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INFLUENCE OF NATURAL AND MECHANICAL VENTILATION ON THE INDOOR CLIMATE

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DESCRIPTION

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Influence of Natural and Mechanical Ventilation on the Indoor Climate

Abstract

In modern societies every building should have an adequate ventilation system to avoid a several number of problems: deficiency of fresh air, bad quality of indoor air (uncomfortable temperature, humidity, etc.), different contaminants in the air (from indoor or outdoor sources).

Choosing ventilation system is a question of health, comfort and cost. In this work, the most suitable variant of ventilation system is selected by analyzing measurements, comparing them with Russian and Finnish standards and with results of questionnaires. Investigations were carried out in three case buildings. The first has natural ventilation and is situated in Saint-Petersburg, the second has combined type of ventilation and is situated in Mikkeli, and the last one is also in Mikkeli and has mechanical supply and exhaust ventilation. Each case building was examined according to a six stage measurement plan. First is describing buildings, their ventilation systems and occupants. Second part is executing measurements (thermal conditions, flow rates, carbon dioxide (CO_2) level). Third - accomplishing questionnaire about occupants’ sensations (where possible). Forth - analyzing results, bringing them to the simple visual form (diagrams, graphics, etc.). After those measurements results are compared with standards and questionnaire and finally, the following conclusions are made:

- Natural ventilation systems do not provide proper temperature (in summer) and CO_2 level
- Mechanical exhaust ventilation systems provides good thermal conditions but are not energy efficient
- Mechanical exhaust and supply ventilation systems provide the most comfortable conditions. In spite of this, when designing these systems, the minimum humidity level should be calculated.

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1. INTRODUCTION

Designing ventilation systems is a very important part of building engineering. Every building should have an adequate ventilation system to avoid a several number of problems: deficiency of fresh air, bad quality of indoor air (uncomfortable temperature, humidity, etc.), different contaminants in the air (from indoor or outdoor sources).

In modern societies the number of possible pollutant sources increases day by day. They may be various – from production of people's activities to extracts from harmful building materials, e.g. asbestos or formaldehyde. The sources of contaminants are everywhere: our furniture, carpets, pets, technical devices (e.g. printers, copy machines), plants and other. Even uncleaned or bad-designed ventilation system may be the reason of unhealthy and dirty air.

Another important target for ventilation system is saving energy. Of course, the problem of fresh air may be solved by opening the window, but would it be efficient? First, if there is bad air quality in the room – the window might be opened. Then the temperature becomes for e.g. too low and the heat input to the room should be increased. A lot of energy is wasted. In the same time, installing heat-recovery system will prevent these energy losses.

Comfortable conditions inside the building are very significant, too. Well-designed ventilation system means not only fresh clean air, but also some other factors. It should provide the same temperature in all parts of the space, absence of draughts, silence. However, often it is very difficult to meet all of these requirements.

Ventilation systems can be divided into two principal types: natural and mechanical ventilation. Natural ventilation is older, but it still has some advantages. Technologies are developing, mechanical ventilation is used more and more often nowadays – and it brings some new problems, such as noise, dust and other. Is natural ventilation only a technology of past? Could it be used now? What problems mechanical ventilation may cause?

Choosing ventilation system – it is a question of health, comfort and cost. In this work, the most suitable option of ventilation system is selected by analyzing measurements, comparing them with Russian and Finnish standards and with results of questionnaires. To answer these questions, three case buildings were studied. The first has natural ventilation and is situated in Saint-Petersburg, the second has combined type of ventilation and is situated in Mikkeli, and the last one is also in Mikkeli and has mechanical supply and exhaust ventilation. Each case building was examined according to a six-stage measurement plan. First is describing buildings, their ventilation systems and occupants. Second part is executing measurements (thermal conditions, flow rates, carbon dioxide (CO_2) level). Third - accomplishing questionnaire about occupants' sensations (where possible). Fourth - analyzing results, bringing them to the simple visual form (diagrams, graphics, etc.). After those measurements results are compared with standards and questionnaire and finally, conclusions are made, based on analysis and comparison of the case study buildings.

2. LITERATURE REWIEV

For creating healthy and safe work environment by the virtue of ventilation it is necessary to understand and follow the three main stages: setting a goal and finding potential problems, evaluating of these problems and risks and find solutions to these problems. /1, p. 1./

2.1. Thermal comfort

The first thing that should be provided by ventilation is thermal comfort. First of all, thermal comfort depends on heating system, but ventilation system is significant, too. In some cases (e.g. during summer period) ventilation system has even a key role in providing thermal comfort.

The main factors, which influence on thermal comfort, are: air temperature, mean radiant temperature, relative air velocity, water vapor pressure in ambient air, activity level and the clothes resisting level. The condition of thermal comfort is thermal balance of the body – this means that heat losses from the body to environment must be the same as heat production of the body. Heat losses depend on the clothes resistance, air temperature, velocity, temperature of connected surfaces and heat producing depend of the activity level and special features of each person. According to these factors, it is possible to predict the percentage of persons, who will be dissatisfied of the particular indoor climate conditions. This value is called percentage of dissatisfied (PPD).

Discomfort may be caused not only by too low or high temperature, but also by draughts (the reasons of draughts are high air velocity, too low temperature and turbulence intensity), variations of temperature (horizontal or vertical) and contacting with too warm or cold surfaces – asymmetric thermal radiation (it can be windows, exterior walls, floors, etc.). The predicted thermal sensation is evaluated by predicted mean vote (PMV), which determines sensations of large group of individuals on the 7-point scale. In fact, PMV does not take into account all factors (e.g. physiological and psychological state, habits and behavior). In office buildings often the amount of work, relationships between the different persons and work process intensity also influence on thermal comfort. In spite of it, PMV makes close to reality picture, by evaluating the main points. /2, p. 181-184./

2.2. Air quality

The term "indoor air quality" refers to the cleanliness of the air, in other words – the amount of pollutants in the air. Pollutants may have different nature (gaseous pollutants, particles, micro-organisms), sources, physical properties and effect of health and comfort. The sources of contaminants can be indoors (building materials, furniture, office equipment, people, tobacco smoking, pets, microbial growth, inadequate ventilation system) and outdoors (traffic, industries, plants (pollen) and other.) /3, p. 113-115./ According to Nillson /3/, office buildings usually have dirtier air than residential and other buildings for the several reasons:

- Location in the center of city – high level of traffic around
- High concentration of people in one place
- Specific office equipment (big capacity of printers, copy machines, etc.)
- A lot of smoking – sometimes inside the building

Futhermore, residential buildings may have poor ventilation and several sources of air pollutants, and inadequate or none filtration of supply air, thus resulting in poor air quality. The different contaminants may cause the following effects:

- Odors (bio-effluents, hydrogen sulphide)
- Allergies (pollen, allergen from pets)
- Irritation (certain volatile organic compounds, ozone, nitrogen dioxide)
- Infection (virus and bacteria)
- Toxic reactions (lead, formaldehyde, endotoxins from bacteria)
- Cancer (certain polycyclic aromatic hydrocarbons, radon progeny, asbestos, environmental tobacco smoke) /3, p. 118-120/

The function of ventilation is to dilute and/or reduce the amount of contaminants for providing safe and clean air to breath. In the office buildings proper ventilation system is especially important, because the quantity of contaminants in the air increases very fast, as a result of high people concentration (in comparison with residential buildings) on the limited area.

2.3.Productivity and indoor climate

According to Mendell the main problems of office buildings indoor climate are:

1. Accumulating moisture, caused by water leaks in the building envelope or plumbing, incorrect design HVAC systems, or infiltration of water vapor through the envelope;
2. Incorrect amount or quality of supply air as a result of improper design, operation, or maintenance of the HVAC systems;
3. Dust, accumulating by the reason of seldom or ineffective housekeeping, after repairing, extracting from bad selected interior materials;
4. Pollutant gases and odors from outdoor sources;
5. Improper thermal control in account of inadequate design of HVAC systems;
6. Unwillingness of building management to recognize the importance of indoor air quality problems and to find some way of solving them. /4, p. 436-440/

At the same time, all these problems influence the health of people in the office buildings and their productivity. It depends mostly on the concentration, which can be determined by the measuring of brain rhythm patterns. Frequency of concentrated person brain rhythm is 12-30 Hz. Researching revealed that this value can be increased by improving work environment and indoor climate. Furthermore, the profit from growing productivity exceeds inputs for renovating building systems and improving work environment. /5, p. 3-4./

The investigation /5, p. 107-111/, which took place in USA, included people, who work, visit, do business or were the customers in commercial buildings. The total number of investigated buildings was 4 149 000. The total area of these buildings was 5,4 million m^2 and the total number of workers in it was 68,9 million. According to this investigation, the summary of total productivity benefits is next:

Table 1. Summary of total productivity benefits /5, p.111, table 9.2/

title	*value*
Productivity and health benefits	

Annual total productivity benefits	\$54.7 billion/year
Annual reduced health costs	\$8 billion/year
Annual total productivity and health benefits	\$62.7 billion/year
Including annual sales benefits	\$211.2 billion/year
Annual employee-related benefits, total	\$3,065/worker/year (\$39.11/m^2 per year)
Cost to implement	
Implement all identified IAQ improvements	\$120 billion
Average cost per area	\$22.22/m^2
Average cost per worker	\$1,742
Initial average economic simple payback	0.56 years
Annual cost to sustain all improvements	\$6.6 billion/year
Net 20-year present value of benefits less cost (interest =3%)	
For all improvements	\$2,924 billion
Per square meter for all improvements	\$541.48/m^2
Per worker for all improvements	\$42,438/worker

These results show that providing good work environment is not only a care about health of workers, but also a possibility to make a substantial profit.

2.4.Energy efficiency

It is difficult to determine, which ventilation system is more energy efficient, because both mechanical and natural ventilation types have their benefits in this question. Natural ventilation does not need electric energy for air moving but it causes permanent cooling of building through the leakages that means heat losses and increasing of heat power demand. On the other hand, mechanical ventilation needs electricity, but it allows to install heat recovery system, which brings heat from exhaust to supply air and thus decreases the need of heat energy.

2.5.Comparison of Finnish and Russian requirements

2.5.1. List and character of Finnish requirements

When designing ventilation system in Finland, several documents could be used.

- D2 National building code of Finland. Indoor climate and ventilation of buildings. Helsinki, Finland. Ministry of the Environment on the indoor Climate and ventilation of buildings. 2002. /6/
- Classification of Indoor Environment 2008. Target Values, Design Guidance and Product Requirements. Finnish Society of Indoor Air Quality and Climate. FiSIAQ publication 5. Trinklet Oy. Helsinki 2010. /7/

D2 is the obligatory requirement that must be met in all buildings. It includes regulations about indoor climate parameters (thermal conditions, air quality, acoustic conditions, lightning conditions) and requirements for ventilation systems.

Classification of Indoor Environment 2008 is used for improving the quality of indoor climate and divide the final product into the categories. The classification has target values for indoor environment (S), guidance for design and construction (P) and requirements for building products (M).

2.5.2. List and character of Russian requirements

At present time the system of Russian requirements is at the stage of reconstruction. All regulations (like GOST, SNIP), which earlier were obligatory have been modified into recommendations. Instead of them "technical regulation on safety of buildings" was developed and it is obligatory. But this document has to be improved, because it has just a list of parameters, which must be taken into account, but there are no numerical values and formulas in it. Finally, there are the following main documents:

- Technical regulation on safety of buildings. Federal law of Russia. Approved on 23.12.2009. /8/
- GOST 30494-96. Residential and public buildings. Microclimate parameters of indoor enclosures. International standard. 11.12.1996. /9/
- SNIP 41-03-2003. Heating, ventilation and air conditioning. Moscow. Gosstroy Rossii, 2004. /10/

2.5.3. Comparison of temperature requirements

According to /6, p. 8/ the designed temperature of offices should be +21°C for heating season and +23°C for summer season. The maximum acceptable deviation is ±1°C.

Normally the temperature should not exceed 25°C, but in case when outdoor temperature is higher 20°C during more than 5 hours, inside temperature may exceed this value maximum by 5°C.

Temperature limits for different categories according to /7/ can be determined by Figures 1-3, but for 95% of time the temperature could not be higher than 25°C for S1 category, 25,5°C for S2 category and 26°C for S3 category. The minimum temperature for 95% of time is 21°C for S1 category, 20,5°C for S2 category and 20°C for S3 category.

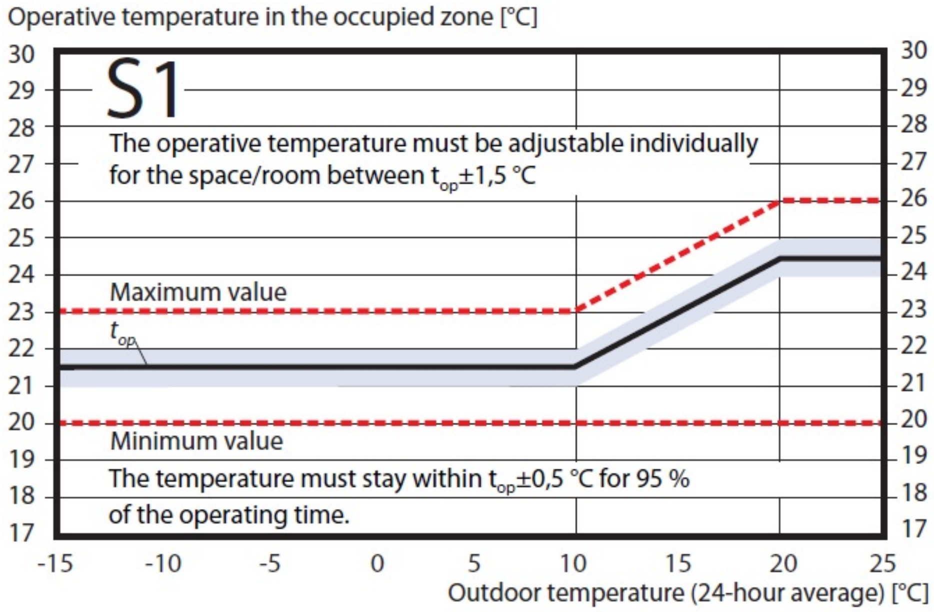


Figure 1. Temperature limits for S1 category /7/

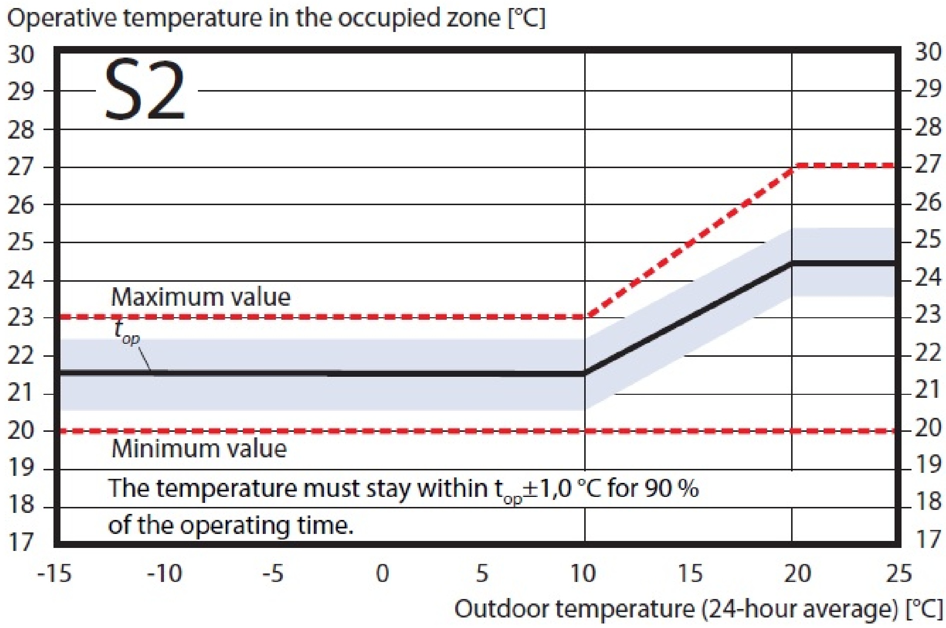


Figure 2. Temperature limits for S2 category /7/

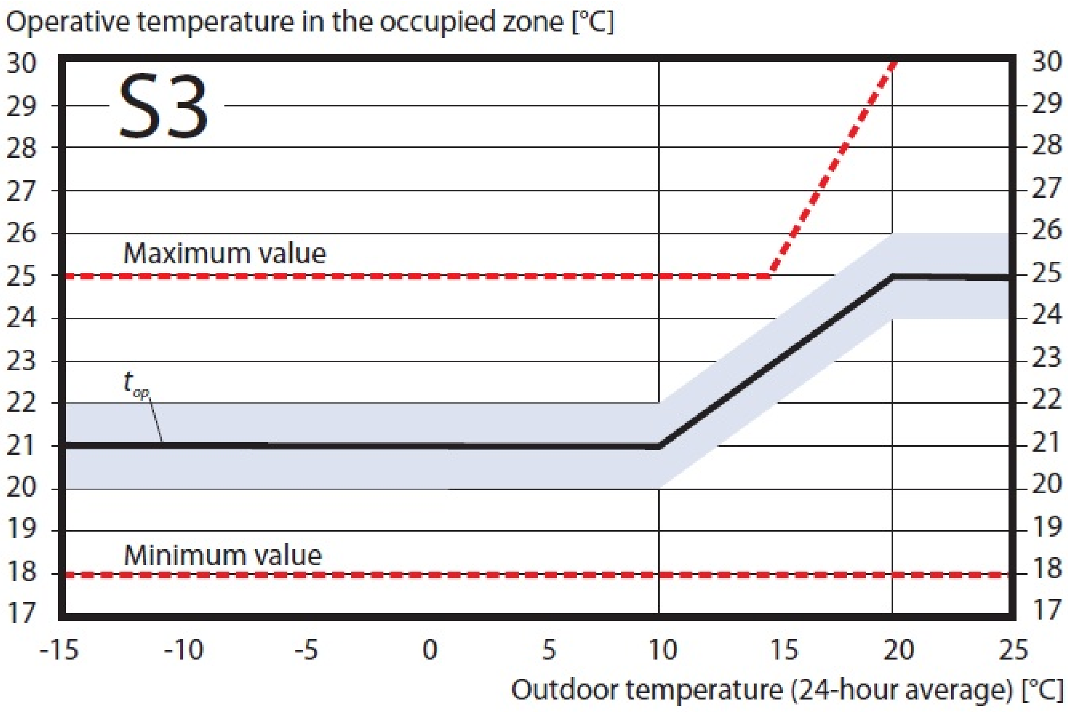


Figure 3. Temperature limits for S3 category /7/

According to the /9/ the temperature of occupied zone of office buildings should be the following:

- During winter period optimal is 19-21°C, possible 18-23°C.
- During summer period optimal is 23-25°C, possible 18-28°C.

2.5.4. Comparison of air velocity and humidity requirements

According to /6, p. 33/ air velocity in offices should not exceed 0,2 m/s in the winter and 0,3 m/s in the summer. There is no regulations about humidity in /6/.
According to /7/ air velocity could be determined by the Table 2.

Table 2. Acceptable air velocities for different categories /7/

Category	S1 (individual)	S2 (good)	S3 (satisfactory)
Temperature			
21 °C	<0,14 m/s	<0,17 m/s	<0,2 m/s (winter)
23 °C	<0,16 m/s	<0,20 m/s	
25 °C	<0,18 m/s	<0,25 m/s	<0,3 m/s (summer)

There is no regulations about humidity in /6/, in /7/ there is only requirement for S1 category – relative humidity should be more than 25%.

According to /9/ air velocity in offices should not exceed 0.2 m/s in the winter and 0.3 m/s in the summer. Relative humidity should be optimal 30-45% and possible 60%.

2.5.5. CO_2 level and concentrations of impurities

According to /6, p. 9/ CO_2 level should not exceed 1200 ppm. Values for concentrations of impurities in indoor air are available in Table 3.

Table 3. Values for concentrations of impurities in indoor air

impuritie	*Design value of maximum concentration*	*unit*
ammonia	20	$\mu g/m^3$
asbestos	0	$fibres/cm^3$
formaldehyde	50	$\mu g/m^3$
carbon monoxide	8	mg/m^3
particles PM_{10}	50	$\mu g/m^3$
radon	200	Bq/m^3
styrene	1	$\mu g/m^3$

According to /7/ CO_2 level and radon concentration should be determined by Table 4.

Table 4. Values of CO_2 level and radon concentration for categeries /7/

	S1	S2	S3
CO_2-concentration, ppm	<750	<900	<1200
Radon concentration, Bq/m^3	<100	<100	<200
Stability of the conditions			
-offices and schools	95%	90%	
-residencies	90%	80%	

In the Russian standards there are no regulations about CO_2 level and impurities in air /9/

In general, the following conclusion could be made:

- Temperature limits are quite similar in all standards, but not less than 18 °C and not more than 30 °C in any case.
- Humidity regulations are only in Russian requirements.

- Air velocity is the same for /6/, S3 category from /7/ and /9/. The value of it is 0,3 m/s for summer period and 0,2 m/s for winter period.
- CO_2 level and impurities are regulated only in Finnish standards.
- The most strict document is Finnish Classification of Indoor Climate /7/.

2.5.6. Air flow rates

According to the /6, p. 33, Table 2/ the air flow rate in office room should be at least 8 dm^3/s per person or 1,5 dm^3/s per square meter.

The Classification of Indoor Environment /7/ determines the following requirements for office rooms:

Category	**S1**	**S2**	**S3**
	Air flow, m^3/s		
per person	**12**	**8**	**6**

Air flow rates could be also calculated by the next formulas:

- S1 category

outdoor air flow = 0,5 dm^3/s*floor-m^2 + 11dm^3/s*person

- S2 category

outdoor air flow = 0,5 dm^3/s*floor-m^2 + 8 dm^3/s*person

According to the russian norms the air flow rate should be 16,7 dm^3/s per person for public buildings. /10/

2.6. Natural ventilation in office buildings

2.6.1. Principle of natural ventilation

Natural ventilation has two driving forces: wind pressure and stack pressure. When the wind strikes a building, it makes positive pressure on the front side of the building and negative pressure on the back side. The pressure generated by wind on the building surface is expressed as the pressure difference between atmospheric static pressure and total pressure at the point.

Stack pressure is the result of temperature or humidity difference (it is also determined as density difference) between indoor and outdoor air. When the temperature inside the room is higher, than outside temperature, the density of inside air is less than outside air density. Inside density rises and air moves into the room through lower openings and leaves the room through upper openings.

Approximated air flow rates that can be provided by natural ventilation are introduced in the table 5. /11, p. 27-30/

Table 5. Estimated air changes per hour and ventilation rate for a 7mx6mx3m room /11, p. 30, table 4.1/

Openings	*ACH**	*Ventilation rate (dm^3/s)*
Open window (100%) + open door	37	1300
Open window (50%) + open door	28	975
Open window (100%) + closed door	4,2	150

*ACH = Air change rate (1/h)

2.6.2. Advantages and disadvantages

There are several advantages of natural ventilation: it is simple to design, install and maintain; it makes no noise; it is cheap; it does not need electricity.

The three main problems of natural ventilation are:

1. Variable driving forces, which cause infiltration. Wind pressure can vanish on account on absence of wind. And stack pressure depends on weather conditions and the height of building;
2. Difficult to control, where the air enters the building and how it is distributed. There is not any possibility to provide good mixing;
3. Infiltration and exfiltration damage the building envelope and reduce energy efficiency of building. /12/

But for office buildings, situated in the center of cities there are some other problems with using natural ventilation: contaminants in the outdoor air. According to the /13, p. 124-126/ the level of outdoor and indoor concentration of sulphur dioxide and lead are the same. Ozone and nitrogen dioxide usually react with the building material, which leads to reducing indoor concentration if the building is airtight. The particle matter transfer depends upon the particle size. Consequently, from the position of air quality natural ventilation is not very good choice for center of city, where usually office buildings are situated.

