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AIRTIGHTNESS OF A BUILDING ENVELOPE

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Abstract

The main investigation object of this paper if the airtightness of a building envelope and its influence of energy efficiency, indoor air quality and thermal conditions inside the building.

First of all, the legislation regulations for the airtightness of buildings and the measuring methods were discovered. Secondly, the airtightness measurement took place at the end of the construction process in the daycare center in a city in Finland. When the building was commissioned, the indoor climate parameters were monitored to discover the influence of the airtightness of the building envelope and air leakages on indoor air quality and thermal comfort of occupants.

Finally, the results were analyzed. It was found out that the building envelope has high airtightness. It was discovered that there is no significant influence on thermal conditions inside the building. The temperature and relative humidity did not fluctuate much. However, it was discovered that the low air leakage rate leads to a reduction of fresh air income inside the building, which leads to the increase of indoor air pollutants and the decrease in indoor air quality. That means that the ventilation system should be adjusted if the predicted number of occupants increases.

The study showed that the improvement of airtightness leads to a reduction of the energy demand of the building. However, the reduction of fresh air income should be taken into account when the ventilation system is designed.

Keywords

airtightness of a building envelope, energy efficiency, indoor climate, air leakage rate

CONTENTS

1 INTRODUCTION

Energy efficiency is one of the most important issues in the 21st century. Since 1970 the awareness that energy sources are not unlimited grew up /1, p. 5/. The understanding of this fact makes people all over the world think about the reduction of energy consumption and search for alternative sources of energy. In spite of this fact, the world's energy consumption grew by 2,9% in 2018. Scientists consider this growth as the highest one since 2010. The growth of energy consumption entails higher emissions of greenhouse gases. /2, p. 2./ Construction industry and buildings take approximately 40% of the energy produced in European Union countries and give off about 36% of total direct and indirect CO_2 emissions. Almost 75% of all buildings in Europe are not energy efficient. Renovation of old buildings and making new buildings energy efficient may significantly decrease energy production for their erection, maintenance and improve global air quality. Moreover, energy becomes more and more expensive. The reduction of energy consumption of buildings will shorten their costs and make them more economically and socially beneficial. /3./ According to existing legislation, all new and existing buildings must meet energy efficiency requirements and should save as much energy as it is possible.

One way of saving energy for heating and ventilation of a building is to make its envelope more airtight. The airtightness of a building envelope shows how much air infiltrates through the building envelope uncontrollably. Poor airtightness of the building envelope may increase the amount of energy needed for heating of the building. It also may cause thermal discomfort of residents and even moisture damages in the building. The main object of this bachelor's thesis is the airtightness of a building envelope.

In this paper, the airtightness of a building envelope will be investigated. It will be described how the airtightness of a building envelope is measured and estimated according to the legislation requirements, how air leakages influence the energy demand of the building and how heat loss for the leakage air may be determined. It will also be found out if airtightness of a building envelope has a significant influence on indoor air quality and thermal comfort. The measurement processes and methods, as well as equipment, will be described in detail.

The main aim of this bachelor’s thesis is to estimate the amount of heat loss for the air leakage for the investigated building, where airtightness of the building envelope is measured. The second aim of this paper is to find out if the relatively high airtightness of the building envelope improves or deteriorates indoor air quality and thermal comfort of occupants.

The remainder of this paper is structured as follows: the first part is related to the literature review and theoretical background. After that, the investigated building, the equipment, and devices are described as well as the locations, times, intervals and the process of the measurements. At the end of this paper, the results of measurements and monitoring are presented. They are compared to the requirements in the existing legislation. Finally, the recommendations on how to improve indoor air quality are given.

2 ENERGY PERFORMANCE OF BUILDINGS

Energy performance of a building may be defined as the quantity of energy necessary for building maintenance according to its standardized use including building services such as heating, cooling, electricity, and domestic hot water consumption. If a building consumes less energy, it has higher energy performance. Standardized use of a building is determined according to the category of a building and its daily and weekly occupancy. /4, p. 1-2./

The highest amount of energy that buildings consume goes to engineering systems that provide the required indoor climate. They are heating, cooling, ventilation, and air conditioning. The main purpose of modern buildings is not only to be a shelter but also to ensure a safe and satisfactory indoor climate. The internal environment influences humans’ comfort, productivity, and health. Figure 1 presents the distribution of the world’s energy consumption in general and in buildings. As it is shown in the picture, a significant amount of energy consumed by buildings goes to heating and cooling. That means that the influence of external conditions on indoor climate should be reduced to save energy on the maintenance of buildings.

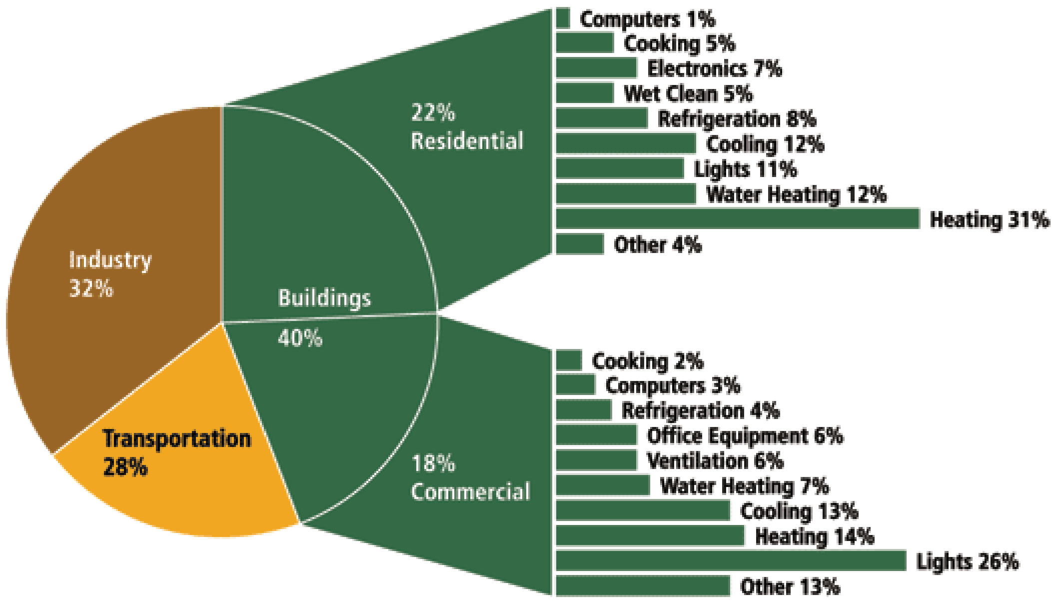

Figure 1. Energy consumption by sector /5/

2.1 E-value

The energy performance of a building is expressed by the calculated energy performance reference value of a building or a building unit (E-value). The calculation of this value is described in Decree of the Ministry of the Environment on energy Performance Certificate of Buildings 1048/2017: «The E-value of a building or of a building unit ($kWh_E/(m^2year)$ is calculated by dividing the building's calculated consumption of delivered energy based on the standardized use of the building, weighted by energy carrier factors, by the net heated surface area of the building (A_{net}) in a year /4, p. 1-2/». Where building's calculated consumption of delivered energy shows the amount of energy used for its maintenance and creation of the desired indoor climate. Energy carrier factors show the need for delivered energy and are not used in calculations of energy that comes from environmental energy in the surrounding areas of the building. Net heated area is determined as the area of the heated part of the floor plate which is taken on the basis of the internal surfaces of the external walls. /4, p. 1-2./

E-value is presented on the first page of the energy certificate and it defines the energy performance class of the building. There are limitations of E-value for different categories of buildings and for the determination of the energy class of buildings. All the limitations according to categories are described in the Decree of the Ministry of the Environment on energy Performance Certificate of Buildings 1048/2017. /4./

The choice of calculation zones for calculation of E-value depends on the building purpose. If a building has single intended use it should be calculated as a single calculation zone. A building may also be divided into several calculation zones if it has different intended uses according to the exact purposes of the exact parts. /6, p. 8./

According to legislation, the calculations of E-value should include the heat losses calculations through the building envelope. These calculations are made on the basis of the internal dimensions of the building envelope. Thermal bridges, air leakage, the impact of the ground and crawl space should be taken into account during heat loss calculations. /6, p. 8./

2.2 Airtightness of a building envelope

There are many technologies that help to make building more energy efficient and achieve the desired indoor conditions at the same time. One of them is making the building envelope more airtight. Airtightness of buildings shows how much outside air comes inside the exact building and leaves it through leakages in the building envelope. It is not only an indicator of the energy efficiency of the building but also an indicator of building quality in general. Air leakages increase heat losses of the building and influence structure’s toughness. They also usually cause unwanted draughts, increase the concentration of indoor air pollutants, enchain supply ventilation demand. Uncontrolled air leakage may become a reason of too high or too low moisture content in the building and may lead to erosion of structure. /7./ These facts show the necessity of control of airtightness of buildings. According to legislation, the amount of leakage air should be reduced to the required level. Regulations regarding airtightness of buildings are different for different countries but the strategy is to make structures more airtight and control air exchange through ventilation.

2.2.1 Determination of airtightness of building envelope

Airtightness of a building envelope may be defined as the opportunity of the building envelope to inward or outward air leakage through unintentional leakage points or areas. It is a key issue in the reduction of energy consumption and making a building a low energy one. Air leakage is an uncontrolled airflow through defect points in the building envelope.

The calculation of the consumption of heat energy for leakage air of spaces of the building is done according to the airtightness of the building or building unit. The airtightness of the building is expressed by the air leakage rate figure for the building envelope, q_{50}, $m^3/(h \cdot m^2)$. It shows the average leakage airflow of the building envelope per square unit of the envelope for one hour when there is a pressure difference between outside and inside area of a building is 50 Pa. The measurement ways of buildings' airtightness and determination of air leakage rate of the building envelope will be described below. /4, p. 9./ According to legislation, if airtightness of a building is proven by an industrial building construction quality assurance procedure or by measurements the resulting rate figures for building envelope should be used in heat loss and E-value calculations. Otherwise, the value of 4 $m^3/(h \cdot m^2)$ is taken into account as the air leakage rate figure for the building envelope. /6, p. 8./

Before 2012, airtightness of buildings was described by the air leakage value of the building with a 50 Pa pressure difference between inside and outside space of a building, n_{50}, 1/h. This value shows the number of air changes in a building per hour under the created conditions. It is a good way to describe the airtightness of a building envelope because it is very informative, and it is still used for this purpose. There is a relation between the air leakage rate of the building envelope, which is the modern way to describe the airtightness of the building, and the air leakage value of the building. Equation 1 represents this relation /4, p. 9/.

$$q_{50} = \frac{n_{50}}{A_{envelope}} \cdot V \tag{1}$$

where	q_{50}	the air leakage rate of the building envelope at a 50 Pa pressure difference	[m^3/(h m^2)]
	n_{50}	the air leakage value of the building with a 50 Pa pressure difference	[1/h]
	$A_{envelope}$	the surface area of the building envelope (including the lower floor)	[m^2]
	V	the air volume of the building	[m^3]

The surface area on the building envelope is determined according to internal dimensions of the building /4, p. 9/.

There are limitations to the air leakage rate of the building envelope and the air leakage value of the building according to the year of the building's construction.

Table 1.The air leakage value of the building envelope and the building in Finland /4, p. 10/

The year when the building permit became pending	**-1969**	**1969-**	**1976-**	**1978-**	**1985-**	**2003-**	**2008-**	**2010-**	**2012-2018-**
The air leakage value of the building n_{50}	6.0	6.0	6.0	6.0	6.0	4.0	4.0	4.0	
The air leakage rate of the building envelope q_{50}									4.0

Leakage air flow rate, $q_{v\ air\ leakage}$, m^3/s, shows the volume of air that leaves the building through the building envelope per time unit. It is calculated by equation 2 /6, p. 9/.

$$q_{v\ air\ leakage} = \frac{q_{50}}{3600 \cdot x} \cdot A_{envelope} \tag{2}$$

where	$q_{v\ air\ leakage}$	the leakage air flow	[m^3/s]

q_{50}	the air leakage rate of the building envelope at a 50 Pa pressure difference	[$m^3/(h\ m^2)$]
$A_{envelope}$	the surface area of the building envelope (including the lower floor)	[m^2]
x	a factor which depends on the number of storeys in the building (for single-storey buildings is 35, for two-storey buildings is 24, for three-and four-storey buildings is 20 and for buildings taller than these is 15)	[-]
3600	a factor converting the air flow from m^3/h to m^3/s	[-]

The energy that is needed to heat air flowing in and out due to air leakages, $Q_{air\ leakage}$, W is calculated by equation 3 /8/.

$$Q_{air\ leakage} = q_i \cdot C_p \cdot q_{v\ air\ leakage} \cdot (T_{ind} - T_{out}) \tag{3}$$

where

$Q_{air\ leakage}$	energy required to heat air leakage	[W]
q_i	density of air, 1,2	[kg/m^3]
C_p	specific heat capacity of air, 1000	[J/kg,K]
$q_{v\ air\ leakage}$	the leakage air flow	[m^3/s]
T_{ind}	indoor air temperature	[°C]
T_{out}	outdoor air temperature	[°C]

A building should be airtight enough to provide the correct function of a ventilation system according to its design. For buildings in which the designed ventilation system includes heat recovery, airtightness is a crucial factor in the energy performance of the system. In addition, airtightness of a building envelope has a huge influence on the indoor climate. /9, p. 3./ These facts are the main reasons why the airtightness of buildings should be measured controlled and taken into account.

2.3 Measurement of airtightness of a building envelope

The airtightness of building envelope should be measured because it is usually difficult to detect gaps and cracks in the building fabric only by visual inspection in normal conditions. As the airtightness of the building envelope has a significant influence on energy efficiency, indoor air temperature and moisture content it is required that the airtightness of the building envelope should be measured and documented when a building is taken into use. In this case, a smaller value than the reference air leakage value may be taken into account in heat loss calculations.

