Indoor Climate and Energy Performance in Typical Concrete Large-panel Apartment Buildings

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1. Introduction

Energy consumption in buildings is between 20% - 40% of final energy (USA: 40%, EU: 37%, World: 24%), which is bigger than that in industry and transport. To improve energy efficiency, the EU Heads of State and Government has set a series of demanding climate and energy targets that must be met by the year 2020, known as the "20-20-20" targets: to reduce greenhouse gas emissions in the EU at least 20% below the 1990 levels, to produce 20% of the energy in the EU from renewable resources and to reduce primary energy use by 20% when compared with projected levels. The housing stock consists mainly of still existing old dwellings which strongly influence the energy performance of buildings. To improve energy performance the buildings need extensive renovation. Before the renovation process, it is necessary to obtain information about the current situation, i.e. about the indoor climate and the energy use. It should be emphasized that energy consumption in apartment buildings is closely connected with indoor climate.

The dwelling stock in Estonia is relatively adequate in size; however, the main problems concern quality and energy-efficiency in the dwellings. 71% of the population In Estonia occupy apartment buildings, the remaining population lives in detached or terraced houses (20%) and in farmhouses (9%). The majority (84%) of apartment buildings were erected after World War II, primarily between 1961-1990. One of the main types of building during that period was prefabricated concrete large-panel building, Fig. 1.

The thermal properties of the building envelope of these typical apartment buildings are modest

- Thermal transmittances
  - External wall 0.5…1.3 W/(m² · K)
  - Window3.0 W/(m² · K)
  - Roof 0.7…1.1 W/(m² · K)
- Air tightness of the building envelope: n_{50}: 6.1 h^{-1}, q_{50} 4.2 m^3/(h · m^2)

The actual indoor temperature and humidity conditions are important data for assessing indoor climate and thermal comfort as well as energy consumption. To guarantee thermal comfort indoors, both the heating and the ventilation systems and the building envelope play a considerable role. In winter, continuous heating systems should keep the temperature according to the set point of thermostats. In old multi-storey prefabricated apartment

Fig. 1. Examples of typical apartment buildings composed of prefabricated concrete elements (left: type 1-464A-15, right: type 1-464 Д-84)

buildings, radiators are typically without thermostats and the system is typically equipped with standpipe valves. The one-pipe heat distribution system is typical of old multi-storey prefabricated apartment buildings. If the one-pipe system is properly installed and balanced, it can work satisfactorily. If improper modifications have been made and as the balancing of the heating system is complicated, the stability and the temperature level may cause problems during the heating season.

Air tightness of the building helps to avoid uncontrolled airflows through the building envelope. This can lead to problems related to the hygrothermal performance of the building envelope, energy consumption, health, performance of the ventilation systems, thermal comfort, noise, and fire resistance.

Almost all building envelopes have thermal bridges - locations where the thermal resistance of the assembly is locally lower. Due to lower temperatures on the thermal bridge, higher RH occurs. While surface condensation starts at the 100% of the RH, the limit value for RH in respect of mould growth is above 75% to 90% RH depending on the material. Thermal bridges lead to an increase in heat losses. If large poorly-insulated or non-insulated envelope areas exist, the surfaces will be cold in winter and may cause problems with thermal comfort due to cold draughts or radiation (in particular, asymmetric radiation).

The paper presents the results of the study of indoor climate and energy use and the factors that affect them in typical apartment buildings. As constructions and outdoor climate also influence the indoor climate and the energy use they should always be taken into account. The study is confined to the investigation of the problem in cold climate (Estonia) and to the apartment buildings erected from prefabricated concrete elements.

2. Methods

To give an overview of the indoor temperature and humidity conditions and energy use in old multi-storey apartment buildings composed of prefabricated concrete elements, long-term field measurements were carried out in 39 apartments in 20 blocks of flats in Estonia (Kalamees et.al. 2009).

The buildings were heated by district heating and a one-pipe radiator heating system. Radiators, as a rule, were not equipped with special thermostats, therefore individual control of the room temperature was impossible. Room temperature for the whole building was controlled in heat substations, depending on outdoor temperature. The data about energy use were collected from the building studied separately (room heating including heating of ventilation air), heating of domestic hot water (DHW), use of electric energy (for appliances, equipments, lighting, technical systems, etc.).

The temperature and the RH in the rooms were measured with data loggers at 1-h intervals over a 1-year period. The data loggers were located on the separating walls mainly in master bedrooms. The temperature range measured by the data loggers was between 20ºC and +70ºC with an accuracy of ±0.35ºC and the RH range was between 5% and 95RH% with an accuracy of ±2.5RH%.

Indoor thermal conditions in the apartments studied were assessed on the basis of the target values from the standards (CR 1752, 1998, EN-15251, 2007). The II indoor climate category (normal level of expectation, for new buildings and renovations) and the III indoor climate category (acceptable, moderate level of expectation, for existing buildings) were selected for the comparison. The indoor temperatures during the winter season in the II indoor climate category must be in the range of +22±2ºC and in the III indoor climate category +22±3ºC. During the summer indoor temperature dependency on the outdoor temperature according to the standard (EN-15251, 2007) was used as old apartments are typically without mechanical cooling systems. The indoor RH values should be in the range of 25 % < RH < 45 % during the winter season and in the range of 30 % < RH < 70 % during the summer.

Based on the standard (EN-15251, 2007), various indicators of the indoor environment can be used for thermal evaluation purposes:

- Hourly criteria: the performance can be evaluated by calculating the number of actual hours or the % of the time when the criteria are met or are outside a specified range;
- Degree hours criteria: in respect of the thermal environment the degree hours outside the upper or lower boundary can be used as a performance indicator of a building for a warm or a cold season;
- Overall thermal comfort criteria (weighted PMV criteria): the time during which the actual PMV exceeds the comfort boundaries is weighted by a factor which is a function of the PPD. Starting from a PMV-distribution on a yearly basis and the relation between PMV and PPD, the following is calculated.

In this study hourly criteria and degree hour's criteria were used for the thermal evaluation.

The air tightness of each apartment was measured with the standardized (EVS–EN 13829, 2001) fan pressurization method, using "Minneapolis Blower Door Model 4" equipment (flow range at 50 Pa 25–7.800 m^3/h, accuracy ±3 %). To determine typical air leakage places and their distribution during the winter period, an infrared image camera was used FLIR Systems E320 (accuracy 2% or 2° C, measurement range; -20…+500° C). To compare air leakage of different apartments, the air flow rate at pressure difference 50 Pa was divided by the apartment's envelope area (including intermediate walls and floors) resulting air leakage rate at 50 Pa q_{50}, $m^3/(h \cdot m^2)$ or by the internal volume of the building resulting in the air change rate at 50 Pa, n_{50}, ach). As a rule, from each building the air tightness of one apartment was measured. If there were more measurements from one building, the average value was calculated to represent the air tightness of the building.

From the measurement results, the reference value of air tightness for different types of buildings was calculated. The reference value $q_{50,delc}$ (Eqn. 1) represents the median value

(50% fractile) with a confidence level of 90% for air tightness. The reference value of air tightness is applicable for energy calculations, when air tightness is not measured or the air tightness base value given in energy performance regulation is not suitable for use (too large or too small).

$$q_{50,decl} = q_{50} + k \cdot \sigma_{q_{50}} \text{ , m}^3/(\text{h}\cdot\text{m}^2) \tag{1}$$

where: q_{50} is the mean value of air tightness of this building type, m³/(h·m²); *k is* a factor to take into account the median value with a confidence level of 90% (Eqn. 2), and $\sigma_{q_{50}}$ is the standard deviation of air tightness measurement results (Eqn.3).

$$k = \frac{1.645}{\sqrt{n}} \text{ , -} \tag{2}$$

where: n is the number of measurements.

$$\sigma_{q_{50}} = \sqrt{\frac{\sum_{i=1}^{n}(q_{50,i} - q_{50})^2}{n-1}} \text{ , m}^3/(\text{h}\cdot\text{m}^2) \tag{3}$$

where: $q_{50,i}$ is a single air tightness measurement result.
Additionally, an interview questionnaire was completed for each apartment, where the building characteristics, occupants' habits, typical perceptions, complaints and symptoms related to the indoor climate were included.
Indoor temperature and RH were continuously measured for each apartment building at 1-h intervals over a 1-year period. Outdoor climate was measured near the apartment buildings studied or climatic data were retrieved from the nearest weather station.

3. Energy use in typical apartment buildings

Most of the buildings were heated by district heating, a small part of them by local boiler houses and a one-pipe radiator heating system. Radiators as a rule were not equipped with special thermostats, therefore individual control of the room temperature was impossible. Room temperature for the whole building was controlled in heat substations depending on outdoor temperature. Data on energy use in the buildings studied were collected separately, room heating including the heating of the ventilation air, heating of domestic hot water (DHW), electricity use (for appliances, equipments, lighting technical systems etc.).
In spite of problems concerning the work of one-pipe heating systems the heat consumption in those buildings within the 35 years (1974-2009) has still decreased considerably.
The decrease has first of all taken place due to a decrease in the DHW consumption (Koiv, Voll & Hani, 2010, Koiv, Hani & Voll, 2009) and to a certain lowering of the internal temperature (the latter becoming possible owing to the use of automatic heat substations and the balancing of the heating systems) and partly by renovating the envelope elements of the buildings, all in all about 170 kWh/m² (per gross area of apartments), see Fig. 2. 115 kWh/m² of the decrease in the heat consumption was made up by a decrease in the DHW consumption, because by that time the DHW systems in bigger towns had mostly been

renovated. It can be seen that the 80s saw a very slight change in the heat consumption in apartment buildings, but after that it started decreasing very quickly. A decrease in the DHW consumption did not bring about any special problems.