2.7. Mechanical ventilation in office buildings

2.7.1. Principles of mechanical ventilation

Mechanical ventilation use fans to move supply air to the rooms and extract air from the rooms. Depending on desires, the air may be filtered, heated, cooled, humidified or dehumidified. Normally in office buildings air is just filtered and heated and sometimes cooled. There are no requirements about humidity in office buildings in Finland, so humidifying/dehumidifying is not popular. The systems are usually equipped with heat recovery for saving energy. Some part of exhaust air may be recirculated. However, recirculation is very seldom used in Finland. /2, p. 245-246/

2.7.2. Advantages and disadvantages

There are several advantages in using mechanical ventilation in office buildings:

1. Possibility of controlling air flow rates, air temperature and humidity. Possibility of using heat recovery.
2. Independence from weather and climate conditions. Mechanical ventilation can work everywhere, if electricity is available.
3. It is possible to install filtration systems for air purification (from microorganisms, particles, gases, odors etc.)
4. The outdoor air for the mechanical ventilation is collected from the selected place, that allows to exclude unfavourable points of collecting air.

The problems of mechanical ventilation are:

1. Installation and maintenance costs may be high. Mechanical ventilation system needs to be cleaned, it uses electricity and the cost of equipment is rather high.
2. Mechanical ventilation produces sound, which can annoy occupants. /11, p. 9-10./

3. CASE 1. OFFICE BUILDING WITH NATURAL VENTILATION IN SAINT-PETERSBURG, RUSSIA

3.1. Description of the building

3.1.1. Construction

This office building is situated in Kirovsky area of Saint-Petersburg and it was built around 1938 (shown in Figure 4). It is made of concrete blocks and has five floors. The height of each stage is about 3,5m. The walls between the rooms are made of gypsum plasterboard. It has two stairs in the opposite ends of the building. In the center of each stage along the bigger side of the building there is a corridor. All rooms are connected to these 5 corridors. Toilets are in the left end of the building, near the stairs. Close to them there is a ventilating shaft. On the second floor there is a café with kitchen.

The area of office rooms varies from 6 to 15 m^2. Most rooms have their own balconies. Windows are not very big. Each room has one to five working places. Some rooms have separate printers and copy machines, but the main devices are in the corridors.

Figure 4. Outside view of case 1 (office building with natural ventilation in Saint-Petersburg)

3.1.2. Ventilation

The building has natural ventilation. Ducts from rooms with exhaust air are going to the ventilating shaft. Unfortunately, some of ventilation diffusion cells are completely plugged up by the gypsum plasterboard. The reason for it is replannig of the building many times without any attention to ventilation. Supply air gets to the rooms from windows and leakages. In the toilets there are exhaust fans, which move dirty air to the ventilating shaft. There is also an exhaust fan in the kitchen. Some office rooms (but less than a half of the whole number) are equipped with separate air-conditioner units. Each room with it is equipped by two blocks – one inside and one outside. Other rooms in summer time often use fans that just move air inside the room. The typical room with an air-conditioner is shown in Figure 5 and room without air-conditioner is in Figure 6.

Figure 5. Typical room of model 1 with air-conditioner.

Figure 6. Typical room without air-conditioner.

3.1.3. Occupants

The number of people, working in this building, is about 250. They are different specialists in the construction field: secretaries, estimators, engineers, designers and other. Some of them have irregular working hours, but most work from 10.00 till 19.00 with dinner time from 13.00 till 14.00. Some people also do not spend all their time in the office.

3.2. Methods

3.2.1. Measurements

Two types of the temperature measurements were made in this building. The first one is monitoring temperature during the office hours (from 10.00 till 19.00), with 30 min intervals. The second one is recording results three times a day, at 12.00; 15.00 and 18:00 during 21 day. Both inside and outside temperatures were measured at the same time. Measurements were made in an office room with three office desks and without an air-conditioner. The area of this room is about 10 m^2. The inside device was situated in the center of the room, between tables and outside – on the balcony. The instrument was "thermometer RST 02100" and its measuring range is from -50°C till

+70°C inside and from -10°C till +50°C outside. The accuracy of the device is ±0,5 °C.

3.2.2. Questionnaire

The employees were asked to fill in an indoor air quality questionnaire, which was based on «FIOH questionnaire concerning indoor air quality on the workplace». It was translated to Russian language by the author of this report. It contains some background information, questions about work environment, work conditions, present symptoms, that possibly could be connected with bad indoor air, and some past illnesses. Some extra questions about work conditions were added. The number of respondents was 22 persons. All of them were working in case building more than 3 months.

3.3. Results

3.3.1. Indoor and outdoor temperature

The temperature measurements, which you can see in Figure 7, were made during 21 days of the hottest summer month. The Figure 7 shows inside temperature (t in, blue color), outside temperature (t out, red color) and lines that show requirements for inside temperature. As we can see in the Figure 7, the inside and outside temperatures are rather similar. The average outside temperature was 23,9 °C and the average inside temperature was 24,5 °C. The reasons for it are the windows, which are open during the whole day in summer period. At the beginning of the work day (at 9 o'clock) temperature inside is a somewhat lower than outside. The windows have not yet been opened, and the air inside is still cold after the night. But outside air (especially if it is sunny) is warmed up faster at this time. At about 12 o'clock temperatures inside and outside the building are the same. After that inside temperature becomes higher. There are some people and devices (computers, printers etc.) inside the rooms as internal heat loads. Closer to the evening both temperatures decrease. You can find a more detailed diagrams and tables with measurement in Appendix 1.

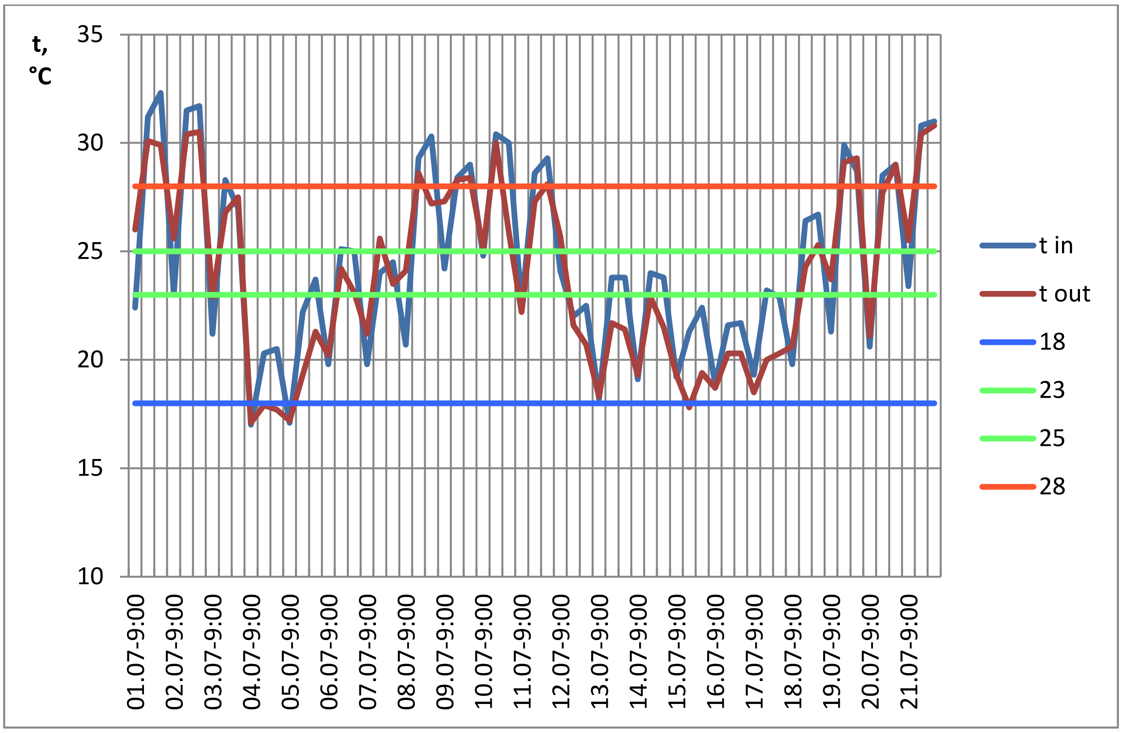


Figure 7. Temperature measurements during 21 days in case building 1.

The temperature measurements on the Figure 8 illustrate variations in inside and outside temperature during one day (8.07.2011). The temperature was measured every 30 minutes from 9:00 till 18:00 (during the work time). The average inside temperature was 26,6 °C. As we can see on the Figure 8, in the first half of a day outside temperature is higher than inside. On the day of measurements it was sunny, but before at about 13:00, the sun was shining at another side of a building. Another reason is that in the first few hours of a day, people in this building don’t work hard. In the second half of the day the temperature inside becomes higher than outside. Different devices like computers and printers extract a lot of heat, the number of people in the room increases, so people extract more heat, too. Sun light comes straight through the windows and warmed up the room. Outside temperature after 3 pm starts decreasing. You can find more detailed diagrams and tables with measurement in Appendix 2.

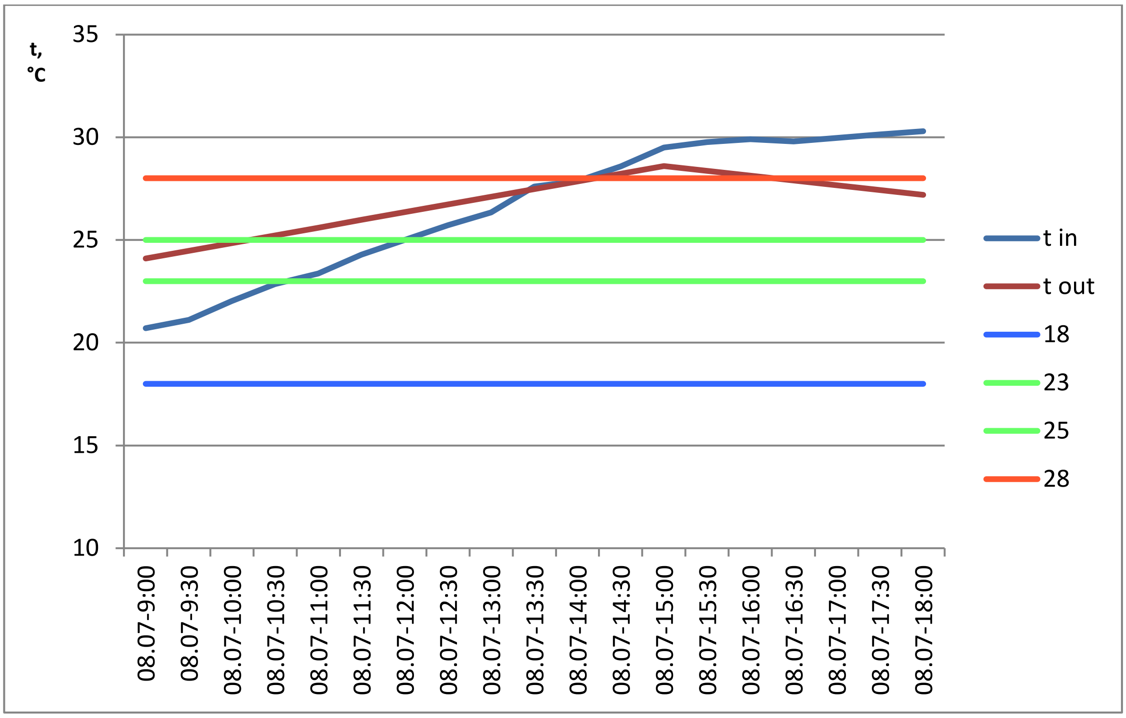


Figure 8. Temperature measurements during one day.

3.3.2. Occupants perceptions of indoor climate

This questionnaire describes people's sensations during the last three months. The year of birth of the respondents (totally 22 persons) varied from 1946 to 1987 (age from 24 to 65). They have worked in this company from 4 months to 15 years. Less than a half of them smoke. Most of people find their work interesting and stimulating, but almost all of them have too much work to do. Only about half of them can influence on their work conditions. Most of people feel stress - more or less often.

Work environment

The problems displayed on the diagrams were observed by respondents every week or more often. The greatest problems of this building are: too high air temperature, stuffy air and not enough ventilation. The last two problems are actual in both types of rooms: with air conditioners and without them. But the problem with high temperature is not so significant in rooms with air conditioners: only half of occupants have such problem. The reason for it might be that the air conditioner could not be switched on all the time, because it could not provide the same adequate temperature in all parts of the room. The person who is sitting under the device feels cold or draught and asks the others to switch off the air conditioner.

The other significant problems are: noise, problems with light, dust and dirt. But they mostly do not depend on ventilation system. Maybe only the last problem is connected to the opened windows. Windows are opened because people feel bad and stuffy air.

The results of work environment you can find on the Figures 9-11.

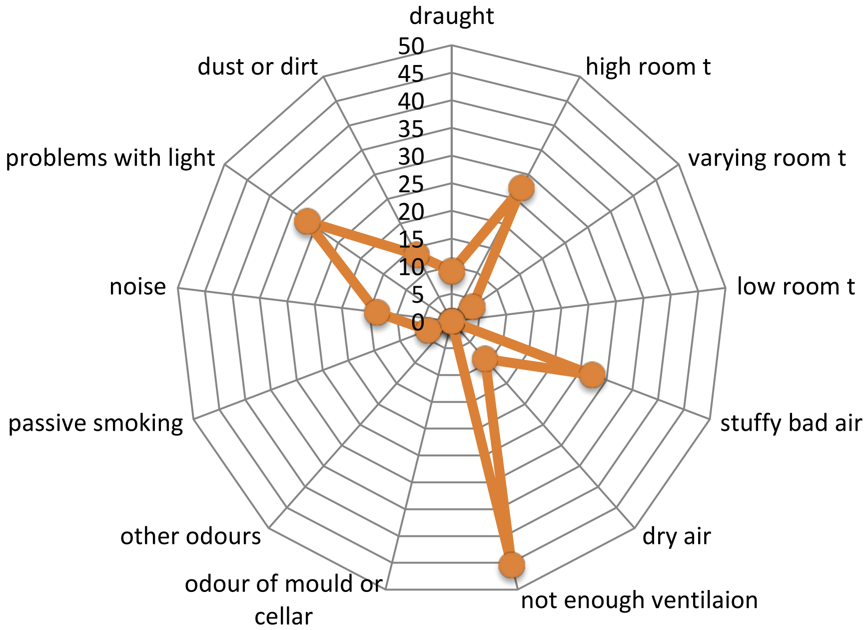


Figure 9. Work environment in all rooms. Problems encountered every week or more often

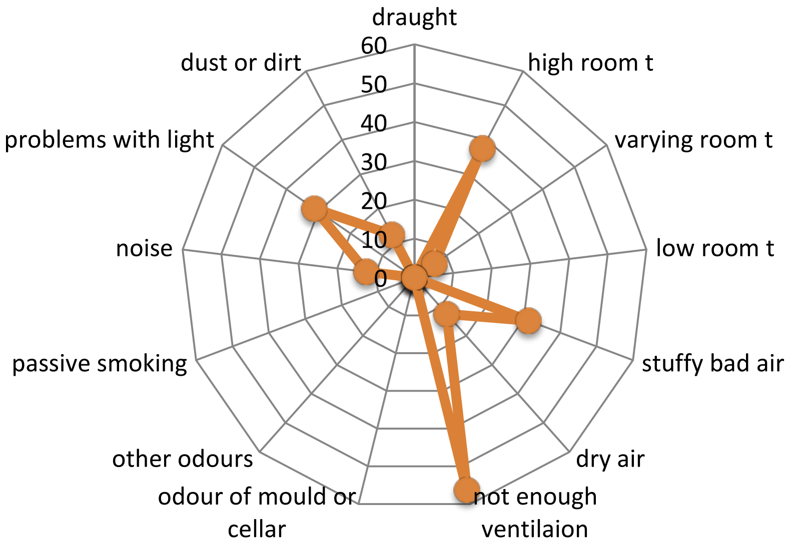


Figure 10. Work environment in rooms without air conditioner. Problems encountered every week or more often

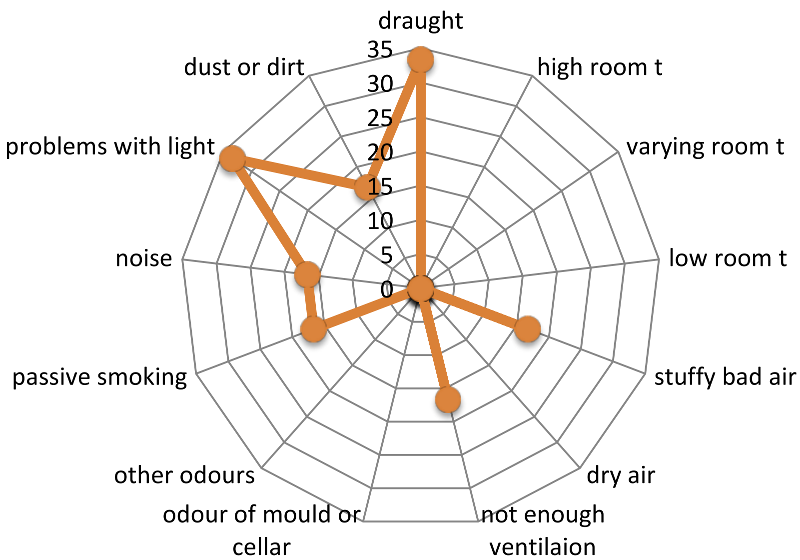


Figure 11. Work environment in rooms with air conditioner. Problems encountered every week or more often

Symptoms

A large number of occupants in this building feel unpleasant symptoms, which are, as they suppose, connected with the indoor climate (see Figures 12, 13, 14). The most often problems are fatigue and itching, burning or irritation in the eyes. The fatigue may be the result of high CO_2 level and too high temperature and itching, burning or irritation in the eyes means that the quality of air is not very good. These all may be connected to the problems with ventilation.

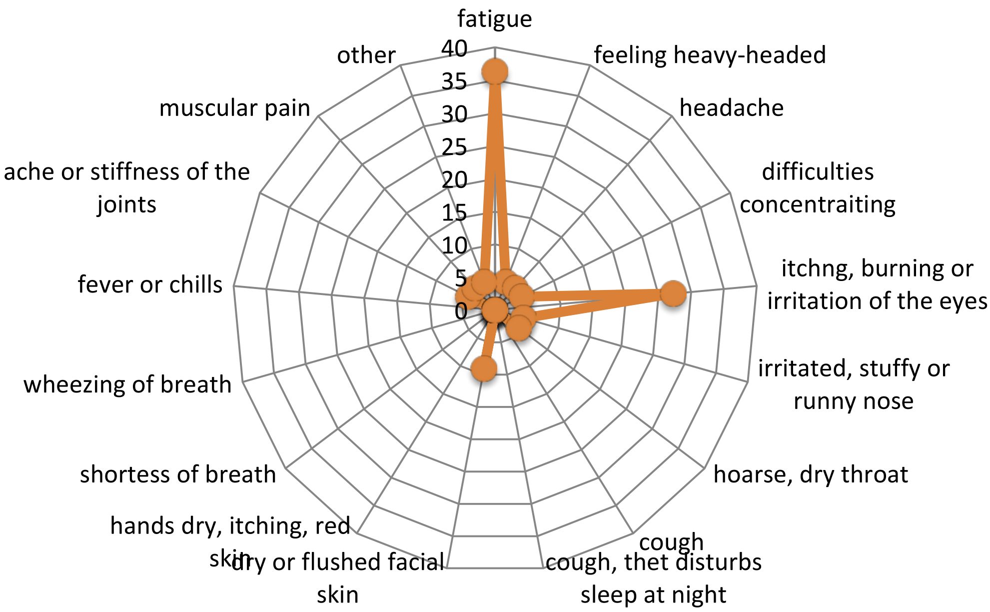


Figure 12. Unpleasant sympthoms felt by people (all rooms) . Problems encountered every week or more often

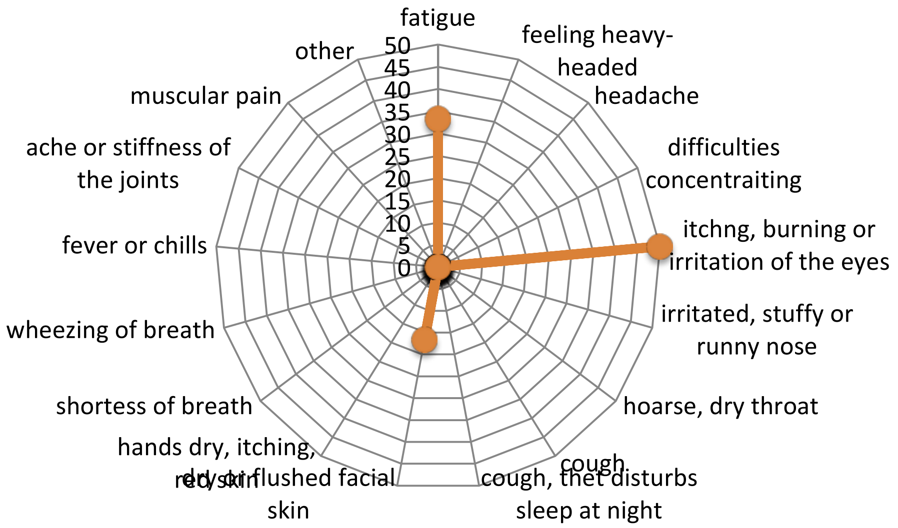


Figure 13. Symptoms felt by people in rooms with air conditioner. Problems encountered every week or more often

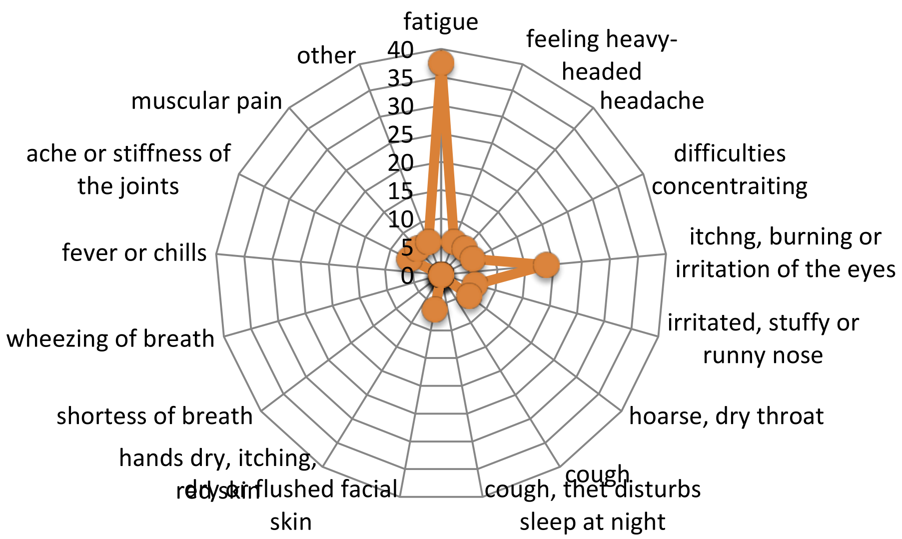


Figure 14. Symptoms felt by people in rooms without air conditioner. Problems encountered every week or more often

4. CASE 2. ADMINISTRATIVE BUILDING WITH NATURAL VENTILATION IN MIKKELI, FINLAND

4.1. Description of the building

4.1.1. Construction

The second case is a hospital administrative building in Mikkeli (shown in Figure 15). In this building there are some administrative offices for example accounts department, a few rooms for patients and doctors. There are also some rooms on the 3rd floor, where the some of the staff live. This building is situated in south Mikkeli. It was built in the 1962. It is made of concrete and has 3 floors. The height of each stage is 2,55m. The walls between the rooms are also made of concrete. The corridors are situated in the center of floors and rooms are on the both sides of them.

The average floor area of office rooms is 12 m^2. Windows are not very big. They are made from glass packs. In one room there is 1 or 2 office desks. On the first floor there is a large room for customers, where can be three or four office desks. Most of rooms have printers or copy machines inside them. The balconies are situated near the stairs.

