Preface

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1. Introduction

Poorly functioning HVAC systems (Heating, Ventilation and Air Conditioning), but also separate heating, ventilation and air conditioning systems are costing the Danish society billions of kroner every year: partly because of increased energy consumption and high operational and maintenance costs, but mainly due to reduced productivity and absence due to illness because of a poor indoor climate. It is estimated that the annual expenses are:

- approx. DKK 10bn in increased start-up, operational (including energy) and maintenance costs (The association DFM, 2002) (Akademisk Arkitektforening et al, 2004). The industry's own analyses show that most buildings and technical installations are carried out with faults.
- approx. DKK 30bn in the form of reduced productivity and absence due to illness because of a poor indoor climate (Wargocki et al, 2000) (Fisk and Resenfeld, 1997) (Wyon, 1996).

There are many reasons why HVAC installations are not functioning optimally: some are wrongly dimensioned, some have installation defects, some are commissioned wrongly, the conditions has changed, e.g. as a result of altered use of the building, some are maintained poorly, many have too poor control possibilities, …. and often, the possibility for the operational staff is poor or their knowledge is not good enough to carry through an optimum plant control.

Typically, the operation of buildings and installations takes place today with traditional building automation, which is characterised by

- being based on static considerations
- the individual sensor being coupled with one actuator/valve, i.e. the sensor's signal is only used in one place in the system
- subsystems often being controlled independently of each other
- the dynamics in building constructions and systems which is very important to the system and comfort regulation is not being considered.

This, coupled with the widespread tendency to use large glass areas in the facades without sufficient sun shading, means that it is difficult to optimise comfort and energy consumption. Therefore, the last 10-20 years have seen a steady increase in the complaints of the indoor climate in Danish buildings and, at the same time, new buildings often turn out to be considerably higher energy consuming than expected.

Other trends in the building industry are

- increased demands regarding comfort
- installation costs constitute a steadily increasing part of the total costs
- increasing demands for interaction between buildings and installations
- increased use of IT
- steadily increasing number of sensors in components

The increased use and capacity of microprocessors, as well as many components in building and installations being born with sensors, increase the possibility of better interplay between building and installation, as still more powerful tools appear within data collection, data processing, statistics, mathematical modelling, etc. This gives rise to huge possibilities which, however, are far from exploited today.

1.1. Multi parameter controllers

One way of dealing with the above problems in buildings is to utilize multi parameter controllers. Multi parameter controllers is - as shown in figure 1 - a combination of physical and virtual sensors. The physical sensor signals may be temperature, air speed, pressure, CO_2, relative humidity, solar radiation but also information on the position of valves, the speed of fans, the power supply to motors, the heating demand etc. Based on the signals from the physical sensors it is possible to generate virtual sensor signals, which cannot or is very difficult to measure but which more precisely characterise the actual condition of the building and installations. This will make a more optimized operation of the building and installation possible leading to reduced energy demand and improved indoor climate,

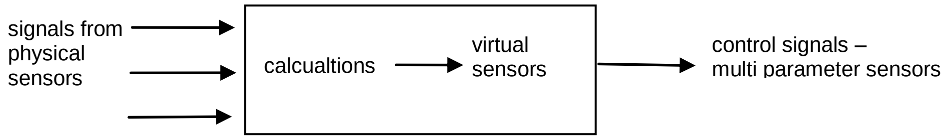


Figure 1. The principle of multi parameter sensors.

One example of a multi parameter sensor is the comfort equation by Fanger (Fanger, xxxx). Using input from physical sensors: temperature, radiation asymmetry, air speed and relative humidity together with information of the level of activity and clouding it is possible to determine the percentages of people who would be dissatisfied with the actual indoor climate. The result is a virtual sensor signal which cannot be measured directly and continuously. It can only be found by asking people bye eg questioners – which of course cannot give continuous values. Fangers equation, however, may be applied for continuously monitoring of the indoor climate without troubling the persons in a room with questions. If this virtual sensor signal is used for controlling the installations Fangers equation is enhanced from multi parameter sensor to multi parameter controller.

The comfort equation by Fanger is based on many years of research and seen in the light of the here proposes multi parameter controllers the number of input parameters is too limited in the Fanger type of empirical/mathematical/parametric equation.

