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RESEARCH ARTICLE

# Impact of minimum surface temperature on air change rate

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***Abstract***

*This recent work demonstrates through the application of monitoring results, that the surface conductance value along the edges and at thermal bridges differs from the overall standard design value. This fact modifies the characteristics of the building behaviour from the perspective of moisture. The lower $h_i$ value has an impact on the required air change rate: in order to prevent the structure from mould growth, a higher air change rate is needed than previously supposed.*

*In the first part of the paper the monitoring is presented and the second part of the work illustrates the determination method of the required air change rate. The method is presented through a case study. A possible solution to decrease the air change rate is also examined: the impact of additional thermal insulation.*

***Keywords***

*air change rate · additional thermal insulation · moisture problems · energetic impact*

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## 1 Current understanding

### 1.1 Degradation and solutions

Mould growth on the internal walls is mainly caused by moisture problems. Fungi appear only when water is present. The following moisture problems relate to the heat exchange between the surface and air:

- if the surface temperature of the internal wall decreases below the dew point the water vapour will condense on the surface,
- if the relative humidity reaches 75% in the boundary layer, it leads to capillary condensation in the surface finishing.
- the presence of water due to capillary condensation assures suitable conditions for mould growth on the surface finishing.

The occurrence of condensation and capillary condensation depends on two parameters: the humidity of the indoor air and the surface temperature of the wall. In order to prevent either capillary or surface condensation the temperature of the internal surface should be higher, or the humidity should be reduced by more intensive ventilation.

One positive energetic impact of thermal insulation is well known: the decrease of transmission losses. However a less well known impact should be emphasized: thermal insulation can decrease the necessary air change rate, thus the ventilation heat losses. The ventilation losses can represent up to 50 % of the total heat loss, which is a significant saving potential. This also refers to buildings with no ventilation system, because the dwellers need to open the windows less frequently, due to the lower risk of mould growth.

### 1.2 Joint behaviour

The joints of the building envelope are critical zones. Due to their complex geometry and their heterogenous nature, the transmission heat losses are much more significant in these areas than at plain surfaces. This phenomenon is the so called "thermal bridge effect". As a consequence the temperature at the surface and in the boundary layer is lower here, and the relative humidity in the boundary layer can reach the critical 75 %. That is the reason why moulding usually appears at the edges.

## 2 Surface conductance at thermal bridges – monitoring

### 2.1 Raising the problem

#### 2.1.1 Calculation of the internal surface temperature

The nominal design values of the external and internal temperatures and the surface conductance values are given by the building regulations. For plain surfaces the latter are:

– for a vertical external surface $h_e = 23 \frac{\mathrm{W}}{\mathrm{m^2K}}$,

– for a vertical internal surface $h_i = 8 \frac{\mathrm{W}}{\mathrm{m^2K}}$.

The external surface conductance depends on several varying parameters (e.g. wind speed, direction, temperature, solar radiation, geometry, environment), which cannot be stated precisely. Similarly the internal surface conductance also depends on several parameters.

Experience shows that fungi recur several times even if the calculated results exclude the capillary condensation. This fact made it necessary to determine the surface conductance by monitoring real conditions.

### 2.2 Description of the monitoring

#### 2.2.1 The building

The monitoring has been carried out in a prefabricated panel building because of their high number, poor quality and critical substance. The selected building was built with medium size prefabricated panels. It is planned to be refurbished, thus comparative data about the thermal behaviour of the building before and after refurbishment can be obtained.

The chosen building is located in Székesfehérvár (8000 Székesfehérvár, Liget sor 4). It was built in 1962, by the Dunaújváros Panel Factory (type:MOT-1-58-10/62). The panels are made of re-enforced slug ash concrete, which theoretically has a relatively low air-to-air conductance ($\lambda_o$=0,49 W/mK, U=1,28 W/m$^2$K), but in practice the slug ash was scrimped during production, thus the thermal resistance is much lower than the calculated value. The size of the blocks is 2.53 × 2.82 (eastern facade element).

The facade has no additional thermal insulation layer according to the technical level of the era. The wooden-framed windows are double-glazed with high air-to-air conductance and poor air-tightness.

The width of the building is 9.5 meters, the length is 50 meters and the long facades face North and South. On the Southern side there are French windows. It is a five-storey and 15.2 meter high building.

The double pipe heating system is connected to the district heating. The radiators have manually operated valves. The heat consumption of the building is measured but the heating costs are shared between the dwellers in proportion to the living area.

Owing to the lack of insulation, the high infiltration and the lack of automatic heating control, the building has a very high energy consumption. At the end facades, especially on the East, the thermal resistance is so poor that extensive moulding occurs. The dwellers also complain about the discomfort and problems.

The eastern facade of the building is planned to be retrofitted after the measurements with 5 cm additional insulation (expanded polystyrene). It is expected that in this way the fabric will be protected and discomforting problems will be eliminated.

#### 2.2.2 The Room

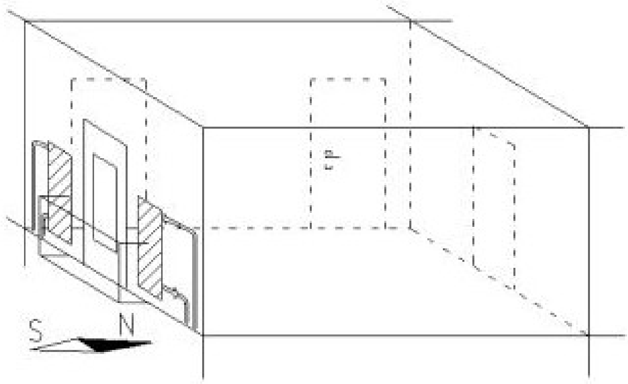


**Fig. 1.** The monitored room

The room selected for the monitoring is located at the most critical point of the building: on the top floor of the east end facade (south-eastern corner). Therefore it has three exposed surfaces in the building envelope, so the heat loss is the highest in the building. It is the living room of a flat and the dwellers complain of asymmetric radiation and discomfort. The main problem of the room is the extensive mould on the eastern wall, especially in the corners. The habitants have to eradicate the mould several times a year. According to their experience the formation of the moulding begins always in the top corner and gradually travels down. They complained of allergic symptoms, which are likely due to mites, occurring together with fungi.