2.3.1 Blower door test

The blower door test is one of the most popular ways to measure how much air infiltrates through the building envelope. It is presented by a huge powerful fan that is installed into the frame of an exterior door or window. Before the start of the test, all other exterior doors and windows should be closed and interior doors should be opened to join all the rooms and spaces. The ventilation system should be also turned off and all the drainage pipes should be closed by a water trap or with tape if the building's drainage system is not completed to avoid the air coming inside the building through the ventilation and drainage systems. The volume and the area of the building envelope should be calculated on the basis of the internal dimensions of the building. When all the preparations have been made and all the equipment installed, the test may be started.

The devices for the blower door test include not only a fan with variable speed but also an adjustable frame and flexible airtight panel usually made from dense fabric which perfectly fits every door frame. There is also a pressure meter to measure the pressure difference between inside and outside areas of the building, computer with the software to control the speed of the fan, analyze the results and make a report and devices for locating the leaking points in the building envelope. Figure 2 shows the basic set of equipment for the blower door test, model Retrotec 5000

Blower Door System, all the parts are named. Such systems are usually used for residential buildings or small commercial building. The number of fans may be increased for testing larger buildings.

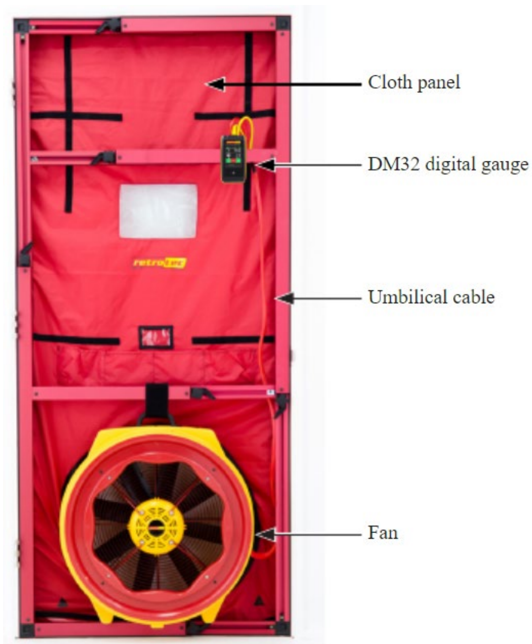

Figure 2. A basic set of the equipment for blower door test /10, p. 1/

During the test, the fan exhausts air out of the building and creates under pressure inside the building. When there is higher pressure outside the building, the air starts to penetrate inside the building through the cracks, openings, and gaps in the fabric. Under the conditions of under pressure inside the building, the amount of air leakage may be defined and the cracks and gaps in the fabric may be found by various devices such as a thermographic camera or by a smoke pencil. The duration of the blower door test is from 2 hours for residential and 1-3 storey commercial buildings to 4 hours for larger buildings /11/.

There are two types of blower doors: calibrated and uncalibrated. It is better to use the calibrated one because it provides information about the amount of air exhausted outside of the building during the time unit. When using the calibrated blower door it is possible to define the amount of air leakage but it could not be done by using not calibrated blower door. /12./ The main points of the calibrated blower door test are presented in figure 3.

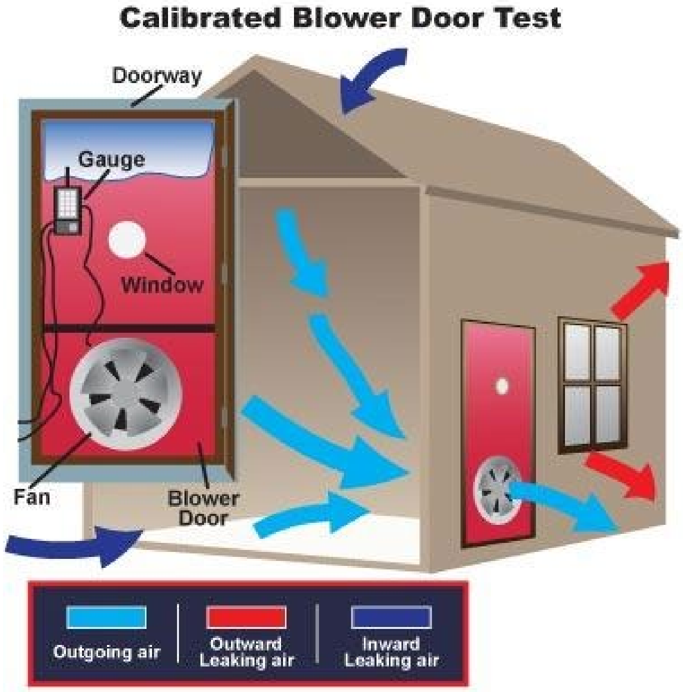

Figure 3. Calibrated blower door test /11/

As it was said above, the amount of air leakage could be defined as the created conditions of under pressure inside the building. The pressure difference between inside and outside spaces of the building is usually 50 Pascals for a blower door test. The test provides the following values: air changes per hour at 50 Pascals and cubic meter per hour of air at 50 Pascals. The first value is n_{50} and it shows the number of air changes in the building for one hour. If the air changes 5 times or less, it means that the building is relatively airtight. If the amount of changes varies from 5 to 9 per one hour the building is moderately leaky, and if the air in the building changes more than 9 times per hour, the building is not airtight at all. In new systems, the program software calculates air leakage rate, q_{50}, automatically. The second value shows the volume of air that is taken away from the building by the fan for one hour to create the under pressure 50 Pascals. If this value is less than 2100 m^3/h the building is airtight. The value between 2200 and 5000 m^3/h shows that the building is moderately leaky. The value of more than 3000 m^3/h means that the building has a very low airtightness and it is characteristically for older buildings. /11./

The test also provides a series of pressure differences and the corresponding airflows through the fan. According to this data, the air leakage curve may be calculated by equation 4. It is also may be calculated automatically and provided by the software. /13, p. 8./

$$Q = C \cdot \Delta P^n \tag{4}$$

where	Q	the airflow required to create a pressure difference Δp = 50 Pa	[m^3/h]
	C	flow coefficient	[$m^3/(h \cdot Pa)^n$]
	ΔP	pressure difference between outdoor and indoor air	[Pa]
	n	exponent (depends on type of air flow, varying from 0,5 (laminar) to 1,0 (turbulent))	[-]

When the blower door test is carried out, various corrections should be applied to the result data that take into account temperature and density variations in the test conditions. It is obvious that the amount of leakage air would be different in different temperature and density of the air. The conditions are usually corrected to the standard temperature of 20°C and a barometric pressure of 101325 Pa. the following corrections should be carried out before analyzing the results of the blower door test:

- correct the readings from the airflow measuring device for differences between actual test conditions and those for which the device was calibrated;
- correct the measured airflow rates for differences in temperature between air passing through the airflow measuring device and air passing through the building envelope;
- correct the airflow rates through the building envelope to standard temperature and barometric pressure conditions (STP).

These corrections are usually done by software before creating an air leakage curve. However, if the measurement of airtightness of a building envelope is carried out by using a ventilation system to depressurize or pressurize a building or software is unable to apply these corrections they may be carried out by using equations 5 – 7. /13, p. 11./

Correction for the difference between actual conditions in the airflow measuring device and conditions when it was calibrated:

$$Q_m = Q_c \frac{\rho_c}{\rho_m} \tag{5}$$

where	Q_m	the actual air volume flow rate in the measuring device	[m^3/h]
	Q_c	the air volume flow rate from calibration of the measuring device	[m^3/h]
	ρ_c	the air density in the measuring device	[kg/m^3]
	ρ_m	the air density from calibration of the measuring device	[kg/m^3]

Correction for the indoor/outdoor temperature differences between air passing through the airflow measuring device and air passing through the building envelope:

$$Q_{env} = Q_m \frac{T_o + 273}{T_i + 273} \tag{6}$$

where	Q_{env}	the actual air volume flow rate through the building envelope	[m^3/h]
	Q_m	the actual air volume flow rate in the measuring device	[m^3/h]
	T_o	the mean outdoor temperature during the test	[°C]
	T_i	the mean temperature in the measurement device during the test	[°C]

Correction of the airflow rates through the envelope to standard temperature and barometric pressure (STP), 20°C and 101325 Pa.

$$C_s = C_{env}\left(\frac{\rho_{env}}{p_s}\right)^{(1-n)} \tag{7}$$

where	C_s	the air leakage flow coefficient at standard temperature and pressure	[m³/(h·Pa)ⁿ]
	C_{env}	the air leakage flow coefficient through the building envelope during the test	[m³/(h·Pa)ⁿ]
	ρ_{env}	the density of air through the building envelope (equals the density of indoor air for pressurization tests or outdoor air for depressurization tests)	[kg/m³]
	ρ_s	the air density at STP (1.2)	[kg/m³]

The corrected value of the air leakage flow coefficient, C_s, can then be used to calculate Q_{50}, the airflow rate at 50 Pa. This is then used to calculate the air leakage index, air permeability, equivalent leakage area, etc. /13, p. 11./

2.3.2 Detection of leakages by using thermal imaging camera

When the under pressure is created inside the building by the blower door device the cracks and gaps in the fabric of the building could be easily found by using a smoke pencil or thermographic camera. Thermographic imaging is a perfect way to detect building envelope defects such as missing insulation, delaminating render, gaps, cracks and condensation problems /1, p. 15/.

It is known that every object that has a temperature above absolute zero emits radiation in the infrared region. The infrared radiation is invisible for the human eye but it can be felt by human skin as heat. Warmer objects emit more infrared radiation. This fact is fundamental in understanding the principle of how a thermal imaging camera works. Firstly, infrared energy comes from an object. Then it is caught by the optics and transferred onto the infrared detector. After that, the detector sends the information to the sensor electronics where the image is processed. Finally, the electronics translate the data coming from the detector into an image that is presented on the screen. /1, p. 9./ The results may be imported and edited by software that is recommended by the manufacturer. The thermographic camera may be used to scan HVAC installations as well as an entire building. This device gives a total view of the situation. /1, p. 11./

Figure 4 shows an example of how a thermal image of a building looks like.

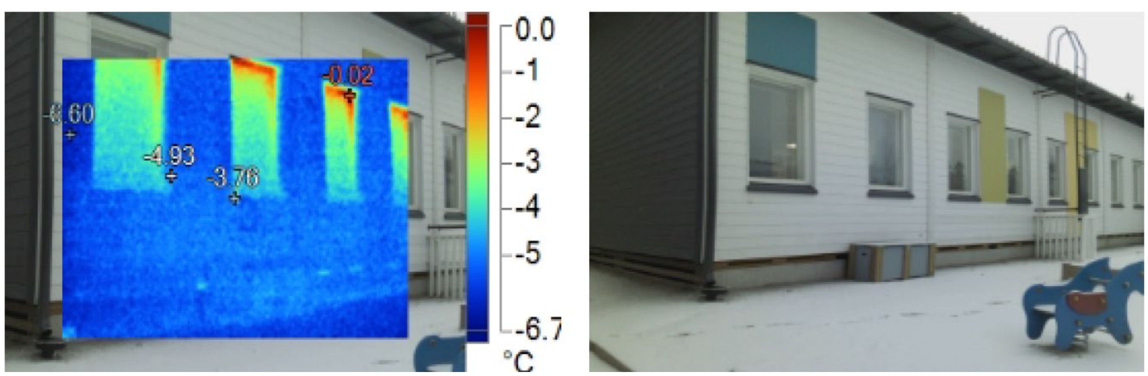

Figure 4. An example of a thermal image of a building made in the outside

To detect defects that cause air leaks, like cracks, gaps, poor joints, by using a thermographic camera both temperature and pressure differences are needed. By thermographic camera, it is possible to detect the temperature difference that usually happens when cold air is penetrating through a leak in the construction inside the building, goes along a surface and cools it down. This is the main reason why the inspection should be carried out when there is under pressure created inside the building. /1, p. 17./

The main leakage points are usually located in the connections and interfaces between the building envelope components. They are presented in figure 5. The main junctions, which are shown in the picture should be insulated to avoid air leaking through a building envelope. These points are usually checked with a thermal imaging camera or a smoke pencil during the blower door test.

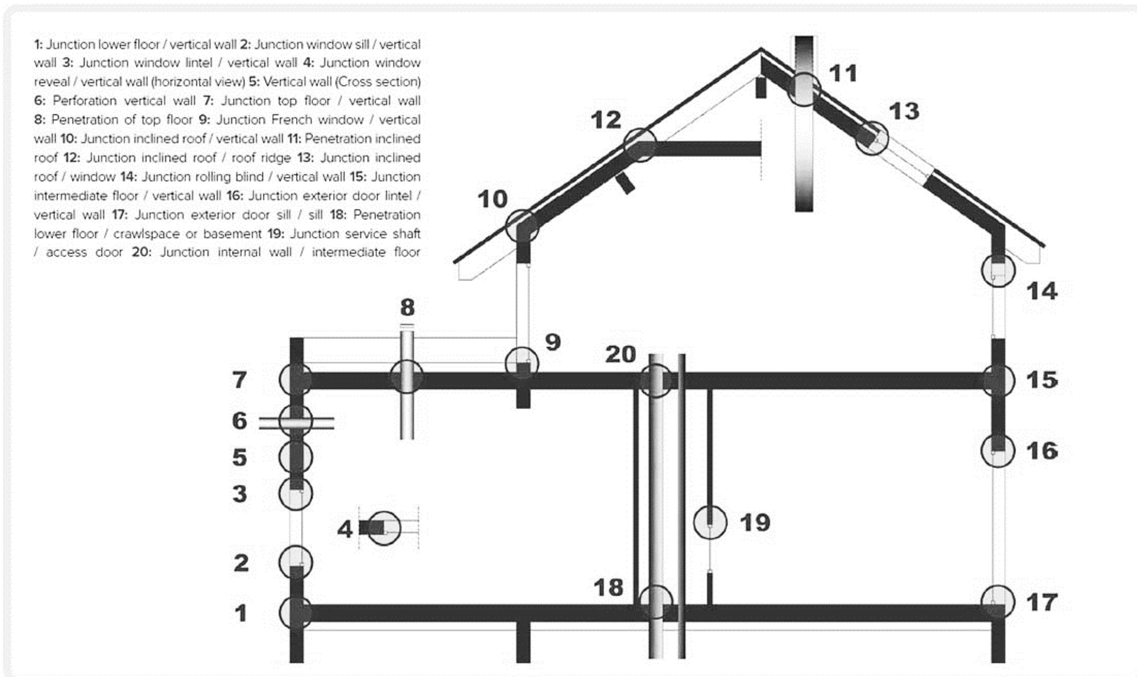

Figure 5. Diagram showing some of the potential main junctions and penetrations in a building envelope, where good airtightness detailing and workmanship will be required /14/

According to regulations in Finland, both temperature and pressure differences between inside and outside spaces of a building are required to verify the thermal performance of the finished structures and for air leakage detection /15, p. 2/. Figure 6 shows an example of the thermal image that is made in the conditions of under pressure of 50 Pascals inside the building where air leakage of the building envelope is detected.