The term multi parameter controllers may be enhanced by switching from the above parametric type of correlation to non parametric correlations based on statistical analysis and treatment of the signals from the physical sensors. Using this technique the number of input signals from the physical sensors may in principle be infinite. The technique further allows that insignificant signals are excluded so that their although small influence don’t lead to a wrong characterisation of the conditions in the building and installations. There is no need for deterministic correlations between the many sensor signals. The correlations are obtained by means of advanced statistical and mathematical data analysis and mathematical modelling. The multi parameters may be tailors to fit the actual purpose.

When controlling buildings and installations there are many non or difficult measurable conditions of main importance for the control of the building and installations – eg the indoor climate. The main purpose of buildings is to ensure a good indoor climate – however, the indoor climate is complex consisting thermal indoor climate, air quality, light conditions, acoustic, working environment, etc. All areas were it is difficult to measure the actual conditions using traditional measuring instruments. The multi parameter sensor has here its strength as it by means of traditional sensor signals are able to generate virtual sensor signals which better characterise the actual conditions - of which Fangers comfort equation may be a part of.

It is, therefore, anticipated that the development of multi parameter sensors and multi parameter controllers will be a major step forward in the direction of more optimal controlled buildings and installations with a minimized energy demand and increased indoor comfort.

A better characterization of buildings and installations will most often by itself lead to a better understanding of the actual conditions which again may lead more optimized control of the buildings and installations. However, for an optimal control it is necessary that an online characterisation is used for an online control of the building and installations – ie that the multi parameter sensors are transformed to multi parameter controllers.

1.2. Purpose of the project

The purpose of the present project is to investigate the type of multi parameter sensors which may be generated for buildings and further to carry out a preliminary evaluation on how such multi parameter controllers may be utilized for optimal control of buildings.

The aim of the project isn't to develop multi parameter controllers – this requires much more effort than possible in the present project. The aim is to show the potential of using multi parameter sensors when controlling buildings.

For this purpose a larger office building has been chosen – a office building with at high energy demand and complaints regarding the indoor climate – see chapter 2. In order to obtain data for the project a logging facility was installed in the Building Management System (BMS) of the building – see chapter 3.

The aim of the project is to log whatever is available from a traditional BMS (only few extra sensors have been added) in the form of sensor signals, set points, valve positions, energy demand, etc. and by means of advanced statistics and mathematical modelling investigate the multi parameter sensors this reveals. The aim is thus to investigate how control via traditional BMS can be enhanced by adding multi parameter sensors and controllers.

Another aim is to investigate how the availability of the above mentioned time series may enhance traditional inspections of the buildings and installations.

2. The building and installations

The building Tuborg Boulevard 12 – chosen for the project - is situated in a newer build-up area mainly containing larger office buildings situated in the northern outskirt of Copenhagen. Figure 2.1 shows a photo from the air of the building.

Figure 2.1. Tuborg Boulevard 12.

The building is as seen in figure 2.1 a non rectangular shaped building with an atrium in the middle. The foot print of the building is 4,946 m². It is a five story building with basement. The total area from the Danish Building Register is 21,199 m² of which 18.726 m² is heated. The floor area of the atrium is 1,182 m².

Figures 2.2-2.9 show pictures of the building.

Figure 2.2. The West façade. Orientation: 31° from West towards South.

Figure 2.3. The South façade. Orientation: 15° from South towards East.

Figure 2.4. The East façade. Orientation: 15° from East towards North.

Figure 2.5. The North West façade. Orientation: 35° from North towards West

Figure 2.6. The atrium seen towards South.

Figure 2.7. The atrium seen towards North West.

Figure 2.8. The roof of the Atrium.

Figure 2.9. The roof of the atrium seen from outside.

2.1. Constructions

Figures 2.2-2.9 show that main part of the thermal envelope consists of glazing. There are four main types of glazing in the building:

- transparent glazing in the facade
- opaque glazing in the façade – this is shown in figure 2.10
- transparent glazing in the roof
- transparent glazing facing the atrium

Figure 2.10. Opaque glazing in the façade.