The room is 5 m long, 3 m wide and 2.63 m high. During the measurement all the furniture was moved with a minimum 60 cm from the measured walls. There were two radiators in the room on the southern facade flanking a French window.

There is an assumption that gives a possible explanation for the fact that fungi appear only on the eastern and western facades. The southern facade is heated by direct solar radiation. The radiators are allocated all along the southern and northern facades. They have two positive effects: first, they simply give more heat to the facade they are close to. Second, they warm up the air around themselves and warm air rises up. This airflow next to the surface increases the internal $h$ value of the wall creating higher surface temperatures at which the capillary condensation and moulding cannot evolve. However at the eastern and the western facades these positive effects do not exist.

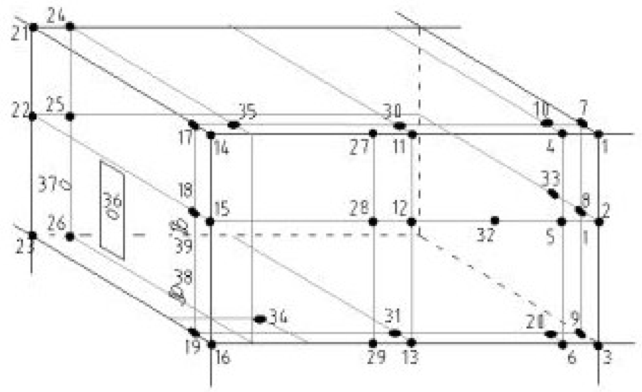

**Fig. 2.** Allocation of sensors

### 2.2.3 Description of monitoring

Forty-one sensors were allocated on the critical points of the room. Eighteen of the sensors were placed on the inner side of joints with three dimensional heat flows, nine of them on joints with two dimensional heat flows, three of them on plain surfaces (one dimensional heat flow). In addition the temperature of the inner side of the window glass (36), the primary (39) and return (38) temperature of the heating water, the external surface temperature of the facade (37), the external and the internal air temperature (data loggers) were also measured.

Near the south-western and south-eastern corners there were heating pipes and radiators. The sensors in these corners were shaded with aluminium foil in order to moderate the disturbing radiant effect of the pipes and radiators. The sensor on the external side of the facade and the one on the window surface were also shaded so that the disturbing effect of solar radiation was also decreased.


**Fig. 3.** Scheme of the thermal wire

All the sensors and data loggers were calibrated. They measured the temperatures every 30 minutes. The sensors were made of insulated thermal wire (AHLBORN Fe-CuNi J). The measured temperature values were registered by a data collector with 40 channels made at TUB) and saved in files on a PC. The external and internal air temperatures were registered by TESTO data loggers.

The period of the measurement was from 16.02.2000 to 27.03.2000. For meteorological and technical reasons the evaluated period was shorter (17.02-23.02 and 01.03-07.03.2000) than previously planned.

### 2.3 Calculation of thermal bridges

In the first step the following joints have been analysed, because these are typical ones and they cause the majority of the so called "linear heat losses" (Fig. 4): a simple wall with parallel surfaces (32), the joint of two perpendicular facades (15, 18), the joint of two continuous panels (12, 28), and two joints of a facade and an internal wall (2, 5, 8 and 22, 25).

The calculations were carried out for those points of the internal surface, where the sensors were allocated (usually at the edges and 20 cm from them).

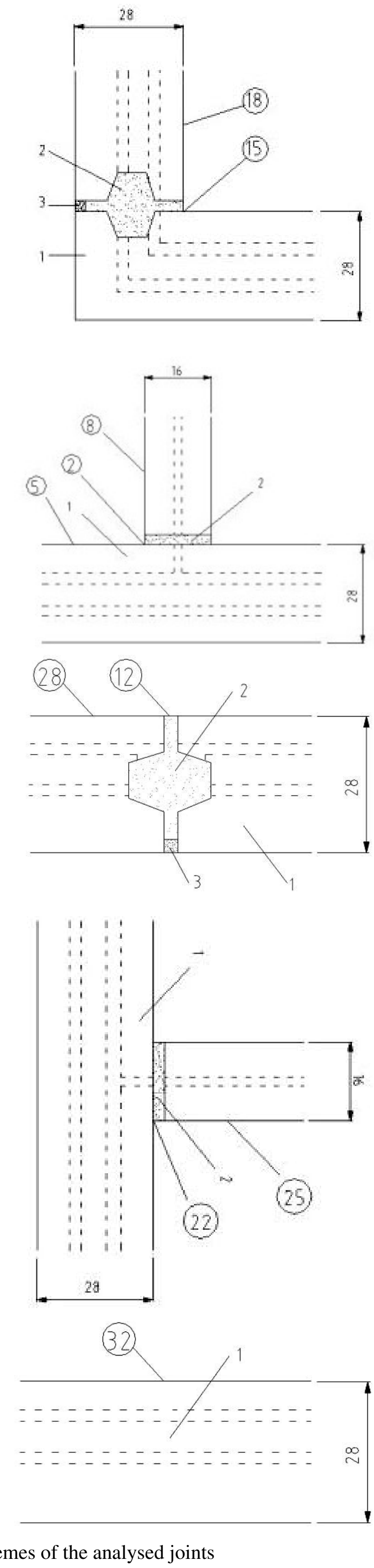

**Fig. 4.** Schemes of the analysed joints

The input data used for the calculations are as follows:

**Tab. 1.**

| | | |
|---|---|---|
| material 1: | slag ash concrete | $\lambda_1$ = 0,49 W/mK |
| material 2: | concrete infilling | $\lambda_2$ = 1,55 W/mK |
| material 3: | stuffing | $\lambda_3$ = 0,1 W/mK |
| external surface | | $h_e$ =23 W/m$^2$K |
| internal surface | | $h_i$ =8 W/m$^2$K |
| internal temperature (average of the measured values) | | $t_i$ =21,3 ˚C |

As the figures show in the first round of calculations the design $h$ values were taken into consideration.