A decrease in the heating costs became possible due to the renovation of the heat substations (boiler houses) and in part of the buildings also to that of the heating systems, as well as the renovation of the building envelope (first of all the windows).

By replacing the windows it was possible to economize on the heat consumption, but to a great extent it took place at the expense of decreasing the air change, which considerably deteriorated the indoor climate and often caused mould in apartments (Koiv, Voll, Mikola, Kuusk & Maivel, 2010).

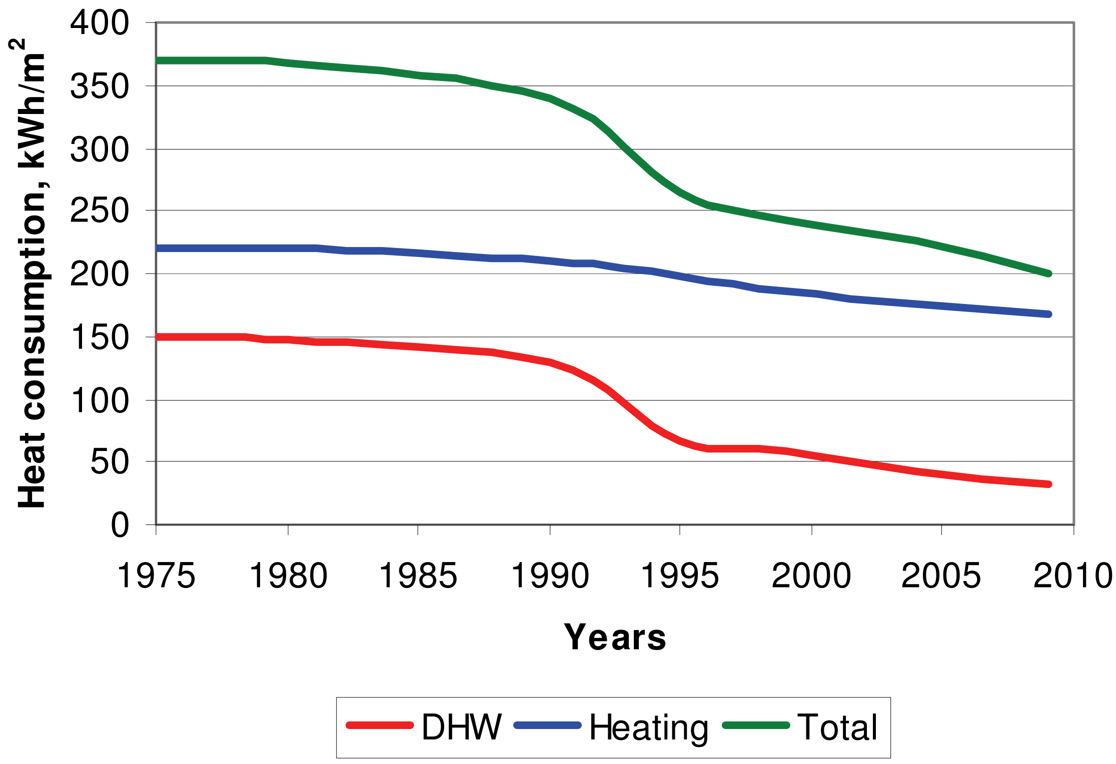


Fig. 2. Approximate heat consumption of DHW, heating (room heating and heating of ventilation air) and the total for the years 1975-2009 (per gross area of apartments)

4. Performance of ventilation

The ventilation system of the apartment buildings investigated was natural (passive stack) ventilation, Fig. 3. In some apartments kitchens were supplied with a hood. In all of the dwellings studied, windows could be opened for airing purposes. The air change in such buildings is unstable, being affected by external temperature, the height of the ventilation channel and also by the strength of the wind and its direction. Though mechanical ventilation has been the standard installation in new apartment buildings in Estonia during the last two decades, old apartment buildings have preserved natural ventilation due to the complexity of the ventilation renovation.

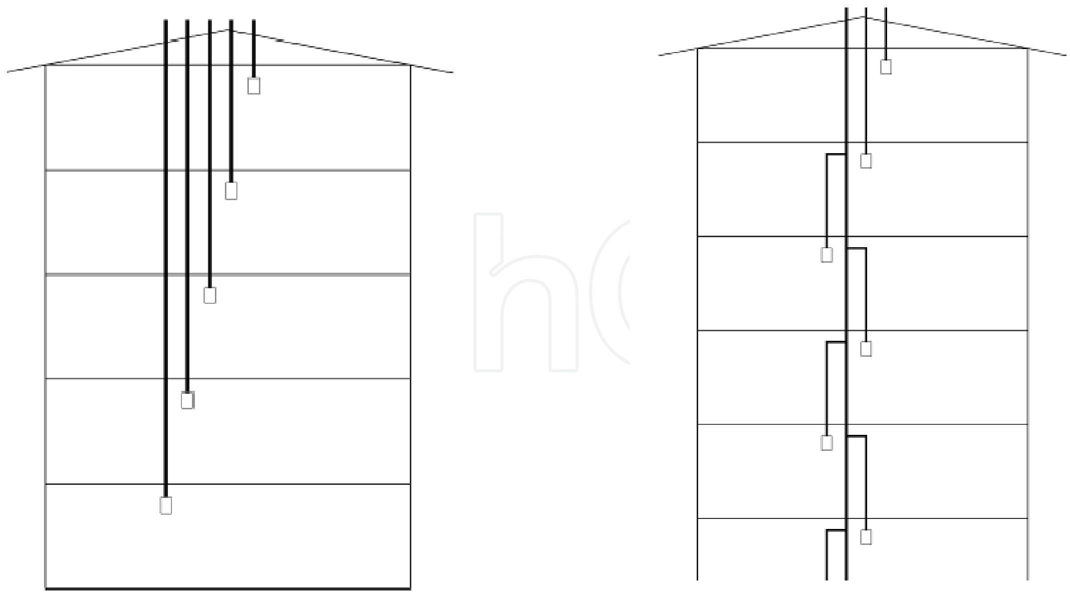


Fig. 3. The ventilation system of the apartment buildings investigated (left: up to a five-storey building, right: higher than a five-storey building)

It is practically impossible to achieve necessary airflows in apartments with natural ventilation. It is possible to use window airing, but this may worsen thermal comfort during the winter season. Because of worsened thermal comfort due to outdoor air inflow from stack (caused by wind) occupants seal the stack and ventilation outlets, Fig. 4.

Fig. 4. Ventilation stack is closed by occupants due to cold air inflow caused by wind

Ventilation airflow in apartments is smaller than required (Fig. 5 left) and the CO_2 level is higher than the one permitted (Fig. 5 right). In such a situation the RH is also high and it is often accompanied by a rise of mould.
Replacing the old non-hermetic windows with more airtight ones in such apartment buildings results in dramatically worsened indoor air quality. The replacement of windows without renovating the ventilation results in lower air leakage and ventilation airflows, Fig. 6. In partly renovated apartment buildings problems with low air change often arise.

