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Technical Condition of Prefabricated Concrete Large Panel Apartment Buildings in Estonia

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ABSTRACT

The majority of apartment buildings built with prefabricated concrete elements (PCLPAB) were constructed primarily between 1961-1990. Today the first dwellings from this "constructional wave" are approaching the end of the service life intended by the designer. Commonly, the mechanical resistance and stability is fulfilled in most cases and the main problems relate to building physics, indoor climate, and energy efficiency. Despite the overall acceptable condition of external surface of external walls, serious problems with joints between panels (lack of wind- and water-tightness) exist. Status with the frost resistance of the concrete of the facade and balcony elements is of high concern. Facades need to be repaired, reinforced and/or protected. Serious thermal bridges are a major problem in old PCLPAB, resulting in mould growth, surface condensation, soiling of surfaces, larger energy loss etc. Mould growth and surface condensation on the internal surfaces of thermal bridges are unavoidable without additional external insulation and/or lowering internal humidity loads. The performance of ventilation in the studied apartments was very low and concentration of CO_2 was high. The buildings under study need extensive renovation. As large investments are needed to improve and maintain the quality of dwellings, renovations should be conducted in a cost-effective way. The largest saving here is to make the investment once and in a correct way.

KEYWORDS

Technical condition of dwellings, service life, energy efficiency, prefabricated concrete large panel.

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1 INTRODUCTION

In Estonia multi-storey apartnment buildings constitute about 60% of the whole dwelling stock. The majority (75%) of apartment buildings were built primarily between 1961-1990. Today the first buildings of that "construction wave" are approaching the end of their design life (service life intended by the designer - 50 years).

Service life is the period of time after installation during which a building or its parts meet or exceed the performance requirements. In most cases we may use six essential requirements set in the Construction Products Directive [CPD 1988] for the performance requirements: mechanical resistance and stability; safety in case of fire; hygiene, health and the environment; safety in use; protection against noise; energy economy; and heat retention. The service life of a building and its components is a function of: the quality of the component, design level, work execution level, indoor environment, outdoor environment, in-use conditions, and maintenance level [ISO 15686-2].

The overall living standards in the older part of the housing stock need to be improved to meet today's requirements in the functional, urban design, architecture and constructional-technical terms. The extent and selection of renovation works depend strongly on the technical condition of buildings and on the renovation works done. As thoroughgoing investigations and surveys are a good basis for the renovation design, different investigations should be done. During the 1990s many investigations [EKK 1994, EstKonsult 1996, Õiger et. al. 2000, Õiger 2006] were conducted in Estonia to find out primary renovation needs. Today, after 15 years, the possible decay has progressed, energy prices have increased, understanding about the quality of indoor climate and living condituons has changed. Therefore technical investications should be revised and up-to-date renovation solutions should be worked out. This paper presents the current technical condition of prefabricated concrete large panel apartment buildings in Estonia, but the overall results of the study about Estonian old multi-storey apartment buildings composed of prefabricated concrete elements are reported in [Kalamees et al. 2009].

2 METHODS

2.1 Types of Buildings Studied

Field investigations and measurements were conducted in prefabricated concrete panel apartment buildings (PCLPAB). Load bearing structures under study were: alongside and transverse, internal and external concrete walls and reinforced concrete ceiling (floor) panels. The external walls were insulated (by ~10 cm of fibrolite, mineral wool, phenoplast or expanded polystyrene) sandwich panels (U≈0.8…1.2 W/(m^2·K)) or 300…350 mm thick single-layer expanded-clay lightweight concrete walls (U≈1.2…1.5 W/(m^2·K)). PCLPAB represent one of the most common construction types for apartment buildings in the former Soviet Union. The main type-series of PCLPAB were: 1-464, 121, 111-133, 111-66, and 84. These types of PCLPAB were constructed in Estonia from the 1960s up to 1990. Today's Estonian housing stock is constituted of 96 % of privately owned and 4% of social (municipal) housing. As most of the buildings are privately owned (each apartment has an independent owner), it would be controversial and complicated to demolish these buildings.