The calculations aimed at the determination of the mathematical relationship between the actual internal surface temperature and $t_i - t_e$. According to the expectations this relationship was linear in all cases.

For one-dimensional case:

$$\dot{q} = U\,(t_i - t_e) = h_i\,(t_i - t_{32})$$

This result can be generalised also for two-dimensional cases as follows:

$$t_x = t_i - \text{const}\,(t_i - t_e) = 21,3 - \text{const}\,(t_i - t_e) \qquad (1)$$

The missing constants were determined using a computer program for steady state conditions. These constants are calculated with the application of design $h$ values and can be seen in the diagrams (Figs. 6-10) later.

## 2.4 Monitoring results

### 2.4.1 General results

The minimum external air temperature of the evaluated period was –3.8 ˚C, the maximum was 15.66 ˚C. The average internal temperature was 21.3 ˚C (this value was also taken into consideration for the calculations). The average external temperature was 3.38 ˚C, the standard deviation of the internal temperature was 0.669 ˚C and the standard deviation of the external temperature was 3.689 ˚C.

Each surface temperature was examined as a function of $t_i - t_e$. Owing to the thermal capacity of the walls, there is a retardation effect between the outdoor air temperature and the internal surface temperature. The value of the time lag for this case has been determined on the base of the correlation between $t$ and $t_i - t_e$ as a function of the retardation. The correlation factors reached their maximum always after 8 hours.

The correlation between $t_i - t_e$ and $t_{13}$ was −0.037 without delay and −0.706 with 8 hours time lag. Thus in Fig. 6 the evaluation of $t_{13}$ can be seen after this correction (the curve of $t_{13}$ is displaced by 8 hours to the left). This figure also proves that the peaks of $t_i - t_e$ and the peaks of $t_{13}$ fit together after the correction.

Since there were numerous disturbing effects, such as air movement, radiation and screening, a statistical analysis has been carried out. For more precise and secure calculations, a

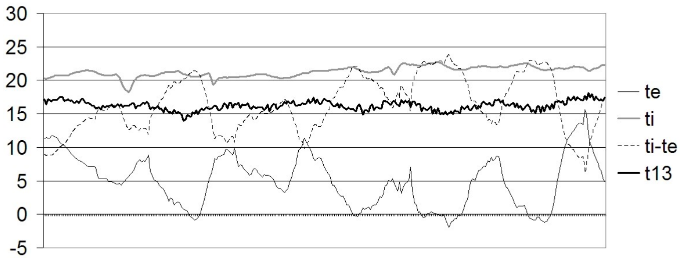


**Fig. 5.** Evaluation of $t_{13}$ after time lag correction

surface temperature line has been determined corresponding to a 5% risk level. This means that it can be stated with 90 % probability level that the real surface temperature will be in the 2.08 K wide band ($t_{13}$). This correlation band follows the evaluation of the regression line. Certainly other risk levels can also be taken into account.

### 2.4.2 Comparison of measured and calculated results

Figs. 6 to 10 show the measured and calculated results for each type of thermal bridge. The regression line of the measured values is also given in the figures.

The correlation between $t_i - t_e$ and the actual surface temperature is different for each joint. It varies between −0.689 and −0.161. The disturbing effects provide the reason for such a difference: in the corner (sensors 22, 25) with low correlation values there was a rising pipe and a radiator which warmed up the air near the corner through convection and warmed directly the surface through radiation. In addition to that it caused an airflow and influenced the $h_i$ value. This effect existed also in another corner (sensors 15,18), but not so significantly (correlation factors: sensor 15: −0.689, sensor 18: −0.405), so it is possible to evaluate the results of this corner, unlike the other (22,25). In addition other disturbing effects influenced the circumstances of the inner side: draught, air circulation in the room caused by the radiator and the internal heat gains (two computers, a television, the dwellers).

There are other effects of less importance decreasing the correlation: the $h_e$ value can vary significantly with the meteorological conditions (wind, solar radiation, temperature, etc.). Certainly it influenced all the examined building parts, but not the same way. The solar radiation was stronger on the South, and the angle of the wind was also different for the two facades.

Since the monitoring focused on the internal side, these effects were not examined.

### 2.4.3 Analysis of results

Examining the diagrams two general statements can be made:

First, the slope of the calculated line and the regression line of the measured surface temperature values are different. The calculated line is steeper than the measured one, due to the surface conductance varying as a function of the temperature. (But in the regulations and design, in practice a constant $h_i$ is taken into account.)

Second, in some cases there is a constant difference between the calculated and measured surface temperatures. That proves that the $h_i$ prescribed by the regulation is higher than in the reality. This increases the risk of condensation and moulding, because the surface temperature decreases.

