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MECHANICAL SUPPLY AND EXHAUST VENTILATION IN RESIDENTIAL BUILDING

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Mechanical supply and exhaust ventilation system in residential building

Abstract

All residential buildings need a supply of fresh air in order to have comfort and health conditions, to remove pollutants and control condensation. Mechanical supply and exhaust ventilation system with heat recovery helps saving energy by recovering heat from exhaust air and by using energy efficient ventilation equipment.

The aim of my bachelor thesis is to answer the question do the modern mechanical ventilation system meet in reality the requirements of comfort of the residents and energy efficiency.

Modern ventilation systems with heat recovery are very important because of two reasons: they exchange air inside the apartment and help to get rid of any excess moisture. Heat recovery ventilation systems are energy efficiency. They help to reduce costs of heating a space for householder. Because the fresh air is pre-warmed, heat loss from ventilation is largely avoided.

The prevalence of mechanical ventilation system with heat recovery in residential buildings in Finland has increased over the last years. The increase in energy efficiency through heat recovery systems such as these contributes to as more sustainable society.

This bachelor thesis is designed in order to study mechanical ventilation system one of the renovated buildings in Kuopio owned by Niiralan Kulma Company. In order to get all needed data the measurements were made with several devices.

Subject headings, (keywords)

Ventilation, mechanical ventilation, heat recovery, swegon

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CONTENTS

1 INTRODUCTION

As people in Europe spend a lot of time indoors nowadays, they want to have comfortable conditions in their dwellings. Building materials, furniture and interior materials influence the comfort of inhabitation, but are there other factors? Of course there is a question of indoor climate. Indoor climate includes thermal conditions, air quality, radiation conditions, electric properties, lighting and noise. By means of well designed engineering systems we can achieve sufficient conditions of indoor climate.

It is important to have good indoor climate because it reduces the number of illnesses, number of detected sick building syndrome symptoms, improves productivity and improves sense of comfort. Good indoor environment incudes several factors a comfortable temperature range, the absence of odors and other polluting substances, low level of noise and suitable lighting.

The quality of the indoor air affects the human health. Children and elderly people are sensitive to quality of indoor air mostly. If occupants are provided with good quality indoor air it can have positive effects on the health, productivity and mood.

First of all, ventilation is one factor in creating good indoor air. The main purpose of ventilation is to sustain a healthy and comfortable level of indoor air in buildings. This means that ventilation system should be constructed in such a way that it can remove impurities and to supply outdoor air as “refill”.

Good quality of indoor air is achieved by finding out optimal air flow rates for each apartment in a residential building. Nowadays there are a lot of different types of ventilation systems in residential buildings. Ventilation can be arranged by gravity pressure differences (natural ventilation) and forced air flow (mechanical ventilation). Nowadays, new residential buildings are equipped with mechanical ventilation system in Finland. The modern systems with mechanical supply exhaust and heat recovery meet in reality the requirements of comfort of the residents and energy efficiency.

The aim of this bachelor thesis is to answer these questions by studying carefully the mechanical supply and exhaust ventilation system in a residential building in Kuopio, Finland.

2 THEORY PART

Theoretical part presents information about aspects of indoor climate, National Building Code standards and about mechanical ventilation system with heat recovery.

2.1. Indoor climate in residential building

There are many factors which are included in the general concept of indoor environment. They can be divided into four groups: building design, acoustics, lighting and indoor air quality and climate. These four groups contain many different specific parameters which have influence on human comfort. But majority of factors that significantly affect the human comfort are part of the group which called “indoor air quality and climate”. /1, p. 6./ This thesis investigates quality of indoor climate and air.

2.1.1 Thermal conditions

Thermal conditions are one of the parameters of indoor climate. Thermal conditions include air temperature, surface temperature, air flow, air velocity and relative humidity of indoor air. The primary criteria of thermal comfort and health are air temperature and humidity indoor. Thermal conditions depend on heating system and ventilation system. Ventilation system shall provide good indoor thermal conditions especially during summer time. Unsuitable temperature levels can cause sense of discomfort. For example if the temperature is too low it can cause increasing feeling of draught, harmful effects on elderly people, impairing finger dexterity. At the other side excessively high temperature can cause feeling of discomfort, increasing feeling of air dryness, increasing emissions from building materials. Indoor air temperature takes into account the convective heat transfer between the body and the environment; and describes the thermal conditions of thermally uniform space.

Indoor thermal conditions regulated according to National building code D2 Regulations and guidelines 2003 “Indoor climate and ventilation of building”. These regulations and guidelines describe acceptable indoor climate and ventilation of new residential building.

“2.2.1. Buildings shall be designed and constructed in such a way that a comfortable room temperature in the occupied zone can be maintained during periods of occupancy so that unnecessary energy use is avoided

2.2.1.1 The designed temperature for the heating season that is normally used for room temperature in occupied zone is 21 ^{o}C. The designed temperature for the summer season that is normally used for room temperature in occupied zone is 23 ^{o}C. Room temperature can be designed on the basis of a value that differs from guidelines value where justified reasons for such action exist.

The maximum acceptable deviation from the room temperature design value for the occupied zone measured at the center of the room at the level of 1.1 meters, is ± 1 ^{o}C
2.2.1.2 During period of occupancy, the temperature in the occupied zone should not normally be greater than 25 ^{o}C” /2/.

2.1.2 Carbon dioxide concentration indoors

Carbon dioxide concentration is often used as an indicator of pollution generated by humans, because it is easily measured.The main source of carbon dioxide indoors is occupant metabolism and occupant activity. The CO_2 concentration is usually use as a factor of pollutant generated by occupants. Usually indoor concentration of carbon dioxide should not exceed 700 ppm.

Carbon dioxide (CO_2) is a common constituent of air which is sometimes listed as a pollutant, but does not present a problem unless the concentration level high. CO_2 does, however, serve as an excellent surrogate in testing for other gases produced or accumulated by humans /3.p10/.

2.1.3 Indoor air humidity

Relative humidity introduce (in percent) how much water vapour is in the air compared to how much there would be if the air were saturated at the same temperature. Indoor air humidity depends on the outdoor air conditions, production humidity indoors and air exchange rate

Guidelines for indoor air humidity from D2 National Finish building code:
"2.3.2 Building shall be designed and constructed in such a way that the humidity of indoor air will remain within the values specified for the intended use of the building
2.3.2 The humidity of indoor air shall not be harmfully high on a continual basis, nor shall humidity be allowed to concentrate on structures or on their surfaces or in the ventilation system in such a way that it will cause moisture damage, growth of microbes or micro-organisms or any other health hazard.
2.3.2.1 In order to minimize any harmful effects that may be caused by a low relative humidity of indoor air, unnecessarily high room temperatures shall be avoided during the heating season." /2/.

The humidity has an impact on the thermal sensation, for example 10% higher relative humidity is felt as being as warm as 0.3 ^{0}C higher. When the indoor humidity increase it can cause mould, microbes, hygiene risks, emission of building materials in the other case when the indoor humidity decreases it can cause dustiness, airway infections, static electricity chocks.

The absolute humidity is the actual amount of water vapour contained in the air

2.1.4 Air flow rates in dwelling areas

The requirement of D2 National building code /2/ says that in the residential building ventilation is normally designed on the basis of the extract air flow rates in such a way that the air change rate of the dwellings is at least 0.5 l/h, while the adequacy of outdoor air flows is ensured to at least equal the guideline values (Table1).

TABLE 1. Air flow rates according D2 /2./

*- Guideline value when the boosting of cooker hood air flow rate can be controlled separately for each room or each dwelling; otherwise the guideline value for cooker hood is 20 dm^3/s

**- Guideline value when the boosting of air flow rate can be controlled separately for each room or each dwelling; otherwise the guideline for the air flow is the same as the boosting value during period of occupancy.

Total extract air flow rate is about 5% higher than total supply air flow rate.

Space type	Outdoor air flow (dm^3/m) per person	Outdoor air flow (dm^3/s)/m^2	Extract air flow (dm^3/s)	Sound level $L_{AeqT}/L_{A\,max}$ (dB)	Air velocity (winter) m/s
Dwelling areas:	6				
Dwelling rooms		0.5		28/33	0.2
Kitchen		Outdoor air flow is normally subsided with trans-ferred air flow con-ducted from the dwelling room	8*	33/38	0.2
-boost during occupancy			25	33/38	0.2
Cloakroom, storage room			3	33/38	
Bathroom			10**	38/43	0.2
-boost during occupancy			15	38/43	0.2
WC			7**	38/43	
-boost during occupancy			10	38/43	
Utility room			8	38/43	0.3
-boost during occupancy			15	38/43	0.3

2.2 Mechanical ventilation system

In order to get good indoor air climate it is important to have well designed ventilation system. Ventilation is a system that supplies clean air into dwelling rooms and removes unclean air from dwelling rooms. There are several types of ventilation systems in common use: natural exhaust ventilation, natural ventilation boosted with a cooker hood, mechanical exhaust ventilation, mechanical exhaust ventilation boosted with a cooker hood, mechanical supply and exhaust air ventilation system equipped with heat recovery, ventilation combined with air heating system.

In case of mechanical supply and exhaust ventilation system each flat can have its own air conditioning unit or one central unit can serve all flats in the building. The occupant may adjust the air flow rate as required with the aid of a blower (fan). Minimal ventilation is possible while the flats are unoccupied, lower level of basic ventilation. Possibility to control air flows with the aid of flat-specific valves – a smaller range of control, compared to flat specific air conditioning unit, a centralized system requires a large air-conditioning unit (machine room), the installation of which is more difficult within the building, most maintenance procedures are carried out in the machine room.

Mechanical ventilation is also used in such cases when you can't open window to ventilate space (classroom, office and apartment) because of traffic noise or because the outdoor air is full of pollutants. Mechanical ventilation shall be provided by mean of supply and exhaust air. The amount of supply air should be equal or about 5% less to the amount of exhaust air. The mechanical ventilation system should be designed in a way to deliver required amount of supply air to the occupied zone. Figure 1 shows an apartment unit for air supply and exhaust.

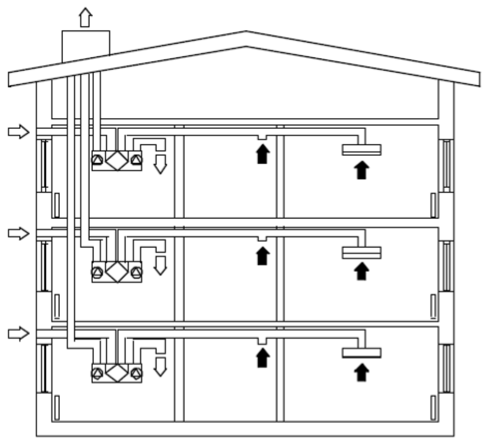

FIGURE 1. Apartment based supply and exhaust air ventilation /4./

There are a variety of mechanical ventilation systems. One of these systems is mechanical supply and exhaust ventilation system as shown on the figure 1. This system should not affect the pressure balance of the interior space. The balanced systems have fans for supply and exhaust air and duct for supply and exhaust air. For minimizing energy losses ventilation system with heat recovery is used.

2.2.1 Advantages and disadvantages of mechanical supply and exhaust ventilation system

It is clear that mechanical supply and exhaust ventilation system has advantages and disadvantages. First of all let's figure out what are the advantages of this system. When the mechanical supply and exhaust ventilation system is used there is possibility for exhaust air heat recovery. In this type of system the heated supply air is caused lower risk of draught. There is also a possibility to control flat-specific air flow as required. As supply air is filtered it causes lower level of allergy risk and cleaning requirement. The required flow of supply air can be delivered directly into bedrooms and living rooms. The building's envelope can be made air-tight and more energy efficient.

The mechanical ventilation system has disadvantages too. There is equipment investment (acquisition costs). There is also question about space, because this type of ventilation system requires additional space for heat recovery unit and ducts. The main disadvantages are connected with operating costs for maintenance and for electricity consumption.

Possible advantages of mechanical ventilation systems might be turned into drawbacks if quality assurance in planning and execution are not taken into account.