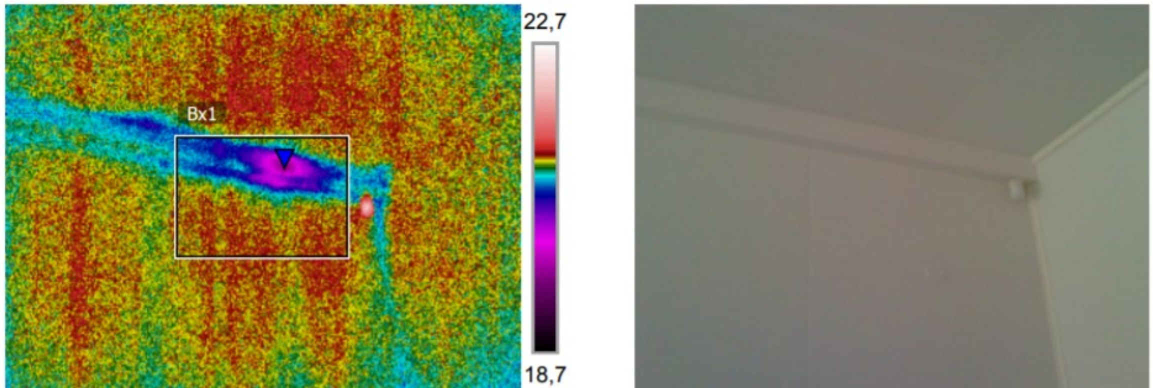

Figure 6. An example of a thermal image made in the created conditions of under pressure inside the building to detect air leakage

2.4 Influence of airtightness of a building envelope

2.4.1 Influence on energy efficiency

Uncontrolled air leakages through the building envelope have a huge influence on the energy efficiency of the building. In fact, airtightness is a key point in the energy efficiency of the building because leakage of air from inside of the building reduces the efficiency of the thermal insulation, heat resistance of the structure, efficiency of heat recovery system and increase losses for the ventilation. As a result, heating and sometimes cooling demand of the building increases to compensate for the additional heat losses. Higher consumption of energy means higher costs for building maintenance.

Figure 7 represents the dependence of the annual specific heating demand and specific thermal loss by ventilation from airtightness of the reference energy-efficient building with a heat recovery system, which efficiency is 85%. The reference building's location in Central Europe, it is made from wooded mass materials and contains two storeys. The net heated area is 150 m^2, the area of the building envelope is 420 m^2 and the volume of the building is 440 m^3. /16, p. 4./

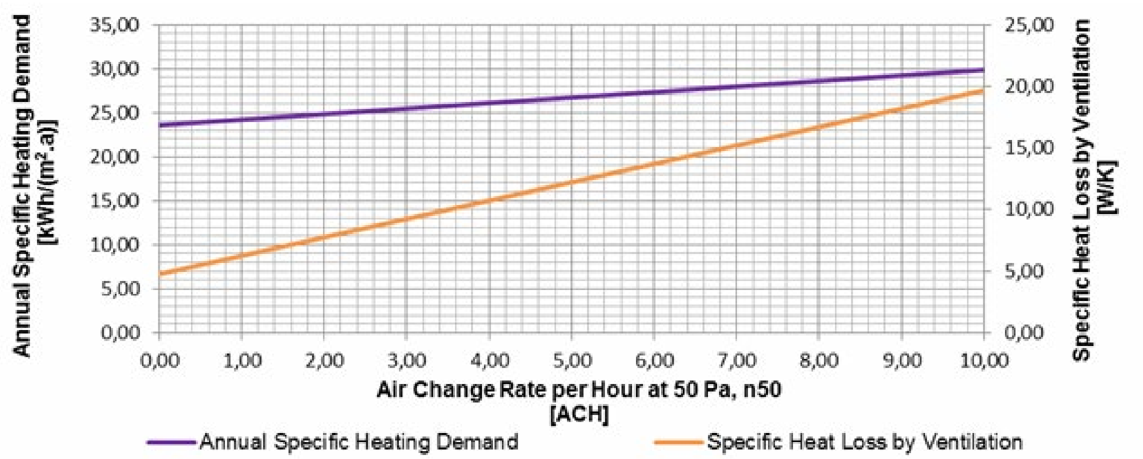

Figure 7. Relationship between air change rate and annual specific heating demand and specific heat loss by ventilation /16/

It is obvious that the lower air change rate and air leakage rate the building has the lower its heating demand. According to figure 7 specific heat loss for ventilation is 4 times more and the heating demand of the building is 1,25 times more if the building has poor airtightness.

2.4.2 Influence on indoor climate

It is known that air leakages cause air infiltration through the building envelope. However, uncontrolled infiltration is not a good method of air supply in the building because it causes moisture penetration, draughts, and uncontrolled temperature differences.

However, increased airtightness of the building leads to decreasing of air coming inside the building. It may increase the number of indoor air pollutants. The research shows that improved airtightness of the building from 1,3 to 0,6 ACH may reduce incoming fresh air for 33% and reduce indoor air quality level. Figure 8 shows the changes that happen when the airtightness of the building envelope is improved without adjusting ventilation. In the first case, the indoor air quality is moderate and in the second case, the indoor air quality is considered to be poor. The results are got from the simulations using SIREN software from French CSTB official body (“Centre Scientifique et Technique du Batiment”) and indoor air quality is level is estimated according to CO_2 concentrations. /17, p. 6./

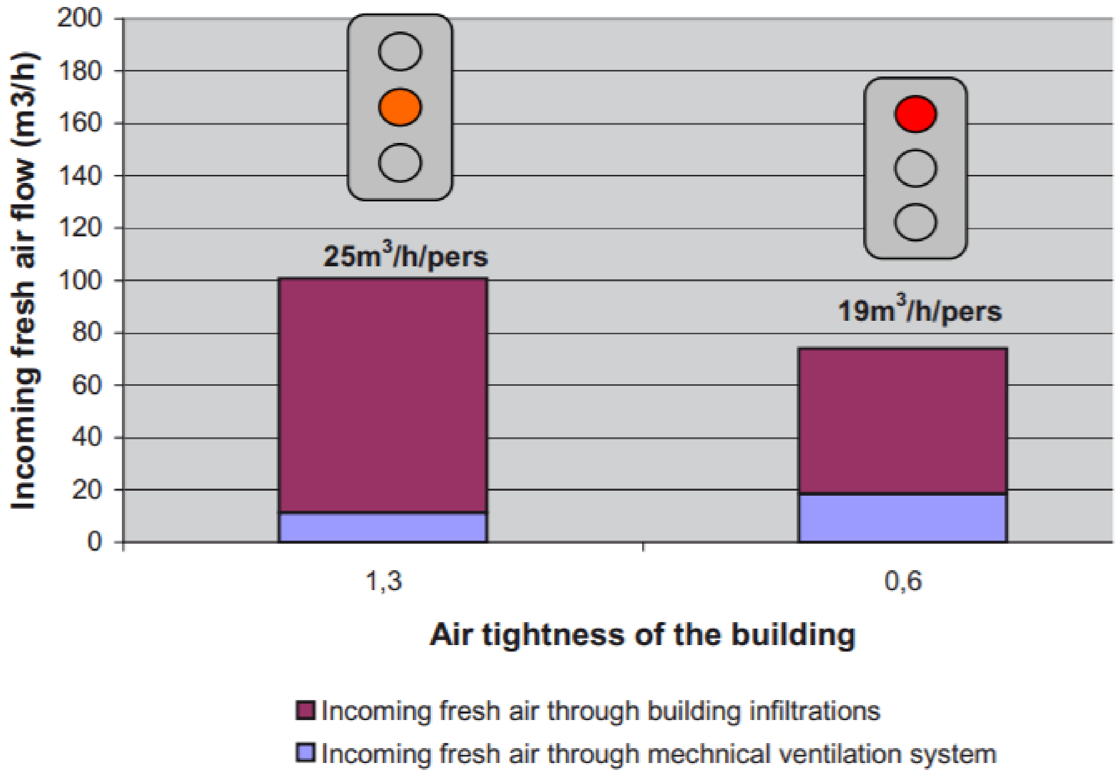

Figure 8. Incoming fresh air repartition with humidity-controlled ventilation /17, p. 7/

This means that when improvements of airtightness of the building are made the ventilation system should be adjusted to provide a satisfactory indoor air quality. That is why indoor air quality should be also monitored in the building to discover if the supply airflow rate is enough in the existing conditions.

3 METHOD

3.1 Description of the building

As a case building a daycare center was chosen. A daycare center is a childcare facility that is created to let parents leave their children for the working day for care, supervision or learning. Sometimes daycare centers work 24 hours per 7 days and give an opportunity for parents to leave their children for several days and nights.

The studied daycare center building is presented in figure 9. The building is located in Lahti, the city of Finland in the South of the country. The city is situated in the II climatic zone of Finland, where the designed outdoor air temperature is -29°C.

Figure 9. The investigated building of the daycare center

The description of the studied daycare center is provided below.

Address: Kerinkallionkatu 6, 15520 Lahti.

The case building: the new part of the daycare center.

The number of storeys: 1.

Area of the building envelope on the base of internal dimensions of external walls: 1474,7 m^2.

Net heated area: 564,6 m^2.

The volume of the building: 1863,18 m^3.

The year of construction: 2019.

The construction of external walls:

- Plasterboard EK 13 mm;
- Plastic vapor barrier SFS 4225;
- Vertical panel 48x248 mm + non-combustible stone wool 250 mm;
- Gypsum sheathing board 9 mm;
- Vertical supporting rails 30x100 mm;
- Horizontal paneling 23x175 mm.

U-value of external the walls: 0,17 W/m$^2 \cdot$ K.

The construction of ceiling:

- Roofing profile sheet k300 25 x100 mm;
- Trussed rafters R30 + blowing wool 120 mm + non-combustible mineral wool 250 mm;

- Fire-resistant plasterboard 15 mm;
- Wooden frame 42 x98 mm + mineral wool 100 mm;
- Plastic vapor barrier SFS 4225;
- Lathing k300 mm 23 x120 mm;
- Acoustic insulation 13 mm.

U-value of ceiling: 0,09 W/m^2 · K.

The construction of base floor:

- Carpet;
- Chipboard 22 mm;
- Board 23 x100 /underfloor heating 23 mm;
- Floor beams wooden k400 mm 45 x270 mm + non-combustible stone wool 270 mm
- Fiber cement 9 mm
- Protection board 19 x100 mm k400 mm 19 mm;
- Pressurized wood.

U-value of base floor: 0,16 W/m^2 · K.

U-value of windows and doors: 1 W/m^2 · K.

Working hours: 24 hours per 7 days.

3.2 Description of the sample room (room 391)

As a sample room, a room where there are outer door and detected leakage points was chosen because there is the highest amount of leakage airflow and it causes the possibility of low temperatures and high moisture content. Children spend a lot of time in the sample room, they play and sleep there. The number of children who spent time in the room during the day when measurements took place is 11. The age of the group of children who spent time in the sample room is from 3 to 5 years old they were nursed by 2-3 adults during the day.

The location of the sample room 391 on the plan of the first floor is presented in figure 10. The area of the room is 46 m^2.

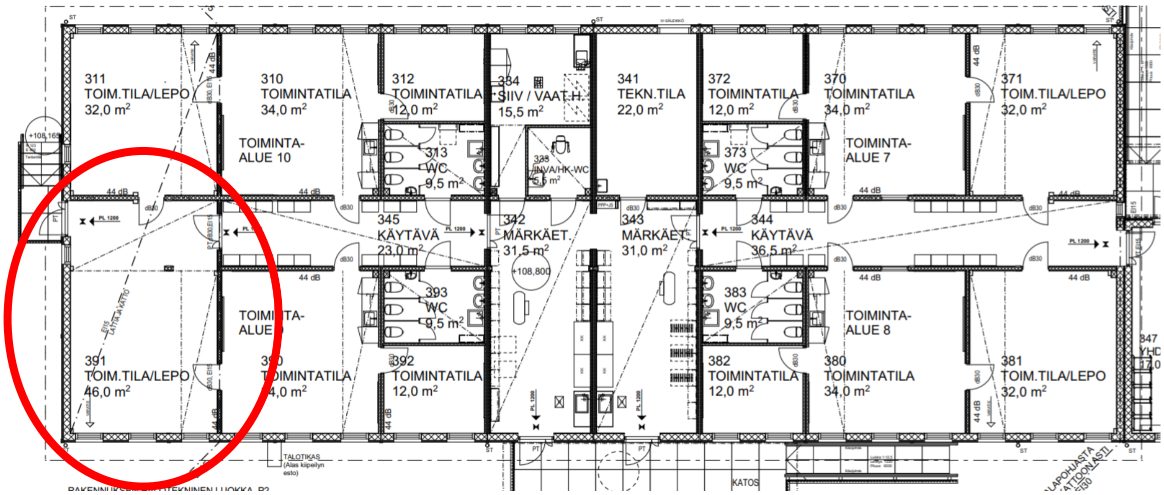

Figure 10. The location of the sample room 391 on the plan of the first floor

3.3 Description of the measurements and measuring equipment

3.3.1 Measuring airtightness

First of all, at the end of the construction process measurement of airtightness of the building envelope took place. It was carried out according to the international standard ISO 9972. According to ISO 9972, the depressurization test should take place when the building envelope is fully constructed /18, p. 5/. However, it should better be made when finishing works are not completed yet to fix the cracks in the building envelope easily if they are found.

