How to extend the service life of school buildings by improving their indoor climate conditions?

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Abstract. Mold- and moisture problems have damaged a part of buildings in Finland; typically, the problems have occurred in school buildings but also in other public buildings. Even relatively young buildings have suffered those problems. The reasons arise roughly from three factors: design defects, deficiencies during construction and use. The learning environment has deteriorated. Both pupils and teachers have had symptoms, in some cases they have been unable to use the building anymore. The procedure has been mostly a continuous repair cycle – the indoor environment and conditions have not always reached been at a satisfactory level.

In this presentation, firstly, the solutions and reasons to indoor air problems are presented in different cities and then is described, how the lifetime of two school buildings has been extended. The existing problems are described and how the indoor environment have been tried to make on safe and healthy level. In both cases the recent situation is analyzed, and then realized some renovation based on monitoring and measurements, which are briefly described. After modifications and repairs the buildings have been monitored during 2 years. The aim was to keep both buildings in use during a limited time. The use of the other building was discontinued and the other building will change the use. In both cases the community decided to try to extend the service life instead of a new school building. Massive and deep renovation was excluded because of the costs; there should be a way found how to have more time for planning and financing new schools without using temporary spaces.

The other building was over pressurized after repairs, which is not normally used; in other building targeted repairs were done.

In this presentation, the research and monitoring program, starting point, renovation measures and monitoring results are presented. Special attention has been paid to ventilation systems and also to the typical reasons for indoor problems – very often one cannot name just one factor, but the performance is depending on more than one factor.

The performance of a building depends on how well the building systems are integrated to operate together – envelope, heating, ventilation and automation systems – and also performance depends on the use, users and weather conditions.

Keywords: Buildings in operation, Renovation of buildings, Indoor environment and health, Moisture safety and water damage

1 Introduction

1.1 Problems in existing building stock

The Finnish educational building stock is relatively old; 19 % of the floor area is built between 1960 – 1969 and 21 % in years 1940 – 1959 [1]. In 2010 the share of educational buildings account for about 30% of the public building stock [2]. It is estimated that about 25% of school buildings are affected by moisture and mold damages [3]. The significant moisture and mold damages have been estimated in schools and kindergartens from 12 to 18%, with users of 200,000.

The costs caused by absences, sicknesses, decline of work efficiency, and on the other hand, by repairs, are high. Indoor condition surveys have made in every case using various methods. Mainly, depending on the assignment and doers, only a part of the factors dealing with indoor conditions have been resolved. Based on these results they have begun to make renovation plans. There are many cases where the indoor problems or symptoms have continued - a second renovation round has been done, and repairs have been continued. In many cases the school or part of it works in temporary relocation during deep renovation or waiting the new building.

Building codes and a new healthy housing degree 545/2015 (Ministry of Environment) and the its guidelines for application (Valvira/National Supervisory Authority for Welfare and Health, 8/2016) define acceptable conditions and limit values for indoor climate.

Indoor conditions are always a sum of many factors. The performance of buildings must be evaluated on the basis of different factors, all the reasons cannot always be found. The problems and damages have evolved over a long period of time. Through a holistic approach and extensive measurements and surveys can be found at least some of the causes that have led to indoor air problems. By repairs should make the work environment and conditions into such level, that working can safely be resumed in the building. For indoor air problems should be developed a comprehensive commissioning procedure. The most important to increase the building quality both in new and especially in renovated buildings. “Renovation debt” is a general term (used in all communities describing the investments needed) which describes the gap between the required investment costs and the available funding, when there are no resources to keep the building at an acceptable level. This may lead to demolition [4].

1.2 How the communities meet and have reacted to indoor condition problems

The indoor air problems in schools (and other type of buildings) have led in the worst case to removing from use or demolition of the school building, to the temporary relocation, to closing the whole building or part of it. Teachers and students get symptoms, and when the symptoms get worse, they cannot work in certain classes or in the school

building. The communities (and the building owners) react after complaints; cities have started various programs to mapping problems and to prevent them. It is noteworthy that these problems have become more pronounced in the last 10-15 years, even those damages have been found also earlier. The main reason for increased discussion are healthy problems recognized and connected with indoor environment.

Decisions and experiences of a bigger city. In a bigger city Oulu (in Finnish scale, 235 000 inhabitants) the Building Supervision Office (BSO) has developed quality control of buildings since the beginning of 2000`s. One form are different type of quality control guidance and information cards. Also, moisture management procedure for building sites has been created [5].