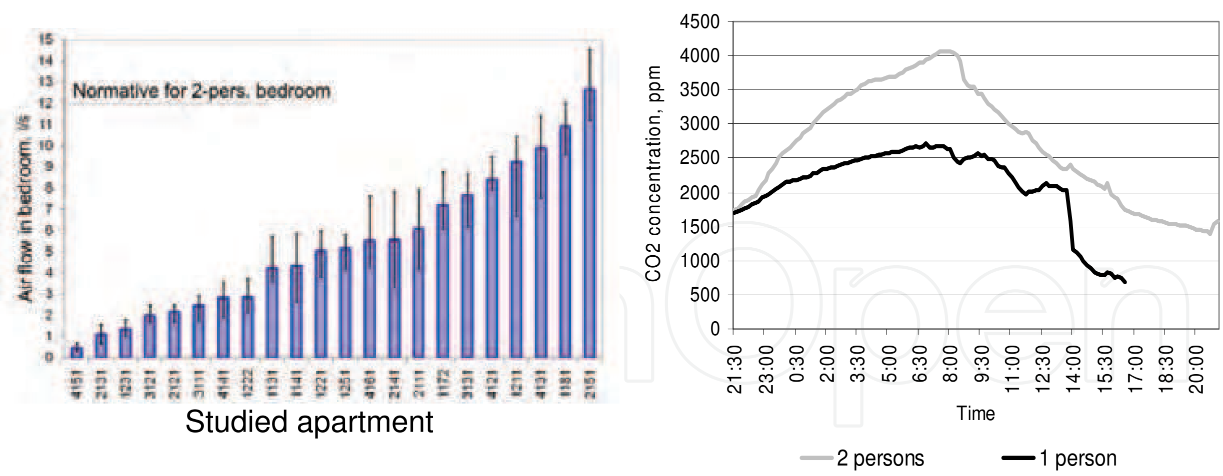


Fig. 5. Ventilation airflow (left) and CO_2 level (right) in bedrooms

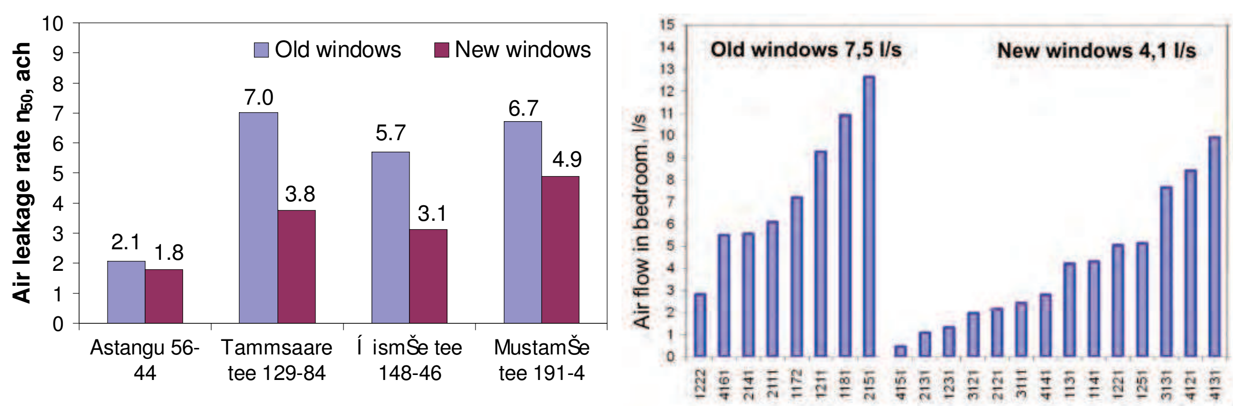


Fig. 6. The influence of the replacement of old windows on the air tightness of the apartment (before and after the replacement) (left) and on the air flow in bedrooms (right)

5. Indoor temperature and humidity conditions

5.1 Dependence of indoor temperature and humidity on outdoor temperature

To give an overall view of the indoor climate the dependence of the indoor temperature and the RH on the outdoor temperature was analysed. From each room at each average daily outdoor air temperature, all average daily indoor temperature values were selected, Fig. 7 left. From all the indoor temperatures at the corresponding outdoor temperature, the average value was calculated. Each individual thin solid lightly shaded curve in Fig. 7 (right) represents the average value from the average daily indoor temperature at the corresponding average daily outdoor temperature in one apartment. The dotted curve represents the average curve from all the apartments.

A one-pipe heat distribution system was installed in the apartments studied. As radiators were not equipped with thermostats, there was no possibility to control the room temperature. The room temperature was controlled in the boiler room based on the outdoor temperature. If the slope and the level of the control curve of the temperature of the supply water are correct, the room temperature does not depend strongly on the outdoor temperature. Fig. 8 (right) and

Fig. 8 (left) shows the measurement results from the buildings where the control curve is incorrect. Then during a cold period an apartment will be overheated. As occupants had no possibility to control the room temperature, the room temperature was typically lowered by opening the windows. Lowering temperature during winter-time by opening a window instead of using the thermostats of the radiators wastes energy.

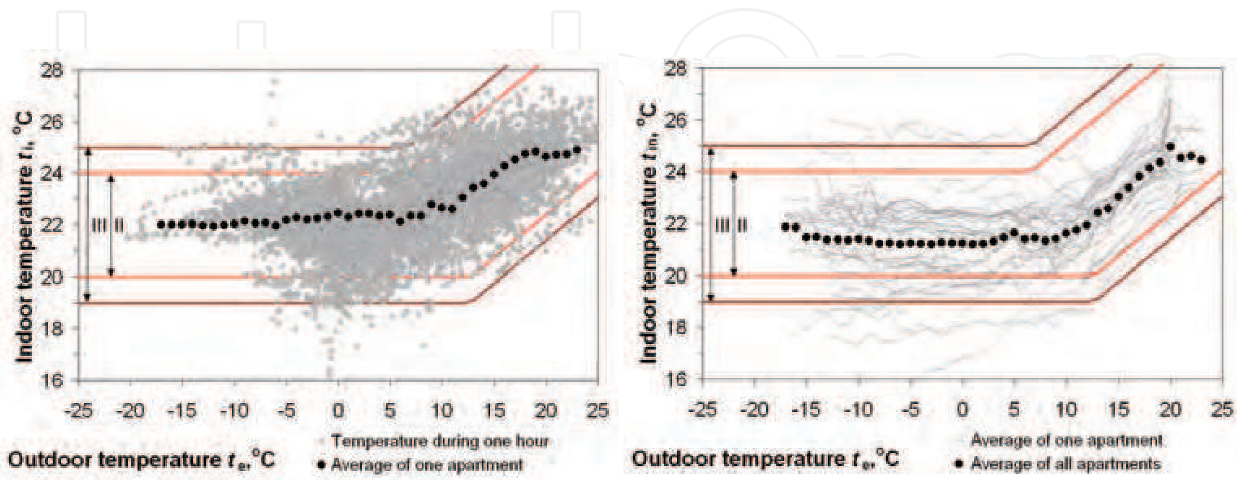


Fig. 7. Dependence of the indoor temperature on the outdoor temperature in one room (left) and the comparison of all rooms (right)

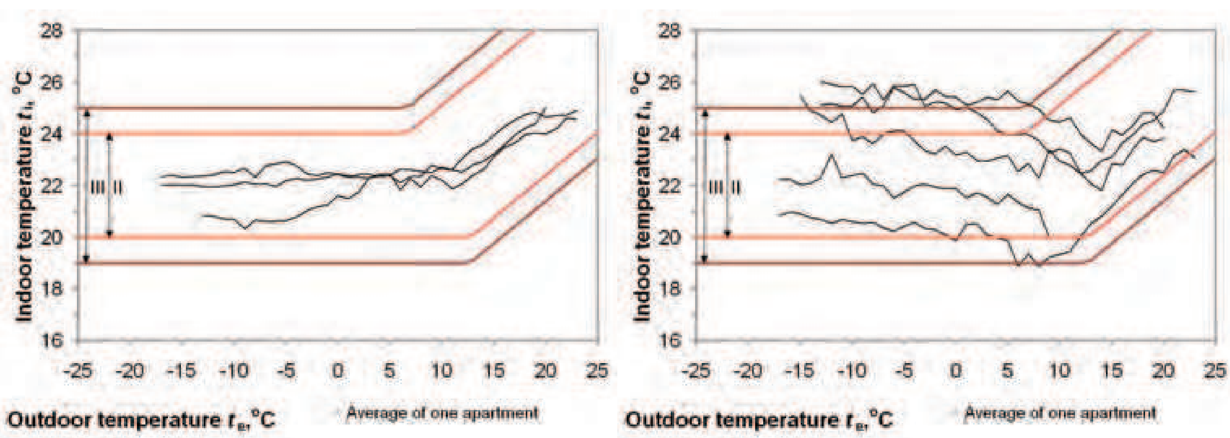


Fig. 8. Dependence of the indoor temperature on the outdoor temperature in buildings with correct (left) and incorrect (right) supply water temperature control curve

Similarly to the room temperature, the dependence of indoor RH on the outdoor temperature was also analyzed. In Fig. 9 (left) average daily indoor RH values from one room are divided according to the average daily outdoor air temperature. From all the indoor RH at the corresponding outdoor temperature, the average value was calculated (dotted line). Each individual thin solid lightly shaded curve in Fig. 9 (right) represents the average value of the average daily indoor RH at the corresponding average daily outdoor temperature in one apartment. The dotted curve represents the average curve of all the apartments. Even the average RH in the apartments studied stays within target values of RH in most of the apartments we can see large variations of indoor RH.