To avoid false expectations the limits of a mechanical ventilation system have to be pointed out: Each room should have the possibility for an additional window ventilation to increase the comfort and support the individual demands of the occupants.
A mechanical ventilation system just provides the hygienic demand of fresh air and is and is not an air conditioner. The ventilation plant can be "upgraded" to an air conditioning plant, but this concept can possibly damage the overall energy efficiency of a building. To achieve high energy efficiency it is import to keep the main principle of

building physics stated by Prof. Karl Gertis in mind: First build appropriate to the climate, then adjust the technical building equipment appropriate to the building. In other words: the quality of the building shell for heating and cooling has to be very high and cannot be compensated by air conditioning. If the building shell reaches passive house standard, heating solely with heated air can be possible. Unpleasant smells from outdoors can usually not be avoided. An optimal indoor air quality cannot be achieved solely by mechanical ventilation systems. Additionally the avoidance of harmful substances in building products, interior fittings, furnishing and usage (smoking, candles) has to be taken into account. However, a mechanical ventilation system relieves the problem of indoor air pollutants. /5./

Each kitchen in the building is equipped with the cooker hood. The cooker hood is used for boosting the elimination of cooking induced aromas and odors. The air flow in the cooker hood must be easily controllable. Each cooker hood should be provided with an easy to clean grease filter. The exhaust air duct must be drawn separately through the roof. In cases where this is not possible, the air must be returned to its room of origin.

The supply air fan and the exhaust air fan ventilate the apartment through two duct systems. The supply air provides to bedrooms and living rooms, while the exhaust air is drawn from the kitchen, bathroom and utility room. Heat is transferred from the warm exhaust air to the cold outdoor air in the heat exchanger. The energy saving could be 50–60 % compared to a system in which heat is not recovered.

2.3 Air handling unit with heat recovery

Air handling unit is a part of the ventilation system that is bringing the filtered air to the dwellings. Usually air handling unit includes heat recovery unit and it can also contain components for air purification. Heat recovery unit transmits heat energy from exhaust air to supply air. It means that demand of energy (or other resources) for heating (or cooling) supply air is reduced.

There are a lot of different types of heat exchangers: One of them is the plate heat exchanger (Figure2). The principle is that heat transfers from extract air to outdoor air through metal plates which are separating the air flows. The supply and exhaust air

ducts are combined to the same heat recovery unit in the plate heat exchanger system. The supply and exhaust air flows separated by the plates and cross by each other with no mixing. Each air flow passes through different air duct, where flows pass through each other them never mixing. The air flow in heat exchanger called cross-flow and the heat exchange called cross-flow heat exchanger counter flow.
The supply air is provides fresh air from outside to the ventilation system of the building through the air inlet situated on the outer wall of the building. The exhaust air removes filled with impurities and heat air from the apartment. Sensible heat energy from the warm air flowing through one side of the exchanger is transferred to the cold air flowing through the other.

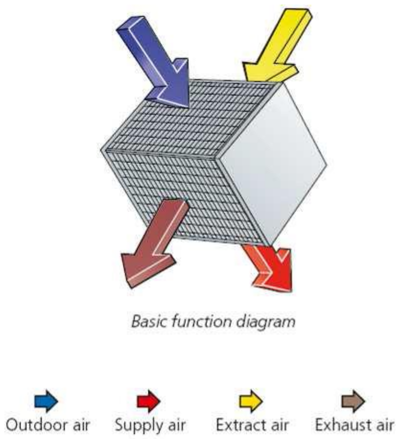

FIGURE 2. Cross-flow plate heat recovery /6./

No doubt that the plane heat exchangers have advantages and disadvantages. In the one side the temperature efficiency of the plate heat exchanger is usually 50-60%. Also the heat transfer is more efficient when temperature difference is high. The plate heat exchanger is easy to operate and maintain, it doesn't require special control devices or pumps. In the other side space requirements for the unit are quite big. Also condensate may freeze to ice outdoors and this could cause risk of frosting.

In cross - flow heat exchanger heat is transferred directly from exhaust air to outdoor air through a plate that separates the air flows from one another. i.e. both ducts cross to each other in recovery unit. There is no mixing between the air flows. Both sensible and latent heat may be transferred when moisture in the exhaust air condensates on the heat exchanger. Moisture is not transferred to the supply air. Only fresh outdoor air goes to the rooms heated by exhaust air. The efficiency of the heat exchanger mostly depends on the size of the heat transfer surface area. Typical temperature efficiency η for cross flow heat exchanger is 0,5-0,8 /7 p.407/

2.2.4 Temperature efficiency of the heat recovery ventilation system

Nowadays heat recovery units in the residential houses are very common in countries with north climate. The plate heat exchanger presents the system that can reduce wasting of energy on heating and cooling of supply air.

The temperature efficiency of heat recovery also could be called as a temperature ratio. The temperature ratio hung upon several factors: the type of heat exchanger, the size of the heat exchanging surfaces and the heat transferring properties of these surfaces. The efficiency can be rated by using results of calculations of temperature ratio for supply and exhaust air.
The temperature efficiency can be calculated using equation

$$\eta_t = \frac{\Delta t_{tot}}{\Delta t_{\max}} = \frac{t_{LTU} - t_U}{t_p - t_U} \quad \text{,where} \qquad (1)$$

η_t temperature ratio

Δt_{tot} theoretical maximum temperature difference

$\Delta t_{\max}$ maximum temperature difference

t_{LTU} supply air temperature after heat recovery

t_U outdoor air temperature

t_p exhaust air temperature

There are many requirements to ventilation system with heat recovery units in Finnish Building Code D2. A heat recovery unit shouldn't be used in systems if the exhaust air is polluted and it prevents the operation of the heat recovery unit or the temperature of exhaust air is lower than +15 ^{0}C during the heating season. A significant value exhaust air shouldn't be transferred to supply air in heat recovery unit. Therefore, construction and pressures of the device should be such as to provide this requirement. /2, p.27./

3 METHODS

The following chapter gives information about object of the research and methods that were using. This is the practical part of the thesis work. The main point is to study indoor air conditions in the apartment in block building. This part of thesis work represents information about all measurements that were done.

3.1. Case study building

This chapter gives information about two residential buildings constructed by Niiralan Kulma company in Kuopio. Niiralan Kulma Company provides apartment for rent in the Kuopio region. At the moment, the Niiralan Kulma Company has more than 5900 residential units and home to more than 10 000 people. Niiralan Kulma Company interested in that research as this company continue to build residential buildings in Kuopio they want to figure out what type of ventilation system suites better for their projects. These buildings are block of flats which are situated in Kuopio, Finland. Object names are Malminkatu 11 and Malminkatu 13.

Both buildings are residential building, they are identical and located in adjacent areas. Renovations have been made sequentially in 2011 for building at Malminkatu 11 and in 2012 for building at Malminkatu 13. There are 7 stores buildings, with nearly the same area inside. Table 2 below describes the basic information about two buildings.

TABLE 2. Basic information about building.

	Malminkatu 13
Year Built	1977
Renovation of the Year	2011
Apartment Capacity	7790 m^3
floor area	1696m^2
Number of dwellings	37 pcs
Rooms	97
Population	62

The building at Malminkatu 13 is equipped with mechanical supply and exhaust ventilation system with heat recovery.

3.1.1 Residential building at Malminkatu 13

In my thesis I will study block of flats located at Malminkatu 13. The following chapter gives the information about renovation in the residential building at Malminkatu 13 in 2011. Figure 3 shows the overview of residential building at Malminkatu 13.

FIGURE 3. Residential building at Malminkatu 13

The reconstruction that was made includes interior renovation, a completely redesigned HVAC equipment, electricity, lights, elevators, exterior doors and windows. The concrete structures of the house and the foundations were not renovated. HVAC equipment was renovated in 2011, during the renovation radiators were renewed, water and sewage equipment were refurbished, and ventilation equipment was refurbished also. The whole control system was redesigned according to the renovation plan in 2011, safety devices was left original. All apartments were equipped with supply and exhaust ventilation system. The common areas are equipped with their own exhaust fans.

Ventilation ducts are made of galvanized steel. The duct connections and joints were approved by the fire authorities in ways that meet necessary requirements. The duct channel components by FläktWoods Company were used for the circular ducts. The bends and tees were made according to industry standard channel sections.
The air-tightness of the ducts require Finish National Building Code D2.

The exhaust valve is manufactured of sheet steel. Figure 4 illustrates the KSO exhaust valves are used. Body of the valve is equipped with cellular plastic gasket to form an airtight seal.

FIGURE 4. KSO exhaust valve by Flacktwoods /8.p 1./

The cooker hood that is situated in the flat is SAFERA PREMIUM by SWEGON company. The cooker hood is provided with safety technology, It is suitable in flats with little children because of the lock at the top of the cooker hood. Also the cooker hood prevents damages made by leakages by the alerting in case if there is the water leakages in the kitchen. The safety technology prevents fire accidents, by switching off the electric power supply of the stove.

3.1.2 Description of the apartment

The following chapter gives the information about typical apartment at Malminkatu 13. The measurement took place in the apartment at the 28th October and 14th November 2014. There is three room apartment: two bedrooms and a living room with kitchen zone. There is a bathroom also. The total area of the apartment is 66 m^2 . There are 3 persons living in the apartment. Two person usually spend night time in bedroom # and one person in bedroom #2.

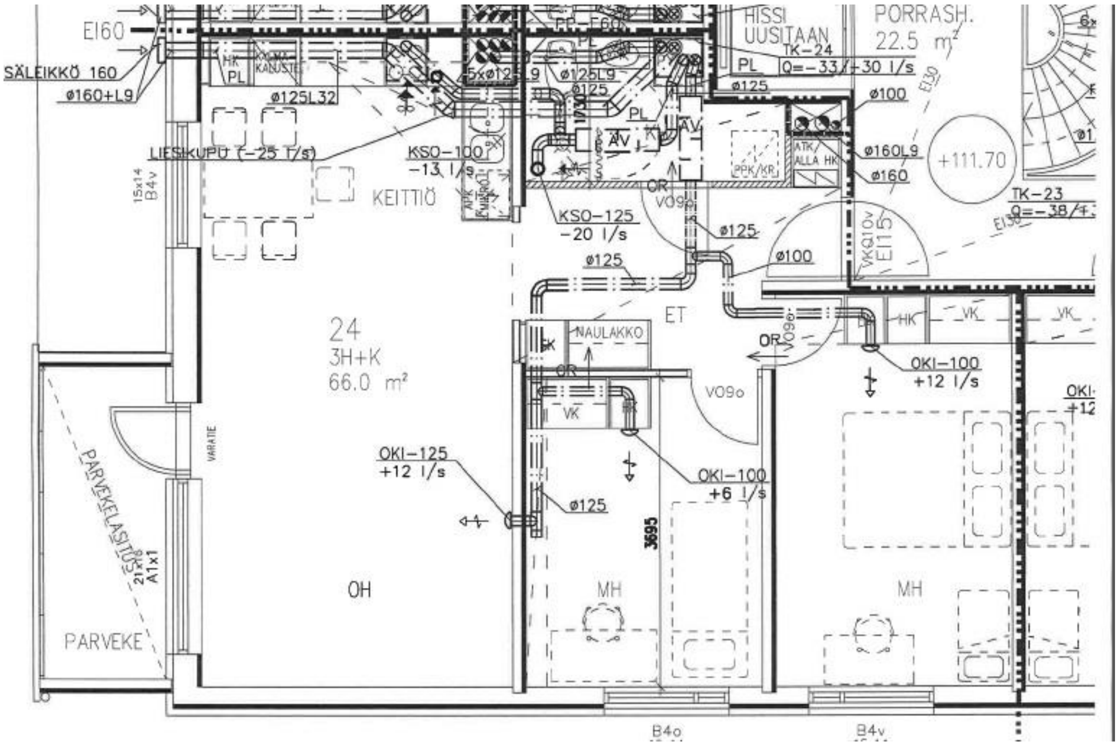

FIGURE 5 Apartment's Layout(Malminkatu 13)

A typical apartment (Figure 5) is equipped with a mechanical supply and exhaust ventilation system. The system where each apartment have own unit is decentral ventilation system. The inlet valve is in the living room and in the bedroom (Figure 6). In the living room, the inlet valve is OKI-125 and in the bedroom OKI-100. The Exhaust valves are located in the kitchen and in the bathroom (Figure7). The kitchen has an exhaust KSO-100 and the bathroom KSO-125. In addition, the kitchen has a cooker hood, it can not be stopped completely, the limitation is 25%.