The background of this phenomenon is the well known fact that surface conductance depends on temperature. It can be divided into two parts, a conductive part and a radiating part [2]:

$$h_i = h_r + h_c \quad (2)$$

where

$$h_c = \left(1,975\sqrt[4]{(t_{air} - t_x)}\right) \quad (3)$$

and $h_r$ is in proportion with the difference of the forth power of the temperatures of the other surfaces and the actual temperature. Certainly those surfaces dominate in the radiation which can be seen at a higher angle from the actual point. In a corner the cold part of the perpendicular wall influenced by the same thermal bridge effect (it is still a part of it) has dominance. This results in lower $h_r$, because the corner "sees" colder surfaces at a higher angle than the free surfaces. Since the $h_r$ is much lower, the total $h_i$ will be lower as well.

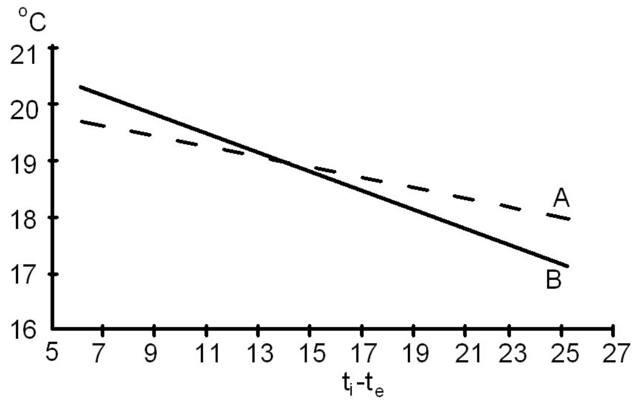


**Fig. 6.** Minimum surface temperatures on a free plain facade (A: 32 measured, B: 32 calculated)

In the one-dimensional case, where the sensor was on the plain panel (Fig. 6) the lines almost fit together, only the slope is different. This means that the $h_i$ design value is correct for one-dimensional cases. The reason for the different slopes is explained above.

Due to the disturbing effect of the radiators in cases of sensors 22 and 25 the correlation is too low to make any conclusions.

In the perpendicular joint of the facades (sensors 15, 18) there is also the disturbing effect of the radiator: the macro-scale air flow in the room, due to the air circulation caused by the radiator represents a forced air movement from the point of view of surface conductance and the boundary layer. However, the correlation is still acceptable (Fig. 8) although the calculated temperatures are not definitely higher or even lower than the measured ones.

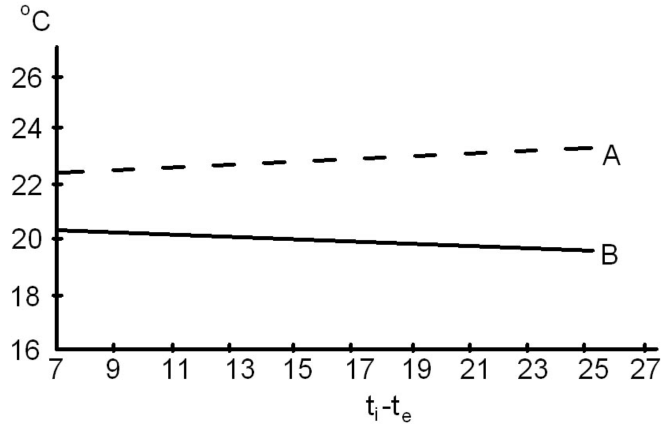


**Fig. 7.** Minimum surface temperatures at a joint of the facade and the inside wall (A: 25 measured - 20 cm from the edge on the inside wall, B: 22 measured - edge))

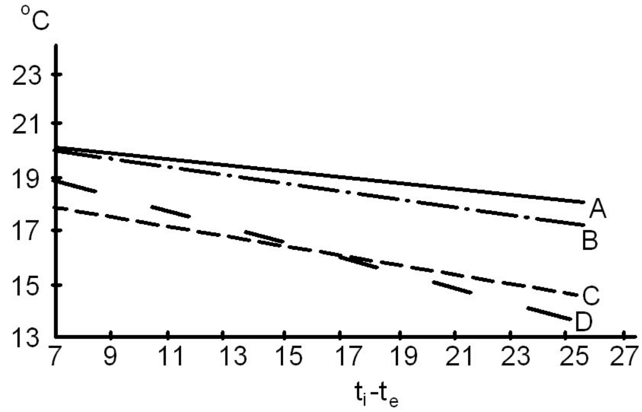


**Fig. 8.** Minimum surface temperatures in an edge (15: edge, A: 18 measured - 20 cm from the edge, B: 18 calculated, C: 15 measured - edge, D: 15 calculated)

This diagram fits the detail explained in the section "Description of the building", namely that moulding does not occur on the northern and southern facades due to the effects of the radiators.

At the thermal bridges with no disturbing effect (sensors 2, 5, 8 and sensors 12, 28) the displacement of the lines are clear (Figs. 9, 10).

For the joint of the two continuous panels the lower surface temperature is caused by another effect, since it has the geometry of an ordinary wall. During construction due to the poor quality of work the joints were not suitably stuffed causing an air gap behind the plugging. If there were holes on the plugging at the bottom and at the top of the room (usually there were) a continuous air channel formed. In this channel an air flow develops owing to the heat flow from inside which warms up the air in the channel. If the rising warm air arrives to a cooler part of the facade condensation occurs. It is well known that the $\lambda$ of the moistened materials is much higher than the design value. Therefore the thermal resistance of the wall decreased resulting in a lower surface temperature inside.

Sensor 8 was on the internal wall 20 cm from the thermal bridge. The graphics definitely show that the cooling effect of the thermal bridge is significantly decreased.

