Analysis of ventilation heat losses in case of refurbished buildings

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Abstract—**Energy saving in the building sector is one of the most important issues. In European countries severe requirements were established related to the overall heat transfer coefficients of the building envelope. Transmission heat losses are drastically reduced and the air tightness of the building envelope is extremely high. However, the fresh air must be provided to the occupants, otherwise health problems may occur. Controlled ventilation with heat recovery can be assured only by installing mechanical ventilation systems. Nevertheless, the heat demand of the ventilation can be higher after refurbishment, than it was initially. In this paper the calculation procedures of the fresh air demands are presented and the effects of the refurbishments on the ventilation heat losses are illustrated by a case study.**

I. INTRODUCTION

According to Directive 2002/91/EC, buildings, accounts for more than 40 % of final energy consumption in the Community and is expanding, [1]. This trend will lead to higher carbon dioxide emissions in this sector. The Directive 2010/31/EU highlights that measures to improve further the energy performance of buildings should take into account climatic and local conditions as well as indoor climate environment and cost-effectiveness. According to this Directive as of 31 December 2020 new buildings in the EU will have to consume 'nearly zero' energy and the used energy will be 'to a very large extent' from renewable sources. In Hungary there were different national projects launched in order to help the owners of houses or flats or local governments to enhance the energy characteristics of buildings. In each of these programs one of the main indicators was the decrease of energy demand after refurbishment of the building envelope and its energy supply system. For a typical detached house with average thermal characteristics of the envelope, in central European countries heating represents between 70-80 % of its energy need. Proper insulation of the opaque building elements can be done either by inorganic fibrous materials or by organic foamy materials. However, the physical properties of these insulating materials are influenced by the building technology and meteorological conditions, so in the energy calculations appropriate thermal characteristics have to be taken into account, [2, 3, 4, 5]. In order to determine the optimal thermal insulation layer thickness for a building envelope, different methods have been developed, [6, 7, 8]. In Hungary the Regulation in force established the requirement related to the overall heat transfer coefficient of the external walls to 0.24 $W/m^2 \cdot K$. Triple glazed windows with low emissivity coatings and inert gases (argon, krypton) can reduce considerably the transmission heat loss trough these building elements. The window frame is an important part of a fenestration product. The glazing spacer and the location of the spacer in the frame may influence the thermal performance of the window. Normal window frames consisting of only wood, PVC, Al or wood/Al. Thereby the overall heat transfer coefficient values of these windows is larger than 0.80 $W/m^2 \cdot K$.

Existing buildings are characterized by low air tightness and relatively high air leakage. This air leakage is driven by differential pressures across the building envelope due to the combined effects of stack, external wind and mechanical ventilation systems. Jokisalo et al. studied the building leakage, infiltration, and energy performance analyses for Finnish detached houses, [9]. According to their results, infiltration causes about 15–30% of the energy use of space heating including ventilation in the typical Finnish detached house. According to Kalamees the typical air leakage places in the studied houses were: the junction of the ceiling/floor with the external wall, the junction of the separating walls with the external wall, penetrations of the electrical and plumbing installations through the air barrier systems, penetrations of the chimney and ventilation ducts through the air barrier systems, leakage around and through electrical sockets and switches, and leakage around and through windows and doors, [10]. Chan et al. analyzed more than 70,000 air leakage measurements in houses across the United States, [11]. Based on a classification tree analysis, they found that the year built and floor area are the two most significant predictors of leakage area: older and smaller houses tend to have higher normalized leakage areas than newer and larger ones. It is clear that after a thermal refurbishment of a building the infiltration will decrease considerably. This side effect of the additional thermal insulation of opaque building elements and windows change respectively, is advantageous from the point of view of heat demand, but creates new commitments from the ventilation point of view.

In building there are different sources of water vapor and the moisture content can rise to risky values, if the necessary air change is not assured continuously. Before refurbishment air leakage of a building, in most of cases "provided" a fresh air flow rate, which kept the absolute humidity of the indoor air under the critical value. After thermal refurbishment, if no mechanical ventilation is installed, mould appeared on the inner surface of the junctions of different building elements. Of course, the occupants can open the windows to change the air in a room, but the energy issues does not encourage the owners to open the windows as frequent as it would be needed on one hand, occupants can endure quite high CO_2 concentrations. Installing mechanical ventilation systems the investment costs can grow considerably. Furthermore operating and maintenance costs have to be taken into account. In this paper the heat demand is analyzed in case of building refurbishments, taking into account the fresh air demand calculated using different requirements established in standards or Regulations.