FIGURE 6.Supply air diffusers in bedroom #1, bedroom #2 and living room

FIGURE 7. Exhaust air diffuser in the bathroom

In addition, the kitchen has a cooker hood SAFERA PREMIUM (Figure 8), it can not be stopped completely, and the limitation is 25%. The point is that, bedroom 1 is used as a bedroom for 2 person and bedroom 2 used as a person for 1 person that means that designed values for supply air flow should be different.

FIGURE 8. Cooker hood and stove

3.1.3 Description of ventilation unit

Each apartment equipped with unit CASA 270KE ECONO (Figure 9). It is a heat recovery unit with counter-flow plate heat exchanger. The main parts of the unit are : supply air filters, extract air filter, plate heat exchanger. The Econo model is connected directly to a heating system. In such case reheating takes place in a water-heated air heater in the ventilation unit. This model makes it possible to cut energy costs.

The Swegon CASA 270KE ECONO is equipped with energy-efficient fans with EC motors, advantageous in that their speed is variably controllable and their efficiency is high even when they operate in the lower speed range. The power supply and control cables of the fans have quick fitted connectors making the fans easily removable from the unit, if required/9./

FIGURE 9. Air handling unit Swegon Casa 270KE ECONO. Inside view /9/

The fan can operate at four different speeds. First is “absent” air flow speed. It can be used when no one is present in the dwelling. Second is called “home” it is a normal airflow. Third and fourth are “boost” air flow. It is a high airflow used in connection with cooking, taking a sauna bath, etc.

There is a plate heat exchanger made of aluminum foil. The heat exchanger operates according to the counter-flow principle. The airflows conveyed to the heat exchanger and flowing from it pass through separate channels and are not mixed together. The unit’s mechanical bypass damper steers the extract air to bypass the heat exchanger when heating is not needed.

There is a possibility to set the required value for supply air temperature. The supply air temperature should be lower than the room temperature. The set point can be easily adjusted with a thermostatic valve inside the unit.

The heat exchanger is equipped with anti-freeze protection it is a temperature sensor that protects the water-heated air heater from freezing. If the air heater’s temperature has dropped to a low level, the red signal lamp on the control panel will flash, but the ventilation unit will operate normally. If the air heater’s temperature drops further, the controller will stop the ventilation unit to prevent the air heater from freezing.

As a residential house equipped with hot water heating system with radiators, the air hot water heater in the ventilation unit can be switched on as an extra radiator, which gives a more economical heating means that with an electric heater.

3.1.4 Description of the cooker hood

The cooker hood that is situated in the flat is SAFERA PREMIUM by SWEGON company (Figure 10). The cooker hood is provided with safety technology, it is suitable in flats with little children because of the lock at the top of the cooker hood. Also the cooker hood prevents damages made by leakages by the alerting in case if there is the water leakages in the kitchen. The safety technology prevents fire accidents, by switching off the electric power supply of the stove.

The cooker hood is situated above the stove in the kitchen - living room. The cooker hood is not used only for remove exhaust “bad” air in the cooking time but also for controlling the air handling unit. The cooker hood that is situated in the flat is SAFERA PREMIUM by SWEGON company. The cooker hood is provided with safety technology, It is suitable in flats with little children because of the lock at the top of the cooker hood. Also the cooker hood prevents damages made by leakages by the alerting in case if there is the water leakages in the kitchen. The safety technology prevents fire accidents, by switching off the electric power supply of the stove.

The cooker hood plays a big role in the ventilation of the flat. The supply air flow is regulated with help of switcher situated at the cooker hood panel. Nowadays it is very accepted type of controlling the position of air handling unit.

The extract air from the cooker hood does not pass heat exchanger, but instead is extracted directly out to the extract air fan. The using of cooker hood gives a lower cost installation, because there is no need of an extra fan, extract air duct and roof penetration.

FIGURE 10. Swegon Safera premium /10./

3.2 Measurements

This chapter presents description of different measurements and technical devices which were used in practical part of work. First part of measurements was made on the 28th October and second on 14th November.

3.2.1 Outdoor measurements

The data logger EBRO EBI 20 was placed in balcony in order to get information about outdoor air temperature and humidity. The data from meteorological radar was used also.

3.2.2 Air temperature and humidity measurements

The measurements of temperature and humidity were made with several devices. The data loggers EBRO EBI 20 (Figure 11) were used for collect information of temperature and humidity of supply and exhaust air flows inside air handling unit also the data loggers was measuring temperature and humidity in the apartment. It is possible to make a monitoring of air temperature and humidity values during the some certain period of time and it possible to collect the data and based on it to make a curve which shows the air temperature changes. The one of data loggers was measuring temperature and humidity in the living room during two week period. The second was measuring temperature and humidity during two hours in the bedroom (for 2 persons).The third was placed outside in order to measure outside weather conditions. Moreover, the data loggers were placed inside air handling unit in order to get the information of temperature and humidity of the supply and exhaust air. The device is making samplings of the temperature and humidity at the same time.

FIGURE 11. Ebro EBI-20TH. Monitoring of temperature and humidity of the air /11./

Also values of the room temperature, °C, relative humidity, %; dry-bulb temperature, °C; wet-bulb temperature, °C; liquid content, gm3,absolute humidity, g/kg enthalpy, kJ/kg was made with Vaisala HUMICAP HM40 device (Figure 12)

FIGURE 12. Vaisala HUMICAP HM40 device /12/

3.2.3 Carbon dioxide level measurements

The TGE-0010 by Tinytag (Figure 13) monitors CO2 concentration using infrared sensor to determine CO2 concentrations. It can help to verify that indoor ventilation systems are performing correctly, thus preventing CO_2 levels exceeding recommended limits.

FIGURE 13. TGE-0010 by Tiny tag /13./

The temperature, relative humidity and carbon dioxide concentration were measured from 12:57 28.10.2014 till 13:37 14.11.2014. The monitoring devices were located in the living room at the high 1,5m.The diagrams of results presented in Appendix

The Rotronic CP11 handheld multimeter instrument (Figure 14)was monitoring CO_2, relative humidity and temperature in the living room and in the bedroom from the 12:00 14.11.2014 till 13:57 14.11.2014.

FIGURE 14. Rotronic CP11 /14./

3.2.4 Supply and exhaust air flows rates measurements

Firstly, measurements of supply and exhaust air flows were made with Airflow Instruments Micromanometer by TSI Company (Figure 15).

FIGURE 15. Airflow Instruments Micromanometer by TSI Company /15./

Secondly, the supply and exhaust airflow rates were measured with help of SWEMA air 300 flow device with sensor “Swema flow 125” (Figure 16).Also for measuring air flow rates the TSI Airflow Instruments Micromanometer was used.

FIGURE 16.SWEMA air 300 flow device with sensor “Swema flow 125” /16./

3.3 Calculations

This part of thesis gives information about process of calculating temperature efficiency. This value will be calculated for four different fan positions. The temperature efficiency can be calculated using equation (1)

$$\eta_t = \frac{\Delta t_{tot}}{\Delta t_{\max}} = \frac{t_{LTU} - t_U}{t_p - t_U} \qquad (1)$$

4 RESULTS

The data from the long-term measurements were collected during the entire two week measuring program. During the short-term measurements the greater part of measurements was focused on air flow rates.

In this chapter all results of measurements are presented. All measures data were carried and analyzed. The information is collected in tables mostly.

4.1 Air temperature and humidity

Table 3 presents information about indoor measurements.

TABLE 3.The results of measurements 14.11.2014

	Living room and kitchen	Bedroom1	Bedroom2	Bathroom
Room temperature, °C	22.3	21.5	22.9	21.6
Relative humidity, %	40.8	33.5	32.7	45.6
Dry-bulb temperature, °C	6.9	4.7	5.6	9.3
Wet-bulb temperature, °C	13.8	12.6	13.4	14.5
Liquid content, gm^3	7.34	6.33	6.68	8.67
Absolute humidity, g/kg	6.2	5.33	5.66	7.33
Enthalpy, kJ/kg	38.42	35.24	37.47	40.33

Table 4 presents information about indoor measurements of temperature and relative humidity.

TABLE 4.Temperature and relative humidity.28.10.2014

	temperature, C^0	RH,%
Living room	23,6	45.8
Bedroom 1	23,3	46,3
Bedroom 2	23,4	47,6
Bathroom	23,1	50,1

Figure 17 presents diagram of temperature during a day in the living room.

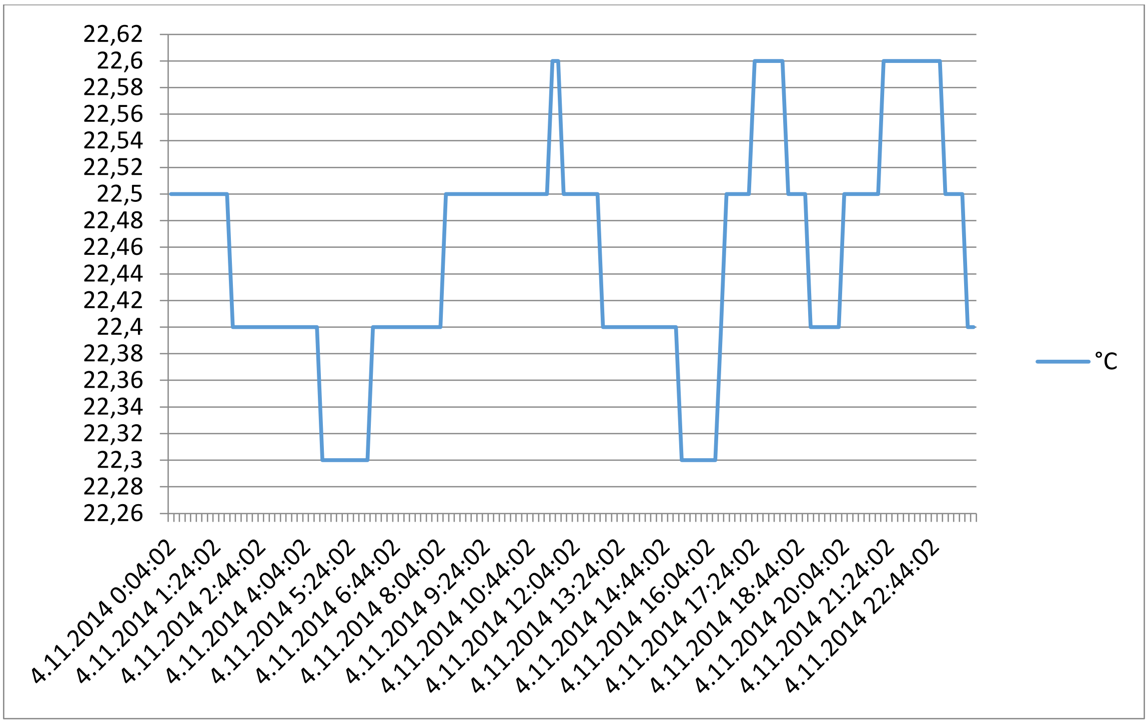

FIGURE 17 Diagram of temperature during a day in living room

Figure 18 presents information about relative humidity during a day in living room.

