# THE USE OF BUILDING OWN VENTILATION SYSTEM IN MEASURING AIR TIGHTNESS


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## ABSTRACT

The improvement of energy efficiency is the key issue after the energy performance of buildings directive came into the force in European Union countries. The city of Kuopio in Finland participate a project, in which different tools will be used and tested to improve the energy efficiency of public buildings. In this project there were pilot buildings e.g. schools. The other pilot school consumed much more heating energy than the other same type of school. Air tightness was measured using the own ventilation system of the building and by remote control from the central operation room. In this paper the procedure and some results are presented. There is also one example about a kindergarten, a health center, about a swimming hall and a new administration building in City of Oulu, in which the air tightness was measured using Blower-Door method and building's own ventilation system. Thermography, air tightness test and other supporting measurements can be used together to solve energy loss problems – if these measurements will be carried out by proper way. The ventilation system of the building can be used to test air tightness within certain limitations.



## KEYWORDS

Air tightness, Blower Door, Energy efficiency of buildings, Building performance


## 1. INTRODUCTION

Air tightness of a building or part of the building can be measured by specific device or set of devices (s.c Blower Door). The own ventilation system of a building can also be utilized with certain limitations. Tracer gas-method, such as concentration decay method can also be used, especially in case of uniform and continuous large volume buildings, like sport halls. In ongoing ENEFIR-project [1] the objective is to develop new measurement and instrumentation concepts both analyzing tools to improve total energy efficiency of buildings. In the project one sub targets was to verify the performance of building envelope by thermography and supporting tools. Three municipalities participate the project, one of them is Kuopio. The energy consumption of the public building stock of Kuopio has been relatively low compared with the cities same size, in the year 2008 the weather corrected consumption of heating energy of the building stock was 31,5 kWh/m$^3$ and electricity 14,1 kWh/m$^3$. The average consumption of heating energy of school buildings in the whole country was 45, 4 kWh/m$^3$ and the consumption of electricity 14, 6 kWh/m$^3$.

City of Kuopio chose 2 schools, 2 kindergartens and an art museum for the project. The buildings were selected based on their specific energy consumption – the other school and the other kindergarten consumed relatively much energy compared with their counterparts. The aim was to analyze the possible reasons for that and to know which factors caused the differences in energy consumption.. School 1 (building volume 13 210 m$^3$) was renovated in the year 2007 and the specific consumptions in 2009 were: Heating 43 kWh/m$^3$ and electricity 21, 8 kWh/m$^3$. School 2, renovated in the year 2005 (the cubic content 30 012 m$^{3)}$ consumed in 2009 25, 6 kWh/m$^3$ of heating energy and 10, 9 kWh/m$^3$ electricity. The specific consumption of energy in the school 2 was only 56 % of the consumption of the school 1. Both schools were connected in district heating system. In school 1 the most problematic space was the library. In the winter 2009 - 2010 additional heaters were used to keep the indoor temperature in acceptable level. The complaints related to decreased thermal comfort. There were no reclamations from school #2.

## 2. MEASURING AIR TIGHTNESS BY BUILDING'S OWN VENTILATION SYSTEM

### 2.1 Preconditions

There have not been requirements of numerical values dealing with air tightness in Finland before 2008. Requirements of energy performance calculations caused changes in building codes 2008 and then 2010. According the new energy performance code from July 2012 [2], air tightness number $q_{50}$ cannot be more than 4 $m^3/(h*m^2)$. Better air tightness can be shown by measurements. The air infiltration must be calculated in compensation calculations based on air tightness number 2.0 $m^3$/ (h*m2). Air tightness measurement standard SFS-EN 13829 is presented in the building code [3].

Measurements has been done using blower-door or self-made equipments. Also tracer-gas method has been used. The ventilation system of a building has sometimes been used to determine air tightness – mainly in connection of research projects or occasional experiments. There have been two main factors which makes the use of ventilation system difficult in air tightness measurements: The fans of air supply units have been two-step type devices; it means that the machine has run either by 1/1 or by ½ -power. The other obstacle has been difficulties to measure air flow in primary air ducts. Normally the ducts have been equipped with measurement connections, that Pitot-tube or thermoanemometers can be used. In some cases ducts has been equipped with measuring devices. Modern systems have frequency controlled fans, often remote controlled from operation room. Also pressure difference over than fan is measured, or there are at least fittings to do that. Pressure differences can be converted to air flow units, and in the wall of the machine an installed indicator/meter can be found. If the fans are frequency controlled and the primary air flow is measurable, air tightness test can be done in principle.