II. Ventilation Rate Demand in Buildings

The pollution sources in a building are the occupants and their activities, materials in the building, including furnishing, carpets household chemicals and the ventilation or air conditioning system. Many pollution sources emit hundreds or thousands of chemicals, but usually in small quantities, [12]. The sensory pollution load on the air is caused by those pollution sources having impact on the perceived air quality. The sensory pollution load in a space may be found by adding the loads caused by all the different pollution sources in a space.

The air quality may not be the same throughout a ventilated space. What really counts for the occupants is the air quality in the breathing zone. The air distribution type has the most important impact on the indoor air quality. This is expressed by the ventilation effectiveness, [12]:

$$\varepsilon_v = \frac{c_e - c_s}{c_i - c_s}. \qquad (1)$$

where: ε_v – is the ventilation effectiveness; c_e – is the pollution concentration in the exhaust air; c_s – is the pollution concentration in the supply-air; c_i – is the pollution concentration in the breathing zone.

The required ventilation rate for comfort can be calculated from the equation, [12]:

$$\dot{V}_c = 10 \frac{G_c}{C_{c,i} - C_{c,0}} \frac{1}{\varepsilon_v}. \qquad (2)$$

where: G_c – is the sensory pollution load, [olf]; $C_{c,i}$ – is the desired indoor air quality, [decipol]; $C_{c,0}$ – is the perceived outdoor air quality at air intake, [decipol].

The ventilation rate required from a health point of view is calculated using equation (3), [12]:

$$\dot{V}_c = \frac{G_h}{C_{h,i} - C_{h,0}} \frac{1}{\varepsilon_v}. \qquad (3)$$

where: G_h – is the pollution load of a chemical, [μg/s]; $C_{h,i}$ – is the guideline value of a chemical, [μg/l]; $C_{c,0}$ – is the outdoor concentration of a chemical at air intake, [μg/l].

In CR 1752 the required ventilation rates are given for different building categories taking into account both the minimum ventilation rate for occupants only ($\dot{v}_p$) and the additional ventilation for building ($\dot{v}_B$). The sum of the ventilation rates give the fresh air needed for ventilation, [13].

$$\dot{V}_{tot} = N\dot{v}_p + A\dot{v}_B. \qquad (4)$$

where: $\dot{V}_{tot}$ - is the total ventilation rate of the room, [l/s]; N – is the number of persons in the room; A – room floor area, [m^2].

CR 1752 classifies the buildings into three categories (A, B, C) and gives the $\dot{v}_B$ values for low-polluting and non low-polluting buildings. In case of a department store the minimum ventilation rate for occupants is 2.1, 1.5 and 0.9 l/s·m^2, for A, B and C building category respectively. The $\dot{v}_B$ values for low-polluting building are: 2.0, 1.4, and 0.8 l/s·m^2, for A, B and C building category respectively. Meanwhile, for non low-polluting building, the $\dot{v}_B$ values are 3.0, 2.1, 1.2 l/s·m^2, for A, B and C building category respectively. Thus, important differences will appear between the required total ventilation rates, depending on the building category.

A building is called low polluting or very low polluting, when the majority of building materials used for finishing the interior surfaces meet the national or international criteria of low-polluting or very low polluting materials, [13]. EN 15251:2007 classifies the buildings into three categories (I, II, III) and gives the $\dot{v}_B$ values for very low-polluting, low-polluting and non low-polluting buildings. In case of very low polluted building the $\dot{v}_B$ values are: 1.0, 0.7 and 0.4 l/s·m^2, for I, II and III building category respectively. For low-polluting and non low-polluting buildings the proposed values are similar to the values required by CR 1752. It can be observed, that the requirement is three times higher in case of non low polluting building in comparison with a very low polluting building. This will lead to significant differences between the calculated ventilation rates of buildings.