The blower door test took place to define the airtightness of the building envelope. Equipment: Retrotec 6000 fan, DM32 WiFi digital pressure gauge. The installed equipment is shown in figure 11.

Figure 11. The installed equipment Retrotec 6000 with DM32 WiFi digital pressure gauge /19/

When the depressurization was completed, air leaks in the building envelope were detected by thermal camera FLIR E60. The camera is shown in figure 12.

Figure 12. Thermal camera FLIR E60 /1/

The thermal images were taken according to the instruction card regarding thermal images that describe buildings. According to the instruction card, the following conditions are required when checking the thermal performance of finished structures: for air leakage detection at under pressure inside the building of 50 Pa the temperature difference of at least 5°C is needed (the resolution of the thermal imaging camera is not more than 0.1 degrees and a resolution of at least 19000 pixels).

In addition, weather changes in thermal imaging must also be taken into account during the measuring process. Temperature fluctuations shall be recorded in the measurement report and take into account when interpreting the results if the outdoor temperature changes over 5°C and room temperature over 2°C during measurements.

3.3.2 Monitoring indoor air quality and thermal conditions

When the building was commissioned, indoor air quality and thermal conditions were monitored to check if the supply airflow rate is enough for the studied building and to investigate if temperature and relative humidity meet the requirements.

The CO_2 concentration was measured by data logger TSI IAQ-CALC 7535. Before the start of the monitoring, the device was calibrated. The calibration process is presented in figure 13.

Figure 13. The calibration process of TSI IAQ-CALC 7535

The target values for CO_2 concentrations are mentioned in the CLASSIFICATION OF INDOOR ENVIRONMENT 2018 Target Values, Design Guidance, and Product Requirements instructions.

Temperature and relative humidity were monitored by –ebro– EBI 20 data logger. The device fulfills the guidelines according to international standard EN 12830. The device is presented in figure 14.

Figure 14. –ebro– EBI 20

3.3.3 Measuring locations, times, and intervals

Airtightness measurement took place on 03.07.2019. Temperatures during the measurement process:

- in the beginning: indoors 21,8°C, outdoors 14,6°C;
- in the end: indoors 21,8°C, outdoors 14,6°C.

Other conditions: atmospheric pressure: 100,2 KPa, wind speed: 4 m/s moderate breeze.

The blower door fan was installed on the main door. The location of the blower door fan is shown in figure 15.

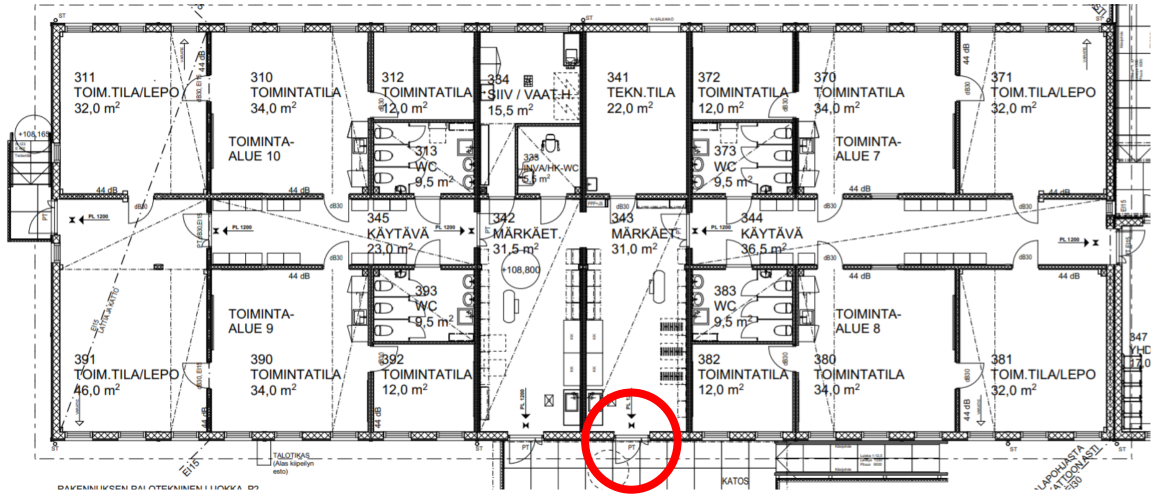

Figure 15. The location of blower door fan

Thermal conditions monitoring took place on 08.11.2019. The weather conditions during the monitoring day are presented in figure 16.

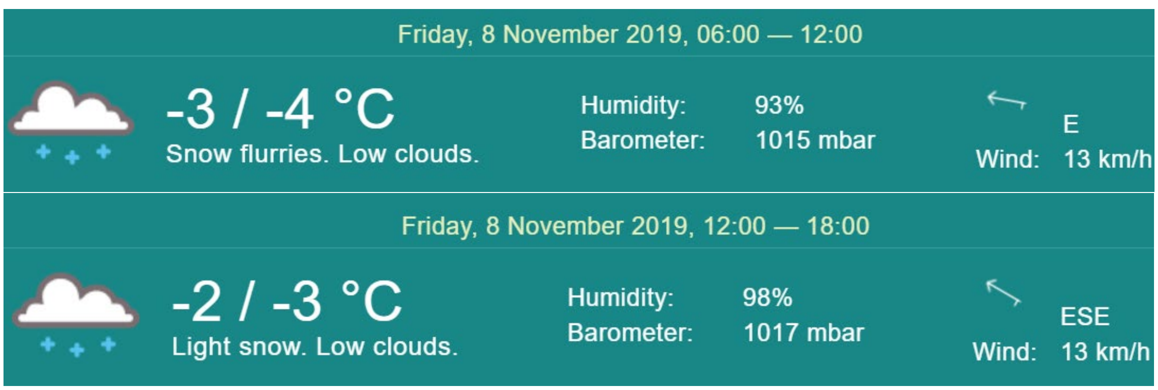

Figure 16. Weather in Lahti on 08.11.2019 /20/

The average outside CO_2 concentration in front of the sample room 391 was 437 ppm.

The place where the –ebro– EBI 20 and TSI IAQ-CALC 7535 data loggers were installed is presented in figure 17. Figures 18 and 19 represent the photos that were taken during the monitoring process in the sample room 391 where the measurement devices location is shown.

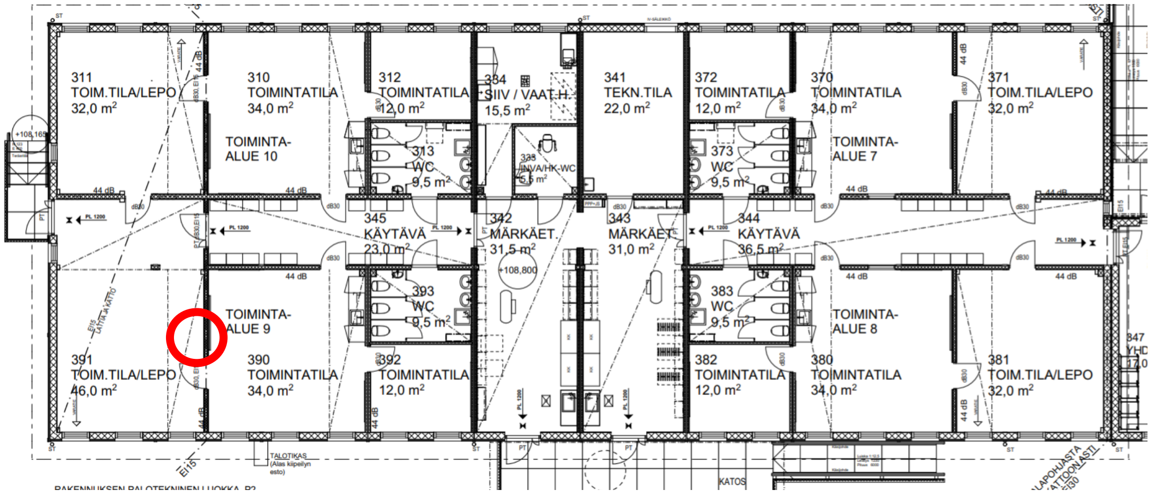

Figure 17. The location of –ebro– EBI 20 and TSI IAQ-CALC 7535 data loggers during monitoring on the plan of the building

Figure 18. The location of –ebro– EBI 20 and TSI IAQ-CALC 7535 data loggers during monitoring on the photo of the sample room 391

Figure 19. The location of –ebro– EBI 20 and TSI IAQ-CALC 7535 data loggers during monitoring on the photo of the sample room 391

The choice of the location of the devices was influenced by the fact that children spend a lot of time in the sample room 391 and they should have no possibility to reach the instruments.

The monitoring took place from 9:00 to 16:00. The sample interval of 1 minute was installed for both –ebro– EBI 20 and TSI IAQ-CALC 7535 data loggers when they were programmed. The indoor climate in the sample room 391 was influenced by the adjoining room 390 because the door between them was opened from time to time not to prevent children from one group to move from one room to another. The doors to the corridor were closed most of the time.

The approximate activity of the group of children and 3 adults during the monitoring hours in the rooms 390 and 391:

- 9:00 – 9:50 children and nurses moved between rooms, children played in both rooms and had breakfast in room 390;
- 10:00 – 11:40 children left both rooms and went for a walk;
- 11:40 – 12:00 children had lunch in room 390;
- 12:00 – 13:40 children slept in room 390;
- 13:40 – 14:30 children had afternoon snack in room 390, played and moved between rooms 390 and 391;
- 14:30 – 15:30 an activity took place in the sample room 391, it was occupied by the whole group of children and 3 adults;
- 15:30 – 16:00 everyone left the rooms.

The results will be presented in graphs and compared to the legislations and target values.

4 RESULTS AND ANALYSIS OF RESULTS

4.1 Airtightness of the building envelope

The results of the airtightness measurement should be presented in two parts. In the first part, there are results of the blower door test where the air leakage rate is determined. In the second part, there are the results of the leakage point detection in the building envelope.

4.1.1 Results of the blower door test

As a result of the blower door test leakage rate of the building envelope, q_{50} was defined. For the case building the result is q_{50} = 0,796 m^3/hm^2 at a pressure difference of 50 Pa. This value does not exceed the limit value for the air leakage rate in Finland that is presented in table 1. That means that the building meets the requirements regarding the airtightness of the envelope. The full results are shown in table 2 and table 3. Table 2 shows that the number of air changes per hour is 0,63 and this value is close to the passive house requirements, the buildings that have very high energy performance. Table 3 shows the series of the pressure difference between inside and outside of the building and fan airflow rates that are required to create the test pressure difference. The target test pressure is highlighted by color.

Table 2. The combined results of the blower door test

Combined results	Value	Range		Uncertainty
Airflow rate 50 Pa, V_{50} [m^3/h]	1174,0	1146,5	1202,5	+/-2,4%
Air changes per hour N_{50} [1/h]	0,63	0,61	0,64	+/-3,2%
Air leakage rate q_{50} [m^3/hm^2]	0,796	0,771	0,821	+/-3,1%

Table 3. The series of test pressure and airflows of the fan

Test pressure [Pa]	-9,2	-16,2	-22,4	-28,0	-33,1	-40,0	-46,5	-51,1	-58,6	-63,7
Airflow, [m^3/h]	323	492	624	768	875	1051	1108	1192	1284	1405
Corrected airflow [m^3/h]	317	483	613	754	859	1032	1088	1171	1261	1379
Error [%]	1,0%	-1,9%	-2,7%	0,7%	1,2%	5,6%	-0,5%	-0,2%	-2,9%	-0,1%

The air leakage curve is presented in figure 20. It is created by the Retrotec software according to the data in table 3. It shows the airflow rate of the blower door fan to create the test pressure difference.