The practical problems in the use of the own ventilation system is:

1. Do you measure the whole building or only part of it?
- In that case one must secure that the area what is going to be measured can be separated tightly enough from the other part of the building
2. If there are many units, one must choose the unit effective enough (in general the biggest unit) and verify if that particular device can be used. In addition, one must reserve another fan if the test cannot be carried out with one fan.
3. Is it possible to operate with wan exhaust fan without probles to stop other fans?
- control system can include forced connection and some manual operations should be used (discontacting the alarm functions, sometimes removing fuses, to shut manually dampers, to disconnect blast regulators)
4. Sealing and tightening:
- Is it possible to ensure that all the potential lead-troughs which could disturb to have correct measurents are sealed?
5. Measurement of air flow
- Can we use reliably the measuring options of the system (either from the machine and/or in the control room)?
- the pressure-flow chart and specific curves of the fan which is used must be available
6. Measurement of pressure conditions

- Is it possible to measure pressure conditions from each facade and also from different levels, if needed?

### 2.2 Course of the procedure

Preliminary works:

Sealing and tightening:

- Air inlets (outdoor air) must be closed and covered.
- All the air exhausts of the air supply units must be closed and covered, except the one which will be used in the test.
- All fans and roof exhaust fans must be stopped and roof exhaust fans must be covered (plastic foil, inneer tubes of football, volley ball or specific devices).
- If tightening can not be done in the machine, the vents must be taped in service areas of the fan.

Measurements:

Measurement of air flow (depressurization)

- Pressure drop over the fan must be measured both from the unit and in the control room (if possible)
- Use calibrated meters (the displays, pressure transducers and indicators of the system can give false readings) in parallel of existing measuring devices
- the pressure-flow chart and specific curves of the fan which is used must be available
- normally the fan frequencies are from 0 Hz up to 60 Hz – using 10 Hz steps
- In each stage the pressure difference between outdoor and indoor must be measured
- drive the fan at least two times from the minimum value to maximum value and back

Measurement of pressure conditions

- at least from two facades
- the measurer of pressure conditions must have on-line connection (cell phone or SW phone) with the operator/machine room

Also the pressurization can be carried out using the procedure above. In that case one must use one air supply fan and the other devices must be stopped. Typically, the most time consuming operation is preliminary works. It will take 2-4 hours, depending on how much assistance is available and, of course, on the size of the building. Measurements can be done in one hour.

## 3. MEASUREMENT OF AIR TIGHTNESS IN TWO SCHOOLS

Both schools were connected in remote monitoring system of the city. The heating and ventilation system could be controlled and consumption monitored from control room which situates in the center of the city. The in-situ operations involved indoor and outdoor thermal scanning in prevailing conditions, pressure drop measurements between indoors and outdoors, and indoor temperature and relative humidity (RH) measurements in all workspaces.

Measurements were focused on the library, where the indoor environment problems occurred. The library was depressurized. To the same service area of ventilation system belonged also the gym and the canteen. The canteen was not directly connected with the library –other room space was between them. The other spaces of the service area of same air supply unit were separated from the tested area but there was no full certainty about that; it might be possible that there will be some leaks through the ducts from the other areas, too. The breakthroughs, vents, blast controls and dampers were shut, and the incoming air unit was closed by plastic film. The exhaust fan was driven by frequency controller in 25 % steps from 0 % to 100 % capacity and the air flow was measured from the pressure difference units over the fan – the pressure difference can be converted to volume flow using the specific curve of the fan. By the same the pressure difference between indoors and outdoors was measured on each capacity range. The measured air flow of the exhaust fan represents air leaks through building envelope. The measured air flow at 50 Pa pressure drop is divided by the volume of measured area. The result represents the air leakage number and gives a conception of the air tightness of the building (in this case the air tightness of measured part of the building). If 50 Pa pressure difference cannot be reached, an estimated value based on the calculations and leakage curve equation can be used. In this case only negative pressure difference was used because of practical reasons.

The structures were scanned again by thermal imager then under the maximum pressure difference reached. By comparison of the thermal images in actual normal conditions and images under negative pressure drop one can evaluate the thermal performance of the building envelope and locate air leak patterns. By thermal scanning in normal operating conditions it's also possible to monitor the performance of ventilation system (supplied air and exhaust air temperatures) and the functioning of heating system (surface temperature of radiators).

