Energy efficiency and Indoor climate 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/m^2 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 educational buildings without mechanical ventilation and partly renovated old apartment buildings. With the help of simulation programs energy conservation achievable with renovation has been analysed in apartment buildings as well as in educational 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, CO_2 concentration, Apartment buildings, Educational buildings, 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 (DH).
Heating systems were connected to DH network by simple jet pump connection mode, Fig.1.

Jet pump works both as a mixing device and as a pump, the difference in the pressure in the DH network necessary for functioning is usually 20 m of water column.

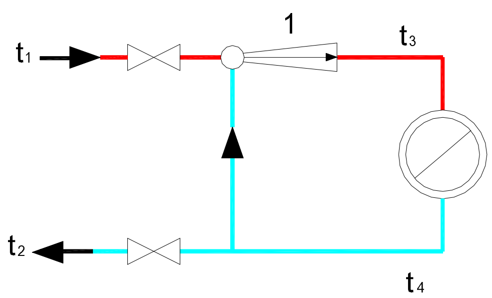

Fig.1 Heat substation that is based on the heating system connected to DH network by jet pump
1 – jet pump; t_1- flow pipe of DH network; t_2- return pipe of DH network; t_3- flow pipe of heating system; t_4- return pipe of heating system.

In the years 1960-1990 the U-values of building envelope elements were the following:
External walls - 1.0 W/(m^2□K)
Roof-ceilings – 0.9
Windows – 2.9

Ventilation in apartment buildings was as a rule natural, Fig.2.

The Fig.2 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.

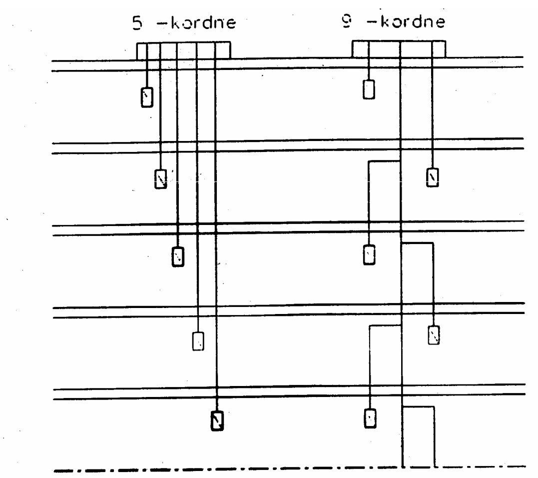

Fig.2. Natural ventilation of apartment buildings

To improve air change in upper apartments ventilators were used in WCs, bathrooms and kitchens.

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, Fig.3

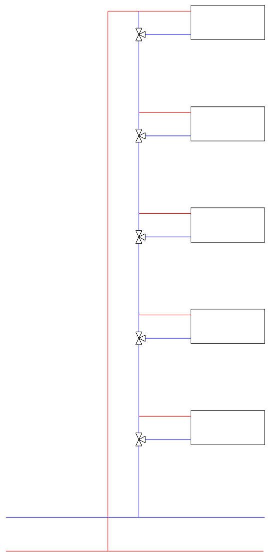

Fig.3. One-pipe heating system with radiator valves

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 heating systems.

The latter was the precondition in using a simple connection mode (for example, the jet pump connection mode, Fig.1) to connect the heating systems to the district heating network.

At the beginning of the 1990s the first steps were taken in renovating district heating systems. First heat substations were renovated.

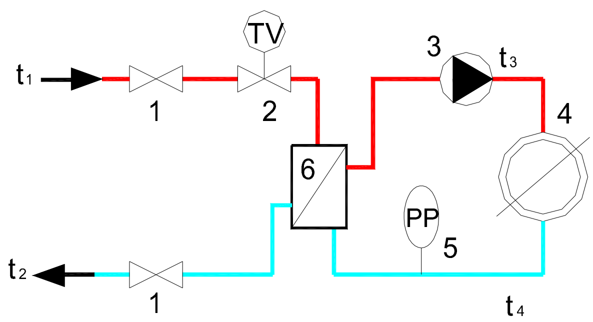

Fig.4. Heat substation that is based on the heating system connected to DH network by heat exchanger: 1 – valve; 2 – control valve with actuator; 3 – circulation pump; 4 – heating system; 5– expansion vessel; 6 – heat exchanger

That made it possible to prevent overheating at higher outdoor temperatures, if the temperature in the flow pipe is constant, Fig.5.

