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INDOOR CLIMATE STUDY OF THE BRICK AND STONE BUILDINGS IN TARTU

Tallinn
2013

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1. Foreword

This report presents measurement results of two buildings indoor climate in two brick buildings in Tartu, subject to INTERREG IVB program project Nr 61 "Co_2ol Bricks" performed by Hevac Ltd for the Centre of Development Programs EMI-ECO (Project partner 12). Obtained results cover the period from 23.03.12 to 01.04.13.

2. Investigated buildings

Based on the former agreement, the indoor climate study covers following buildings:

Tiigi 11

Herne 32

2.1. Tiigi 11

Tiigi 11 building description:

- 3-store brick/stone building with metal roof. Protected as architectural heritage building. Uninsulated external walls. Insulated roof.
- Water-heating system (radiators), natural ventilation, windows with an opening option.
- Building net internal area 657.7 m^2, net internal volume 3970 m^3.

The following photos describe the building exterior appearance.

Figure 1 Tiigi 11

2.2. Herne 32

Herne 32 building description:

- Constructed in 1925 and renovated in 2005. Building locates in milieu area.
- 3-store brick and stone building with metal roof. Uninsulated exterior envelope. Building has an attic. Insulated roof structure.
- Building has its own boiler house and central-heating system (water radiators).
- Natural ventilation. Windows with an opening option.
- Building net internal area 530 m^2, net internal volume 2039 m^3.

The following shots describe the building exterior appearance.

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Figure 2 Herne 32

3. Methodology and measuring equipment

The following describes the equipment and methodology involved in this study:
Data loggers TR-76Ui for indoor climate measurements:

- CO_2: measurement range 0-5000 ppm, accuracy +/- 50 ppm;
- Air temperature: measurement range -30…+80, accuracy +/- 0,3 oC;
- Air relative humidity: 0…99%, accuracy +/- 2,5 %;

- Calculation of the moisture content in air based on the indoor air temperature and relative humidity measurement results;
- There was 3 data loggers installed in Tiigi 11 building and 5 data loggers in Herne 32 building;
- Data loggers recording interval is 0.5 hours;
- Additional data loggers were measuring outside air temperature and relative humidity near Tiigi 11 and Herne 32 location area;
- Study of the external air temperature effects and their impact on the indoor air temperature;
- Indoor air moisture content study;
- Indoor air carbon dioxide content study.

Figure 3 Data logger TR-76Ui

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4. Measurement results

The data were obtained with data loggers within three following periods:

23.03-04.06.2012
04.06-09.11.2012
09.11.2012-01.04.2013

The data elaborated in three periods was formed into single annual measurement period (01.04.2012 – 31.03.2013) and then analysed. Annual measurements and analysis results are described in the next chapter.

Since the outside air temperature has an essential effect on the indoor climate, it is relevant to divide annual period into shorter periods and study them in more detail. Measurement results of spring (March-April), warm (July–August) and cold periods (January–February) are studied in the report appendix 1, 2 and 3.

5. Analysis

Herne 32 is residential building and Tiigi 11 is an office building.

Duration diagrams related to Tiigi 11 building in this study include only working hours (9:00-17:00, 5 days a week), where usual graphs are based on the complete period.

5.1 Tiigi 11

Following figures describe location of data loggers in the building:

LOG 6 I floor room nr 15
LOG 8 I floor room nr 16
LOG 7 II floor room nr 27

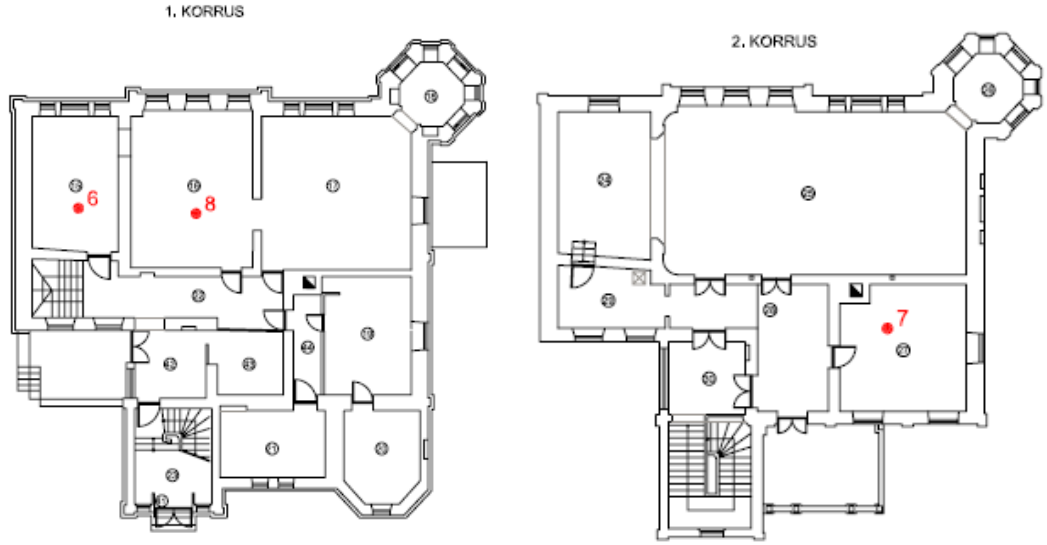

Figure 4 Data loggers location in building Tiigi 11

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5.1.1 Air temperature

The following graph (Figure 5) illustrates the indoor air temperature annual measurement results (non-working hours are included).

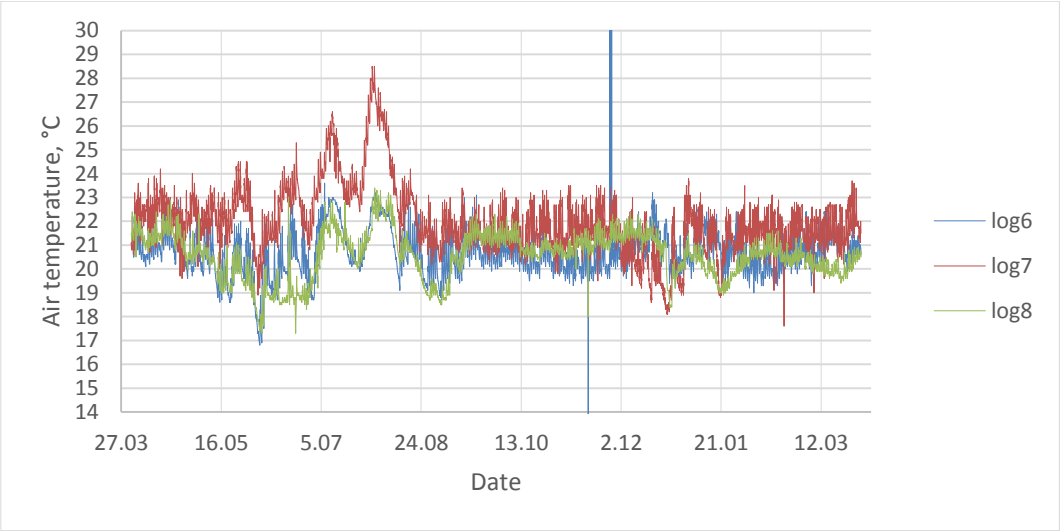

Figure 5 Room air temperature in Tiigi 11 (annual period)

The following duration diagram (Figure 6) displays the measured annual indoor air temperature within working hours (9:00 – 17:00).

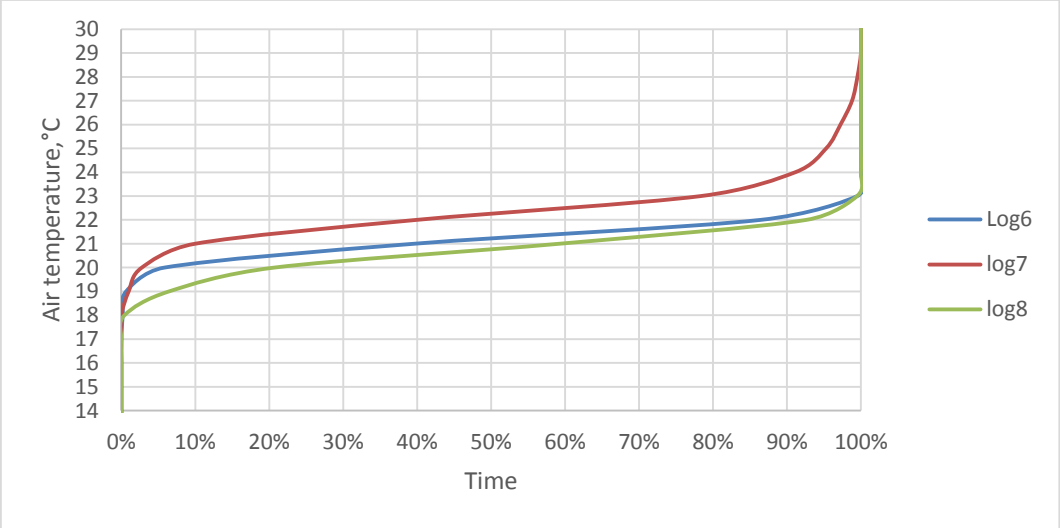

Figure 6 Duration diagram of the room air temperature in Tiigi 11 (annual period, working hours only)

The following duration diagram (Figure 7) illustrates the measured indoor air temperature within period September-May.

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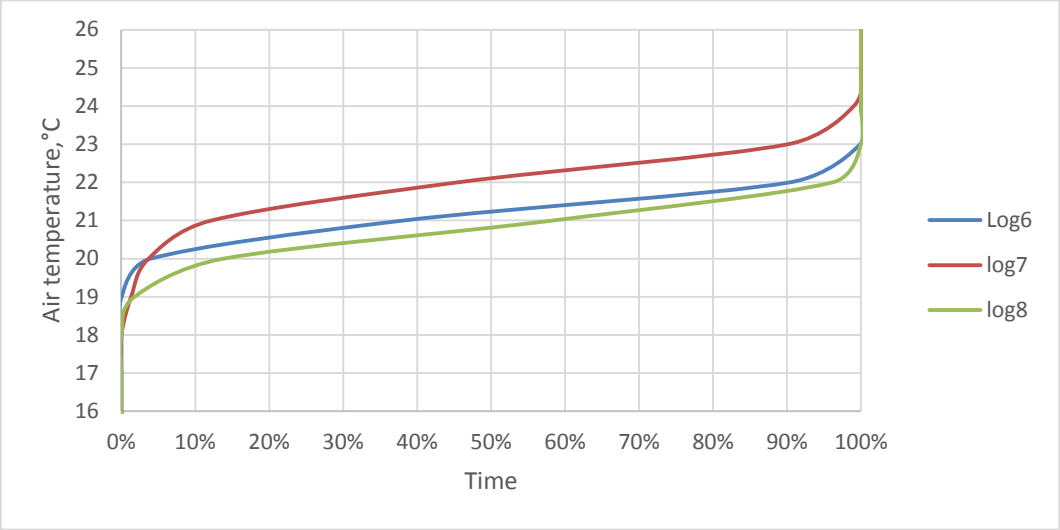

Figure 6 Duration diagram of the room air temperature in Tiigi 11 (September-May, working hours only)

The following conclusions can be drawn regarding the measured indoor air temperature in Tiigi 11 building:

- Air temperature in rooms during September-May (heating period) varies 18…24 °C (indoor air temperature below 17 °C occurred due to open windows);
- During the summer indoor air temperature varies 17…28 °C;
- II floor room (logger 7) air temperature is ca 1 °C higher compared to other measured rooms;
- Air temperature in the second floor room exceeded 21 °C ca 90% of the heating period duration. First floor room (logger 6) and third floor room (logger 8) air temperature exceeded 21 °C ca 50% of the heating period duration;
- During the summer air temperature in the second floor room exceeded 25 °C about 5% of the time during the year;
- First and third floor rooms air temperature was below 25 °C during the year.

5.1.2 Relative humidity

The following graph (Figure 7) illustrates indoor air relative humidity annual measurement results (non-working hours are included).

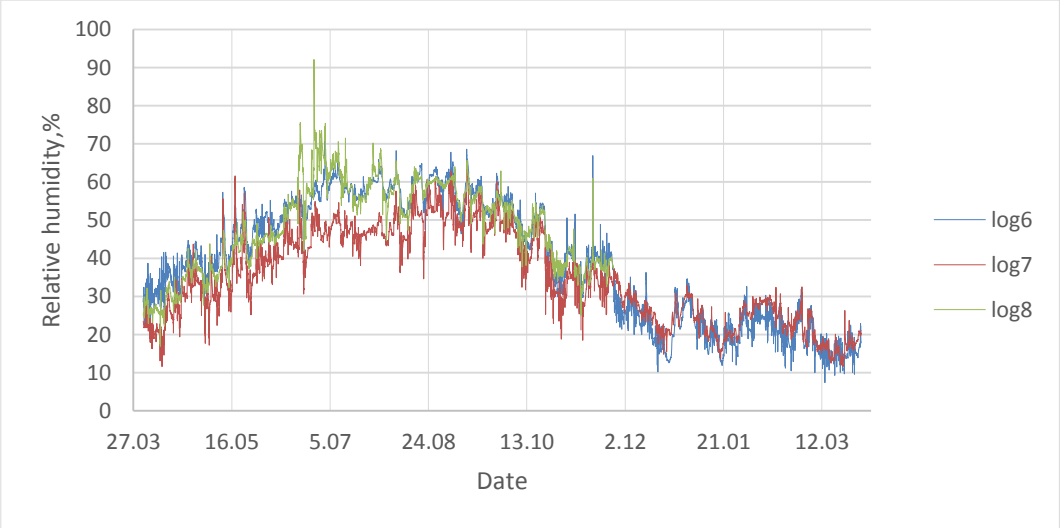

Figure 7 Room air relative humidity in Tiigi 11 (annual period)

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The following duration diagram (Figure 8) displays the measured annual indoor air relative humidity within working hours (9:00 – 17:00). Due to construction works in the third floor room (logger 8), the data logger was damaged (June/July). Therefore, elaborated data from data logger 8 is not sufficient/adequate to be plotted on the duration diagram.

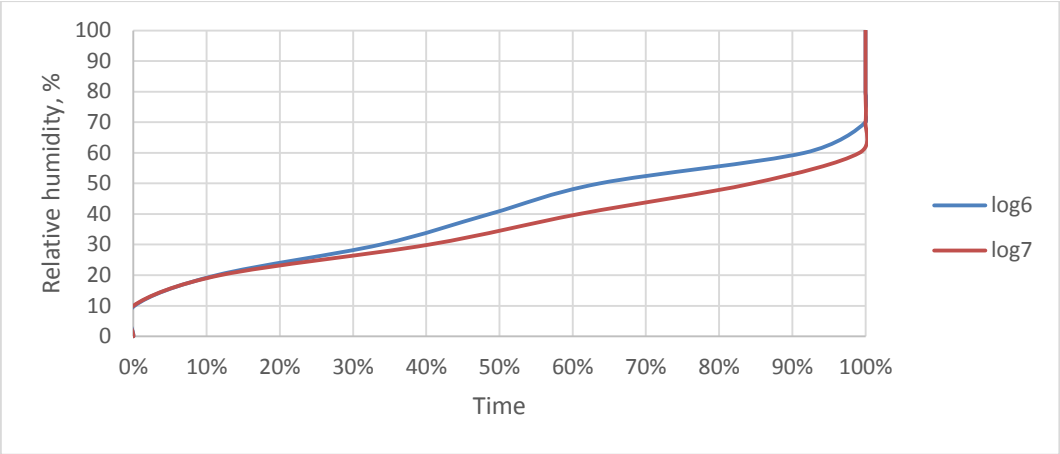

Figure 8 Duration diagram of the room air relative humidity in Tiigi 11 (annual period, working hours only)

The following conclusions can be drawn regarding the measured indoor air relative humidity in Tiigi 11 building:

- Room air relative humidity varies 10…70 %;
- During the May-September (summer) period indoor air relative humidity varies 45…70%;
- During the December-February (winter) period indoor air relative humidity varies 10…32%;
- Indoor air relative humidity stayed below 20% ca 10% of the time during the year;
- In comparison to second and third floor room's measurement results, the first floor room air relative humidity was lower during the winter and higher during the spring/summer.

5.1.3 Moisture content

Indoor air quality is characterized by the difference between indoor and outdoor air moisture content, which is defined as moisture excess. The higher the indoor air moisture excess value, the lower is the air exchange in the room and the higher is the risk of moisture damage. Moisture excess values during the winter season should not exceed 2,5 g/kg (3 g/m3). According to the detailed winter period measurement results analysis (appendix 3) , the moisture excess in Tiigi 11 building was not exceeding the recommended value and varied 1…2 g/kg. Spring period (appendix 1) moisture excess reached 3 g/kg.

5.1.4 Carbon dioxide content (CO_2)

The following graph (Figure 9) illustrates indoor air carbon dioxide content annual measurement results (non-working hours are included). Due to construction works in the third floor room (logger 8), the data logger was damaged (July). Therefore, elaborated data from data logger 8 is not sufficient / adequate to be plotted on the duration diagram.