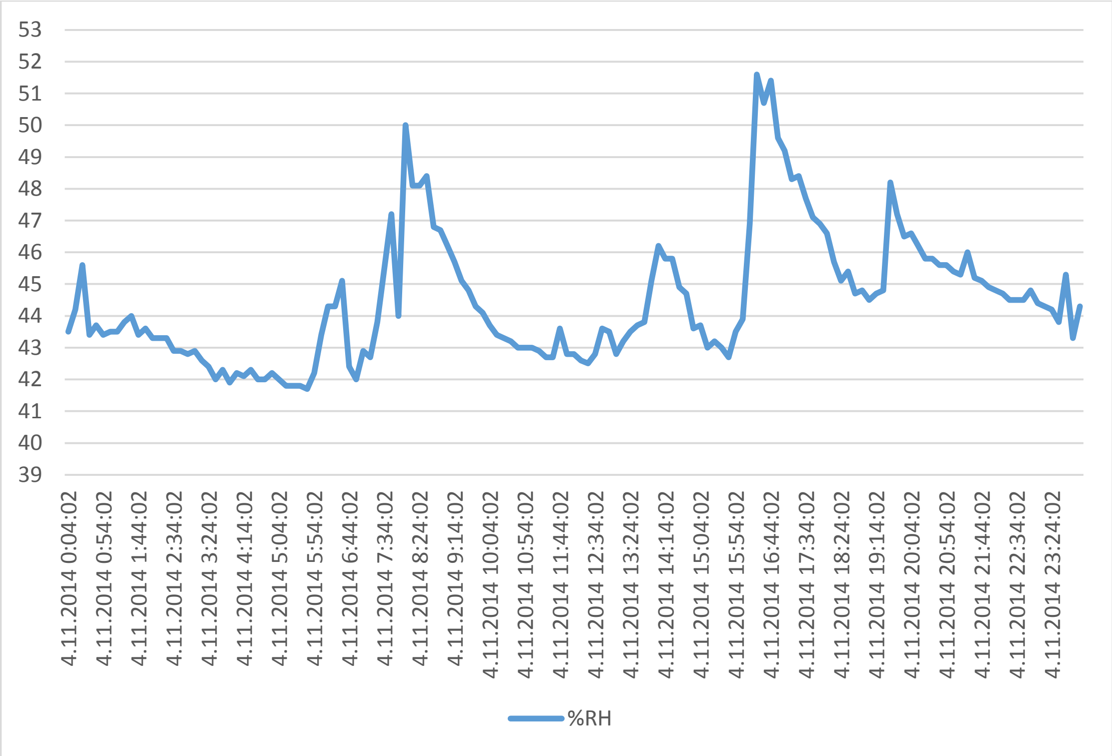

FIGURE 18 Diagram of Relative humidity during a day in living room

Figure 19 presents information about of absolute humidity during two weeks in living room

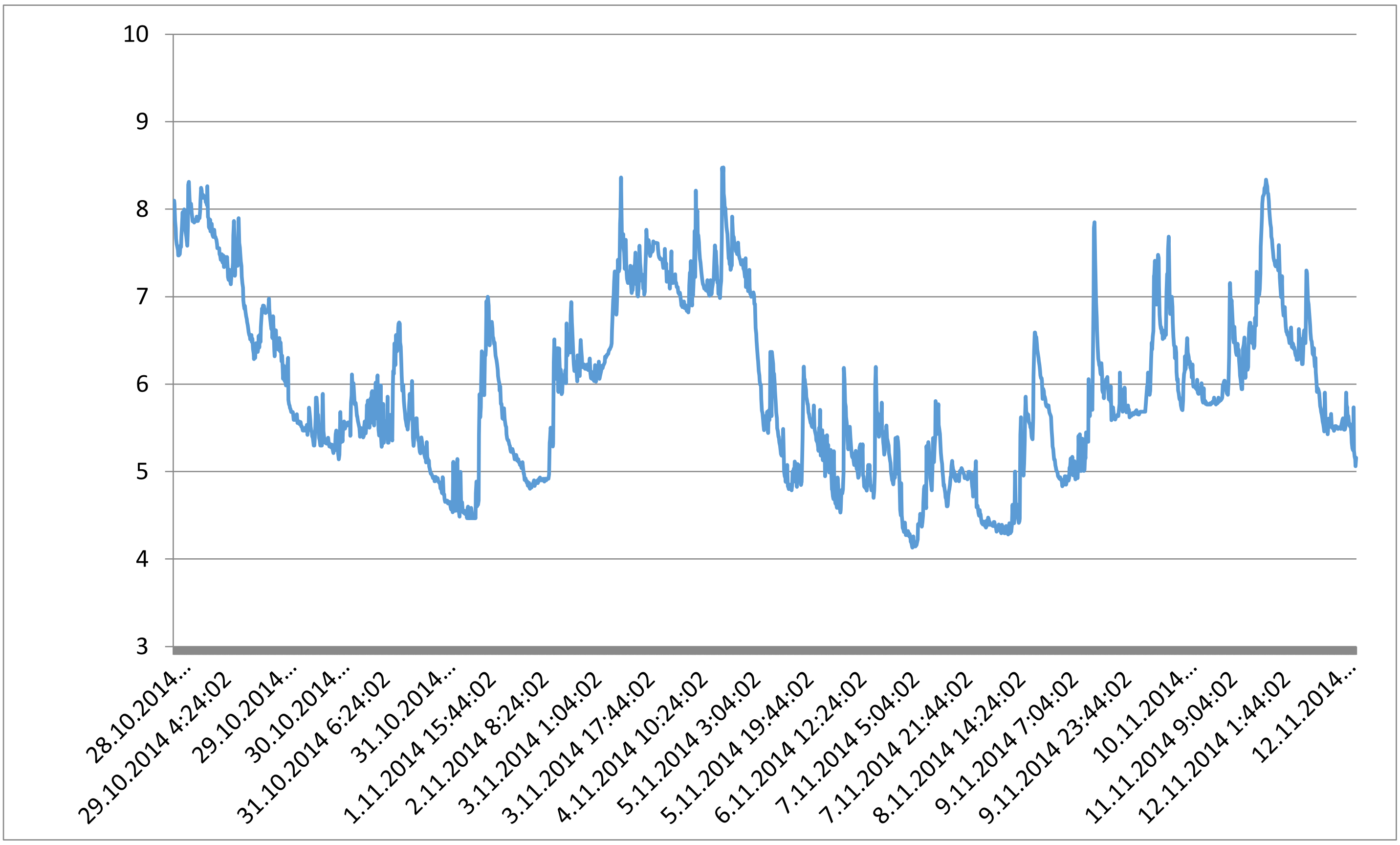

FIGURE 19 Diagram of absolute humidity during two weeks in living room.

Figure 20 presents information about absolute humidity during a day in living room.

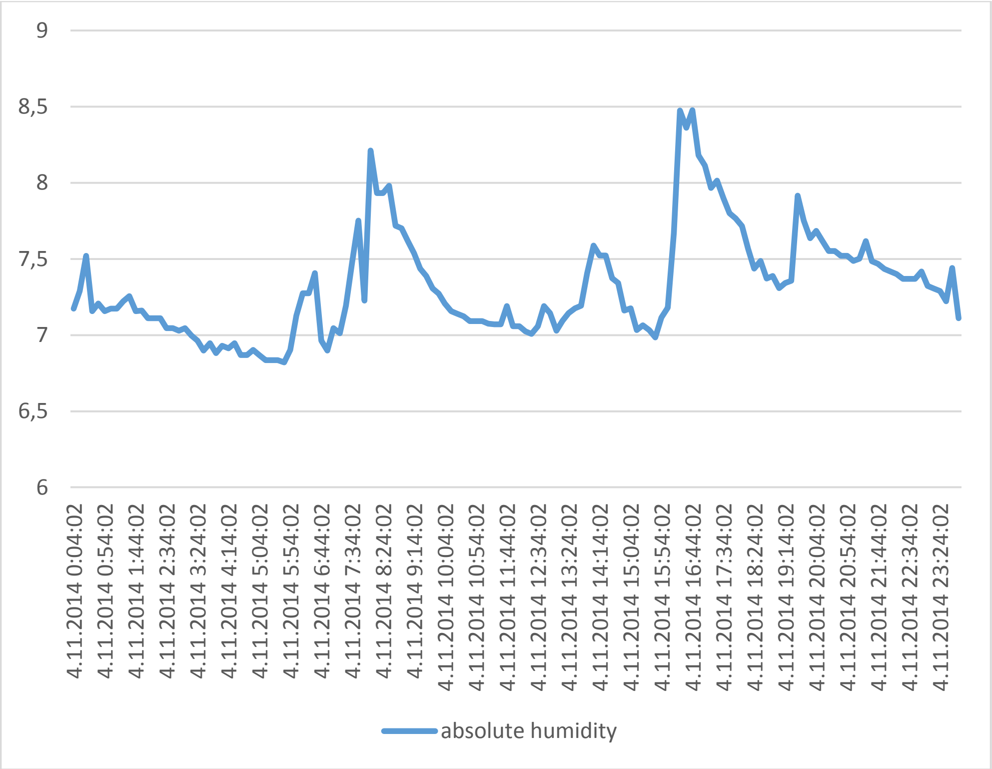

FIGURE 20 Diagram of absolute humidity during a day in living room

4.2 Air flow rates

The following chapter gives information about air flow measurments

TABLE5. Supply air flows.28.10.2014

	Min(l/s)	Avg (l/s)	Max (l/s)
Living room	11.54	11.64	11.73
Bedroom 1	7.15	7.19	7.24
Bedroom 2	11.53	11.73	12.00

Exhaust air flow rates measured in the kitchen and bathroom from terminals. Exhaust air flow rates should also be measured in the minimum, maximum and normally used speed position of the fan. In order to calculate air change rate of the house the sum of the exhaust air flow rates could be used.

TABLE6. Exhaust air flows.28.10.2014

	Min(l/s)	Avg (l/s)	Max (l/s)
Living room	10.7	10.9	11.3
Bathroom	17.0	17.4	17.6

TABLE 7. Supply air flow rates 14.11.2014

	1 fan position(“absent” when nobody is at home) at12:46	2 fan position(normal fan position) at11:35	3 fan position “boost” (when taking a shower) at12:03	4fan position boost (when taking shower or sauna) at 12:30
Living room	5.9 (l/s) (T_{supply}=23.7)	11.4 (l/s) (T_{supply}=23)	16.8 (l/s) (T_{supply}=22.8)	22.4(l/s) (T_{supply}=22)
bedroom1(for 2 persons)	3.1 (l/s)	6.0 (l/s)	8.4 (l/s)	12.1 (l/s)
bedroom2	7.4 (l/s)	12.4 (l/s)	15.1 (l/s)	24.1 (l/s)

TABLE . Exhaust air flow rates 14.11.2014

	1 fan position("absent" when nobody is at home) at12:46	2 fan position(normal fan position) at11:35	3 fan position "boost" (when taking a shower) at12:03	4 fan position boost (when taking shower or sauna) at 12:30
Living room	7.2 (l/s)	11 (l/s)	14.8 (l/s)	19.1 (l/s)
bathroom	11.7 (l/s)	21.3 (l/s)	24.6 (l/s)	41.4 (l/s)

Then, the measurements were made in case where the cooker hood is in use. The position was switched on to 3rd.
The following table presents result for supply and exhaust air flow rates when fan position is 3.

TABLE 8. Supply and exhaust air flow rates

	Supply air flow rate	Exhaust air flow rate
Living room	16.3 (l/s) T_{supply}=23 C^o	9.1 (l/s)
Bedroom 1	9.2 (l/s)	21.5 (l/s)
Bedroom 2	21.4 (l/s)	30.6 (l/s)

During the measurement process the cooker hood was out of use. The measurements of supply and exhaust air flow rates were made for four positions of air handling unit. Then, the cooker hood was switched on to the third position, so called "boosted" and the measurements of the supply and exhaust air flows was made again.