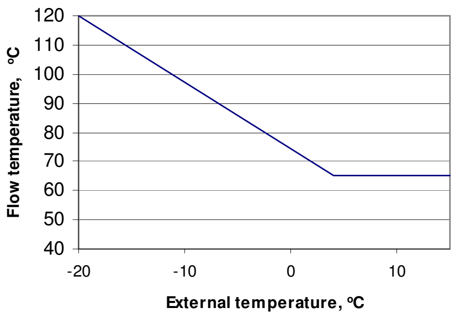

Fig.5. Temperature graph in flow pipes of district heating network

At that time the indoor temperature was lowered to a certain extent in apartment buildings. 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.

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/m^2 per year.

The measures mentioned together with a considerable decrease in DHW consumption lowered the specific heat consumption of apartment buildings to about 275 kWh/m^2 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.6.

The Fig.6 characterizes the DHW consumption in different periods of time: 6.6 l/per m^2 per day in 1974 and 2 l/per m^2 per day in 2004.

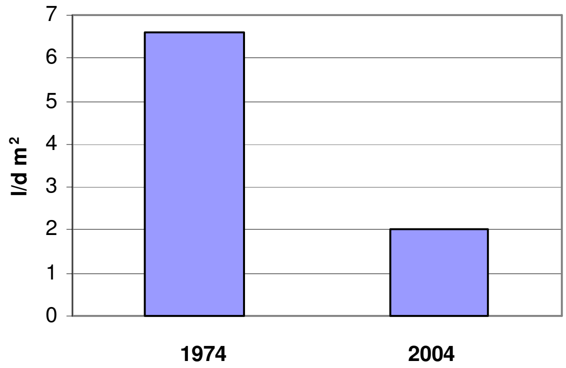

Fig.6. DHW consumption in apartment buildings in 1974 and 2004.

Further investigations showed a continuing decrease in DHW consumption, Fig.7.

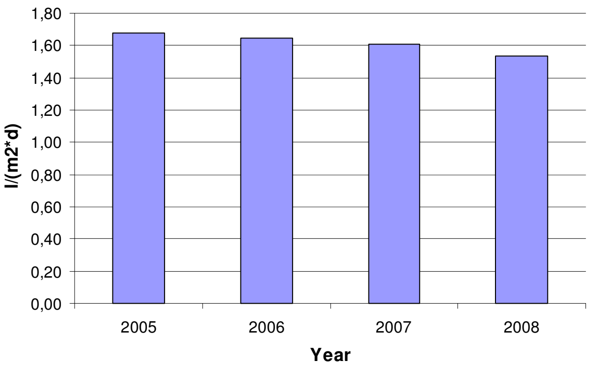

Fig.7. DHW consumption in apartment buildings of Estonia in 2005-2008.

Problems of energy conservation and indoor climate in residential and educational buildings and the importance of both of them have been dealt with by many authors such as Ken-ichi Kimura [4], Walker [5], Jalas [7], Daisey [8], Koiv [9], [10], Tali [11], Stavova [15], and sources such as Schools [6], Energy [12], Energy-Efficient [13].

The energy efficiency of apartment buildings have been investigated by many researchers [4, 5, 11, 18].

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.

2 Problem

2.1 Indoor climate investigation in educational buildings

This problem of indoor climate seriously concerns schoolhouses and other children's institutions. In Fig.8 we can see that in the schoolhouses with natural ventilation sometimes at the end of the class the CO_2 level rises up to more than 3000 ppm and surpasses 3 times the one permitted. Fig.8 shows the CO_2 concentration in the classroom during a class in different schools.