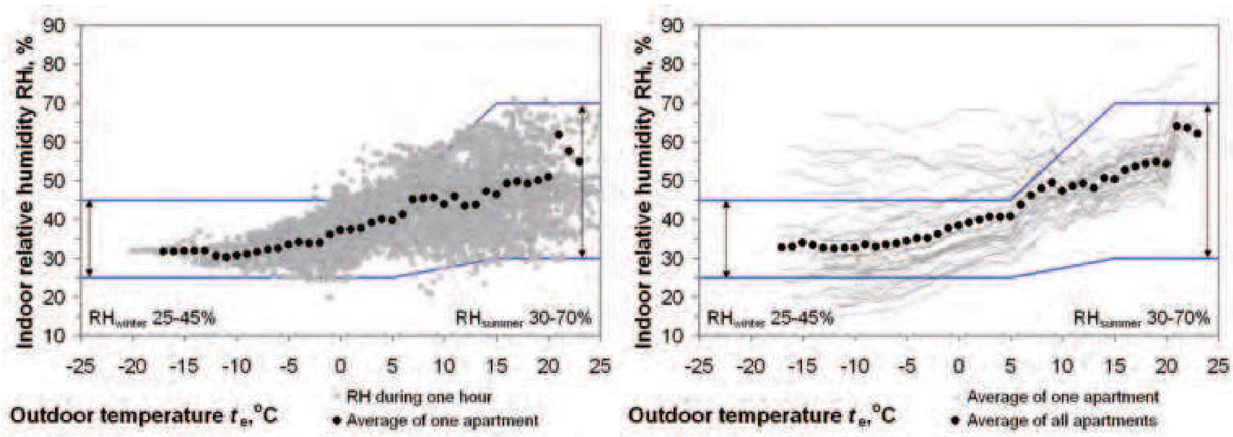


Fig. 9. Dependence of the indoor RH on the outdoor temperature in buildings with correct (left) and incorrect (right) supply water temperature control curve

5.2 Indoor temperature and humidity conditions during the winter season

Fig. 10 shows the indoor temperature (left) and the RH (right) in three sample apartments. All the temperature and the RH measurement results in the apartment buildings measured during the winter seasons are shown in Fig. 11. Each curve represents one apartment measured. Dotted curves show the average of all the rooms. Indoor climate during the winter season was analyzed based on the measurements during three winter months. The average indoor temperature during the winter season from all the apartments was +21.3 °C (min. average being +16.3 °C and max. average +25.8 °C) and the average indoor RH was 37 % (min. average being 23 % and max. average 65 %). Even the generally average temperature was between +19 and +22°C, larger variations in temperatures (Fig. 11 left) show problems related to the control of the heating system. The large deviation of the RH (Fig. 11 right), in addition to temperature variations, indicates that problems exist in the performance of the ventilation system.

The temperature in the apartments on the top floor was approximately one degree lower, (Fig. 12 left) and the RH was 10 % higher, (Fig. 12 right), than in the apartments on the lower floors. The significantly higher (P=0.03) RH on the upper floors is caused by higher humidity loads (lower air change rate due to smaller stack height). The type of the window had an insignificant influence on the room temperature and humidity.

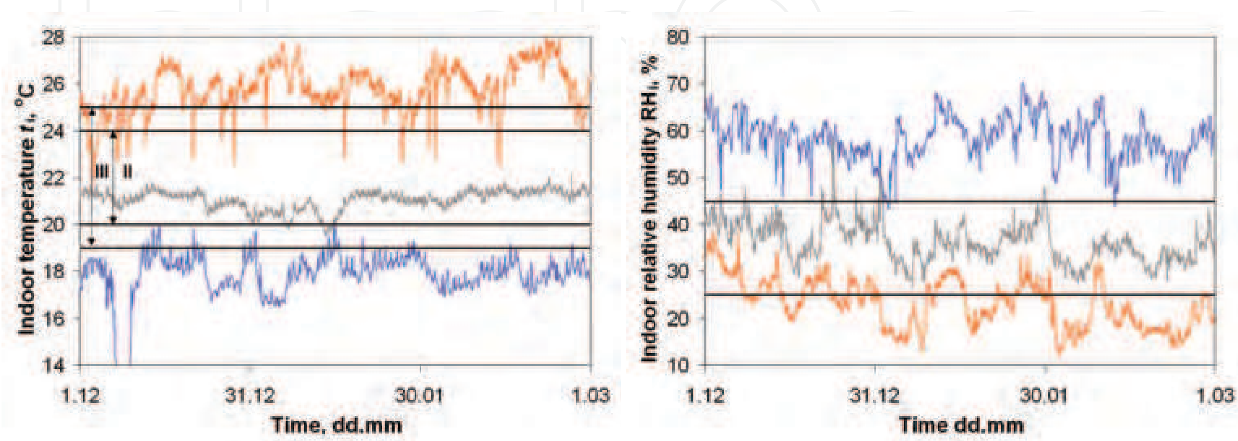


Fig. 10. Indoor temperature (left) and RH (right) in three sample apartments during the winter season

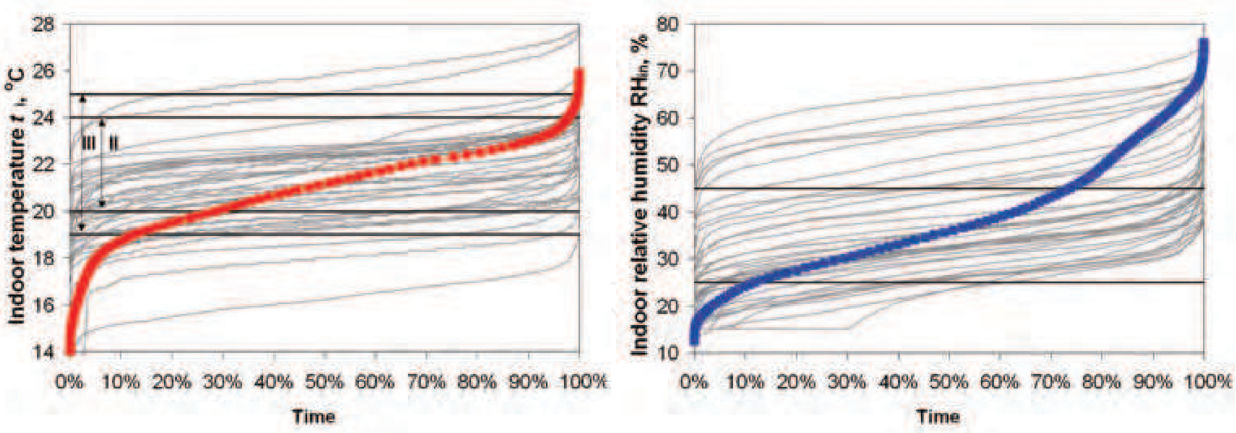


Fig. 11. The distribution of the indoor temperature (left) and the RH (right) in the winter season in Estonian old multi-storey apartment buildings composed of prefabricated concrete elements

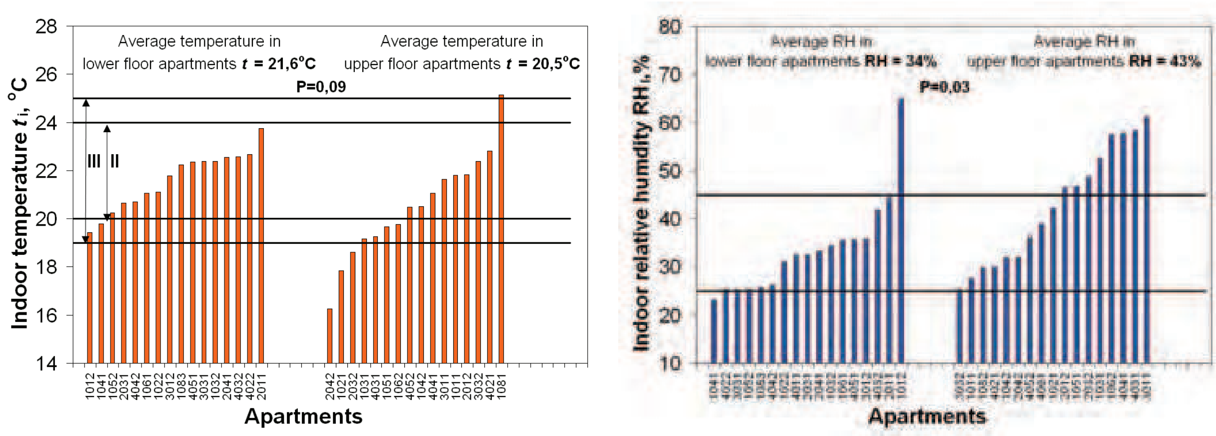


Fig. 12. The comparison of the average indoor temperature (left) and the RH (right) between the upper and lower floor apartments during the winter season

5.3 Indoor temperature and humidity conditions during the summer season

The average indoor temperature during the summer season of all the apartments was +23.4 °C (min. average being +20.2 °C and max. average +25.2 °C) and the average indoor RH was 52% (min. average being 43 % and max. average 70 %). All the temperature and RH measurement results in the dwellings measured during the summer seasons are shown in Fig. 13. Each curve represents one apartment measured. Dotted curves show the average from all the rooms.

Indoor temperature during summer depends mostly on the direction and properties of the window. Indoor temperature in rooms with windows facing the north was lower than those with windows facing the south, however, the difference was small (0.5 ºC) and insignificant (P=0.4).

To assess and compare thermal comfort in apartments the number of hours during the summer season (1 June … 31 August) in which the fixed air temperature of 27°C is exceeded was calculated for each apartment. In this study the amount of weighted excess hours 150 h during the summer season is used as the criterion of the acceptable thermal comfort. The limit of weighted excess hours 150 h during the summer season was exceeded in 10 % of the apartments.