Figure 15. Hospital administrative building.

4.1.2. Ventilation

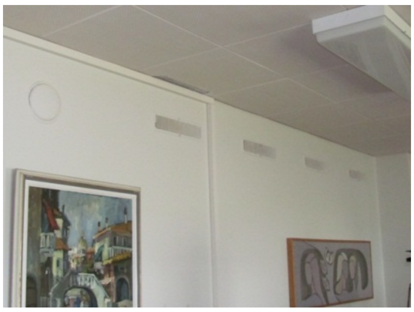
In the past the building had mechanical supply and exhaust ventilation on the first floor and mechanical exhaust ventilation in all other rooms. The fan, which provides ventilation, is located on the attic (Figure 16). In the past it was controlled distantly, but nowadays this system (Figures 17 and 18) does not work.

Figure 16. Fan on the attic.

Figure 17. Distantly controlling system.

Figure 18. Distantly controlling system.

There are 4 exhaust and 2 supply main ducts moving air from this unit to the building. However, it is not used at all for some reasons. Supply ventilation does not work in correct way (it is shown in the results) and exhaust ventilation is switched off because of complaints of staff. The problem is low temperature and draughts, caused by mechanical exhaust ventilation.



Figures 19 and 20. Ventilation devices on the 2nd and 1st floors.

4.1.3. Occupants

The number of people, working in this building, is about 20 persons. They are mostly administrative workers, staff and also some doctors. Some of them have irregular working hours, but most work from 8:00 till 16:00. Most of them spend all their work time in the office.

4.2. Methods

4.2.1. Measurements

Measurements were done during two weeks: the first week the fan, which provides mechanical exhaust ventilation, was switched off and the second week it was switched on. Measurements included: temperature, humidity and CO_2 level monitoring during the week; instantaneous measurements of air flow and draft rate. Temperature, humidity and CO_2 level monitoring was made twice, each time was 7 days long. Air flow rate and draft rate were measured also when the fan was switched on.

The temperature, humidity and CO_2 level monitoring were performed from 11.30 27.09.2011 till 11.10 04.10.2011 (fan switched off) and from 11.10 04.10.2011 till 11.30 13.10.2011 (fan switched on). Values of temperature and relative humidity were measured in two rooms and outside. Rooms were situated on the first floor (room 1) and on the second floor (room 2). The room 1 is on the Figure 21 and the room 2 is on the Figure 22. The first one was the room for customers with area about 30 m^2 and 3 workplaces and the second one was an office room with area about 10 m^2 and one workplace. The room 1 has both supply and exhaust ducts and the room 2 has only exhaust ducts. Outside measurements were done on the balcony near the stair. CO_2 level monitoring was performed only in room 2 on the second floor. Air flow rate and draft rate were measured on the 13.10.2011 in the same rooms.

Figure 21. Room 1.

Figure 22. Room 2.

Temperature and humidity were measured by data loggers (Ebro). Loggers were put at the work tables. The limits of measuring conditions for this type of devices are: from -30°C to +60°C and from 0 to 100% rH. The accuracy is ±0,5 °C and ±0,5% rh. CO_2 level was measured by TSI instruments HP12 3RT. The accuracy is 5 ppm. It was installed at the height of 1,7 m. Draft rate and air flow rate was measured by Swema air 300. Draft rate was measured at the level of 1,7 m. Air flow rate measurement in room 1 is shown in the Figure 23.

Figure 23. Air flow rate measurement in the room 1.

4.3.Results

4.3.1. Temperature measurements with switched off fan

The temperature measurements (Figure 24), were made from 11.30 27.09.2011 till 11.10 04.10.2011 in room 1 which is situated on the first floor. The fan (and so the mechanical ventilation) was switched off during this period. Figure 24 has several lines: temperature line and limits: at 22˚C and at 24˚C. These limits are based on the calculating percent of dissatisfied persons in several conditions. When the temperature changes between 22˚C and at 24˚C there will be 10% of dissatisfied persons, if the metabolic efficiency is about 1-1,2 met = 105 - 125 W(office working) and insulation in clothing is between 1-1,2 clo (inside clothing). Outside temperature during this period is shown on the Figure 24.

Inside temperature during this period varied between 20.6 and 22.3 ˚C, which is mostly under the lowest limit of comfortable temperature (22 ˚C). During the day long temperature graphic has a form of hill. The reason for it not only rising outside temperature (illustrated by Figure 25, more detailed in Appendix 9), but also heat from people and devices inside the room. (Extremely hot outside temperatures on the picture are not actual. They are accounted by direct sun light at the location, where the instrument was.) The top of «hill» corresponds to the middle of the work time between 11:00 and 13:00 and has values of temperature between 21.8 and 22.3 ˚C. There are no "hills" on the 1st and 2nd of November, because it was holidays and there was nobody inside the room. You can find a more detailed in Appendix 3.

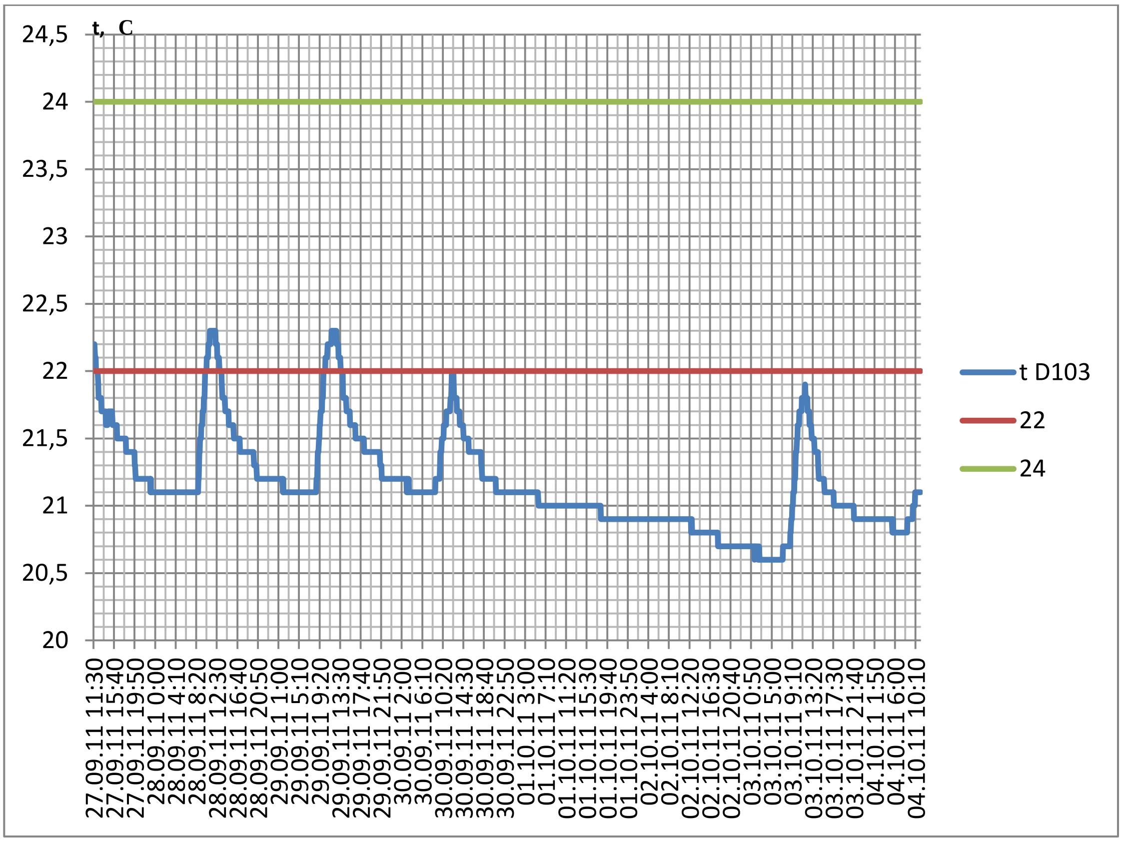


Figure 24. Inside temperature in room 1 from 11.30 27.09.2011 till 11.10 04.10.2011 (fan switched off).

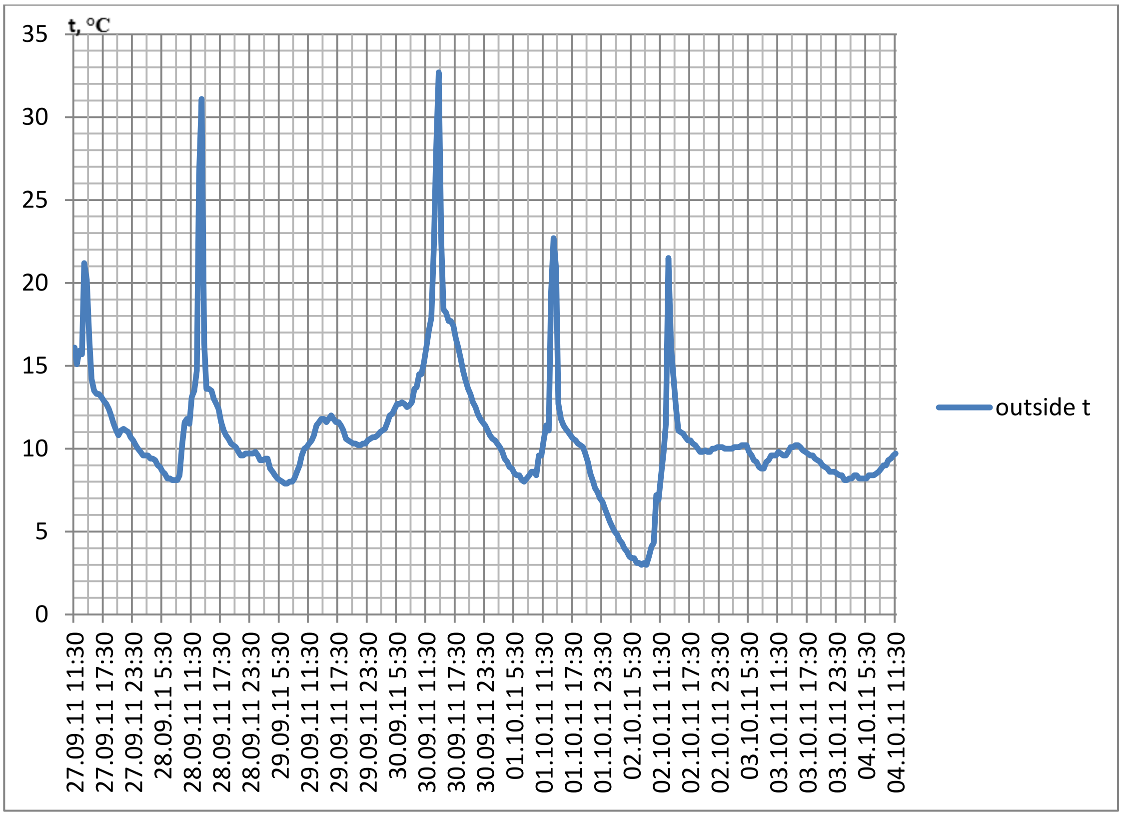


Figure 25. Outside temperature from 11.30 27.09.2011 till 11.10 04.10.2011 (fan switched off).

The inside relative humidity is illustrated in Figure 26. There is no Finnish requirement for humidity, but in any case it does not amount to the uncomfortable for human level.

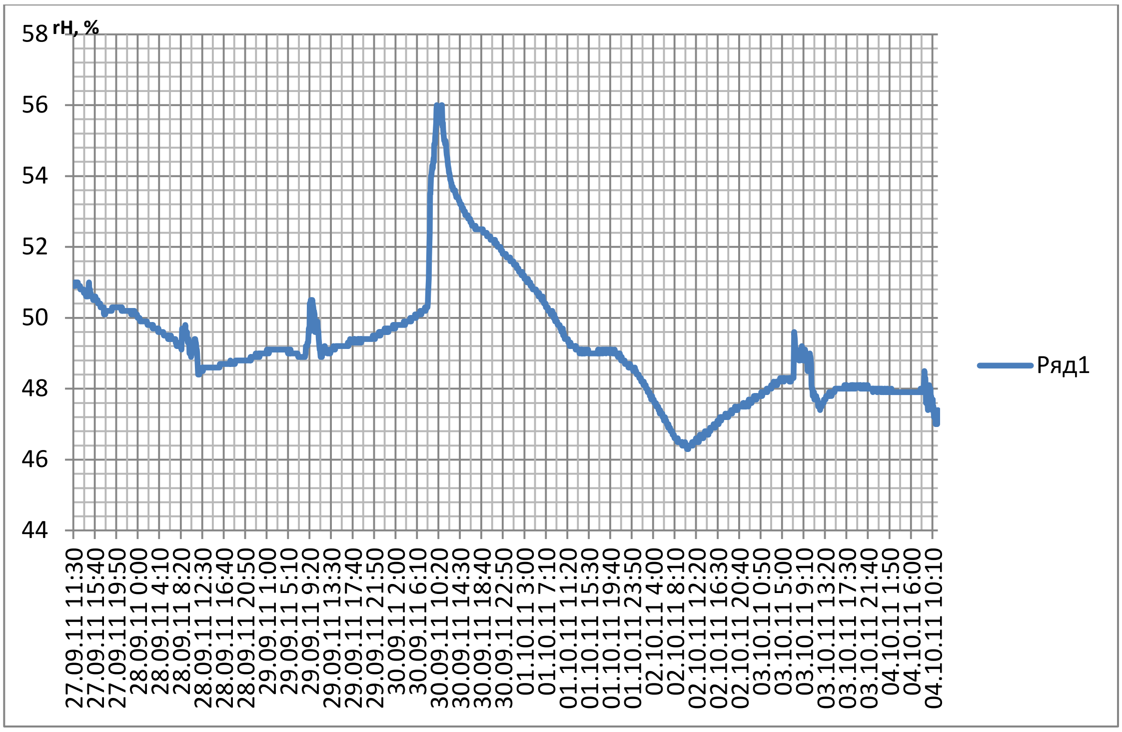


Figure 26. Relative humidity in room 1 from 11.30 27.09.2011 till 11.10 04.10.2011 (fan switched off).

The temperature measurements, which you can see in Figure 27, were made during the same period and in the same conditions in the room 2 which is situated on the second floor. Comparing these results with measurements, which were made in the room 1, it could be noticed that during the whole measurement period inside temperature met the requirements. The reason for it is that the room 2 is situated upper, than room 1, it is also smaller and has not got so big windows, as the second one. The other reason is that D103 has some space for customers and also has an extra door, which is situated near the entrance door. When the customers come in some extra cold air from outside got into the room and decrease the temperature of indoor air. The whole character of graphic is the same as in the room downstairs. Humidity measurement results show also the middle values and could be found on Figure 28. You can find a more detailed diagrams in Appendix 4.

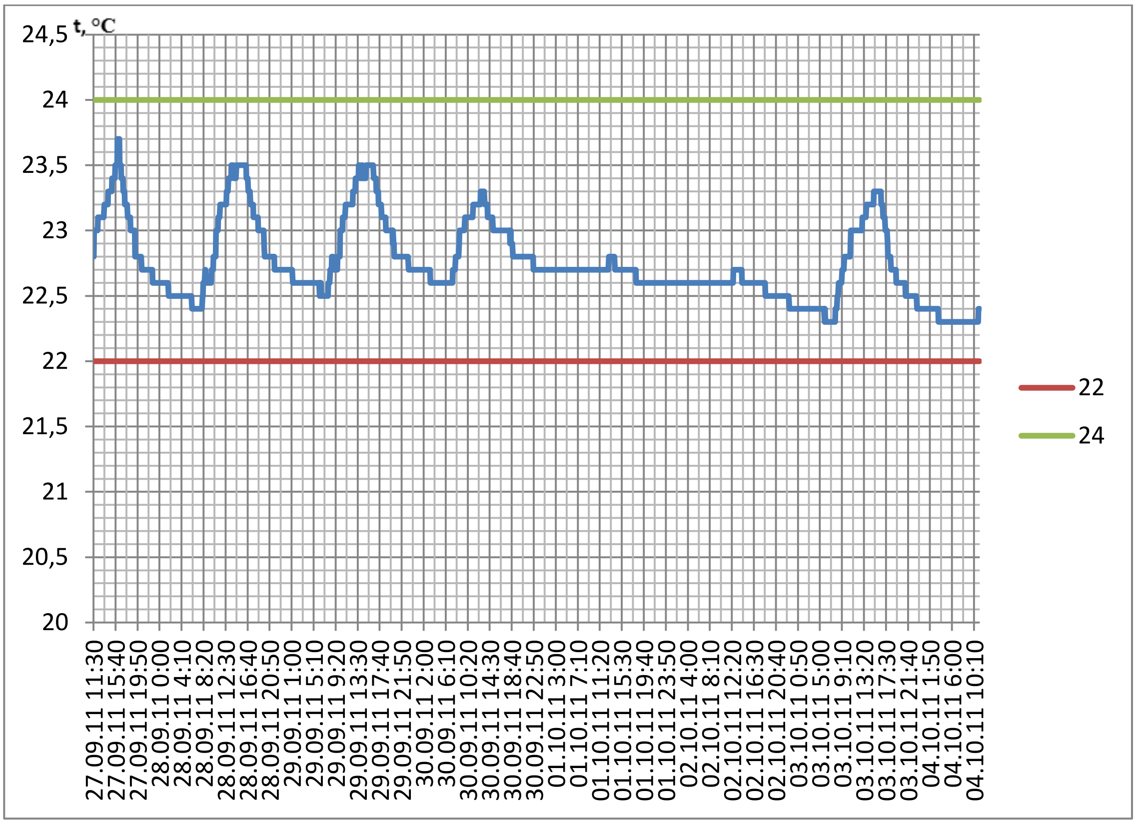


Figure 27. Inside temperature in room 2 from 11.30 27.09.2011 till 11.10 04.10.2011 (fan switched off).

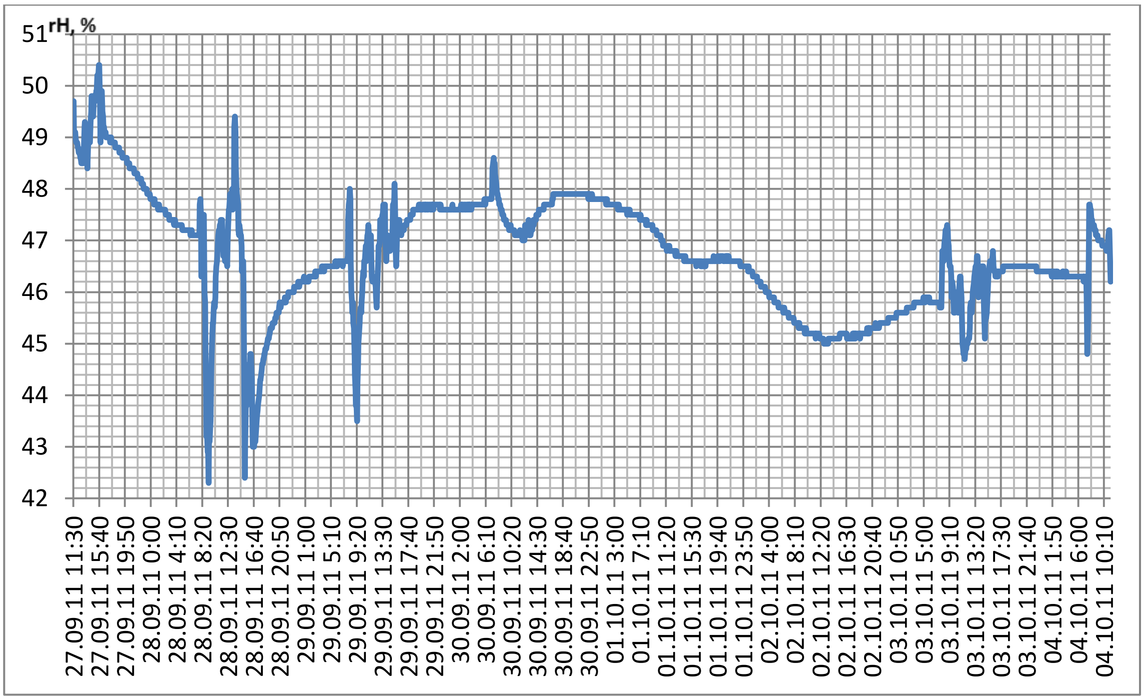


Figure 28. Relative humidity in room 2 from 11.30 27.09.2011 till 11.10 04.10.2011 (fan switched off).

4.3.2. Temperature measurements with switched on fan

The temperature measurements, which you can see in the Figure 29, were made from 11.10 04.10.2011 till 11.30 11.10.2011 in the room No 103, which is situated on the first floor. The fan (and so the mechanical ventilation) was switched on in this case. On the Figure there are several lines: temperature line and limits: at 22˚C and at 24˚C. They are the same as in the previous case. Outside temperature during this period is shown in the Figure 30.

Inside temperature during the most part of this period was changing between 19 and 21 ˚C, which is at the lower end of comfortable temperature (22 ˚C). It can be explained in the following way. As it is shown in the next section, the supply air flow rate is lower, than exhaust air flow rate, so there is underpressure in the room (comparing to the outside pressure). As a result of it, the outside fresh air comes into the room through leakages and through the door, leading to the hall, where is rather cold because of the entrance door. During the day temperature graphic has formed a "hill", as in the previous case, but these "hills" are not so high as "hills" with switched off fan, because exhaust ventilation leads to more effective mixing of internal and external (outside and in cold hall) air. The other reasons (heat loads from people and devices, outside temperature), that were illustrated in the previous section are also existing here. The graphic of outside temperature you can see in the Figure 30 (more detailed in Appendix 10), (the extremely hot temperatures in the middle of days are also inaccuracies, caused by location of measuring device in direct sun light). You can find a more detailed diagrams in Appendix 6.

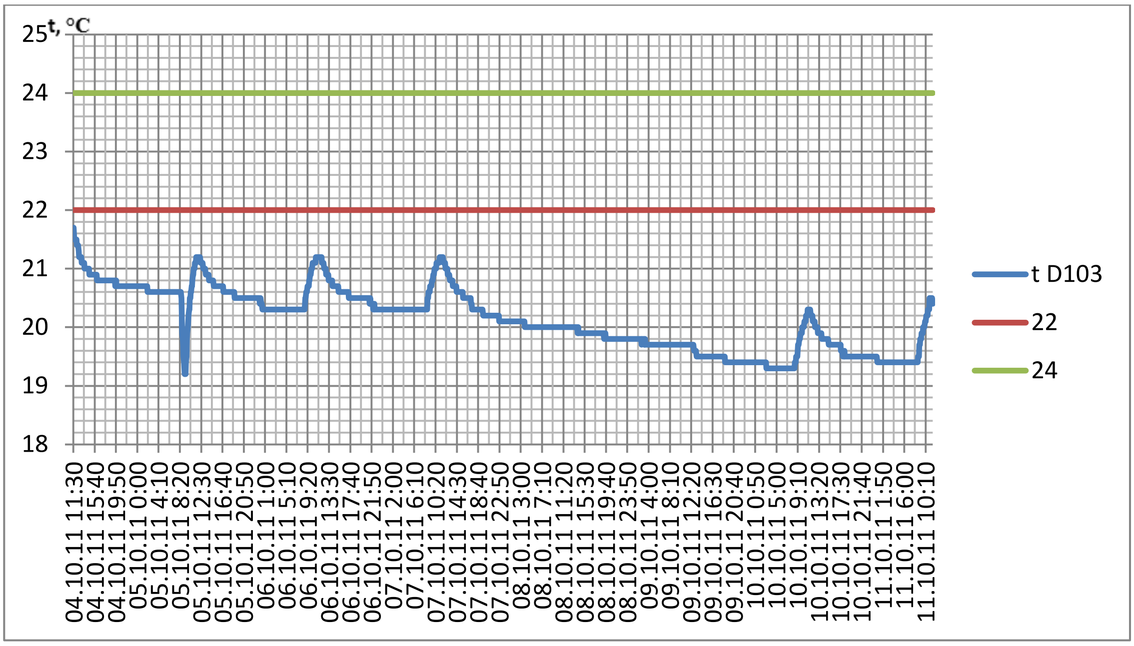


Figure 29. Inside temperature in room 1 from 11.10 04.10.2011 till 11.30 13.10.2011 (fan switched on).