One new project is a quality card for commissioning of renovated apartment houses. In renovation of residential buildings (and other buildings) it is important, that the set requirements will be met and the building performs as designed and new repairs are not needed.

Even the most buildings perform as designed, there exist too much defects and problems, caused by design, realization and use. The existing building stock is a crucial in improving energy efficiency and indoor environment, because in the last years the volume of new building has been 1-2 % from the whole building stock and the buildings which require the most repair is built in 60`s – 80`s.

The building board of the city of Oulu established in June 2017 a group for the review of demanding renovation projects [5]. The board deals with part of building renovation permits. The audit team include experts of Building Supervision Office, from private sector, and additionally also other authorities, e.g. health inspectors, if needed. One of the essential results is to get a unified vision of different building sectors from that particular project. In Oulu area, there is at this moment buildings, also schools, which are not in use because of indoor air problems.

The measures required by the group, especially in the projects dealing with indoor conditions repair will give an important response for the requirement level and what type of subassemblies must be done in the project before the permit can be granted. Too often the parties engaged in a building project deals renovation project only with individual elements, and have not considered the building as a whole by sufficiently broad range. The legislation which defines the construction requires anyhow, that both the renovation and new building projects must be considered as an entity, not as a sample of single parts in buildings.

The coming regulations require, that ventilation will be designed almost balanced, unless, for example a clear negative pressure drop compared with outdoors in some room space is appropriate. This is concerning both new building and renovated targets. Balancing, means in the first place, supplied and exhaust air flow, but also that there will be no significant pressure differences e.g. between different ventilation service areas (sometimes it is needed to prevent dispersion of contaminants). Typically, in all existing school- and office buildings ventilation is controlled automatically by time of the day and other measured variables. The system is not originally designed to manage that there will be no pressure difference between service areas. A very typical example is pressure conditions between stairway and surrounding spaces.

New air handling units are also more accurate to adjust for managing pressure differences.

Condition and indoor environment assessments, middle-size city 1. A middle-size city (22 000 inhabitants) in eastern Finland was made indoor environment and condition assessments for many public properties.
Results will be used as a base to develop a new strategy for commercial premises and for facility management.

In the strategy for commercial premises a long-term renovation and action program is presented. Based on the assessment results, specific programs were also drawn up for the necessary measures to ensure the availability of buildings up to a larger renovation or replacement investment. The necessary renovation measures to ensure the use of the buildings have partially already been carried out. [6].

The biggest reasons for renovation needs have been;

- decreased indoor conditions
- building defects and damages
- especially changes of use (the most general case)

Significant reasons for indoor air problems are;

- concentrations in the air from structures
- these concentrations have increased after e.g. sealing repair
- after repair of building parts, e.g. change of windows
- when the ventilation rate is intensified

Air supply routes have been directed, in addition to existing air supply units, also to the air leakage points, especially if pressure conditions have not been checked. This means that part of supplied air comes through the structures, not from air supply units. The pressure conditions may also vary because of shortcomings in the control system or because of different running times – if there are several different ventilation units in use.

The most important reasons for the presence of indoor air problems in the building stock in that city, according to the studies are;

- over time increased repair debt, because: refurbishments and partly maintenance operations have been moved into the future; there has not been possible to budget enough money for the investment program for renovation/replacement investments
- problems to control and manage make-up air and pressure conditions of buildings; this is seen especially in the targets, where mechanical ventilation is increased or boosted
- supplied air is infiltrating to the room space through wrong places, e.g. through structures which contains impurities
- the selection of a contractor only based on price competition can often lead to the choice of low-quality contractor; too busy timetables in the projects, which leads critically short drying times of materials and too short testing and balancing period before in-use
- deficiencies of weather protection in the building site – building parts are wetted in some stage of building process, e.g. because of improper storage

- defective indoor air related guidance and control in building- and renovation projects – this applies both design-, realization and use stages.
- the tightness of ventilation ducts is also important, e.g. in the breakthroughs where ducting goes through different material layers like insulation etc.

The most common reasons are listed above, but depending on the target, also other causes have occurred. They can be summarized, that almost all risk presented in sc. DryChain-10 [4] risk list has been realized in some constructions.

The city authorities have also used overpressurization in some buildings, which have had indoor air problems. By that way the service life of the building has been extended before decommissioning.

Indoor environmental problems, middle-size city 2. In another middle-size city (20 000 inhabitants, in Middle Finland) the users in two schools (high school and secondary school) started to complain about indoor air problems. In these two case-study school buildings, the learning environment could be improved; but unfortunately, the symptoms of some users continued.