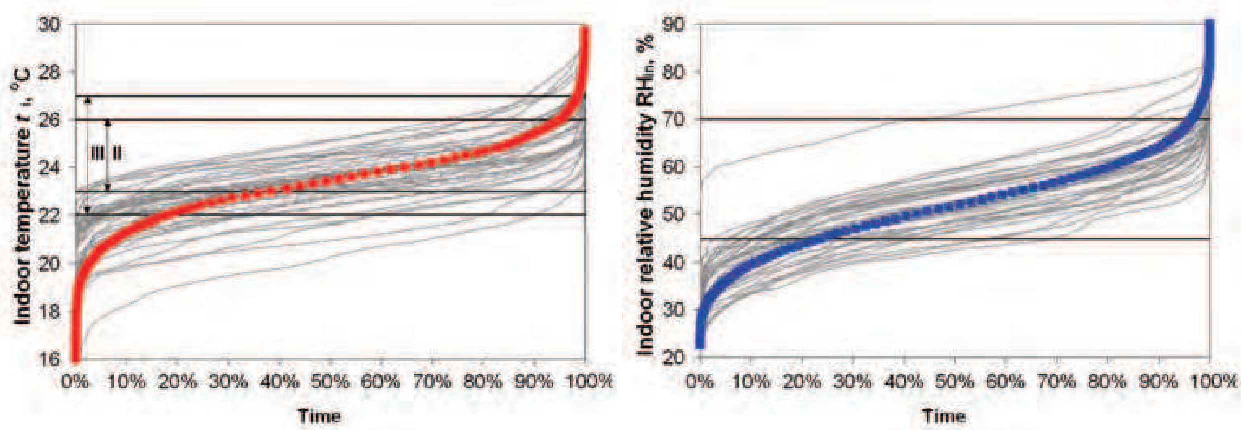


Fig. 13. The distribution of the indoor temperature (left) and the RH (right) in Estonian old multi-storey apartment buildings composed of prefabricated concrete elements during the summer season

5.4 Correspondence of the indoor thermal conditions to the target values

Target values for the room temperature and the RH in the average (II) and the lowest (III) indoor climate categories (CR1752, 1998, EN-15251, 2007) were selected to assess the indoor thermal conditions. Values outside the III category should only be accepted for a limited part of the year. Allowable rate for the target values of the indoor temperatures that may be exceeded was 5% of the measured time length.

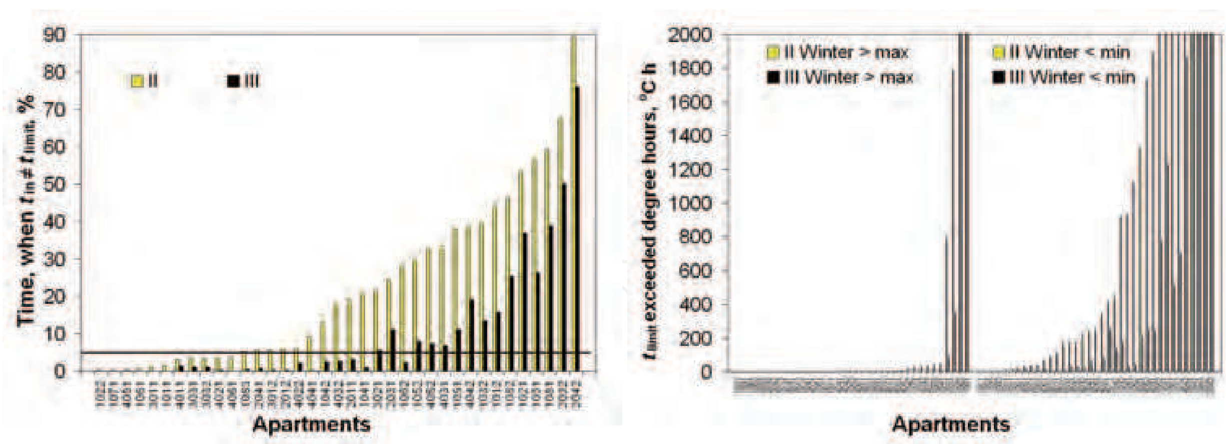


Fig. 14. Percentages of time when the indoor temperature exceeded the target values (left) and temperature target values exceeded degree hours during winter (right)

In 41% of the apartments the room temperature did not correspond to the indoor climate category III criteria allowing 5% excess, Fig. 14 (left). In 41% of the apartments the temperature was not within the target values during the winter season and in 14% of the apartments the temperature was not within the target values during the summer season. The target values of the temperature for the indoor climate category II were exceeded in 70% of the apartments (65% during the winter season and 42% during the summer season). The analysis of the degree hours outside the target values revealed that thermal problems in old multi-storey apartment buildings composed of prefabricated concrete elements relate to low room temperatures. Target values were exceeded at the highest rate there (Fig. 14 right).

6. Air tightness of the building envelope

In the apartments measured, the mean air leakage at the pressure difference of 50 Pa in the entire database was 4.2 $m^3/(h{\cdot}m^2)$, the minimum being 0.3 $m^3/(h{\cdot}m^2)$ and the maximum 15 $m^3/(h{\cdot}m^2)$. The mean air change rate at the pressure difference of 50 Pa from all the databases was 6.0 h^{-1}, the minimum being 0.4 ach and the maximum 24 h^{-1}. The entire database allowed analysing the influence of different external wall structures on the air tightness of the envelopes. The average values of air tightness and their reference values in different subdivisions are shown in Table 1. Older buildings were significantly more non-hermetic (Fig. 15). With these data it is possible to calculate the air infiltration rate and the results can be used for analysing energy performance.

Air leakage rate, q_{50}, $m^3/(h{\cdot}m^2)$		Air change @50Pa, n_{50}, h^{-1}	
Average	Reference value	Average	Reference value
4.2	4.7	6.0	6.8

Table 1. Results of air tightness measurements in apartment buildings composed of prefabricated concrete elements

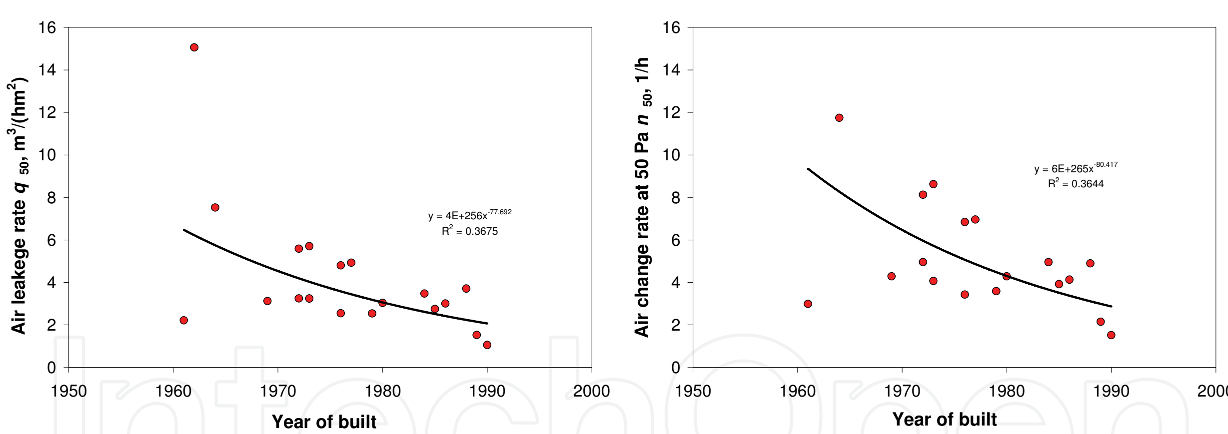


Fig. 15. Comparison of air tightness of building envelope depending on the age of the building

7. Principles of renovation for improving the indoor climate and energy efficiency

The overall living standards in the older part of the housing stock need to be improved to meet today's requirements in functional, urban design, architectural (visual, planning) and constructional-technical terms. Buildings are in an inadequate condition due to low requirements for energy performance in old building standards, a historical lack of attention to quality in construction materials and practices, poor record of operation, maintenance and regular renovation.

The needs for renovation can be viewed from the following aspects:

- Urgent repairs to guarantee safety of buildings (mechanical resistance and stability; safety in case of fire safety in use);
- Improvement of indoor climate (hygiene and health aspects);
- Improvement of energy performance of buildings and HVAC systems;
- Improvement of architectural planning, visual quality, overall living quality, and additional comfort.

In the process of renovation the indoor climate and energy performance of buildings in cold climate the following three components must be considered.

- Performance of ventilation;
- Hygrothermal performance of building envelope;
- Performance of heating systems.

7.1 Renovation of ventilation

In the current situation the renovation of the ventilation is inevitable. To improve the air change in old apartment buildings, it is necessary to use either central or more flexible individual mechanical ventilation. Typically mechanical exhaust ventilation is the easiest solution to implement. Challenges here are how to guarantee the thermal comfort during winter (one possibility is to combine fresh air inlets with radiators. It is possible to improve energy performance with heat pump (to heat up the domestic hot water). The mechanical exhaust ventilation solution is not suitable for all types of buildings (especially for buildings with a combined stack).

Balanced ventilation with room units is another possible solution to renovate the ventilation in old apartment buildings. Where to put room units (a little space); how to solve problems with sound pressure levels; where to put air channels (room height 2,5m); how to solve air flow in an apartment through existing doors are questions that need to be solved during the design process.

In addition to technical questions, also social/human questions need to be solved: occupants have different possibilities and motivations to pay the cost of renovation. Typically occupants do not accept any additional ventilation channels in their apartment. Understanding of the importance of ventilation is very poor.

