heating system by radiator heating elements installed on the walls. The results of measurements of vertical air temperature profile in twelve height levels from the floor toward the ceiling in the building B are presented in Table 7.

The results of the measurements show the great influence of the height in the hall on air temperature. With increasing height increases the air temperature which shows quite significantly even during this situation with minimum heating and under conditions in the hall with low air temperatures. The difference between the air temperature at floor level (7.1 °C) and temperature at the highest point near the ceiling (10.9 °C) is 3.8 K, which is at these low temperatures very significant difference.

The results of measurement of vertical temperature profile in different parts of the building B show that there is a big difference between the temperature near the floor (working area) and the top of the room (near the ceiling). It causes huge heat losses of the buildings. In conditions of higher air temperatures inside the hall this difference could be increased even more, and cause greater heat loss through the roof to outside air (Zajicek & Kic, 2014). This is the problem of many similar buildings.

It would be better to use for heating radiant ceiling panels. The proposal of necessary components for installation and estimated cost are shown in the Table 8. According to the information available from the literature (Kotrbaty, & Kovarova, 2002; Zajicek & Kic, 2014) achieved energy savings in large buildings are about 40 to 60% of costs.

Table 7. Vertical profile of average air temperatures from the floor toward the ceiling in the building B. Different superscript letters (a, b, c, d, e, f) are the sign of high significant difference (*ANOVA; Tukey HSD Test*; *P ≤ 0.05*)

Height from the floor, m	Temperature, °C ± SD
7.7	10.9 ± 0.78^{f}
7.0	10.9 ± 0.48^{f}
6.3	10.6 ± 0.20^{f}
5.6	$10.5 \pm 0.27^{e,f}$
4.9	9.9 ± 0.14^{e}
4.2	9.3 ± 0.17^{d}
3.5	$9.0 \pm 0.18^{c,d}$
2.8	$8.9 \pm 0.12^{c,d}$
2.1	$8.5 \pm 0.17^{b,c}$
1.4	8.2 ± 0.20^{b}
0.7	7.7 ± 0.37^{a}
0	7.1 ± 0.29^{a}

SD – Standard deviation

Table 8. Elements used in the implementation of heating with mounted radiant ceiling panels

Part	Unit, m; pcs	Unit costs including work, €	Total costs including work, €
Radiant strip KSP-750	57 m	73.85	4,209.45
Distribution pipelines	76 m	17.31	1,315.56
Fittings	9 pcs	23.65	212.85
Modification of boiler	1 pcs	173.08	173.08
Control unit	1 pcs	311.54	311.54
Total cost including VAT	-	-	7,466.54

Comparison of average vertical temperature profile in current (measured) status with estimated profile using radiant ceiling panels is presented in the Fig. 4. The value of the vertical temperature profile with ceiling radiant panels are derived from the previous research work (Kotrbaty & Kovarova, 2002; Zajicek & Kic, 2014).

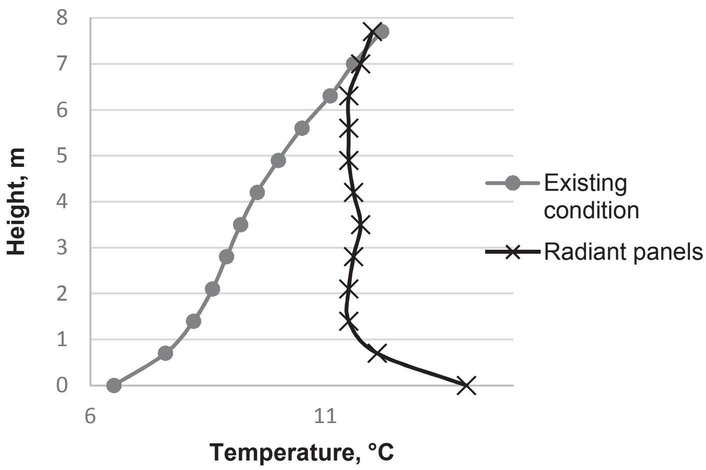

Figure 4. Comparison of vertical temperature profiles current (measured) situation and estimation using radiant ceiling panels.

CONCLUSIONS

This paper shows an overall view on the issue of thermal properties of buildings and some of methods of reduction of energy consumption in large industrial or agricultural buildings. The basic ideas and principles are presented and verified using the example of two different buildings which indicates that:

- in the large ground floor building is the biggest shortage not suitable geometric characteristics of the building and the large area of envelope constructions. The useful method and approach for improvement is comparison of new project with the theoretical compact building and consequently choosing appropriate shape of the building and arrangement of adequate heating method with respect to the shape of the building;
- The solution which can be used for existing large ground floor buildings is improvement of the thermal insulation and replacement of old windows and doors;
- in the large and high building with large glass parts of the structure the suitable solution is to change the heating system; radiant ceiling panels are in this case the most suitable solution;
- described changes should be considered for modernization of older buildings;
- basic ideas outlined in this article should be taken into the account during the design of new buildings; architectural and structural design should take into the consideration the need to minimize energy for heating since the beginning of project preparation.

REFERENCES

Bernardinová, A. & Mareš, M. 2013. *Processing of building energy performance certificate: a practical guide for all owners of houses and apartment buildings, housing and real estate agents*. Linde, Praha, 148 pp. (in Czech).

Basta, J. 2010. *Large Radian Heating*. Grada Publishing, Praha, 128 pp. (in Czech).

Cihelka, J. 1961. *Radian Heating*. SNTL, Praha, 373 pp. (in Czech).

Kic, P. 2013. Hot-air heating of family houses with accumulation of energy in the floor. *Agronomy Research* **11**(2), 329–334.

Kic, P. 2015. Hot-air distribution in the floor heating. *Agronomy Research*, **13**(2), 494–499.

Kotrbaty, M. & Kovarova, Z. 2002. Heating by suspended radiant panels. *Vytapeni, vetrani, instalace* **4**, 134–138. (in Czech).

Vio, M. 2011. *Climatization with Radiant Systems.* Editoriale Delfino, Milano, 264 pp. (in Italian).

Visockis, E., Vucenlazdans, P., Ansone, V. & Morozova, I. 2011. Research on possibilities for decreasing heat losses in buildings. In: *10th International Scientific Conference Engineering for Rural Development*. Latvia University of Agriculture, Jelgava, 342–347.

Zajicek, M. & Kic, P. 2014. Heating of large agricultural and industrial buildings. *Agronomy Research* **12**, 237–244.