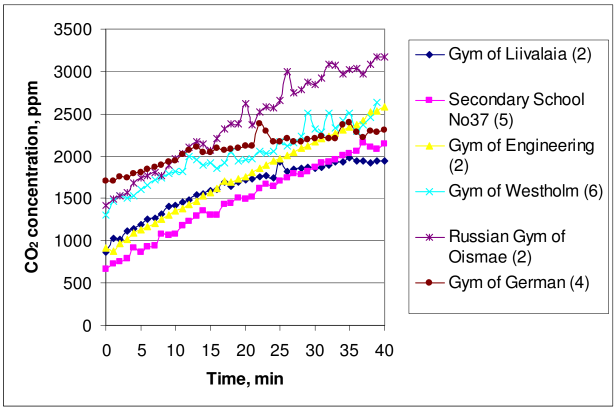

Fig.8 CO_2 concentration in the classroom during a class in different schools

Air change in room with natural ventilation we can calculate by equation (2.1) [14]

$$\frac{L}{V}\cdot\tau=-\ln\frac{\frac{m}{L}+C_v-C}{\frac{m}{L}+C_v-C_o} \qquad (2.1)$$

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,
τ - time.

In investigated schools without mechanical ventilation the air change in classes was from 0.7 to 2.6 L/s per pupil.
The rise in indoor temperature was considerable, from 18 to 24°C, Fig.9.

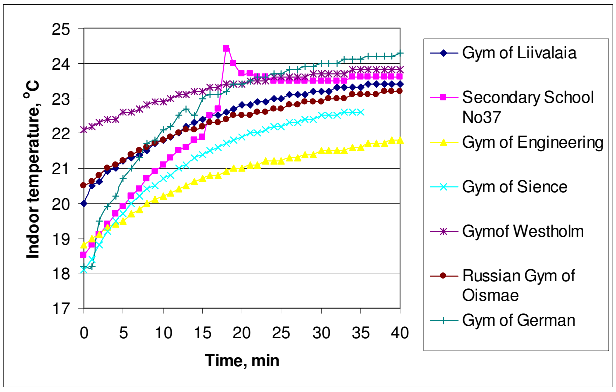

Fig.9. Dynamics of the indoor temperature in classroom with natural ventilation

External air parameters were: temperature approximately 2°C, relative humidity 55% and carbon dioxide concentration 370 ppm.
Relative humidity in classrooms with natural ventilation is presented in tFig.10.

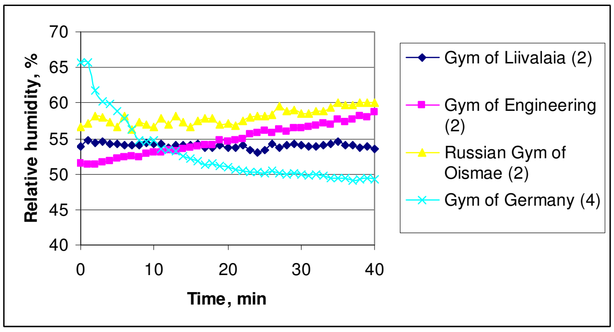

Fig.10. Relative humidity in classrooms with natural ventilation

In schoolhouses with balanced ventilation the level of carbon dioxide in classrooms is on a satisfactory level, Fig.11.

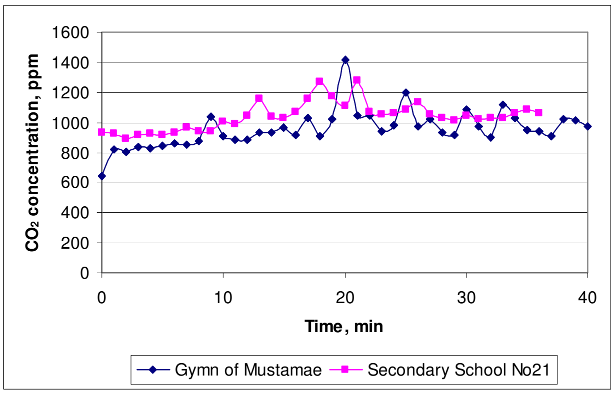

Fig.11. Change in the carbon dioxide concentration in classrooms with balanced ventilation

Fig.12 presents indoor temperature dynamics in the classroom with balanced ventilation during a class

The level of the indoor temperature in classrooms with balanced ventilation is either on a good (21 Secondary School) or satisfactory level (Gymnasium of Mustamae).