The following table gives information about the total sum of the air flow rates in the apartment

TABLE 13. Total air flow rates

	Total Supply air (l/s)	Total exhaust air(l/s)
1 fan position	16.9	18.9
2 fan position	29.8	32.3
3 fan position	40.3	39.4
4 fan position	58.6	60.5

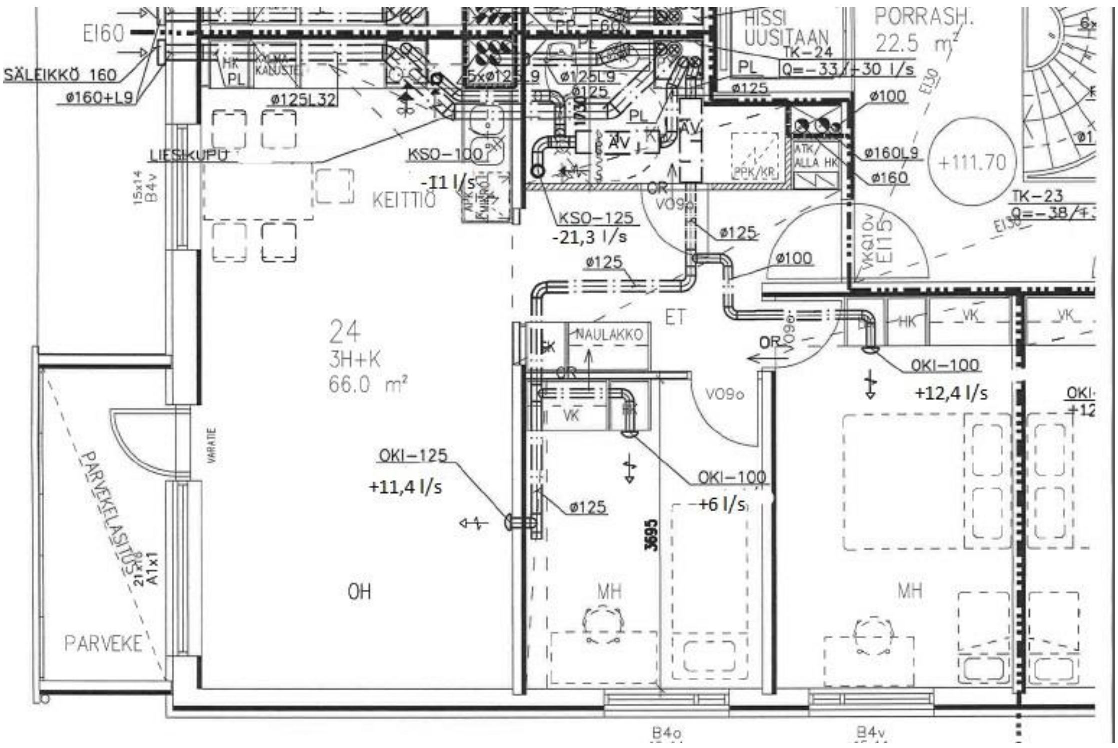

FIGURE 23 Measured air flow rates

4.3 Outdoor measurements

TABLE 9. Outside conditions

Time	11:30	12:46
T_{out}	-2.4	-2.2
Dew point	-5.6 C^{o}	-5.3 C^{o}
Velocity(from the west)	1m/s(max 2m/s)	1m/s(max 2m/s)

Humidity	79%	79%

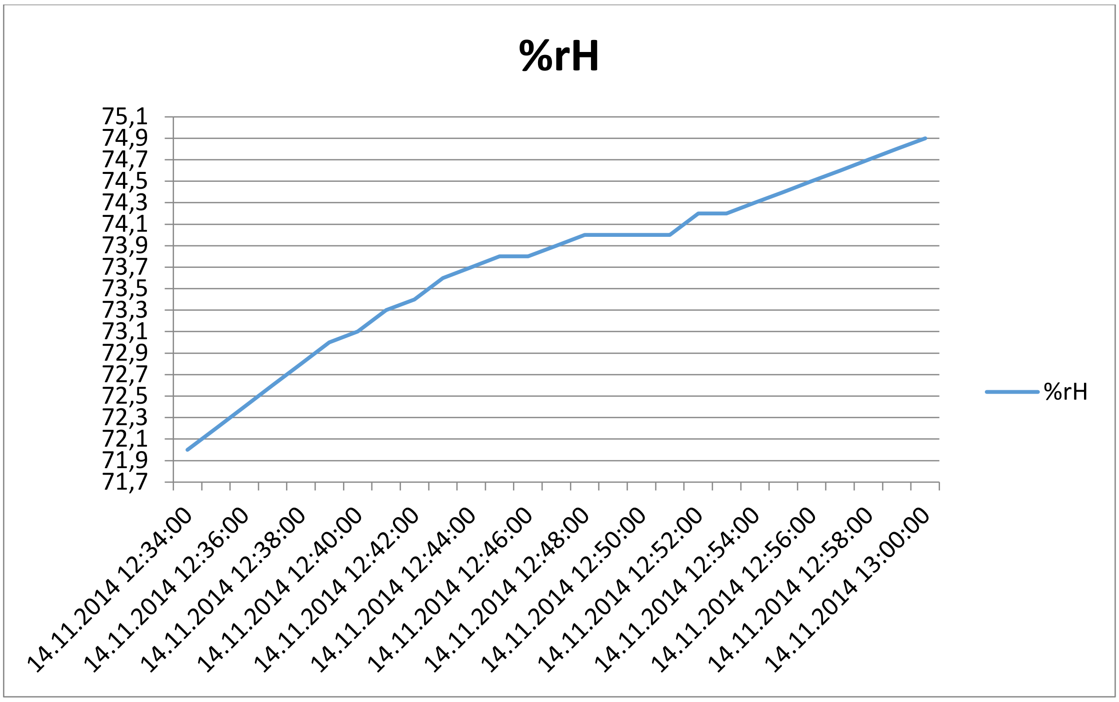

FIGURE 19. Diagram of outside relative humidity

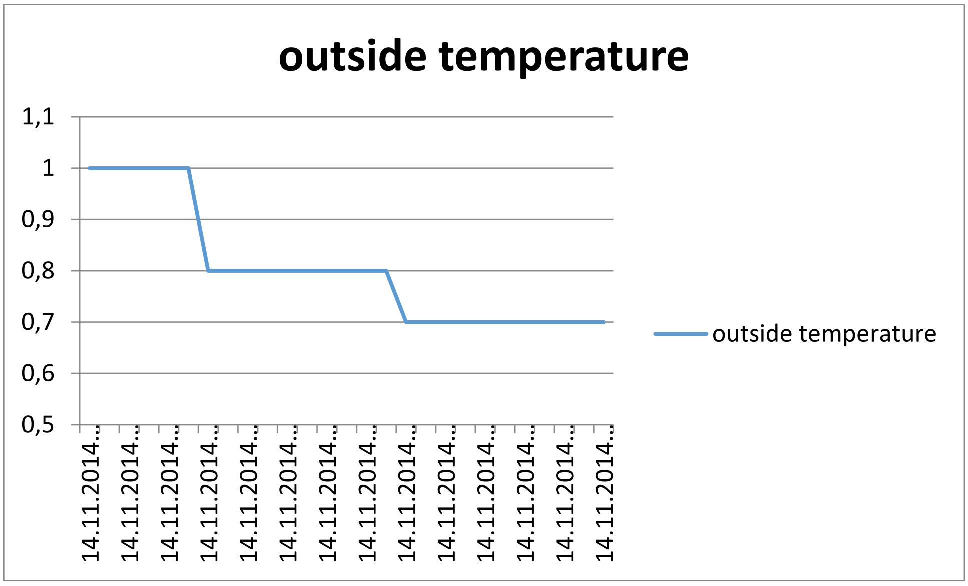

FIGURE 19. Diagram of outside temperature

4.4 Carbone dioxide level

During two week period the average carbon dioxide level was 777 ppm. Carbon dioxide level maximum was 1250 ppm and minimum 458ppm during two weeks period.