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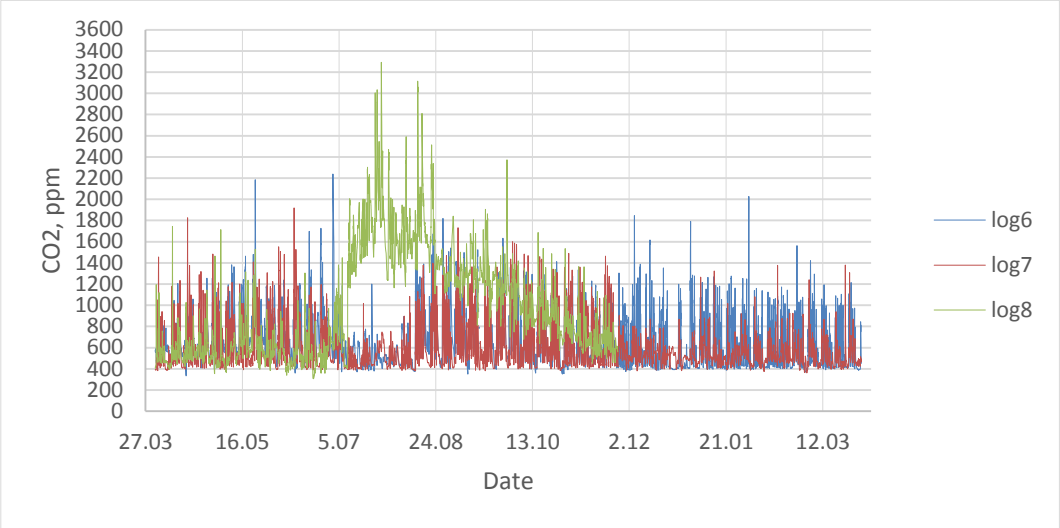

Figure 9 Room air carbon dioxide content in Tiigi 11 (annual period)

The following duration diagram (Figure 10) displays the measured annual indoor air carbon dioxide content within working hours (9:00 – 17:00).

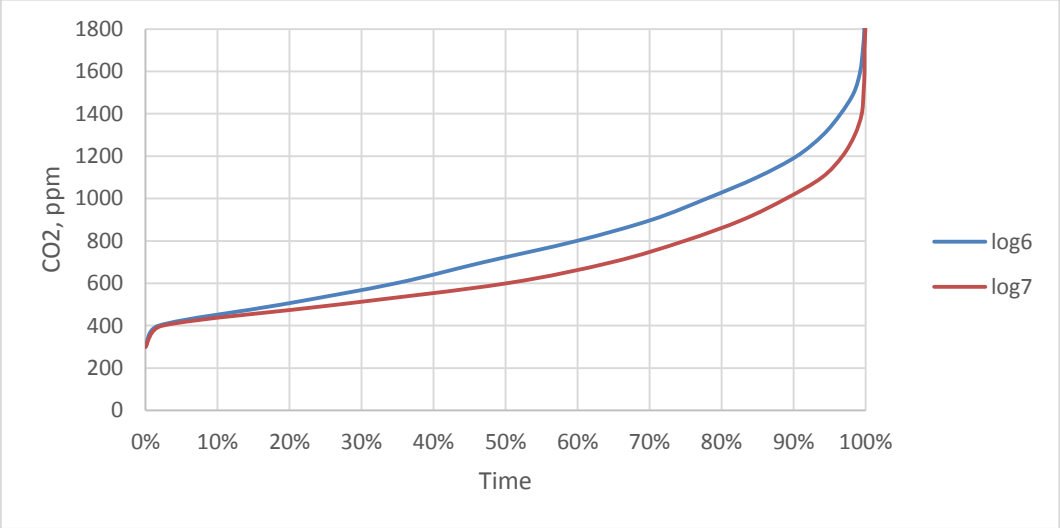

Figure 10 Duration diagram of the room air carbon dioxide content in Tiigi 11 (annual period, working hours only)

In accordance with the World Health Organization (WHO) recommendations, CO_2 content in the indoor air should not exceed 1000 ppm.
The following conclusions can be drawn regarding the measurement results in Tiigi 11 building:

- Room air CO_2 content reached its peak value of 2200 ppm;
- Room air CO_2 content exceeded 1000 ppm ca 10…20% of the time during the year, which is quite good result for the building with natural ventilation.

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5.2 Herne 32

Following figures describe data loggers location in the building:

LOG 1 and LOG 3	I floor
LOG 4	II floor
LOG 5	III floor
LOG 2	attic

The measurement results are illustrated in the following graphs.
It was not possible to elaborate some parts of the first floor apartment logger data (logger 1), because apartment owner was out of Estonia. There is some data elaborated from the attic is missing due to lack of the power supply at some periods (May-June), where air temperature reads are quite high but no records of relative humidity measurement. Taken above into an account the data elaborated from the data logger nr.1 and nr.2 was not included in duration diagrams.

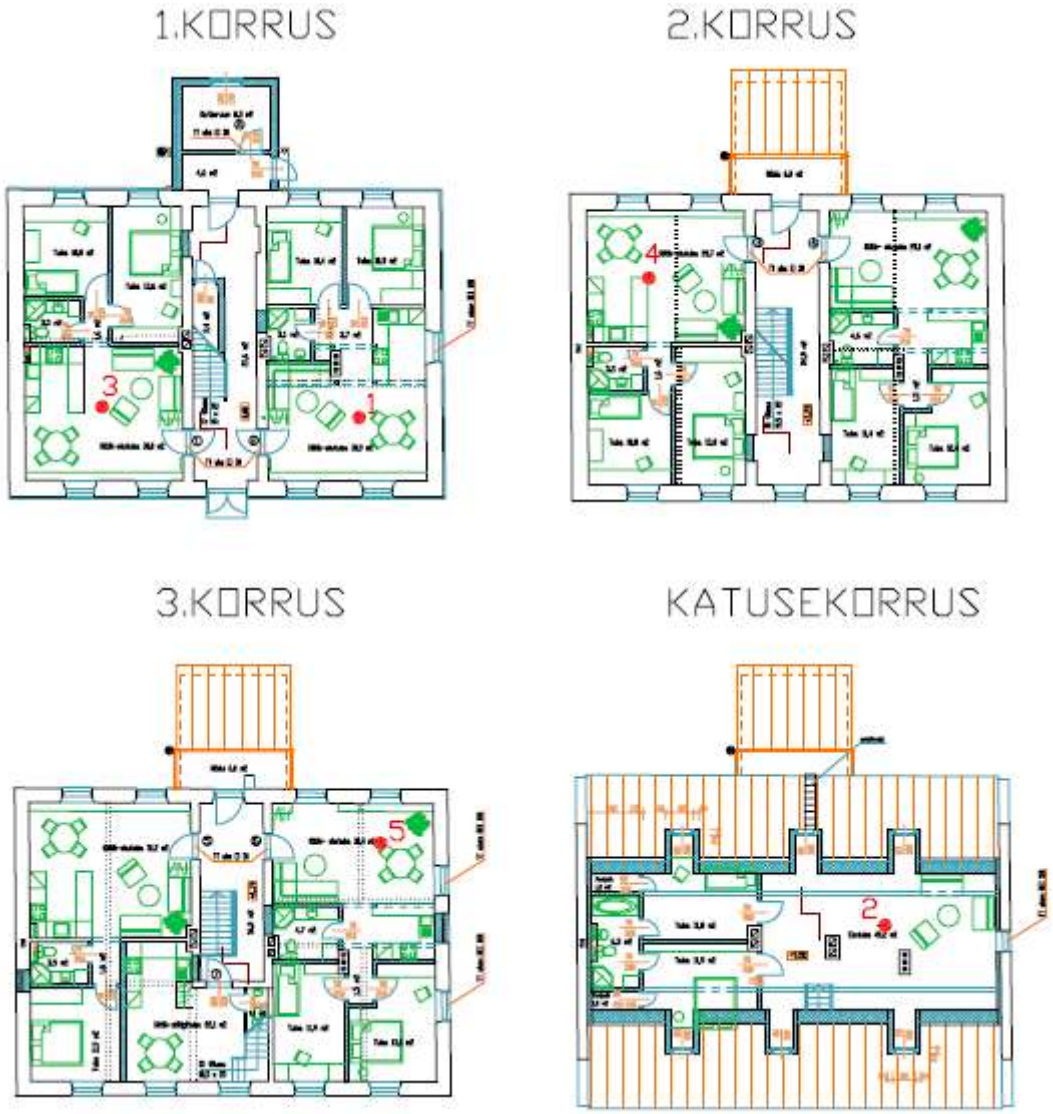

Figure 11 Data loggers location in building Herne 32

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5.2.1 Air temperature

The following graph (Figure 12) illustrates indoor air temperature annual measurement results. Data logger nr.1 and nr.2 measurement results are not included in the duration diagram.

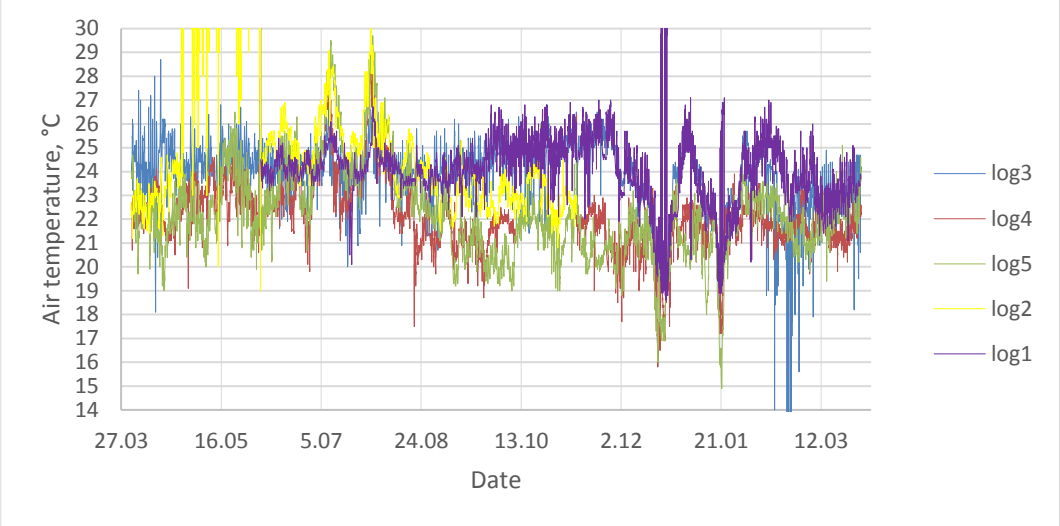

Figure 12 Room air temperature in Herne 32 (annual period)

The following duration diagram (Figure 13) displays the measured annual indoor air temperature.

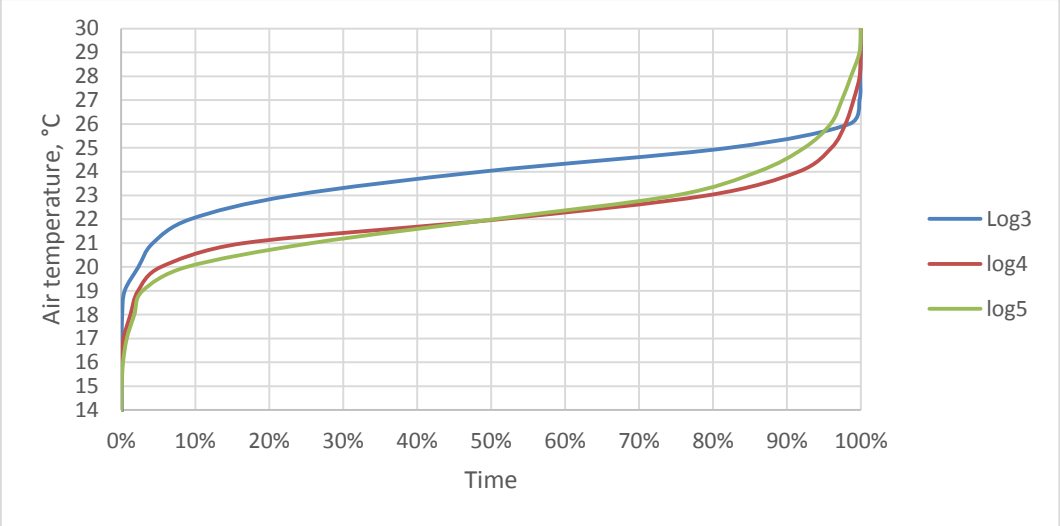

Figure 13 Duration diagram of the room air temperature in Herne 32 (annual period)

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The following duration diagram (Figure 14) illustrates the measured indoor air temperature within September-May period.

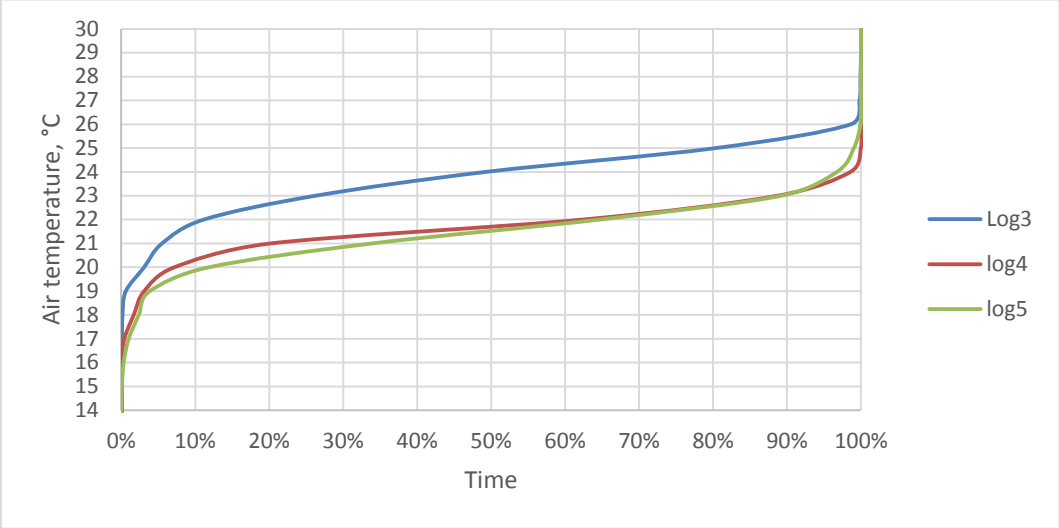

Figure 14 Duration diagram of the room air temperature in Herne 32 (September-May)

The following conclusions can be drawn regarding the measured indoor air temperature in Herne 32 building:

- Air temperature in rooms during September-May (heating period) varies 15…27^{o}C (indoor air temperature below 15 ^{o}C occurred due to open windows);
- Due to outside air temperature drop below -20 ^{o}C during the night, indoor air temperature in the third floor room (logger 5) dropped to 15 ^{o}C and lasted for ca 8 hours. At the same time air temperature in other rooms dropped to ca 17…18 ^{o}C;
- Air temperature in the first floor room (logger 3) is ca 1,5…2 ^{o}C higher in comparison to other rooms air temperature;
- Air temperature exceeds 21 ^{o}C in the first floor room for ca 95% of the heating season (September – May) duration, for ca 80% in the second floor room (logger 4) and for ca 65% in the third floor room. The building is over heated based on the results above;
- Indoor air temperature stays below 18 ^{o}C during the heating season for ca 2% of the time in the second and third floor rooms. Heating system could not meet the demand in those rooms.
- Air temperature exceed 25 ^{o}C during the heating period for ca 20% of the time in the first floor room (logger 3) ;
- During the summer air temperature in the second and third floor rooms exceeded 25 ^{o}C ca 4…8% of the time during the year, which is ca 350…700 hours a year.

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5.2.2 Relative humidity

The following graph (Figure 15) illustrates indoor air relative humidity annual measurement results. Data logger nr.1 and nr.2 measurement results are not included in the duration diagram.

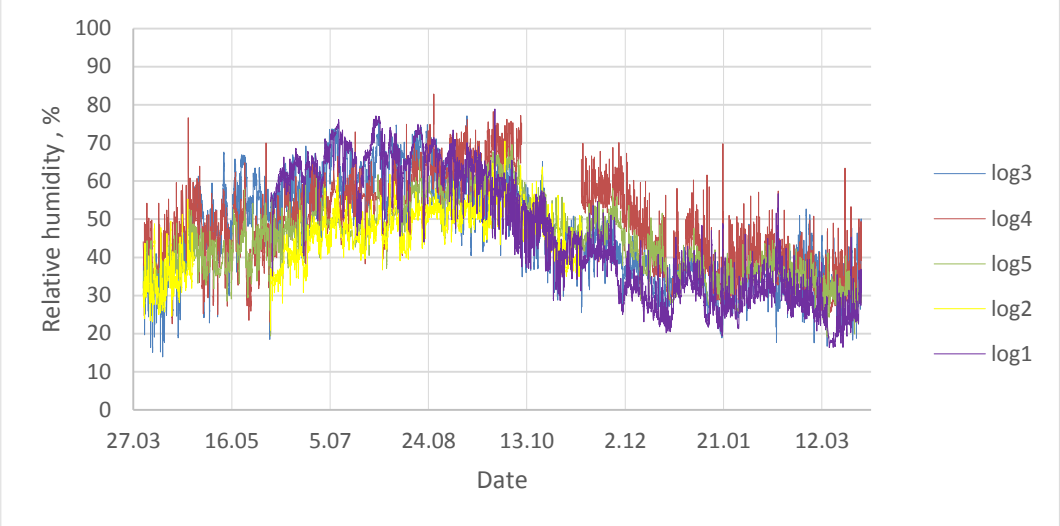

Figure 15 Room air relative humidity in Herne 32 (annual period)

The following duration diagram (Figure 16) displays the measured annual indoor air relative humidity.