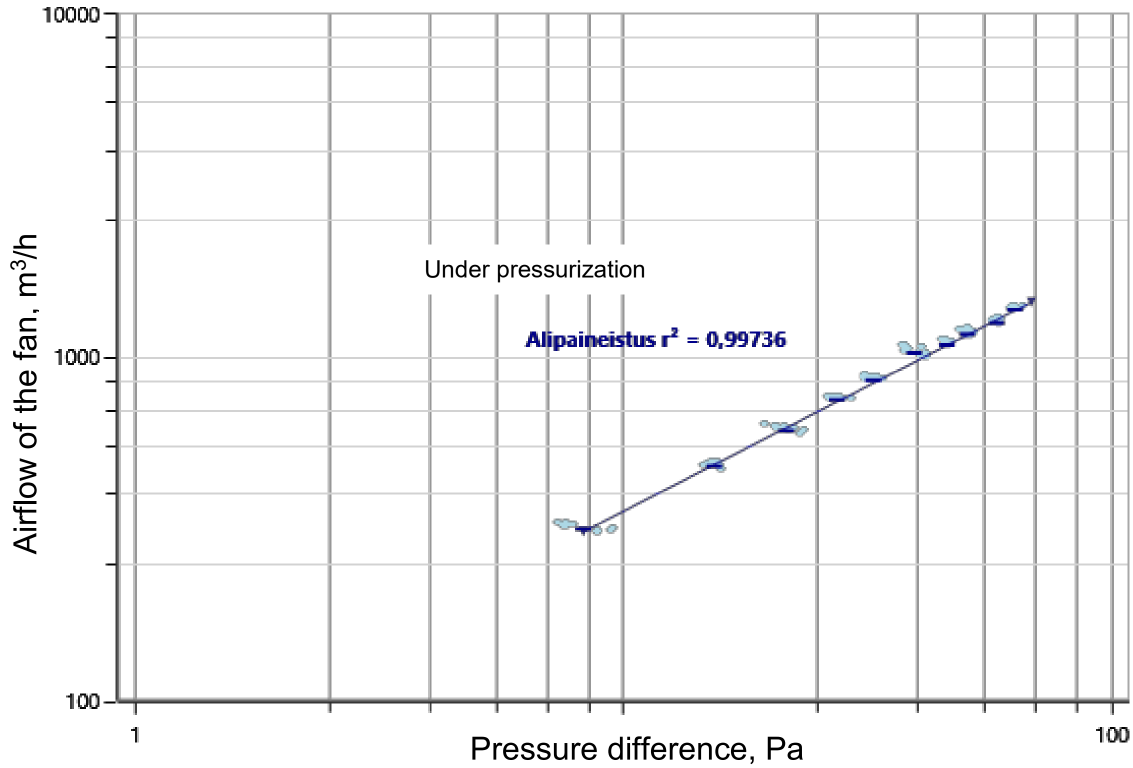

Figure 20. Air leakage curve created by the Retrotec software

According to the air leakage rate, the class of the building may be defined. According to the limitations for air leakage rate the studied daycare center has class B. That means that the studied building has a high airtightness of the building envelope that shows a good quality of the construction. Figure 21 shows the determination of the class of the building according to the air leakage rate. It must be mentioned that the energy class of a building depends not only on air leakage rate but on many other things that have an impact on the energy demand of a building.

Figure 21. Tightness measuring rating

Leakage air flow rate, $q_{v\ air\ leakage}$, is calculated by equation 2. For the studied building:

$$q_{v\ air\ leakage} = \frac{0{,}796}{3600 \cdot 35} \cdot 1474{,}7 = 0{,}00932\ m^3/s$$

Heat loss for air leakage, $Q_{air\ leakage}$, is calculated by equation 3. The design outdoor temperature for Lahti is -29°C. Designed indoor temperature is +21°C For the studied building:

$$Q_{air\ leakage} = 1{,}2 \cdot 1000 \cdot\ 0{,}00932 \cdot \big(21 - (-29)\big) = 559{,}2\ W$$

This value for the studied building is relatively low that means that there is not much energy needed to compensate for the heat loss due to air leakage.

4.1.2 Detection of air leakages by the thermal imaging camera

The leakage points detected by thermal imaging camera FLIR E60 at the created conditions of under pressure of 50 Pa inside the building in the sample room 391 are presented in figures 22 and 23.

As it may be seen in the thermal images, the temperature differences are small that means that the air leakages are relatively small and do not influence much on the thermal comfort of the residents. However, that means that the sample room 391 is relatively airtight and the income of the fresh outside air may be reduced that may cause poor indoor air quality. That is why the indicator of indoor air quality, CO_2 concentration should be monitored and it should be checked if this value meets the target values. The results of the monitoring are presented below.

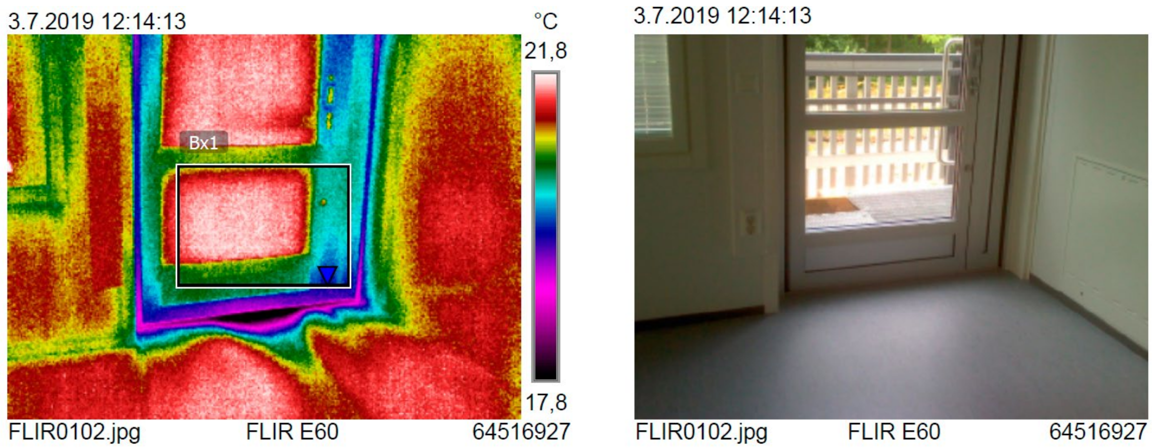

Figure 22. The air leakage detected by the thermal imaging camera that is caused by the outer door in the sample room 391

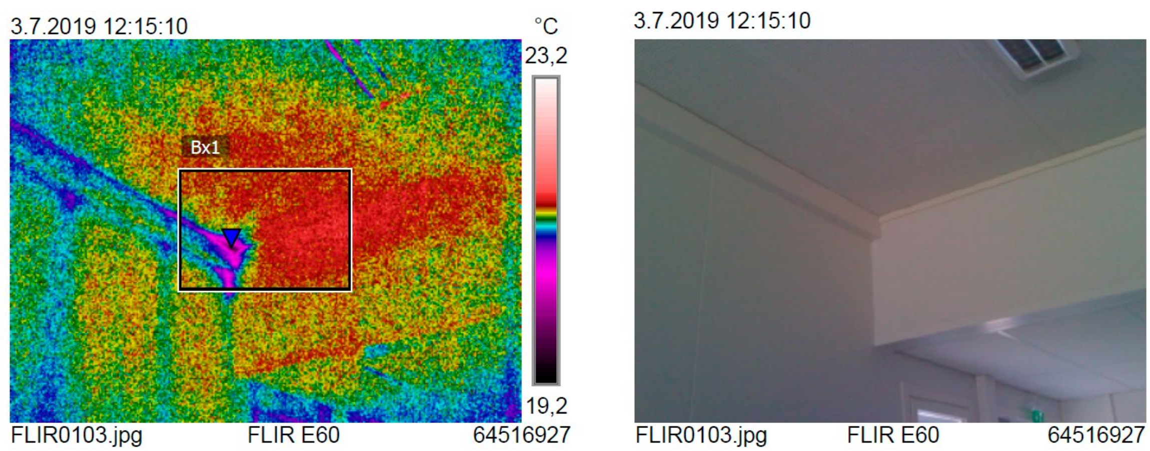

Figure 23. The air leakage detected by the thermal imaging camera that is caused by the crack in the building envelope in the sample room 391

There is a thermal image taken on 08.11.2019 by the thermal imaging camera Fluke TiS45 (figure 24). The outside temperature was -3°C, the inside temperature was +21,5°C, no created under pressure. The image shows that the temperature difference in winter is relatively high that is why the thermal conditions should be monitored and it should be checked if the temperature and relative humidity meet the target values. The results of the monitoring are presented below.

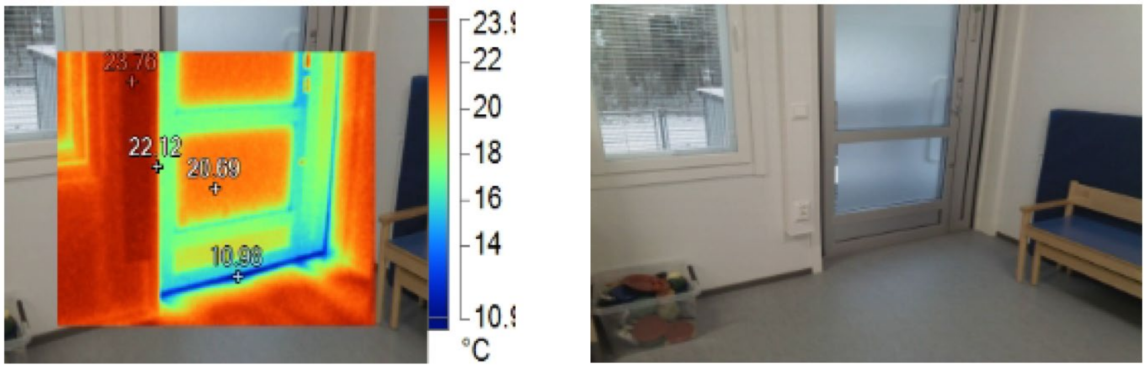

Figure 24. The outer door in the sample room 391

All the leaking points in the building are presented in figure 25. The full reports of the blower door test that took place in the building on 03.07.2019 are presented in appendix 2 and appendix 3. All the leaking points of the building envelope are located in the most common places.

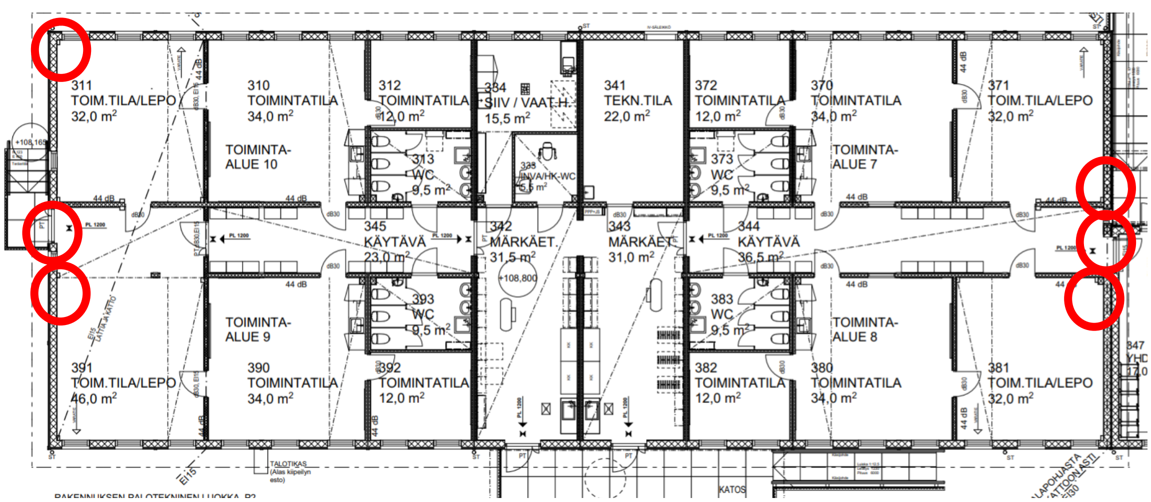

Figure 25. Leaking points detected by the thermal imaging camera FLIR E60 at the created under pressure of 50 Pa inside the building

4.2 Indoor climate

The results of the monitoring of temperature, relative humidity, and CO_2 concentration show that the thermal conditions and indoor air quality in the sample room 391 are acceptable.

4.2.1 Temperature and relative humidity

The monitoring results show that the maximum temperature in the sample room 391 did not exceed 22,3°C during the monitoring hours. The average temperature was 21,8°C that is very close to the design value of 21°C. The minimum temperature inside the room during the monitoring hours was 21,4°C. These values show that the temperature did not fluctuate much even when the room is occupied by the maximum number of people. The temperature also did not drop below the lowest comfort value of 20°C that means that heat loss for air leakage is well compensated. Figure 26 represents the results of the temperature monitoring that took place on 08.11.2019 from 9:00 till 16:00.

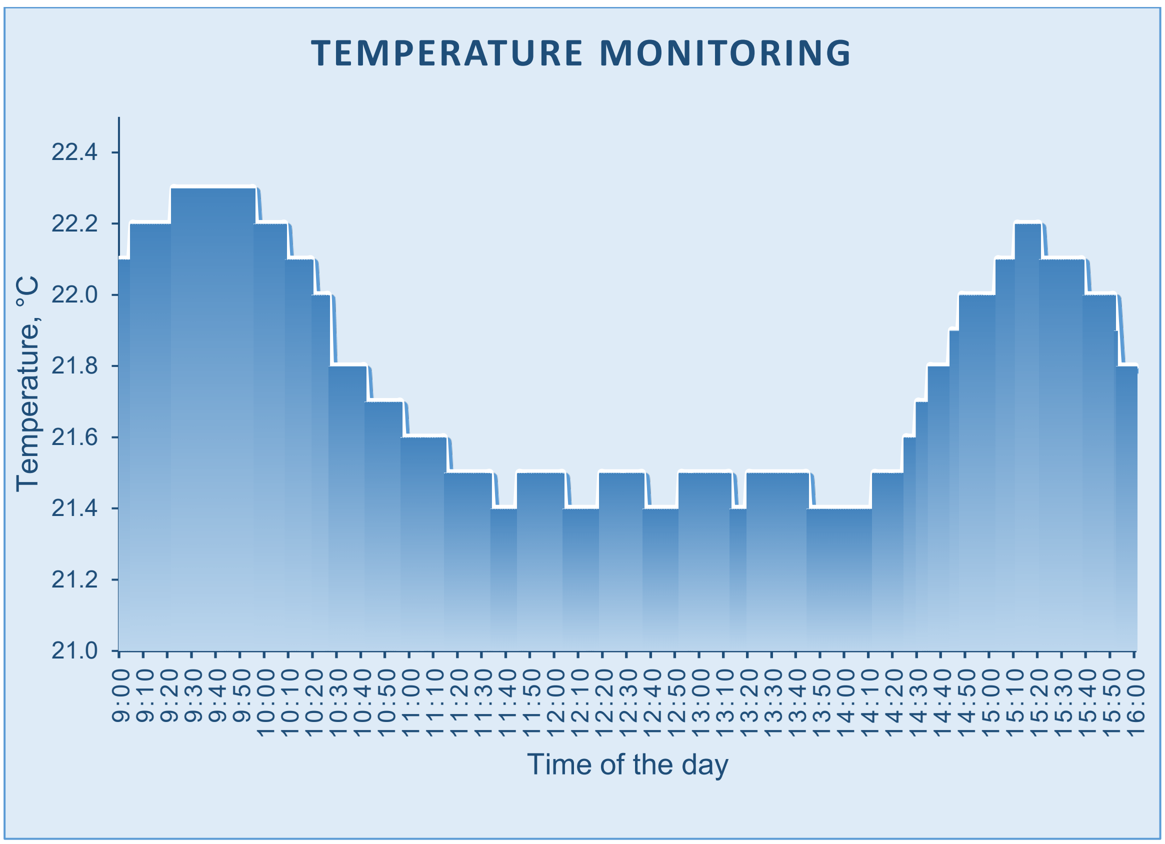

Figure 26. The results of temperature monitoring on 08.11.2019 at 9:00-16:00 in room 391

The results of the monitoring of relative humidity show that the highest relative humidity during monitoring hours in the sample room 391 was 28,3%. The average value for relative humidity is 24,7%. The minimum relative humidity was 22,6% when the room was not occupied by the group of children and adults. The comfort range for relative humidity inside the building is considered to be 40-50%.