The pressure condition in the normal situation in the library was -4 Pa, which can be considered as normal; the balancing of the ventilation system was properly done. Air flow rates were not measured. The canteen was under highly negative pressure difference (-30 Pa) compared with outdoors. The problem was caused by the kitchen which had a separate ventilation system but which was connected with canteen. Also the gym had -30 Pa negative pressures drop. The kitchen was under -40 negative pressure drop compared with outdoors. The ventilation of kitchen was totally unbalanced which also caused problems to the canteen. The first conclusion was that the ventilation system of the kitchen should be checked – there was no possibility to isolate the canteen from the kitchen area, so the kitchen ventilation affected the indoor conditions of the canteen. After repairs carried out in the summer 2010 (based on the results of the first measurements) the measurements were repeated in the school 1.

## 4. RESULTS OF AIRTIGHTNESS OF TWO SCHOOLS

Indoor thermography showed the problems in the library – the surface temperature of ventilation ducts all over the way were low (4 – 5 ºC) and the temperature of supplied air was 14 ºC (18 ºC recommended as minimum). Figures 1 and 2 show the situation in the ceiling – the surroundings of the supplied air duct were cold and also some extremely low surface temperatures in rear part of the library, where the works space of librarians are situated. In the shower room the surface temperatures were below 0 ºC at lowest (the outdoor temperature had been very low in the night), which means that there was a risk of condensation and structural damages. The radiators seemed to work properly, and except some leaks from window weather-strip and spotty low surface temperatures in the junction of exterior wall and ceiling. There was no possibility to reach -50 Pa pressure difference using the exhaust fan – by the maximum capacity (100 %) the negative pressure drop was -31 Pa. This indicated leaks. Figure 3 shows the air leak curve. Air leak number must be evaluated using the equation of the curve. N50 was approximately 7 - 8 1/h (changes/hour) which is a very poor result. The acceptable value, taking into account the age of the building and structures could be 2 – 3 1/h at 50 Pa. The eligible value should be 0, 5 – 1 1/h at 50 Pa. It was very probable that without very exhaustive repairs it would be difficult to achieve a proper level of air tightness. The actual level of air tightness caused significant uncontrolled leakage air ventilation which will increase the consumption of heating energy. In generally, the library part of the building was very leaky – one reason for that could be the renovation which was carried out in 2007 was not properly done.