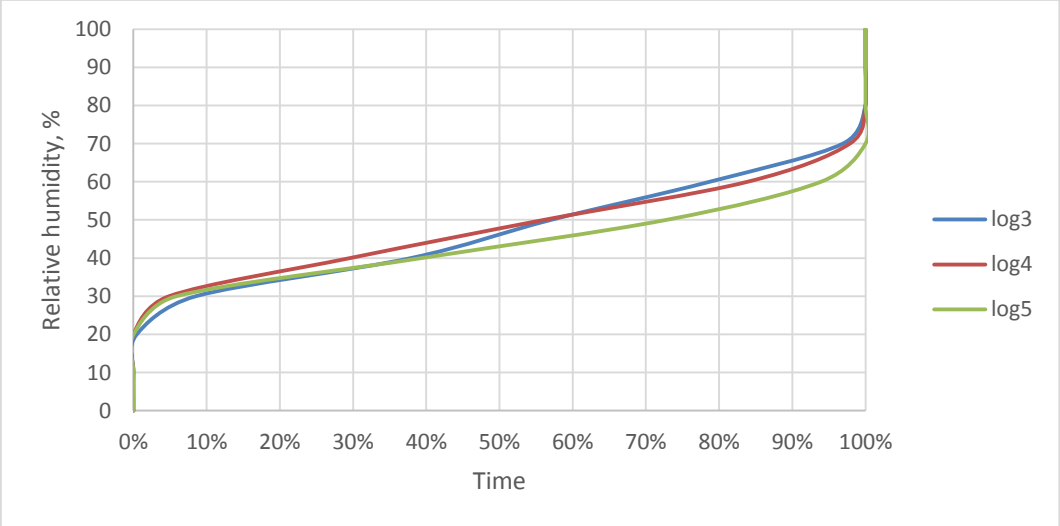

Figure 16 Duration diagram of the room air relative humidity in Herne 32 (annual period)

The following conclusions can be drawn regarding the measured indoor air relative humidity in Herne 32 building:

- Room air relative humidity varies 15…80 %;
- During the May-September (summer) period indoor air relative humidity varies 30…80%;
- During the December-February (winter) period indoor air relative humidity varies 20…70%;
- Relative humidity in the first and second floor rooms exceeded 70% for ca 2% time of the year.

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5.2.3 Moisture content

During the cold period (Appendix 3) daily average moisture excess in Herne 32 apartment building was continuously exceeding recommended 2,5 g/kg, same can be said for the spring period (Appendix 1). The maximum of 5,5 g/kg moisture excess appeared in the second floor room during the winter period. Average Herne 32 apartment's moisture excess during the winter exceeded 3 g/kg. High moisture excess indicates that the air exchange (ventilation) in the building is not sufficient. The building has a high risk of moisture damage.

5.2.4 Carbon dioxide content (CO_2)

The following graph (Figure 17) illustrates indoor air carbon dioxide content annual measurement results. Data logger nr.1 and nr.2 measurement results are not included in the duration diagram.

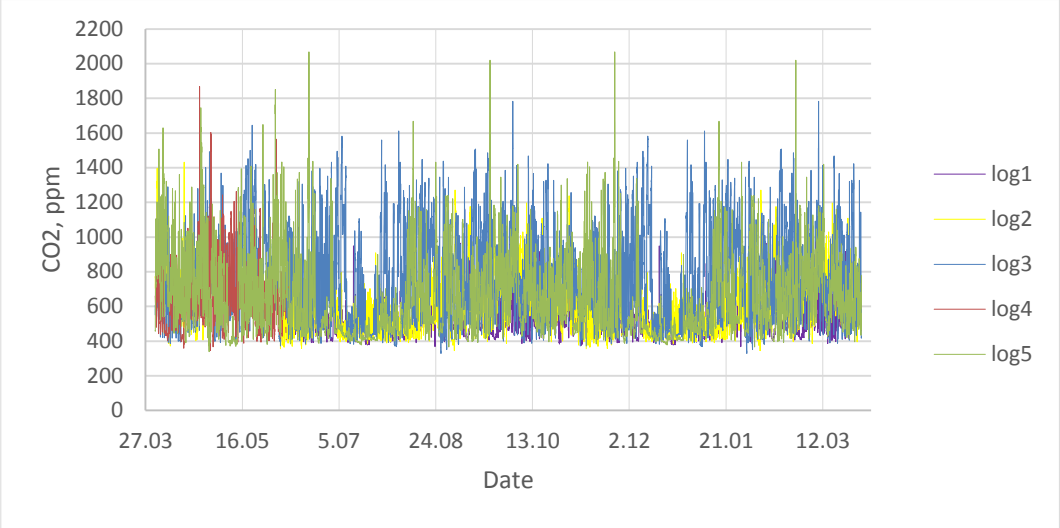

Figure 17 Room air carbon dioxide content in Herne 32 (annual period)

The following duration diagram (Figure 18) displays the measured annual indoor air carbon dioxide content.

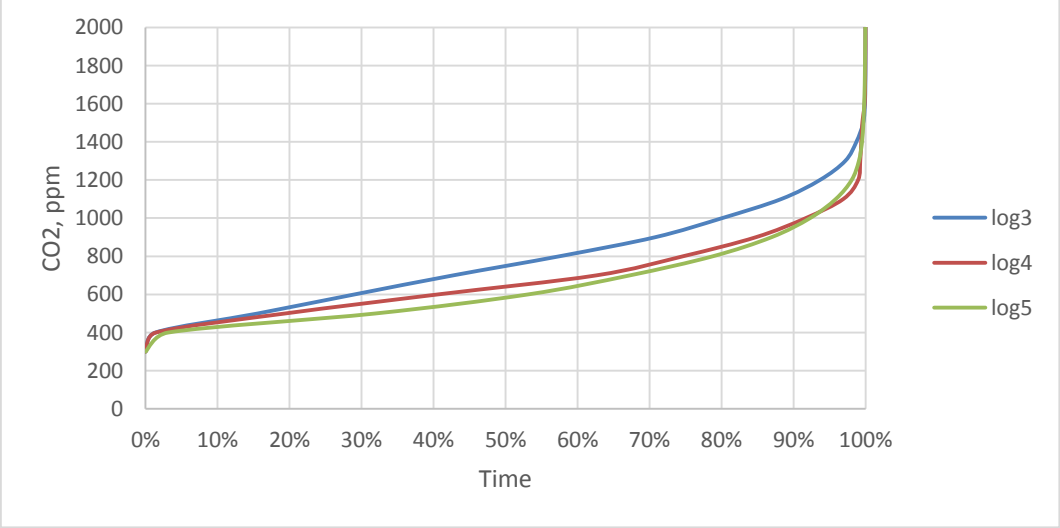

Figure 18 Duration diagram of the room air carbon dioxide content in Herne 32 (annual period)

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The following conclusions can be drawn regarding the measurement results in Herne 32 building:

- Room air CO_2 content reached its peak value of 2000 ppm;
- First floor room (logger 3) air CO_2 content exceeded 1000 ppm ca 20% of the time during the year;
- Second floor room (logger 4) and the third floor (logger 5) air CO_2 content exceeded 1000 ppm ca 8% of the time during the year.

6. Summary

Office building (Tiigi 11). Indoor air temperature and moisture conditions in the meet the requirements. From the perspective of the building energy performance, the air temperature set point should be lowered ca 1 ^{o}C to sustain average air temperature at 21 ^{o}C. The building is naturally ventilated, though the air exchange rates are acceptable: air carbon dioxide content during the working hours exceeded 1000 ppm for only 10…20% of the time. Low moisture excess in the office building rooms, which not exceeded recommended value of 2,5 g/kg during the winter season, is the result of the fair air exchange in the rooms. During the cold period, room moisture content was in good correlation with the outside air temperature. Summer period in 2012 was relatively cool and outside air temperature exceeded 25 ^{o}C (max 33 ^{o}C) only for several days. Thanks to the building thermal inertia, indoor air temperature exceeded 25 ^{o}C only in one room out of three measured. The duration of the temperature over 25 ^{o}C in that room was relatively small. The indoor climate conditions in Tiigi 11 building are quite decent.

Apartment building (Herne 32) was overheated and the indoor air temperature exceeded 21 ^{o}C for ca 65…95% of the heating season duration in different rooms. Throughout the summer period, indoor air temperatures continuously exceeded 25 ^{o}C. In fact, the building indoor air temperature conditions were not in the optimal range. The average daily moisture excess in the building within the winter and spring seasons exceeded sometimes twice the recommended 2,5 g/kg value. Taken above into an account, moisture conditions in the building are not acceptable and there is a risk of moisture damage. High indoor air moisture content is a result of the insufficient air exchange (ventilation) in rooms. The moisture excess has some correlation to human activity in the apartment. In different rooms air carbon dioxide content exceeded recommended 1000 ppm for ca 8…20% of the time during the year. Short-term maximum CO_2 concentration reached its peak at 2000 ppm. The apartment building indoor climate conditions cannot be considered as acceptable.

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APPENDIX 1

Spring period measurement results analysis

1. Tiigi 11

1.1. Air temperature

The following graphs illustrate Tiigi 11 building air temperatures during the spring period (March-May), when outside air temperature varied from -6 to 18 ^{o}C.

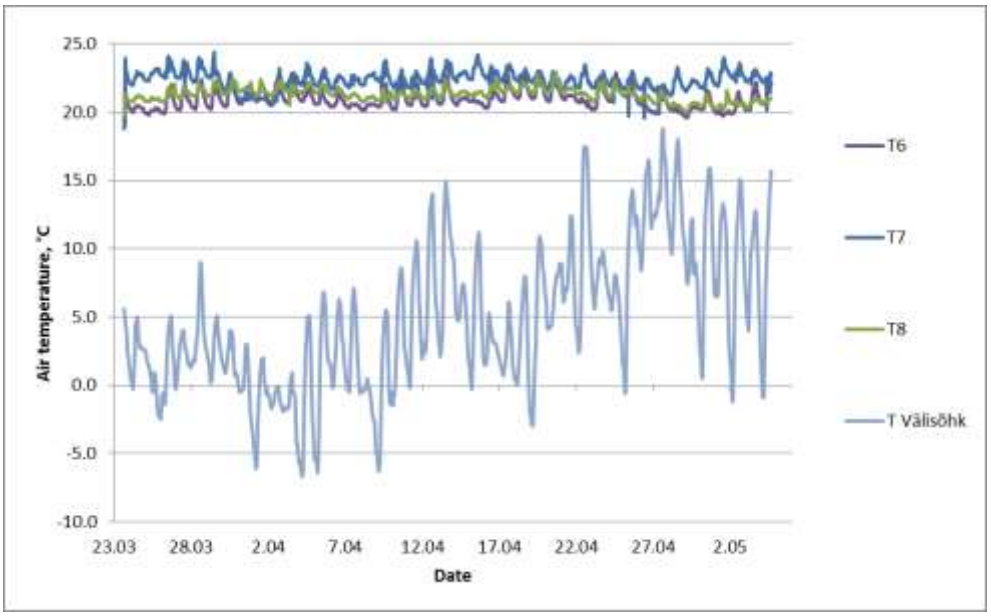

Figure 1 Outside air temperature and indoor air temperature in Tiigi 11 building (March – May period)

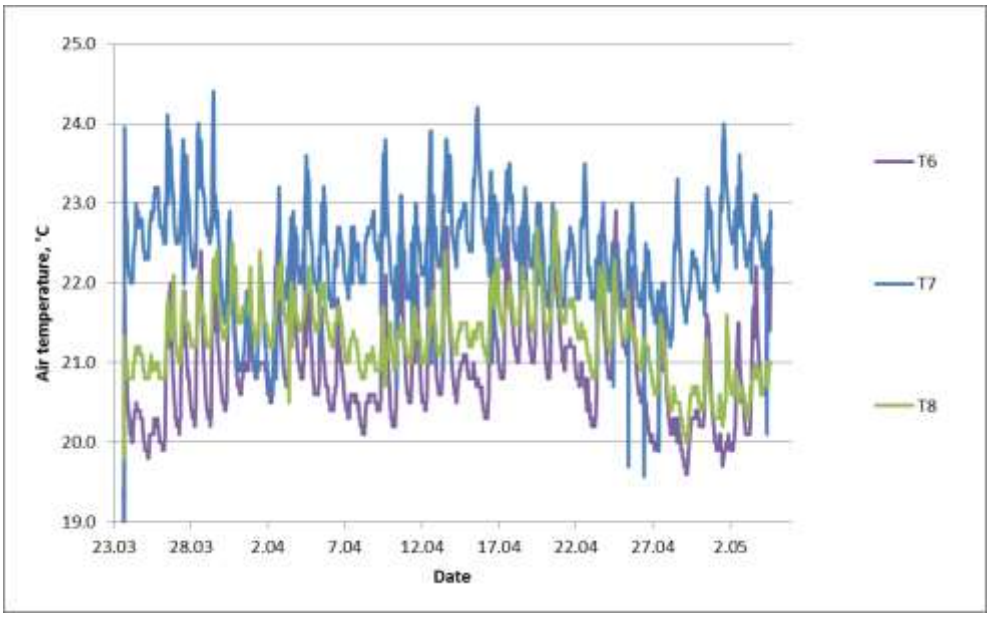

Figure 2 Indoor air temperature in Tiigi 11 building (March-May period)

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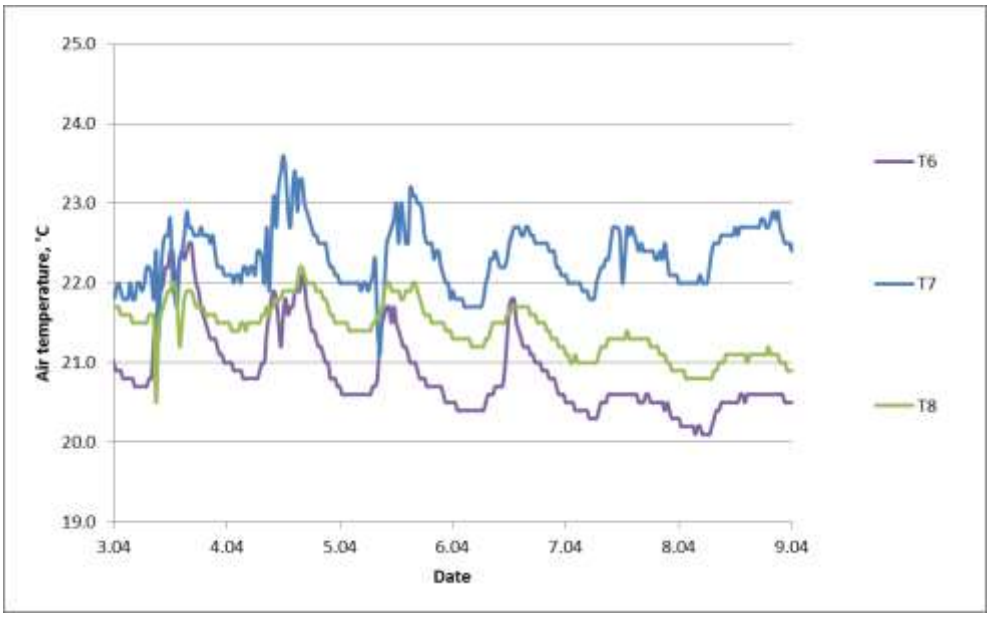

Figure 3 Indoor air temperature in Tiigi 11 building during the week period, when outside air temperature varied -6…6 °C

The following conclusions can be drawn regarding the measured indoor air temperature in Tiigi 11 building:

- Indoor air temperature varies 19,8…24,3 °C,;
- II floor room (logger 7) air temperature is ca 1…1,5 °C outsidehigher compared to other measured rooms. From energy performance perspective the heating set point in the room should be lowered by ca 1…1,5 °C;
- During the working hours indoor air temperature fluctuation is ca 1…1,5 °C;
- The building heating system have managed to react on the outside air temperature changes in time and ensured stable air temperature conditions in rooms.

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1.2. Relative humidity and moisture content

The following graphs describe the Tiigi 11 building indoor air relative humidity.