However, in winter the indoor relative humidity is usually lower than in summer because the air is relatively dry in winter. The average calculated moisture content in the outside air is 2,86 g/kg. The average calculated moisture content in the indoor air is 4,07 g/kg. The results of the monitoring of relative humidity in the sample room 391 is presented in figure 27.

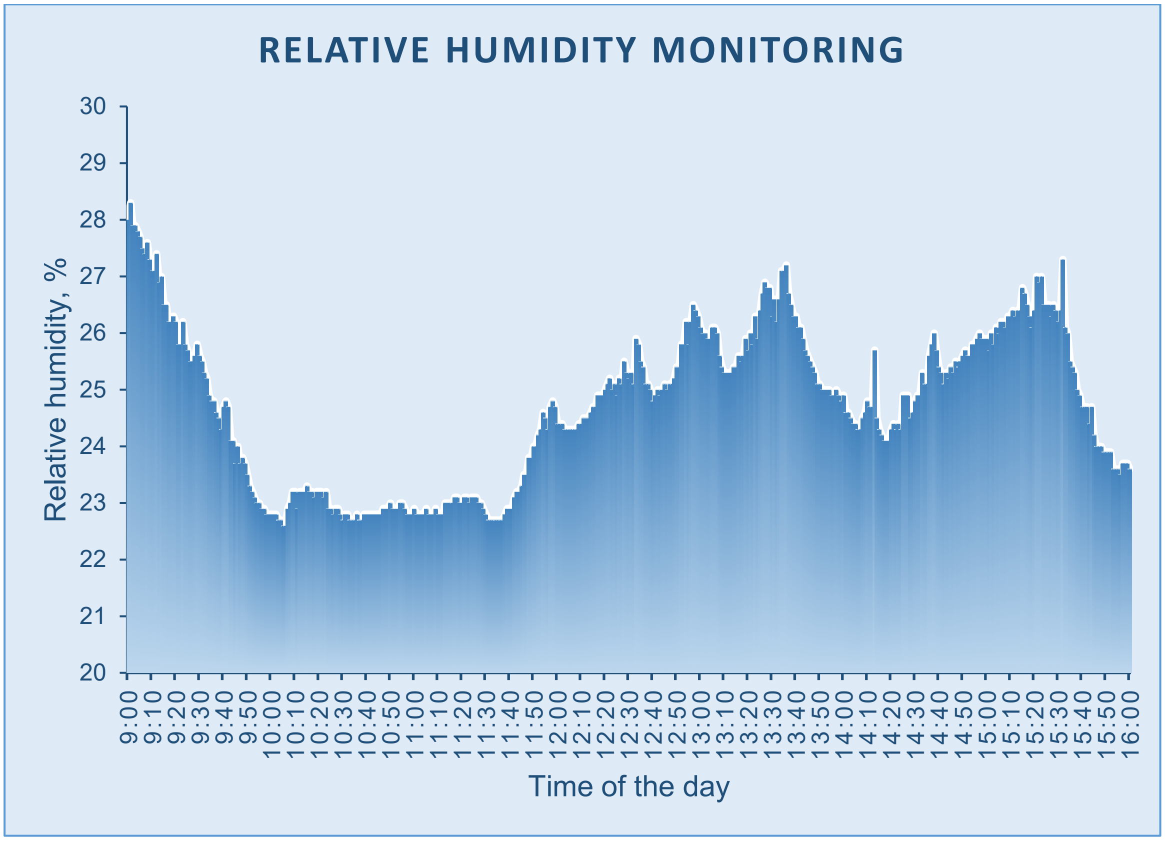

Figure 27. The results of relative humidity monitoring on 08.11.2019 at 9:00-16:00 in room 391

4.2.2 CO_2 concentration

The results of the CO_2 concentration show that the maximum value was 1273 ppm and it took place at the beginning of the monitoring. The minimum value was 362 ppm and it was when the room was not occupied. This value was lower than the average outside CO_2 concentration. That happened because the outside CO_2 concentration is influenced by the activity next to the building, for example, by cars. The outside CO_2 concentration was higher in the beginning and at the end of monitoring because a lot of parents brought their children to the daycare center took them home by car. The average CO_2 concentration during the monitoring hours in the sample room 391 was 600 ppm.

Figure 28 represents the results of the monitoring of CO_2 concentration and the target values for categories S1, S2 and S3. The category S1 means that the indoor air quality inside the building is considered to be high. The target value of CO_2 concentration for the category S1 should not exceed the outside CO_2 concentration by 350 ppm. The category S2 shows that the room has good indoor air quality. The indoor CO_2 concentration for this category should not exceed the outdoor concentration by 550 ppm. The category S3 shows that the room has acceptable indoor air quality. The indoor CO_2 concentration for this category should not exceed the outdoor concentration by 800 ppm.

The results show that most of the time indoor air quality in the sample room 391 is considered to be high. However, at the beginning of the monitoring, the indoor CO_2 concentration exceeded the acceptable range. That means that the supply airflow rate of the ventilation system maybe not enough for the higher occupancy.

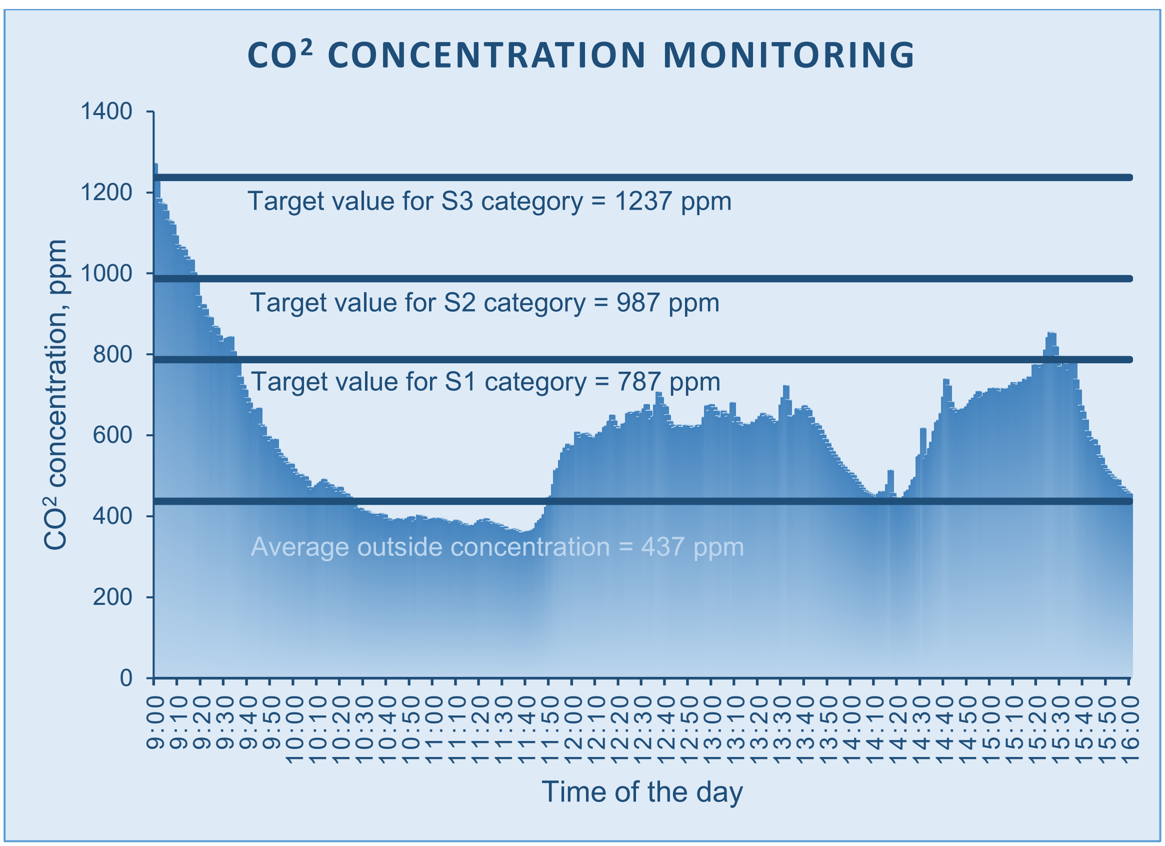

Figure 28. The results of CO2 concentration monitoring on 08.11.2019 at 9:00-16:00 in room 391

5 DISCUSSION

Airtightness of a building envelope as a key point in the improvement of energy efficiency of a building because air leaks become a reason for uncontrolled heat loss and increase the amount of energy consumed for heating and ventilation. However, decreased income of fresh air in the building may worsen indoor air quality.

This study was designed to discover the influence of the airtightness of a building envelope on energy efficiency, heat loss and indoor climate of a building. The airtightness of the case building was measured at the end of the construction process. After the building was commissioned, indoor climate values were monitored during maximum occupancy.

The main results showed that the studied daycare center has a low air leakage rate. That means that the building envelope is very airtight. The heat loss for leakage air is very low, which means that there is a very small amount of energy needed to compensate for it.

The monitoring of the thermal conditions (temperature and relative humidity) in the sample room, where the air leakage is estimated to be the highest one in the building, showed that in this case air leakages have a negligible effect on the thermal conditions inside the room and have almost no influence on the comfort of residents.

The monitoring of CO_2 concentration that determines the indoor air quality showed that reduced income of fresh air due to the high airtightness of the building envelope may cause the increase of indoor air pollutants if the occupancy of the room will increase. That means that the supply airflow rate should be changed if the estimated occupancy increases.

All the measured and monitored values meet the requirements in the legislation. According to them, the building has high energy performance and indoor air quality.

However, the total energy class performance of the building cannot be estimated only by air leakage rate.

Though the indoor climate and energy efficiency of the building meets all the requirements, there are some suggestions. First of all, the outer door should be closed by insulation or tape because according to figure 24 there is draught in winter that may influence the comfort of occupants. It will also reduce the air leakage rate.

To sum up, the studied building meets all the requirements of legislation in Finland, however, there are some improvements that may be applied to increase energy efficiency and indoor climate quality. The airtightness of a building envelope should not be increased without increasing supply airflow rate to create satisfactory indoor air quality.

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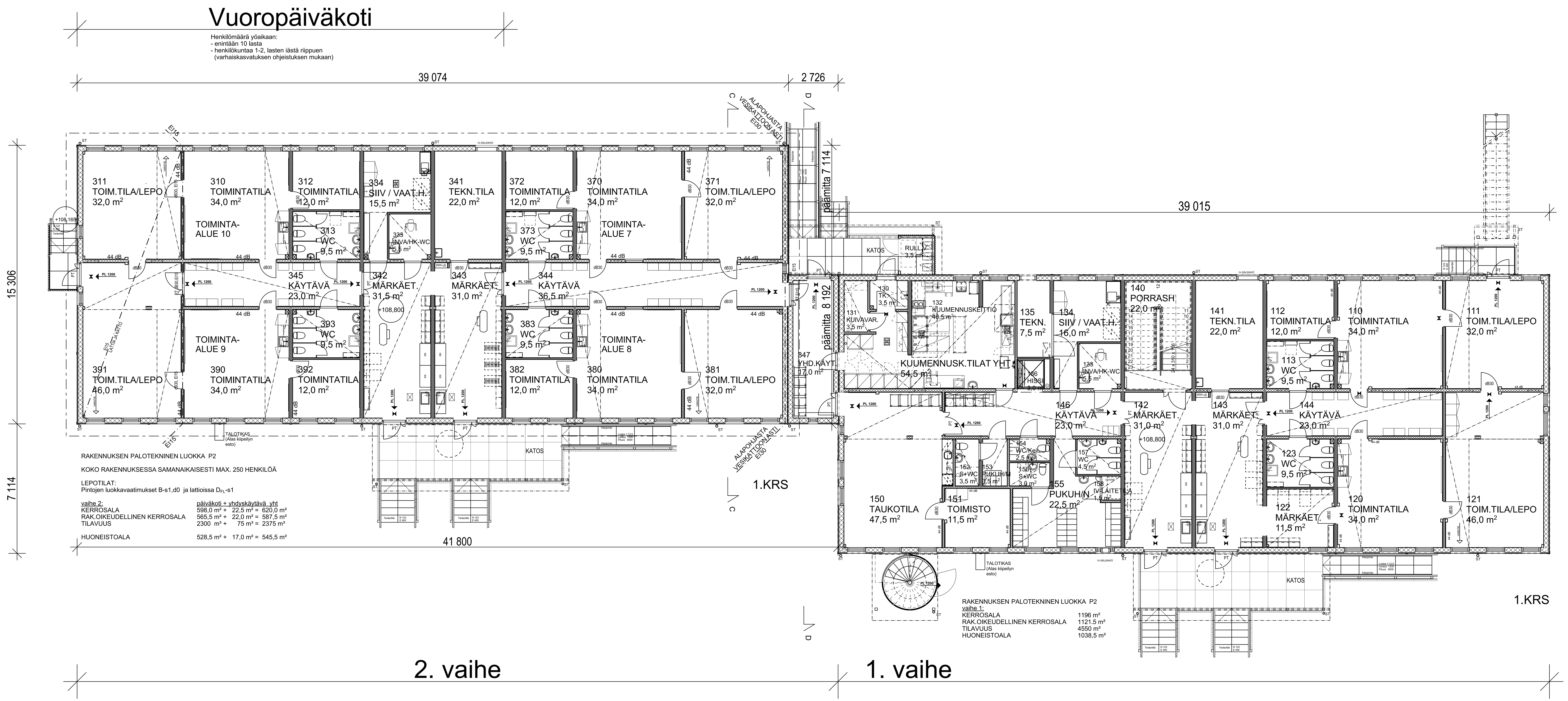
LIST OF FIGURES