In the following we will analyze possible solutions of the renovation of ventilation. They can be divided into:

- ventilation system without heat recovery,
- ventilation system with heat recovery.

Principal renovation solutions are proposed for a three-room apartment.

7.1.1 Ventilation system with heat recovery

Here are three main renovation solutions for the ventilation system:

1. Supply-exhaust air handling units (AHU) with heat recovery, Fig. 16 (left). Guarantees very good indoor climate if the maintenance of the AHU is good. Expenses on heating the air are small. Expenses on the maintenance and the consumption of electricity are bigger. The fitting costs are the biggest, about 4000 €. To avoid noise problems it needs careful installation and a good choice of the equipment. The height of standard

apartments being small (about 2.5 m), the owners of the apartments are against fitting the ventilation channels on the ceiling of rooms. Annual changing of filters is necessary.

2. Solution with room supply-exhaust AHU with heat recovery and with exhaust ventilators in WC, bathroom and kitchen, Fig. 16 (right). Good indoor climate is guaranteed. The efficiency depends on the control of exhaust ventilators. Compared with the previous solution the fitting costs are 2…3 times smaller. Needs annual changing of filters. In using effective equipment the consumption of electricity is small. Expenses on air heating are slightly bigger than in the previous solution.
3. Solution based on the exhaust air heat pump of the ventilation, Fig.17. Fresh air is sent to rooms through fresh air valves. A mechanical exhaust ventilation system together with cooling batteries to draw the heat of the exhaust air is built. The general working process of the system based on exhaust air heat pumps is the following:
   - exhaust air is removed from the kitchen and sanitary rooms of apartments,
   - a ventilator and a cooling battery are placed on the exhaust air channel; in the cooling battery the exhaust air cools down from 21°C to 7°C,
   - the water-glycol solution is directed from the cooling battery into the evaporator of the heat pump. With the help of the heat pump the temperature of the cooling agent is raised to 55°C. With the heat produced by the heat pump the DHW is heated and in low-temperature heating systems the temperature of the water is raised.

The efficiency of the system depends on the level of the initial air change in apartments and the temperature curve of the heating system as the temperature of the water leaving the heat pump is relatively low. Both the solution based on heat pump and the one with room supply-exhaust AHU may require additional heating coils in apartments in case this solution has not been taken into account in designing the system.

7.1.2 Solutions without heat recovery

Even nowadays the ventilation system without heat recovery is not preferable. In some cases the ventilation system is renovated without heat recovery (to reduce investment costs). The most important thing is to provide healthy living conditions for occupants. This requires minimum ventilation airflows in the apartment. Below we present main solutions for renovating the ventilation system without heat recovery.

1. Increasing the efficiency of natural ventilation by fitting fresh air valves into bedrooms and living-rooms (e.g. in the case of renovated windows). At least satisfactory air quality is achieved, but expenses on heating the ventilation air increase several times. It is important to find a suitable place, as, for example, behind the radiator or between the heating coil and the window sill. The cost of the renovation is small.
2. Mounting fresh air inlets in living- and bedrooms and exhaust air ventilators into WC, bathroom and kitchen. This solution guarantees acceptable indoor climate and control of the flow rates of the exhaust air. Owing to the control of the air change it is possible to decrease the costs on ventilation. The cost of the renovation is relatively small.
3. Fitting exhaust air ventilators above ventilation channels on the roof. This guarantees good indoor climate. The costs on heating the ventilation air are big (in new apartment buildings it makes up about 50% of the heating costs. In old apartment buildings in Estonia it has been used in single cases.

Fig. 16. Balanced ventilation solution with apartment AHU with heat recovery (left) and one room supply-exhaust AHU with heat recovery (right)

7.2 Renovation of the heating system

As radiators were not equipped with thermostats, it was not possible to control room temperature. Room temperature was controlled in the heat substation based on the outdoor temperature. If the slope and the level of the control curve of the temperature of the supply water are correct, room temperature does not depend strongly on the outdoor temperature, Fig. 8 left. Other problems concerning the heating system are:

- Incorrect water flow rate of the heating system or risers,
- Lack of direct room temperature control,
- Lack of maintenance and improper modifications of the heating systems.

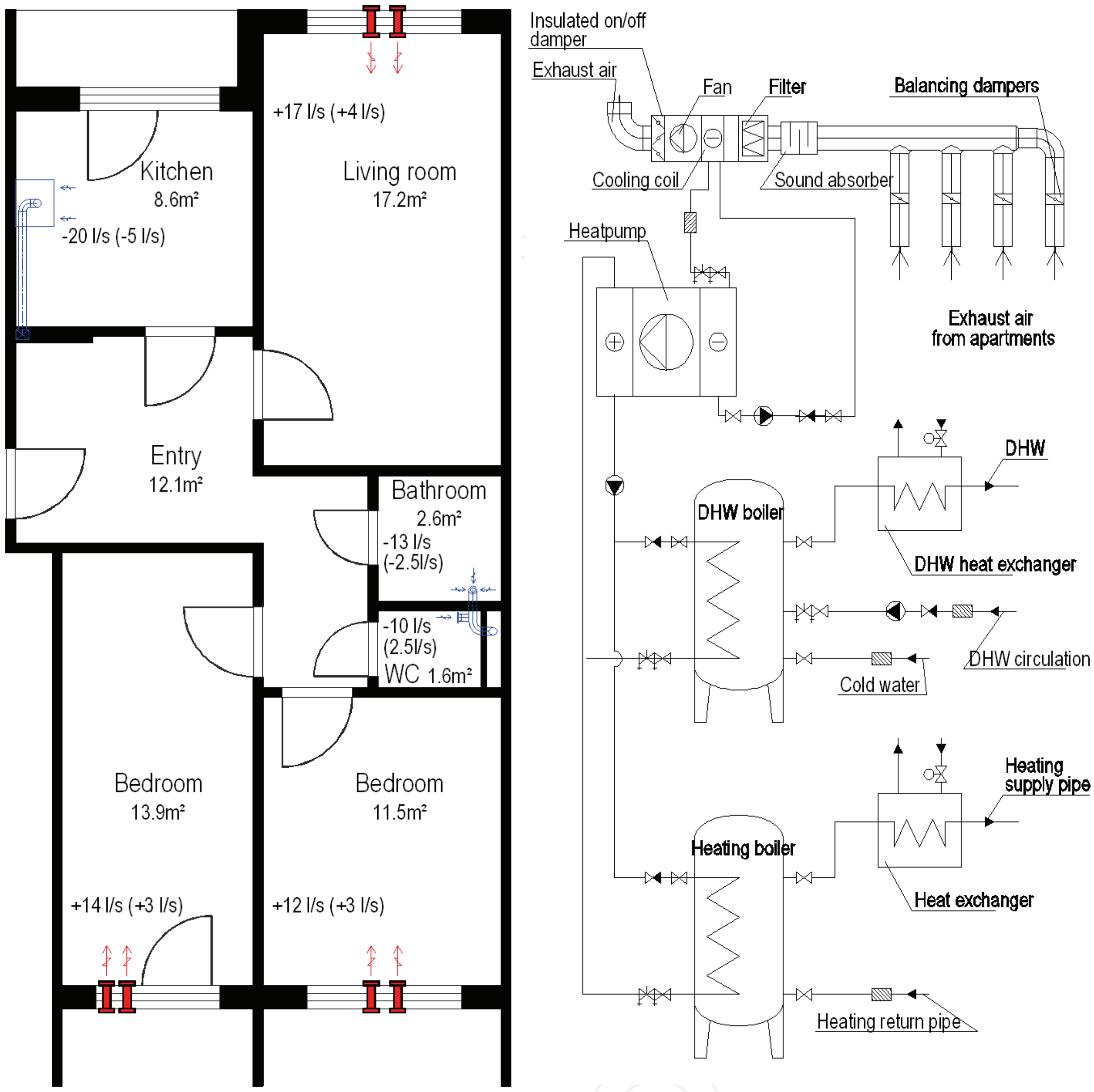
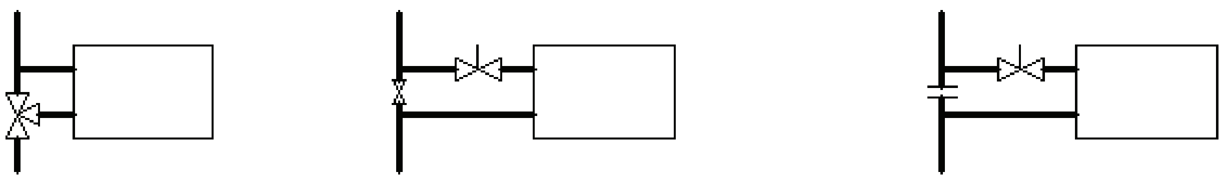


Fig. 17. Ventilation with exhaust air heat pump: solution in three room apartment (left) and the principal system (right)

To renovate the existing one-pipe heating systems it is necessary to find out the condition of the system, i.e. in which state are the heating coils and the pipes. This determines the solution of renovation:

- in case the heating coils and the pipes have exhausted their resources the heating system should be renovated completely, i.e. a new two-pipe heating system should be built,
- should the heating coils and the pipes be in a good condition (e.g. used are cast iron section radiators and the steel pipes still have a 15-20 year long lifetime) the connection unit of the heating coils of the one-pipe heating system should be renovated by making it controllable, Fig. 18.