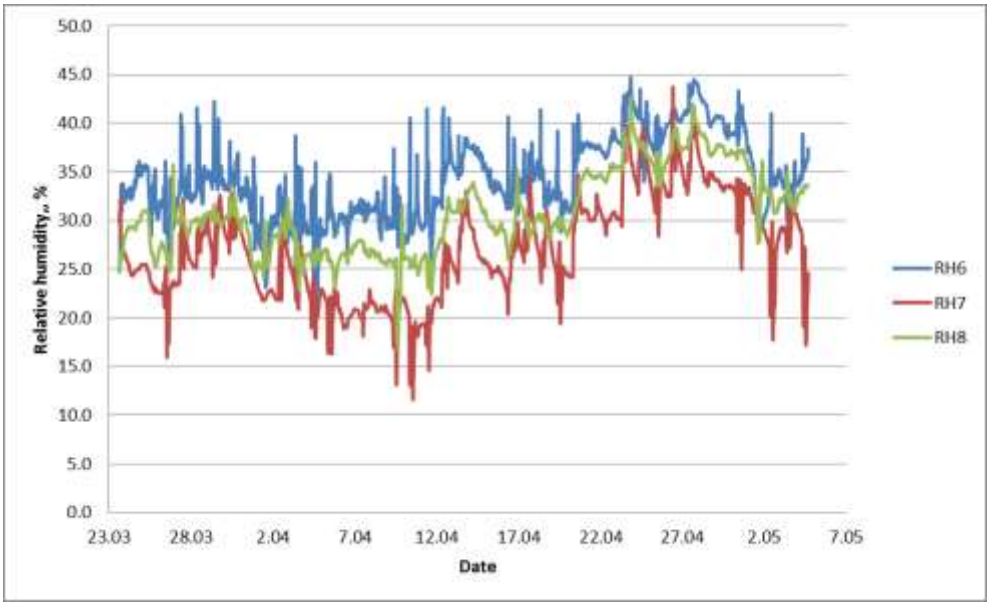

Figure 4 Tiigi 11 building indoor air relative humidity

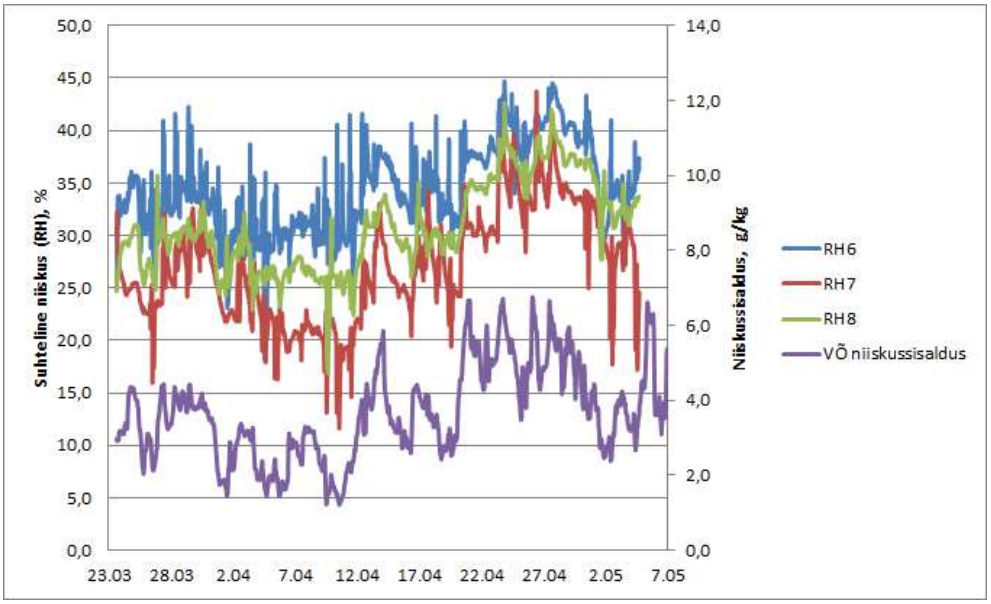

Figure 5 Outside air moisture content and indoor air relative humidity correlation in Tiigi 11 building (spring period)

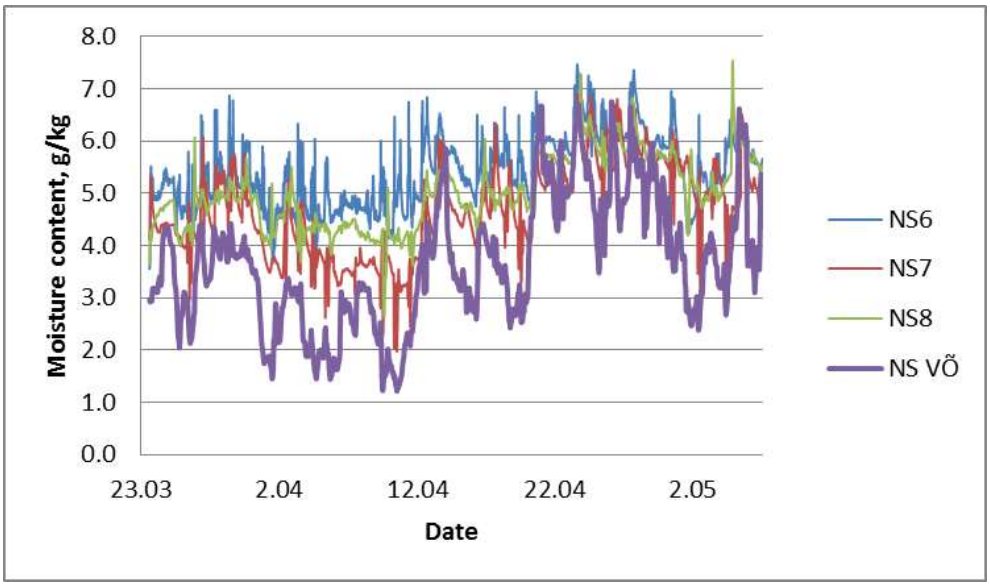

Figure 6 Outside and indoor air moisture content in Tiigi 11 building (spring period)

Indoor air quality is characterized by the difference between indoor and outdoor air moisture content, which is defined as moisture excess. The higher the indoor air moisture excess value, the lower is the air exchange in the room and the higher is the risk of moisture damage. Moisture excess values during the winter season should not exceed 2,5 g/kg (3 g/m3). The following graph describes the daily average moisture excess in measured rooms depending on the outside air temperature.

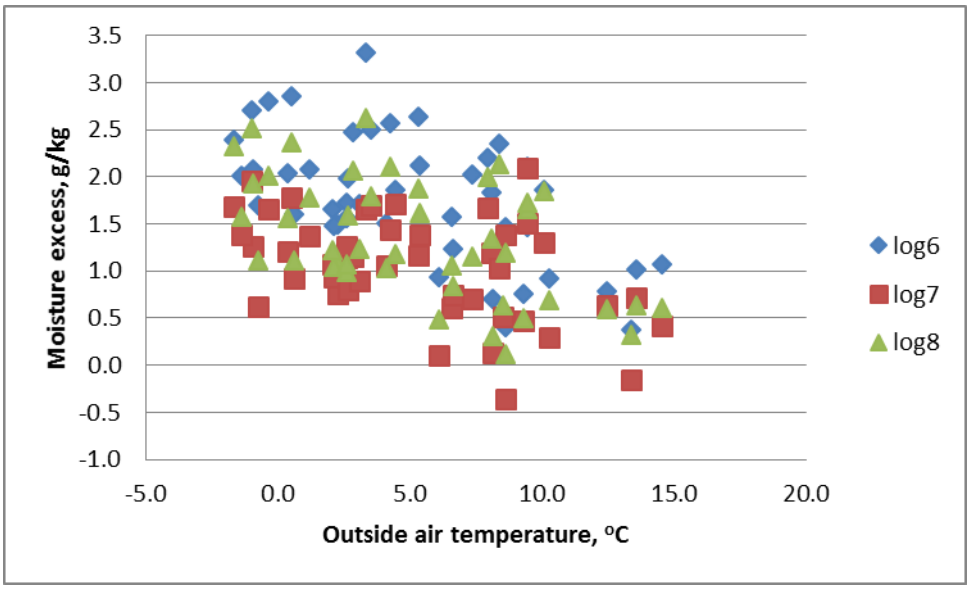

Figure 7 Daily average moisture excess content depending on the daily average outside air temperature

The following conclusions can be drawn regarding the measurement results within spring period:

- Indoor air relative humidity varies 15…45%;
- Indoor air relative humidity is tend to be lower in room (logger 7) with higher indoor air temperature in comparison to room (logger 6) with lower indoor air temperature;
- Indoor air relative humidity correlates to outside air moisture content;
- Daily average moisture excess did not exceeded 3 g/kg. The building has a slight risk of moisture damage.

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1.3 Air carbon dioxide content (CO_2)

The following graphs describe the Tiigi 11 building indoor air carbon dioxide content within spring period.

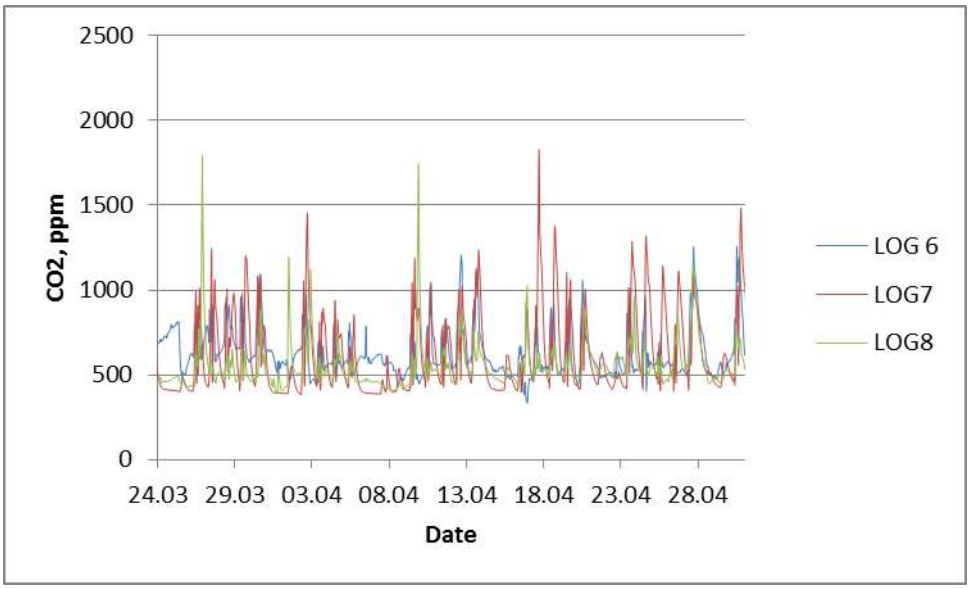

Figure 8 Indoor air CO_2 content within spring period

The following graph illustrates indoor air CO_2 content within basic week period.

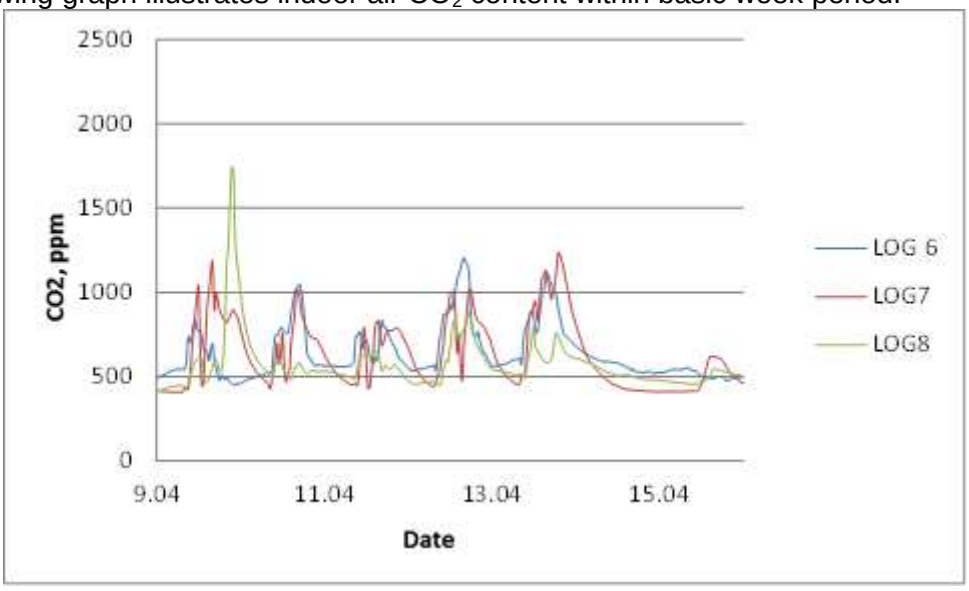

Figure 9 Indoor air CO_2 content within basic week period

In accordance with the World Health Organization (WHO) recommendations, CO_2 content in the indoor air should not exceed 1000 ppm.
The following conclusions can be drawn regarding the measurement results in Tiigi 11 building:

- General CO_2 content during working hours stayed below 1000 ppm;
- Indoor air carbon dioxide content exceeded recommended 1000 ppm value for several hours a day;
- Considering that the building is being naturally ventilated, the air exchange effectiveness for this type of system is sufficient.

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2. Herne 32

2.1. Air temperature

The following graphs illustrate Herne 32 building air temperatures during the spring period (March-May), when outside air temperature varied from -6 to 18 °C.

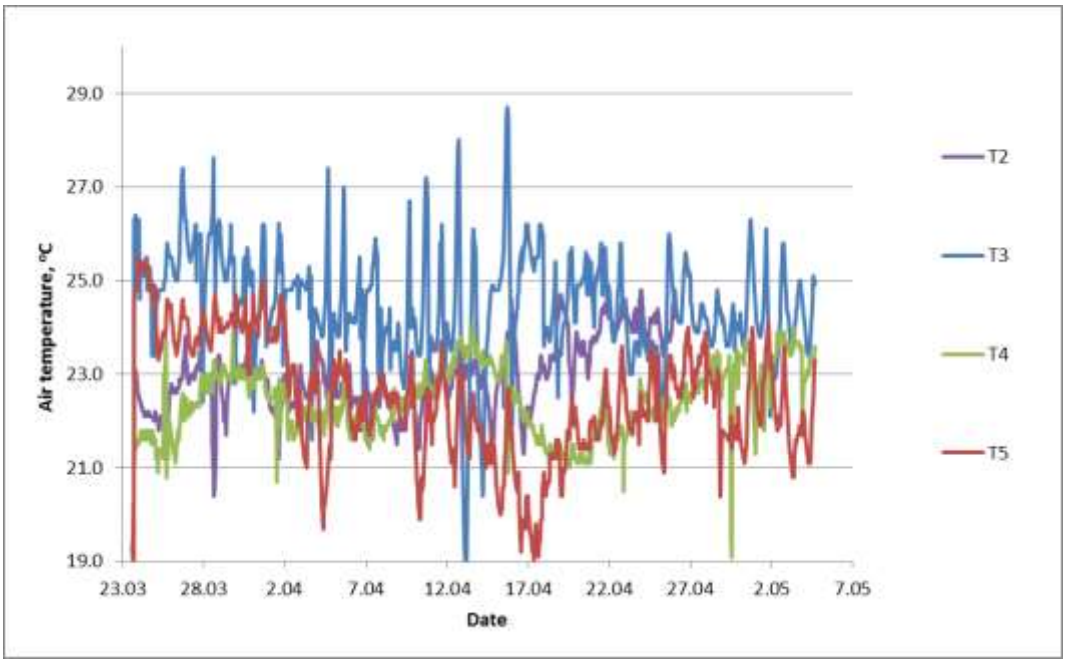

Figure 10 Indoor air temperatures in Herne 32 building (March-May)

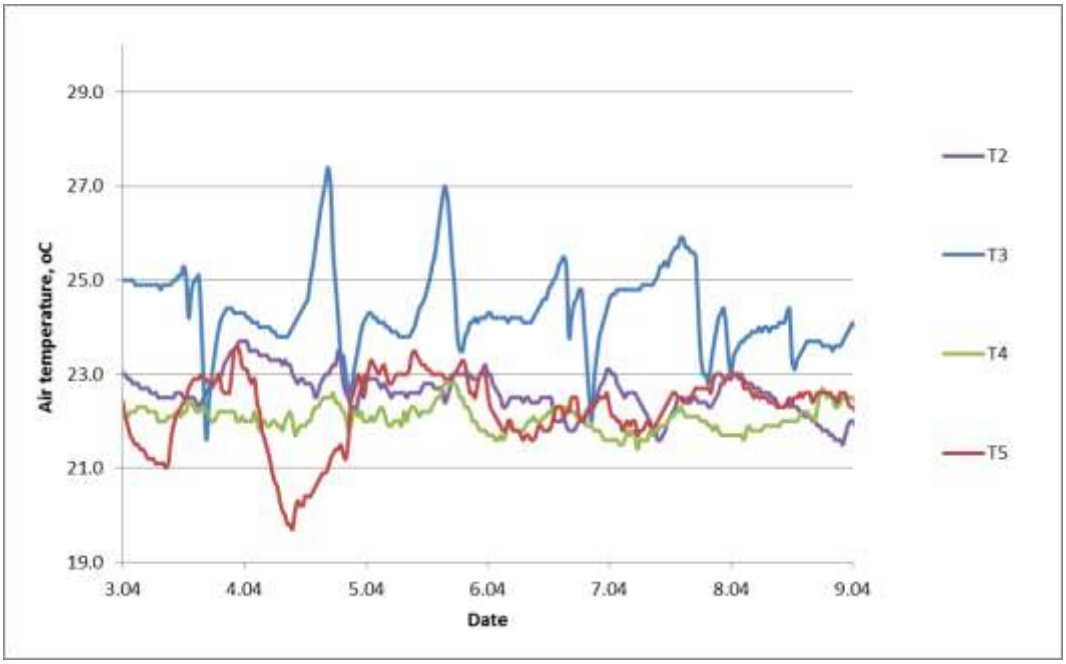

Figure 11 Indoor air temperature in Herne 32 building during the week period, when outside air temperature varied from -6 to 6 °C

The following conclusions can be drawn regarding the measurement results in Herne 32 building:

- Indoor air temperature varies 21…27 °C within spring period;
- Short-term indoor air temperatures below 21 °C apparently occurred due to opened windows, when cold air entered the room;

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- The average measured temperature of 23,3 ^{o}C within the spring period is rather high. High heating set point of the air temperature provides an increase in the heating energy consumption. In example, if this building average indoor air temperature would stay at 21 ^{o}C instead of 23,2 ^{o}C, the annual heating energy consumption would be ca 15% lower;
- There is a noticeable air temperature difference depending on the location of the measured room. Air temperature in room, where logger 3 was located, stayed at 24,5 ^{o}C. Other rooms air temperature varied in 22,7…23 ^{o}C range;
- The building heating system have managed to react on the outside air temperature changes in time and ensured stable air temperature conditions in rooms.

2.2. Relative humidity and moisture content

The following graphs describe the Herne 32 building indoor air relative humidity.

