Energy and comfort aspects of infiltration at closing elements of buildings

F. Kalmár, T. Kalmár, E. Varga, I. Kocsis, T. Jenei and Gy. Csomós
University of Debrecen, Faculty of Engineering

ABSTRACT

Nowadays, due to the energy saving purposes in the building sector, at new buildings and at refurbishments, modern closing elements are built-in, with very good thermal insulation and air tightness properties. The frame of these elements may be from wood, plastic or metal. Each of them has advantages and disadvantages, but during the exploitation the initial value of air tightness may become higher. This phenomenon may appear because of the initial tensions in the materials or due to the failures in the built-in procedure. The infiltrated air-flow through the frame gaps may be significant. Of course there are lots of factors which have an influence on the infiltration beside the gaps surface such as wind pressure, extractor fans etc. Having infiltration the energy properties of the building are changed considerably and, depending on the rooms' position in dwelling, comfort problems may appear. In this paper the infiltration is analysed from energy and thermal comfort point of view. Calculus has shown that having lower air tightness the energy consumption for heating up the infiltrated fresh air flow can be 3-5 times higher than the design value. If the infiltrated air is not heated up to the internal set point value the internal temperature can decreased significantly.

1. INTRODUCTION

According to the last Directives of the European Union in the field of energy consumption and environment protection the energy consumption of buildings have to be reduced considerably and the energy saving possibilities have to be emphasised. The new buildings have to meet the requirements of the new regulations which came into force taking into account the Directive 91/EC/2002. So, the high energy consumption problems appear especially at the existing buildings. In the European countries there are different national programs related to refurbishment of the existing buildings and there are good examples of successfully retrofitted buildings (NEP, 2001). Replacement of the existing closing elements represents one of the most important aspects of the buildings rehabilitation. There are lots of windows or door types on the market with different glass or frame materials. If the element is not chosen correctly or there are failures in the built-in procedure a window replacement may have positive but even negative consequences (Kovács Plajos, 2007). The most important question is: how the fresh air flow is assured after the window replacement. Usually the new windows and doors have very good air tightness properties, so the fresh air may be introduced using a mechanical ventilation system or opening the windows. The analysis of necessary fresh air flow depending on the thermal bridges type was analysed (Kalmár, 2001). If there are gaps practiced on the top and bottom of the window frame the infiltrated fresh air flow is influenced even by the used heating system type (Kalmár and Kalmár, 2007). Unfortunately there are cases when the gaps appear due the failures in the frame material or built in technology or procedure. The effects of the solar radiation, wind and rain can have a negative influence on the frame too. Because of the bigger dimensions doors are more exposed to these effects then windows. In the following let us see which the energy and thermal comfort effects are of the infiltrated fresh air.

2. AIR TIGHTNESS OF CLOSING ELEMENTS AND INFILTRATION

In most residential buildings there are no mechanical ventilation systems. The fresh air is introduced opening the windows or having a ventilation chimney placed in usually in the bathroom. In the kitchen there is an extractor fan which operates during the cooking.
If there is no ventilation chimney and all the windows and doors are closed, the fresh air enters in the building through the windows and doors gaps because of the wind pressure. The infiltrated air flow may be determined using the following relation:

$$\dot{V} = aP\Delta p^{0.67} \quad (1)$$

where: a – represents the air tightness coefficient of closing element, [$m^3/(h\ m\ Pa^{0,67})$]; P – perimeter of the mobile windows/doors, [m]; Δp – pressure difference between the two sides of the closing element, [Pa].
The air tightness coefficient of the most used windows is 0.2…0.4 $m^3/(h\ m\ Pa^{0,67})$ (Helios, 2003).
The yearly average wind velocity in Hungary is 3.5 m/s. If the energy losses are analysed due to the infiltrations only that wind velocities have to be taken into account which appears during the heating season. These values are presented together with the specific degree day curve in Figure 1 (Macskási, 1952)