2.2.1. Glazing

external: 6 or 8 mm Stopray Elite 67/37
14 or 16 mm with Argon
internal: 4 or 6 mm clear float
U-value: 1.12 W/m²K
g-value: 0.4

Opaque glazing in the façade located in front of the supporting columns:

external: 6 mm hardened float
14 mm air
internal: 6 mm hardened glass with enamel on side 4
U-value: 2.8 W/m²K

Transparent glazing in the roof - skylight:

external: 6 mm Silver 43/25
15 mm with Argon
internal: 6 mm safety glass
U-value: 1.12 W/m²K
g-value: 0.27

3% of the skylight can be opened for smoke ventilation.

Transparent glazing facing the atrium:

external: 6 mm clear float
14 mm air
internal: 4/1/4 mm laminated clear float
U-value: 2.8 W/m²K

U-values incl. framing

There is no information of these Uvalues. They are instead estimated to be:

Transparent glazing in the façade:	1.3-1.5 W/m²K
Opaque glazing in the façade:	2.8 W/m²K
Transparent glazing in the roof:	1.3-1.5 W/m²K
Transparent glazing facing the atrium:	2.8 W/m²K

Solar shading

Façade:

Venetian blinds on the west façade only?

Roof light:

There are installed horizontal solar curtains under the roof light in the atria – see figure 2.12 in order to decrease over heating risk and light level in the atria due to incoming solar radiation.

2.1.2. Opaque constructions

External walls:

external: 30 mm natural stones
20 ventilated air gap
150 mm mineral wool (Venti-bats)
internal 200 mm concrete
estimated U-value: 0.23 W/m²K

Floor above basement:

Atrium:

from top:20 mm granite
60 mm mortar
105 mm concrete with heating tubes
50 m hard insulation
hollow core floor slap
100 mm insulation
25 mm lathing
25 mm wood-wool
estimated U-value: 0.23 W/m²K

Kitchen:

from top:tile
hollow core floor slap
100 mm mineral wool
25 mm lathing
25 mm wood-wool
estimated U-value: 0.32 W/m²K

Canteen:

from top:parquet flooring on laths
hollow core floor slap
100 mm mineral wool
25 mm lathing
25 mm wood-wool
estimated U-value: 0.32 W/m²K

Roof

external: roofing felt
TF insulation

wedge-shaped insulation – slope 1:40
hollow core floor slap
estimated U-value: 0.1 W/m²K

Vertical part of the roof light:

external: steel plate
125 mm insulation
steel plate
16 fibre board
20 mm air gap
perforated steel plate
estimated U-value: 0.28 W/m²K

2.2. Installations

2.2.1. Heating system

The building is heated by district heating.

Space heating in the working areas is supplied by means of radiators along the façade of the building – see figure 2.11, while the atrium is heated via floor heating and convectors just under the skylight - the latter in order to prevent downdraft – see figure 2.12. There are further heating coils in the ventilations systems for heating the fresh air to the building during periods with low ambient air temperature.

Figure 2.11. Example of a radiator along the façade.

2.2.2. Ventilation systems

There are 11 ventilations systems in the building.

- Vent1, Vent2, Vent3, Vent4 and Vent7 are balanced ventilation systems with heat recovery
- UDS1, UDS2, UDS3, UDS4, Vent6 are exhaust ventilation systems
- Vent5 is a fan for moving air in the parking space in the basement towards the exhaust fan of the parking space

Figure 2.12. Convectors at the skylight in the atrium.

Vent1, Vent2 and Vent3 servers each approximately one vertical third of the working areas in the building as indicated in figure 2.13.

The ventilation systems are all located in the basement. Table 2.1 shows the designed air flow volumes of the ventilation systems.

Ven1-3 and Vent7 has all heat recovery with a rotating wheel with an efficiency of: Vent1 and 3 74.5 %, Vent2 74 % and Vent7 xxx at the dimensioning flow rates stated in table 2.1. The heat recovery in Vent4 is fluid clutched batteries with an efficiency of 45.3 %.

In Vent1-4 and Vent7 there are cooling coils for conditioning of the fresh air in order to prevent the building from overheating.