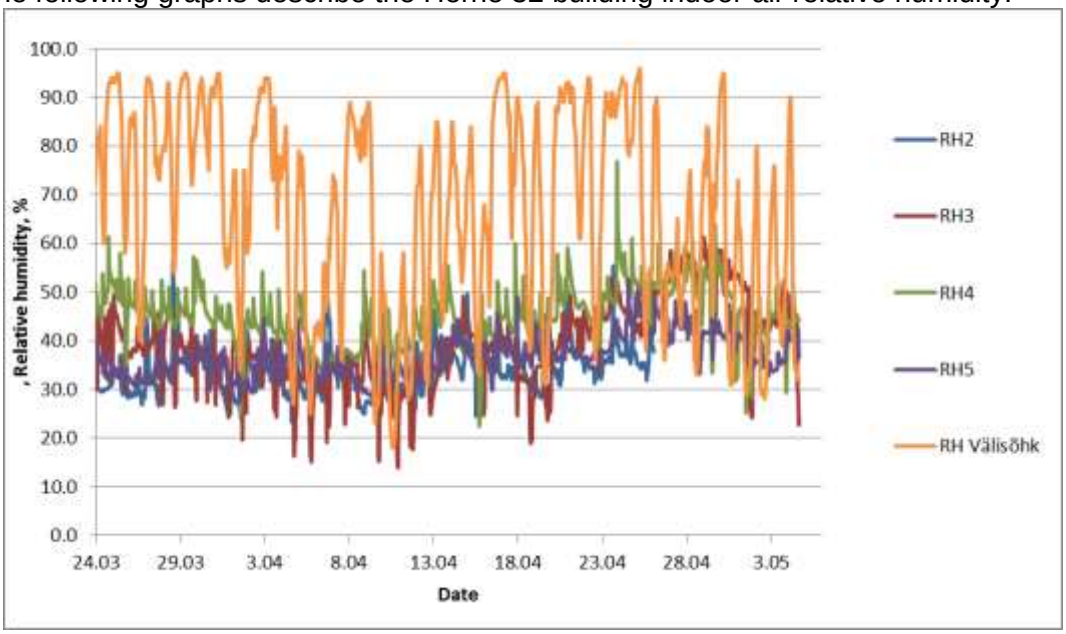

Figure 12 Herne 32 building indoor air relative humidity (March-May period)

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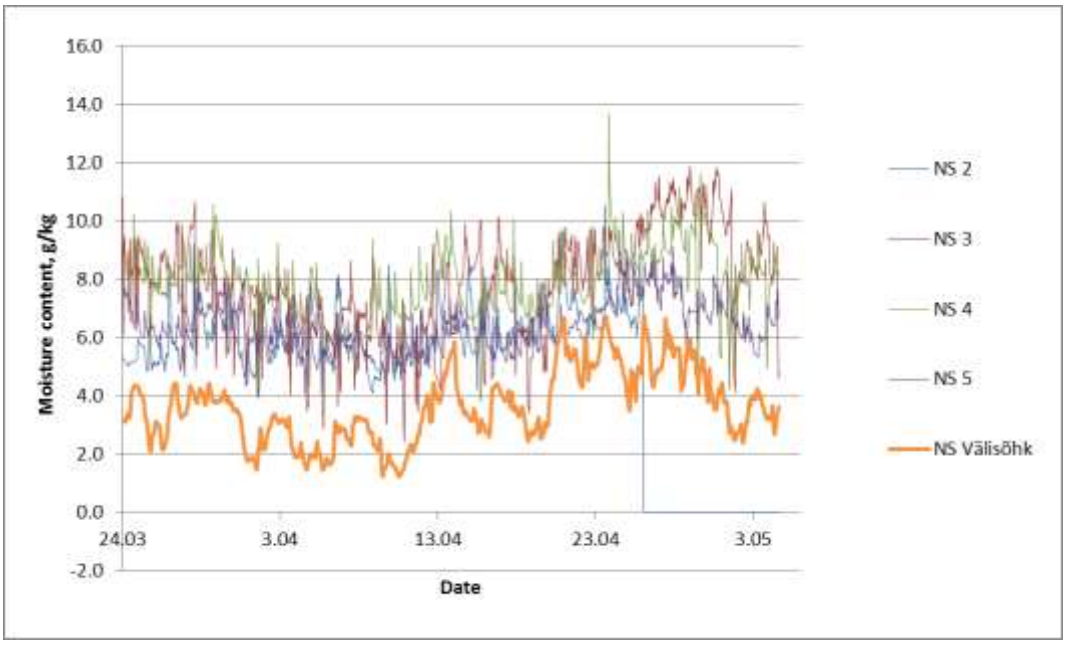

Figure 13 Outside and indoor air moisture content in Herne 32 building (spring period)

Indoor air quality is characterized by the difference between indoor and outdoor air moisture content, which is defined as moisture excess. The higher the indoor air moisture excess value, the lower is the air exchange in the room and the higher is the risk of moisture damage. Moisture excess values during the winter season should not exceed 2,5 g/kg (3 g/m3). The following graphs describes the daily average moisture excess in measured rooms depending on the outside air temperature.

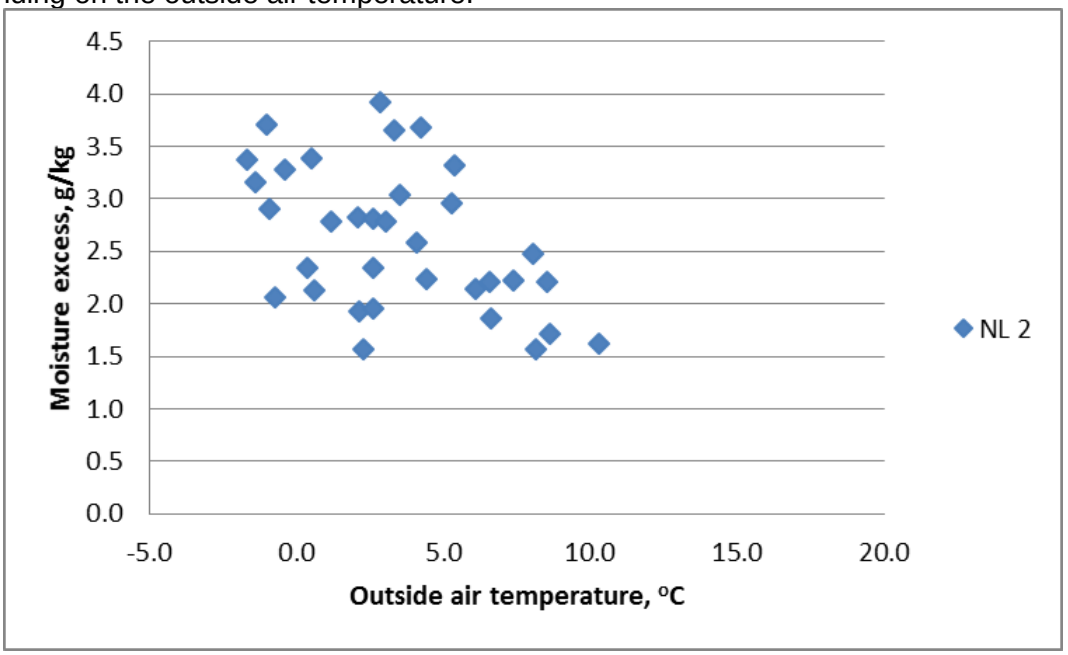

Figure 14 Daily average moisture excess content in room (logger 2) depending on the daily average outside air temperature

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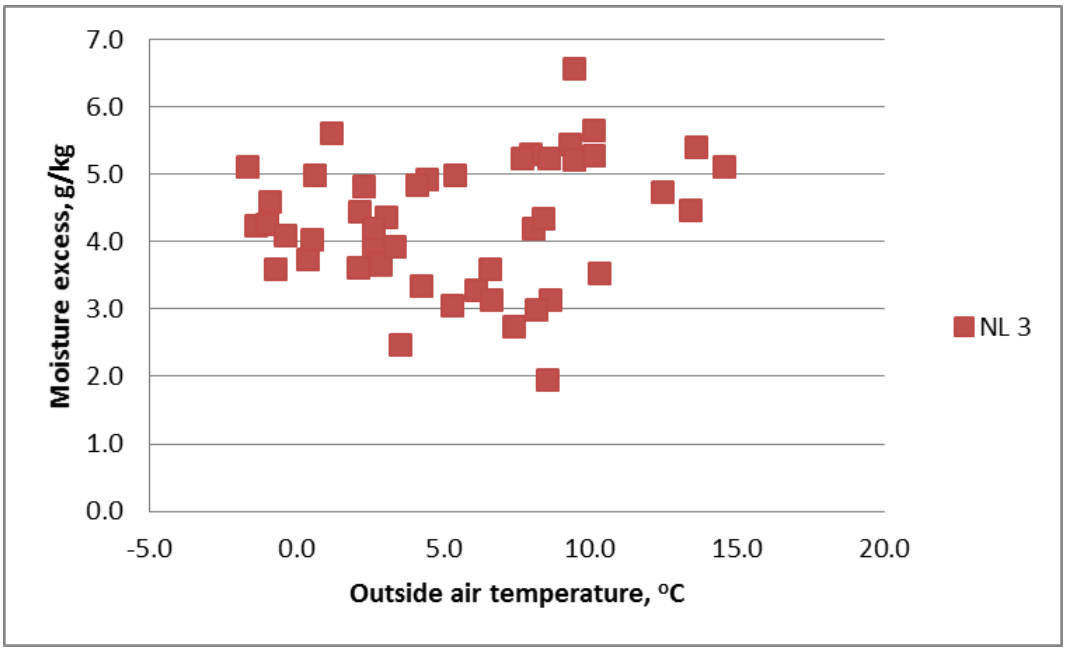

Figure 15 Daily average moisture excess content in room (logger 3) depending on the daily average outside air temperature

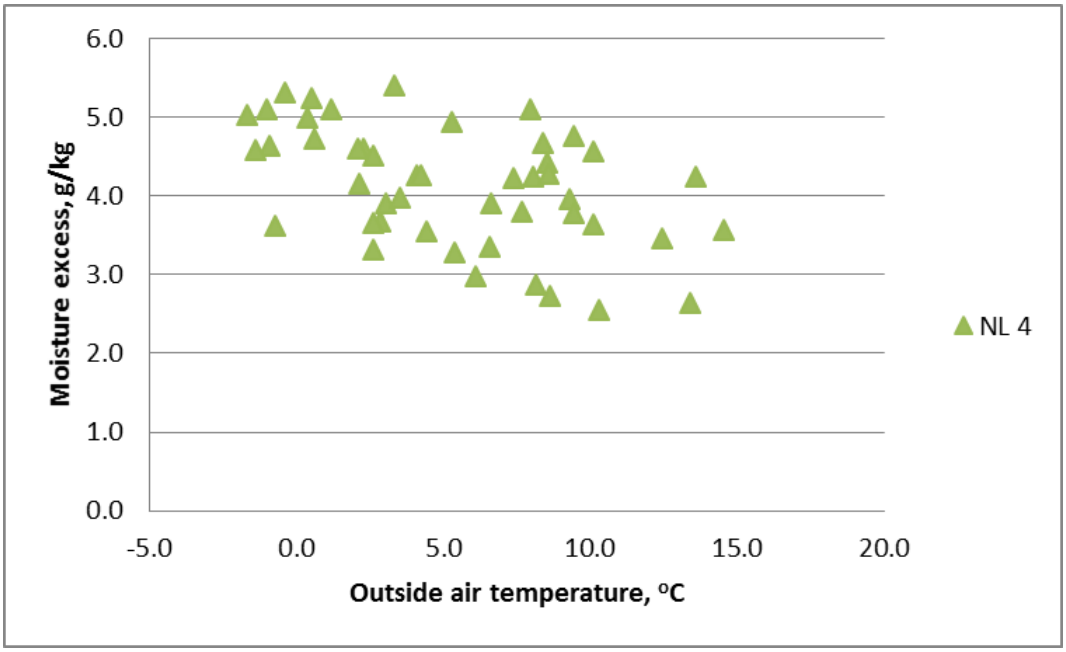

Figure 16 Daily average moisture excess content in room (logger 4) depending on the daily average outside air temperature

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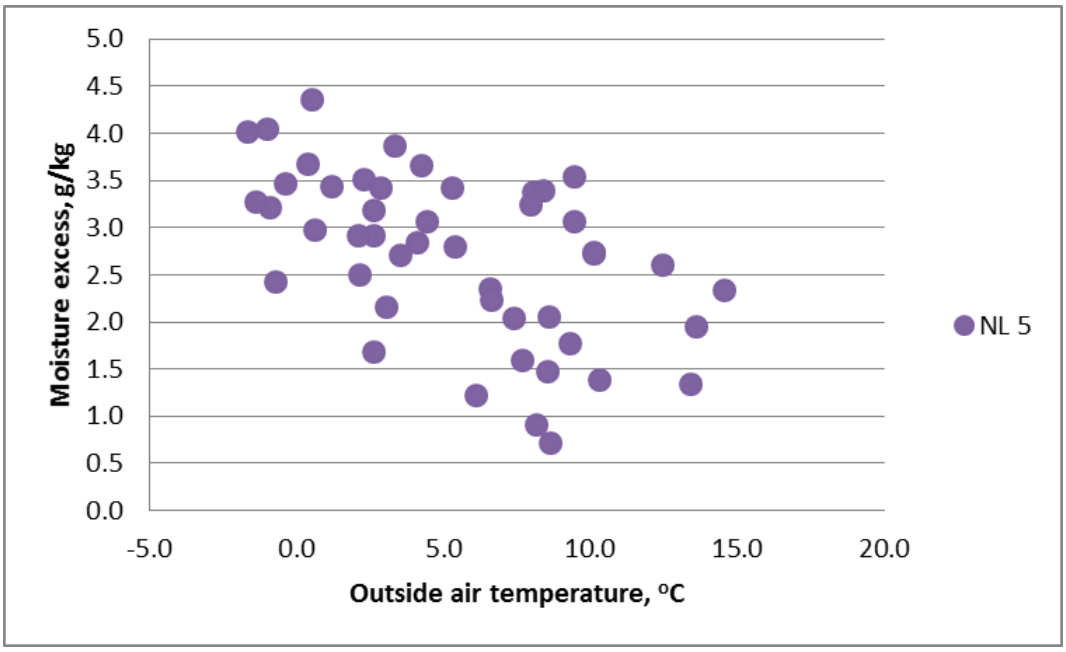

Figure 17 Daily average moisture excess content in room (logger 5) depending on the daily average outside air temperature

The following conclusions can be drawn regarding the indoor air relative humidity measurement results in Herne 32 building:

- Indoor air relative humidity varies in 25…60 % range;
- The indoor air moisture excess during the spring period significantly exceeded (sometimes twice) recommended value of 2,5 g/kg and there is a high risk of moisture damage. The peak moisture excess was recorded in rooms, where data logger 3 and 4 were located.
- Not sufficient air exchange (ventilation) rate in the building results in a high moisture excess of the indoor air;
- As the outside temperature decreased, the moisture excess in the room air increased. This indicates, that during the colder weather period windows in rooms are being less opened.

2.3. Air carbon dioxide content (CO_2)

The following graphs describe the Herne 32 building indoor air carbon dioxide content within spring period.

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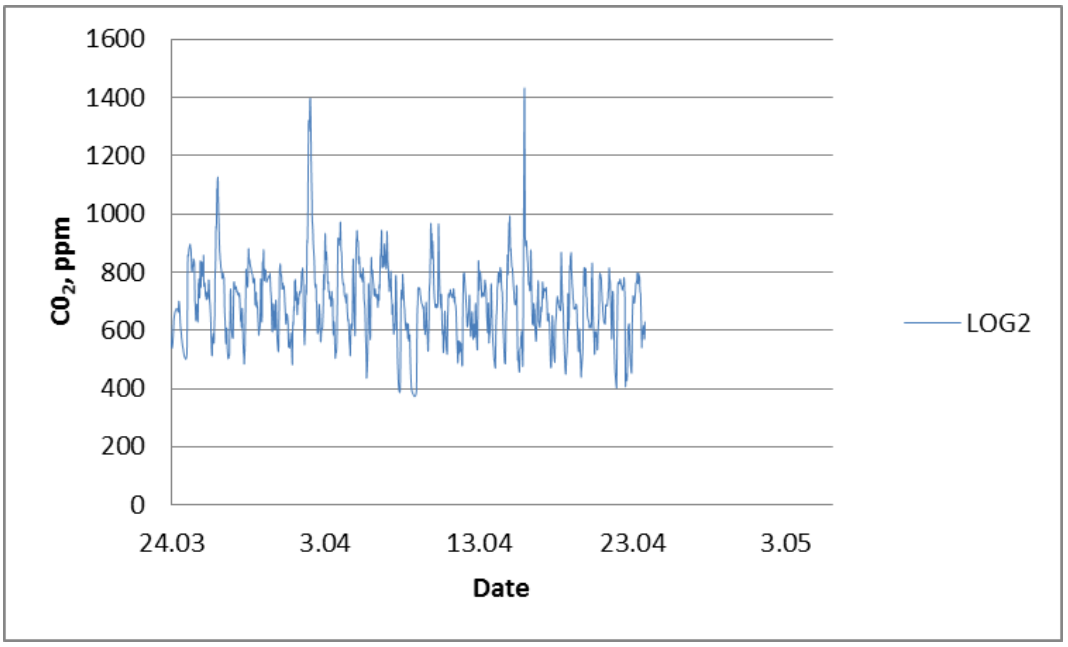