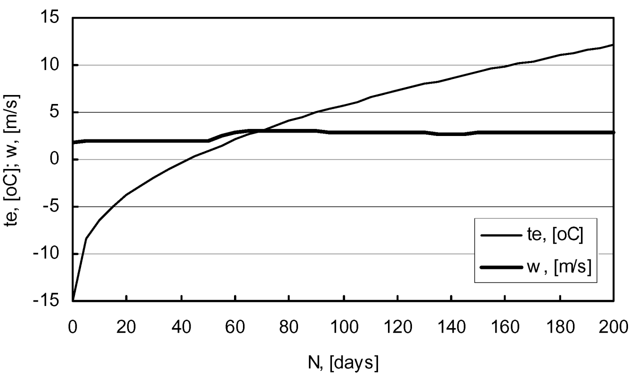

Figure 1: Degree day curve and average wind velocities in the heating season

According to this diagram it can be seen that a mean value of 2,5 m/s wind velocity can be taken into account for energy calculus. During the summer period (higher outdoor temperatures) the daily average wind velocities are higher but these values have no influence on the energy consumption for heating up the infiltrated air. Also, if the wind pressure is negligible, the infiltration is closed to zero.
Having a ventilation chimney placed in the house/dwelling due the indoor-outdoor temperature differences the infiltration is continuous. If there are no inlet elements placed on the windows frame, the fresh air enters in the rooms/buildings through the gaps of closing elements. These gaps are quite small. For new windows and doors the thickness of these gaps, taking into account the air tightness coefficient, can be around 0,08 mm. Due to these very small values, the obtained air change rate is much lower than it is necessary because of the air quality conditions. To obtain the required fresh air flow an extractor fan has to be placed in the dwelling with several inlet gaps for fresh air. If there are no inlet gaps and extractor fan installed the infiltrated air flow can be determined using the following equation:

$$\dot{V} = \mu A \sqrt{\frac{2\Delta p}{\rho_e}} \quad (2)$$

where: A – is the area of the closing elements' gaps; μ - correction factor which depends on the gap geometry.
In this case the pressure difference is obtained because of the outdoor-indoor air density difference:

$$\Delta p = (\rho_e - \rho_i) gh \quad (3)$$

where: ρ_i - is the indoor air density, [kg/m^3]; h – is the height between the inlet and outlet gap, [m].
The air density may be determined using the following simplified relation:

$$\rho = \rho_0 \frac{273}{273 + t} \quad (4)$$

where: ρ_0 – is the air density at 0 °C (1.2829 kg/m^3); t – is the temperature, [°C].
Having the air flow the air change rate (*ACH*) can be determined and then the heat loss coefficient which characterize the infiltration:

$$K_f = \rho_e c_p ACH \cdot V \quad (5)$$

where: c_p – is the specific heat of air (1004 J/kgK); V – is the heated/ventilated volume, [m^3].
The degree day curve might be approximated with the following mathematical function (Kalmár, 2005):

$$t_e = -15 + 3.55x^{0.3835} \quad (6)$$

where x is the number of days.
If in relation (7) the external temperature is equal to the balance point temperature (t_b) of the building, then the number of days in a heating season can be determined:

$$N = \left(\frac{t_b - t_{e0}}{3.55} \right)^{2.6} \quad (7)$$

where t_{e0} is the external design temperature for heat losses.
Using relation (6), (7) and (8) the energy consumption in a heating season to heat up the infiltrated air can be determined, [kWh]:

$$E_f = 0.024 K_f N \left[(t_i - t_{e0}) - 2.566 N^{0.3835} \right] \quad (8)$$

3. NUMERICAL EXAMPLE

n the following let us see for a small family house which the effects of infiltrations are on the energy consumption and thermal comfort. According to these data the net floor area is 65 m^2, the heated volume is 182 m^3, the total length of gaps is 33 m. The building was built in 2003 and the frame of closing elements is realised from wood. Because of the effects of environmental factors now the wood frames have small deformations, so the gaps are higher than the design values. In the house there is no ventilation chimney placed, but there is an extractor fan in the kitchen. Using the relation (1)-(9) a theoretical analysis was done in order to see which the infiltrated air flow values are. The calculus was done for the case when there is no ventilation chimney and for the case when a ventilation chimney (ϕ100) is placed in the bathroom. When the infiltration is calculated depending on the wind pressure a length of 28.2 m gap is taken into account, because this is the worst case. In Figure 2 the air change rate values are shown in the design situation depending on the external temperature both for gravitational (μ=0.8) and wind pressure difference.

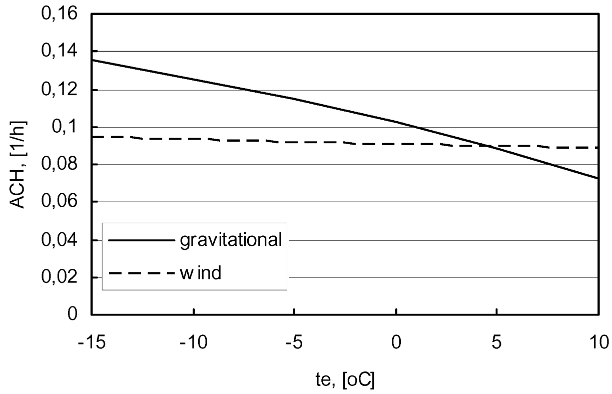

Figure 2: Air change rate in design situation

It can be observed that the infiltrated air flow is higher in the case when a ventilation chimney is installed, as far as for wind a velocity of 2.5 m/s can be used. At the same time these values are much lower than the minimum required for ventilation. For these values the daily energy consumption can be determined (Fig. 3).