Databases of the Union of Co-operative Housing Associations and local administration were used to select the buildings. Detailed research and long-term measurements were conducted in 20 buildings. In addition, visual investigation and expertise was done in a number of buildings. Building types, ages (min. 19, average 32, max. 48 years) and heights (5-9 storeys) all differed. The typical ventilation system was passive stack ventilation with window airing (referred to as natural ventilation in this study) and a one-pipe (less pipe material) system (typically without room thermostats on radiators) was the typical heat distribution system.

2.2 Research Methods

This research is composed of the following studies and measurements:

- preliminary work: collection of initial information about the drawings of the building, information about main damages, results of previous research and investigations in similar buildings, risk assessment, analysis of research alternatives, and drafting of the research plan;
- survey of conditions of facades (frost resistance (EVS 814), compressive strength (EN 12390, EN 12504), carbonization of concrete, quality of finishing joints between the panels, corrosion of reinforcement, salt depositions etc.);
- investigation of technical systems (heating, ventilation, water, sewerage, electricity, and gas);
- thermography investigation (EN 13187) and numerical simulation (EN ISO 10211) of thermal bridges;
- measurement of air tightness of building envelope (EN 13829);
- long-term (1 year at 1-hour interval) measurement of indoor climate (temperature, relative humidity, CO_2, performance of ventilation and heating) and internal humidity loads (moisture excess and moisture production);
- measurements (EN ISO 140) and calculations (EN 12354) of sound insulation;
- to analyze active mould content in air, the air sampler RCS was used; to determine inhabiting fungi on the surface of structural elements and the interior, the tape lift sampling was used;
- analysis of hygrothermal performance of external walls (EN ISO 13788);
- calculations of load bearing structures for possible extensions;
- financial viability of renovation and energy-saving concepts;
- questionnaire for the survey of occupant habits, typical complaints, and symptoms related to indoor air quality, etc.

3 RESULTS

Commonly, the first essential requirement of mechanical resistance and stability is fulfilled in most cases and the main problems relate to building physics, indoor climate, and energy efficiency. Mechanical resistance and stability may emerge as topical when the fulfilment of other requirements shows improvement. In the following some main technical problems of PCLPAB are described.

Despite the overall acceptable condition of external surface of external walls, serious problems with joints between panels (lack of wind- and water-tightness) exist. This was somewhat surprising because earlier studies have already highlighted this problem and proposed solutions for renovations. Unmade renovations indicate passivity of occupants to deal with renovation works that will directly repair dangerous defects or that are not directly cost-effective (some energy saving renovation works). Carbonization depth was 2…3 cm from the external surface (Figure 1, left). The small corrosion depth could be the reason because of corrosion of the reinforcement existing only when the reinforcement was very close (<1 cm) to the surface of the panel (Figure 1, right). As carbonization depth depends strongly on the age of the building, it is a question of time when the neutralization of the concrete takes place and the alkaline protection for the reinforcement finishes. Therefore, facades need to be protected.

The frost resistance of facade concrete was studied based on the loss of mass after 56 cycles of freezing and thawing. For the facade (frost resistance class KK1), the loss of mass should be ≤ 0.5 kg/m^2. Both the laboratory tests (Figure 2, left) and visual inspection of buildings (Figure 2, right) indicated to a small remainder frost resistance of the facade concrete and balcony elements (Figure 3). Only half of the specimens fulfilled the criteria for the frost resistance: loss of mass ≤ 0.5 kg/m^2. None of the buildings fulfilled the criterion for the frost resistance. Status with the frost resistance of the concrete of the facade and balcony elements is of high concern. Facades need to be repaired, reinforced and/or protected.