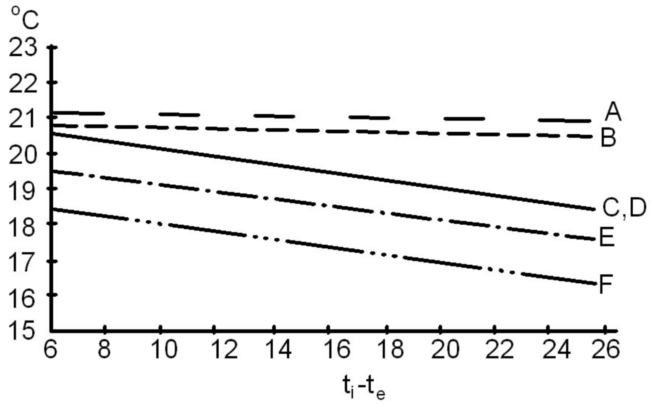


**Fig. 9.** Minimum surface temperatures at a joint of the facade and the inside wall (A: 2 measured - edge, B: 8 measured - 20 cm from the edge on the inside wall, C: 2 calculated, D: 5 calculated - 20 cm from the edge on the façade wall, E: 5 measured, F: 8 calculated)

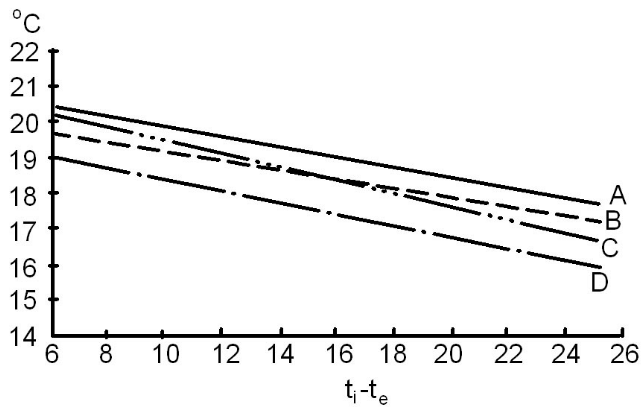


**Fig. 10.** Minimum surface temperatures at a joint of two continuous panels (A: 28 calculated - 20 cm from the joint, B: 28 measured, C: 12 calculated - in the joint, D: 12 measured)

### 2.5 The corrected internal surface conductance

Analysing the internal surface conductance in such a way that input $h_i$ values were modified until the surface temperature fitted those measured at $-5$ °C external temperature, it has been established that the calculated internal surface temperatures fit those measured if the average $h_i$ determined from the monitoring results was taken into account. The analysis was carried out for the design external temperature ($-5$ °C), in order to obtain useful $h_i$ values for more precise design.

For the edge with no disturbing effects (sensors 2) the corrected surface conductance:

$$h_i = 6 \frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}} \tag{4}$$

Due to the random disturbing effects surface temperatures exhibit a quite wide range, which is mainly the consequence of the dispersion of the surface conductance. From the point of view of condensation the lower the surface conductance, the lower will be the surface temperature and the higher the risk of fabric damage. Providing less than 5 % risk is accepted, the $h$ value, belonging to the lower range of the temperature band of the 90 % correlation interval should be taken into account: it is $h_i = 4,7 \frac{W}{m^2K}$. On the other hand, if heat losses are calculated, higher surface conductance is risky, thus the upper value should be taken into account, which is $h_i = 7,3 \frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}}$ for the edges.

Twenty centimetres from the edge this value is much closer to the design value of free plain walls, it is $h_i = 7,6 \frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}}$.

The determined surface conductance in the corner disturbed by the radiator (both for sensors 15 and 18) is much higher than in the other corner: $h_i = 11 \frac{\mathrm{W}}{\mathrm{m}^2\mathrm{K}}$. This is due to the macro scale air circulation in the room, which represents a forced airflow from the point of view of the surface conductance and boundary layer.

## 3 Impact of minimum surface temperature on air change rate – case study

### 3.1 Calculation method of required air change rate relating to moisture content

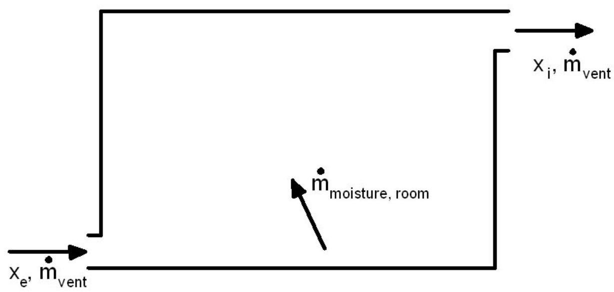


**Fig. 11.** Moisture balance of the room

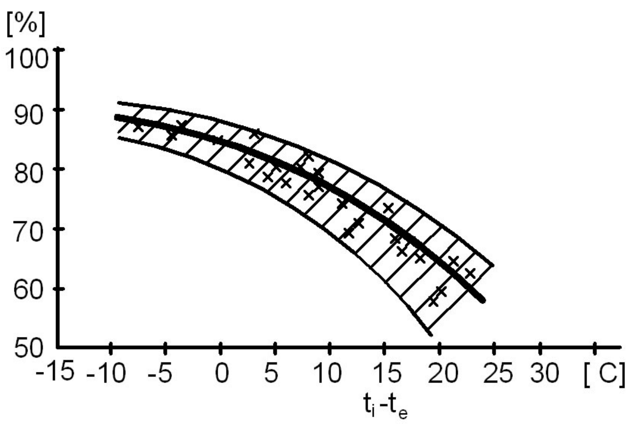


**Fig. 12.** Evaluation of the outdoor relative humidity

The majority of the moisture produced in the room is removed by natural or forced ventilation. Another process of less importance that also decreases the moisture is the vapour diffusion through the walls. It is essential to know this for building preservation, but negligible in the moisture balance of the room. Therefore in the calculations vapour diffusion is ignored. It is also supposed that the fresh air mixes perfectly and immediately with the room air, what means that the absolute humidity will be equal at the edges and in the middle of the room. With these stipulations the moisture balance of the room (Fig. 11):