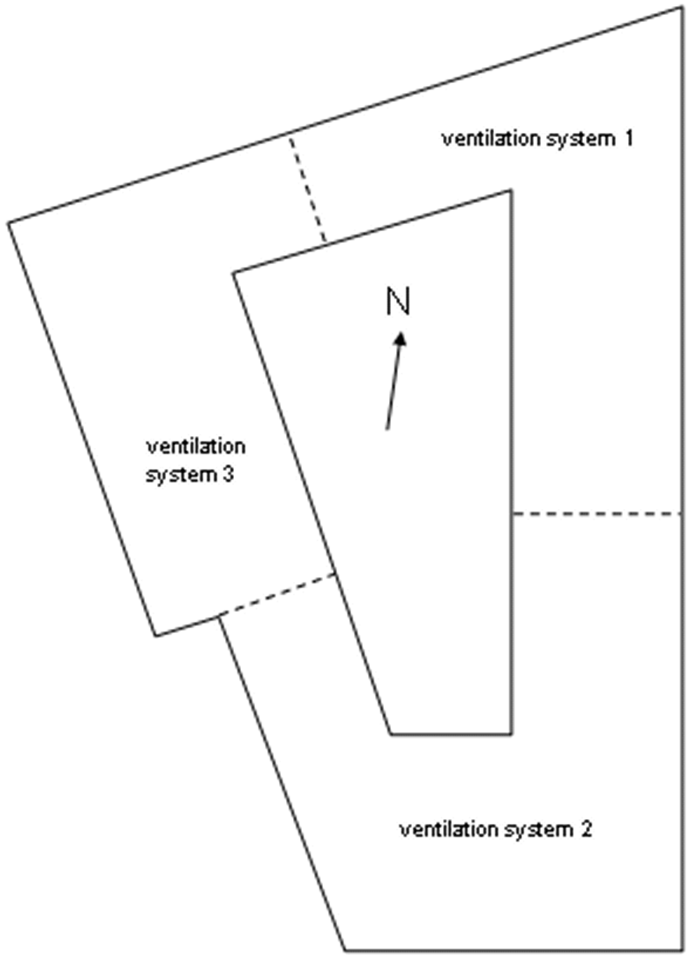


Figure 2.13. The vertical division of the building for Ven1-3.

Ventilation System	Fresh air m³/h	Exhaust air m³/h	Main function
Vent1	25,600	25,600	Conditioning of office spaces
Vent2	27,600	27,600	Conditioning of office spaces
Vent3	25,600	25,600	Conditioning of office spaces
Vent4	19,370	13,440	Conditioning and exhaust of kitchen and canteen
Vent5	-	2 x 20,000	Air circulation in parking space in the basement
Vent6	-	4,000/8,000	Exhaust from the room with the refrigeration plants
Vent7	xxxxxx	xxxxxx	Conditioning of education room on the first floor located at the South end of the building – see figure 2.14
UDS1	-	2,270	Exhaust from toilets
UDS2	-	2,270	Exhaust from toilets
UDS3	-	2,270	Exhaust from toilets
UDS4	-	6,575	Exhaust hoods in the kitchen

Table 2.1. Designed air volume flows of the ventilations systems in the building.

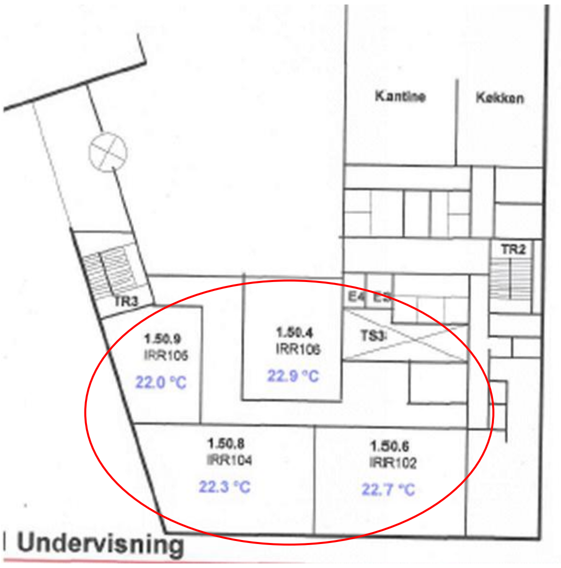


Figure 2.14. Education rooms on the first floor conditioned by Vent7.