LIST OF TABLES

Appendix 1



05.08.2019 TSi Osoitettu vuoropäiväkotina käytettävät tilat ja määritelty henkilömäärä

04.07.2019 TSi Päiväkodin yksikerroksinen osuus muutettu vuoropäiväkodiksi
- 1-kerroksisen osuuden pääty osastoitu EI30
- lepotilat erotettu EI15-rakennusosin
- pintojen luokkavaatimukset esitetty

KOORDINAATTIJÄRJESTELMÄ ETRS-GK26	KORKEUSJÄRJESTELMÄ N2000
Kaupunginosa/Kylä: KERINKALLIO (20); Kortteli/Tila: 49; Tontti/Rnro: 2	Viranomaisten arkistointimerkintöjä varten
Rakennustoimenpide: Laajennus	Piirustuslaji: Pääpiirustus; Juokseva nro: .
Rakennuskohteen nimi ja osoite: KERINKALLION PÄIVÄKOTI, vaihe 2, Saarnikatu 2, 15520 LAHTI	Piirustuksen sisältö: 1. kerros; Mittakaava: 1:100
PARMACO Oy, Haarlankatu 4 F (PL 50), 33231 TAMPERE, Puh. 020 734 0011 — Suunn/Piirt: Tiina Siren RA, Tampere 28.10.2018	ARK - 6318 - 002

Appendix 2

YLÄPOHJA (YP1) EI30, RISTIKOT R30 u<0.09 W/m² K
B-s1,d0
VESIKATE PROFIILIPELTI
VESIKATTORUOTEET k300 25x100 mm
ALUSKATERIMA 25x50 mm
ALUSKATE
NAULALEVYRISTIKKO R30
+ PUHALLUSVILLA 120 mm
+ PALAMATON MINERAALIVILLA 250 mm
PALOKIPSILEVY 15 mm
PUURUNKO 42x98 mm
+ MINERAALIVILLA 100 mm
HÖYRYNSULKUMUOVI SFS 4225
KOOLAUS k300 mm 23x120 mm
AKUSTO-/KIPSILEVY 13 mm

ULKOSEINÄ (US1) u<0.17 W/m² K (osastoiva seinä EI30)
B-s1,d0
KIPSILEVY EK 13 mm
HÖYRYNSULKUMUOVI SFS 4225
PYSTYRUNKO 48x248 mm
+ PALAMATON KIVIVILLA 250 mm
TUULENSUOJAKIPSILEVY 9 mm
PYSTYKOOLAUS 30x100 mm
PANELOINTI VAAKA 23*175 mm

ALAPOHJA (AP1) u<0.16 W/m² K
D_{FL}-s1
MUOVIMATTO
PONTATTU LASTULEVY 22 mm
(KOSTEISSA TILOISSA VANERI)
HARVALAUTA 23x100/LATTIALÄMMITYS 23 mm
LATTIAPALKIT KERTOPUU k400 mm 45x270 mm
+ PALAMATON KIVIVILLA 270 mm
KUITUSEMENTTILEVY (tuulens.) 9 mm
SUOJALAUDAT 19x100 mm k400 mm 19 mm
PAINEKYLLÄSTETTYÄ PUUTA

IKKUNAT JA OVET u =1,0 W/m²K

RAKENNUKSEN PALOLUOKKA P2

ALAPOHJA (VÄLIKKÖ) u<0.16 W/m² K

MUOVIMATTO
PONTATTU LASTULEVY 22 mm
(KOSTEISSA TILOISSA VANERI)
LATTIAPALKIT KERTOPUU k400 mm 45x270 mm
+ PALAMATON KIVIVILLA 270 mm
KUITUSEMENTTILEVY (tuulens.) 9 mm
SUOJALAUDAT (19+23)x100 mm k400 mm 19+23 mm
PAINEKYLLÄSTETTYÄ PUUTA

VÄLISEINÄ (VS1) 44 dB
(viipaleväliseinä)

KIPSILEVY EK 13 mm
PUURUNKO 42x66 mm 66 mm
+ PALAMATON KIVIVILLA 70 mm
HOMESUOJATTU VANERI 6.5 mm
ILMARAKO (elementtisauma) 37 mm
HOMESUOJATTU VANERI 6.5 mm
PUURUNKO 42x66 mm 66 mm
+ PALAMATON KIVIVILLA 70 mm
KIPSILEVY EK 13 mm

VÄLISEINÄ (VS2) B-s1,d0 (osastoiva seinä EI15)
(huoneiden välinen ei-kantava seinä)

KIPSILEVY EK 13 mm
KIPSILEVY N 13 mm
VANERI 12 mm
PUURUNKO 42x98 mm 98 mm
+ MINERAALIVILLA 100 mm
VANERI 12 mm
KIPSILEVY N 13 mm
KIPSILEVY EK 13 mm

VÄLISEINÄ (VS3) 44 dB/ R30 B-s1,d0
(kantava väliseinä)

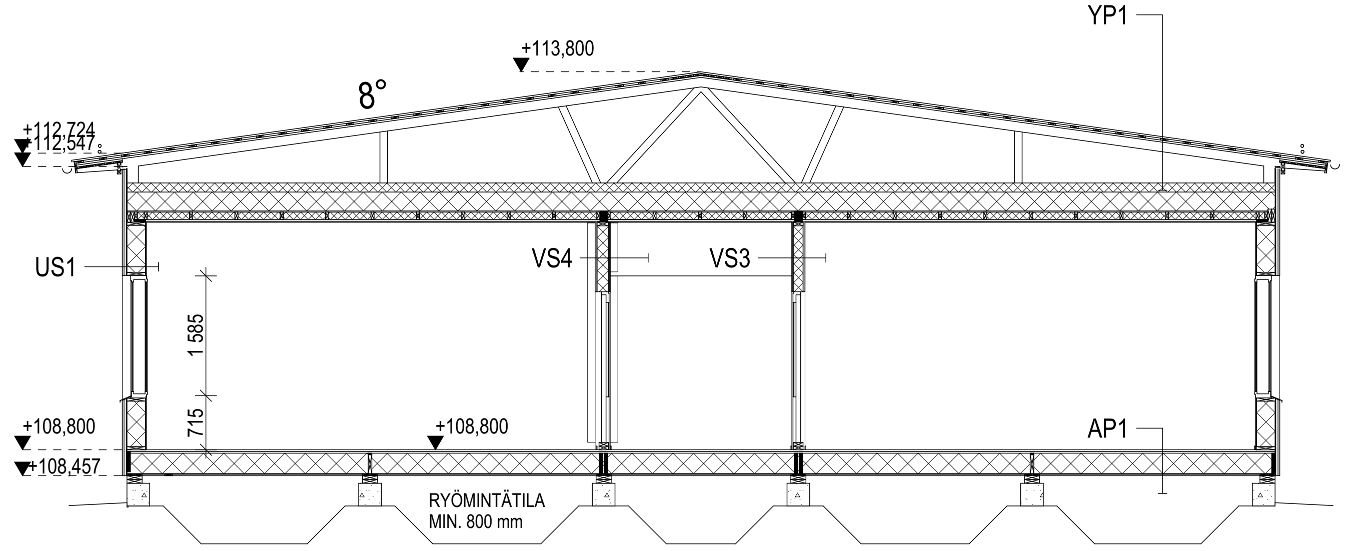
KIPSILEVY EK 13 mm
KIPSILEVY N 13 mm
PUURUNKO 48x123 mm 123 mm
+ MINERAALIVILLA 125 mm
KIPSILEVY N 13 mm
KIPSILEVY EK 13 mm

VÄLISEINÄ (VS4) 44 dB/ R30 B-s1,d0
(kantava väliseinä, jossa jakotukit)

KIPSILEVY EK 13 mm
KIPSILEVY N 13 mm
PUURUNKO 48x148 mm 148 mm
+ MINERAALIVILLA 125 mm
KIPSILEVY N 13 mm
KIPSILEVY EK 13 mm

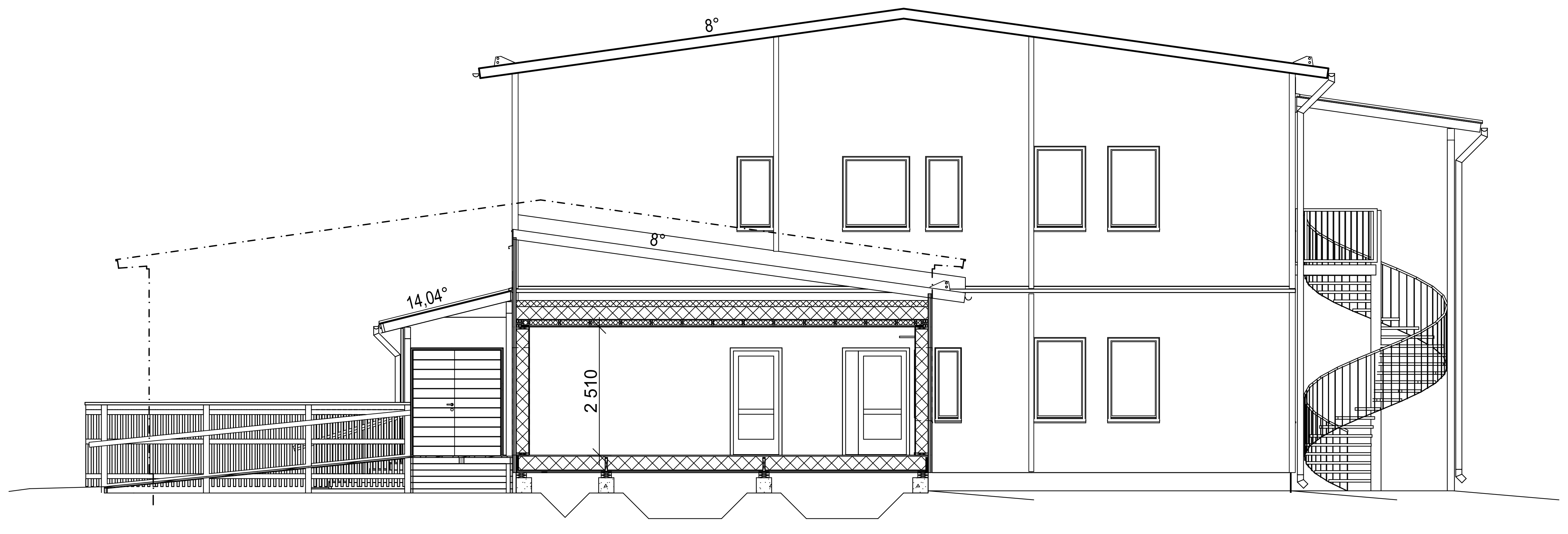
VÄLISEINÄ (VS5)
(kevyt väliseinä)

KIPSILEVY EK 13 mm
PUURUNKO 42x66 mm 66 mm
+ MINERAALIVILLA 70 mm
KIPSILEVY EK 13 mm



PERUSTUKSET, SALAOJAT JA ROUTASUOJAUS ERIKOISSUUNNITELMIEN MUKAAN

LEIKKAUS C - C



PERUSTUKSET, SALAOJAT JA ROUTASUOJAUS ERIKOISSUUNNITELMIEN MUKAAN

LEIKKAUS D - D

04.07.2019 TSi Päiväkodin yksikerroksinen osuus muutettu vuoropäiväkodiksi
Rakennetyyppeihin merkitty: US osastointi EI30, VS osastointi EI15,
rakenteiden pintaluokat

KOORDINAATTIJÄRJESTELMÄ ETRS-GK26	KORKEUSJÄRJESTELMÄ N2000
Kaupunginosa/Kylä: KERINKALLIO (20) — Kortteli/Tila: 49 — Tontti/Rnro: 2	Viranomaisten arkistointimerkintöjä varten
Rakennustoimenpide: Laajennus	Piirustuslaji: Pääpiirustus — Juokseva nro: -
Rakennuskohteen nimi ja osoite: KERINKALLION PÄIVÄKOTI, vaihe 2 Saarnikatu 2 15520 LAHTI	Piirustuksen sisältö: Leikkaus — Mittakaava: 1:100
PARMACO PARMACO Oy Haarlankatu 4 F (PL 50) 33231 TAMPERE Puh. 020 734 0011 Suunn/Piirt: Tiina Sirén Tiina Siren RA Tampere 28.10.2018	ARK - 6318 - 005

Caverion

05.07.2019

ILMATIIVIYDEN TESTIRAPORTTI

Noudattaa standardia ISO 9972

Kohteen tiedot

Rakennuksen osoite:
Kerinkallionkatu 6
Lahti, 15520
Testaaja:
Jouni Haimilahti
Yritys:
Caverion Suomi Oy

Rakennuksen tilavuus: **0**
Vaipan kokonaispinta-ala: **1 474,7**
Rakennuksen tuulialttius: **Osin suojattu rakennus**
Rakennuksen mittojen virhe: **0%**

Laitteisto - Puhallin: Retrotec 6000 , SN: - Painemittari: DM32 , SN: 408681

Tulos q_{50} = 0,796 m^3/hm^2

Yhdistetyt tulokset	Arvo	Vaihteluväli		Epävarmuus
Ilmavirtaus 50 Pa, V_{50} [m^3/h]	1174,0	1146,5	1202,5	+/-2,4%
Ilmanvuotoluku N_{50} [1/h]				
Ilmanvuotoluku q_{50} [m^3/hm^2]	0,796	0,771	0,821	+/-3,1%

Lisätiedot:
Laitteisto oli asennettuna valmiiseen pääoveen.