$$\dot{w}_{\text{out}} = \dot{w}_{in} + \dot{w}_{\text{room}} \tag{5}$$

$$x_i \dot{m}_{\text{vent}} = x_e \dot{m}_{\text{vent}} + \dot{w}_{\text{room}} \tag{6}$$

where $x_i$ and $x_e$ [g/kg] are the absolute humidity of the indoor air and the external air, $\dot{m}_{\text{vent}}$[kg/h] is the ventilated air mass flow, $\dot{w}_{\text{room}}$ [kg/h] is the internal moisture charge, $\dot{w}_{in}$ and $\dot{w}_{\text{out}}$ are the incoming and outgoing moisture flows transported by ventilated air. After reducing the equation, the required ventilated air flow:

$$\dot{m}_{\text{vent}} = \frac{\dot{w}_{\text{room}}}{x_i - x_e} \left[\frac{\text{kg}}{\text{h}}\right] \tag{7}$$

$$\dot{V}_{\text{vent}} = \frac{\dot{m}_{\text{vent}}}{V_{\text{room}}} \left[\frac{\text{m}^3}{\text{h}}\right] \tag{8}$$

The air change rate:

$$n = \frac{\dot{V}_{\text{vent}}}{V_{\text{room}}} \left[\frac{1}{\text{h}}\right] \tag{9}$$

In order to calculate the outlet mass flow of fresh air, all the missing parameters ($x_e$, $x_i$, $\dot{w}_{\text{room}}$) in the balance equation have to be determined. Notice that from the fabric protection point of view the absolute humidity of exiting air is determinant, but the moisture absorptive capacity of the air depends also on the humidity of the supplied external air.

### External humidity

Design conditions depend on the climate. Both process of capillary condensation and mould growth are relatively slow, thus periods shorter than five consecutive days do not present a risk. Therefore the design external temperature should be based on a mean pentad value. At Hungarian climatic conditions it is −5˚C (the monthly mean in January is −2 and the design value for heating load calculation is −13˚C).

The external relative humidity is shown on the diagram in Fig. 13. The diagram is based on statistical data and shows the most probable values of the external humidity as a function of temperature. The band along the curve represents the standard deviation of the humidity values.

According to the diagram, the relative humidity at −5 ˚C is approximately 85 %. From the Mollier h-x diagram absolute humidity can be read off: it is 1.9 g/kg.

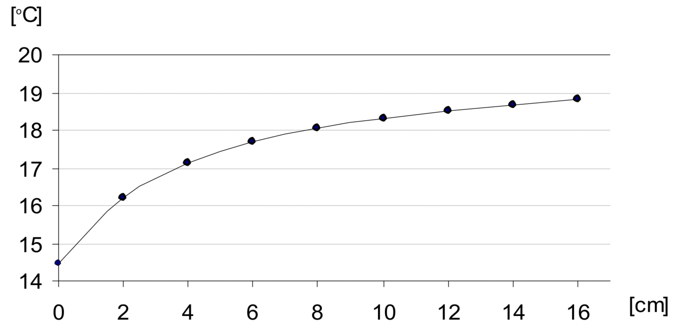


**Fig. 13.** Minimum internal surface temperature as a function of insulation thickness (te = $-5^o$C)

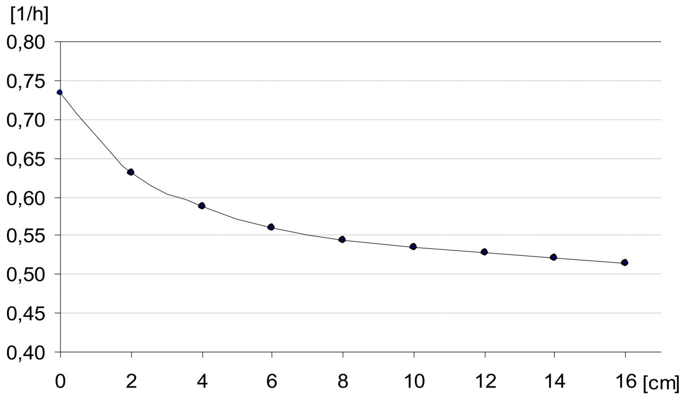


**Fig. 14.** Minimum air change rate as a function of insulation thickness (te = $-5^o$C)

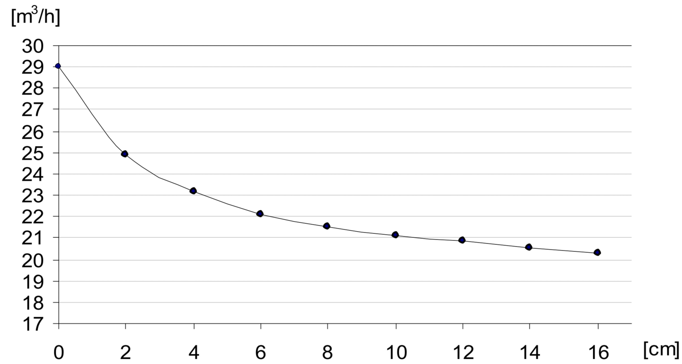


**Fig. 15.** Minimum ventilated air volume as a function of insulation thickness (te = $-5^o$C)

### Admissible internal humidity

The admissible absolute humidity of the room air is determined by the minimum surface temperature. Since perfect air mixing is supposed the absolute humidity is equal all over the room as well as in the boundary layer at the wall surface. The admissible relative humidity in the boundary layer is 75 %. The minimum surface temperature is calculated with the previously determined input surface conductance data of 4.7 W/m$^2$K.This means that a 5 % risk level is taken into account. From the surface temperature and the 75 % relative humidity the admissible absolute humidity of the indoor air can be obtained using a Mol-

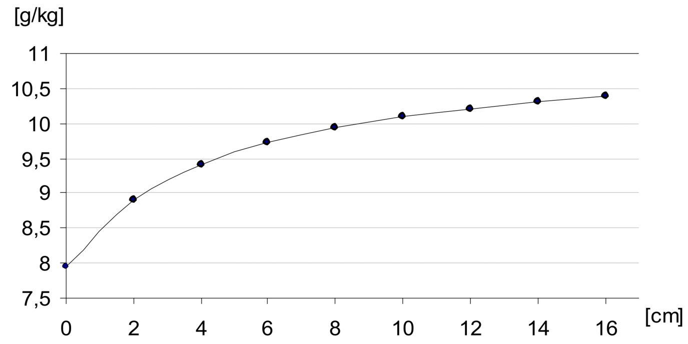


**Fig. 16.** Maximum admissible absolute humidity of the room as a function of the insulation thickness (te = $-5^{o}$C)

lier diagram.