In all the specimens, compressive strength was over the value, $f_{c,cube}>15$ N/mm^2 that characterizes the compressive strength of the concrete mark 150.

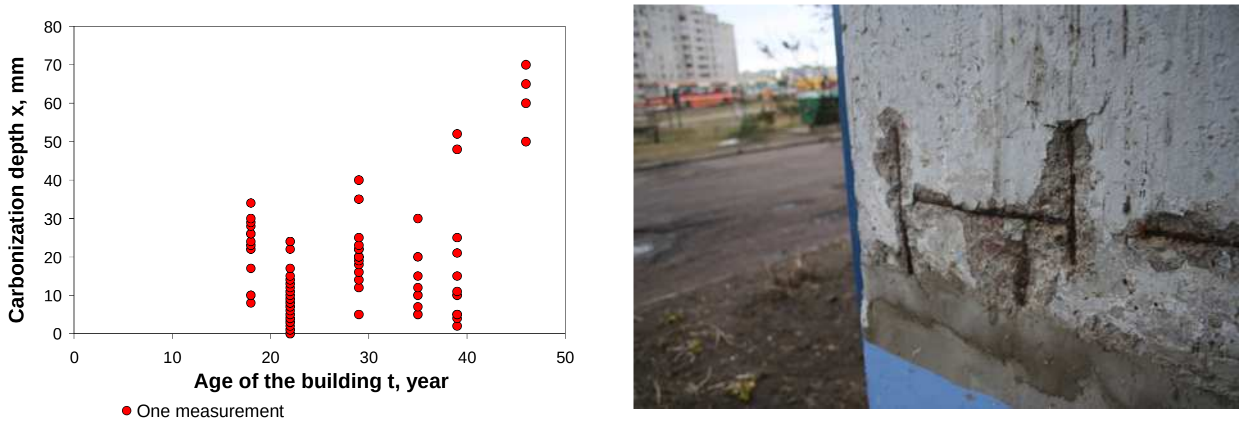


Figure 1. Carbonization (left) and corrosion of the reinforcement of the concrete facade (right).