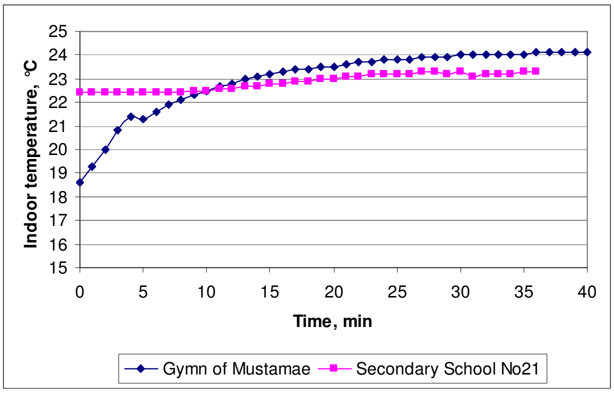

Fig.12 Indoor temperature dynamics in the classroom with balanced ventilation during a class

2.2 Residential buildings

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 up to about three times and that of the relative humidity about two times, Fig.13 and 14.

Fig.13. Carbon dioxide concentration level in the bedroom with one or two people sleeping in it respectively

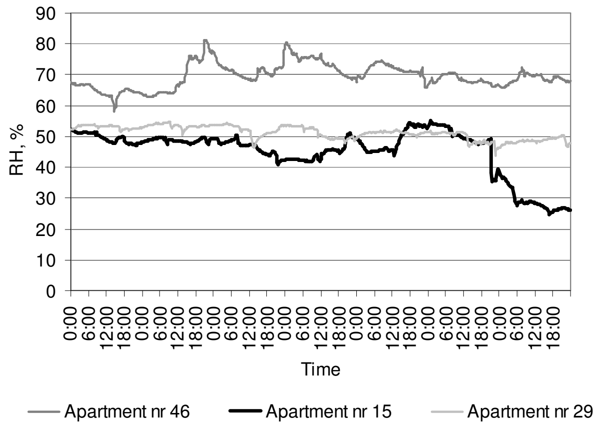

Fig.14. Relative humidity level in bedrooms of renovated 60-apartment building in the winter of 2009.

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

Extensive indoor climate investigation in a nine-storey apartment building showed a generally high carbon dioxide level in bedrooms, Fig.15. External temperature was from -3 to +9°C [19].

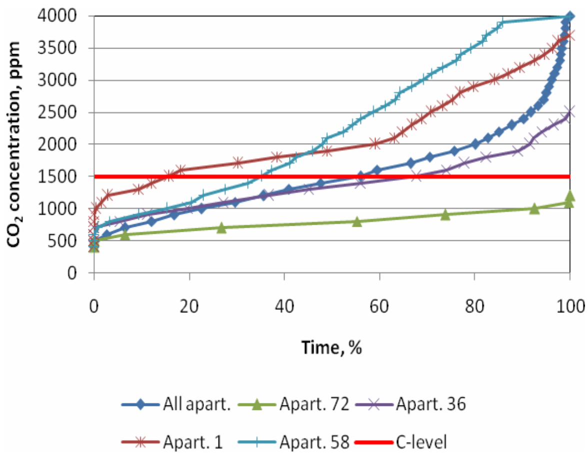

Fig.15. Cumulative graph of carbon dioxide level in bedrooms of 9-storey apartment building

2.3 Energy consumption in old apartment buildings

Table 1 characterizes energy consumption for heating in unrenovated old buildings in an average year (e.g. 1990).

Table 1 Energy consumption for heating in old unrenovated apartment buildings, kindergartens and schoolhouses (Tallinn and Tartu, Estonia)

Type of building	Address	Heat energy consumption kWh/m^2 per year
Apartment building	Angerja 11	201
Apartment building	Sutiste 35	202
Apartment building	Akadeemia 7A	179
Apartment building	Kuldnoka 8	208
Apartment building	Karberi 13	211
Apartment building	Oismae 79	201
Apartment building (Tartu)	Anne 89	197
Apartment building (Tartu)	Moisavahe 43	193
Apartment building (Tartu)	Kalda tee 18	191
Kindergarten	Liivaku	252
School	Liivalaia	162*

*Comfortable indoor climate both in indoor temperature and air change is not guaranteed in the schoolhouse.