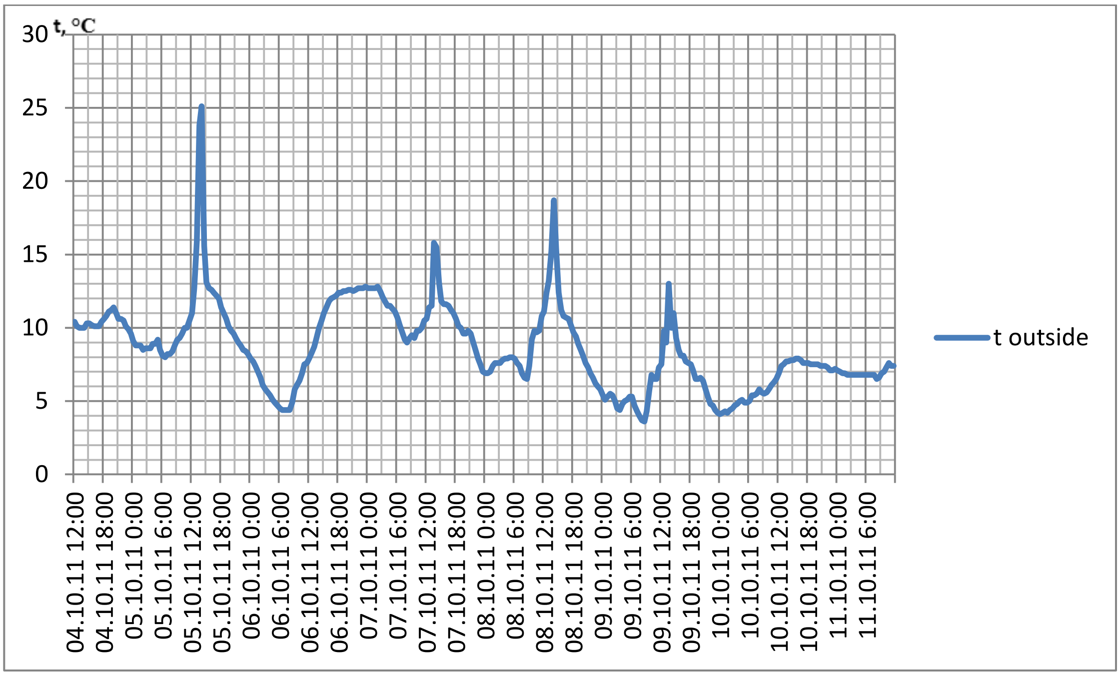


Figure 30. Outside temperature from 11.10 04.10.2011 till 11.30 13.10.2011 (fan switched on).

The inside and outside relative humidity are illustrated by Figures 31 and 32. Their graphics have mostly the same character, but the values of inside humidity are lower. This can be explained by Mollier diagram (Figure 33). When the outside air (f.e. 06.11.2011 20:00; 12,6 ˚C; 97,9% rH) after getting inside is heated to the temperature of 20,5 ˚C it’s relative humidity decreases to the 58 %. This process is illustrated on the Figure 33. On the Figure 31 there is an another value of relative humidity at the end of the process, but this inaccuracy can be explained by moving air inside the room, uneven air heating and unknown temperature on which air is expected to be heated (only temperature of air in fixed point is known, near radiators, for example, it’s another).

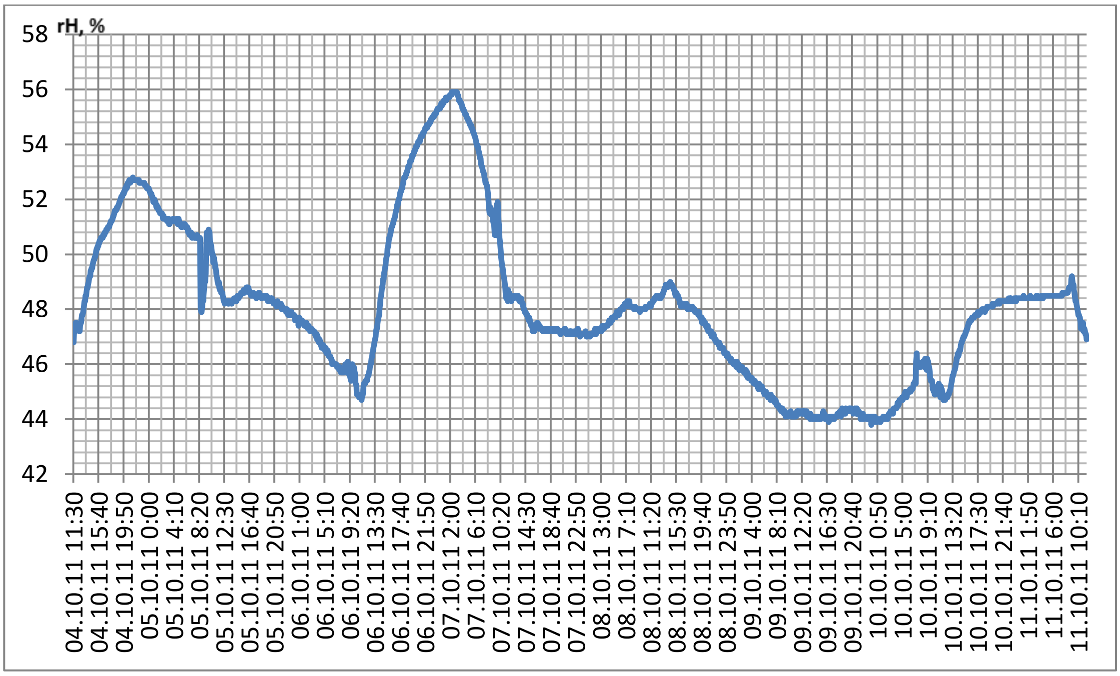


Figure 31. Relative humidity in room 1 from 11.10 04.10.2011 till 11.30 13.10.2011(fan switched on).

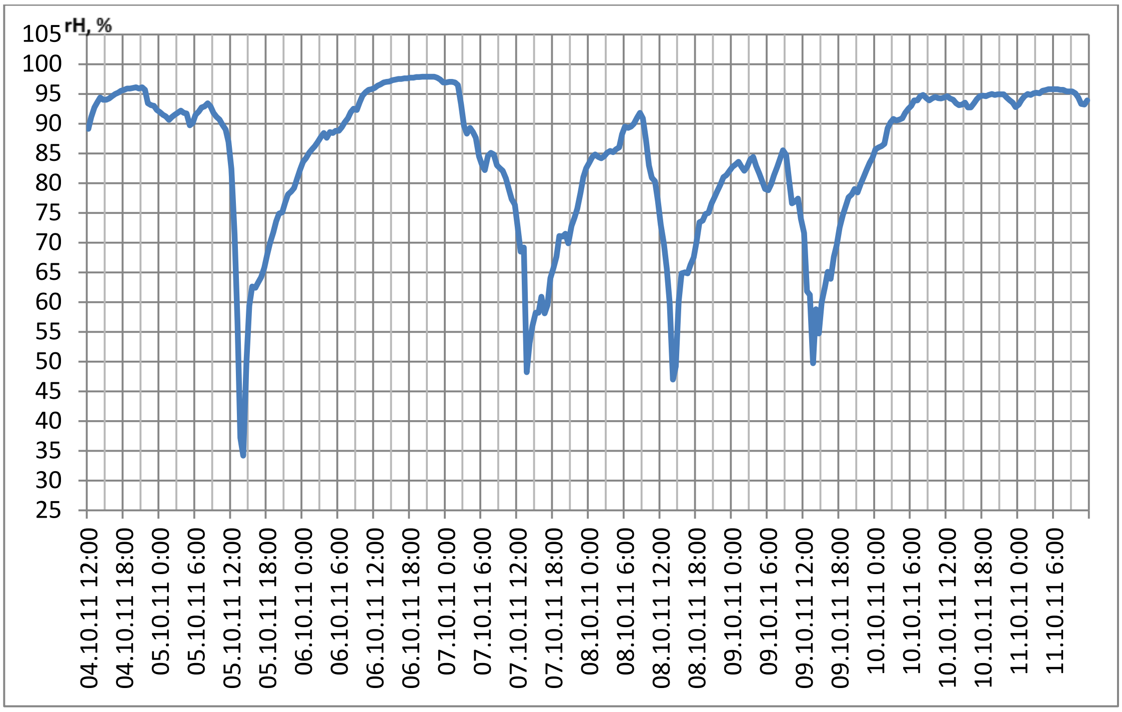


Figure 32. Outside relative humidity from 11.10 04.10.2011 till 11.30 13.10.2011.

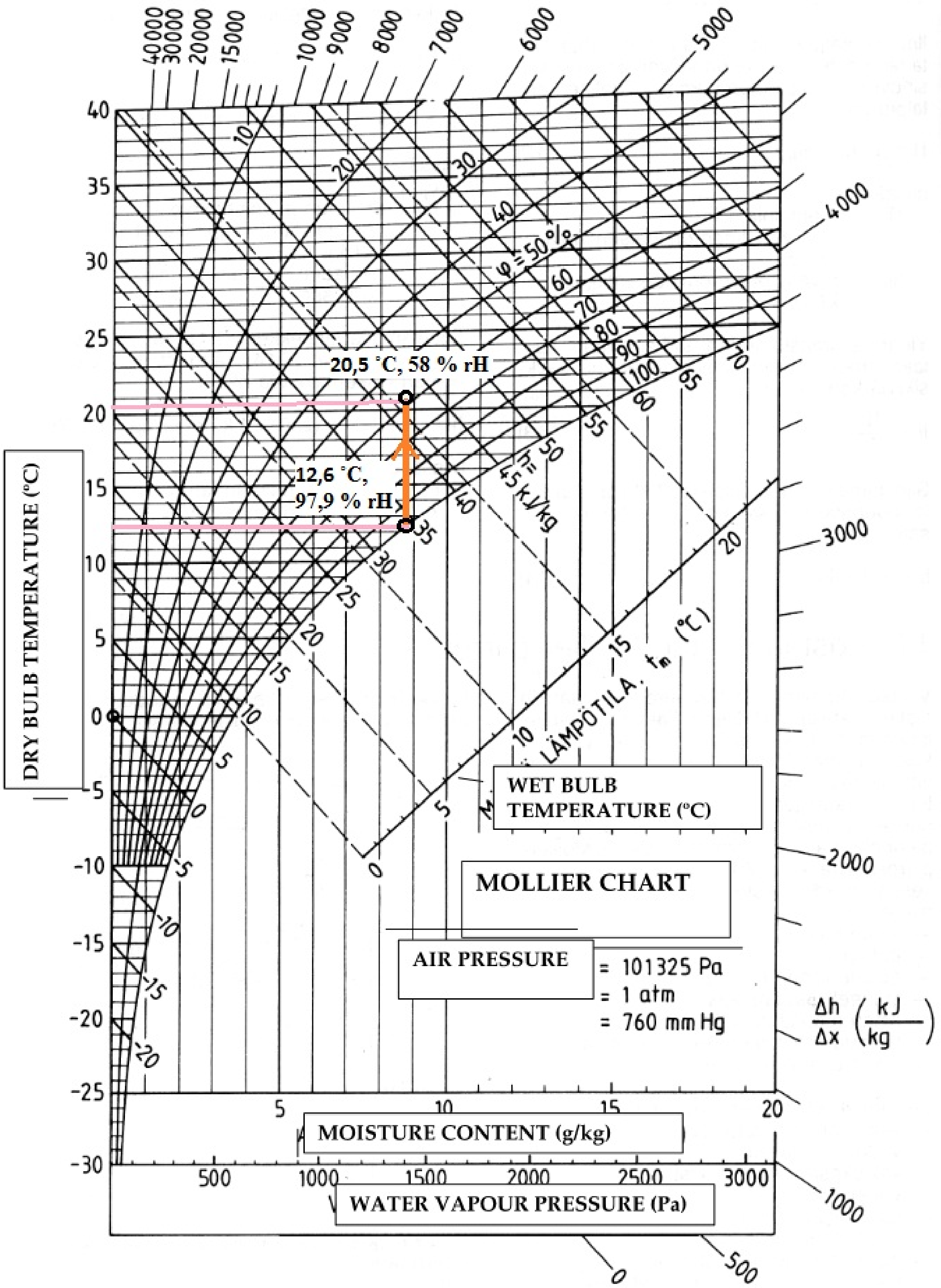


Figure 33. Mollier diagram with process of decreasing humidity inside the building.

The temperature measurements, which you can see on the Figure 34, were made during the same period and in the same conditions in the room 2 which is situated on the second floor. On this graphic temperature decreases from 23 ˚C to 20 ˚C. This is also higher, than in the room downstairs, but this temperature is not very comfortable. It does not meet requirements even in spite of heating of the room was increased after complaints on the low temperature from occupants of the room. But the temperature was not very low, so these complaints might be cause by draught (at the low temperatures draught is felt better). About the draught rate will be the section below. You can find a more detailed diagrams in Appendix 7.

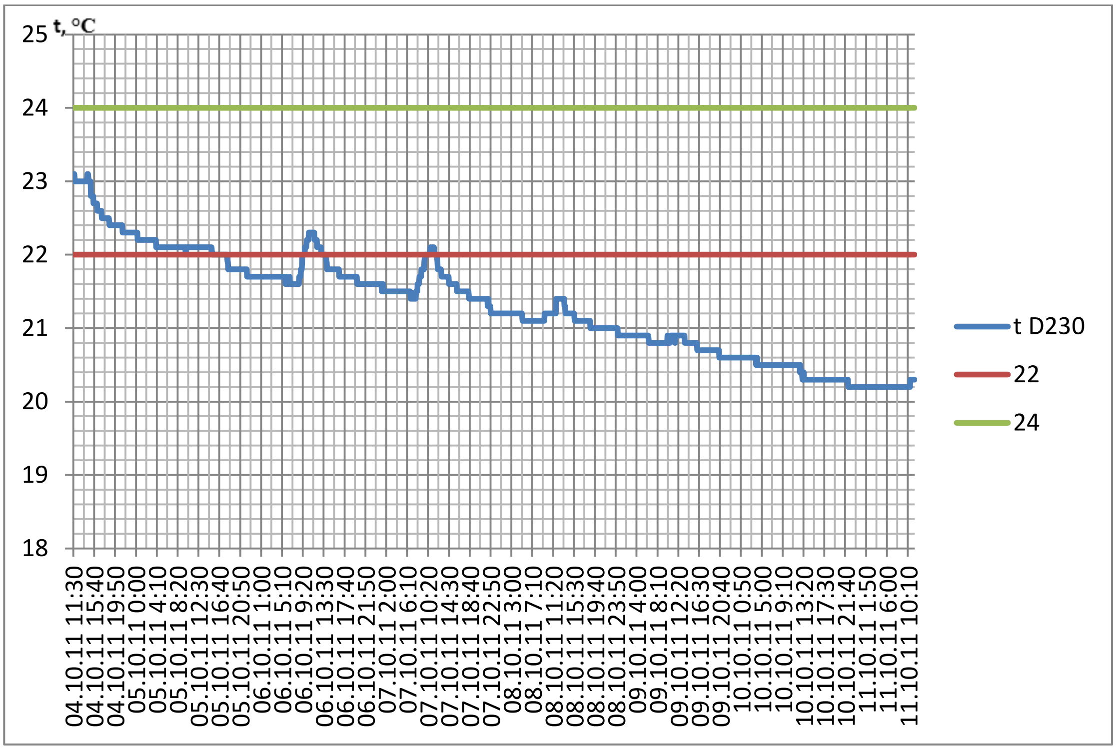


Figure 34. Inside temperature in room 2 from 11.10 04.10.2011 till 11.30 13.10.2011 (fan switched on).

The same as in the room 1could be said about relative humidity in the room 2. It is lower than outside relative humidity because of heating the air (Figure 35).

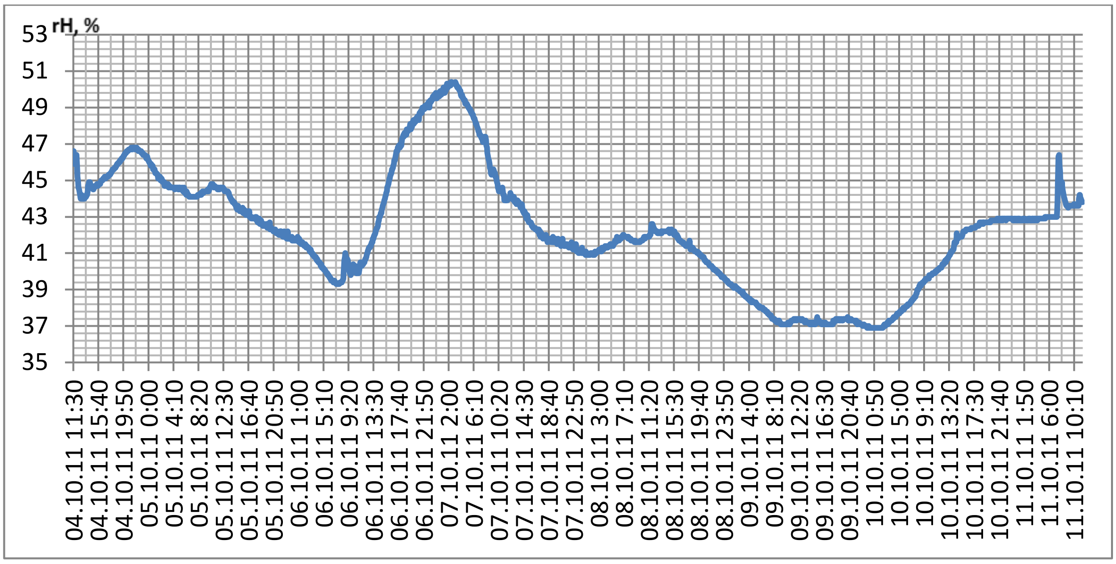


Figure 35. Relative humidity in room 2 from 11.10 04.10.2011 till 11.30 13.10.2011(fan switched on).

4.3.3. CO_2 concentrations

CO_2 concentration from 11.30 27.09.2011 till 11.10 04.10.2011 (fan switched off) in the room 2 is shown on the Figure 36 (more detailed in Appendix 5).

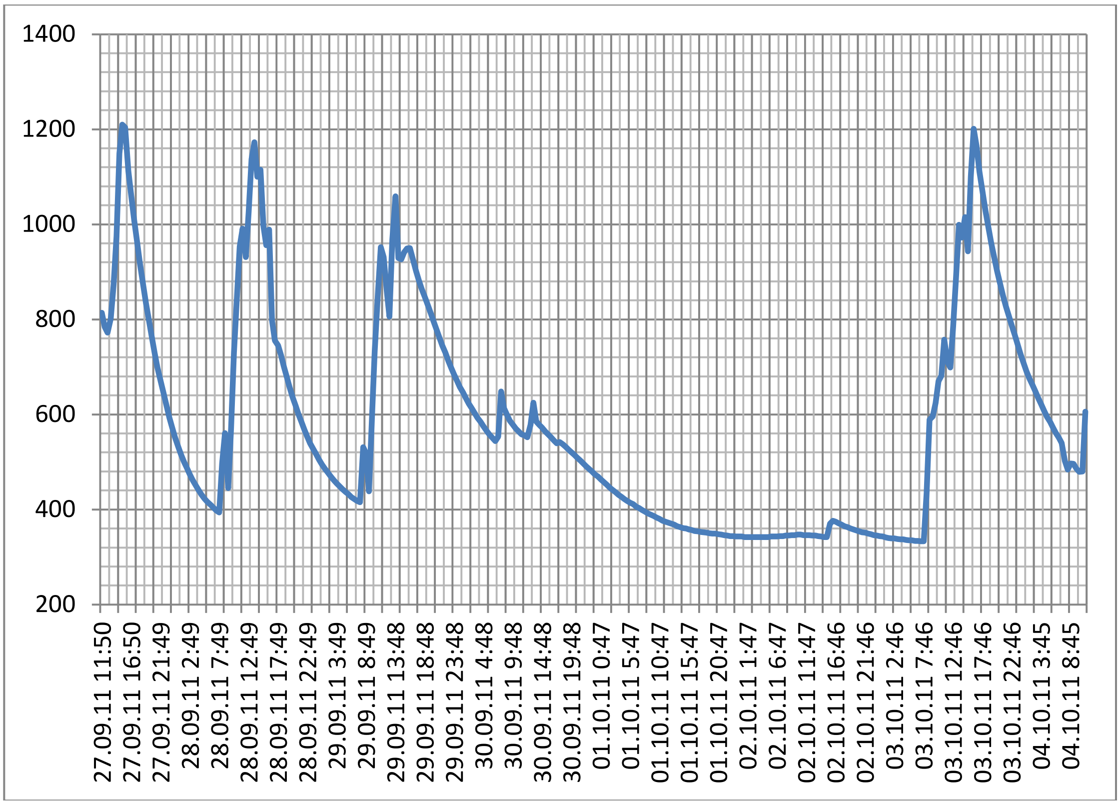


Figure 36. CO_2 level from 11.30 27.09.2011 till 11.10 04.10.2011 (fan switched off) in the room 2.

According to the D2 /6/, the maximum CO_2 level is 1200 ppm. As we can see in the Figure 36 in the middle of the day CO_2 level is close or higher than this value. It is so in spite of the occupants of this room often open the door, because they feel that the air is stuffy. The maximum CO_2 level was 27.09.2011 at 15:20 and was 1210 ppm. So, the real problem with CO_2 level is detected in room 2.

Changing of CO_2 level from 11.10 04.10.2011 till 11.30 11.10.2011 (fan switched on) in the room 2 is shown in the Figure 37 (more detailed in Appendix 8). During this period CO_2 level does not exceed 550 ppm. As the result of the exhaust ventilation without supply ventilation (described in 4.3.5 Air flow measurements) the room becomes underpressured compared to the outside pressure. Outdoor air comes through the leakages and some air comes from corridor, which cause reducing of CO_2 level. According to the requirements of "Classification of indoor climate 2008" /7/ this room is in category S1 (concentration of CO_2 level lower than 750 ppm). Consequently, it can be noticed, that exhaust ventilation in this building can solve the problem with CO_2 level.