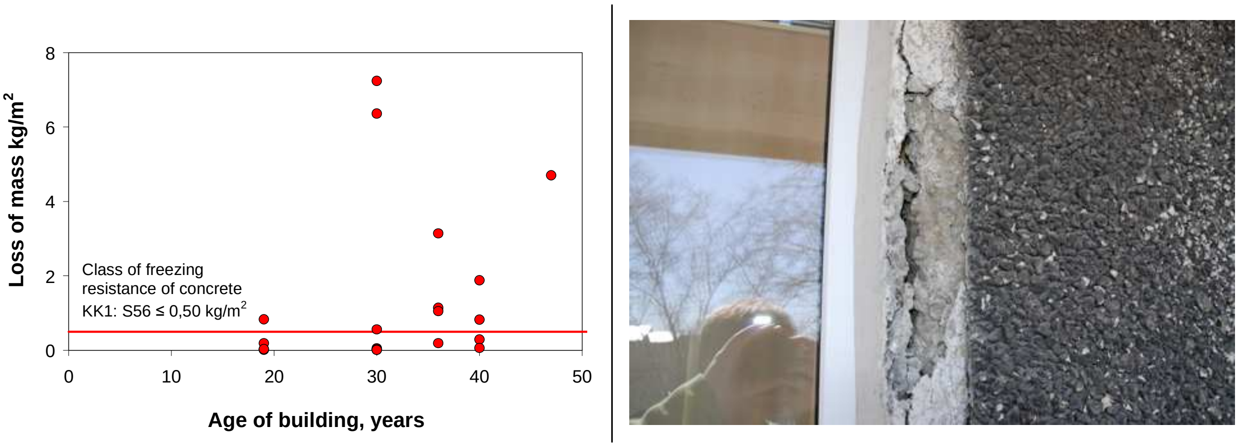
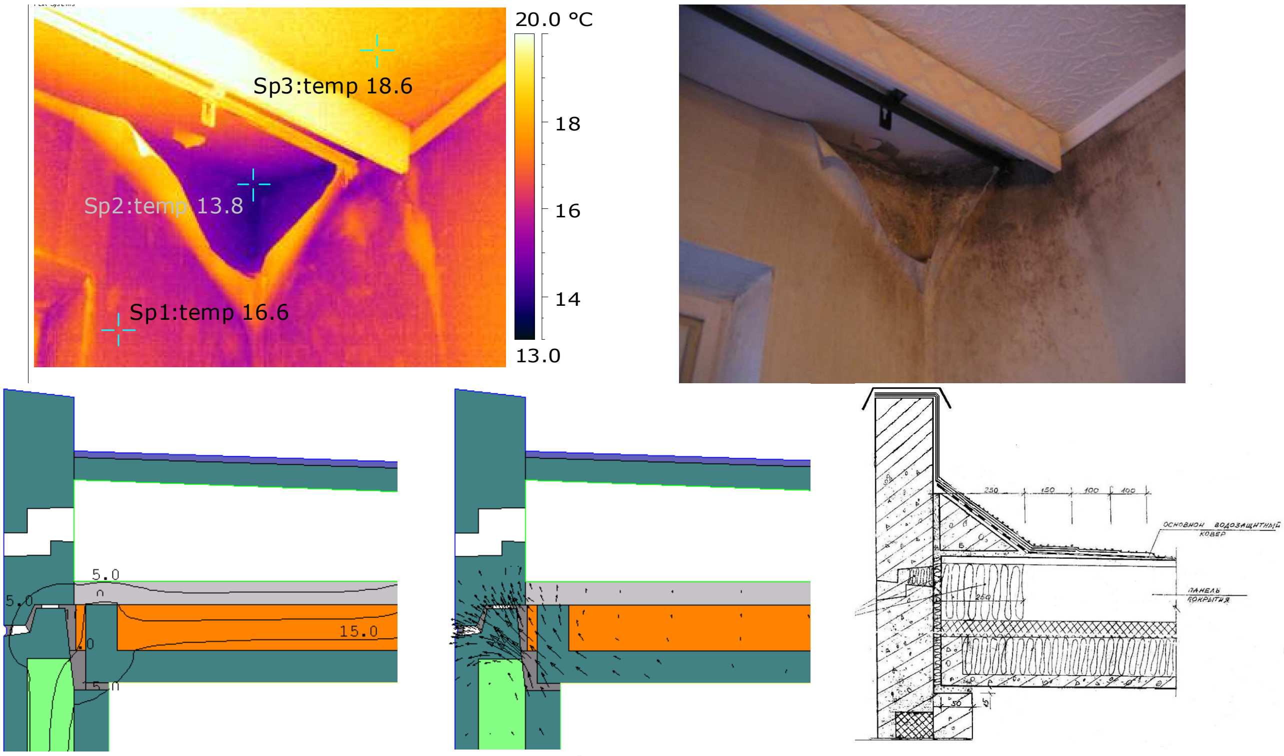


Figure 2. Loss of concrete mass of the facade panel during frost resistance tests (left) and decay of the facade due to low frost resistance (right).

Figure 3. Damages of balcony elements.

Serious thermal bridges are a major problem in old PCLPAB, resulting in mould growth, surface condensation, soiling of surfaces, larger energy loss etc. Field measurement showed that the main locations of thermal bridges in PCLPAB are: horizontal and vertical joints between external wall panels, junction of the external wall and the balcony slab, junctions of the external wall (especially end sides) and the roof, bonds between panels' inner and outer layers of the external walls, socket panels. The problem of thermal bridges is emphasized due to high indoor humidity loads (low ventilation rate and high moisture production) that are typical of PCLPAB. An average temperature factor $f_{Rsi} = \frac{R_T - R_{si}}{R_T} = \frac{t_{si} - t_e}{t_i - t_e}$ was between 0.56 and 0.73. The limit value of the temperature factor is between 0.65 and 0.8 depending on indoor humidity loads [Kalamees 2006]. Mould growth and surface condensation on the internal surfaces of thermal bridges are unavoidable without additional external insulation and/or lowering internal humidity loads.