Figure 1. Ventilation duct, inlet to the library

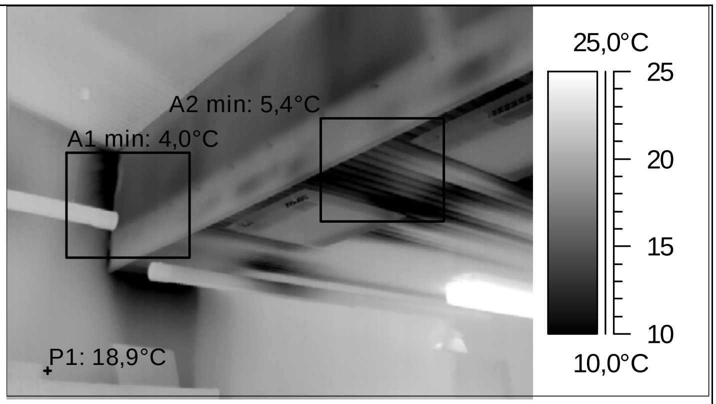


Figure 2. Thermal image of the same point

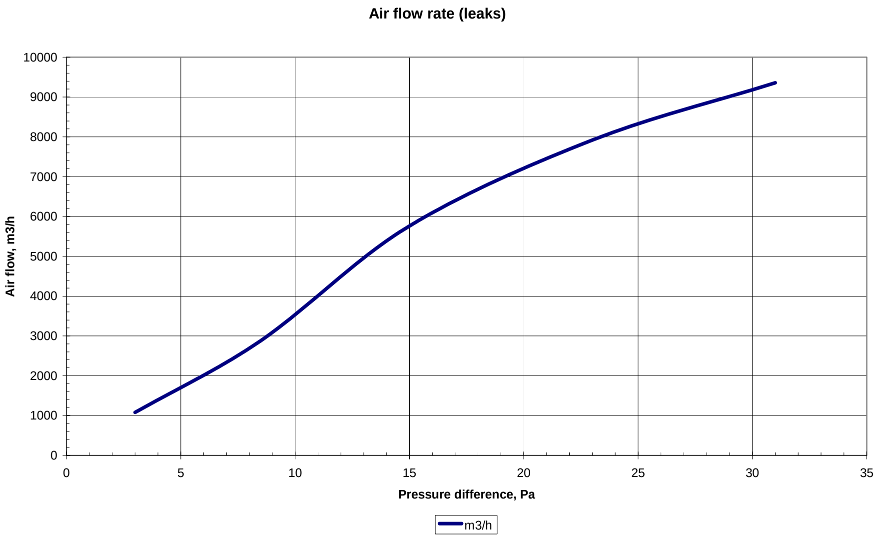


Figure 3. Air leak curve

# 5. OTHER CASE STUDIES

## 5.1 Case study: Kindergarten

Except 2 schools, in ENEFIR-project two kindergartens were studied and compared, built 1991 and 2001. The structures were more or less equal, but the older kindergarten consumed significantly more energy than the point of comparison. The results of measurements showed the reason for higher energy consumption in the older kindergarten. The lowered thermal comfort was caused by thermal bridges of structures, and air leaks of windows and doors. Figures 4 and 5 show one example of window leaks – the surface temperatures were extremely low (winter conditions) because of narrow metallic window frames and air leaks. In kindergartens the occupation zone of the children is close to floors and also close to wall-floor junctions. In these facilities special attention must be paid to structural details and must try to avoid cooling air leaks and cold surfaces.

In the older kindergarten the ventilation system was two-step operated; no frequency control and no flow measurement options. In this case the exhaust air flow was measured both by Pitot-tube and by thermo anemometer according to valid measurement standards. The results are presented in table 1. The measured air flow rates were surprisingly close to each other. The measurement point was the same. The goal of 50 Pa negative pressure difference was not reached. Interference distance requirements were fulfilled, which is not always possible in small machine rooms with short straight part tubing. In the other kindergarten it was possible to carry out measurements using frequency controlled fan and pressure difference-based exhaust air flow measurements. Also 50 Pa pressure difference was reached.

| Meter type | Pitot | TA | |
|---|---|---|---|
| Capacity | flow | flow | diff. |
| | m3/h | m3/h | % |
| 50 % (1/2) | 1435 | 1452 | 1,2 |
| 100 %/(1/1) | 3897 | 4087 | 4,6 |

Table 1. Results of two different measurements

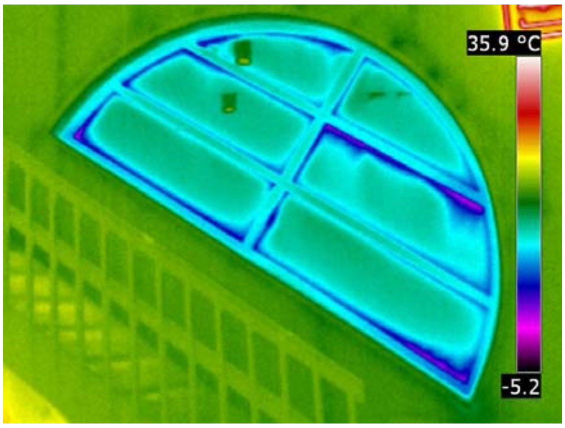


Figure 4. Window at normal conditions

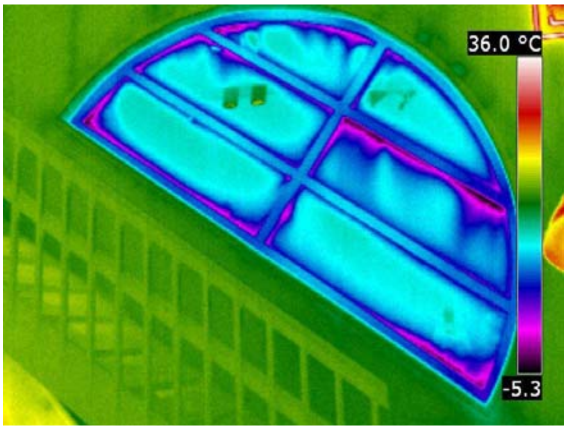


Figure 5. Window under depressurization

### 5.2 Case Study: Health Center

One pilot building was a health center and it`s sickroom department. The air tightness was determined causing just a service area of one air supply unit, which covered on floor of the building. In this case the measurements could be done using the own ventilation system after certain adjustments of the control unit; it was not possible to switch off the air supply fan without doing some manual operations. In many systems exhaust and supplied air fans are operating with forced connection.