### Moisture development in a room

In a flat, moisture charges differ from case to case. The most frequent sources are: human breath, sanitary equipment, plants, aquariums, cooking, washing, drying, ironing, i.e. normal household activities. When the moisture load is detected the emitted moisture flow can be estimated using statistical data or normative ones, given in standards.

After determining the external absolute humidity, the admissible internal humidity and the internal moisture load, the required ventilated volume and the air change rate can be calculated according to the previously presented formula.

## 3.2 Case study

In order to exemplify the relationship between thermal bridges and required air change rate, and to demonstrate the significance of external thermal insulation a case study has been carried out. The subject of this case study was the living room where the monitoring took place.

For first step the critical joint was chosen. It was the edge where the internal wall joined to the facade (sensor 2), and where no disturbing effect on the surface conductance was detected. Thus 4.7 W/m$^2$K surface conductance can be taken into account.

The internal moisture sources of the living room were: an aquarium, some plants and the occupants (two persons). The estimated moisture emission was 200 g/h.

In the basic example no additional insulation was taken into consideration. In fact this was the case in reality. In further calculations the output data were determined for different thicknesses of additional insulation. The results for –5 $^{o}$C external temperature are illustrated by the diagrams in Figs. 13-17.

## 3.3 Evaluation

Regarding the diagrams the following statements and comments can be made:

1 At low insulation thickness the amelioration is significant. It means that in most cases 2 or 4 centimetres of insulation is enough to avoid capillary condensation and moulding.

2 Above 8-10 cm the amelioration per centimetre is so low that no more insulation increase is economic, because the price of insulation exceeds the savings.

3 Regarding the air change rates: there is a biologically required minimum air change rate that has to be obligatorily kept, otherwise the occupants will not get enough fresh air. In extreme cases suffocation can occur. This biologically needed air change rate is 0.5/h and has to be maintained even if it is not necessary from the moisture and energetic point of view. If the external temperature is higher than $-5$ ˚C the required air change rate and thus the ventilation losses will be higher, too. The necessary air change rate values were determined for $-15, -10, -5, 0, +5, +10$ ˚C. Fig. 17 illustrates the results. It can be stated that the required air change rate due to moisture is generally higher than the biologically needed value. Fig.18 compares the ventilation and transmission losses as a function of outdoor temperature.

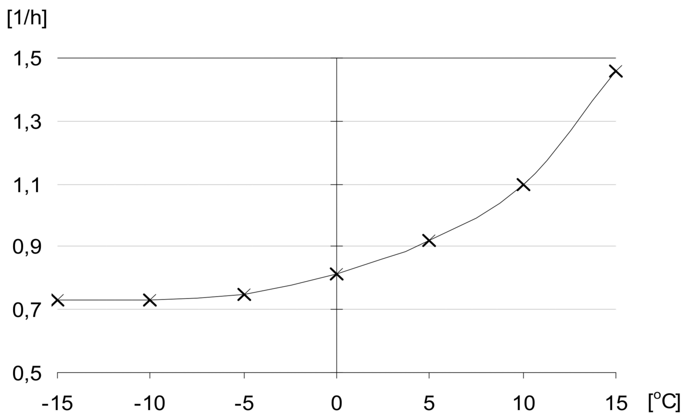


**Fig. 17.** Required air change rate as a function of external temperature (no thermal insulation)

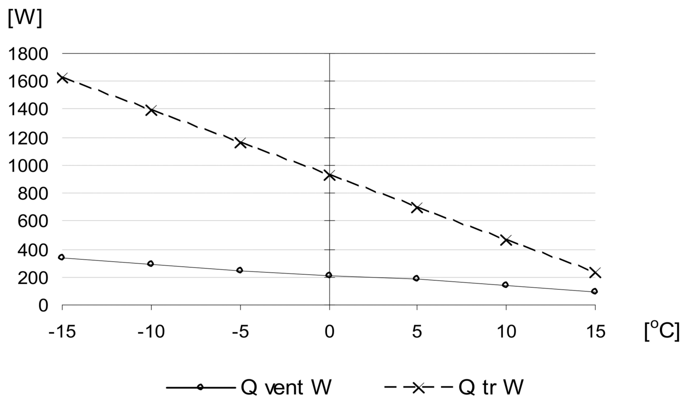


**Fig. 18.** Transmission and minimum ventilation losses as a function of external temperature (no thermal insulation)

4 It has been supposed that the ventilated fresh air mixes with the room air perfectly and immediately. In reality perfect air mixture never occurs. Certain zones in the room, like hidden spaces behind furniture, zones next to the corners far

from windows or vents are more or less isolated from the so called "primary air flow". In these zones secondary air flows develop. This means that the moisture transport from these zones is not as effective as previously calculated. Therefore higher ventilation rates or more efficient air movement is required. On the other hand the moisture sources are usually not in these zones, so the moisture flow into these zones is also lower. Up to now, in practice there is no effective and fast method to handle this phenomenon (apart from some complicated computer programs). Therefore the impact of higher ventilated air volume can only be estimated and further research should examine the vapour diffusion in the room in order to obtain a more precise model.
However thermal insulation definitely decreases the risk of mould growth, since both the internal surface temperature and as a result the admissible humidity increases.