3 Problem Solutions

3.1 Renovation of the envelope elements and heating-ventilation systems

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 valves 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. Resent 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 valve, Fig.16.

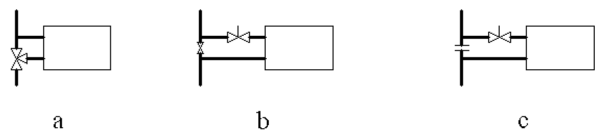

Fig. 16. Connection modes of the heating coils of the 1-pipe controlled system: a)- with a 3-tee valve; b)- with a 2-tee valve and with an adjusting valve on a bypass; c) - with a 2-tee valve and with a throttle on a bypass.

As to the heat substations of the district heating system we can say basically they have been renovated.

New apartment buildings predominantly use mechanical exhaust ventilation, Fig.17, 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. One of the solutions 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, Fig.18.

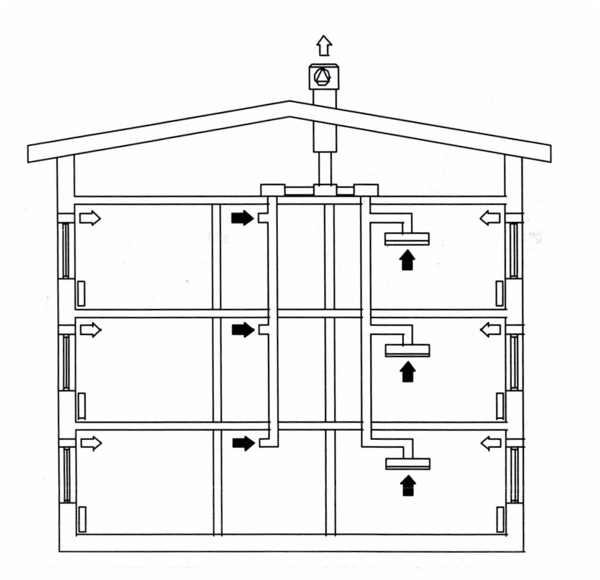

Fig.17. Mechanical exhaust ventilation in new apartment buildings

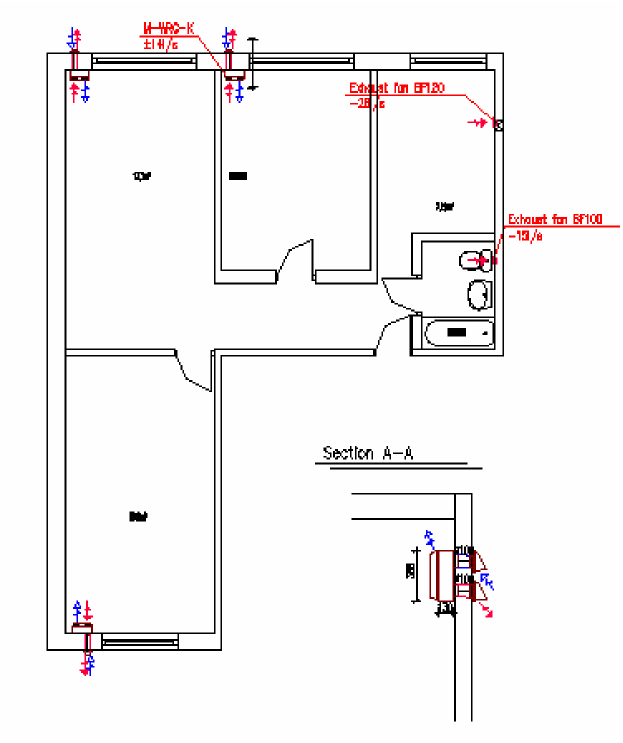

Fig.18 The air change arrangement by room heat recovery units (3) and programmable exhaust ventilators in toilets and bathrooms