Figure 6 shows the air tightness curve and results. Air leakage number $n_{50}$ was 1, 9 1/h (changes/hour), which is excepted result but not acceptable if the question would be about a new hospital. The main leaky points were the windows (figures 7 and 8). Because the patients in health centers are mainly elderly people (in this case old long-term or chronic patients), the indoor conditions should be best possible; if there is draft in the rooms, it will be compensated by increasing indoor temperatures, which will increase also energy consumption.

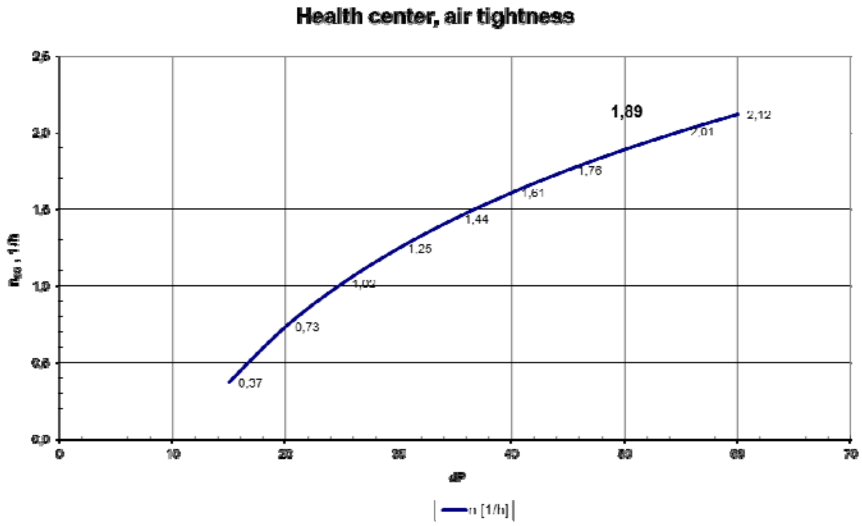

Figure 6. Leakage curve


Figure 7. Windows of a sickroom

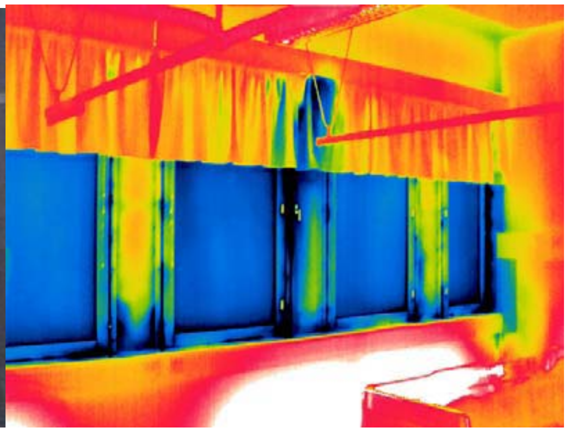
Figure8. Windows at negative pressure difference

### 5.3 Case Study: Swimming Hall

A swimming hall in Northern Finland was tested in aim to have information for planning renovation measures. The ventilation system of the hall was renovated 2002-2003 and the hall was built in 80`s. The test was limited concerning the pool and dressing room department. The strongest moisture load is against the structures in the pool section and also in showers and saunas. In normal operating conditions the pool section had -10 Pa negative pressure drop at height of 1, 5 m compared with outdoors. It means that the pressure difference against roof structures is very small or even positive. The indoor temperature was +30 °C at the same level. The air tightness of the space to be studied was determined with the own ventilation system of the hall by closing all other ventilation fans, shutters and using exhaust fan of the pool section. The designed capacity of the fan is 7 $m^3/s$. Air flow of the exhaust fan was controlled by frequency converter. The pressure drop over the fan was measured by calibrated pressure difference meter. When compared the measured readings with readings given by pressure difference transmitter/indicator, it came out that the values did not match with measured from fittings – it means that the operator will have false readings and false air flow values during operation. This is not so unusual when talking about the local measurements an devices – in general, sensor and detectors can be inappropriately or wrongly installed, pressure tubes could be blocked, pressure difference signal (or other measuring signal) could be interfered or incorrectly adjusted etc.