Isotherms Flux vectors Principal drawing of the connection

Figure 4. An example of the thermal bridge in the external wall and roof connection: thermographic investigation (above, t_i=3°C, t_e=19°C), numerical simulation (below).

The average value of the air leakage rate at the pressure difference of 50 Pa in the entire database was q_{50}=4.3 m^3/(h·m^2) (min. 1.1 m^3/(h·m^2) and max. 15.1 m^3/(h·m^2)). The average value of the air change rate at the pressure difference of 50 Pa from the entire database was n_{50}=4.9 h^{-1}. Newer buildings proved more airtight than older ones. The declared value to be used for energy calculations (50 % fractile with a confidence level of 95 %) of air tightness of old (built 1) was $q_{50,decl}$= 4.7 m^3/(h·m^2) and $n_{50,decl}$ = 6.8 h^{-1}.

According to the current standard (EVS 842), the sound insulation requirements in buildings are R'w ≥ 55 dB for air noise and for impact noise L'n,w ≤ 53 dB. Measurements and calculations showed deviations from the target values. Sound insulation of separating walls was between R'w 47…53dB and that of floors was between R'w 48…53dB. The sound insulation index of the impact sound was between L'n,w 54…67 dB.

Indoor temperature and RH were continuously measured in 39 apartments in 20 buildings at 1-h intervals over a 1-year period. Figure 5 shows the overall view of the indoor temperature (left) and relative humidity (right) dependence on the outdoor temperature. The one-pipe (less pipe material) heat distribution system is typical of old apartment buildings. Typically there are no room thermostats on radiators and the system is typically fitted from standpipe valves. Room temperature was regulated in the boiler room based on the outdoor temperature. This results in large variations of indoor temperature and low correspondence of the indoor thermal conditions to the target values of the indoor climate standard. In 41% of the apartments the room temperature did not correspond to the lowest indoor climate category. Other problems concerning the heating system are: incorrect water flow rate of the heating system or risers, lack of direct room temperature control, difficulties to balance the one-pipe heat distribution system, lack of maintenance and improper modifications.

The performance of ventilation in the studied apartments was very low: average air change rate in bedrooms was 0.13 h^{-1} (cased on tracer gas (CO_2) measurement with closed windows). The performance of ventilation has worsened dramatically after the replacement of old windows. The replacement of windows without the renovation of ventilation results in lower air leakage and ventilation airflows. The concentration of CO_2 in bedrooms stayed between 370 and 3900 ppm. CO_2 concentration was below 1500 ppm only in three apartments. CO_2 concentration was above 1500 ppm during 26% of the measured time length (included also periods when the apartment was not used). It is practically impossible to increase airflows, if necessary, in apartments with natural ventilation. A possibility is to use window airing, but this may worsen the thermal comfort during winter. Because of worsened thermal comfort due to outdoor air inflow from stack (caused by wind), the occupants have sealed the stack and ventilation outlets.