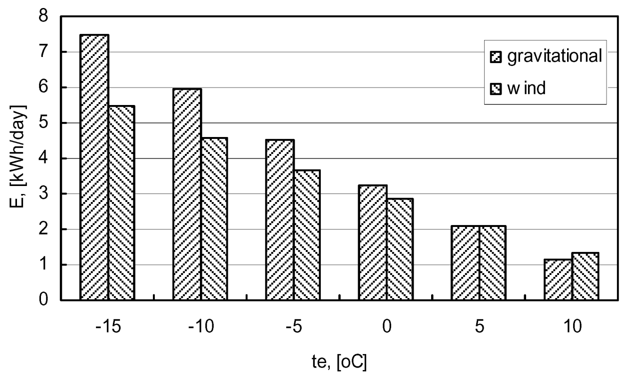

Figure 3: Daily energy consumption for heating up the infiltrated air

It can be observed that the energy consumption is higher when the infiltration is determined by wind pressure only for days having mean outdoor temperatures equal or higher then 10 °C. If the gaps thickness is higher then 0.08 mm then for both cases higher air change rate values are obtained. In the case of gravitational ventilation these values are presented in Figure 4. It can be seen that for gap thickness higher than 0.8 mm ACH values are higher than 0.5 for the whole heating season. The highest ACH values are obtained for the lowest outdoor air temperatures and in this case the infiltrated air flow cannot be controlled. Of course there are special inlet elements which operation can be controlled depending on the occupant needs but this is not our case. The infiltrated air has to be heated up to the internal set point temperature otherwise comfort problems may appear. Beside this the surface temperature of different building elements can decrease under the dew point temperature of the internal air, so condensation may appear (Kalmár, 2007).

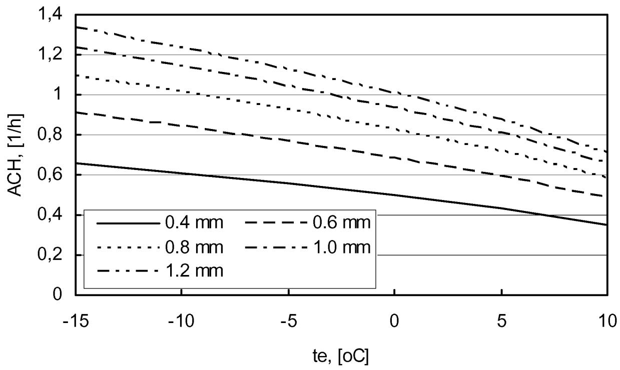

Figure 4: Air change rate values for bigger gap thickness (gravitational)

In Figure 5 the air change rate values are shown for two gap thicknesses having the infiltration determined by wind pressure.

For the whole heating season the energy needed to heat up the infiltrated air for design values of air tightness of the closing elements is 622.5 kWh (gravitational) and 457.2 kWh (wind). Taking into account gaps with 0.4 mm thickness these values will increase respectively to 3027 kWh and 1728 kWh.

If we analyse separately the room no. 1 and the entrance hall the differences between real and theoretical values of the daily energy consumption are presented in Figure 6.

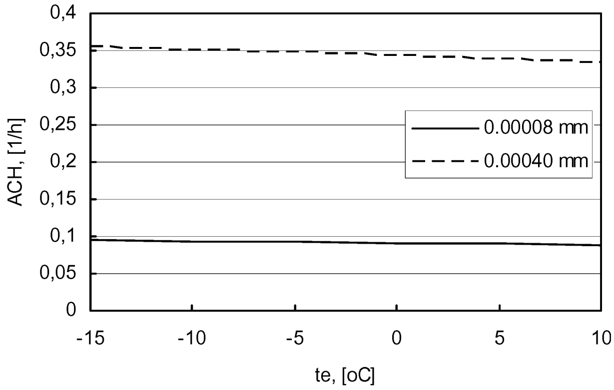

Figure 5: Air change rate for bigger gap thickness (wind)