Thereinafter is the overview of the indoor problems of the two schools, of the research method and the repairs made [7].

2 School cases

2.1 The aim and objectives of the study

The city authorities (middle-size city 2) decided to find a way to extend the service-life of two schools instead of relocation or demolition for a limited time (2 years), after a new high-school building was planned to build and the secondary school was planned to change the use. The question was how to improve the indoor environment of these schools into an acceptable and safe level to work. The procedure is presented in the next three chapters. In both schools a systematic research program was carried out, and after renovation works based on recommendations of the studies, the indoor environment was monitored during the rest service life. The research program is introduced in the chapters 2.3 and 2.4.

2.2 Background

The first target building 1. *is a high school building (case 1.)* in Middle Finland. The teachers and students had symptoms caused by indoor conditions for years. Some students have not been able to study in the building. The original stone-made building is from 1959. The three-part wood-made extension has completed in years 1964-1968. This extension is on a slope. The property includes a sports facility connected with the older part. The total gross area is 7958 m2. The building has mechanical ventilation with heat recovery and it is connected with district heating system.

The school has been repaired since the mid-90's, when the ventilation system was renewed. In 90`s several roof leaks were found in the new part of the building. Moisture

damages have been found in other places, too. In the late 2000s sealing repairs have been made and some changes and new installations in ventilation systems have been made.

Earlier made studies were used to define the need for repair. In performance evaluation has come forward that the building could temporarily be over pressurized. The total performance evaluation of the building was made in terms of indoor environment, including the evaluation of starting point (2014) and a proposal for urgent repairs. The object was also to introduce measures, using which the school could be used during two next years (2014-2016) without to take temporary relocation in use.

The new school building was due to be completed 2016, but it was delayed to 2017. The newer part of the old school building was demolished.

The other school building 2. (case 2.) was also in the same city, a stone-made *secondary school*, built 1953. The users had indoor air-related symptoms. 40 % of teaching staff have had symptoms. Part of the teachers and pupils could not work in the building. The building had 4 aboveground floors, an attic and a basement. The gross area is 690 m2 and volume 27200 m3. The school was renovated in 1975 and repaired during 1993-1996. The ventilation system was renewed during the second repair cycle. Kitchen and dining room were renewed 2012. The building is connected with district heating system and it has mechanical ventilation with heat recovery. The building is locating on very wet ground.

During 2013 a condition survey and condition assessment was made. Microbe damages were found from intermediate floors. The room spaces were usable except two classrooms. However, it was found in order to maintain the usability of the premises, measures should be taken to bring the building to a level that is in line with current indoor air quality standards.

A holistic performance evaluation was made in 2015 in terms of indoor conditions, including the mapping of existing situation and a proposal for urgent repairs. The need for repair was found out, and alternative measures, that the school was possible to keep in use to the end of 2018. After that the building will change the use.

In both cases during the final use stage on-line data collection was used to confirm the proper working conditions [8].

2.3 Case 1. High school (target building 1.)

To define the starting point and preliminary need f of repair the following program was realized (stage 1, in 2014):

- mapping the recent situation and a proposal for urgent repairs, based on existing material, documents, site visits, measurements and condition assessments in the site
- air tightness measurements by blower door and own ventilation system, air leaks location by IR-camera, main air flow measurements of ventilation system, supplied and exhaust air flow measurements both pressure condition measurements in selected classrooms
- separately defined indoor condition- and concentrations measurements and sampling for microbe surveys

- interviews of users and maintenance staff, conclusions and reporting

During the first stage (2014) new repairs were carried out. Two wings of the newer part removed from the use by a solid partition wall. All materials and furniture in classrooms were cleaned (HEPA-vacuum cleaning, wipeout and fumigation), also sealing of structure seams. In addition, changes have been made to the ventilation system and ventilation was intensified and service areas were isolated from each other at a door. The school building was decided to be overpressurized during the rest of its service life (2 years).

Stage 2 included monitoring of indoor conditions, concentration measurements and analysis of results from 2014 on. Indoor conditions were monitored 2014-2016 in separately selected rooms during 6 periods, the periods being from one week to one month. The monitored factors were:

- pressure conditions between indoors and outdoors, air flow measurements
- indoor conditions: relative humidity (RH), room temperature, carbon dioxide (CO2)
- microbiological studies by contact plate sampling from surfaces
- thermography and air tightness test before and after repairs

2.4 Case 2. Secondary school (target building 2.)

The research plan followed mainly the plan for high school (target building 1.).
The baseline was checked in 2015, including the controls of ventilation systems, the indoor air quality, sealing of structures. The first report was given in autumn 2015 and the building was monitored 2015-2017 like in the case of the high school.