Table 2 Parameters of the envelope elements and energy consumption of the Liivalaia schoolhouse

	A	B
U-value, W/(m^{2}K)		
External wall	0.91	0.28
Roof-ceiling	0.70	0.22
Floor	0.35	0.35
Window	2.9	1.4
Total energy consumption for heating, kWh/m2	162	109

A – unrenovated building, natural ventilation. Comfortable indoor climate in indoor temperature and the required air change in the schoolhouse are not guaranteed.
B – the building has been insulated and the windows changed, balanced ventilation with heat recovery installed.

Renovated educational buildings have balanced ventilation systems that solve the indoor climate problems.

3.2 Energy consumption by simulation

By renovating the envelope elements and the ventilation systems in educational buildings (schoolhouses and kindergartens) it is possible to reduce considerably the energy consumption and improve the indoor climate.
Energy consumption simulations carried out with software IDA ICE show the possibilities of diminishing the energy consumption of the existing buildings. Table 2 presents the parameters of the envelope elements of the schoolhouse and the specific energy consumption in renovated and unrenovated schoolhouses. Table 3 shows the parameters of the envelope elements and the key-numbers of the specific consumption of heat energy and electricity of a kindergarten.
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Table 3 Parameters of the envelope elements and the specific energy consumption of the Liivaku kindergarten

	A	T	B
U-value, W/(m^{2}K)			
External wall	0,96	0,25	0,25
Roof-ceiling	0,89	0,64	0,64
Floor	0,45	0,45	0,45
Window: glass/frame	2,6 /2,6	1,4 / 1,7	1,4 / 1,7
SHGC/T	0,75/0,69	0,64/0,54	0,64/0,54
Air flow rate for kitchen l/(s·m^2)	10	10	10
Air change 1/h	0,32	0,5	2
Total energy requirement, * kWh/m2	252	207	186
Electrisity, kWh/m2	44.8	44.8	60.6

* DHW consumption included.

A – unrenovated building, natural ventilation;
T – the building has been insulated and the windows changed, natural ventilation; air change is quaranteed by opening the windows.
B – the building has been insulated and the windows changed , balanced ventilation with heat recovery. The ratio of the temperature of the heat recovery unit is 0.8 and the temperature of the supply flow is +17°C.

Fig.18 presents the consumption of heat energy and electricity in the Liivaku kindergarten.

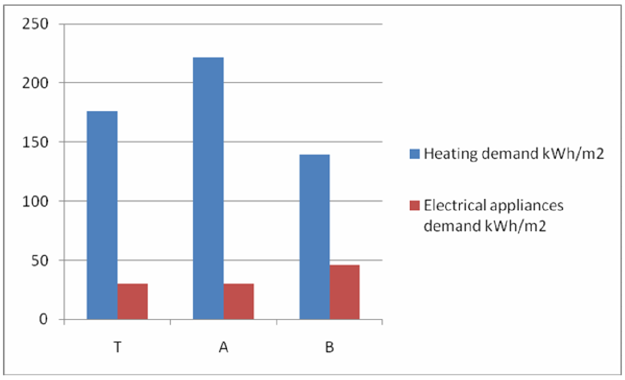

Fig.18. Heat energy and electricity consumption in the Liivaku kindergarten

Table 4 Parameters of the envelope elements and specific energy consumption of the old apartment building.
Heated area 4534 m^2, 72 apartments.

	A	B
U-value, W/(m^{2}K)		
External wall	1.2	0.26
Roof-ceiling	1.0	0.22
Floor	1.37	1.37
Window: glass/frame	2. /2.0	1.6 /2.0
SHGC/T	0.75/0.69	0.5/0.38
Air change 1/h	0.45	0.5
Total energy requirement, * kWh/m2	222	130
Electricity, kWh/m^2	20.0	20.5

* Included DHW 31 kWh/m^2.