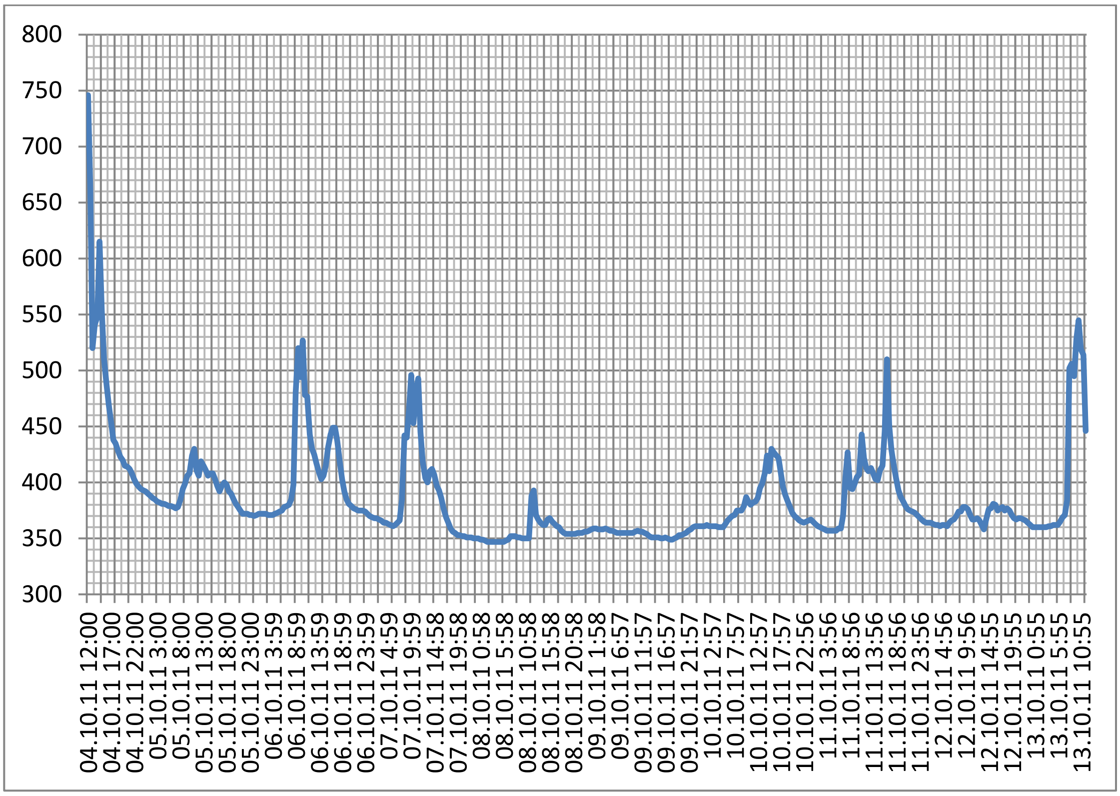


Figure 37. CO_2 level from 11.10 04.10.2011 till 11.30 11.10.2011 (fan switched on) in the room 2.

4.3.4. Draft rates

Draft rate measurements were made on the 11.10.2011 at 11.40. In the room 1 it was 14% and in the room 2 - 9%. These values are normal. For example, according to the European Committee for standardization /15/ this draft rate (<15%) will cause 6% of dissatisfied (the lowest percentage) and corresponds to the category A.

4.3.5. Air flow rates

Air flow rate measurements were made on the 11.10.2011 at 12.00. In the room 1 there were 3 exhaust ducts and 4 supply ducts. But not all of them were functioning in the correct way. In the room 2 there were only 2 exhaust ducts. The results are summarized in the Table 6.

Table 6. Air flow rates in ventilation ducts.

	No. of duct	Air flow rate, dm^3/s, room 1	Air flow rate, dm^3/s, room 2
exhaust	1	14,5	2,7
	2	24,4	4,7
	3	0	-
supply	1	0	-
	2	5,7	-
	3	0	-
	4	0	-

According to the “D2. Table1” /6/, supply air flow rate should be at least 8 dm^3/s per person – so it should be at least 24 dm^3/s if we have 3 persons in this room. There is only 5,7 dm^3/s and it does not meet the requirements. In the same time exhaust air flow rate is (24,4+14,5)=38,9 dm^3/s, which mean that the room is under pressured and outdoor air comes from leakages to compensate under pressure. This leads to the decreasing of temperature inside and demands more heating power. The same situation is in the room 2. There is only exhaust ventilation that cause underpressure concerning to the outside pressure and moves the outside air through the leakages to the room. During the autumn it does not cause big problems with inside temperature, but in winter, when the temperatures become lower, this ventilation type will strongly increase heating demands, reduce energy efficiency of building and create some draughts.

5. CASE 3. OFFICE BUILDING WITH MECHANICAL SUPPLY AND EXHAUST VENTILATION IN MIKKELI (FINLAND)

5.1. Description of the building

5.1.1. Construction

The third case is an office building in Mikkeli (Figure 38). This building has office rooms, classrooms, rooms for staff, restaurant, etc.

This building is situated near the center of Mikkeli. It was built in 2011. It is made of concrete, metal and glass and has 3 floors. The height of each floor is about 2,75m. The walls between the rooms are also made of concrete and plasterboard. The corridors are situated in the center of floors and rooms are on the both sides of them.

The average floor area of office rooms is 12 m^2. The windows take most part of the wall in office rooms. They are made from glass packs. In one room there is from 1 to 3 office desks. Most rooms have printers or copy machines inside them.

Figure 38. Office building (case 3).

5.1.2. Ventilation

The building has modern mechanical supply and exhaust ventilation system. The thermal conditions are controlled in most of rooms individually by using separate sensors and control boards in each room. In office rooms there is displacement supply ventilation through the special devices located in the ceiling.

Mechanical ventilation of the building brings air, which is heated to the 18 °C, to the rooms. There is also a cooling system, which works in summer. Cooling system is actuated by 4 compressors and works by a principle of refrigerator. The mechanical ventilation is equipped by a heat recovery system (rotating wheel type). The supply air flow rate to the whole building is 4355 dm^3/s, the exhaust air flow rate is 4365 dm^3/s.

5.1.3. Occupants

The number of people, working in this building, is about 50 persons. They are office, administrative workers, staff and teachers. Standard work hours are from 8:00 to 16:00, but most of office workers have irregular timetable. They do not spend all of the work time in their rooms.

5.2. Methods

5.2.1. Measurements

In this case the same measurements as in the hospital administrative building were made: temperature, humidity and CO_2 level monitoring during the week; air flow and draft rate measurement. Temperature, humidity and CO_2 level inside monitoring was made from 17.11.2011 17:00 to 24.11.2011 17:00. At the same period outside temperature monitoring was performed.

The inside measurements were made in room situated on the 1st floor. The area of it is about 12 m^2 and there is one office desk in it. The person, who is working in this room has variable schedule and does not spend all the day long inside this room. The room has extract air ducts on the ceiling and displacement supply ventilation also through the ceiling.

Temperature and humidity were measured by data loggers (Ebro). Devices were situated at the work tables. The limits of measuring conditions for this type of devices are: from -30°C to +60°C and from 0 to 100% rH. The accuracy is ±0,5 °C and ±0,5% rh. CO_2 level was measured by TSI instruments HP12 3RT England device. The accuracy is 5 ppm. It was installed at the height of 1,7 m. Draft rate and air flow rate was measured by Swema air 300. Draft rate was measured at the level of 1,7 m.

5.3. Results

5.3.1. Temperature and humidity

The temperature measurements, which you can see on the Figure 39 (more detailed in Appendix 11), were made from 17:00 17.11.2011 to 17:00 24.11.2011 inside the room which is situated on the first floor. The mechanical ventilation was switched on during this period. On the picture there are several lines: temperature line and limits – at 22˚C and at 24˚C. These limits are based on the calculating percent of dissatisfied persons in several conditions. When the temperature changes between 22˚C and at 24˚C there will be 10% of dissatisfied persons, if the metabolic efficiency is about 1-1,2 met = 105 - 125 W(office working) and insulation in clothing is between 1-1,2 clo (inside clothing). Changing of inside and outside temperature during this period is shown on the Figure 39.

Inside temperature during this period was changing between 19,9 and 21,7 ˚C, which is mostly under the lowest limit of comfortable temperature (22 ˚C). During the day long temperature graphic has a form of hill, but the amplitude of the temperature is small: maximum 2 ˚C. The inside temperature does not depend on outside temperature. The temperature in the room meets the requirements of /6/, /9/ and corresponds to the S3 category of /7/.

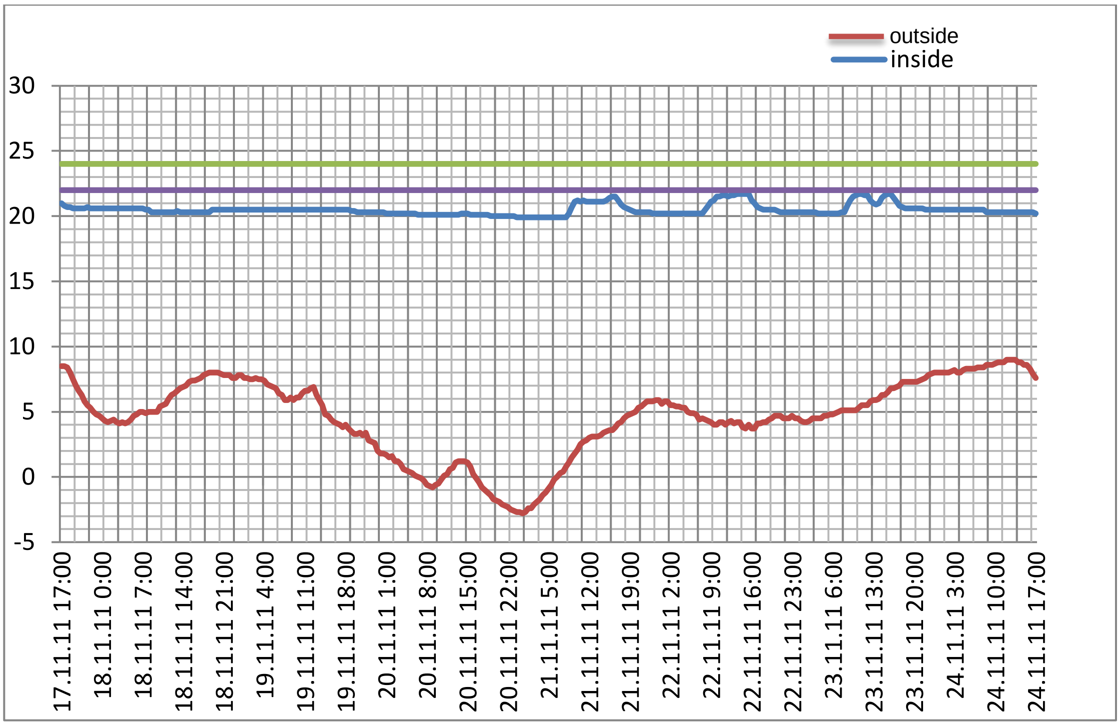


Figure 39. Inside and outside temperature from 17:00 17.11.2011 to 17:00 24.11.2011.

The inside and outside relative humidity is illustrated by Figure 40. Inside relative humidity is lower than outside but has the same character. There is no Finnish requirement for humidity, but according to Russian standards (/9/) it should be a bit less (30-45%).

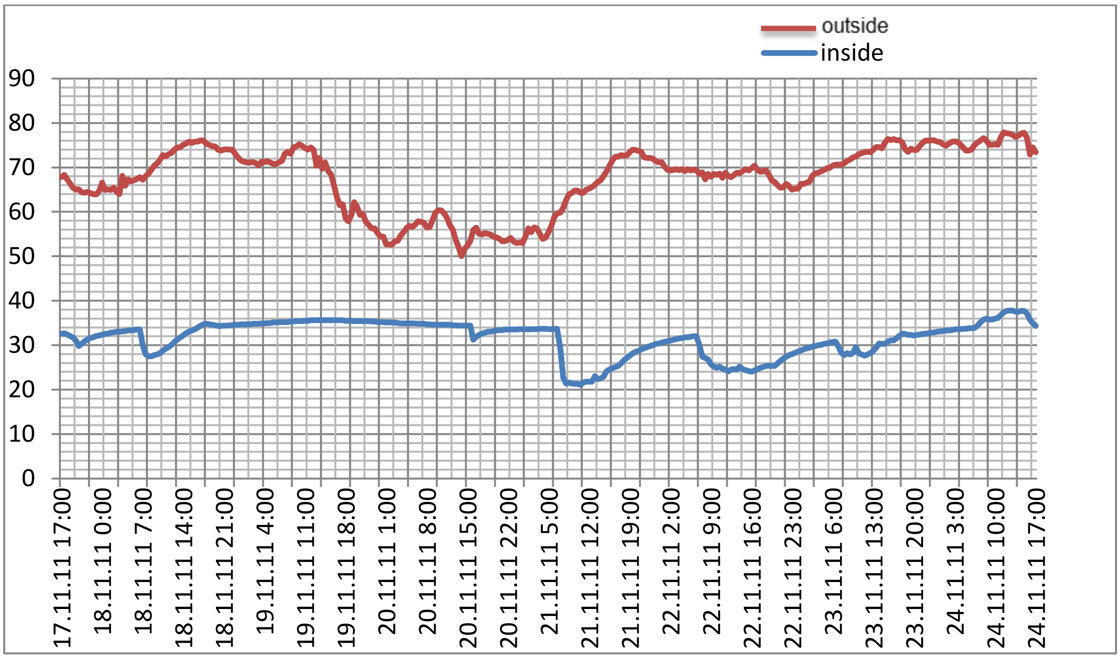


Figure 40. Inside and outside relative humidity from 17:00 17.11.2011 to 17:00 24.11.2011.

5.3.2. CO_2 concentrations

CO_2 concentration from 17:00 17.11.2011 to 17:00 24.11.2011 in the room is shown on the Figure 41 (more detailed in Appendix 12).

According to the D2 the maximum CO_2 level is 1200 ppm. As we can see on the Figure 41 in the middle of the work day CO_2 level does not exceed 600 ppm. So there is no problem with CO_2 level in this room.

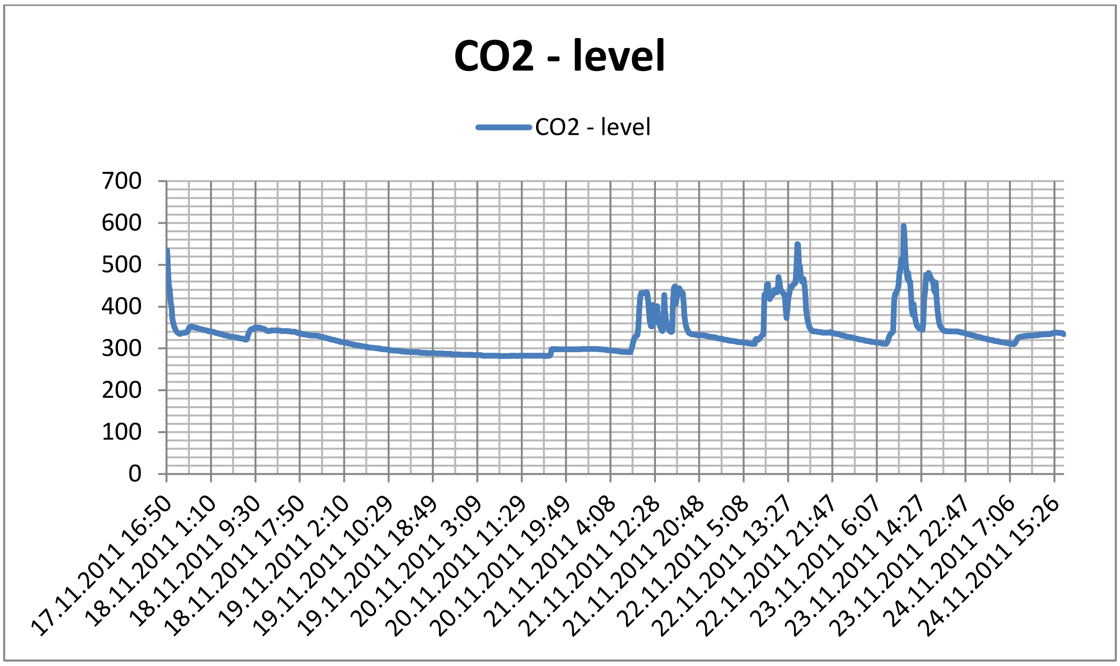


Figure 41. CO_2 level from 17:00 17.11.2011 to 17:00 24.11.2011 in the room.

5.3.3. Draft rates

Draft rate measurements were made on the 17.11.2011 at 17.30. Draft rate in the investigated room was 8% when the temperature was 21,1 ˚C and the air velocity 0,084 m/s. Comparing these values with /6/, /7/, /9/ requirements the following conclusion could be founded: the values meet all of requirements. Air moving does not disturbs thermal comfort of occupants.

5.3.4. Air flow rates

The supply air flow rate to the room is 50 dm^3/s and exhaust air floor rate is 50 dm^3/s. This value meets all discussed requirements (/6/, /7/, /10/).

6. COMPARISON OF CASE STUDY BUILDINGS

The comparison of measurement results for different ventilation systems is presented in the Table 7. The results for natural ventilation system in summer period corresponds to the case 1 (Chapter 3), the results for natural ventilation system in autumn period – to the case 2 with switched off fan (Chapter 4), mechanical exhaust ventilation system – to the case 2 with switched on fan (Chapter 4) and mechanical exhaust and supply ventilation system – to the case 3 (Chapter 5).

Table 7. Comparison of different ventilation systems. The measurement data is based on the three case study buildings

	Natural ventilation (summer period)	*Natural ventilation (autumn period)*	*Mechanical exhaust ventilation*	*Mechanical exhaust and supply (with heat recovery)*
Temperature level, indoors	17,1 – 32,3 ˚C	20,6 – 22,3 ˚C	20,2 – 23,1 ˚C	19,9 – 21,7 ˚C
Temperature level, outdoors	17,5 – 31 ˚C	3 – 15 ˚C	3 – 15 ˚C	-3 – 9˚C
Temperature fluctuations indoors during the work day	10 ˚C	1,2 ˚C	0,6 ˚C	0,5 ˚C
Humidity	No data available	46,6 – 56,9 % rH	50,4 – 36,9 % rH	21,6 – 37,7 % rH
CO_2 level	No data available	400 – 1200 ppm	350 – 520 ppm	300 – 590 ppm
Draft rate	-	-	9%	8%
Air flow rate	-	-	7,4 dm^3/s per room	50 dm^3/s per room

According to the Table 7, there are problems with temperature in natural ventilation system in summer period. In other systems the temperature level is adequate (according to /6/, /7/, /9/), but the most comfortable conditions provides mechanical exhaust and supply ventilation system. It also has the minimum variability of temperature. Mechanical exhaust ventilation shows also good results, but it is not energy efficient because the system has no heat recovery unit.

Finnish requirements /6/, /7/ has no regulations for humidity level. In this case the rH level is not critical low, but during designing this kind of ventilation system the question of humidity should be took into account. In spite of absence requirements about humidity, the author of this thesis supposes, that too low level of relative humidity may cause discomfort.

Problems with CO_2 level were noticed in natural ventilation system. According to /6/ the CO_2 level should not exceed 1200 ppm. Any kind of mechanical ventilation solves this problem. Draft, caused by mechanical ventilation is characterised by draft rate. The level of draft rate does not produce any problems in the studied buildings that were equipped with mechanical ventilation.

7. CONCLUSION

According to the comparison, there are problems with temperature in natural ventilation system in summer period. In other systems the temperature level is adequate (according to /6/, /7/, /9/), but the most comfortable conditions provides mechanical exhaust and supply ventilation system. It also has the minimum variability of temperature. Mechanical exhaust ventilation shows also good results, but it is not energy efficient because the system has no heat recovery unit.

Finnish requirements /6/, /7/ has no regulations for humidity level. In this case the rH level is not critical low, but during designing this kind of ventilation system the question of humidity should be took into account. In spite of absence requirements about humidity, the author of this thesis supposes, that too low level of relative humidity may cause discomfort.

Problems with CO_2 level were noticed in natural ventilation system. According to /6/ the CO_2 level should not exceed 1200 ppm. Any kind of mechanical ventilation solves this problem. Draft, caused by mechanical ventilation is characterised by draft rate. The level of draft rate does not produce any problems in the studied buildings that were equipped with mechanical ventilation.

On the base of results analyzing the following conclusions were made:

- Natural ventilation systems do not provide proper temperature (in summer) and CO_2 level
- Mechanical exhaust ventilation systems provides good thermal conditions but are not energy efficient
- Mechanical exhaust and supply ventilation systems provide the most comfortable conditions. In spite of this, when designing these systems, the minimum humidity level should be calculated.

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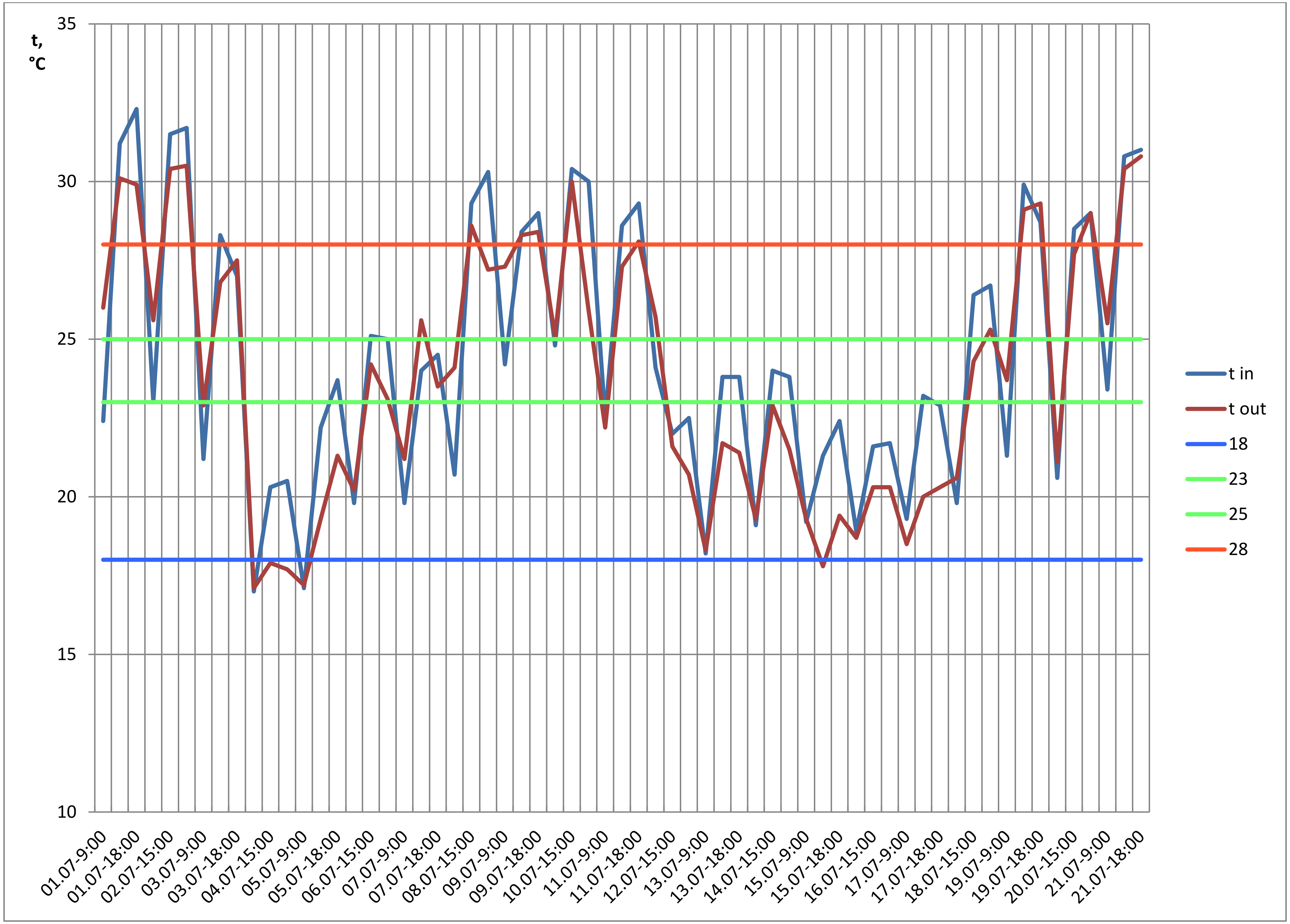
APPENDIX 1. TEMPERATURE MEASUREMENTS FOR CASE 1 (DURING 21 DAYS)

date	time	t inside	t outside
01.07-9:00	9:00	22,4	26
01.07-15:00	15:00	31,2	30,1
01.07-18:00	18:00	32,3	29,9
02.07-9:00	9:00	23	25,6
02.07-15:00	15:00	31,5	30,4
02.07-18:00	18:00	31,7	30,5
03.07-9:00	9:00	21,2	22,9
03.07-15:00	15:00	28,3	26,8
03.07-18:00	18:00	27	27,5
04.07-9:00	9:00	17	17,1
04.07-15:00	15:00	20,3	17,9
04.07-18:00	18:00	20,5	17,7
05.07-9:00	9:00	17,1	17,2
05.07-15:00	15:00	22,2	19,3
05.07-18:00	18:00	23,7	21,3
06.07-9:00	9:00	19,8	20,2
06.07-15:00	15:00	25,1	24,2
06.07-18:00	18:00	25	23,1
07.07-9:00	9:00	19,8	21,2
07.07-15:00	15:00	24	25,6
07.07-18:00	18:00	24,5	23,5
08.07-9:00	9:00	20,7	24,1
08.07-15:00	15:00	29,3	28,6
08.07-18:00	18:00	30,3	27,2
09.07-9:00	9:00	24,2	27,3
09.07-15:00	15:00	28,4	28,3
09.07-18:00	18:00	29	28,4
10.07-9:00	9:00	24,8	25,1
10.07-15:00	15:00	30,4	30
10.07-18:00	18:00	30	25,9
11.07-9:00	9:00	22,5	22,2
11.07-15:00	15:00	28,6	27,3
11.07-18:00	18:00	29,3	28,1
12.07-9:00	9:00	24,1	25,7
12.07-15:00	15:00	22	21,6
12.07-18:00	18:00	22,5	20,7
13.07-9:00	9:00	18,2	18,3
13.07-15:00	15:00	23,8	21,7
13.07-18:00	18:00	23,8	21,4
14.07-9:00	9:00	19,1	19,3
14.07-15:00	15:00	24	22,9