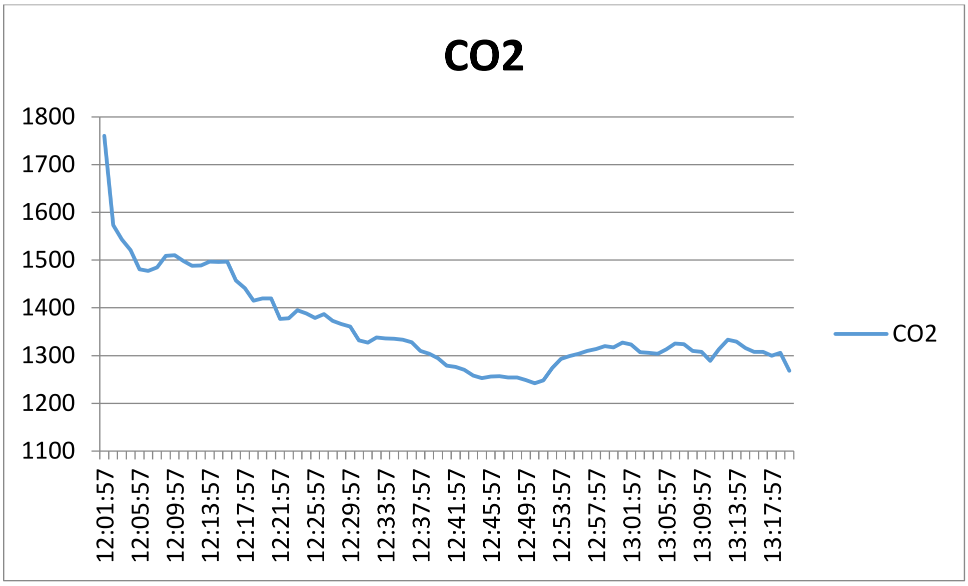

FIGURE 15. Carbon dioxide concentration in the living room. 14.11.2014

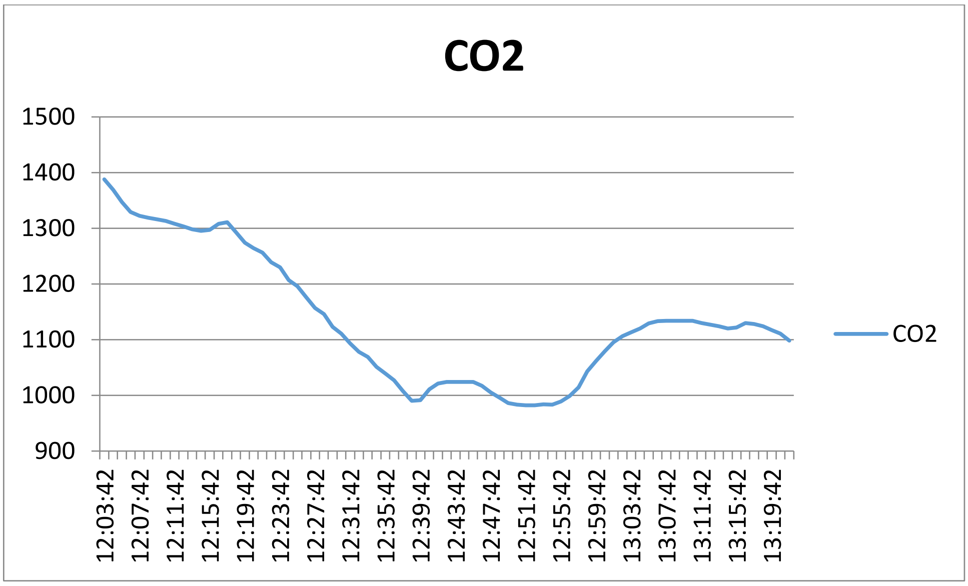

FIGURE 16.Carbon dioxide concentration in the bedroom. 14.11.2014

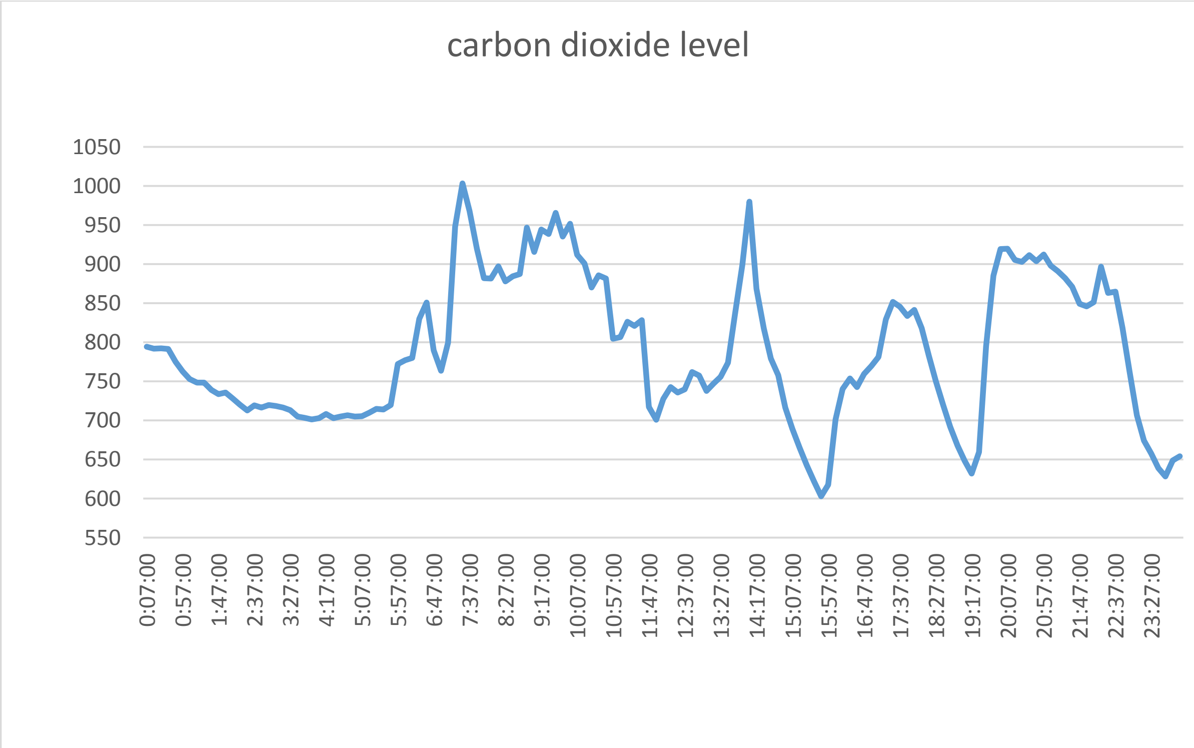

FIGURE carbon dioxide level in living room 4.11.2014

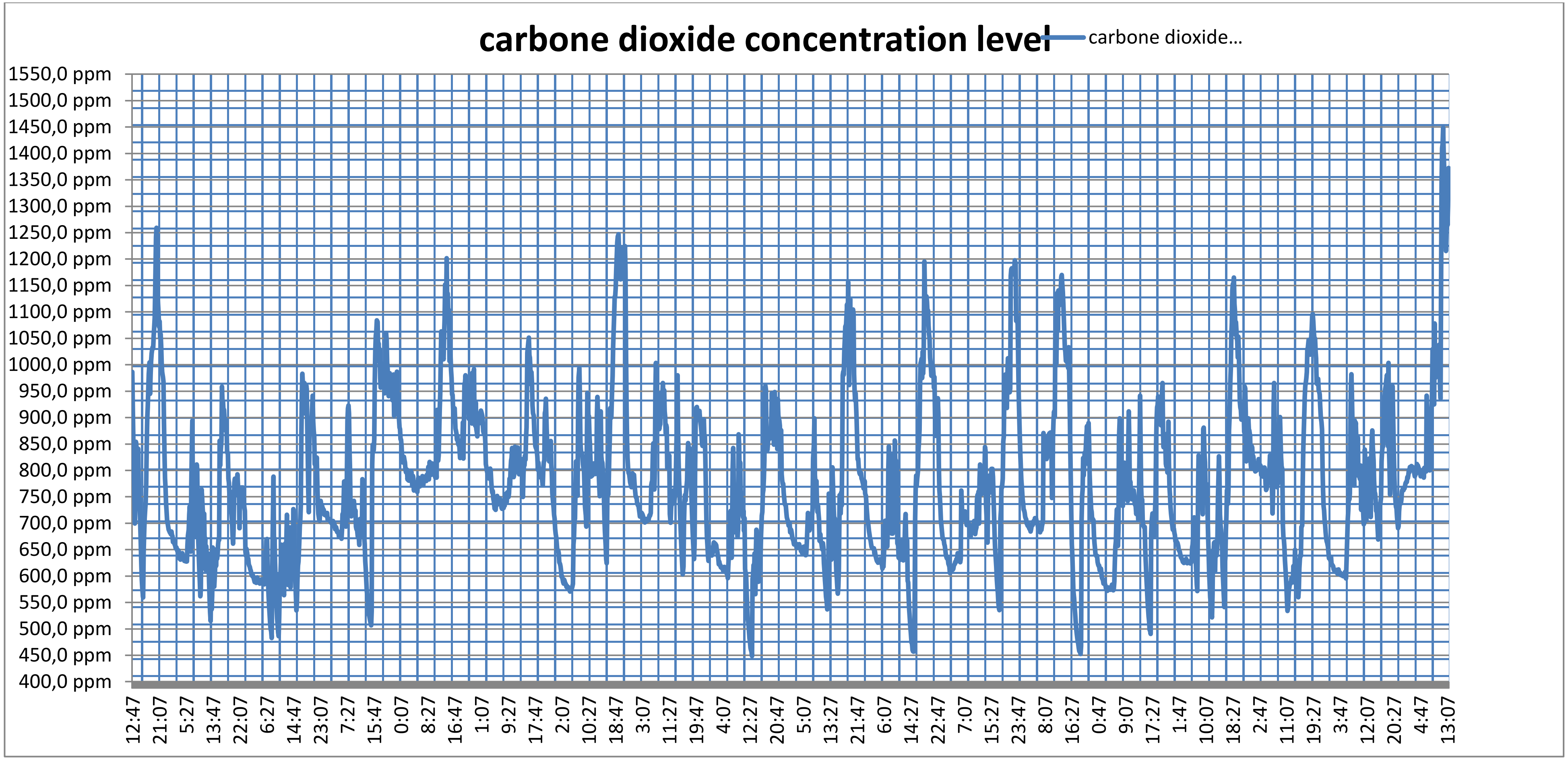

FIGURE carbon dioxide level in living room 28.10.2014-12.10.2014

4.5 Indoor air quality questionnaire

In order to clarify inhabitants' satisfaction with the premises the indoor air quality questionnaire have been made.

The following answers were achieved:

Inhabitants do not feel too high indoor temperature in winter, only in summer because of apartment orientation. They do not have sense of "bad" air. They are feeling that in winter time indoor air is more dry that in summer time. Ventilation system is required as good and effective, but sometimes it is become noisy at the third and fourth fan position. There is no mould, odors or other unpleasant occurs detected in the apartment.

4.6 Efficiency of heat recovery

First case, when it is first position of the fan. The values of temperature is given in Appendix 2

$$\eta_T = \frac{11,6-0,22}{22,5-0,22} * 100\% = 51\%$$

For the fan positions two, three and four the same calculation were made

This table presents temperature ration for different fan position.

TABLE 10. temperature ratio of heat recovery

First fan position	Second fan position	Third fan position	Fourth fan position
51%	58%	52,3%	48,5%

It is obvious that temperature ratio on the second fan position is bigger than other. This is means that normal fan position provides better temperature efficiency of air handling unit.

The following table gives information about comparison indoor air temperature in apartment

TABLE 11. Comparison of air temperature in apartment

	D2 National Building code °C	Apartment °C
Living room	21	22.3
Bedroom 1	21	21.5
Bedroom 2	21	22.9
bathroom	22	21.6

Values of supply air flow rates were comparing with Finish National Building code D2 .The air flow rates at the normal(second) fan position

TABLE 12. Air flow rates

	Supply air flow rate(l/s)	Air flow rate According to D2(l/s)	Designed values (l/s)
Living room	11,4	12	12
Bedroom 1	6	12	6
Bedroom 2	12,4	6	12

The bedroom #1 is designed for one person but occupants use it as a bedroom for two persons. It means that air flow is not enough in this room.

	Living room	Bedroom 1	Bedroom 2	Kitchen	Bathroom	Σsupply	Σexhaust	Air change rate 1/h
"Absence"	5.9	3.1	7.4	-7.2	-11.7	16.4	18.9	0.37
air flow rate(l/s) "normal"	11,4	6	12.4	-11	-21.3	30	32	0.63
3rnd fan position	16.8	8.4	15.1	-14.8	-24.6	40.3	39.4	0.77
4th fan position	22.4	12.1	24.1	-19.1	-41.4	58.6	60.5	1.17
Designed values (l/s)	12	6	12	-13	-20	30	33	0.67

5 DISCUSSION

In my studies I considered to study daily pattern of temperature, humidity and carbon dioxide level in living room during one day. The daily pattern gives information about how active were people during the day, how they spent day mostly. The average temperature during the day was 22,45 °C . The minimum temperature on the 4th of November was 22,3 °C from 04:34 to 5:44 and from 15:14 to 16:14. The temperature maximum of 22,6 °C was achieved at 17:04 to 18:14 and from 21:14 to 22:44. The temperature difference during the day was varying not so much.

Temperature rise up to 22 °C but do not exceed 25 °C, the temperature rising could be caused because of number of people in the apartment which is more than normal number of inhabitants. The diagram in Appendix presents information about temperature and humidity during two week period. The average temperature indoor air was 22,4 °C and average relative humidity was 35,96%

The changes in the two weeks pattern was so that the average indoor temperature was 22,4 °C. The minimum temperature of 21,6 °C was on the 7th of November when the outdoor temperature was +9 °C. The maximum indoor temperature was 23,2 °C on the 2th of November. These results mean that temperature variations weren't big enough to cause discomfort or sense of cold.

Total extract air flow rates at different fan positions are 5% higher than the supply air flow rates. The indoor air temperature is required Finish national building code. Ventilation system provides good indoor air to apartment.

In ordinary day (for example 4.11.2014) CO2 level not exceed 1000ppm and minimum is 600ppm. this variations depends of period of a day. For example, If it is night and there is no people in living room, the CO2 concentration is lower than in day time. During a day one person is usually at home, so the CO2 level do not exceed minimum values during day time. But after all, CO2 concentration has adequate values during most period of a day. The high concentration of Carbone dioxide can cause headaches, dizziness, nausea. ASHRAE recommends indoor CO2 levels not exceed the outdoor concentration by more than about 600 ppm
The results shows that ventilation system is designed in proper way can provide fresh air to living room area.

One day (24hours) was chosen to analyze relative humidity changes during day as an example. The measurement was 4.11.2014. Diagram shows relative humidity changes during a day. The maximum relative humidity 54% is achieved at 16.34, but minimum RH is 41% at 05:44. Also the absolute humidity was calculated. The maximum was 8,47 g/kg at 4.11 at 16:24 and minimum value 4,2 g/kg at 7.11 at 4:04.

Designed air flow rate for bedroom 1 is not as required for room for two persons. Supply air flow rate should be 12 l/s in order to require National Building Code D2. Air flow rate for bedroom2 should be 6 l/s, because only one person lives in the room, so air flow rate in bedroom two don’t require National Building Code D2.
The temperature efficiency of air handling unit at the second fan position is bigger than other. This is means that normal fan position provides better temperature efficiency of air handling unit.

The study was designed in order to know does the mechanical exhaust and supply ventilation system meet the requirments of comfort indoor air. The main results shows that indoor air temperature and humidity meet the requirments of Finish National Building Code, carbone dioxide concentration level also meet the requirements.

In conclusion I would like to notice that In Finish houses the mechanical supply and exhaust ventilation with heat recovery has been the most common solution during past 20 years. Nowadays natural exhaust ventilation can not provide apartment with proper temperature in summer time and carbon dioxide level. Mechanical ventilation system solves problems of bad indoor air quality.During the measuring in the apartment an overall good achievement of thermal comfort was found.