5 The extrapolation of the ventilation losses is similar to the curve of transmission heat losses. The saving potential in ventilation losses through thermal insulation is relatively low compared to the potential in transmission losses. However according to the statements in the previous paragraph, the required ventilation flow is significantly higher than the calculated rate, and this is the case of the heat losses as well. In

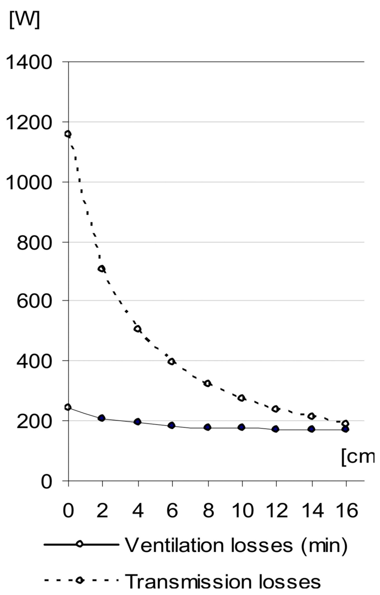


**Fig. 19.** Ventilation heat losses and transmission heat losses as a function of insulation thickness (te = $-5^{o}$C)

addition Fig. 19 shows the losses for –5 ˚C outdoor temperature, although it has been presented in paragraph 3 that at higher outdoor temperatures the rule for ventilation losses is higher. Regarding figure 20 it can be seen that above 12 ˚C outdoor air temperature, the ventilation losses are higher than the transmission losses.
Simply multiplying the heat losses at the different external temperatures and the number of days at certain temperatures, annual energy consumption will be obtained. Fig. 20 shows that the significance of the ventilation losses is much higher when looking at a yearly period than from the design conditions.

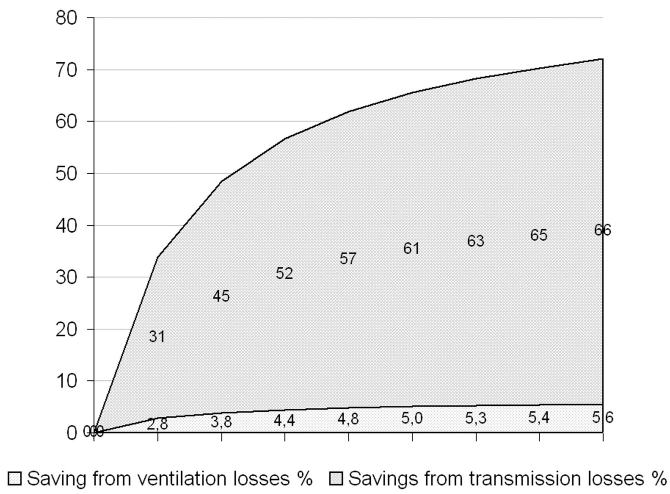


**Fig. 20.** Annual energy saving as a function of insulation thickness

6 The necessary air change rates for controlling moisture levels are lower than the air change rates in most of the existing Hungarian blocks of flats. In reality it varies between 1-1.2 /h and the ventilation heat losses can exceed the transmission losses. It means that by applying additional insulation the infiltration heat losses could be reduced significantly with no risk of moulding. The infiltration losses could be reduced either by reducing the mechanically ventilated air flow or in the case of natural ventilation, by fixing weather strips on the window frames. The saving potential is the difference between the present and the required air change rate (from moisture and biological perspectives).

7 Finally the total saving potential through 16 cm thermal insulation is approximately 65%, from which only 57% is taken into consideration in practice, because designers usually do not know about the effects of thermal insulation on air change rate or neglect it. This is an error of 8%. If designers were to consider the correct savings, it would lead to shorter rate of return from an economic point of view.

## 4 Conclusion

It has been shown by monitoring that the internal surface conductance in the corners and along the edges differs from that of a plain surface and from the values recommended by the building regulations. It has also been estimated that the $h_i$ value varies as a function of the temperature in the boundary layer.

A case study has demonstrated the impact of minimum temperature at thermal bridges on required ventilated air flow. It has been also shown that both thermal insulation and higher air change rate can prevent mould growth.

When calculating the savings potential through thermal insulation, designers should regard not only transmission savings, but also the impact of thermal insulation on air change rates,

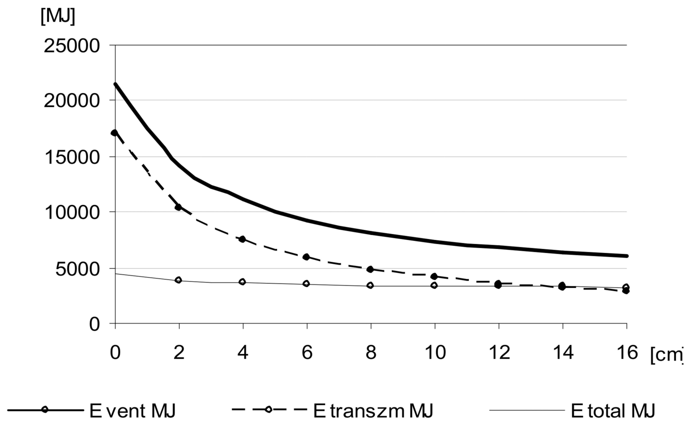


**Fig. 21.** Annual transmission and minimum ventilation heat consumption

otherwise significant mistakes will be made, what would lead to a shorter rate of return.

As already mentioned, the building will be refurbished before the next heating period, therefore it will be possible to obtain comparative data after refurbishment. This will also provide additional data.

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