Indoor climate and Energy efficiency of apartment and educational buildings in Estonia

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Abstract: The years 1960-1990 saw an extensive construction of apartment buildings in Estonia. In 1970s the specific heat consumption of apartment buildings made up about 350 kWh/m² per year. The 1990s saw the beginning of the renovation of heat substations, heating and ventilation systems and building envelopes. The renovation of windows in old apartment buildings was accompanied by problems in the indoor climate. The problem of indoor climate seriously concerns schoolhouses without mechanical ventilation and partly renovated old apartment buildings. Characterised is the influence of the new domestic hot water (DHW) calculation method on the determination on the equipment of heat substations and district heating network. The increase of energy efficiency of buildings by heat recovery of heat of exhaust air by heat pump is analyzed. In old apartment buildings one of the possible solutions is the air change arrangement by room heat recovery units and programmable exhaust ventilators in toilets, bathrooms and kitchens.

Key-Words: Indoor climate, Apartment buildings, Schoolhouses, CO₂ concentration, DHW flow rates, Energy efficiency, Ventilation systems, Renovation.

1 Introduction
Typical of Estonia in the years 1951-1991 were low prices of heat energy and fuels and public utility services. The years 1960-1990 saw an extensive construction of apartment buildings. For example in Tallinn (the capital of Estonia) new residential areas were built to house about 250 thousands inhabitants. Such extensive construction activities could be carried out due to the low prices of building materials and on the basis of possibly simple solutions in heat supply and ventilation. Extensive use was made of district heating.

In the years 1960-1990 the U-values of building envelope elements were the following:
External walls - 1.0 W/(m² □ K)
Roof-ceilings – 0.9
Windows – 2.9

Ventilation in apartment buildings was as a rule natural, Fig 1.

Fig.1. Natural ventilation of apartment buildings

The Fig.1 shows two different solutions to natural ventilation: the one on the left for typical 5-storey apartment buildings and the one on the right for typical 9-storey apartment buildings. The ventilation operates due to the difference in air density indoors and outdoors. Additional influence is exercised by the height of ventilation channels and the strength of the wind.
Most of the educational buildings had mechanical supply and exhaust ventilation systems, but due to the absence of heat recovery units the operative costs were so high that they were not switched on. Additional problems were noise and automatic control of systems.

During the extensive construction period predominating in heating the apartment buildings were one-pipe systems. The advantage of the one-pipe system is the fact that without the up-to-date radiator valves it is possible to secure the stability of the functioning of the systems. The latter was the precondition in using a simple connection mode (for example, the jet pump connection mode) to connect the heating systems to the district heating network.

In the 1970s and the 1980s the DHW consumption in residential buildings was 95 l per day per person. That was confirmed by the investigations carried out both in Estonia and in the Soviet Union [1, 2]. In that period the specific heat consumption of apartment buildings made up about 350 kWh/m² per year (i.e. per heated area of the apartments), including the DHW heating which is 140 kWh/m² per year.

At the beginning of the 1990s the first steps were taken in renovating district heating systems. First heat substations were renovated. That made it possible to prevent overheating at higher outdoor temperatures.

At that time the indoor temperature was lowered to a certain extent. The inhabitants responded to that by sealing or replacing the windows. This due to a decrease an air change was accompanied by problems of air quality in apartments. The measures mentioned together with a considerable decrease in DHW consumption of apartment buildings to about 275 kWh/m² in 1997 [3].

The 1990s saw an extensive renovation of DHW systems: the piping was renovated, the circulation system was balanced and made to work, water meters were installed in apartments and the inhabitants had to pay for the water they had consumed. Renovated were also water outlets in apartments. At the same time there was a constant rise in the prices of water and heat. The impact of these measures is reflected in a change in water consumption, Fig.2.

The Fig.2 characterizes the DHW consumption in different periods of time: 6.6 l/per m² per day in 1974 and 2 l/per m² per day in 2004.

Fig.2. DHW consumption in apartment buildings in 1974 and 2004.

Special problems arose in educational buildings with old mechanical ventilation systems. Owing to noise nonhermeticity and control problems and the absence of heat recovery units the old systems had usually been switched off and new ones had not been installed yet.

The energy efficiency of apartment buildings have been investigated by many researchers [4,5].