14.07-18:00	18:00	23,8	21,5
15.07-9:00	9:00	19,2	19,3
15.07-15:00	15:00	21,3	17,8
15.07-18:00	18:00	22,4	19,4
16.07-9:00	9:00	18,9	18,7
16.07-15:00	15:00	21,6	20,3
16.07-18:00	18:00	21,7	20,3
17.07-9:00	9:00	19,3	18,5
17.07-15:00	15:00	23,2	20
17.07-18:00	18:00	22,9	20,3
18.07-9:00	9:00	19,8	20,6
18.07-15:00	15:00	26,4	24,3
18.07-18:00	18:00	26,7	25,3
19.07-9:00	9:00	21,3	23,7
19.07-15:00	15:00	29,9	29,1
19.07-18:00	18:00	28,7	29,3
20.07-9:00	9:00	20,6	21,1
20.07-15:00	15:00	28,5	27,7
20.07-18:00	18:00	29	29
21.07-9:00	9:00	23,4	25,5
21.07-15:00	15:00	30,8	30,4
21.07-18:00	18:00	31	30,8

optimal	possible		too hot/cold	
23-25	25-28	18-23	>28	<18



t, °C
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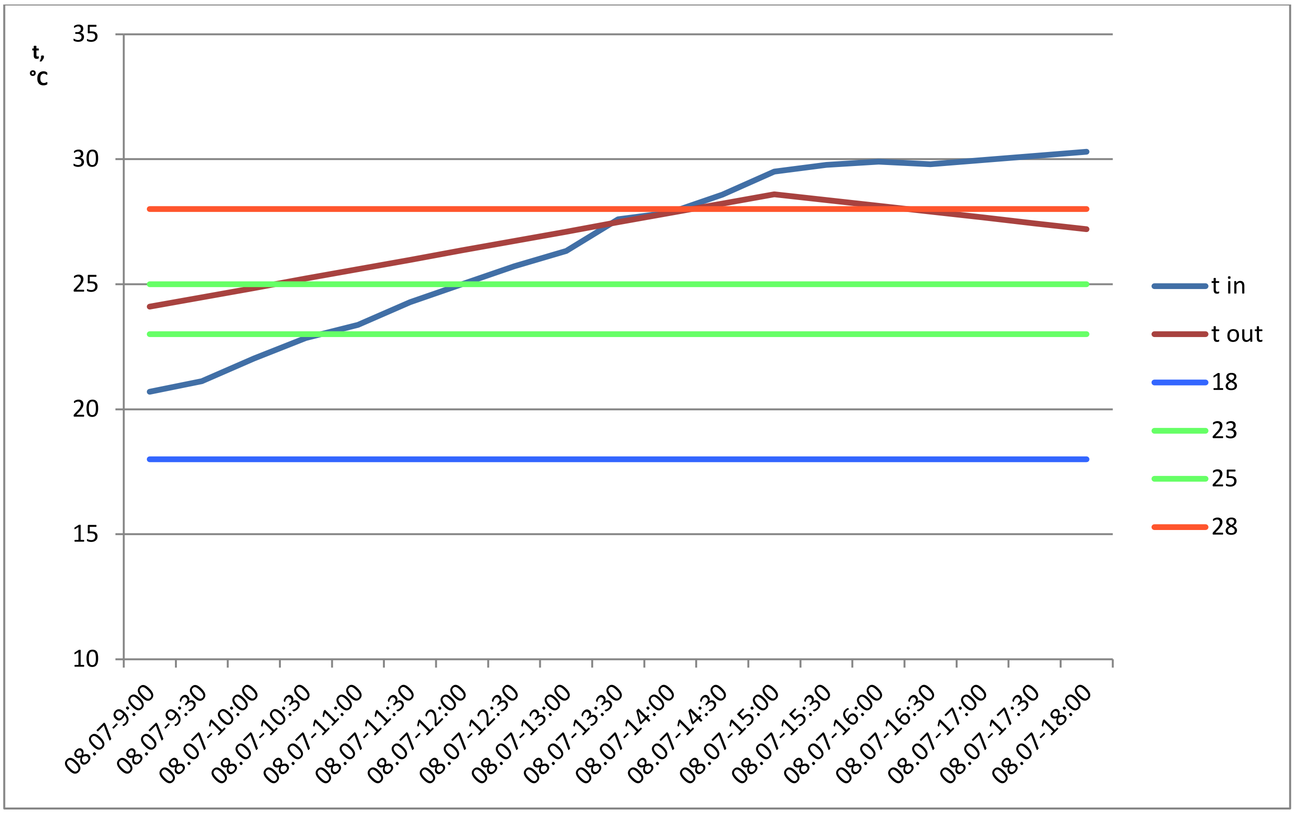
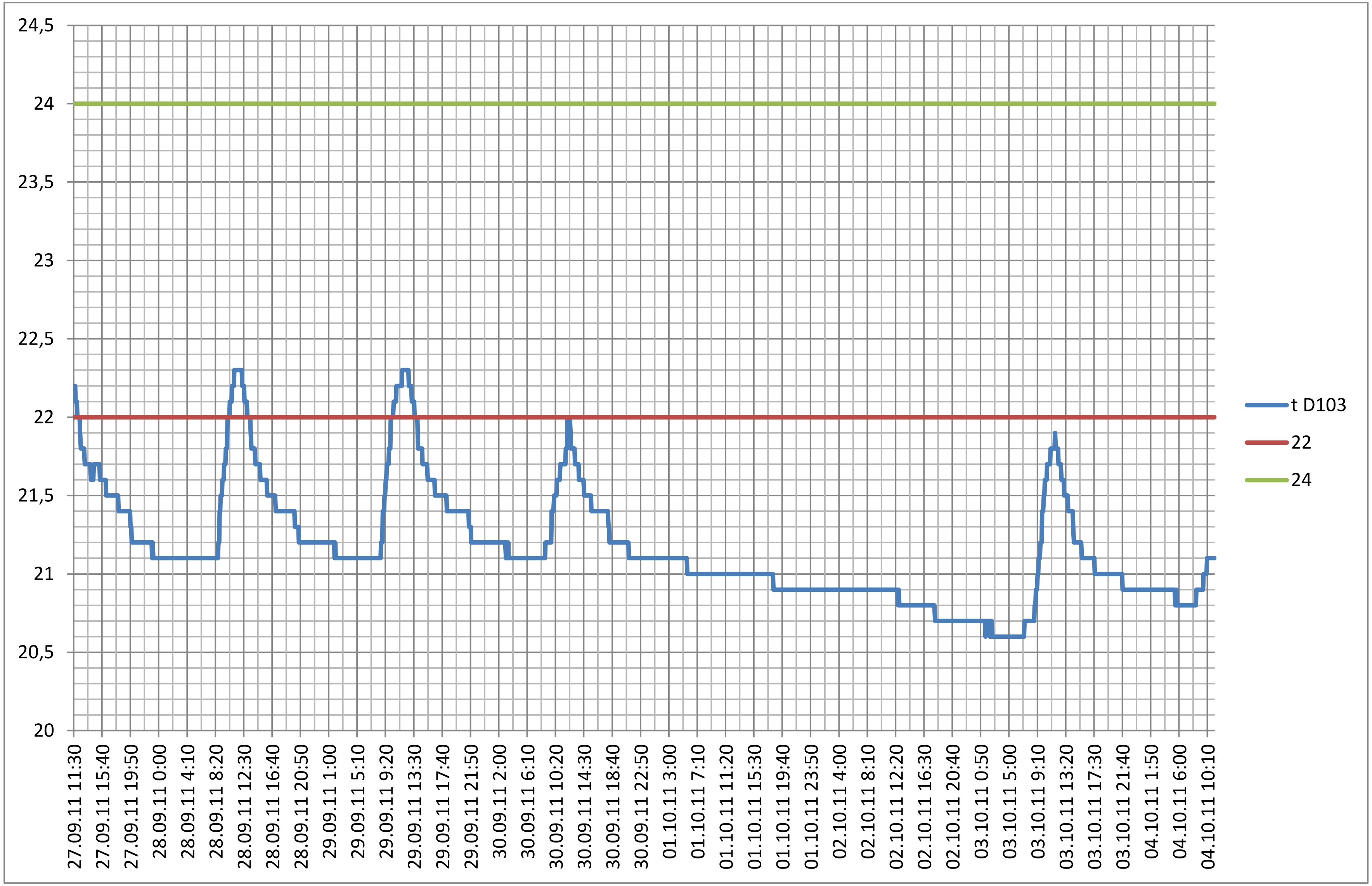
19.07-9:00
19.07-18:00
20.07-15:00
21.07-9:00
21.07-18:00

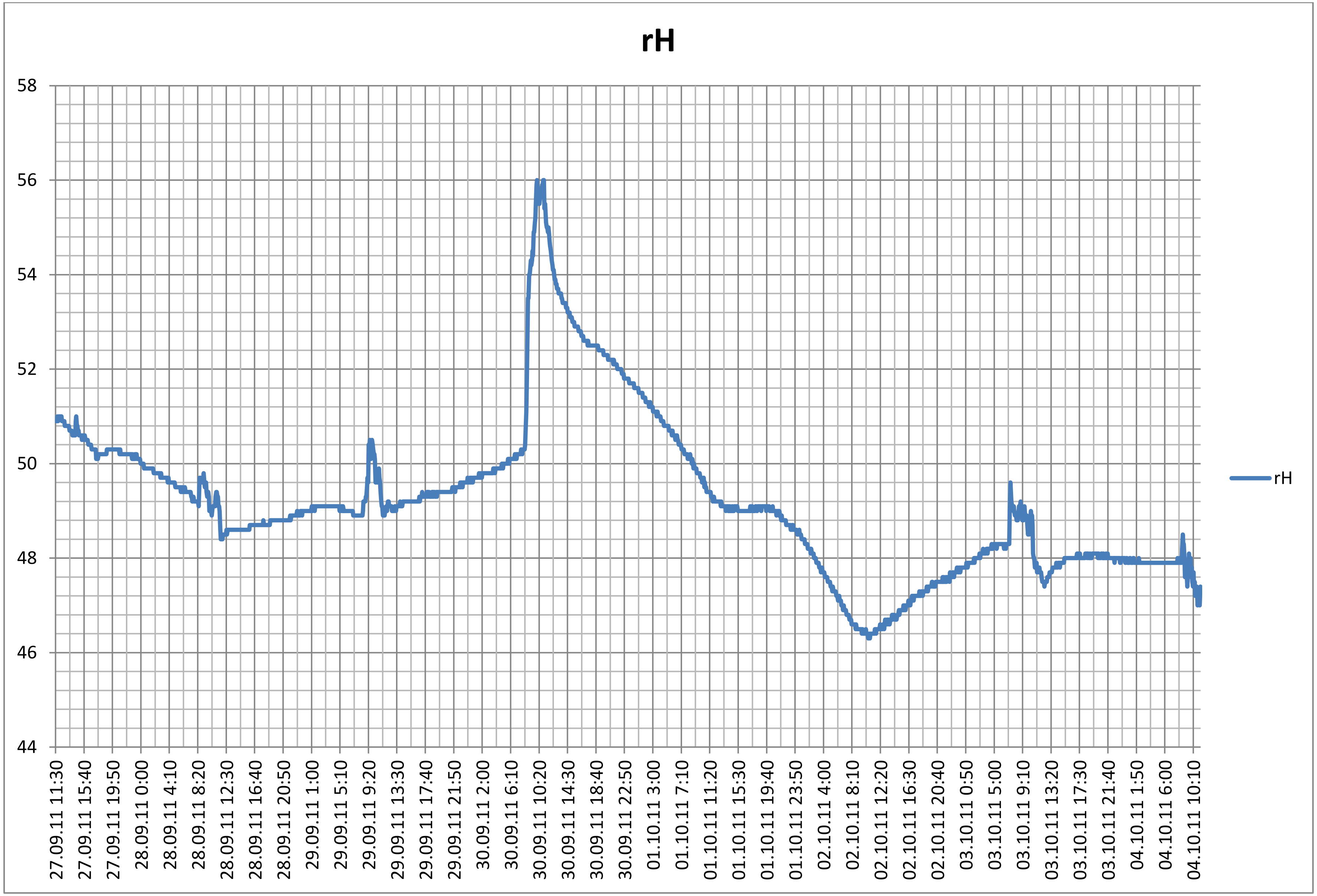
APPENDIX 2. TEMPERATURE MEASUREMENTS FOR CASE 1 (DURING 1 DAY)

08.07-9:00	9:00	20,7	24,1
08.07-9:30	9:30	21,1	24,5
08.07-10:00	10:00	22,0	24,9
08.07-10:30	10:30	22,9	25,2
08.07-11:00	11:00	23,4	25,6
08.07-11:30	11:30	24,3	26,0
08.07-12:00	12:00	25,0	26,4
08.07-12:30	12:30	25,7	26,7
08.07-13:00	13:00	26,3	27,1
08.07-13:30	13:30	27,6	27,5
08.07-14:00	14:00	27,9	27,9
08.07-14:30	14:30	28,6	28,2
08.07-15:00	15:00	29,5	28,6
08.07-15:30	15:30	29,8	28,4
08.07-16:00	16:00	29,9	28,1
08.07-16:30	16:30	29,8	27,9
08.07-17:00	17:00	30,0	27,7
08.07-17:30	17:30	30,1	27,4
08.07-18:00	18:00	30,3	27,2



APPENDIX 3. TEMPERATURE AND HUMIDITY DIAGRAMS FOR CASE 2 (ROOM 1, FAN SWITCH OFF)





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28.09.11 4:10
28.09.11 8:20
28.09.11 12:30
28.09.11 16:40
28.09.11 20:50
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29.09.11 5:10
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02.10.11 20:40
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03.10.11 9:10
03.10.11 13:20
03.10.11 17:30
03.10.11 21:40
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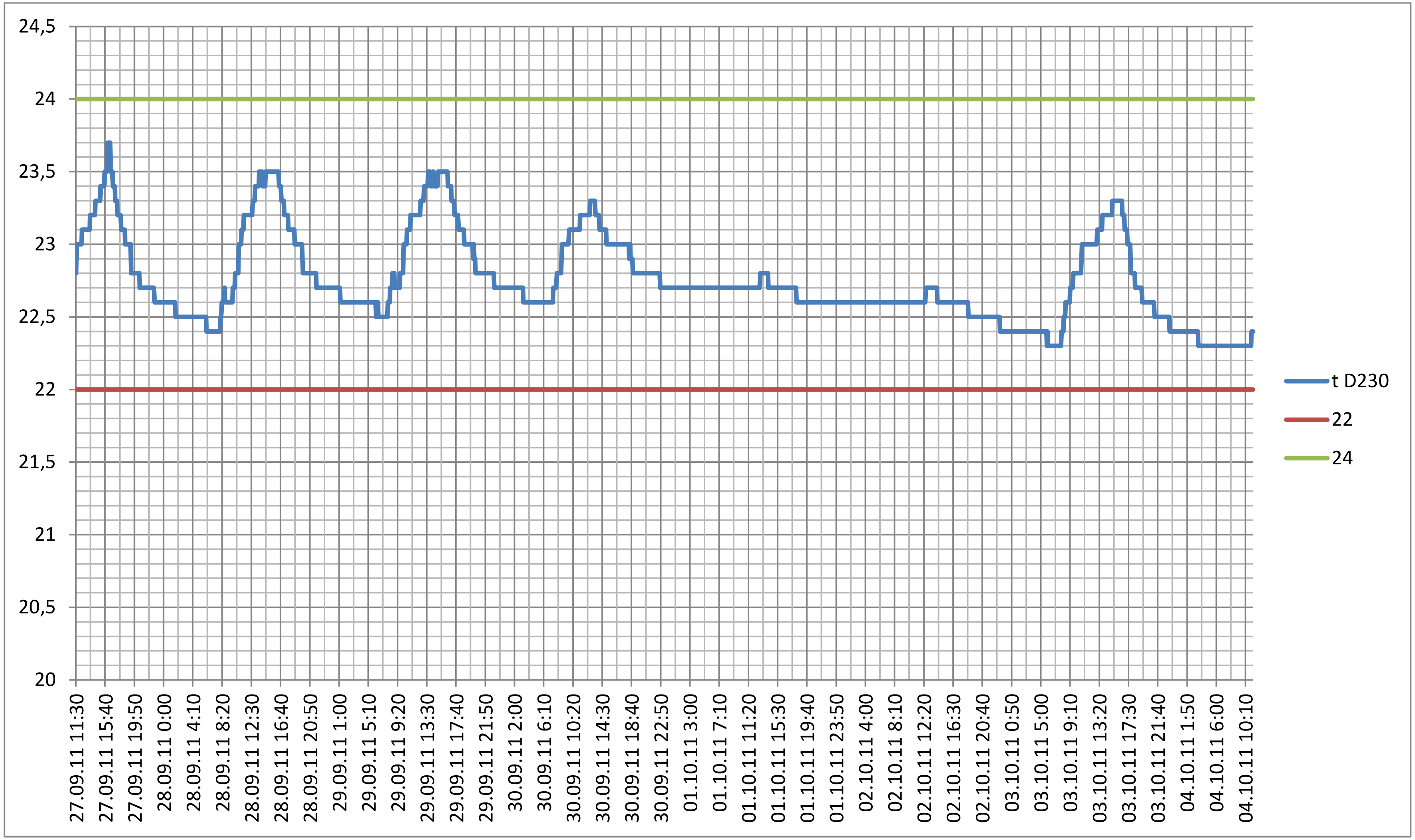
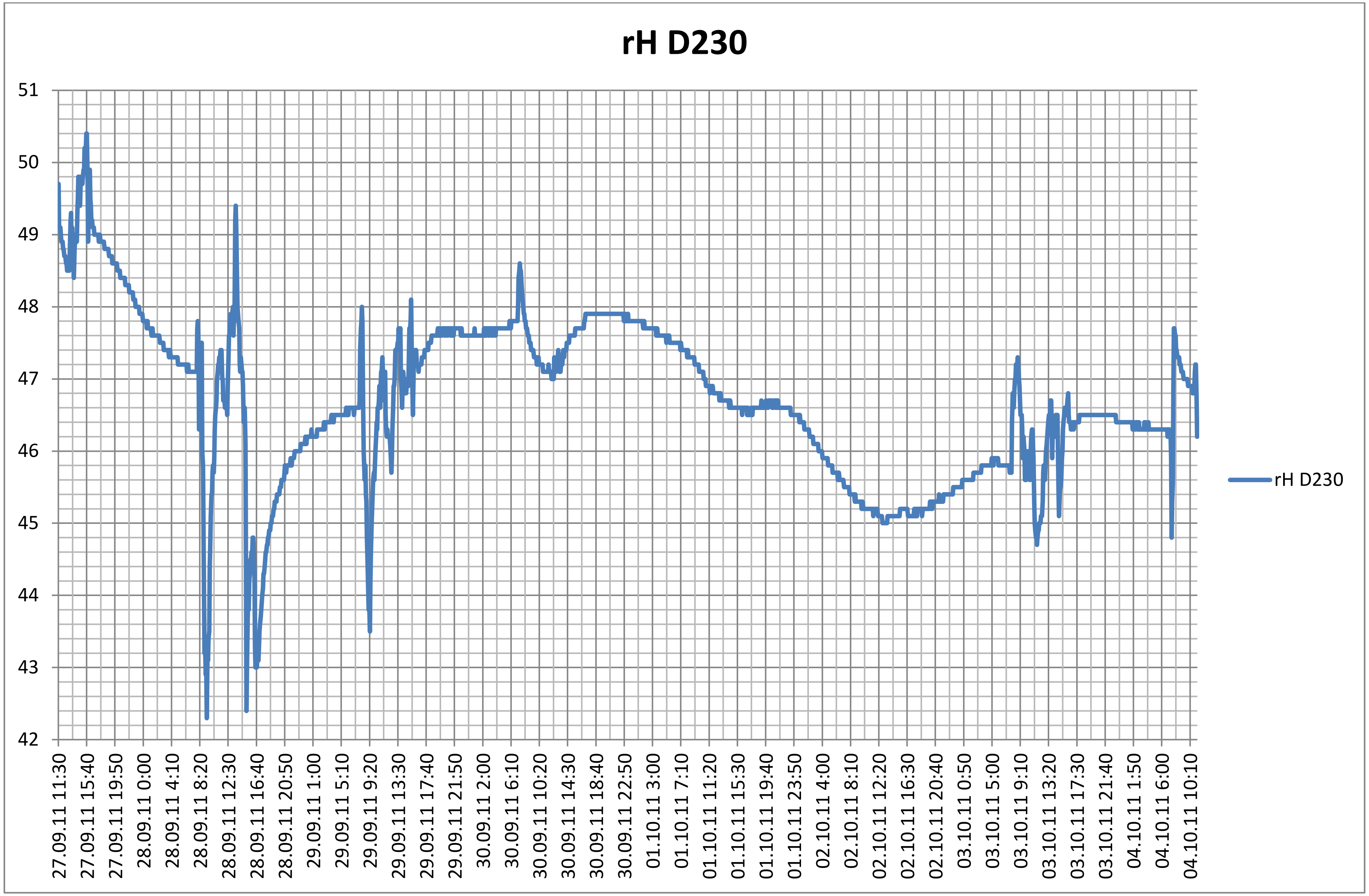
rH