A **-** unrenovated building, natural ventilation;
B - the building has been insulated and the windiws changed**,** balanced ventilation with heat recovery. The ratio of the temperature of the heat recovery unit is 0,6. The heating system of the building has been renovated**.**

Table 5 Parameters of the envelope elements and specific energy consumption of the new apartment building.
Heated area 6682 m^2, 84 apartments

	A	B
U-value, $W/(m^2K)$		
External wall	0.27	0.27
Roof-ceiling	0.24	0.24
Floor	0.6	0.6
Window: glass/frame	1.9 /2.0	1.9 /2.0
SHGC/T	0.52/0.40	0.52/0.40
Air change 1/h	0.55	0.55
Total energy requirement, * kWh/m^2	151	111
Electricity, kWh/m^2	32	40

*Included DHW 21 kWh/m^2.

A - the new building, mechanical exhaust ventilation;
B - balanced ventilation with heat recovery.

Table 4 shows that by renovating the envelope elements and the heating system of the old apartment building and by supplying the ventilation system with a heat recovery unit it is possible to save energy consumption by about 50%.
The basic problem of new apartment buildings is the fact that they have a mechanical exhaust ventilation system that wastes energy, Table 5. By renovating the ventilation and applying heat recovery it is possible to save 30% of energy consumption.

3.3 Improvement of DHW system

In resent years research into DHW consumption and the variability of the consumption has 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 design flow rates of DHW which considerably differ from the ones used till today [16].

Presented below is an empirical formula (1) for determining the heating load of DHW instantaneous heat exchangers if the difference of the temperatures of hot and cold water is 50°C.

$$\Phi_{sv} = 30 + 15 \cdot \sqrt{2 \cdot n} + 0.2 \cdot n \quad \text{kW} \qquad (1)$$

where n is the number of apartments.

The design loads of heating DHW in the heat exchangers determined by formula (1) differ in apartment buildings up to two times from the ones determined by EVS standard.

A new empirical formula is recommended for determining the design flow rates on the basis of which the water heating devices can be selected for schools without a swimming-pool (2)

$$q = 0.04\, N_1 + 0.00053\, N_2 + 0.0036\, N_3 \qquad (2)$$

where q is design flow rate l/sec; N_1 is number of showers; N_2 number of students, N_3 number of DHW outlets.

The design flow rates determined by the calculation formula (2) are 1.1…1.2 times smaller than those calculated by the EVS standard.

As the design flow rates determined by the EVS standard for kindergartens are 1.4…4 times bigger than the measured ones, a new empirical formula is recommended for determining them in selecting water heating devices (3)

$$q = 0.0009\, N_1 + 0.0035\, N_2 + 0.0025\, N_3 \qquad (3)$$

where q is design flow rate l/sec; N_1 is number of showers; N_2 number of children; N_3 number of DHW outlets.

It can be seen that the design flow rates determined by calculation formula (3) are 1.1…2.1 times smaller than those calculated by the EVS standard.

The difference in the flow rates calculated by the old and the new methods is so big that it effects the dimensioning of the pipes of the district heating network.The new method of calculating the DHW load together with the consideration of 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% [17].

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..

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4 Conclusions

Investigations carried out show that old educational buildings with natural ventilation have serious problems with indoor climate. For example, at the end of a class the carbon dioxide level in the classrooms of many schools amounts to 3000 ppm. Even more serious are the problems of indoor climate in old apartment buildings, where the carbon dioxide level in bedrooms amounts to 3500 ppm and the relative humidity up to 60-80%. Because of high thermal conductivity of the envelope elements we can often observe the existence of mold. The renovation of the envelope elements and the heating and ventilation systems of old apartment buildings makes it possible to save energy consumption about 50% and to improve the quality of indoor air.
In new apartment buildings the possible energy conservation that can be achieved by renovating the ventilation system is about one third.
In old educational buildings the renovation of the envelope elements together with a control of heating coils and the renovation of ventilation make it possible to save about 30% of energy.

The renovation of the ventilation system and a good maintenance make it possible to solve air quality problems and the same time increase energy efficiency in residential and educational buildings.

To solve the air quality and energy efficiency questions in apartments and educational buildings it is imperative to establish a close cooperation between research institutions and companies.

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