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).

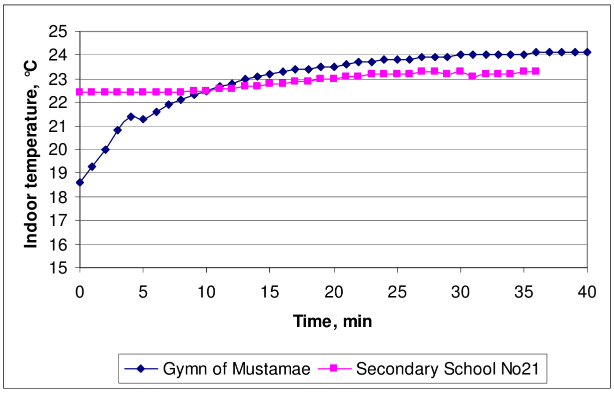

Fig.12 Indoor temperature dynamics in the classroom with balanced ventilation during a class

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

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

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.

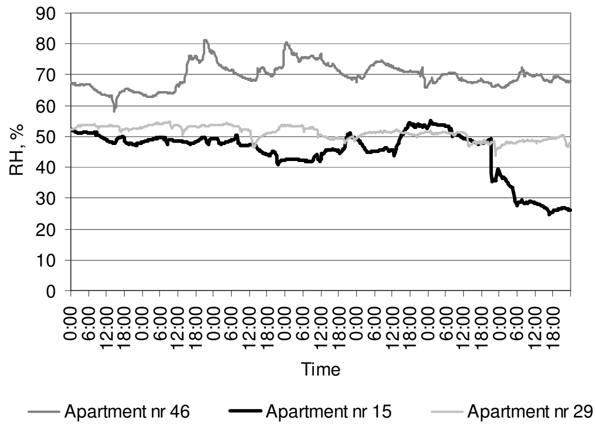

Fig.14. Relative humidity level in bedrooms of renovated 60-apartment building in the winter of 2009.

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].

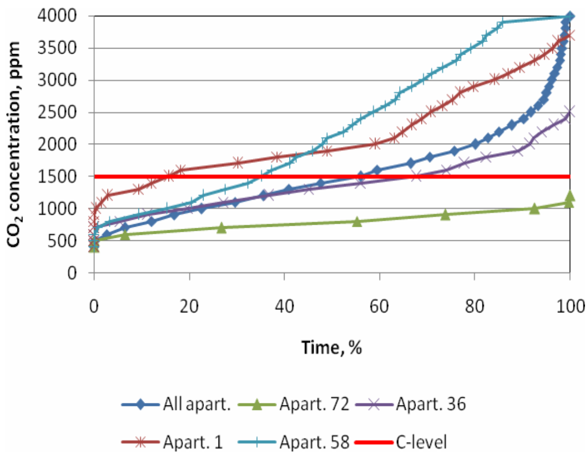

Fig.15. Cumulative graph of carbon dioxide level in bedrooms of 9-storey apartment building

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.

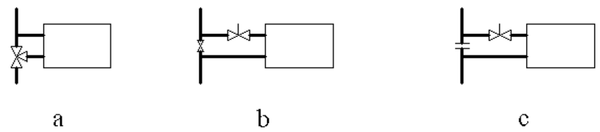

Fig. 16. Connection modes of the heating coils of the 1-pipe controlled system: a)- with a 3-tee valve; b)- with a 2-tee valve and with an adjusting valve on a bypass; c) - with a 2-tee valve and with a throttle on a bypass.

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.

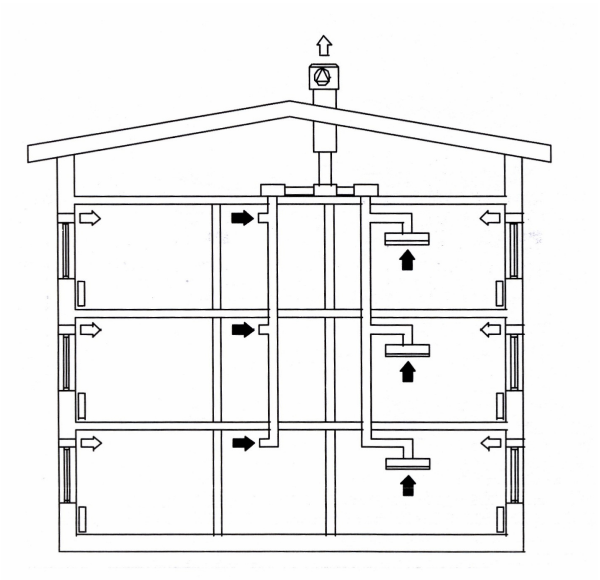

Fig.17. Mechanical exhaust ventilation in new apartment buildings

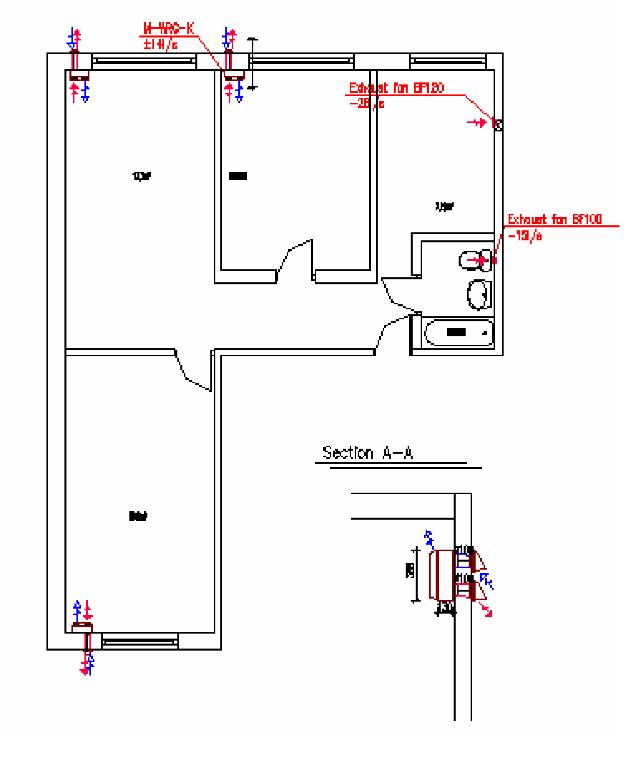

Fig.18 The air change arrangement by room heat recovery units (3) and programmable exhaust ventilators in toilets and bathrooms

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^2K)			
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.

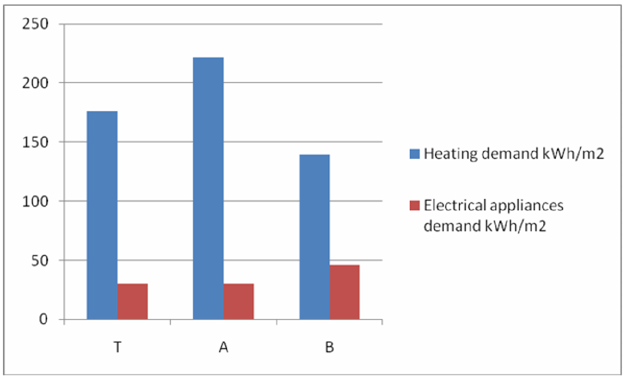

Fig.18. Heat energy and electricity consumption in the Liivaku kindergarten

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^2K)		
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)

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

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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