APPENDIX 4. TEMPERATURE AND HUMIDITY DIAGRAMS FOR CASE 2 (ROOM 2, FAN SWITCH OFF)




rH D230
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29.09.11 21:50
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02.10.11 12:20
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02.10.11 20:40
03.10.11 0:50
03.10.11 5:00
03.10.11 9:10
03.10.11 13:20
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03.10.11 21:40
04.10.11 1:50
04.10.11 6:00
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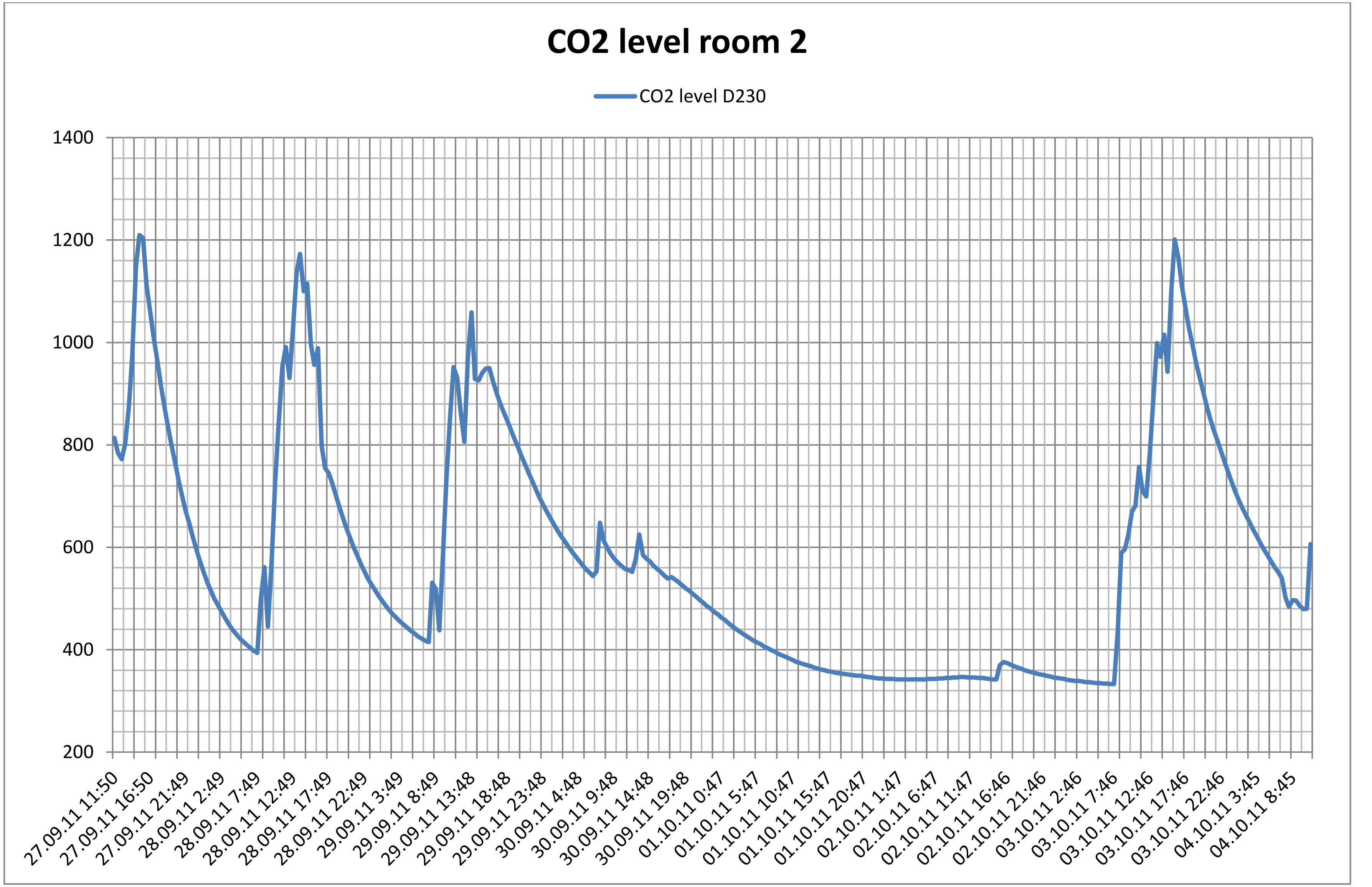
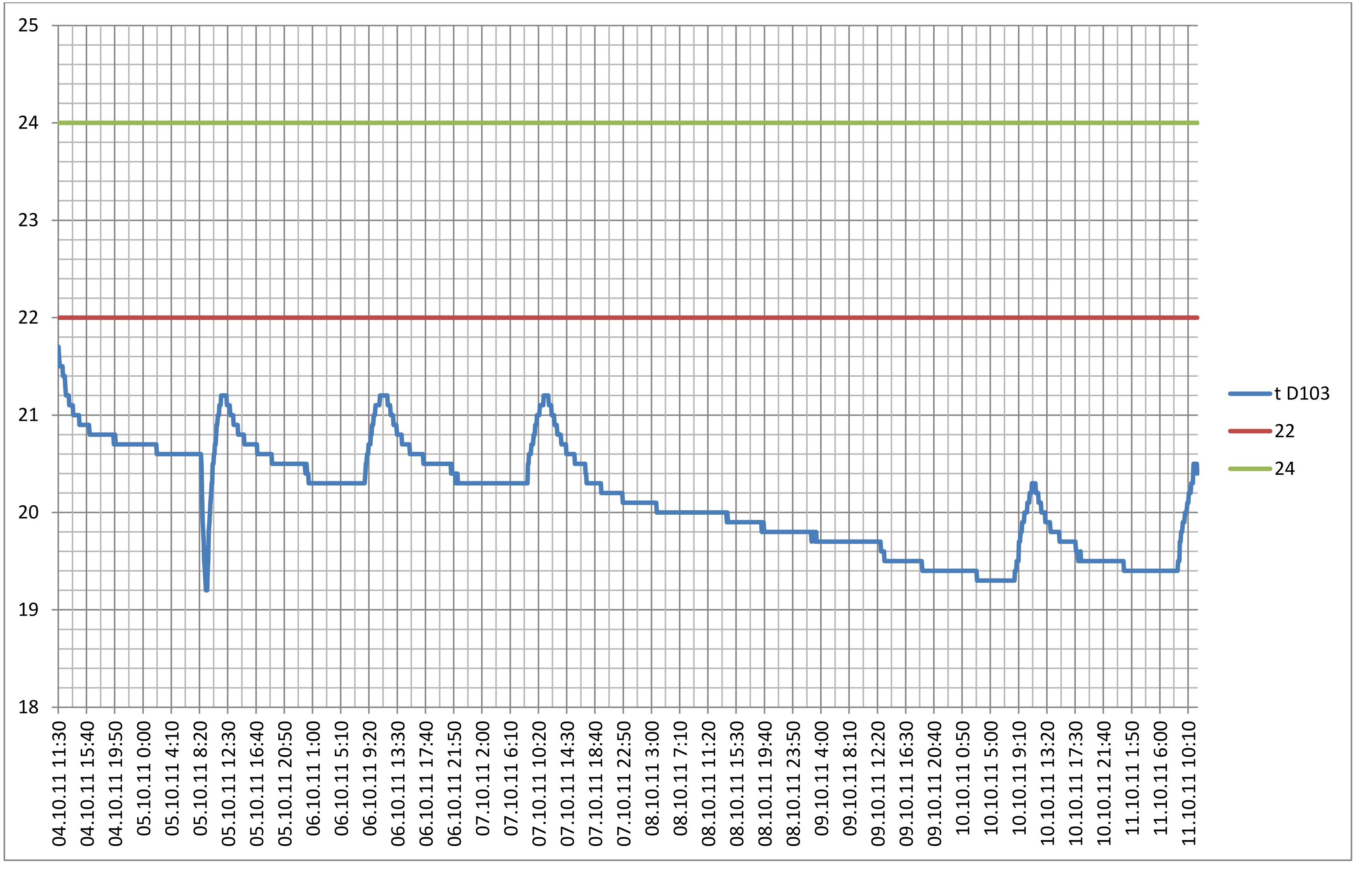
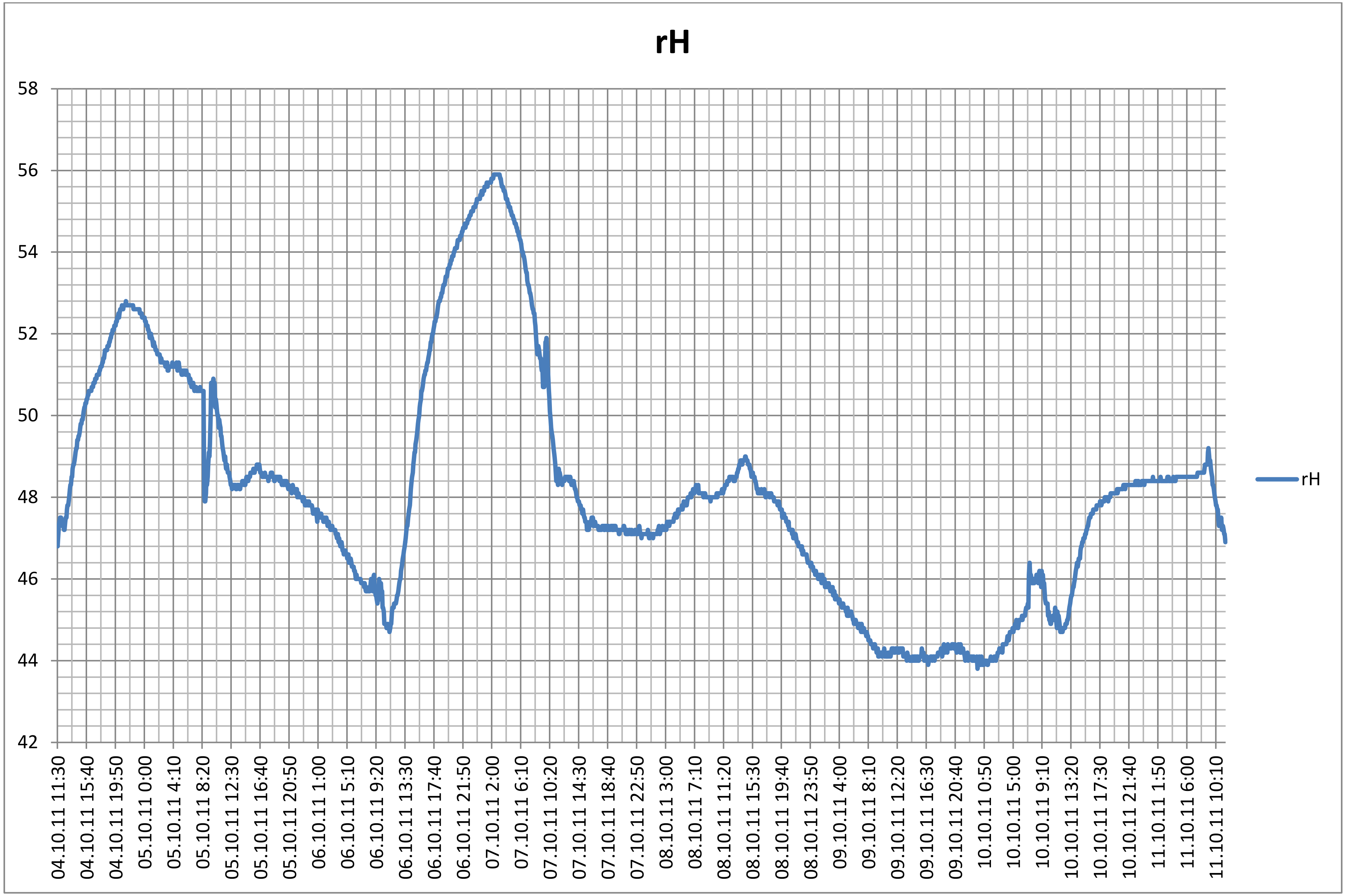
rH D230

APPENDIX 5. CO_2 LEVEL FOR CASE 2 (FAN SWITCHED OFF)



APPENDIX 6. TEMPERATURE AND HUMIDITY DIAGRAMS FOR CASE 2 (ROOM 1, FAN SWITCH ON)





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10.10.11 21:40
11.10.11 1:50
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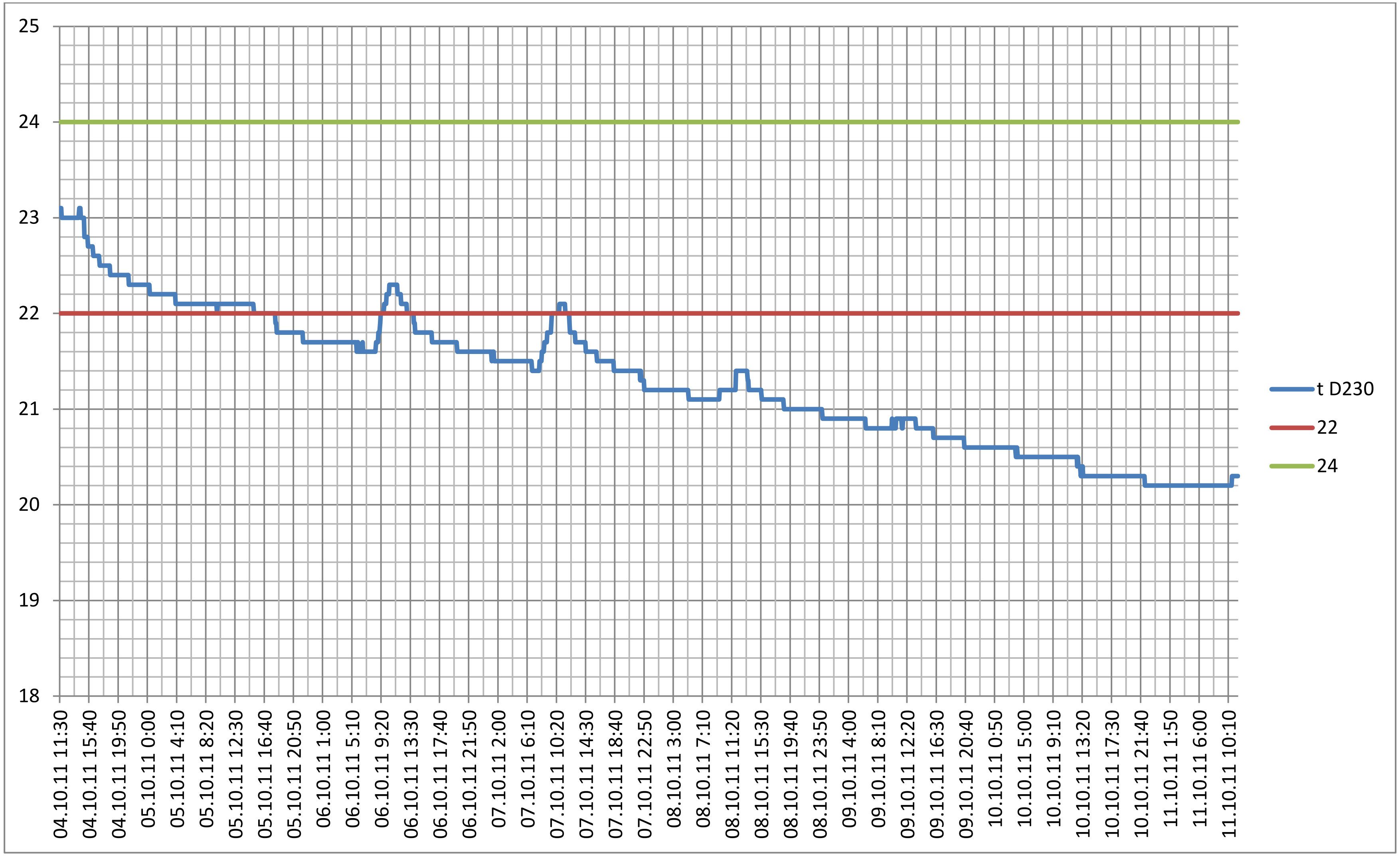
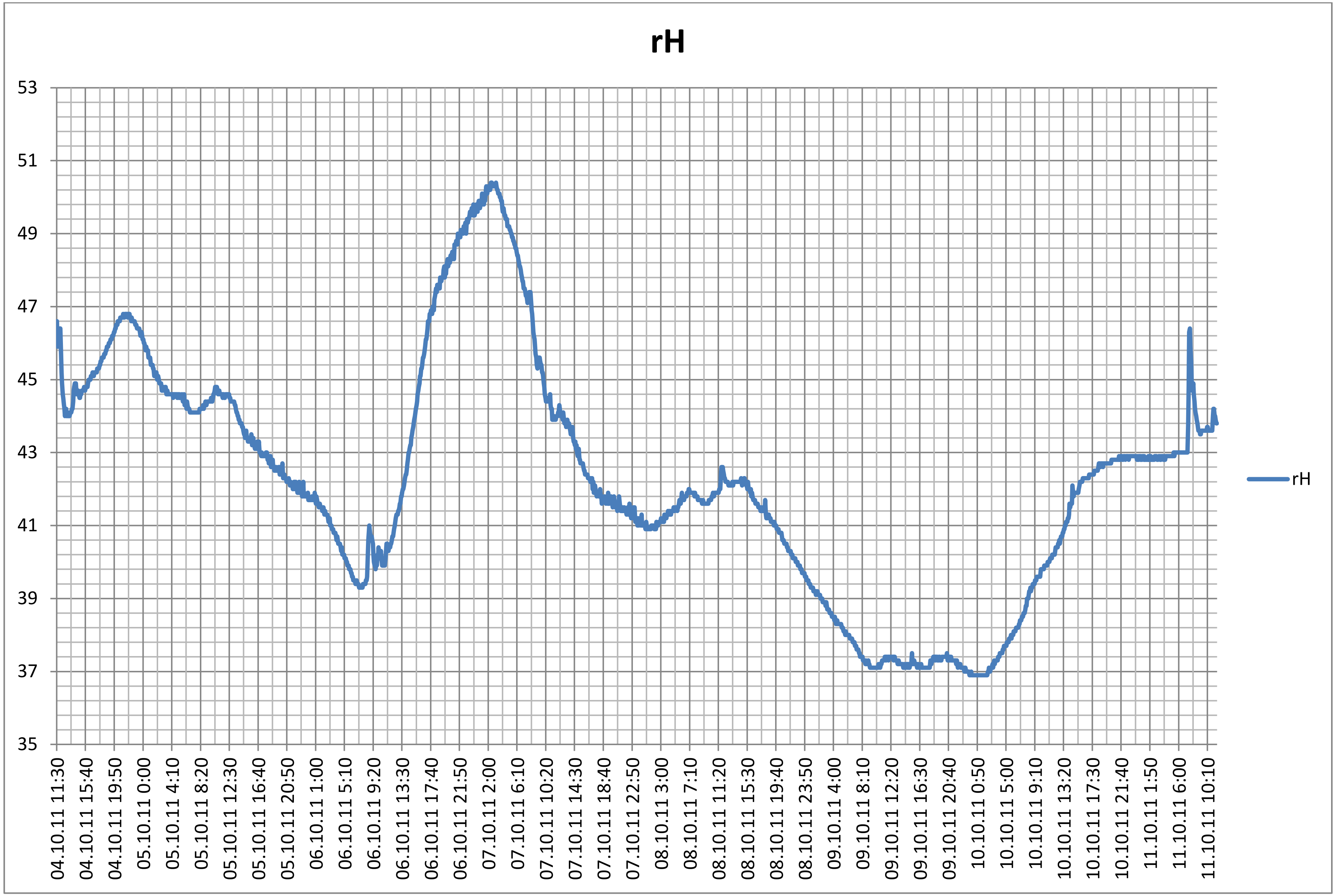
11.10.11 10:10
rH

APPENDIX 7. TEMPERATURE AND HUMIDITY DIAGRAMS FOR CASE 2 (ROOM 2, FAN SWITCH ON)