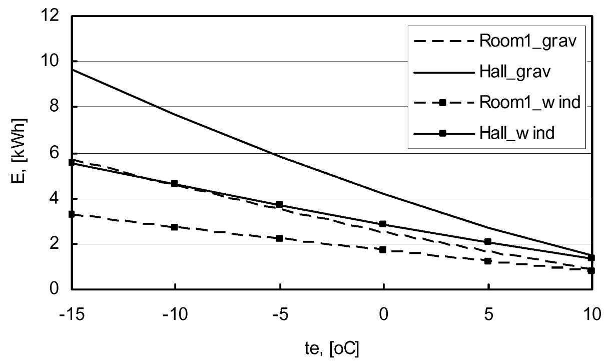

Figure 6: Differences between daily energy consumption

If the infiltrated air fresh air flow is not heated up to the internal set point temperature (no supplementary output and energy consumption at the heating systems) the internal air temperature will decrease. The obtained values of the mixed air temperatures are presented in Figure 7.

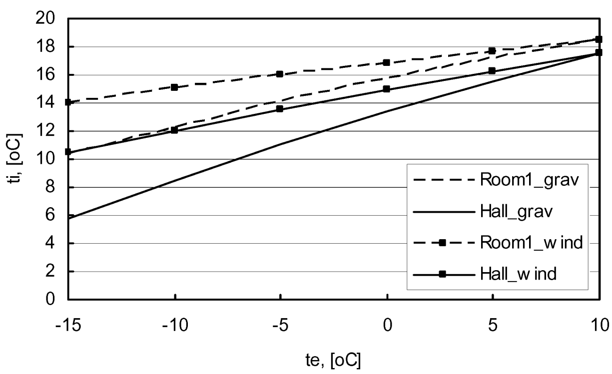

Figure 7: Indoor air temperatures in analysed spaces

The low indoor air temperature affects seriously the thermal comfort in the rooms. This situation of course is avoided increasing the energy consumption for heating.

4. MEASUREMENTS

In January 2006 measurements were done in order to analyse the effects of infiltrated air on the energy consumption at this family house. The biggest gap dimensions were stated at the entrance door. In this case the condensation has already produced a deterioration of a wall portion. The gaps have a bigger thickness in the middle (around 1.8 mm), at the bottom the thickness was 1.4 mm and at the top ca. 0.8 mm. The gap of the window has a thickness around 0.4 mm.

The infiltrated air velocity was measured from 10 to 10 cm of door height and the obtained mean values are presented in Figure 8. The average wind velocity during the measurements was 0.56 m/s.

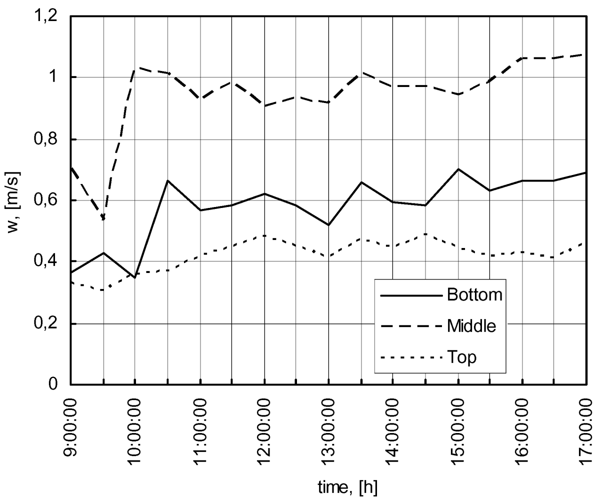

Figure 8: Velocity of the infiltrated air flow (fan switched off)

The measurements were done putting in the operation the extractor fan in the kitchen. The obtained velocity values are presented in Figure 9.
It can be seen that the differences between measured values are between different depending on measuring point. The highest differences were registered for middle 0.37 m/s in average. For the bottom the differences are around 0.2 m/s and for the top the differences are only 0.06 m/s.

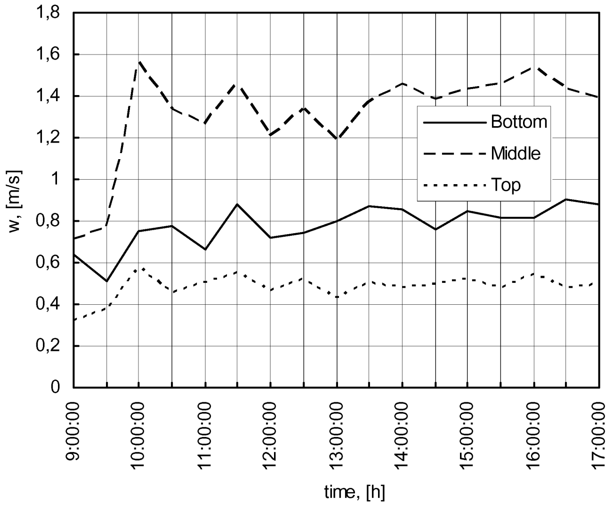

Figure 9: Velocity of the infiltrated air flow (fan switched on)