Figure 18 Data logger 2 measurement results

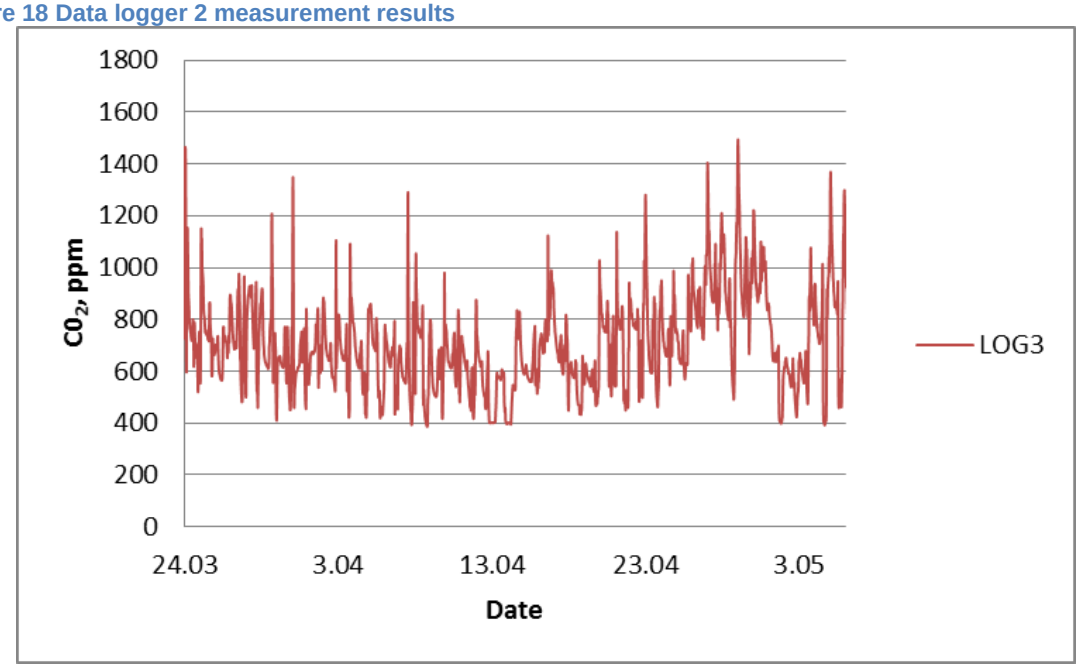

Figure 19 Data logger 3 measurement results

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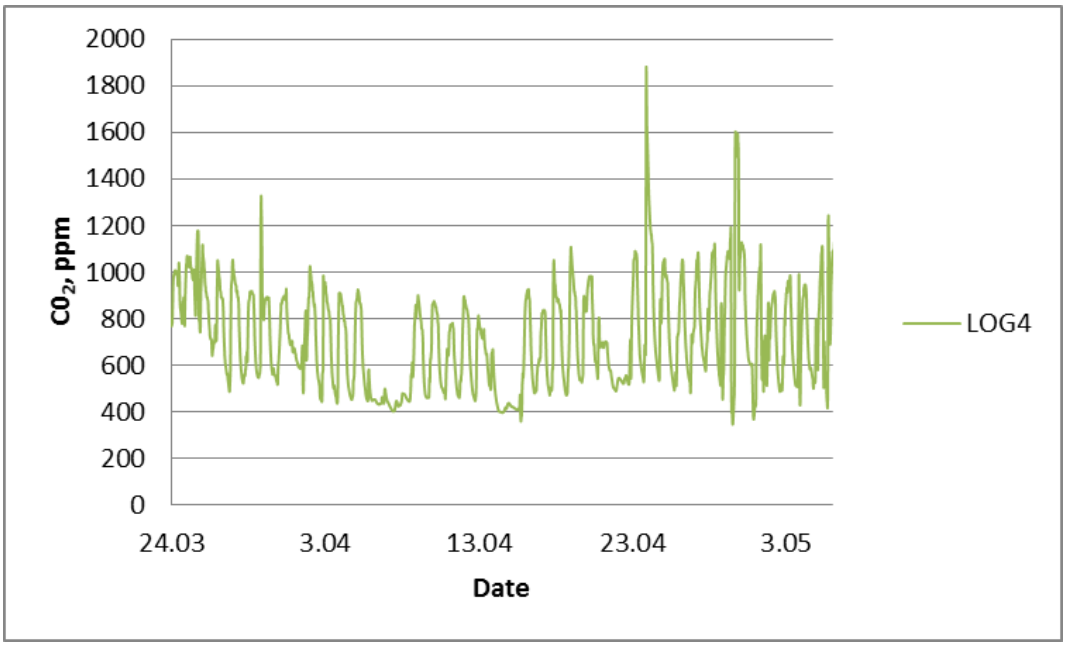

Figure 20 Data logger 4 measurement results

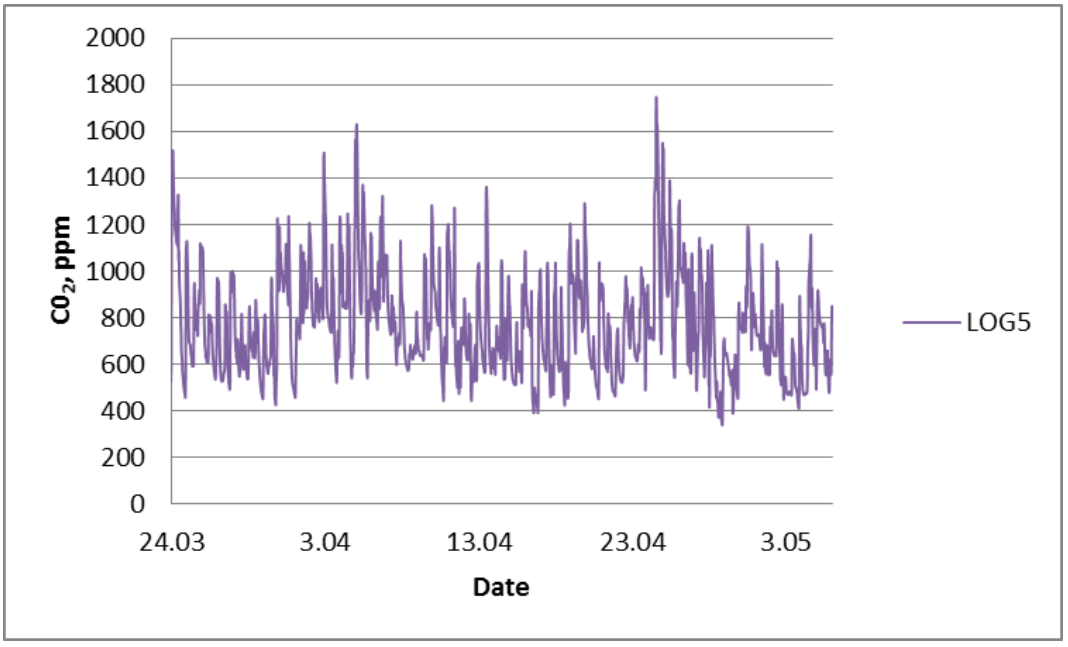

Figure 21 Data logger 5 measurement results

In accordance with the World Health Organization (WHO) recommendations, CO_2 content in the indoor air should not exceed 1000 ppm.
The following conclusions can be drawn regarding the measurement results in Herne 32 building:

- Occasionally, in all measured rooms indoor air carbon dioxide content exceeded 1000 ppm;
- Highest CO_2 content duration over 1000 ppm was recorded in the third floor room (logger 5).

The following graph illustrates the correlation of moisture excess to CO_2 excess (outside air and indoor air CO_2 content difference). There is a noticeable dependency between moisture excess and CO_2 excess.

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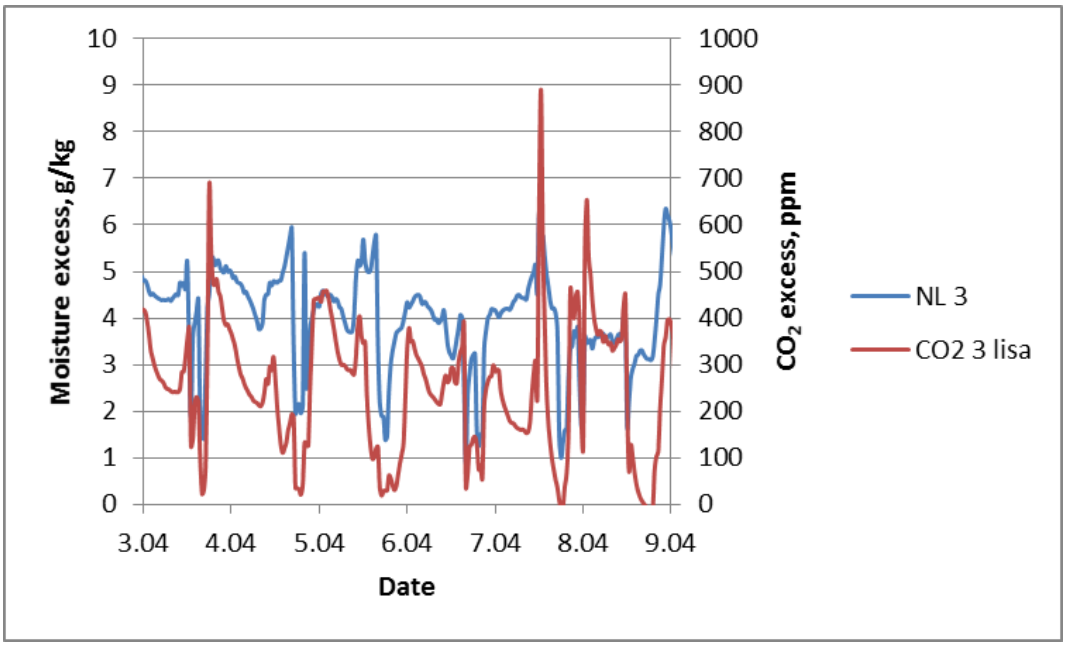

Figure 22 Indoor air moisture excess to CO_2 excess dependency

3. Spring period summary

Indoor air temperature and moisture conditions in the office building (Tiigi 11) are fair and acceptable.

Based on the analysis above, apartment building (Herne 32) is overheated. The indoor air moisture excess during the spring period significantly exceeded (sometimes twice) recommended value and there is a high risk of moisture damage. The air exchange in a building is not sufficient.

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APPENDIX 2

Analysis of measurement results in warm period

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1. Tiigi 11

1.1 Air temperature

Summer period in 2012 was relatively cool and outside air temperature exceeded 25 °C only for several days. At the end of July eventually outside air temperature reached its peak at about 30 °C. The following graph illustrates the indoor and outside air temperature at the end of July.

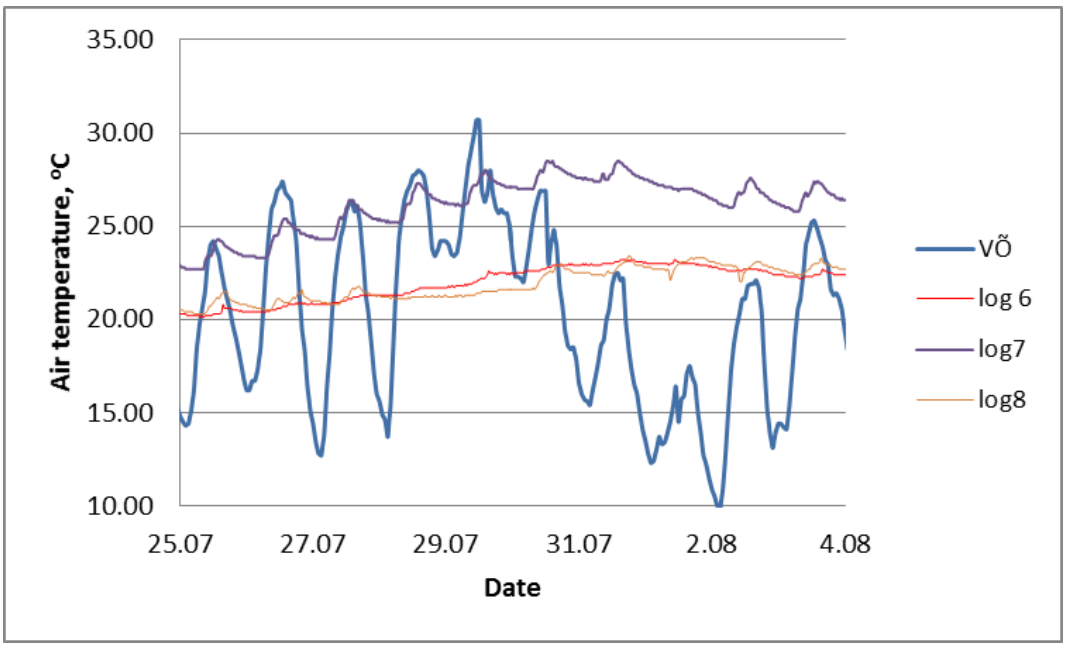

Figure 16 Indoor and outside air temperature in Tiigi 11 building within warm period

Data elaborated from the first floor loggers (nr6, nr7) illustrates that despite the outside air temperature exceeded 25 °C, indoor air temperature remained within the comfort range (below 25 °C). However, second floor room air temperature reached its peak within 27…28 °C range. Despite the low outside air temperature during the night, indoor air temperature decreased less than 1 °C. Daily average outside air temperature rise was accompanied by a slight rise of indoor air temperature. Analysed building has quite significant thermal inertia.

1.2 Relative humidity

Indoor air relative humidity varies in 40…75 % range.

1.3 Air carbon dioxide content

Indoor air carbon dioxide content within working hours fluctuated in the same range, as in spring period (Appendix 1). During the holidays indoor air CO_2 content was significantly lower.

2 Herne 32

2.1 Air temperature

The following graph describes the indoor and outside air temperatures during the warm period.

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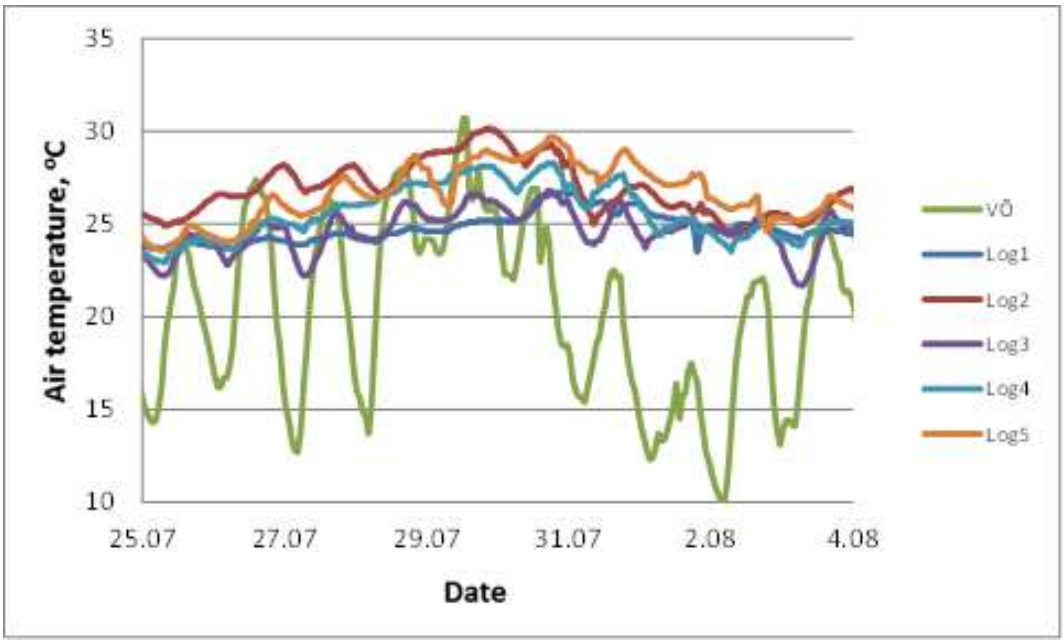

Figure 2 Indoor and outside air temperature in Herne 32 building within warm period

Analysed building has quite significant thermal inertia. Measured indoor air temperature varied in 25 to 30 ^{o}C range during the warm period. None of the measured indoor air temperature exceeded the outside air temperature. The maximum values were recorded in third floor room (logger 5) and in the attic apartment (logger 2).

2.2 Relative humidity

Room air relative humidity varied within 30…75% range, which can be considered acceptable.

2.3 Air carbon dioxide content

Room air carbon dioxide content stayed within same ranges, as during the spring period (Appendix 1)

3 Warm period summary

In the office building (Tiigi 11), thanks to the building thermal inertia and relatively cold summer, indoor air temperature exceeded 25 ^{o}C only in one room out of three measured.
In the apartment building (Herne 32) indoor air temperature continuously exceeded 25 ^{o}C.

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APPENDIX 3

Analysis of measurement results for cold period

Part-financed by the European Union
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1. Tiigi 11

1.1. Air temperature

The following graph describes the indoor and the outside air temperature measurement results within cold period.

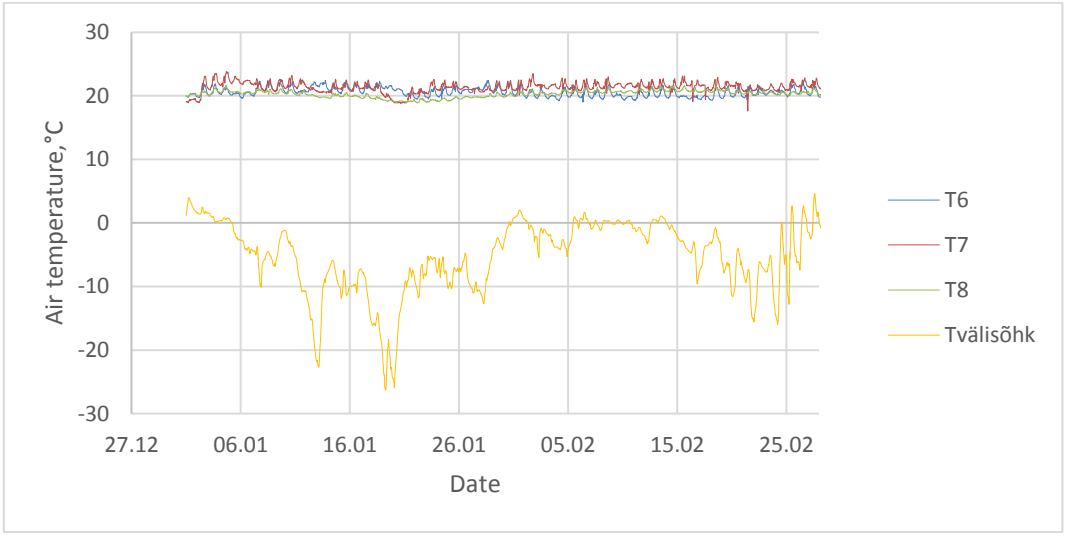

Figure 7 Indoor and outside air temperature within cold period

In the second half of January, the outside air temperature managed to go below -20 °C. Most of the measured period the outside air temperature stayed below 0 °C. When outside air temperature reached -20 °C and below, indoor air temperature dropped below 20 °C.