Thermal scanning was made both indoors and outdoors before pressurization and during depressurization. Figures 8 – 11 show some of the located leak patterns under depressurization.

Especially air flow routes in the roof structures can cause several damages, because the diffusion can drive water vapor into the structures, even the pressure difference across the roof were slightly negative.

Figure 8. Entrance door of pool unit

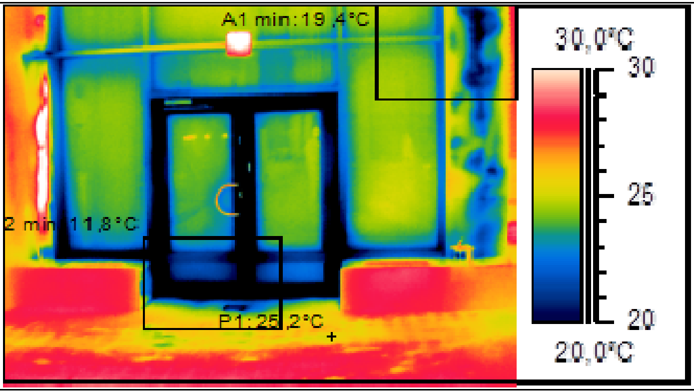


Figure 9. Door at 50 Pa depressurization

Figure 10. Ceiling of spa

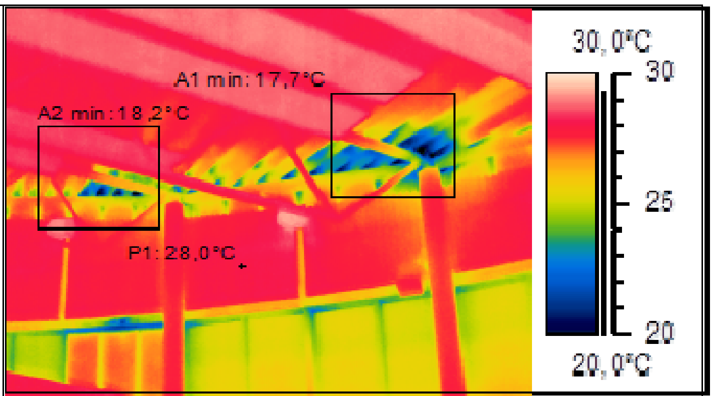


Figure 11. Ceiling under negative pressure difference

### 5.4 Case study: Office Building

A new office building was taken into the use in the summer 2011. The built volume is 28 000 $m^3$. It was designed according to strict demands. The requirements for the building are presented in table 2. The set air-tightness value $n_{50}$ was **1, 0** 1/h. Air tightness was measured both by the own ventilation system and by blower-door. The pressure difference between indoors and outdoors during the test was measured in the middle from both facades (the building is approximately 20 m high). There were 3 air supply units in the machine room and the unit with highest capacity was used, the others were stopped and taped. Also the roof exhaust fans were stopped and taped. Figure and table show the results. The results (table 3) diverged from each other. The mean value $n_{50}$ of air leak number by blower-door under pressurization was 0,41 1/h and $q_{50}$ 1,86 $m^3/h{*}m^2$. The result of depressurization, which can be compared with the result of the own ventilation system was 0,39 1/h (1,78 $m^3/h{*}m^2$ ). The measured result using ventilation system was 0,32 1/h. The tolerance of blower door result is ± 3%, according to manufacturer. The blower-door results are typical, generally pressurized value is a little bit higher than depressurized ones, depending on the structural details. The theoretical tolerance of the exhaust fan of ventilation system under controlled testing conditions according to manufacturer is ± 5 %. In prevailing conditions one can assume that the real margin of error is higher, because the flow profile probably changes compared with fan test conditions.

| Structural component | U-Values<br>SRMK C3-2010<br>(building codes) | TeVi(Tech. center)<br>(city requirements) |
|---|---|---|
| -Wall | **0,17** | **0,15** |
| -Base floor | **0,16** | **0,14** |
| -Roof | **0,09** | **0,09** |
| -Window | **1,0** | **1,0** |
| Structural component adjacent to the ground (Basement wall) | **0,16** | **0,14** |