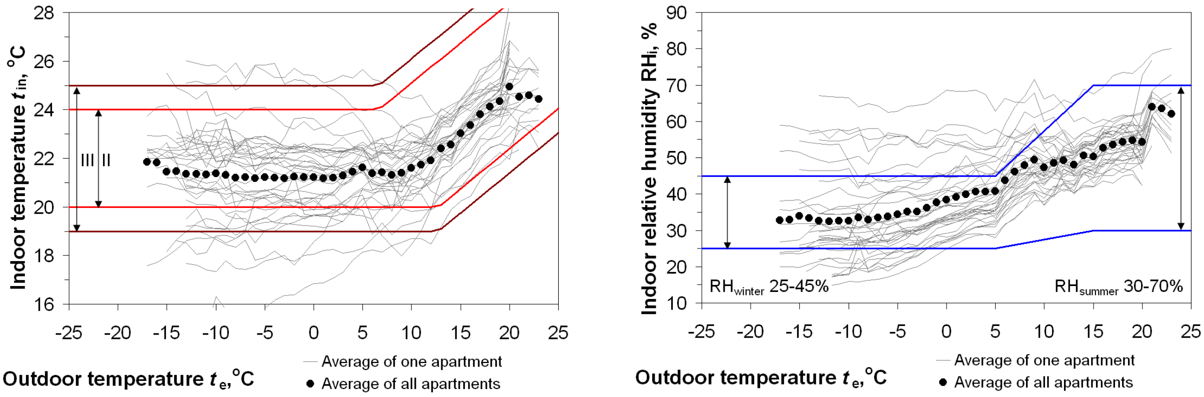


Figure 5. Dependence of the indoor temperature (left) and relative humidity (right) on the outdoor temperature in all rooms.

Indoor humidity load in the studied apartments 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.

The average annual specific heat energy consumption of old-type apartment buildings is 200…230 kWh/(m^2·a) (for space heating 170…220 kWh/(m^2·a) + for domestic hot water heating 15…50 kWh/(m^2·a).

Based on the questionnaire survey, the majority of occupants' complaints pointed out stuffy air (97% from answers), bad sound insulation (90%), condensation on windows (67%), mould growth (43%), high temperatures during summer (43%), and low temperatures during winter (27%).

4 NEEDS FOR RENOVATION

The condition of buildings is inadequate due to low requirements for energy performance in old building standards, historical lack of attention to the quality of 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 use, safety in case of fire);

- improvement of indoor climate (hygiene and health aspects, fulfilment of requirements to ventilation air rates and room temperatures);
- improvement of energy performance of buildings and HVAC systems;
- improvement of architectural planning, visual quality, overall living quality, and additional comfort.

The condition of main load bearing structures was found to be sufficient, allowing planning of renovation works instead of demolition. Similar results have also been obtained by other researchers [Roitman 1985, Ignatavičius 2000&2007]. The main renovation areas to guarantee mechanical resistance and stability include balconies, canopies, and facades. Balconies as the most badly damaged structures may need also rebuilding solutions. Because of low frost resistance and carbonization of facades, it is necessary to protect them. Improving thermal insulation of the building envelope (roof and walls), additional thermal insulation is unavoidable to remove serious thermal bridges. Therefore, additional thermal insulation is needed first of all to protect facades and to liquidate thermal bridges. As additional thermal insulation improves also the energy efficiency, the renovation work is double advantageous.

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

- performance of ventilation;
- hygrothermal performance of building envelope;
- performance of heating systems.

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). Energy performance can be improved by help of the heat recovery system with heat pumps (heat from exhaust air to heat up the domestic hot water of the heating system). The mechanical exhaust ventilation solution is not suitable for all types of buildings (especially for buildings with combined stack). Balanced ventilation with room units is another possible solution to renovation of the ventilation in old apartment buildings. During the design process the following questions have to be solved: where to place room units (a little space); how to solve problems with sound pressure levels; where to place air channels (rooms height 2.5m); how to solve air flow in the apartment through existing doors.

To allow for the temperature regulation in the room level, radiators should be equipped with thermostats. Other aspects that should be kept in mind in the renovation of heating systems are: correct control curve of the temperature of the supply water of the heating system, correct water flow rate of the heating system or risers, balanced heat distribution system, and correct maintenance and proper modifications of the HVAC systems.

In addition to technical problems, also social/human questions need to be solved: possibilities and motivation of occupants to cover the cost of renovation vary.