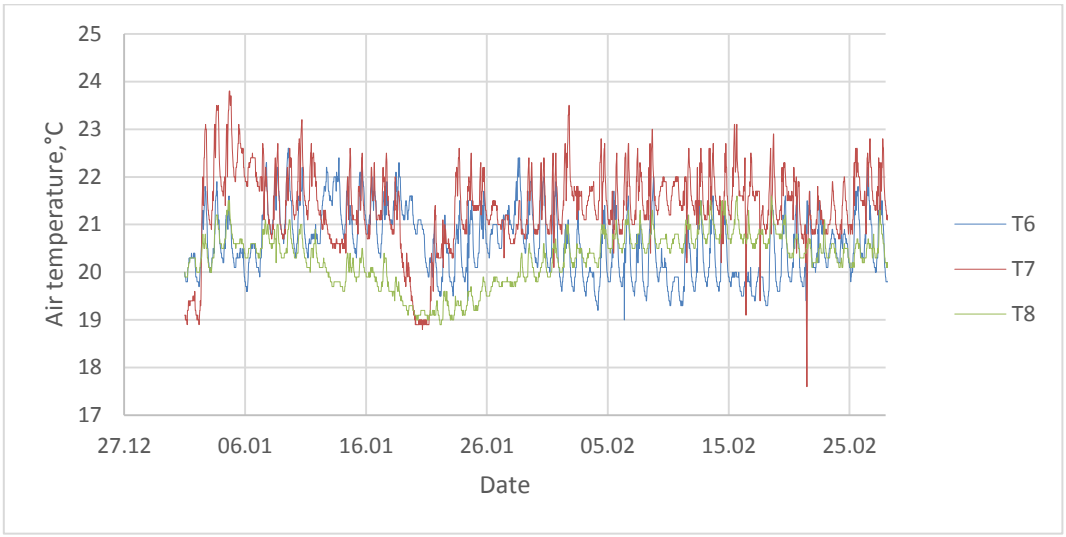

Figure 8 Indoor air temperature within cold period

Second floor room (T7) air temperature was ca 1 °C higher in comparison to first floor rooms.

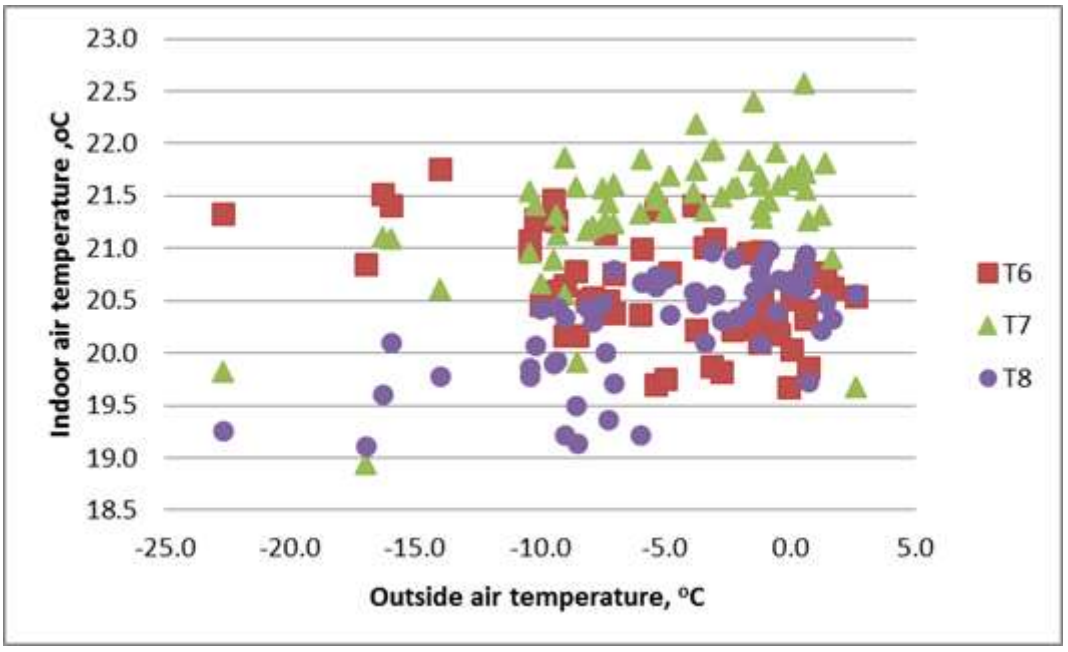

Figure 9 Daily average indoor air temperature depending on the daily average outside air temperature

Whenever the outside air temperature (Figure 3) drops below -10 °C, the set point of 20…21 °C cannot be maintained.

1.2. Relative humidity and moisture content

The following graph describes the indoor and the outside air relative humidity measurement results within cold period.

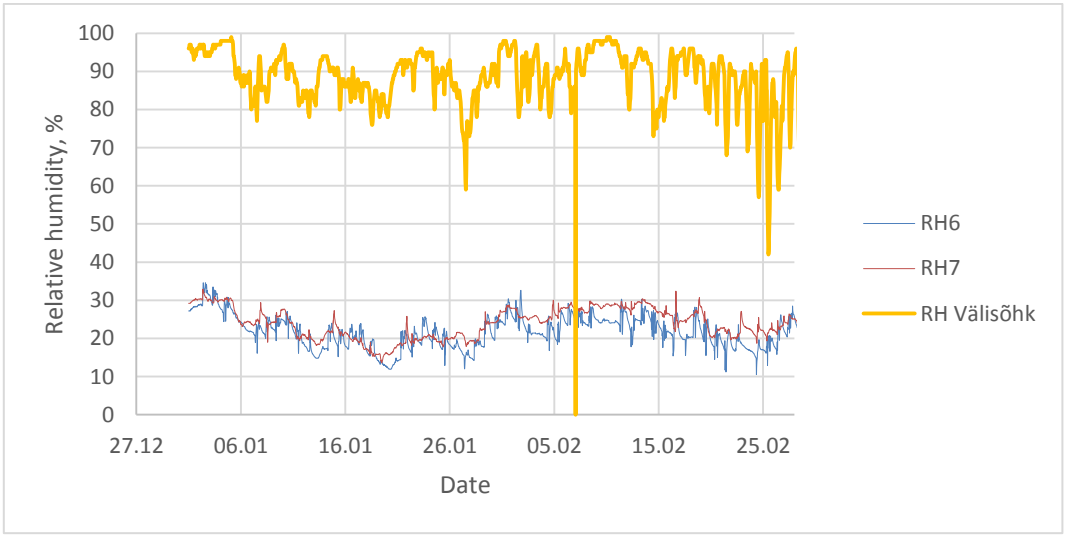

Figure 10 Indoor and outside air relative humidity within cold period

Indoor air relative humidity varied in 10…35 % range within cold period. Indoor air relative humidity correlates to outside air temperature – the colder the outside air is, the smaller is relative humidity value.

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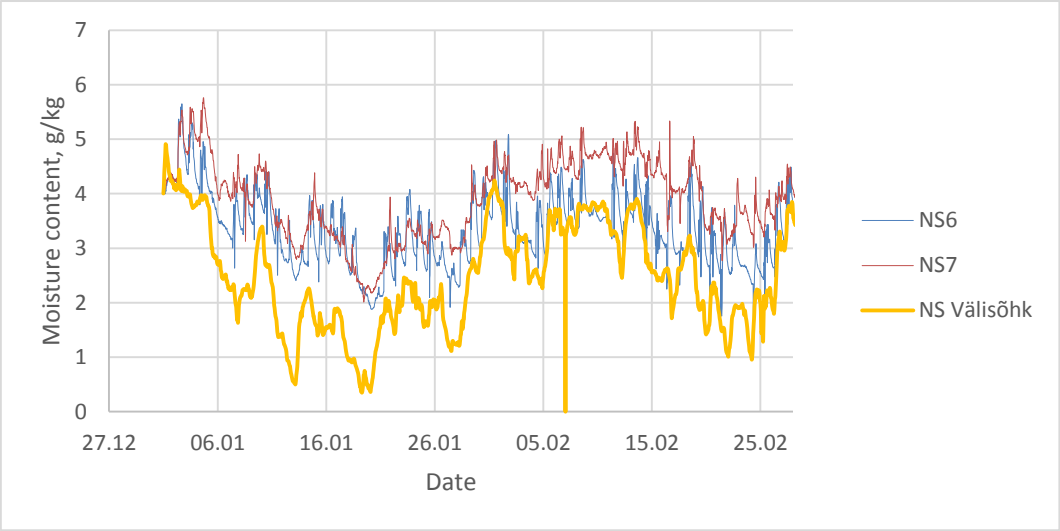

Figure 11 Indoor and outside air moisture content within cold period

Indoor air quality is characterized by the difference between indoor and outdoor air moisture content, which is defined as moisture excess. The higher the indoor air moisture excess value, the lower is the air exchange in the room and the higher is the risk of moisture damage. Moisture excess values during the winter season should not exceed 2,5 g/kg (3 g/m3). The following graph describes the daily average moisture excess in measured rooms depending on the outside air temperature.

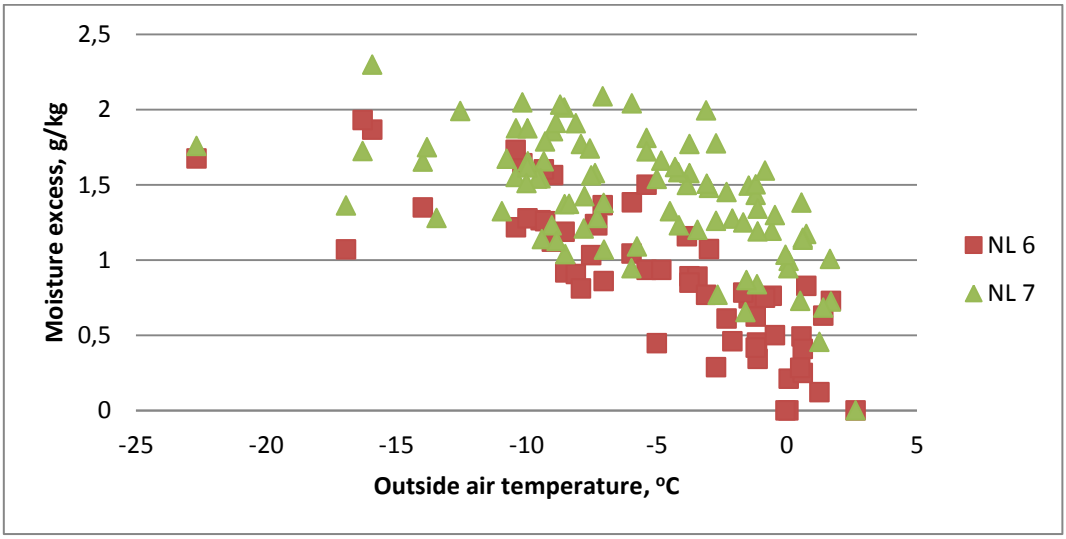

Figure 6 Daily average indoor air moisture excess content depending on the daily average outside air temperature

Indoor air moisture excess within cold period stayed below 2,5 g/kg and the building moisture conditions meet the requirements. There is no moisture damage risk in this building.

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1.3. Air carbon dioxide content

The following graphs describe the indoor air carbon dioxide measurement results.

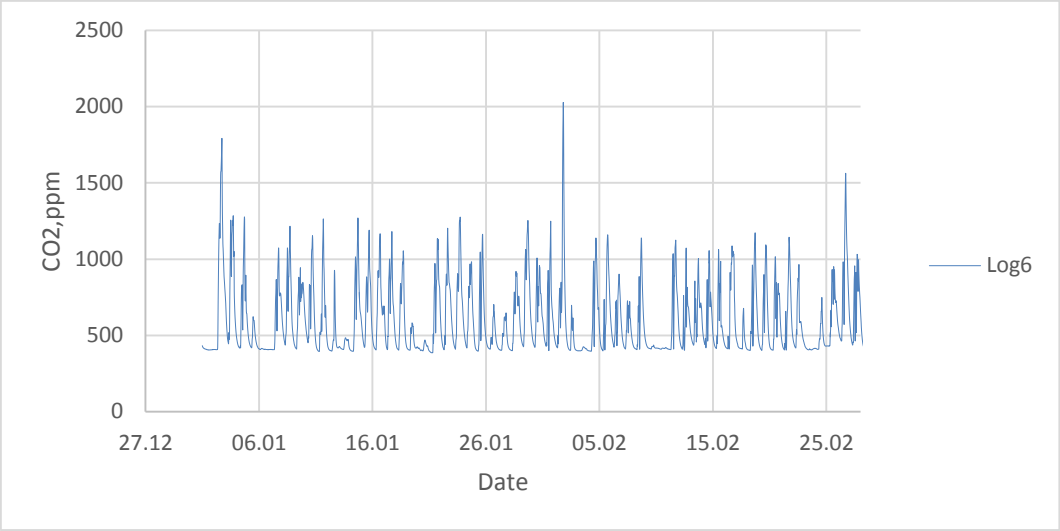

Figure 7 First floor room air carbon dioxide content within cold period

At a short-term perspective, indoor air CO_2 content peaked at ca 1500 ppm, but most of the time CO_2 content was below 1200 ppm.

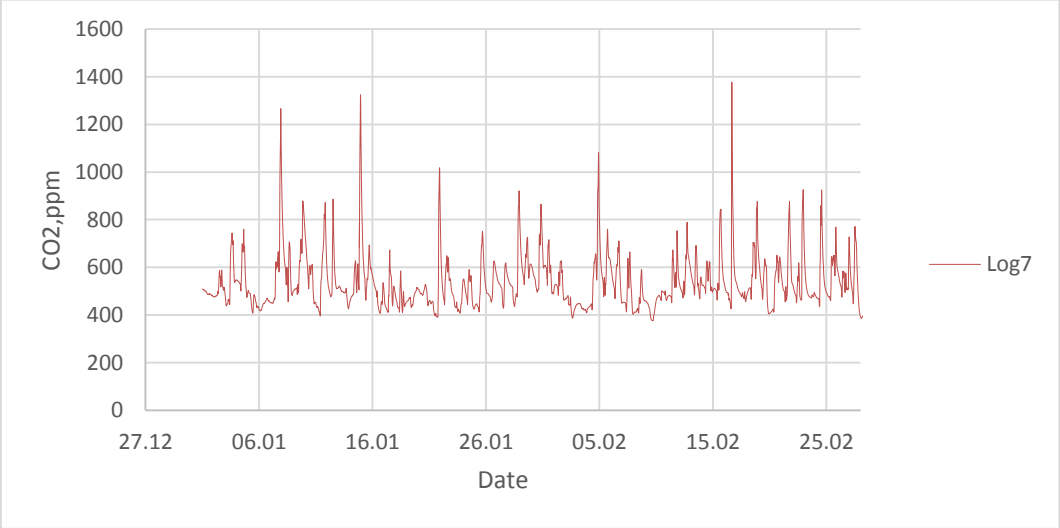

Figure 8 Second floor room air carbon dioxide content within cold period

The second floor room CO_2 content was commonly below 900 ppm, with short-term peaks of ca 1300 ppm.

1.3. Office building summary

During essentially cold weather indoor air temperature dropped below 20 ^{o}C. Most of the time indoor air temperature stayed within 20…23 ^{o}C range. Indoor air carbon dioxide content was in acceptable range. Indoor air moisture excess did not exceeded 2,5 g/kg during the cold period.

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2. Herne 32

2.1. Air temperature

The following graph describes the indoor and the outside air temperature measurement results within cold period.

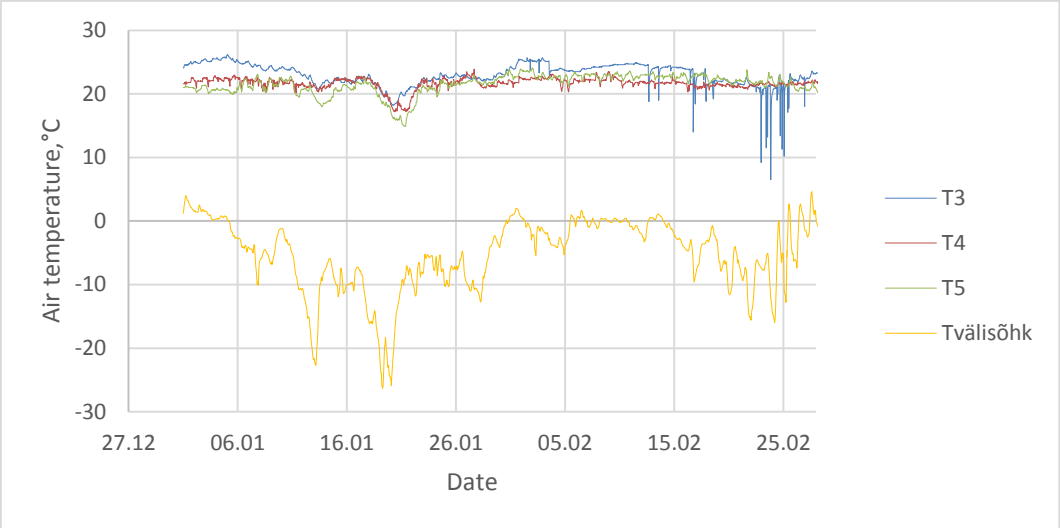

Figure 9 Indoor and outside air temperature within cold period

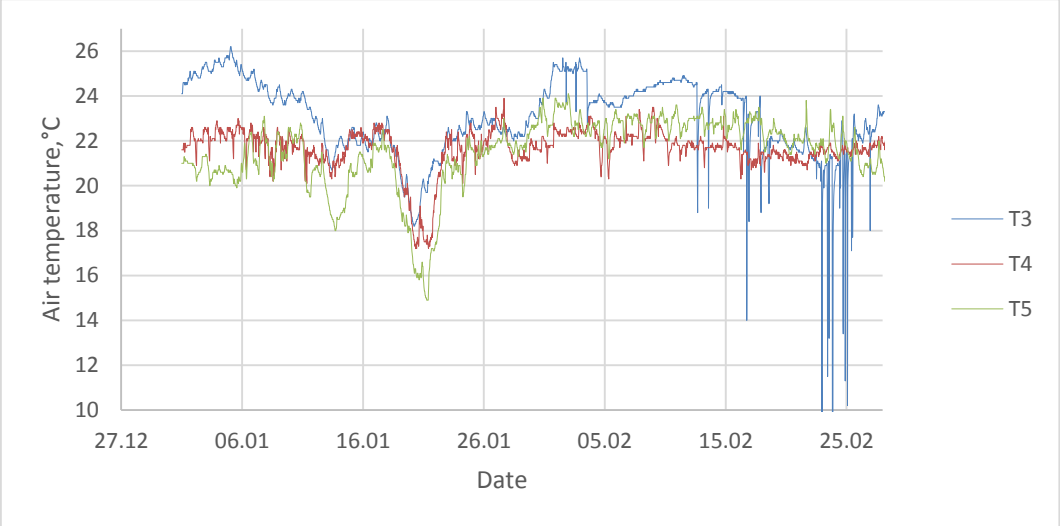

Figure 10 Indoor air temperature within cold period

Whenever air temperature dropped below -20 °C, the building heating system was not able to meet the required indoor air temperature. As a result, the indoor air temperature stayed in range 15…18 °C. The most sensitive to outside air temperature drops was third floor room (T5) .