Table 2. Energy efficiency requirements

The results were close enough and the result using building's own ventilation system gave a good approximation for air tightness. The problem becomes obvious in case that the measured value is close to the requisite value. The difference between blower-door and ventilation system measured results was 18 % calculated from the blower-door value.

| **Comparison of air-tightness results from an office building** | | |
|---|---|---|
| **Test method** | **Result, 1/h; $m^3/(h*m^2)$** | **Estimated air-flow, $m^3$/h at 50 Pa** |
| measured by blower-door (depressurization) | **0,39**/1,78 | 10948 ( +/- 2.7 %) |
| measured by blower-door system(pressurization) | 0,41/1,86 | 11517 ( +/- 2.8 %) |
| n50, measured by ventilation system(depressurization) | **0,32**/1,46 | 8980 ( +/- ? % ) |

Table 3. Measured results

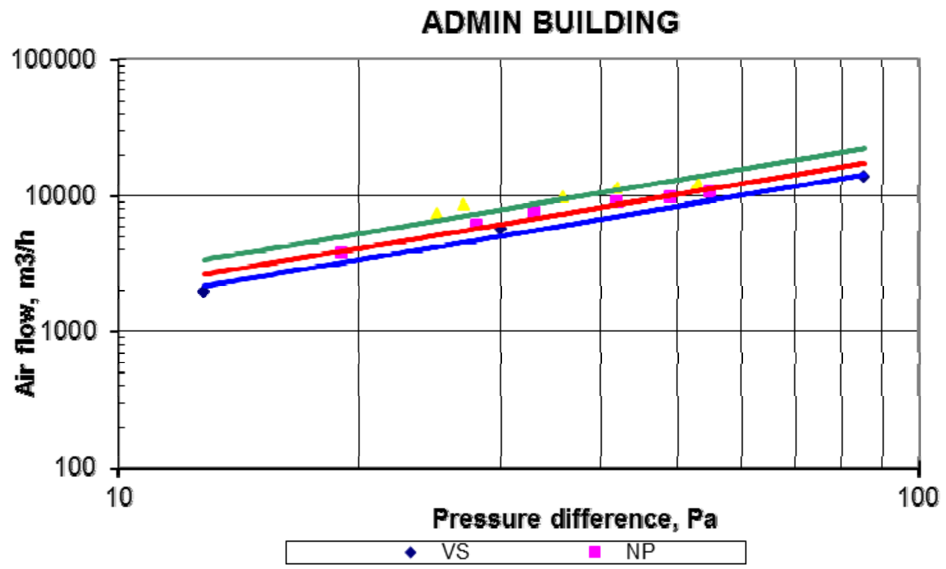


Figure 12. Air tightness test. VS= Ventilation system, negative pressure drop, NP = Negative pressure drop, blower-door, PP = Positive pressure drop, blower door

The result, 0,4 1/h was below the passive-house value (0,6 1/h). During the tests all the windows and breakthroughs were checked, and some windows were not properly adjusted, and some electric tubing lead-ins were not tightened; these works were made after the test. Thermography was not used during depressurization for locating the leaks, because of summer conditions. The building will be tested again in colder climate conditions. The air tightness level was good.


Figure 13. Blower-door

Figure 14. Measurements over the exhaust fan

## 6. CONCLUSIONS

The tests, which were made in the schools were typical measurements when solving existing problems. By thermography it is possible to determine the thermal performance of building envelope and also the functioning of heating and ventilation system within certain limitations and preconditions. Air tightness test will give a good conception of the performance of the building envelope. The results can be compared with the other buildings of same type. Two-stage thermography helps to separate the thermal bridges from air leaks and to find leak patterns which maybe could not be found in normal conditions. Pressure conditions are necessary to measure in connection of thermography. The normal negative pressure difference in cold climate conditions should be < 10 Pa (if the question is about mechanical ventilation system). If big pressure differences exist, there are some problems in balancing or in use of the ventilation system. The studies proved that the air tightness test is possible to make using the building's own ventilation systems – if the fans are frequency controlled and the main air flow can be measured. Based on the experiences of the project a guideline has been written into the use of maintenance staff of the city. In the future they can do air tightness tests by themselves. The main problem is when the measured value is very close to the required value but remains above it; the accuracy of measurements will vary and the tolerance is difficult to determine. The accuracy of blower-door may be better compared with method using building's own ventilation system. Repeatability of the tests using the own ventilation system was good in all tests.

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