According to the Hungarian Regulation the required fresh air flow rate supplied in a closed space depends on the physical demand level of performed work. In case of intellectual (sedentary) work, 30 m^3/h pro person ventilation rate have to be introduced in the room, while in case of light, medium, heavy work the requirement is: 30 m^3/h pro person, 40 m^3/h pro person and 50 m^3/h pro person, respectively, [14].

Desired ventilation rate can be calculated based on the heat and moisture load of the space. When determining the cooling load, all internal heat gains (occupants, lighting, electronic equipments, technologies) and the solar gains have to be taken into account. The ventilation rate demand is calculated as the ratio between the cooling load of the closed space and the difference between the indoor air enthalpy and supply-air enthalpy. When determining moisture load of a closed space all water vapor sources have to be taken into account: occupants, water surfaces, plants, cooking, washing, drying, etc. In this case, the required ventilation rate can be determined as the ratio between the water vapor load of the closed space and the difference between the absolute humidity of the indoor air and absolute humidity of supply-air.

The established ventilation rate is the basic information in the design of mechanical ventilation systems. All the elements (ducts, fans, filters, humidifiers, heat exchangers, air terminal devices, etc.) are chosen, based on the ventilation rate. Thus, the design value of the ventilation rate demand influences both the investment and operational costs of the ventilation system.

In the following a case study will be presented illustrating the effects of the ventilation rate demand calculation, in case of a building refurbishment.

III. Case study

The analyzed building is a two levels furniture store built in 1996, having a net floor area of 751 m^2 in total. The external walls were built from brick with vertical holes, the floor is laid directly on the ground and the attic is unheated. The second floor is on the mansard. The windows and roof windows are double glazed, with an overall heat transfer coefficient of 3.0 $W/m^2 \cdot K$. The overall heat transfer coefficient of the entrance door is 3.5 $W/m^2 \cdot K$, of external walls 0.84 $W/m^2 \cdot K$, 0.294 $W/m^2 \cdot K$ of the mansard roof and of the floor is 0.334 $W/m^2 \cdot K$. In the building there is no mechanical ventilation system. The heat demand for ventilation was calculated for and air change rate of 0.8 h^{-1}. At −15 °C external design temperature, the heat demand of the building is 42481 W (Table I.).

Table I.
Heat Demand of the analyzed building

Room	Net floor area, [m^2]	Indoor air temperature, [°C]	Heat demand, [W]
Exhibition room 1.	319.3	20	18610
Lobby	12.37	17	1569
Office	11.31	22	1650
Boiler room	5.22	16	376
Staircase	17.66	18	3119
Toilet	1.2	16	–48
Store-room	12.37	16	1160
WC	1.73	16	138
Exhibition room 2.	345.1	20	14538
Exhibition room 3.	12.37	20	711
Dressing room	12.37	19	658

The assumed air change rate practically represents a ventilation rate of about 1502 m^3/h. This amount of fresh air would be enough for about 38 persons being at the same time in the building (assuming 40 $m^3/h \cdot person$ the fresh air demand). Practice has shown that simultaneously max. 20 persons are usually in the analyzed building.

According to the Building Energy Performance Regulation in force, if the analyzed building would be refurbished and the refurbishment would be partially supported by the State, the requirements related to the overall heat transfer coefficients of the refurbished envelope are: 0.24 $W/m^2 \cdot K$ (external wall); 0.3 $W/m^2 \cdot K$ (floor); 1.15 $W/m^2 \cdot K$ (windows); 1.45 $W/m^2 \cdot K$ (entrance door); 0.17 $W/m^2 \cdot K$ (mansard roof), 1.25 $W/m^2 \cdot K$ (roof windows) [16]. For external walls graphite-enhanced expanded polystyrene was used as additional thermal insulation (9 cm) and at the roof 10 cm thick PUR foam boards. Along the basement 9 cm extruded polystyrene was assumed.

The new overall heat transfer coefficient values of the building elements are shown in Table II.

Table II.
Overall heat transfer coefficients of refurbished building envelope

Building element	Original U value, [W/ $m^2 \cdot K$]	New U value, [W/ $m^2 \cdot K$]
External wall	0.840	0.234
Floor	0.334	0.217
Roof	0.294	0.161
Windows	3.0	1.0
Roof windows	3.0	1.2
Entrance door	3.0	1.31

Using the new heat transfer coefficient values and keeping the original air change rate, the new heat demand values were calculated (Table III.).