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Appendix 1 The temperature inside AHU at the 1st position

supply before HR(	supply after HR	exhaust before HR	Exhaust after hr	After heating coil	Time
-0.6	10,3	22,5	11,6	20,9	12:47:00
-0,5	10,5	22,5	11,6	21	12:48:00
-0,5	10,6	22,5	11,5	21,4	12:49:00
-0,3	10,8	22,5	11,5	21,8	12:50:00
-0,2	11	22,5	11,4	22,3	12:51:00
0	11,2	22,5	11,4	22,8	12:52:00
0,1	11,5	22,5	11,4	23,3	12:53:00
0,3	11,8	22,5	11,4	23,8	12:54:00
0,4	12	22,5	11,4	24,2	12:55:00
0,6	12,1	22,5	11,5	24,6	12:56:00
0,7	12,4	22,5	11,5	25	12:57:00
0,9	12,5	22,5	11,5	25,2	12:58:00
1,1	12,6	22,5	11,6	25,6	12:59:00
1,2	12,7	22,5	11,6	25,8	13:00:00

The temperature inside AHU at the 2st position

supply before HR	supply after HR	exhaust before HR	Exhaust after hr	After heating coil	Time
7,6	16,6	20	18,8	21,1	11:35
6,9	16,2	20,2	18,1	21,7	11:36
6,1	15,8	20,6	17,4	22,2	11:37
5,4	15,4	20,9	16,7	22,6	11:38
4,8	15,1	21,1	16,2	23,1	11:39
4,2	14,8	21,2	15,7	23,3	11:40
3,7	14,5	21,5	15,3	23,6	11:41
3,4	14,2	21,6	15	23,8	11:42
3	14,1	21,7	14,6	24	11:43
2,7	13,8	21,7	14,3	24,2	11:44
2,4	13,7	21,8	14,1	24,3	11:45
2,1	13,6	21,9	13,8	24,5	11:46
1,9	13,4	22	13,6	24,6	11:47
1,7	13,3	22	13,5	24,6	11:48
1,6	13,2	22,1	13,3	24,7	11:49
1,5	13,1	22,1	13,2	24,7	11:50
1,4	13,1	22,2	13,1	24,8	11:51
1,3	13	22,2	13	24,8	11:52
1,2	13	22,2	12,8	24,9	11:53
1,2	12,8	22,2	12,8	24,9	11:54
1,1	12,8	22,2	12,7	24,9	11:55
1,1	12,8	22,2	12,6	25	11:56
1	12,7	22,3	12,6	25	11:57
1	12,7	22,3	12,6	25	11:58
0,9	12,7	22,3	12,5	25	11:59
0,8	12,7	22,4	12,5	25	12:00
0,8	12,7	22,4	12,5	25	12:01
0,8	12,6	22,4	12,4	25	12:02
0,7	12,6	22,4	12,4	25,1	12:03

The temperature inside AHU at the 2st position

supply before HR	supply after HR	exhaust before HR	Exhaust after hr	After heating coil	Time
7,6	16,6	20	18,8	21,1	11:35
6,9	16,2	20,2	18,1	21,7	11:36
6,1	15,8	20,6	17,4	22,2	11:37
5,4	15,4	20,9	16,7	22,6	11:38
4,8	15,1	21,1	16,2	23,1	11:39
4,2	14,8	21,2	15,7	23,3	11:40
3,7	14,5	21,5	15,3	23,6	11:41
3,4	14,2	21,6	15	23,8	11:42
3	14,1	21,7	14,6	24	11:43
2,7	13,8	21,7	14,3	24,2	11:44
2,4	13,7	21,8	14,1	24,3	11:45
2,1	13,6	21,9	13,8	24,5	11:46
1,9	13,4	22	13,6	24,6	11:47
1,7	13,3	22	13,5	24,6	11:48
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1,3	13	22,2	13	24,8	11:52
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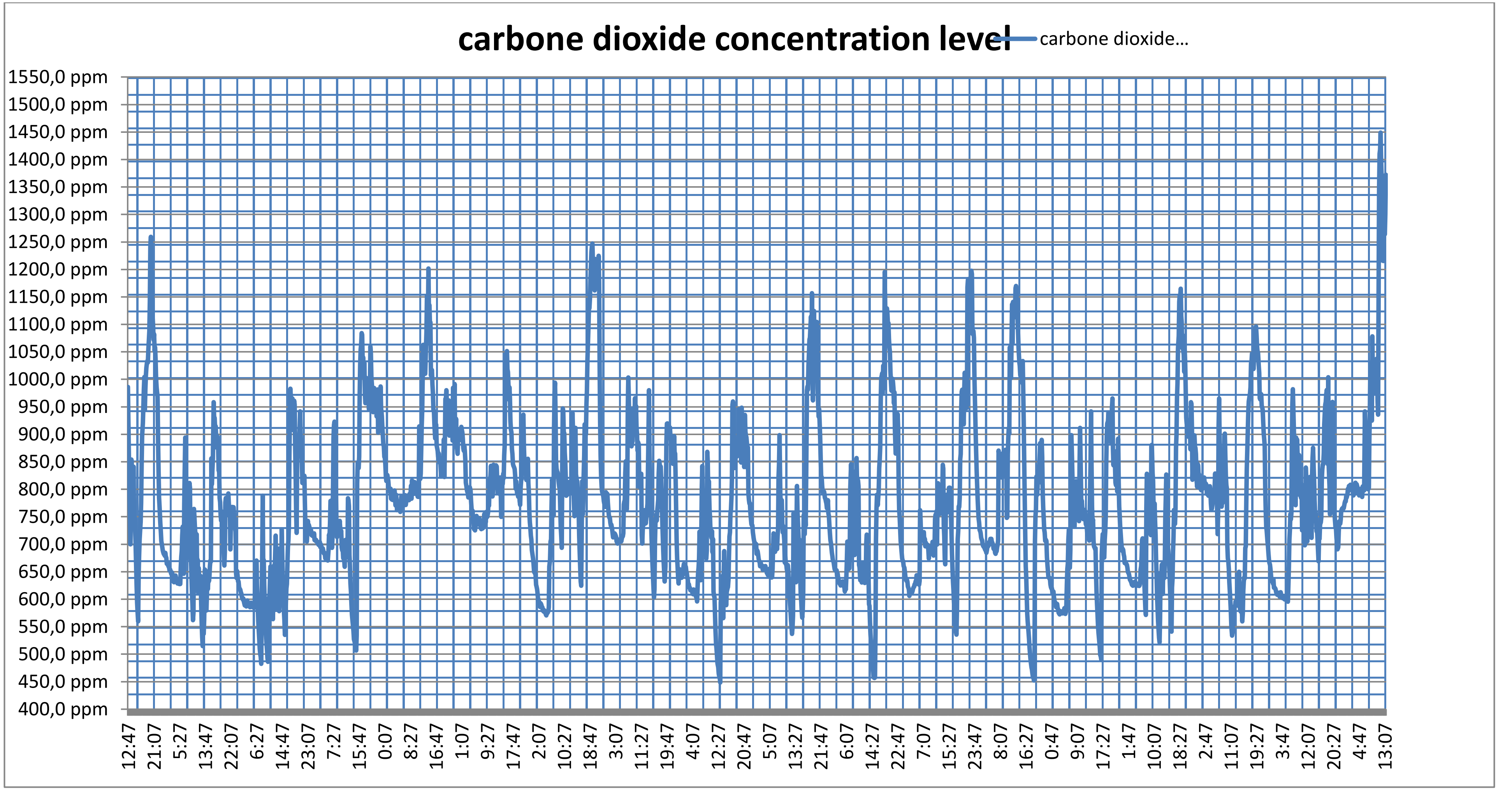
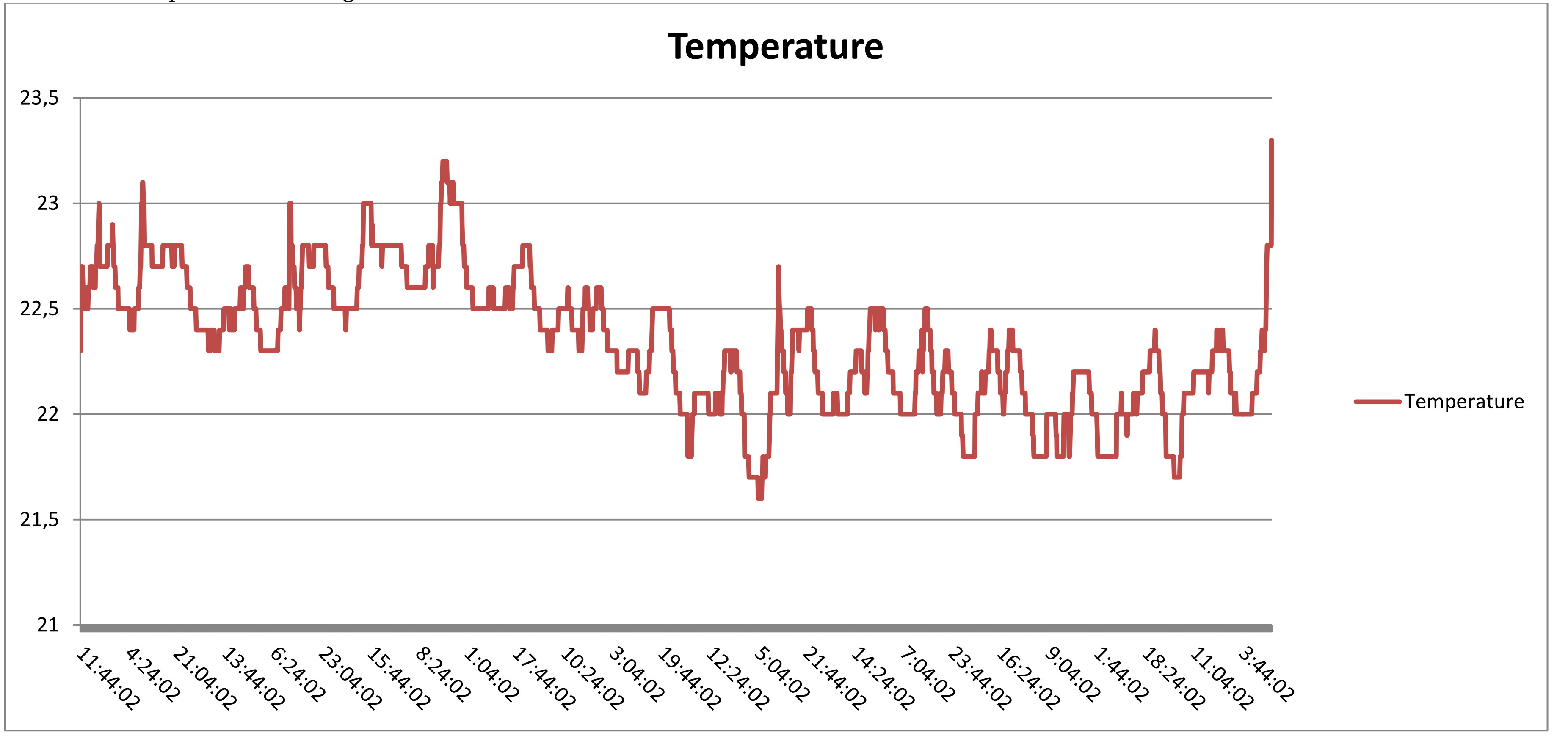
1,2	12,8	22,2	12,8	24,9	11:54
1,1	12,8	22,2	12,7	24,9	11:55
1,1	12,8	22,2	12,6	25	11:56
1	12,7	22,3	12,6	25	11:57
1	12,7	22,3	12,6	25	11:58
0,9	12,7	22,3	12,5	25	11:59
0,8	12,7	22,4	12,5	25	12:00
0,8	12,7	22,4	12,5	25	12:01
0,8	12,6	22,4	12,4	25	12:02
0,7	12,6	22,4	12,4	25,1	12:03

APPENDIX 2(1).