It can be seen that the differences between measured values are between different depending on measuring point. The highest differences were registered for middle 0.37 m/s in average. For the bottom the differences are around 0.2 m/s and for the top the differences are only 0.06 m/s.
The infiltrated air flow when the extractor fan is switched off is 21.8 m^3/h, when the extractor fan is switched on the fresh air flow rise to 29.6 m^3/h (+36%).
Based on the equations the infiltrated air flow and expected indoor air temperature values were calculated for these bigger gaps. The obtained values are presented in Figure 10.

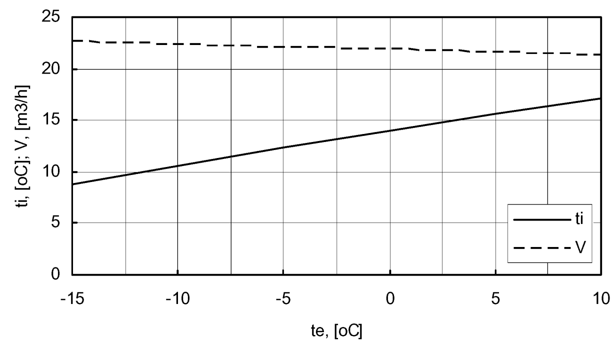

Figure 10: Expected air flow and internal temperature values in the entrance hall

It can be observed that for temperatures around 0 °C the air flow is around 22 m^3/h. For this fresh air flow temperatures around 14 °C were expected. The measured indoor air temperature values are presented in Figure 11.

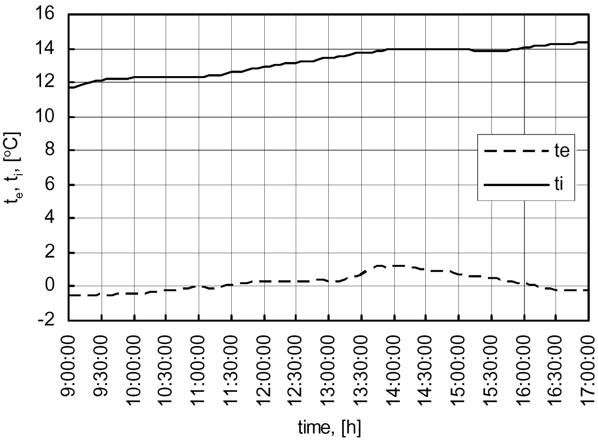

Figure 11: Measured indoor and outdoor temperatures

5. CONCLUSIONS

In the case of new and well executed closing elements infiltrations are so small then the necessary fresh air flow cannot be assured. After some years the windows and doors frame may have deformations and the infiltration can be so high that the heat demand cannot be covered by the heating system.

In this case thermal comfort and condensation problems may appear. If the infiltrated air flow is heated up to internal set point temperature the energy consumption can exceed 3-5 times the expected heat demand for infiltration.

REFERENCES

Halász, E. (2003) Energy saving principles, Proc. NAS EnerBuild Workshop, Budapest, 24-25 January, 2003, Prague: TCAS.

Helios (2003) Lakásszellőzés kialakításának szempontjai, p. 1-2

Kalmár, F. (2001) The interrelation of thermal bridges and ventilation, Bulletin of Faculty of Architectural Engineering, Budapest University of Technology and Economics, p. 145-151.

Kalmár, F. (2004) Adjustment of central heating systems to reduced energy needs of retrofitted buildings:41-48, PhD thesis, Budapest: BUTE.

Kalmár, F. Kalmár, T. (2007) Interrelation between ACH, PMV and heating system type, ROOMVENT 2007, 13-15 June, Helsinki, Finland.

Kalmár, T. (2007) Physical aspects of air infiltration at closing elements of buildings, Int. conf. ICEE, Iasi, Romania.

Kovács Plajos, K. (2007) Windows replacement – a complex problem in every respect, Int. Conf. “Building Installations and Ambiental Comfort”, Timisoara, Romania, p. 52-60.

Macskásy, Á. (1952) Központi fűtőberendezésekkel kapcsolatos előtanulmányok, Tankönyvkiadó, Budapest.

NEP-2006-1: Gazdasági és Közlekedési Minisztérium, Lakossági energiamegtakarítás.