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04.10.11 15:40
04.10.11 19:50
05.10.11 0:00
05.10.11 4:10
05.10.11 8:20
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06.10.11 9:20
06.10.11 13:30
06.10.11 17:40
06.10.11 21:50
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10.10.11 13:20
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10.10.11 21:40
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11.10.11 6:00
11.10.11 10:10
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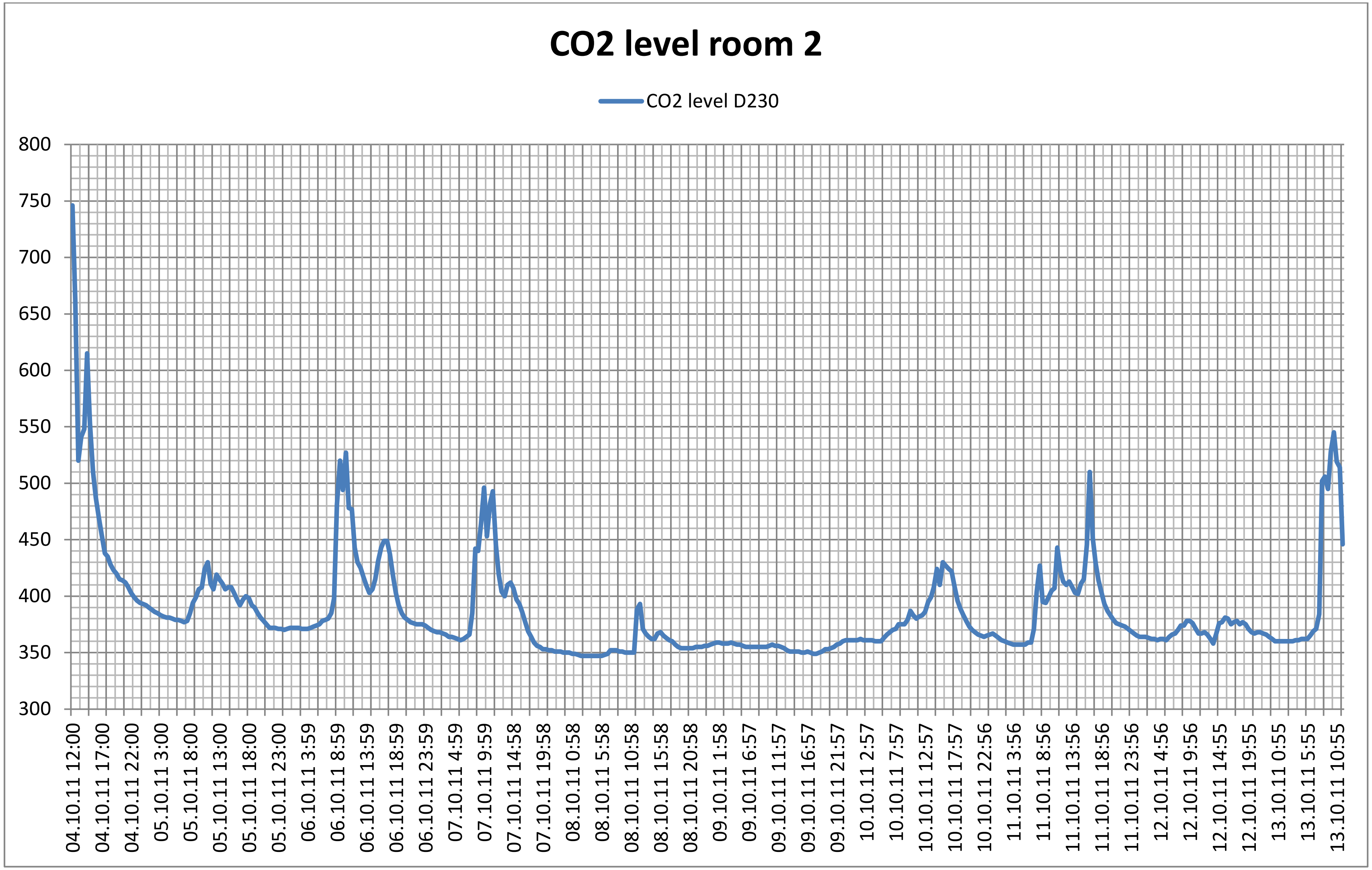
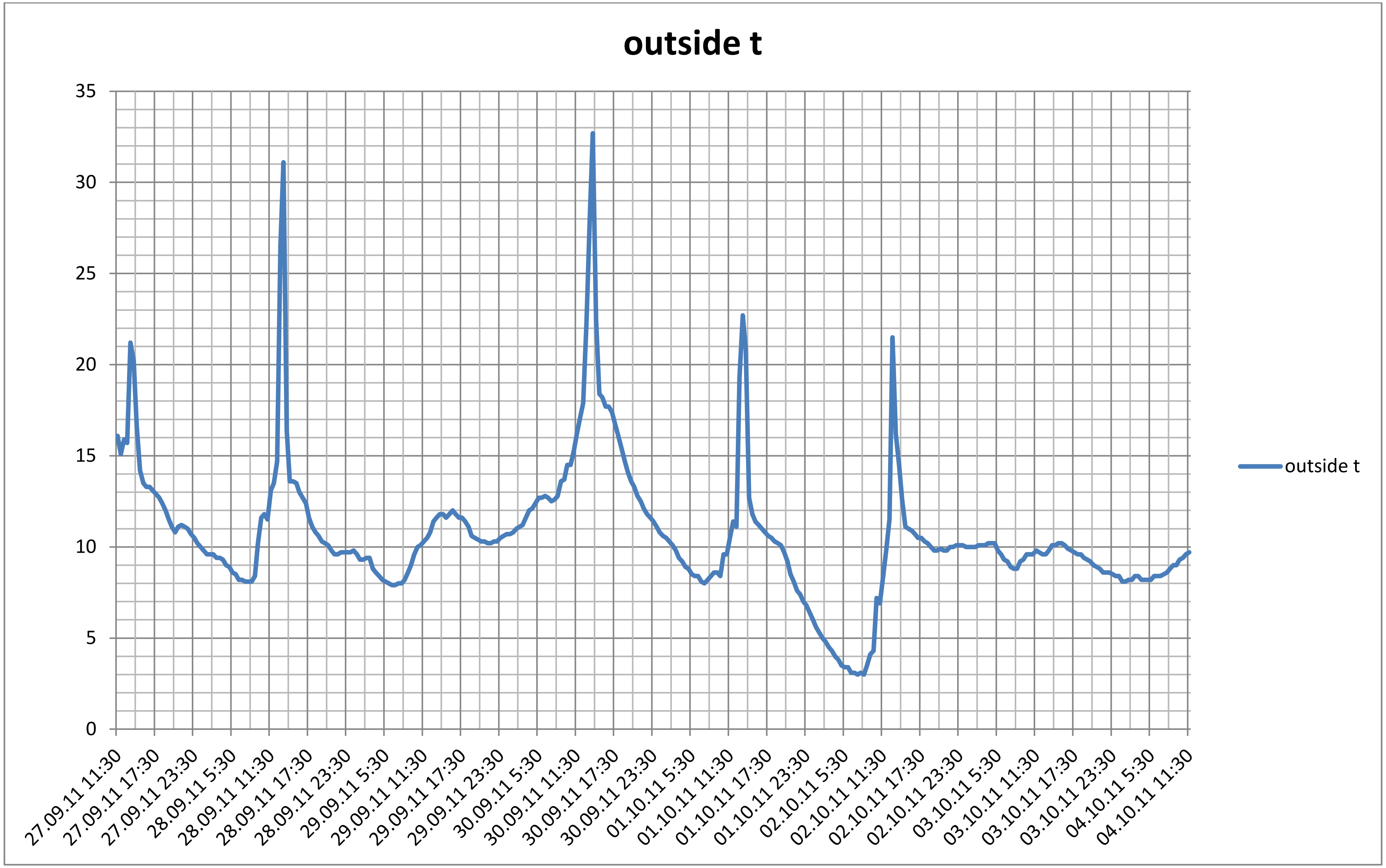
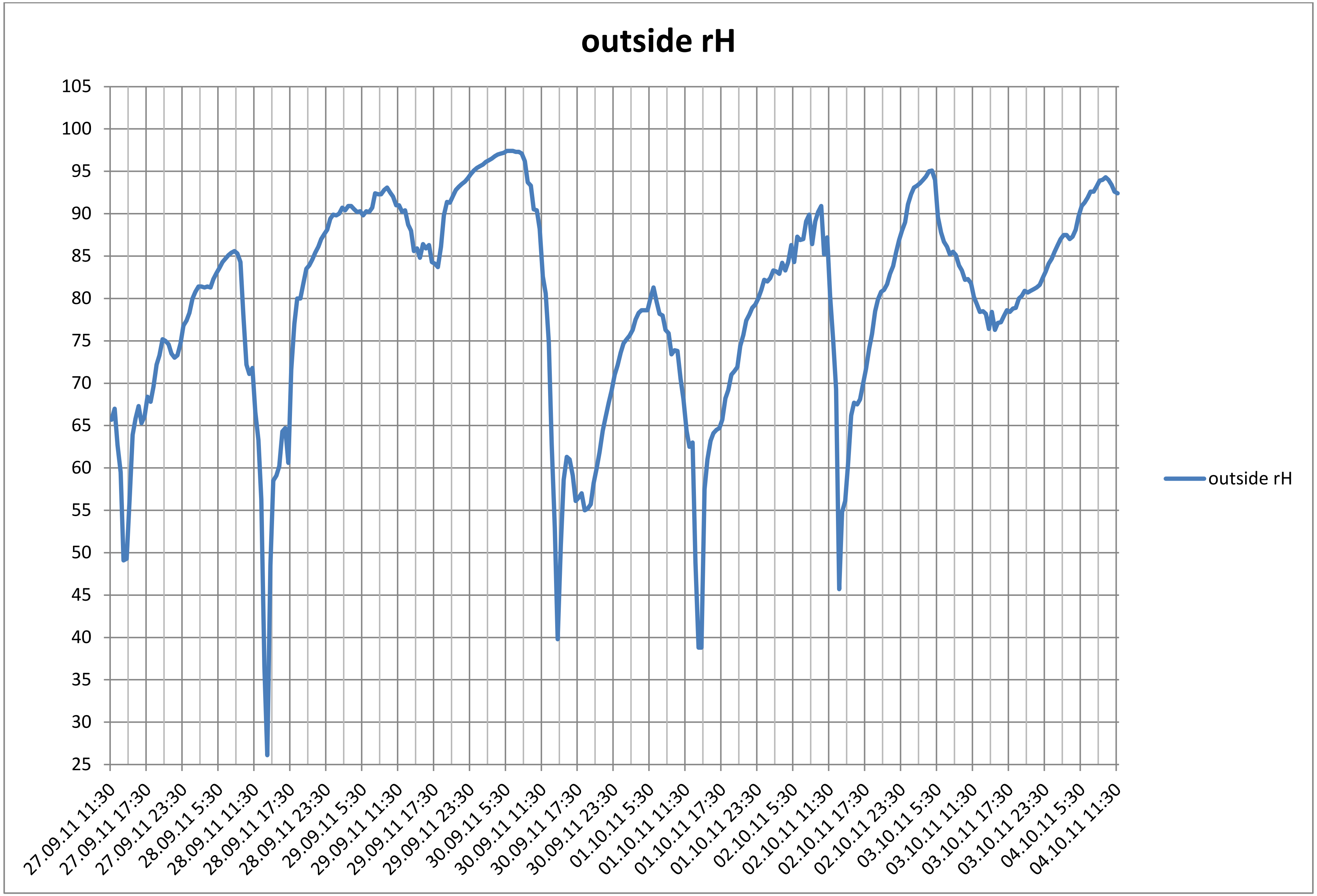
APPENDIX 8. CO_2 LEVEL FOR CASE 2 (FAN SWITCHED ON)



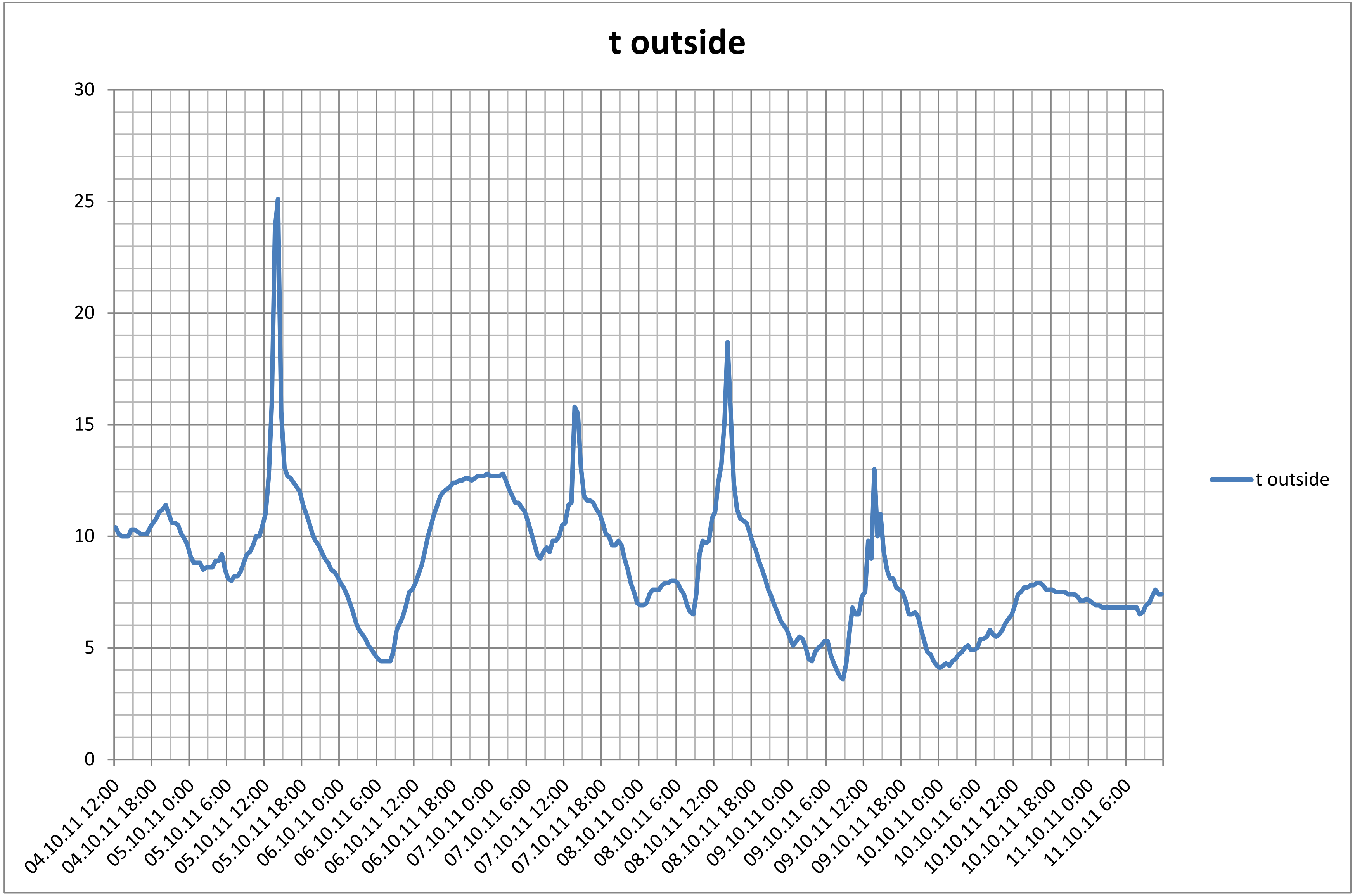
APPENDIX 9. OUTSIDE TEMPERATURE AND RELATIVE HUMIDITY FOR CASE 2 (1 WEEK)

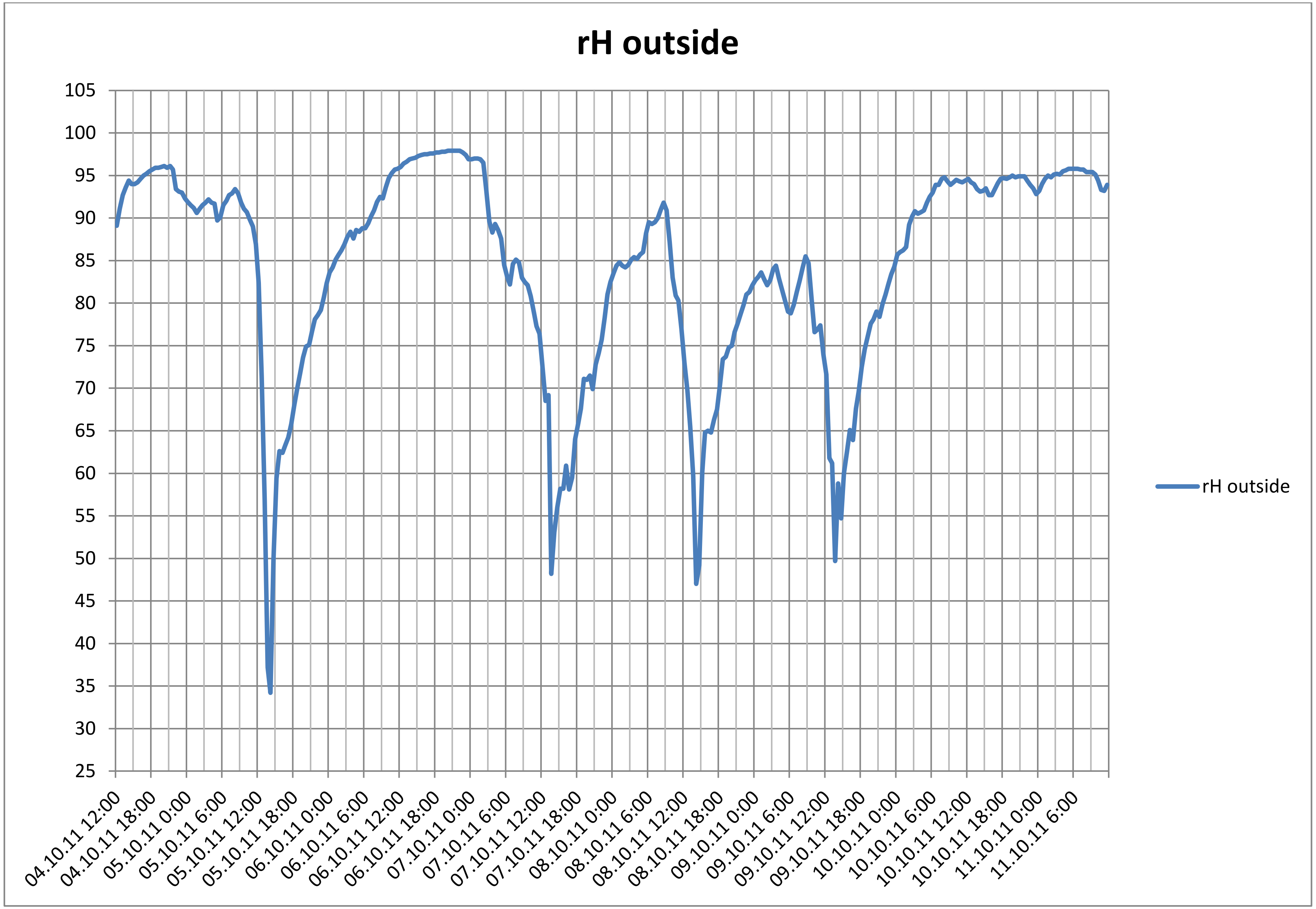




outside rH
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
27.09.11 11:30
27.09.11 17:30
27.09.11 23:30
28.09.11 5:30
28.09.11 11:30
28.09.11 17:30
28.09.11 23:30
29.09.11 5:30
29.09.11 11:30
29.09.11 17:30
29.09.11 23:30
30.09.11 5:30
30.09.11 11:30
30.09.11 17:30
30.09.11 23:30
01.10.11 5:30
01.10.11 11:30
01.10.11 17:30
01.10.11 23:30
02.10.11 5:30
02.10.11 11:30
02.10.11 17:30
02.10.11 23:30
03.10.11 5:30
03.10.11 11:30
03.10.11 17:30
03.10.11 23:30
04.10.11 5:30
04.10.11 11:30
outside rH

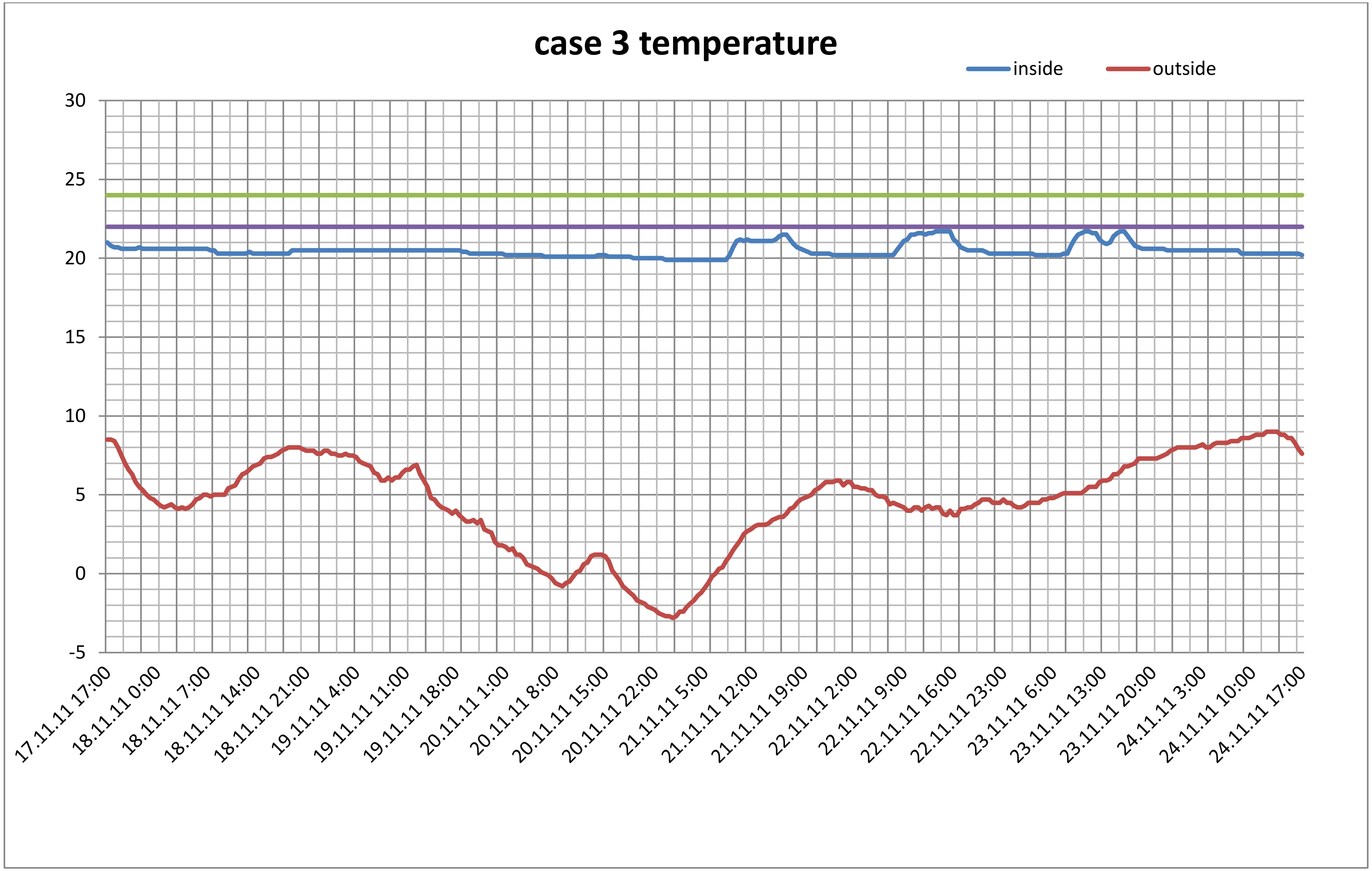
APPENDIX 10. OUTSIDE TEMPERATURE AND RELATIVE HUMIDITY FOR CASE 2 (2 WEEK)

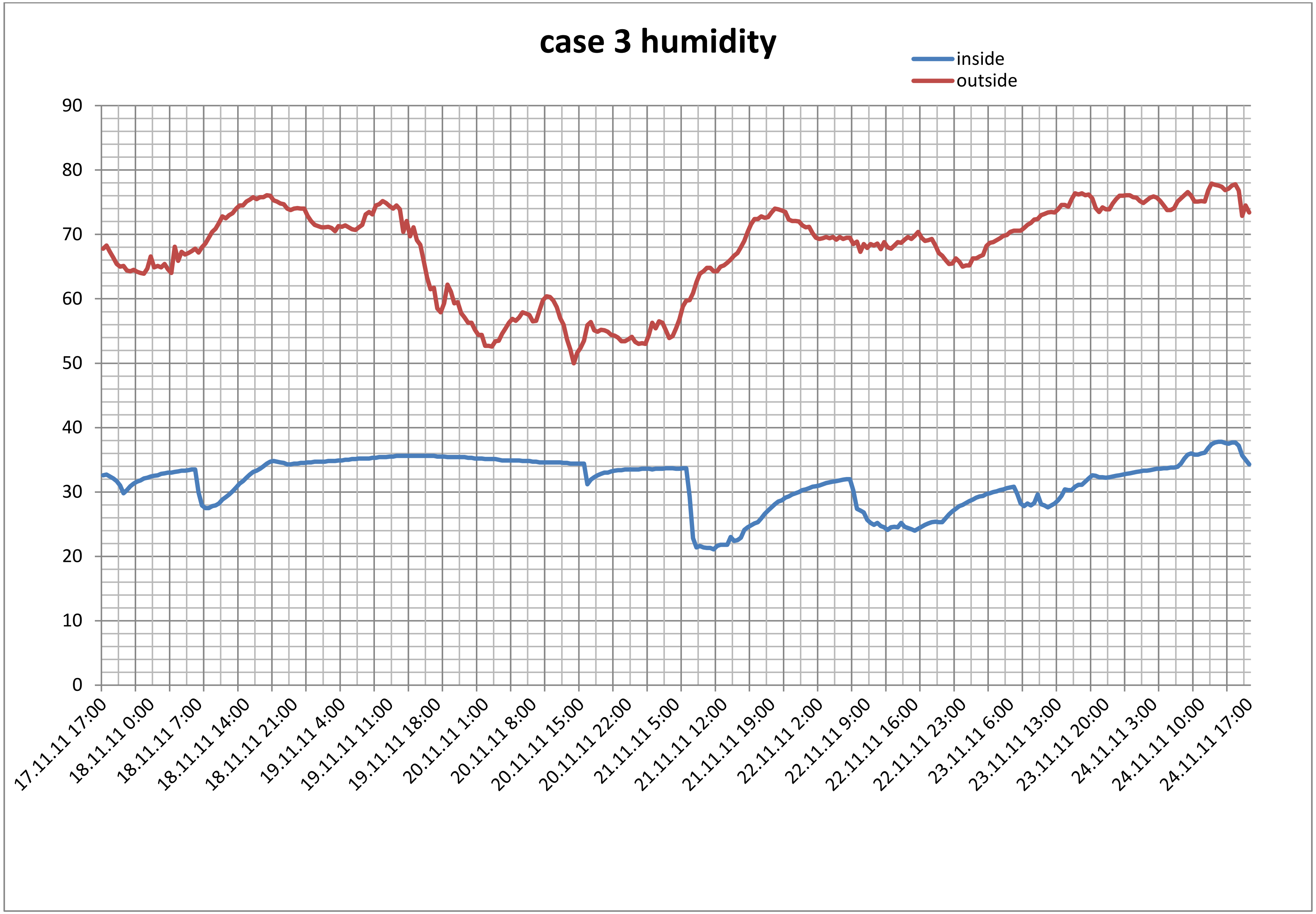




rH outside
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
04.10.11 12:00
04.10.11 18:00
05.10.11 0:00
05.10.11 6:00
05.10.11 12:00
05.10.11 18:00
06.10.11 0:00
06.10.11 6:00
06.10.11 12:00
06.10.11 18:00
07.10.11 0:00
07.10.11 6:00
07.10.11 12:00
07.10.11 18:00
08.10.11 0:00
08.10.11 6:00
08.10.11 12:00
08.10.11 18:00
09.10.11 0:00
09.10.11 6:00
09.10.11 12:00
09.10.11 18:00
10.10.11 0:00
10.10.11 6:00
10.10.11 12:00
10.10.11 18:00
11.10.11 0:00
11.10.11 6:00
rH outside

APPENDIX 11. TEMPERATURE AND HUMIDITY DIAGRAMS FOR CASE 3




case 3 humidity
inside
outside
90
80
70
60
50
40
30
20
10
0
17.11.11 17:00
18.11.11 0:00
18.11.11 7:00
18.11.11 14:00
18.11.11 21:00
19.11.11 4:00
19.11.11 11:00
19.11.11 18:00
20.11.11 1:00
20.11.11 8:00
20.11.11 15:00
20.11.11 22:00
21.11.11 5:00
21.11.11 12:00
21.11.11 19:00
22.11.11 2:00
22.11.11 9:00
22.11.11 16:00
22.11.11 23:00
23.11.11 6:00
23.11.11 13:00
23.11.11 20:00
24.11.11 3:00
24.11.11 10:00
24.11.11 17:00

APPENDIX 12. CO_2 LEVEL FOR CASE 3