(a) (b) (c)

Fig. 18. Variants for making the connection unit of the heating coils of the 1-pipe heating system controllable:
a- with an adjustable 3-way thermostat valve
b- with a 2-way thermostat valve and an adjustable valve on bypass
c- with a 2-way thermostat valve and a drossel on bypass

7.3 Renovation of building envelope

Serious thermal bridges are a large problem in old apartment buildings composed of prefabricated concrete panels (Ilomets et. al., 2011). Mould growth and surface condensation on the internal surfaces of thermal bridges are unavoidable without additional external insulation and/or lowering internal humidity loads. Due to low frost resistance and carbonization of facades, it is necessary to protect them. It is economically viable to make the additional thermal insulation for walls and roofs.

Typical thickness of additional insulation is 10…15 cm for walls and 15…20 cm for roof, made from expanded polystyrene of mineral wool. During insulation works windows remain in their original place. Therefore the thermal bridge connects the window and the insulated external wall (Fig. 19, up) and windows look like embrasure if windows stay in the original place (Fig. 19, down).

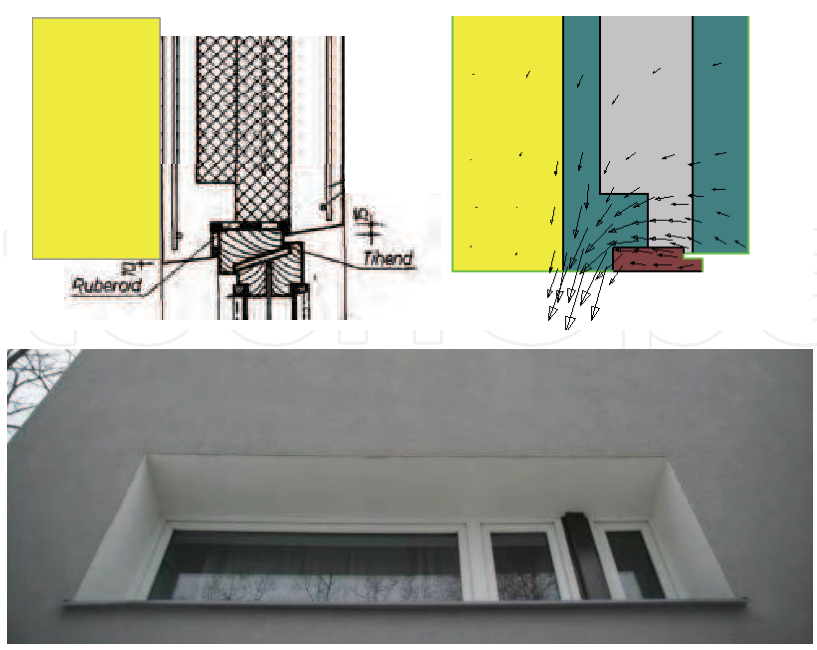


Fig. 19. Thermal bridge in connection of window and insulated external wall (up). Window in insulated wall (down)

Old walls are not flat. To get the final surface flat, air space may become between the original wall and additional insulation. If the air channel stays open from bottom and top, air flow through it can increase the thermal transmittance of the wall Fig. 20.

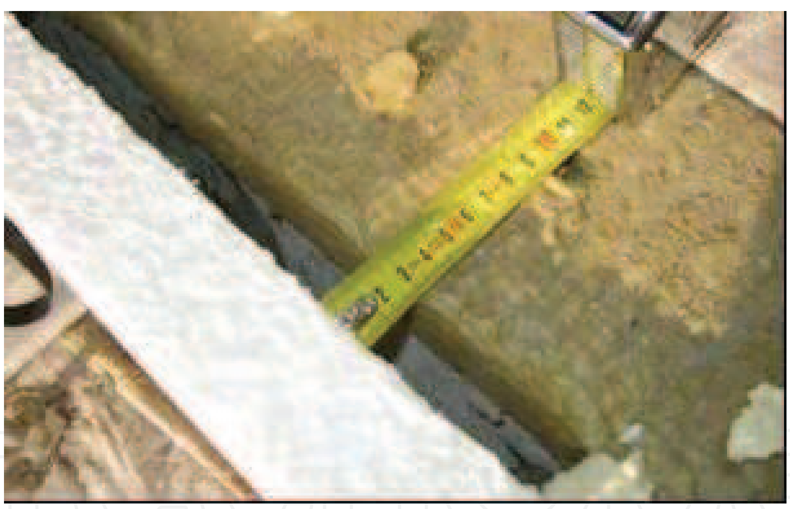


Fig. 20. Air space between the original wall and the additional insulation can cause air flow through it and the thermal transmittance of the wall may increase

Closed loggias generally stay without additional insulation. In the worst case this can cause extensive mould growth on the inner surface of the loggia's walls, Fig. 21.
According to the Estonian renovation practice, renovation works as a rule start in spring and finish in late autumn. The autumn is the typically rainy season in Estonia. The original wall may become wet before insulation works. Drying out moisture may cause much stronger hygrothermal loads than moisture diffusion (or convection). Drying out moisture can cause damage of the finishing layer of the external walls, Fig. 22.

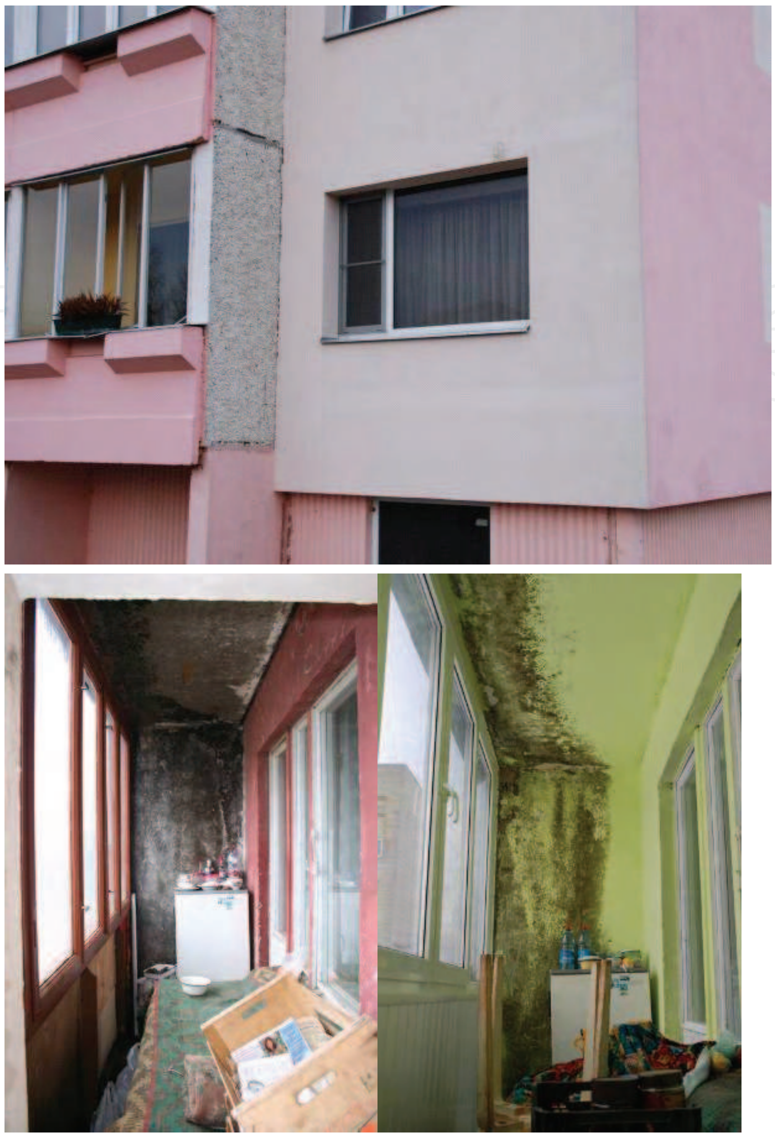


Fig. 21. Closed loggia without additional insulation on walls (left). Mould on the inner surface of the loggia's walls before (left) and after (right) the renovation

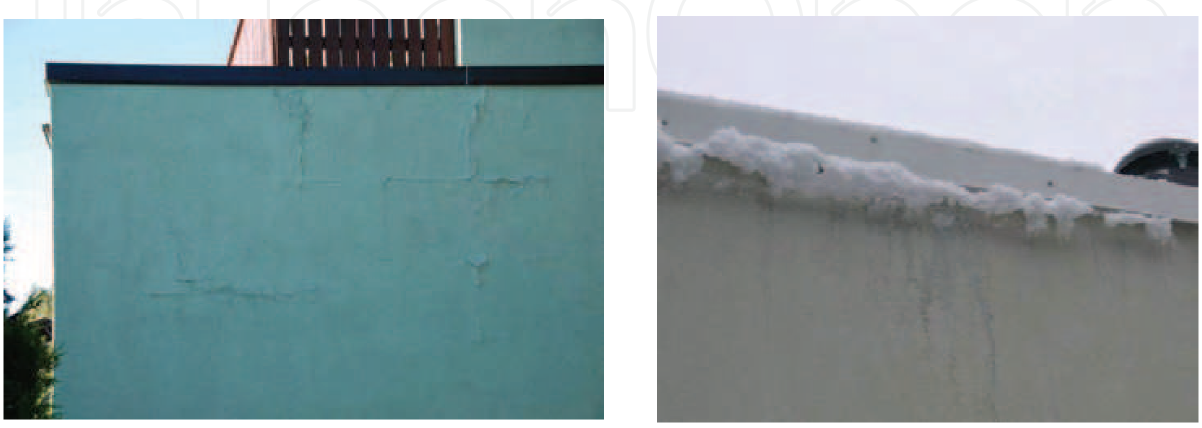


Fig. 22. Deterioration of finishing layer of exterior insulation finishing system due to drying out moisture

Complex renovation (ventilation + thermal envelope + heating systems) is not common in typical renovation practice. The main reasons for this are the lack of knowledge and higher momentary price. Non-complex renovation may result in the poor quality of indoor air and the expected energy savings remain smaller.