Table III.
Heat Demand of the refurbished building

Room	Heat demand, [W]	Reduction of heat demand, [%]
Exhibition room 1.	12114	34.9
Lobby	783	50.1
Office	818	50.4
Boiler room	152	59.6
Staircase	1697	45.6
Toilet	–48	0
Store-room	607	47.7
WC	38	72.5
Exhibition room 2.	11494	20.9
Exhibition room 3.	436	38.7
Dressing room	438	33.4

After thermal refurbishment of the building envelope the total heat demand decreased to 28529 W. This means a reduction with 32.8% of the heat demand. However, after refurbishment was assumed the same air change rate.

Let us see, what will happen with the heat demand of the building, if mechanical ventilation would be installed after refurbishment.

According to EN 15251:2007 (department store, II. category), the 7 m^2/person should be taken into account. This means practically 107 persons in the store! The ventilation rate demand, calculated based on the floor area $\dot{V}_{tot}$ will be 2.9 $m^3/h \cdot m^2$ (2178 m^3/h).

The pollution load in the building is approximately 338 olf. Assuming the desired indoor air quality 1.4 decipol; and the perceived outdoor air quality at air intake, 0.1 decipol, the ventilation rate demand will be 9692.3 m^3/h. The ventilation effectiveness was considered 0.9.

According to the Hungarian Regulation, the specific flow rate might be considered 40 $m^3/h \cdot person$, which means 4280 m^3/h (even with 107 persons in the store).

Certainly, when the ventilation system is designed, the highest ventilation rate demand has to be taken into account. This means an air change rate value after refurbishment of 5.16 h^{-1}. Naturally, the ventilation system operating time is not the whole day (open hours are between 9:00 am and 17 pm). However, in the period when the store is closed an air change rate of 0.3 h^{-1} should be take into account (considering high air tightness of the refurbished building). Assuming that in the mechanical ventilation system a heat exchanger is built-in with a mean heat recovery efficiency 0.73, the heat demand of the refurbished building was recalculated. The new values are shown in Table IV.

TABLE IV.
HEAT DEMAND OF THE REFURBISHED BUILDING, CALCULATING THE VENTILATION RATE DEMAND BASED ON IAQ

ROOM	HEAT DEMAND, [W]
EXHIBITION ROOM 1.	18629
LOBBY	1015
OFFICE	1063
BOILER ROOM	273
STAIRCASE	2405
TOILET	–26
STORE-ROOM	832
WC	69
EXHIBITION ROOM 2.	18168
EXHIBITION ROOM 3.	637
DRESSING ROOM	670

As it could be observed, the heat demand of some rooms increased, even though heat recuperator was taken into account.

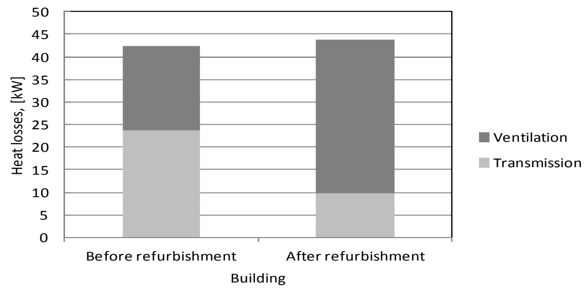

Figure 1. Heat losses of the analyzed building

IV. CONCLUSIONS

Nowadays energy saving is one of the most important priority in the building sector. Existing building stock is the biggest energy consumer in most European countries.

It is obvious that existing buildings should be refurbished from energy pint of view. However, should not be forgotten that, not only the energy requirements became stricter, but also the comfort requirements increased. Buildings are built to assure healthy and comfortable environment to the occupants.

Usually, after a deep refurbishment of the building envelope, important energy savings are expected. Nevertheless, requirements related especially to the fresh air flow rate may lead to an increase of the ventilation heat losses and the expected energy savings will not be met. It was proved that, without properly designed ventilation system CO_2 concentration can increase considerably in closed spaces, [16, 17, 18]. Consequently, controlled mechanical ventilation has to be installed in case of building refurbishments to avoid health related complains.

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