3 Results

3.1 Case 1. High school (target building 1.)

The air leak number n50 of the newer part was 3 1/h. The air tightness n50 of the older part was 1,5 1/h, without sport facility 1,7 1/h. The values represent typical values of construction time, but 3 1/h is too high considering air leaks, moisture transfer and concentrations the air tightness of these two closed wings in the newer part was worse than in the other part. Based on the measurements, sealing measures for several targets were suggested.

- increased concentrations were measured by contact plates in some classrooms
- ventilation pipe of a sewer channel was too close to air intake of one ventilation unit, possibility of contaminant dispersion to interiors – the position of the vent pipe was moved and the pipe was raised
- in the beginning of the 2. stage, after the changes, one part of the newer school was still slightly under negative pressure, otherwise overpressurized - the room spaces suggested to be overpressurized in the level of +5 Pa, the older part of the school was overpressurized as planned

- CO2 level of exhaust air in the older part was max 500 ppm, in the newer part 700 – 800 ppm, in some classes indoor temperatures and CO2 were relatively high during workdays
- some shortcuts from air supply units to exhaust caused by air distribution method, air exchange efficiency was decreased
- additional changes in ventilation

Monitoring was launched in autumn 2014 according to the plan. Feedback was sent to the customer (city authorities) after each monitoring period, and changes or control measures were suggested if needed. Indoor conditions had reached a satisfactory level, based on the monitoring results from the view of the learning environment. Although in individual classrooms, at times, they may be close to the limit values. Microbe contents have remained at a low level. Nevertheless, the questionnaire conducted to pupils who entered the school in the autumn of 2015, showed that also the new students had symptoms. According the measurements the ventilation system was performing according to regulations – but in positive pressure difference as adjusted, to prevent that contaminants from the structures would not infiltrate to indoors. According microbe surveys, the level of various microbes was below the limits.

3.2 Case 2. Secondary school (target building 2.)

A baseline study was done in the summer 2015. Following measurements were made in selected classrooms:

- air tightness measurements
- indoor thermography to locate air leak points
- air flow measurements, indoor air and concentration measurements
- moisture measurements of structures, structural analyzes and microbe surveys

Air tightness number n50 varied in 2nd – 3rd floor between 1,8 – 2,2 1/h, in 4th floor 2,6 – 4,6 1/h. The highest value is too high even the other values represent typical values of construction time. The classrooms in the top floor were leakier than the classrooms in the other floors. The higher values in the top floor indicated that there are leaking areas from the roof and the attic. These figures also include internal transfer leaks from surroundings. Part of the measured classrooms were overpressurized. According to the monitoring results and based also on earlier condition surveys, part of the classrooms had been at least part time overpressurized, part time depressurized.

If there are impurities in the structures, changing pressure conditions can drive contaminants to indoor air and, in the other hand, moisture into the structures. The ventilation system must be balanced and there should not be pressure peaks.

Following measures were suggested:

- running time adjustments of ventilation units, performance evaluation of ventilation units (is there fluctuation)
- adjustment and control of air flow rates (must be in balance floor by floor)
- cleaning of the ducts and terminal devices
- recording and reporting of ventilation measurements in accordance with user needs

- regular filter changes and more attention paid to regular maintenance operations (ventilation)
- seaming of the structures

Internal air flows, caused by pressure difference were defined by smoke tests. Industrial mineral fibers were examined from ventilation system, from ventilation units in from the inner surfaces of supply air ducts. In addition, structural analyzes were made.

The inner surfaces of the building were in normal condition, taking into account the age of the building.

The pressure conditions in the building were varying, the reason could be in part changes in air flows (fluctuation). The air flow data was not available afterwards from the building automation system. Based on air flow measurements, in some classrooms the air exchange rate could fall short, possibly because of shortcuts from air supply units to exhaust vents. Microbe levels were within acceptable levels.

4 Conclusions

It is important, that the main air flows and other factors could be monitored in real-time. That`s why the data collection and processing capacity should be improved. Also, the size of database should be kept limited, but the data should be available to be processed to useful information according to stakeholder's needs.

The factors which affect the performance and indoor environment of a building are:

- building envelope
- heating, ventilation and automation systems
- use and maintenance
- external and internal loads, weather conditions

The structures and building services (HVAC-systems) must integrated to perform well together. The performance must be at a level, that there will be no renovation debt and it is safe and healthy to use the building. Target 1 (case 1) was built in two parts, the new part was a three-part building, built on a descending slope. Target 2 (case 2) was originally built on a wet ground, and water was pumped continuously out from the basement well. Target 2´s (case 2) structures were in a relatively good condition, despite its age. Target 1 (case 1) had roof leaks over time in the lightweight new part. The building was close to a big industrial plant.