8. Discussion and conclusion

This study analyzed the indoor temperature and humidity conditions measured in field conditions in Estonian old multi-storey apartment buildings composed of prefabricated concrete elements, based on field measurements in 39 apartments in 20 buildings.

During the past 35 years immense changes have taken place in the heat energy consumption in typical apartment buildings. The average heat energy consumption in typical apartment buildings has decreased from about 370 kWh/m^2 to about 200 kWh/m^2 (per gross area of apartments). About 115 kWh/m^2 of this decrease was due to a decrease in DHW consumption and the rest due to a decrease in energy used for heating. The latter has decreased owing to the renovation of heat substations (boiler houses) and also to a partial renovation of the building envelope.

Despite nearly sufficient average temperature and humidity in the apartments studied, deviations in measurement results were high, indicating problems with heating system control and ventilation system performance. Correspondence of the indoor thermal conditions to the target values of the indoor standard was low. In 41% of the apartments the room temperature did not correspond to the indoor climate category III criteria. Target values were exceeded at the highest rate during the winter (heating) period. The main reasons for deviations from the target values are:

- incorrect control curve of the temperature of the supply water of the heating system,
- incorrect water flow rate of the heating system or risers,
- lack of direct room temperature control,
- difficulties in regulating heat output of heating coils in the one-pipe heat distribution system,
- poor maintenance and improper modifications of the heating and ventilation systems.

As the amount of weighted excess hours during the summer season was not high and the outdoor air temperature during the summer of 2008 corresponded well to the long-term temperature, we may conclude that overheating during the summer season is not a critical problem in old multi-storey apartment buildings composed of prefabricated concrete elements.

This study supports the results of an earlier study (Kalamees, 2006) that the heating season would change to the summer in Estonian dwellings at this +15 °C… +10 °C average daily outdoor temperature point. This boundary allows the target values of indoor climate conditions to be determined in buildings for winter (heating) and summer (cooling) seasons.

Comparison of the findings of this research into indoor climate in Estonian apartment buildings composed of prefabricated concrete elements with those of other studies in cold climate (Gustavsson, Bornehag & Samuelsson, 2004, Jenssen, Geving & Johnsen, 2002, Norlén & Andersson, 1993, Ruotsalainen & Säteri, 1992, Vinha, Korpi & Kalamees, 2009) may indicate that the indoor climate in Estonian apartment buildings composed of concrete elements is characterized by a larger deviation and lower temperatures and during the heating season by a larger deviation and a higher RH.

Indoor humidity load in the apartments studied was high: the moisture excess (the difference between indoor and outdoor air humidity by volume) at the 10% critical level was close to +7 g/m^3 during the cold period. This causes potentially serious moisture problems for the building envelope and health problems due to mould growth on the surfaces of the building envelope. The high indoor humidity loads were caused mainly due to the lack of ventilation and high occupancy. High indoor humidity loads are a major concern because of serious thermal bridges in the building envelope (Norlén & Andersson, 1993). Renovation of old apartment buildings composed of prefabricated concrete elements by:

- improving thermal insulation of the building envelope (roof and walls) (additional thermal insulation),
- renovation and rebalancing of heating systems with thermostats fitted to the radiators,
- improvement of ventilation (preferably supply-exhaust ventilation with heat recovery) is unavoidable to provide the healthy indoor environment for the occupants. As all these activities also improve the energy efficiency, the renovation is doubly advantageous.

Presented are recommendations for renovating ventilation in typical apartment buildings. They can be classified into systems without exhaust air heat recovery and with exhaust air heat recovery. Considering the prices of energy today the latter systems are more suitable: e.g. solutions based on exhaust air heat pump or apartment AHU.

9. Acknowledgment

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10. References

CR 1752. (1998). Ventilation for buildings: Design criteria for the indoor environment. CEN.

EN-15251. (2007). Indoor environmental input parameters for design and assessment of energy performance of buildings- addressing indoor air quality, thermal environment, lighting and acoustics. CEN.

EVS–EN 13829. (2001). Thermal performance of buildings. Determination of air permeability of buildings. CEN.

Gustavsson,T., Bornehag, C–G. & Samuelsson I. (2004). Temperature, relative humidity and air exchange rate in 390 dwellings. *CIB W40 meeting, Glasgow, UK.*

Jenssen, J A., Geving, S. & Johnsen, R. (2002). Assessments on indoor air humidity in four different types of dwelling randomly selected in Trondhein, Norway. *Proceedings of the 6th Symposium on Building Physics in the Nordic Countries,* June 17–19, Trondheim, Norway.

Kalamees T., Õiger K. & Koiv T.-A.(2009). *Technical condition and service life of Estonian apartment buildings, built with prefabricated concrete elements.* Tallinn University of Technology (in Estonian), ISBN 978-9985-59-947-1.

Kalamees T. (2006). Indoor Climate Conditions and Ventilation Performance in Estonian Lightweight Detached Houses. *Indoor and Built Environment*, (15, 6), 555 – 569, ISSN 1423-0070.

Koiv, T.-A., Voll, H. & Hani, A. (2010). Domestic hot water consumption in educational premises, apartment and office buildings. *WSEAS TRANSACTIONS on Environment and Development*, Issue 1, vol 6, 2010, 54-63, ISSN 1790-5079.

Koiv, T.-A., Toode, A. & Hani, A. (2009). The influence of domestic hot water maximum consumption on the district heating network dimensioning. *WSEAS TRANSACTIONS on Environment and Development*, 1, vol 5, 2009, 104-108, ISSN 1790-5079.

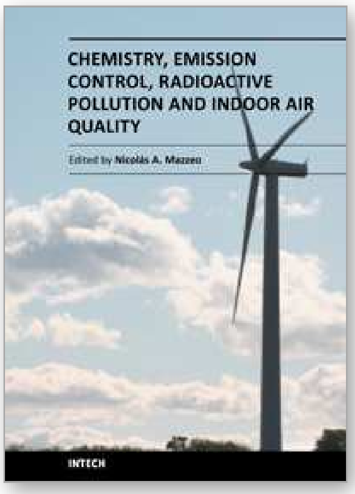
Koiv, T.-A., Voll, H., Mikola, A., Kuusk, K. & Maivel, M. (2010). Indoor climate and energy consumption in residential buildings in Estonian climatic conditions. *WSEAS TRANSACTIONS on Environment and Development*, Issue 4, vol 6, 2010, 247-256, ISSN 1790-5079.

Norlén, U. & Andersson, K. (1993). The indoor climate in the Swedish housing stock. *Swedish Council for Building Research*, D10:1993. Stockholm, Sweden, ISBN 9 1-540-5569-5.

Ilomets, S., Paap, L. & Kalamees T. (2011). Evaluation of the thermal bridges of prefabricated concrete large-panel and brick apartment buildings in Estonia. *Proceeding of the 11th Symposium on Building Physics in the Nordic Countries*, 29 May – 2 June 2011, Tampere, Finland.

Ruotsalainen, R. & Säteri. (1992). Indoor Climate and the Performance of Ventilation in Finnish Residences. *Indoor Air*, No 2, 1992, 137-145, ISSN 0905-6947.

Vinha, J., Korpi, M. & Kalamees, T. (2009). *Air tightness, indoor climate and energy performance of dwellings*. Report 140. Tampere University of Technology (in Finnish), ISSN 978-952-15-2105-8, ISBN 1797-9161.



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The atmosphere may be our most precious resource. Accordingly, the balance between its use and protection is a high priority for our civilization. While many of us would consider air pollution to be an issue that the modern world has resolved to a greater extent, it still appears to have considerable influence on the global environment. In many countries with ambitious economic growth targets the acceptable levels of air pollution have been transgressed. Serious respiratory disease related problems have been identified with both indoor and outdoor pollution throughout the world. The 25 chapters of this book deal with several air pollution issues grouped into the following sections: a) air pollution chemistry; b) air pollutant emission control; c) radioactive pollution and d) indoor air quality.

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