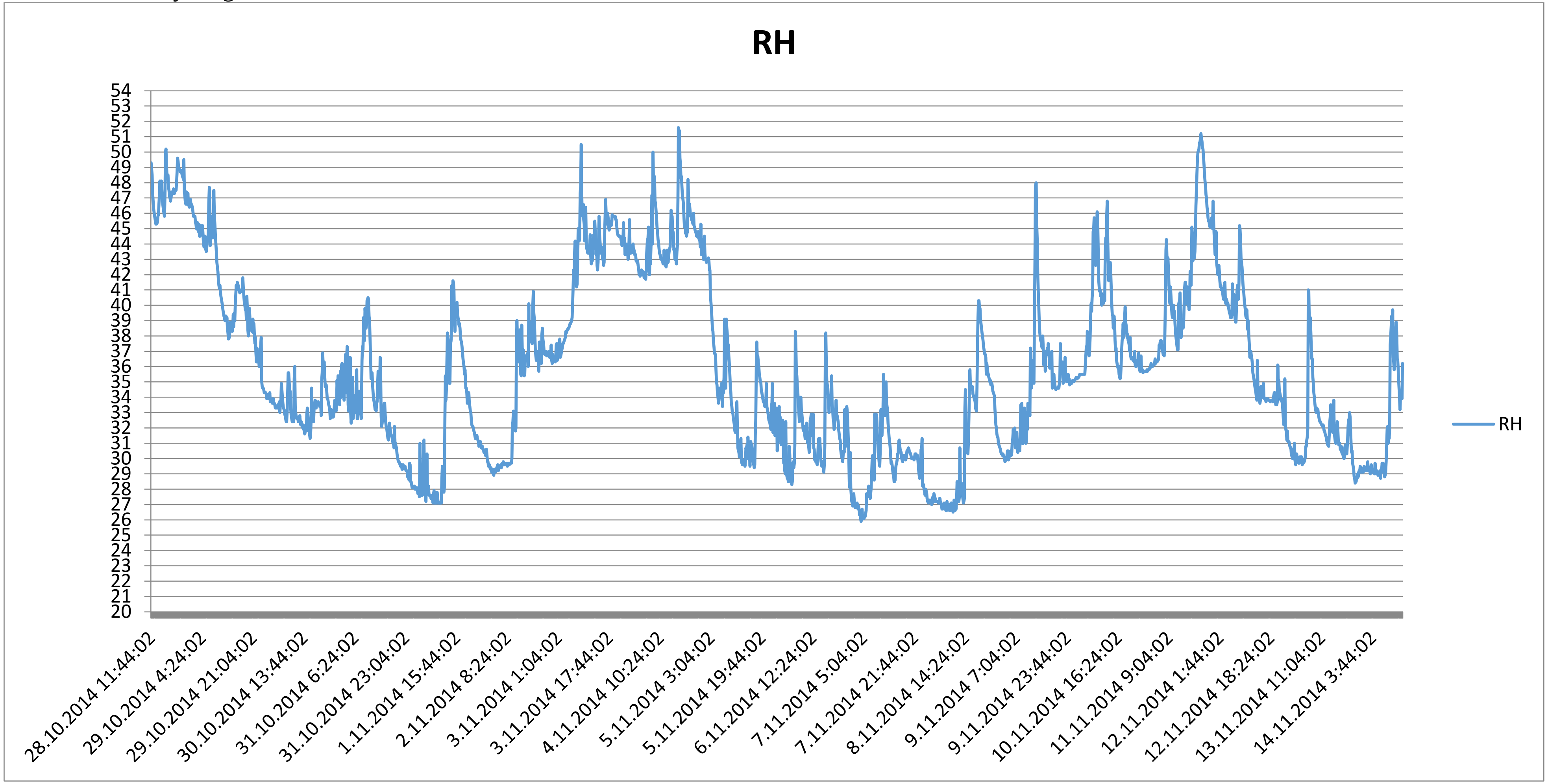
Carbone dioxide level in living room



Indoor air Temperature in living room



Relative humidity diagram



Values of supply air temperature and relative humidity at different fan positions are presented

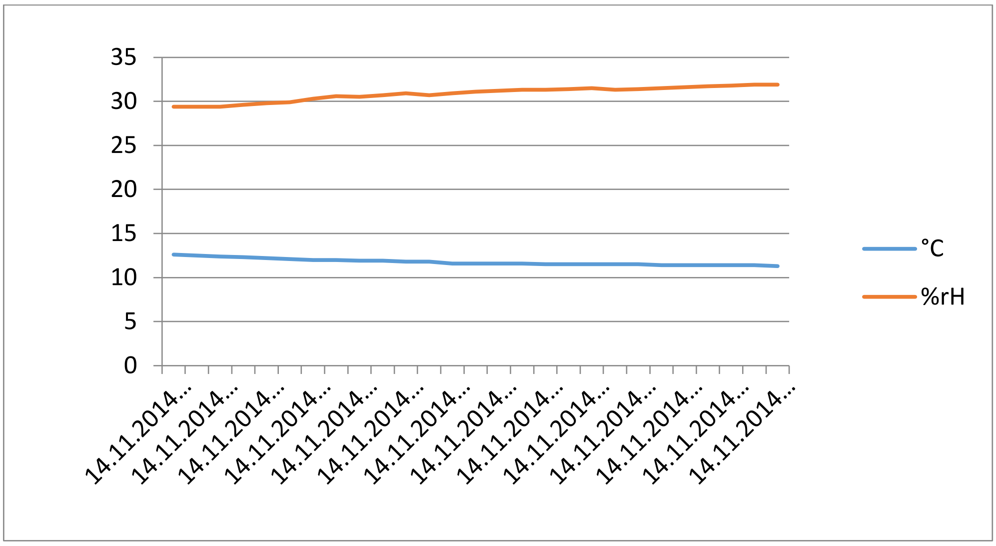


FIGURE 19. Diagram of supply air temperature after heat recovery temperature and relative humidity at first fan position

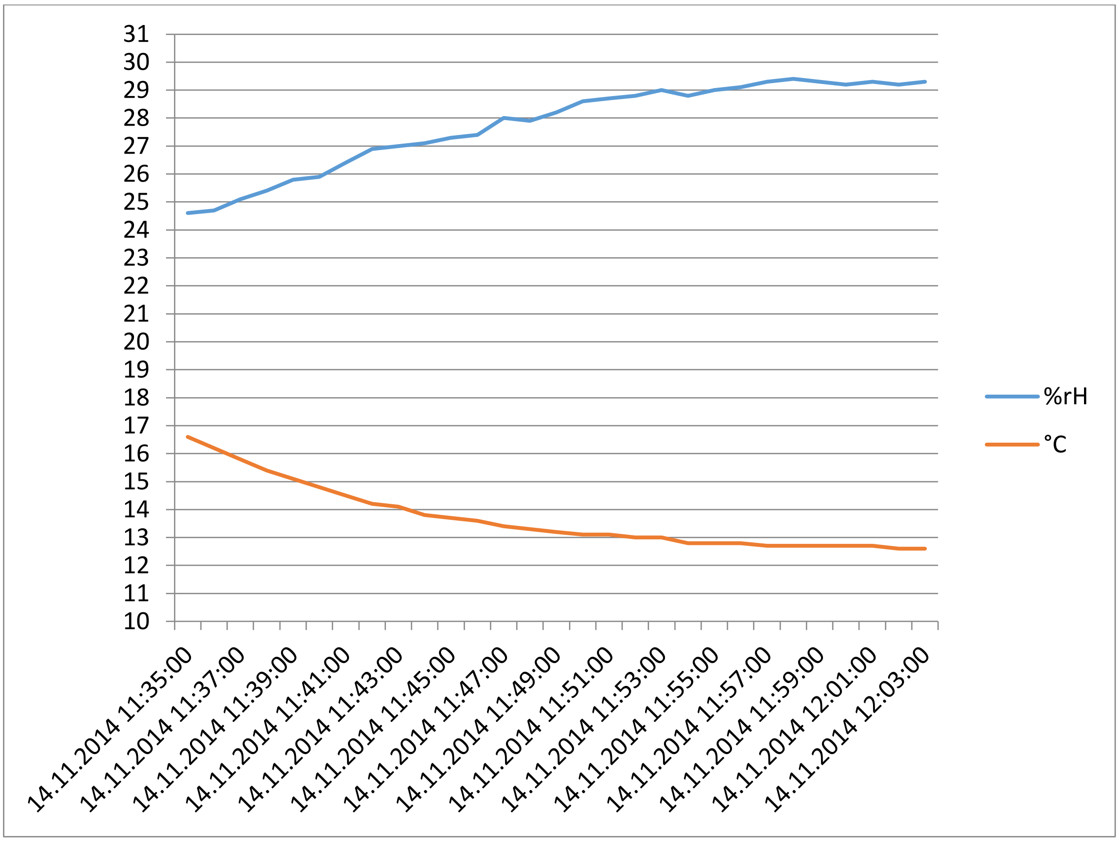


FIGURE 20. Diagram of supply air temperature after heat recovery temperature and relative humidity at second fan position

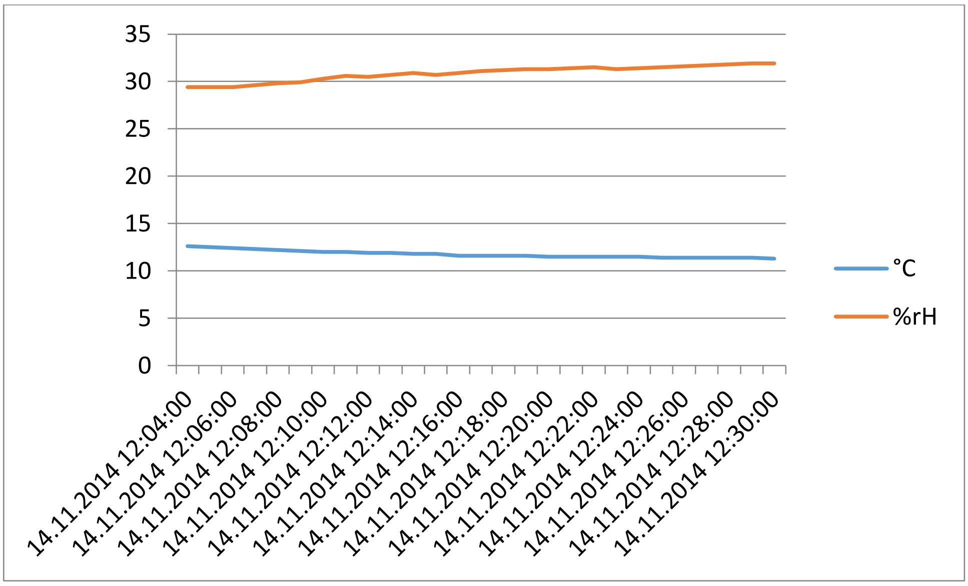


FIGURE 21. Diagram of supply air temperature after heat recovery temperature and relative humidity at third fan position

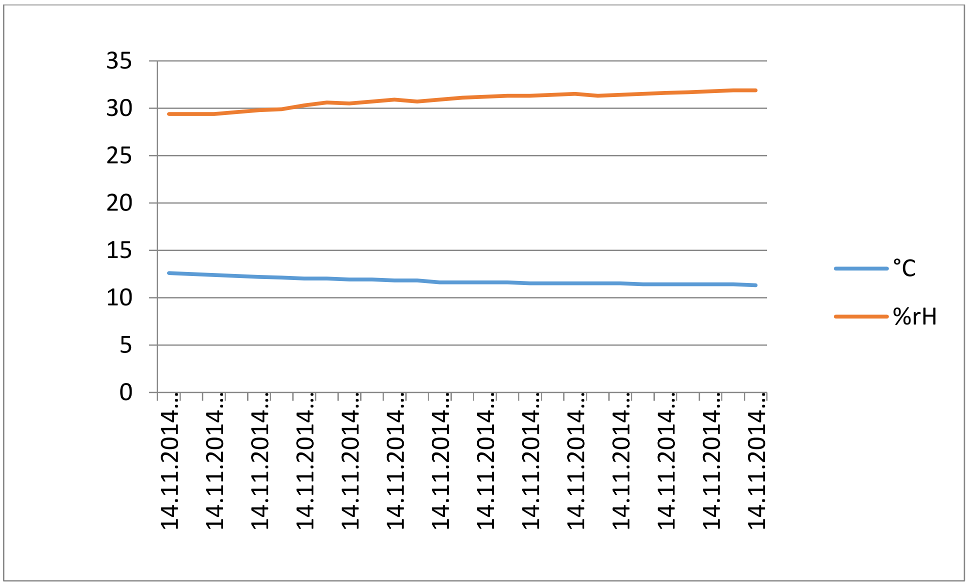


FIGURE 22. Diagram of supply air temperature after heat recovery temperature and relative humidity at fourth fan position