2 Problem
2.1 Indoor climate investigation

This problem of indoor climate seriously concerns schoolhouses and other children’s institutions. In Fig.3 we can see that in the schoolhouses with natural ventilation sometimes at the end of the class the CO₂ level rises up to more than 3000 ppm and surpasses 3 times the one permitted. Fig.3 shows the CO₂ concentration in the classroom during a class in different schools.

The Fig.3 characterizes the CO₂ concentration in the classroom during a class in different schools.
Air change in room with natural ventilation we can calculate by equation (2.1) [7]

\[
\frac{L}{V} \cdot \tau = -\ln \left( \frac{m}{L} + \frac{C_v - C}{m} \right) 
\]

(2.1)

where

- \(m\) - carbon dioxide generation in room,
- \(L\) - air change in room,
- \(V\) - volume of room or design volume,
- \(C_v\) - carbon dioxide concentration in external air (in supply air),
- \(C\) - carbon dioxide concentration in room air (in exhaust air),
- \(C_o\) - carbon dioxide concentration in the air of the room at the beginning of the human activity,
- \(\tau\) - time.

In investigated schools without mechanical ventilation the air change in classes was from 0.7 to 2.6 L/s per pupil.

By now a large number of old windows have been exchanged in old apartment buildings for modern ones which are essentially more hermetic, for example in Tallinn about two thirds have been exchanged. This has resulted in the heat resistance of the windows having increased by about one third. At the same time the installation of new windows made the air change in apartment buildings with natural ventilation to decrease by about three times, resulting in serious disorders in the indoor climate.

In apartment buildings where the envelope and the heating system have been renovated, but the ventilation has not been changed, one can see that the permitted level of carbon dioxide has been surpassed about three times and that of the relative humidity about two times, Fig.4 and 5.

Such a situation is often accompanied by the rise of mold.

Fig.4. CO₂ concentration level in the bedroom with one or two people sleeping in it respectively

Fig.5. Relative humidity level in bedrooms of renovated 60-apartment building in the winter of 2009.

3 Problem Solutions

Envelope elements of old apartment buildings have been more and more actively renovated. Unfortunately quite often only part of the envelope elements have been renovated, while the heating systems have not been provided with a control system on the heating coils, so the conservation of energy has remained much smaller than it was expected. In case the envelopes and the heating systems have been completely renovated an energy conservation of 45% has been obtained. As the ventilation systems have remained unrenovated, a remarkable part of the energy conservation has been achieved at the expense of a decrease in air change that is at the expense of the deterioration of the indoor climate. Recent years have seen a more extensive renovation of heating systems. Existing heating systems have been reconstructed turning them into 2-pipe systems likewise in 1-pipe systems.
the heating coils have been provided with a control system.

As to the heat substations of the district heating system we can say basically the have been renovated. New apartment buildings predominantly use mechanical exhaust ventilation, Fig.6, which guarantees good indoor climate in apartments. Due to the absence of heat recovery units the costs of heating the air in such buildings are equal or even surpass those of the heat losses of the envelope. The solution to the problem is by heat recovery of heat of exhaust air by heat pump.

In old apartment buildings one of the possible solutions is the air change arrangement by room heat recovery units and programmable exhaust ventilators in toilets, bathrooms and kitchens.

Renovated educational buildings use supply-exhaust ventilation systems that solve the indoor climate problems.

In resent years investigations into DHW consumption and the variability of the consumption have been carried out by TUT in residential, educational and office buildings. Worked out on the basis of actual consumption have been new formulas for determining the designed flow rates of DHW which considerably differ from the ones used till today. The difference between the old and the new methods is so big that the new method makes it possible to considerably affect even the dimensioning of the district heating network. The new method of calculating the DHW load and taking into account the probability of the hot water consumption in dimensioning the pipe diameters of different segments give an essential reduction in investments for the district heating network up to 28%. At the same time the decrease in the operating costs is 8%.

The positive influence on energy efficiency of buildings is affected by
- Working out methods for energy auditing and certification of buildings;
- Training more than one hundred energy auditors;
- Preparation of the new international master’s degree curriculum “Energy efficiency of buildings”;
- Creating of the Indoor climate and energy laboratory;
- Working out solutions for energy efficiency renovation of buildings

conducted at TUT.

4 Conclusions

The renovation of ventilation system and good maintenance makes it possible to solve air quality problems and increase energy efficiency in apartments and educational buildings.

It is imperative for solving the air quality and energy efficiency questions in apartments and educational buildings to have close cooperation between universities and companies.

References: