35TH AIVC-4TH TIGHTVENT & 2NDVENTICOOL CONFERENCE, 2014

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ABSTRACT

The aim of improving air tightness of structures is to prevent the uncontrolled air leakages through structures. Built environments contain microbes, particulate and gaseous impurities but removing them is not always necessary. For example, an ageing building envelope commonly contains microbial impurities even when there is no obvious moisture damage. Air leaks convey impurities to indoors where they can lead to poor indoor air quality and associated health problems. Air leaks have also negative impact to energy efficiency and living comfort.

An air tight building envelope prevents air leaks through the envelope structure. Common air leakage places are the joints of structures, i.e. the joint of ground slab and external wall and untight inlets of the envelope. The joints of the structures are typically not air tight without detailed planning. In Finland an air tight building envelope is taken into account in the building regulations and therefore airtightness is relatively good in the new construction. In the existing buildings improving airtightness of structures is a relatively new concept. It can be used in a combination with other renovation methods to solve indoor air quality problems in buildings. In Finland several techniques have been implemented in order to prevent uncontrolled air flux through the structures since 1980's. In practise the air tightness renovation method has been successful in indoor air quality problems in buildings.

The main principle of moisture or microbial damage renovation is that before installing new building materials all moisture or microbially damaged materials are removed and the source of the problem is identified and fixed. However, in practise it is often impossible to remove all impurities and therefore improving airtightness of the new structure has an important role in completing a successful renovation. Improving of airtightness must be applied on to the whole building envelope. Air tightening renovation is never a single renovation action but always a part of other action. The air tightening material must be elastic, safe and long lasting and tested for its purpose. Improving airtightness requires planning, accurate execution on the construction site and supervision. Quality control measurements are in a key role to success. Quality control measurements are done visually and with the trace-gas leak test. It is very important always adjust the ventilation system to match the changed pressure difference.

In Finland there are no guidelines for planning, execution or supervising air tightness renovation method. It is planned to start certification training and publish first guideline in 2014.

KEYWORDS

Improving air tightness, air leakages, microbial damages, indoor air quality, repair method

1 INTRODUCTION

Poor indoor air quality associated problems can have a major impact on occupant health and comfort. Indoor air quality problems in western countries in homes, schools and offices are often caused by complex, inter-related issues. The problems can be caused i.e. by moisture damages, microbial damages, harmful substances, radon or other impurities. In external envelope structures and in the soil under building's ground slab there are almost always some microbial based impurities and radon which can affect negatively to the indoor air quality when transported with the air flux into the room.

Structure's joints are not automatically completely tight and therefore their implementation requires detailed planning. Common air leakage places are the joints of structures, i.e. the joint of ground slab and external wall and untight inlets of the envelope. There is usually air flow from outside to inside the building caused by the building's pressure ratio. The building's pressure ratio is determined by interaction of wind, chimney effect and ventilation as well as the usage of the premises. The pressure ratio will vary and can change very fast and strongly. As a result the air flows from one room to another, between floors or through envelope structures. The air flow conveys heat, moisture and impurities such as particles, mineral wool fibres, microbial and gaseous impurities, radon and other harmful substances.

The aim to improve air tightness of structures is to prevent the uncontrolled air leakages through structures. Methods used to improve the air tightness in structural renovation are called air tightness renovation. Using air tightness renovation energy consumption can be decreased, moisture convection can be prevented and uncontrolled air leakages through structures, junctions and inlets are cut off. The poor indoor air quality associated problems can be decreased and prevented with airtight structures. In Finland, improving airtightness of structures has long been a stabilized renovation method for prevention of radon. In practise air tightness renovation method as part of a larger entity has successfully solved the indoor air quality problems in buildings.

Air tightness factor has been taken into consideration in the National Building Code of Finland and in the regulations of new building. In the existing buildings improving airtightness of structures is a relatively new concept. Practice has shown that the air tightness renovation as its own is not sufficient but requires other actions to solve the problems. An air tightness renovation can fail due inadequate planning, careless implementation or lack of quality control at the construction site. Additionally some structures might have been air tightened where it is not a suitable method. Lack of understanding structures building physical functionality has even caused further damages. In Finland the experts working with the indoor air quality problems have different opinions regarding using the air tightness renovation method, its effect in the indoor air quality, its durability and its effect to the life cycle costs for buildings. Therefore several projects have been started to develop common procedures and guidelines this year.

Demolishing and building new is one option to solve an indoor air quality problem, when the structure is at the end of its lifecycle. In some cases demolishing and building new might be economically better option than renovating old. Demolishing and building new is not always possible for economic reasons. In old protected buildings demolishing is often not permitted. In some cases to remove a small quantity of impurities would require unreasonable demolishing actions. In old buildings it is not possible to remove all risk structures or contaminated materials. It is a fact, that built environments contain microbes, particulate and gaseous impurities but removing them is not always necessary. For example, an ageing

building envelope commonly contains microbial impurities even when there is no obvious moisture damage. The impurities are simply conveyed from outdoor and from soil under the building. As it is not always possible to demolish and build new structures, optional renovation methods are needed, i.e. air tightness renovation. There is also need for more solutions to solve indoor air quality problems.

2 AIR TIGHTNESS OF STRUCTURES IN RADON PREVENTION

Radon is odourless, colourless, harmful and dangerous gas. Harmful quantities should not be released into living spaces. In the National Building Code of Finland it is stated that tight uniform slab solution is safe in respect of radon. Air tightening of the joint between a ground-supported slab and the enclosure wall is necessary, when the enclosure walls are constructed separately. Additionally tightening of lead-ins is extremely important in all structural solutions. A tight concrete structure not susceptible to cracking prevents the penetration of radon through the structure. (Ministry of the Environment, 2004)

Radon prevention methods are e.g. air tightening of the ground slab and enclosure wall and under pressure solutions of soil under the ground slab. In Finland, the air tightening method to prevent radon has been used for decades and it is an established renovation method. The oldest radon renovations with air tightness solutions have been done in the 1980's. Radon is a good indicator for successful air tightness renovation i.e. how much soil-borne air containing radon leaks into the room spaces. Therefore radon measurements before and after the renovation can be used in evaluating the success of the air tightness renovation in radon areas. (Kettunen et. al, 1991)

The essential requirement for preventing radon by air tightening structures is that the air flow paths are cut off totally not only partly. The implementation of air tightening has to be done carefully. When the renovation has been planned, the work has been performed carefully with quality controlling, can the radon containing air leaks into indoor air cut off totally. When the air leakages are cut off, the only way radon can be conveyed through structure is by diffusion. The impact of diffusion is irrelevant for indoor air quality. (Kettunen et. al, 1991)

2.1 Air tightness of external envelope structures in new buildings

The National Building Code of Finland for new buildings requires air tightness for external envelope structures. The air tightness is usually done with vapour barrier which functions at the same time as an air barrier. A massive concrete or brick structure can also function as a vapour and air barrier structure. In an air tight building the supply air is not taken through air leakage but controlled through supply air valves or through mechanical ventilation. (Ympäristöministeriö, 1998, 2010, 2012a, 2012b)

According the National Building Code of Finland, in respect of functioning of the ventilation system, moisture technical functionality, good indoor air quality and energy efficiency reasons the air leakage value q_{50} for envelopes in new buildings should be not more than 1 $m^3/(h \cdot m^2)$. However, it is allowed to be up to 4 $m^3/(h \cdot m^2)$, in some special cases even higher. However a low air tightness value measured from the building does not guarantee completely air tightness of the envelope structures. There can still be locally significant air leakage points. Therefore careful tightening of joints and inlets is very important. (Ympäristöministeriö, 2012b; RIL 107-2012)

Structure's joints are not automatically completely tight and therefore the implementation requires detailed planning. E.g. for ground floor concrete slab it is typical that after casting, cracks will occur at the edges of the new concrete slab due shrinkage which is associated with

drying of concrete. Also cracks can occur at the corners and around pillars due to drying shrinkage. Therefore in concrete structures' joints there are without exception discontinuity points for air leakage if the air tightness is not specifically planned. There is an example of air tightening principle for the ground floor concrete slab in figure 1. The same principal is also used in preventing radon.

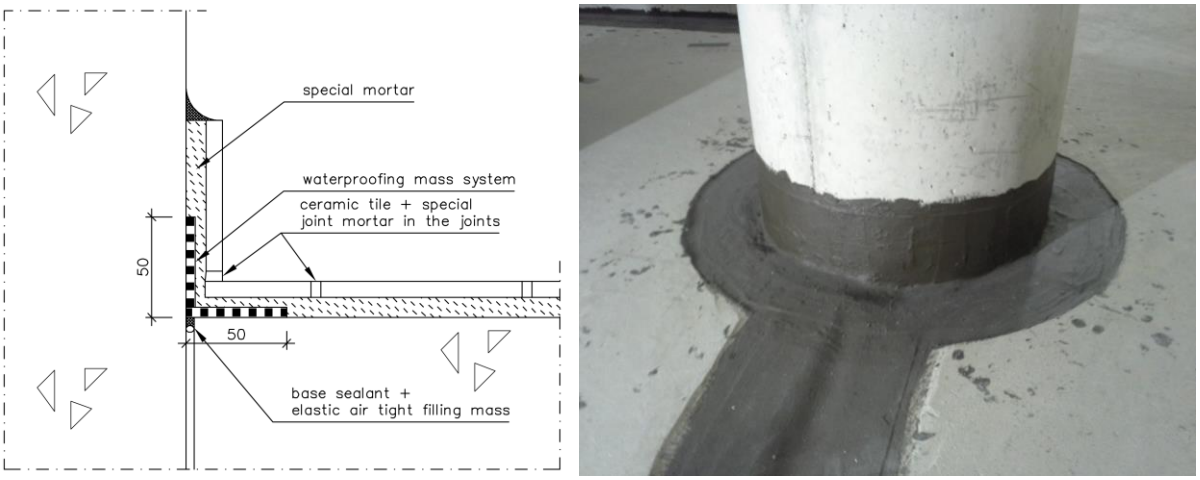

Figure 1: Principal solutions for ground floor concrete slab and concrete wall or pillar joint air tightness renovation with waterproofing mass system. Extract from a plan and photos from impletion at the site.

3 AIM FOR AIR TIGHTNESS OF STRUCTURES

3.1 Effects of air tightness on structure's functionality

Improving air tightness of envelope structure has a positive effect on the following factors:
1. Reduction of energy consumption
2. Prevention of moisture convection
3. Prevention of impurities entering through air leakage flows

Additionally an air tight envelope is a fundamental condition for a reliable and energy efficient mechanical ventilation system. By improving air tightness the living comfort can be improved as the feeling of draft is decreased and the temperatures of inner surface will increase. (Vinha, 2014)

Improving air tightness of envelope structure has a negative effect on the following factors:
1. Air flows drying the envelope structure will decrease
2. The natural moisture of new construction materials e.g. concrete dries more slowly.

However not all air flows through structures have a drying effect. The relative moisture content of soil's porosity is almost 100 % RH and therefore the air flows through ground slab do not dry the structures. In general, the structures should not be tightened without survey, planning and supervision. The building physical behaviour of the tightened structure must always be evaluated prior to the actual renovation.

New low energy construction concepts are challenging especially regarding thick insulation layers and drying of structures. The significance of water vapour and air tightness of inner surface of external envelope will increase. The moisture obtained during construction time dries out more slowly in thicker insulation layers in the absence of air flows through structures. This sets tighter requirements for the site moisture management and weather protection. In some cases the structures need to be dried during installation.

Reduction of energy consumption. The actual effect of air leaks on energy consumption depends on e.g. air leak distribution and pressure differential over the envelope structure. Air flow through structures reduces thermal insulation and cools the structures. Improving air tightness with current heat insulation material thicknesses is a one of the most significant and inexpensive means to reduce energy consumption in modern, already energy efficient buildings. However, the usage of buildings and the habits of the residents have an effect on energy consumption. E.g. window ventilation can increase significantly the need for heating energy in otherwise air tight building. (Vinha, 2014)

Prevention of moisture convection. Air leakages may carry significant amount of water vapour into the building envelope. Moisture damages can occur, when the moisture condensates on the cool surfaces. Moisture provides favourable condition for local microbial growth inside the structures. Harmful moisture convection will decrease when the inner layer of the envelope structures are air tight. Also cooling of the surfaces due to cold air leaks will cause condensation risk which can be controlled by preventing air flows through structures.

Prevention of flow of impurities and its effect on the indoor air quality. There are several factors influencing the indoor air quality. Physical factors, chemical and microbiological impurities, concentration of particles and fibres can be examined using different measurement methods and results can be verified against guidelines in the literature in order to get objective results. Indoor air quality is experienced by each individual subjectively and is affected by individual differences and physiological factors. (Sosiaali- ja terveysministeriö, 2003)

The impurities have a negative effect on the indoor air quality. With air flow through leakages microbial impurities, particles, radon and chemical impurities or other harmful substances can be conveyed into indoor air. Also noise and smell from smoke or food can enter indoor. By air tightness renovation, the inner surface of the structures is made airtight so that the air leakages are cut off. The air tightness of structures will also improve fire safety by slowing the spreading of flue gases. In general, air tightness of inner shell structure has a positive effect to indoor air quality. (Sosiaali- ja terveysministeriö, 2003)

Studies related to air tightness renovation has been done relatively few. In general it is known that with air tightness renovation the impurities entering through air leakages can be prevented and the flow of gaseous impurities will be slowed down. It is not known, what kind of concentration of impurities can be conveyed with air flow. The speed and significance of microbial transportation through materials with diffusion is also unknown. There are no health based limits to evaluate the significance of microbial based exposure. Generally it can be estimated that air leakages convey more significant concentration of impurities than diffusion. The importance of the air tightness of the structures of the indoor air quality is not specific determined. There is a need for some research.

4 PLANNING OF AIR TIGHTNESS RENOVATION

4.1 Air tightness testing methods in existing buildings

Before planning for air tightness renovation and implementation on site, the required actual data has to be collected. The locations of the air leaks in structures can be clarified accurately with tracer-gas leak testing method. In the test the tracer gas is led into the tested structure from where gas leaks along with the air flux into the direction of under pressurized room. In the room the trace gas is detected and the leakage points are located with tracer gas analyser.

The air tightness of building envelope structures can be evaluated from architectural and structural drawings showing the implementation method and materials used. The discontinuity points in structure such as gaps and cracks can be found by visual inspection during site inspection. by opening structures e.g. by removing skirting and window trims, the implementation method of joints can be evaluated. Air movement near joints can be observed by sensory smoke gas. Thermal leakages and some air leakages can be detected with an infra-red camera.

4.2 Principles in planning improving air tightness renovation

When renovating an existing building the aim is principally to achieve the same air tightness as it should have had originally. Renovations are always compromises between technical and building history point of view and e.g. the protection degree of the building may have an effect on the renovation method. When planning an air tightness renovation, the air tightness of the whole envelope structure should be taken into consideration. Air tightness renovations implemented on individual structures or premises do neither significantly improve the air tightness of the building nor decrease the impurities in the indoor air.

Air tightness renovations are not suitable for all structures. In general, the structures should not be tightened without survey, planning, supervision of renovation and control. The building physical behaviour of the tightened structure must always be evaluated prior to the actual renovation. Structures with microbial or moisture damage should not be tightened. Damage is removed from the structure and the cause of the damage is fixed.

Improving air tightness is not a sufficient method for blocking all harmful substances from entering indoor air. E.g. for petroleum hydrocarbons other actions need to be used. When removing of harmful substances is not possible, encapsulation renovation can be used. Encapsulation is a renovation method that aims at preventing the entrance of harmful substances or other impurities from entering into the indoor air both with convection and diffusion. Products used in encapsulation of harmful substances prevent or slow the diffusion of gases.

Air tightness renovation requires structural engineering designing. The designing of air tightness renovation is always done case by case and should not be applied directly on other sites. The renovation designing requires expertise and knowledge of material and methods used. Building’s thermal and moisture technical functionality, which can change after implementation of renovation, has to be taken into consideration. If there is a danger that after tightening the moisture content might increase detrimentally in moisture sensitive structures, tightening should not be done. The drying ability of the structure should be taken into consideration in renovation especially for external wall structures so that there is a functional ventilation gap.

Air tightening renovation should never be the only renovation action but always a part of a larger entity. When improving air tightness, at least the ventilation system should be inspected and when required adjusted to correspond the changed pressure conditions. The optimal pressure difference over the external envelope is after the indoor air renovation close to 0 Pa. Controlled supply air should be taken into consideration. In moisture and microbe damage renovation, the damaged materials are removed, problem is identified and fixed. The structures are renovated so that they building physics properties stay correct. Implementation should be long-lasting and reliable. (Ympäristöministeriö, 1997)

The methods and materials used in air tightness renovation are determined by structural designer. The materials or methods determined in the designs cannot be changed without prior approval from the designer. The expected life expectation of the structure is stated in the designs. The structural engineering designs consist of work plans and required drawing with necessary details of implementation method of the renovation. The extension of dismantling, its implementation and preparation of the surface is determined in the designs. Preparation of the surface requires typically the removal of the surface material because old finishes seldom provide a solid enough surface for a good attachment of the sealing material. The surface should be even enough, strong and clean from any dirt or dust or any other factors reducing adhering.

5 MATERIALS USED IN AIR TIGHTNESS RENOVATION

In Finland, there are presently no requirements by the authorities for the materials used in air tightness renovation. The materials used should however, fill several requirements for the purpose. The products should have sufficient adhesive and elasticity, long-term durability and airtightness for the purposed use. When large surfaces are treated, the designer should pay special attention on material emissions and on their effect on indoor air quality. In Finland, building materials with air permeability max $1 \cdot 10^{-6}$ $m^3/(m^2 \cdot s \cdot Pa)$ are considered as air barriers. E.g. sealing strip, sealant, polyurethane foams, butyl or other special tape or special adhesive tape can be used for improving the air tightness of structures. When using a sealant, polyurethane foam or special tape it should be verified that the tightening is made using a broad enough adhesive area. The air tightness of the structure can also be improved with material combinations. A common method is to use a liquid spreadable waterproof mass system. Liquid waterproofing barriers have an estimated life span of 40 years. An air tight system installed onto brickwork consists of tight filler, glass fibre mesh and a surface treatment e.g. special paint. Air tight building materials include also several coatings and epoxy primers. Also tight building boards such as gypsum board with carefully sealed seams can function as a part of air barrier in the structure.

6 IMPLEMENTATION OF AIR TIGHTNESS RENOVATION ON SITE

Careful implementation of the work is detrimental for the success of renovation. The technical implementation of the air tightness renovation is confirmed on site with appropriate quality control methods. Quality control methods for the assessment of the technical implementation of renovation are determined in the design documents. Control methods include supervision, implementation and evaluation of models and measuring the air tightness with tracer-gas leak test. Model works of different structures to be tightened are important for the success of the implementation. The quality control of air tightness renovation is done on site before installing the surface structures. The quality control investigation is documented. At the moment there are no official qualification requirements for the workers or for the quality controlling. Certification training in planned to for people doing renovation work and supervision in autumn 2014.

6.1 Quality control with tracer-gas leak testing method

In the trace-gas leak testing method the tracer gas is led into the tested structure from where gas leaks along with the air flux into the direction of under pressurized room. In the room the trace gas is detected and the leaking points are located with tracer gas analyser. A constant negative pressure of 10…15 Pa over the examined structure should be maintained (in the testing room) to obtain comparable results. The negative pressure condition is implemented with a mechanical exhaust ventilator machine. Prior to testing the pressure differences of

structure to the room should be verified by measurement. The stability of the prevailing under pressure is recommended to be verified by repeated measurement during the tracer gas testing.