The indoor air problems begun (or it was informed) after ventilation systems repairs in both buildings. When pressure conditions changed strongly, the contaminants from the structures are transmitted to the indoor air.

During the monitoring period, the target 1 (case 1) was tried to keep overpressurized, and air flow rates in accordance to the building codes. Some problems occurred in the control of the ventilation system in the target 2 (case 2), pressure conditions varied and the reason for that was some sensor installation problems. The control of pressure conditions is important – it is difficult if the service areas of each units are not isolated from each other.

In school building the use and load of the classrooms is varying; if the control is based on temperature/CO2 of the total exhaust air flow, the divergent load of one class may remain undetected.

The maintenance of the buildings had properly handled.

After the adjustments, tuning and after targeted light repairs the both schools met well the requirements, but still some symptoms occurred, also among the new pupils who had come to school after the repairs. The repair and research costs were according to the city representatives only approximately 1/10 of the costs compared with relocation.

The sealing of structures in old buildings is difficult. It is almost impossible to attain the current good level of air tightness. The importance of pressure conditions and balancing of ventilation is growing.

A holistic approach is needed, where the structures, HVAC-systems and user's experiences must be examined. The measures should be planned based on them. When selecting research methods, we must often compromise between the extent of measurements and the costs. It would be better to have a covering study in the beginning. Using the recent technology, the building performance could be considerably improved. Facility management is using "management by information" – also in addition to remote control of buildings – which requires to process the measured data to useful information [9]. Data processing and reporting is one part of "management by information". Big amount of data is useless if it not processed (and pretreated) by proper way.

5 Summary

The aim was to extend the service life of two schools, which had indoor air problems. In both schools, some users had symptoms, and some students could not work in the school. Instead to move the activities to a temporary relocation, the city authorities decided to find a way to extend the service-life of both school for 2 years. The new facilities for high school (case 1) was planned to completed 2016, but must postponed to 2017. After that part of this old school was demolished. The secondary school building (case 2) will change the use after 2017. A concept was planned to implement the program – how to keep these schools safe and the learning environment so that the work can continue. The initial situation was mapped in both cases, and after urgent repairs – based on the condition survey – indoor environment was monitored during the rest service life. The repair in both cases were mainly cleaning, sealing (structures) and readjustment of ventilation systems. The operation conditions were attempted to change so that the learning environment would be at satisfactory level. The indoor conditions were monitored in aim to ensure and verify the performance of the building. Based on the results and measurements, indoor environments were at the appropriate level during the monitored time. In the high-school building the solution was to keep the building overpressurized, which normally is not recommendable.

The problem was people who already were exposed; even the improved indoor conditions could not recover them. One can say that based on the measures carried out in school buildings the indoor environment was at acceptable level during the rest of the

service life - the goal was to keep the schools 2 years in use and reach healthy and safe working conditions.

The reasons for indoor air quality problems were caused by many factors in both cases. The reasons could be divided roughly into two parts: ventilation caused reasons and structures related things. The problems have evolved over a long period of time, and principally are depending on each other. Pressure conditions, which depend on the performance and adjustment of the ventilation system and air leak routes are the most important reasons in these targets – but in each case, there are other factors, too and also reasons due to design and building defects – form the construction stage on. It seems that more attention should be paid to ventilation systems and especially pressure conditions, also to pressure differences inside of the building.

When indoor problems start to occur, it is important that a holistic procedure is in use. Because the performance is the sum of many factors, which affect each other the attention must be paid all the factors - even if one obvious reason is found. There is still lack of concepts and procedures (such as building commissioning).

On-line measurements and monitoring are needed; the problem of many building automation system is that afterwards is difficult to find trends, if these trends are not preset; also, the instrumentation does not necessary serve the needs of facility managers and users. Because of the extent of the problems, and the biggest building stock is built in 60`s – 80`s there will be unfortunately new problem cases expected.

The building performance problems should be prevented rather than to correct them afterwards. By wrong measures the buildings may be unusable, by proper measures the service-life can be extended. Very often we are investigating the exact consequences but we should get also into the causes. The main reasons to close the school or move to relocation facilities are symptoms that are considered to be caused by growths and microbes, but the improvements and solutions demand a sufficiently comprehensive and systematic review.

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