ALIPAINE

Mittaustulokset

Päiväys: **2019-07-03**

<u>Olosuhteet</u>: *Ilmanpaine*: **100,2** *KPa*. *Tuulen nopeus*: **4: Kohtalainen tuuli**

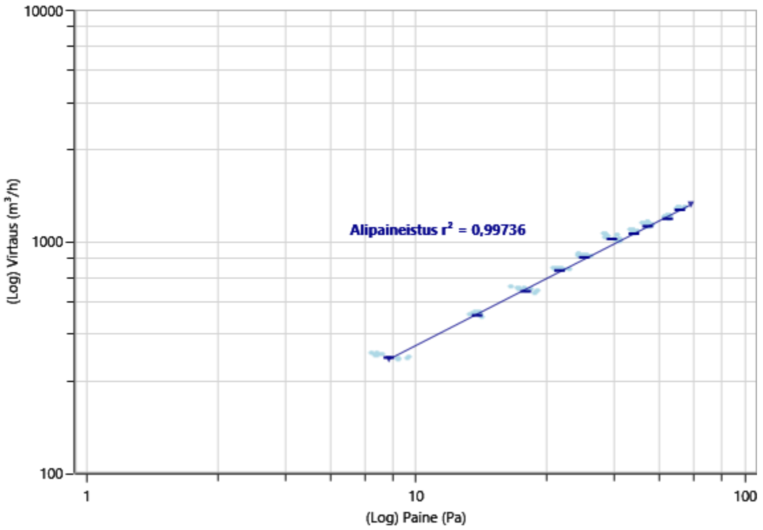
Lämpötilat: Alussa: sisällä **21,8** , ulkona **14,6**. Lopussa: sisällä **21,8** , ulkona **14,6**.

Vallitseva paine alussa[Pa]	**-0,06**	**-0,48**	**-0,66**	**0,12**	**0,0**							
Testipaine [Pa]	**-9,2**	**-16,2**	**-22,4**	**-28,0**	**-33,1**	**-40,0**	**-46,5**	**-51,1**	**-58,6**	**-63,7**		
Vallitseva paine lopussa [Pa]	**-3,66**	**-3,66**	**-2,38**	**0,14**	**0,56**							
Puhallinpaine[Pa]												
Virtaus, V_r [m³/h]	**323,262**	**492,004**	**624,876**	**768,449**	**875,158**	**1051,59**	**1108,49**	**1192,82**	**1284,17**	**1405,01**		
Korjattu virtaus, V_{env} [m³/h]	**317,44**	**483,15**	**613,63**	**754,62**	**859,41**	**1032,7**	**1088,5**	**1171,4**	**1261,1**	**1379,7**		
Virhe [%]	**1,0%**	**-1,9%**	**-2,7%**	**0,7%**	**1,2%**	**5,6%**	**-0,5%**	**-0,2%**	**-2,9%**	**-0,1%**		

Vallitsevan paineen keskiarvot: alussa [Pa] ΔP_{01} **-0,22**, ΔP_{01-} -0,40, ΔP_{01+} **0,06**, lopussa [Pa] ΔP_{01} **-1,80**, ΔP_{01-} **-3,23**, ΔP_{01+} **0,35**

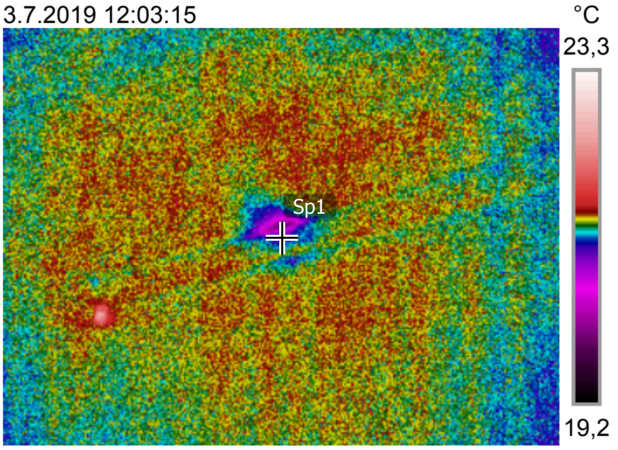
	tulokset	95% varmuus		epävarmuus
Ilmavirtaus 50 Pa, V_{50} [m³/h]	**1174,2**	**1146**	**1203**	**+/-2,4%**
Ilmanvuotoluku 50 Pa, n_{50} [1/h]				
Ilmanvuotoluku 50 Pa, q_{50} [m³/h.m²]	**0,7962**	**0,771**	**0,821**	**+/-3,1%**
Ominaisvuoto 50 Pa, w_{50} [m³/h.m²]	**2,0488**	**1,9849**	**2,1127**	**+/-3,1%**

Ilmavuotokäyrä



040-7075474 jouni.haimilahti@caverion.com

3.7.2019 12:03:15



FLIR0098.jpg FLIR E60 64516927

3.7.2019 12:03:15

FLIR0098.jpg FLIR E60 64516927

Mittaukset

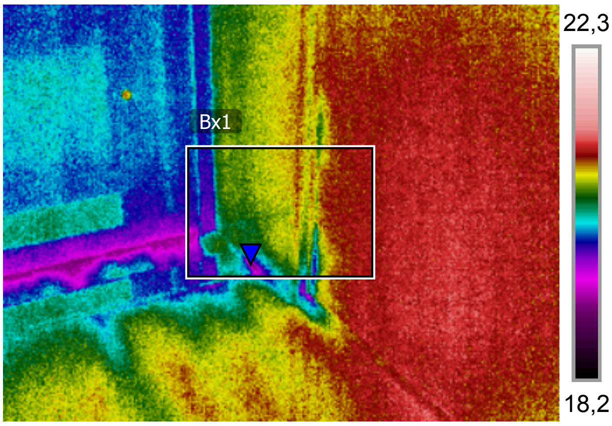
Sp1	21,0 °C

Parametrit

Emissiivisyys	0.95
Heij. näenn.lämp.	21 °C
Etäisyys	2 m
Ilman lämpötila	16 °C
Ulk. optiikan lämpöt.	20 °C
Ulk. optiikan läp.	1
Suhteellinen kosteus	29 %

Kuva 1. Huone 381.
Merkityksetöntä ilmavuotoa seinän sisältä. Syy piilossa.

3.7.2019 12:04:56



FLIR0099.jpg FLIR E60 64516927

3.7.2019 12:04:56

FLIR0099.jpg FLIR E60 64516927

Mittaukset

Bx1	Min	18,9 °C

Parametrit

Emissiivisyys	0.95
Heij. näenn.lämp.	21 °C
Etäisyys	2 m
Ilman lämpötila	16 °C
Ulk. optiikan lämpöt.	20 °C
Ulk. optiikan läp.	1
Suhteellinen kosteus	29 %

Kuva 2. Huone 344.
Pientä ilmavuotoa oven tiivisteistä

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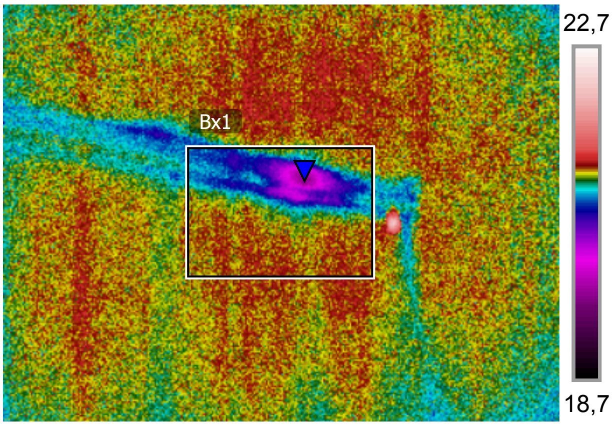
3.7.2019 12:06:35



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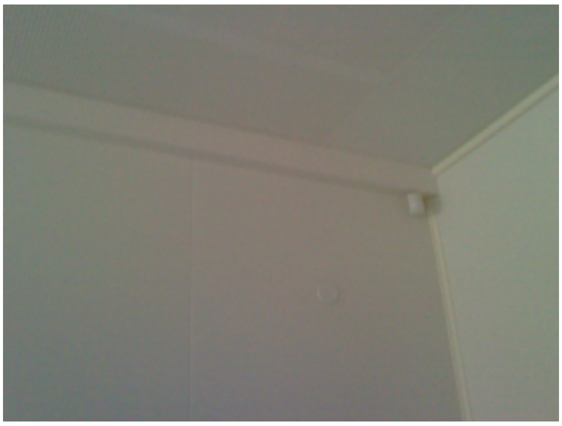


FLIR0100.jpg FLIR E60 64516927

Mittaukset

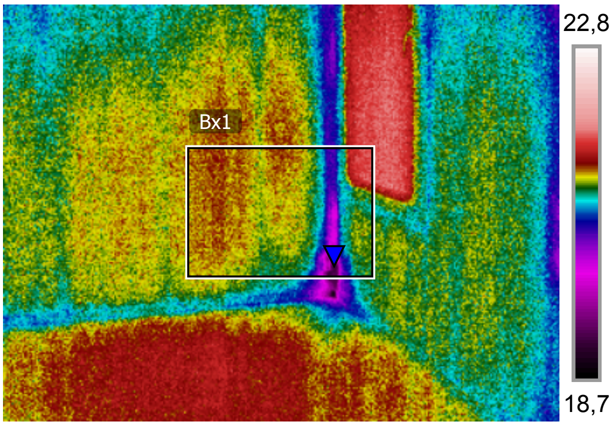
Bx1	Min	19,6 °C

Parametrit

Emissiivisyys	0.95
Heij. näenn.lämp.	21 °C
Etäisyys	2 m
Ilman lämpötila	16 °C
Ulk. optiikan lämpöt.	20 °C
Ulk. optiikan läp.	1
Suhteellinen kosteus	29 %

Kuva 3. Huone 371.
Merkityksetöntä ilmavuotoa seinän sisältä. Syy piilossa.

3.7.2019 12:13:07



FLIR0101.jpg FLIR E60 64516927

3.7.2019 12:13:07

FLIR0101.jpg FLIR E60 64516927

Mittaukset

Bx1	Min	19,0 °C

Parametrit

Emissiivisyys	0.95
Heij. näenn.lämp.	21 °C
Etäisyys	2 m
Ilman lämpötila	16 °C
Ulk. optiikan lämpöt.	20 °C
Ulk. optiikan läp.	1
Suhteellinen kosteus	29 %

Kuva 4. Huone 311.
Merkityksetöntä ilmavuotoa seinän sisältä. Syy piilossa.

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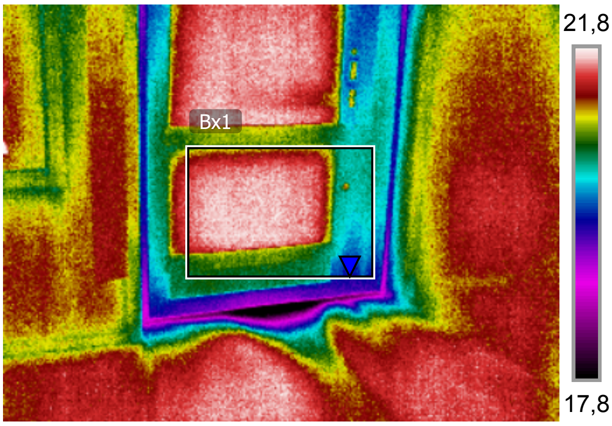
3.7.2019 12:14:13

°C 21,8



17,8

FLIR0102.jpg FLIR E60 64516927

3.7.2019 12:14:13

FLIR0102.jpg FLIR E60 64516927

Mittaukset

Bx1	Min	19,6 °C

Parametrit

Emissiivisyys	0.95
Heij. näenn.lämp.	21 °C
Etäisyys	2 m
Ilman lämpötila	16 °C
Ulk. optiikan lämpöt.	20 °C
Ulk. optiikan läp.	1
Suhteellinen kosteus	29 %

Kuva 5. Huone 391.
Pientä ilmavuotoa oven tiivisteistä.

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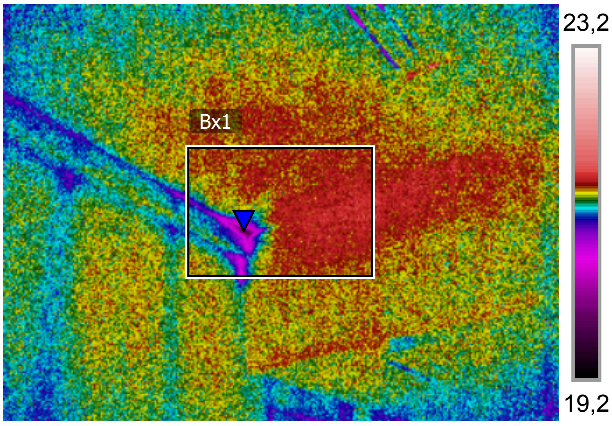
3.7.2019 12:15:10



FLIR0103.jpg FLIR E60 64516927

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FLIR0103.jpg FLIR E60 64516927

Mittaukset

Bx1	Min	19,7 °C

Parametrit

Emissiivisyys	0.95
Heij. näenn.lämp.	21 °C
Etäisyys	2 m
Ilman lämpötila	16 °C
Ulk. optiikan lämpöt.	20 °C
Ulk. optiikan läp.	1
Suhteellinen kosteus	29 %

Kuva 6. Huone 391.
Merkityksetöntä ilmavuotoa seinän sisältä. Syy piilossa.

Caverion Suomi Oy 040 7075474 jouni.haimilahti@caverion.com