Leakage points are detected with tracer gas analyser and the results are interpreted qualitatively. The conclusion is simple: there is ‘’either leakage’’ or ‘’no leakage’’. The concentration of tracer gas in the structure is not known. Therefore the qualification of the investigator is very important. The detected leak points are marked and the tightness is improved with a suitable method. The tracer-gas leak test should be repeated until all leak points have been eliminated. A quality control report should be issued where the detected leak points are marked e.g. to the layout. Figure 2 explains the quality control assessment of air tightness renovation using tracer-gas leak test.

Figure 2: Air tightness renovation of concrete ground slab is done with waterproofing mass system. The tracer-gas leak test is done as part of quality control. In the picture on the right hand, in the test found leakages are marked with an orange tape, so they can be fixed.

7 SUCCESS OF AIR TIGHTNESS RENOVATION AND ITS DURABILITY

7.1 Evaluating the success of the (air tightness) renovation

The evaluation of the success of the renovation is based on user’s subjective experience of condition in the premises and objective measurements to evaluate the technical success of renovation. The success is evaluated by visual inspection, different types of measurements as well as with user questionnaires. The process is defined in the quality control plan. The measurements are verified against guidelines in the literature in order to get objective results.

Because air tightness renovation should never be the only renovation action but always a part of other action, the success of the whole renovation should be evaluated. For example, if the air tightness is done well but the final cleaning has been neglected or the ventilation system does not work as planned, it is obvious that the user experiences that indoor air quality problem is not solved. Feedback is often a good measure for evaluating the success of renovation.

The most important evaluation methods are:

- feedback from users and user questionnaires prior and after renovation

- control measurements of structure's air tightness (trace-gas leak test)
- inspection of ventilation system's functionality
- inspection of cleaning level
- measurement of indoor air factors (temperature, humidity, carbon dioxide, pressure)
- measurements of indoor air's chemical and microbiology concentration, if needed.

In practise evaluations after renovation have been done in individual buildings and the structures have been found as air tight as during quality control on-site. However, practise has also shown, that even the most carefully executed renovation and mould dust cleaning is not enough for the most sensitive people and their symptoms return after returning to the premises.

8 CONCLUSIONS

The National Building Code of Finland for new buildings requires air tightness for external envelope structures. The air tightness is done with vapour barrier or with an air barrier. Structure's joints are not automatically completely tight and therefore the implementation requires detailed planning. In external envelope structures and in the soil under building's ground slab there are almost always some microbial based impurities and radon which can affect negatively to the indoor air quality when transported with the air flux into the room. The impurities can lead to poor indoor air quality associated problems. The aim to improve air tightness of structures is to prevent the uncontrolled air leakages through structures. It is a relatively new renovation method and therefore renovation designing requires expertise and knowledge of material and methods used. Research studies related to air tightness renovation has been done relatively few. Some research still needs to be done.

Air tightness renovation is not suitable for all structures. In general, structures should never be tightened without inspection, planning and supervision. Structures with microbial or moisture damage should not be tightened. Air tightening renovation should never be the only renovation action but always a part of a lager entity. When improving air tightness, at least the ventilation system should be inspected and when required adjusted to correspond the changed pressure conditions. Careful implementation of the work is detrimental to the success of renovation. The essential requirement for preventing air leakages is that the air flow paths are cut off totally not only partly. The technical implementation of the air tightness renovation is confirmed on site with appropriate quality control methods i.e. addition to visual inspection the tightness is tested with tracer-gas leak testing method.

In practise air tightness renovation as part of a larger entity has successfully solved the indoor air quality problems in buildings. In Finland the air tightness renovation method to prevent radon is an established renovation method and it has been used for decades. Air tightness renovation has been used to solve microbial based indoor air quality problems about 15 years. The materials used should fill several requirements for the purpose. In practise evaluations after renovation have been done in individual buildings and the structures have been found as air tight as during quality control on-site. The air tightness renovation can be one solution to solve poor indoor air quality problems.

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