The buildings under study need extensive renovation. As large investments are needed to improve and maintain the quality of dwellings, renovations should be conducted in a cost-effective way. Current economical calculations show that depending on the extent of required indoor climate- and energy-renovation works, the price of the renovation is between 100…300€/m^2 (plus renovations to guarantee structural safety of buildings). Under a standard condition, a bank can give a loan of up to 160€/m^2. Although complex renovation may be needed, but all renovations do not decrease energy consumption (structural renovation, improvement on ventilation air rates). Therefore, without external support and improved living quality and longer service life of building taken into account, renovations may not be rational in terms of cost-efficiency. During the design process it is possible to compare and analyze different renovation alternatives. This allows for dwelling renovation works to be realized in a cost-effective way. The largest saving here is to make the investment once and in a correct way.

ACKNOWLEDGMENTS

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REFERENCES

CPD 1988. Council Directive 89/106/CE on the Construction Products.

EKK. 1994. 'Survey and renovation proposals of prefabricated concrete large panel apartment buildings in Mustamäe', (in Estonain).
EN 12354 'Building acoustics – Estimation of acoustic performance of buildings from the performance of elements', The European Committee for Standardization.

EN 13187 'Thermal performance of buildings - Qualitative detection of thermal irregularities in building envelopes - Infrared method', The European Committee for Standardization.

EN 13829 'Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method', The European Committee for Standardization.

EN ISO 13788 'Hygrothermal performance of building components and building elements -- Internal surface temperature to avoid critical surface humidity and interstitial condensation -- Calculation methods', The European Committee for Standardization.

EstKONSULT. 1996. 'Renovation of dwellings in Mustamäe district in Talllinn', (in Estonain).
EVS 814 'Frost resistance of normal-weight concrete. Definitions, specifications and test method', Estonian Centre for Standardisation.

EVS 842 'Sound insulation requirements in buildings Protection against noise', Estonian Centre for Standardisation.

Ignatavičius Č. 2000. 'Aspects of rehabilitation and modernization of dwelling buildings in Lithuania', Bautenschutz Bausanierung, 23 [1], 16-18 p. (in German).

Ignatavičius, Č., Zavadskas, E. K., Ustinovičius, L. 2007. 'Modernization of large-panel houses in Vilnius', Proc. The 9th international conference "Modern building materials, structures and techniques, Vilnius, Lithuania, 16-18 May 2007, vol. 1. p. 258-264.

ISO 10211-1. 'Thermal bridges in building construction -- Heat flows and surface temperatures -- Part 1: General calculation methods', International Standardization Organization.

ISO 140 'Acoustics -- Measurement of sound insulation in buildings and of building elements', International Standardization Organization.

ISO 15686-2 'Buildings and constructed assets - Service life planning - Part 2: Service life prediction procedures', International Standardization Organization.

Kalamees T; Õiger K; Kõiv T-A, et al. 2009. ‘Technical condition and service life of Estonian apartment buildings, built with prefabricated concrete elements’. Tallinn University of Technology (in Estonian).

Kalamees, T. 2006. ‘Critical values for the temperature factor to assess thermal bridges’. Proceedings of the Estonian Academy of Sciences. Engineering, 12(3-1), 218 – 229.

Õiger, K. 2006. ‘Examenation of Service Life and Serviceability of Concrete Element Houses’. Proc. European Symposium on Service Life and Serviceability of Concrete Structures ESCS-2006, Espoo, Finland, 12-14 June 2006, pp. 57 - 61.

Õiger, K., Hääl, K., Sasi, L. 2000. ‘Renovation and energy saving in multi-storey apartment buildings in Estonia’, Proc. Baltic Symposium on Indoor Air Quality and Building Physics: a satellite conference of Healthy Buildings 2000, Tallinn University of Technology, Estonia, 11-12 August, 2000, p. 36-49.

Roitman A. G. 1985. ‘Reliability of building structures in service’. Moscow: Stroyizdat., 176 p. (in Russian).