The following graph illustrates the dependency of daily average indoor air temperature to daily average outside air temperature.

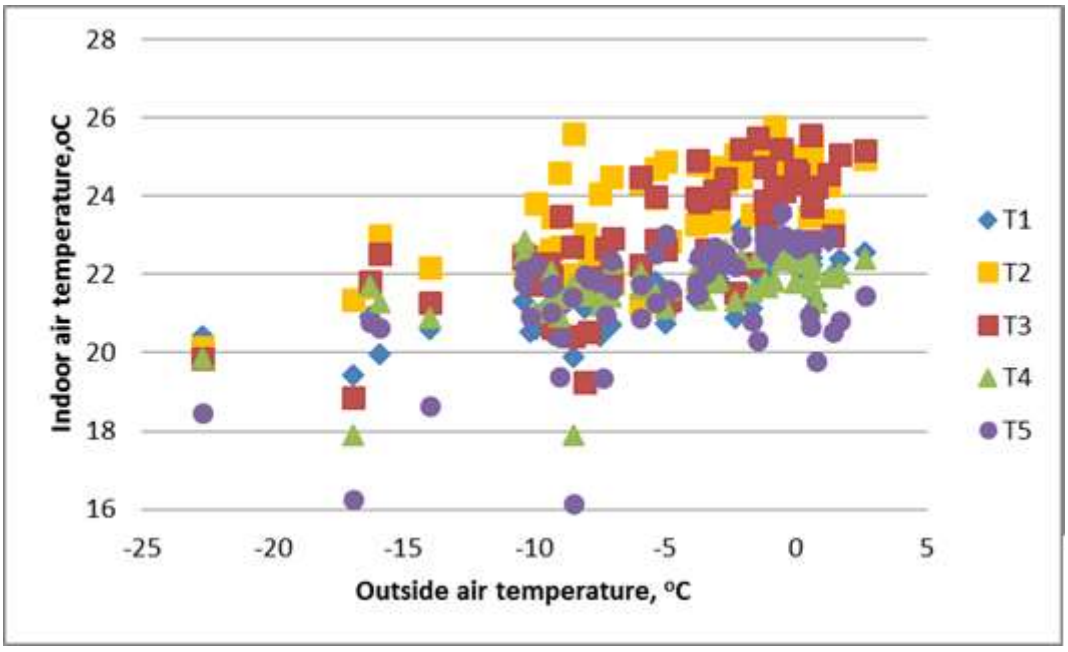

Figure 11 Daily average indoor and outside air temperature within cold period

The colder the outside air is, the lower is the indoor air temperature. The overheating occurred in rooms within cold period.

2.2. Relative humidity and moisture content

The following graph describes the indoor and the outside air relative humidity measurement results within cold period.

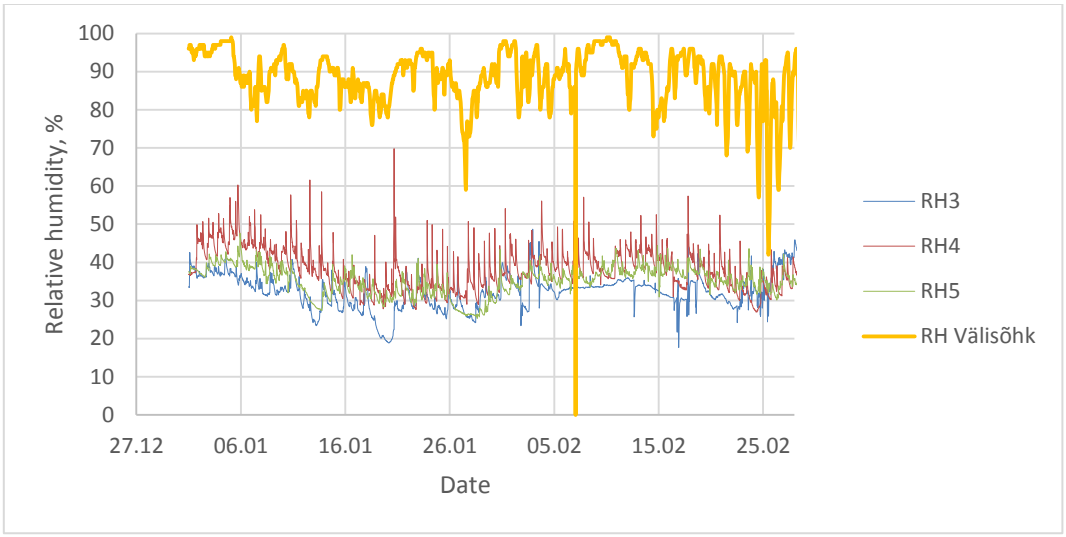

Figure 12 Indoor and outside air relative humidity within cold period

Indoor air relative humidity varied within 25…50 % range.

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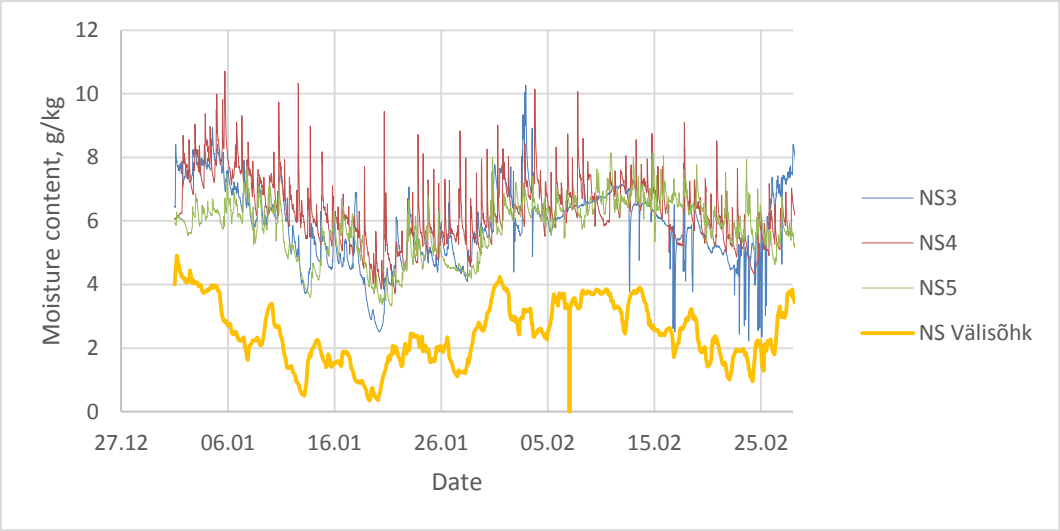

Figure 123 Indoor air moisture content in comparison to outside air moisture content

The following graph displays the daily average indoor air moisture excess at defined daily average outside air temperature.

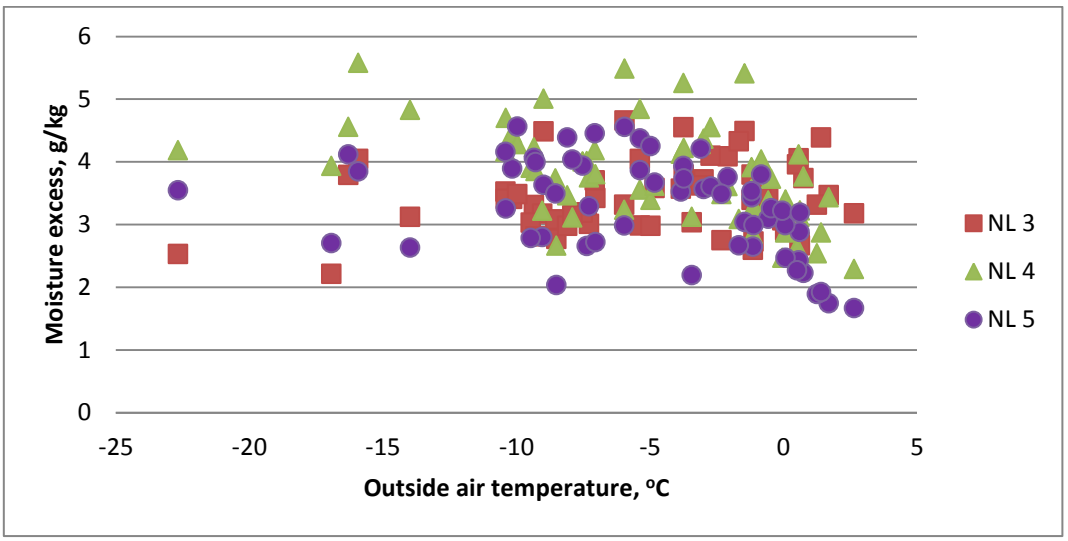

Figure 14 Daily average indoor air moisture excess depending on the outside air temperature

The indoor air moisture excess was continuously above the recommended 2,5 g/kg and the building has a risk of moisture damage.

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2.3. Air carbon dioxide content

The following graphs describe the indoor air carbon dioxide content measurement results.

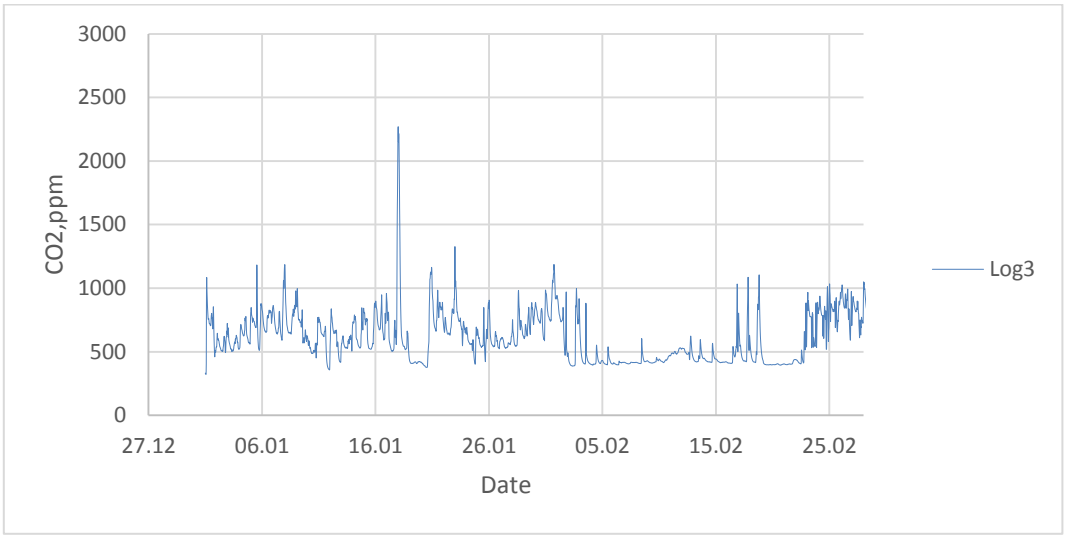

Figure 15 First floor room air carbon dioxide content

Most of the time the air carbon dioxide content stayed below 1000 ppm. CO_2 content reached its peak at 2500 ppm.

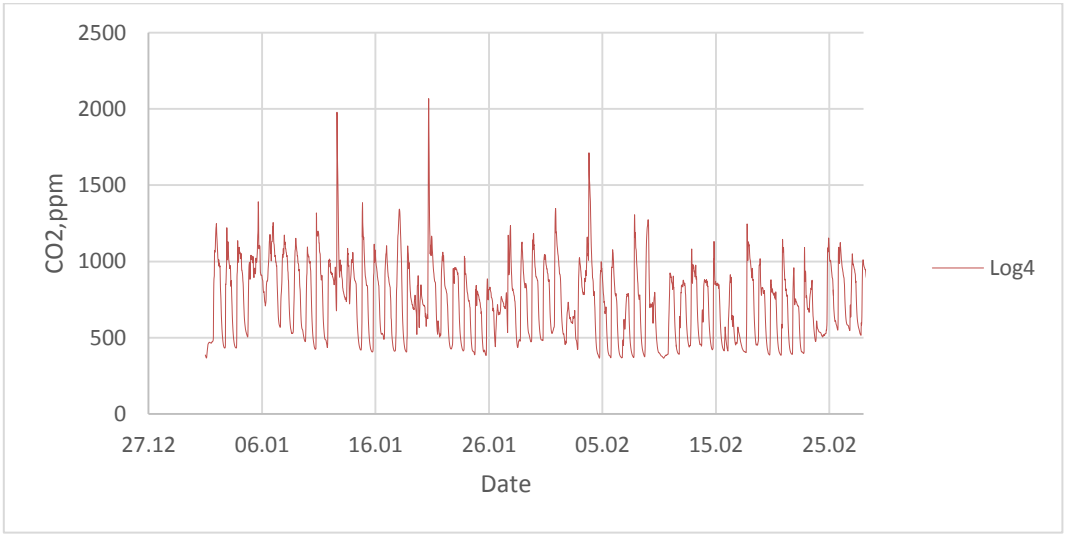

Figure 16 Second floor room air carbon dioxide content

Indoor air carbon dioxide content constantly exceed recommended value of 1000 ppm. During the short-term period, CO_2 content from time to time reached its peak at 1500 ppm.

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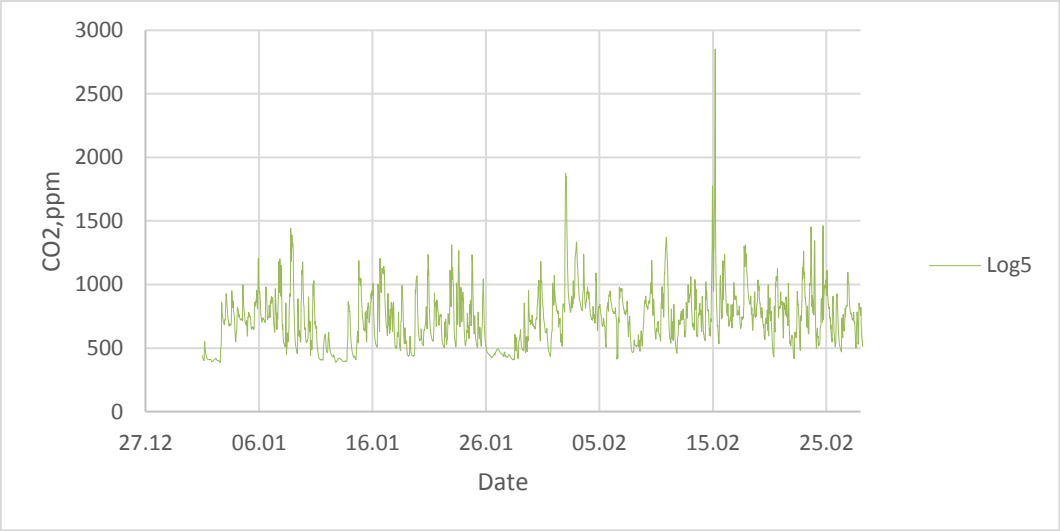

Figure 17 Third floor room air carbon dioxide content

Indoor air carbon dioxide content exceeded the recommended 1000 ppm quite often. CO_2 content reached its peak at 2800 ppm.

2.3 Apartment building summary

During the low outside air temperatures it was not possible to sustain recommended indoor air temperature and it eventually dropped to 15…18 °C. Building was constantly overheated during the cold period. Air carbon dioxide content in measured rooms exceeded 1000 ppm. Indoor air moisture excess was way above the recommended value of 2,5 g/kg and the building has a risk of moisture damage.

3. Cold period summary

In both buildings, due to the outside air temperature drop below -20 °C, the indoor air temperature dropped below 21 °C. Highest temperature drop was recorded in Herne 32 building. Herne 32 building was overheated.
In Tiigi 11 building most of the time indoor air temperature within working hours varied in 21…23 °C range.

Indoor air carbon dioxide content exceeded the recommended value of 1000 ppm in both buildings.
In office building (Tiigi 11) indoor air moisture excess stayed in the recommended range, while in the apartment building (Herne 32) it was significantly higher. High indoor air moisture excess is a result of poor ventilation (air exchange) and can lead to building moisture damage.

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