2.2.3. Cooling systems

The solar gain and internal load of the building is very high. It is therefore necessary to cool the building by means of two cooling systems located in the basement of the building.

The larger system (system 1) with a nominal capacity of 730 kW cools water to the cooling coils of the ventilation systems. The designed temperature set is 6/12°C.

The smaller system (system 2) with a nominal capacity of 225 kW cools water to active cooling baffles located in the ceiling in the workspaces (see figure 2.15). The designed temperature set is 15/18°C.

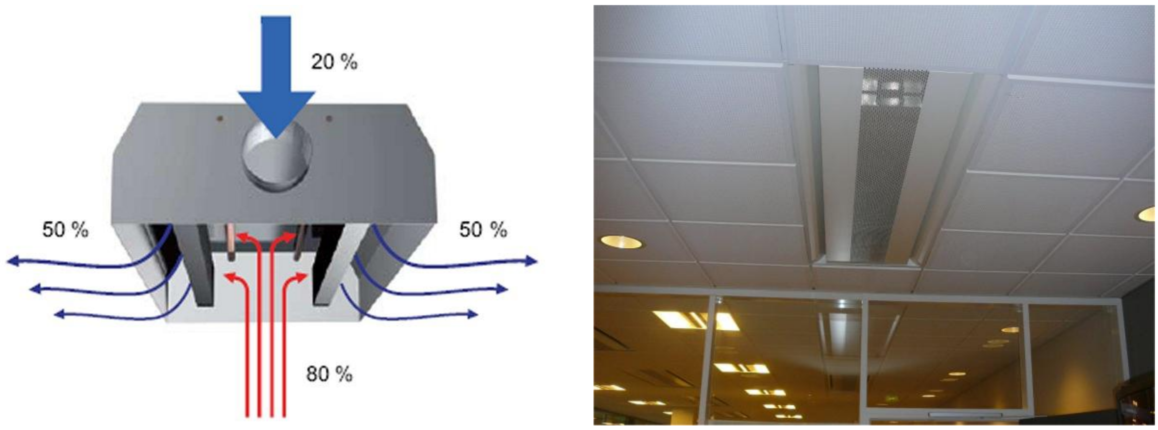


Figure 2.15. The principle of active cooling baffles to the left and an example of cooling baffles in the ceiling at Tuborg Boulevard 12.

The cooling systems are via a secondary cooling circuit connected to four dry coolers at the South end of the roof of the building – see figure 2.1. When the ambient temperature drops below a certain limit it is possible to cool the building without starting the refrigeration machines in the basement and in this way save energy.

User installations

The tenants of the building have installed their own cooling systems for cooling server rooms. The compressor and condensator of these systems are located in the parking space in the basement as shown in figure 2.16.

Figure 2.16. User installation in the basement for cooling server rooms.

2.3. Use of the building

The building was put into operation on May 5th, 2002.

There are three tenants in the building:

Dan-ejendomme – real estate administrator
MicroSoft – sale of computer hardware and software
Regus – runs office hotels

They occupy the following floors:

Ground floor:	Kitchen, canteen, Dan-ejendomme and education rooms for MicroSoft
1st floor:	Dan-ejendomme
2nd floor:	MicroSoft
3rd floor:	Regus
4th floor:	Microsoft

It is estimated that around xxx people work in the building.

To different ways of organization of the floors has been applied:

Dan-ejendomme and MicroSoft:	mainly open-plan offices and few smaller offices and meeting rooms – see figure 2.17
Regus:	only smaller offices – figure 2.18

2.3.1. Thermal loads and temperatures

The following thermal loads were used when designing the building and installations:

- Persons	100 W/person
- pcs: there was assumed 1.2 pc/person (1 pc: 100 W)	120 W/person
- Artificial light	
In offices	15 W/m²
Areas with special lightning (canteen, foyers, etc)	30 W/m²
- Person load in offices	10 m²/person
- Person load in meeting rooms and canteen	2 m²/person

The above thermal load occurs between 9 am and 18 pm.

The flow rate of fresh air should be at least 10 l/s/person.

The indoor air temperature should during the winter stay between 20 and 24°V and during the summer between 23 and 26°C. The indoor air temperature must in the period June-August in the offices not exceed 26°C in more than 110 hours and 27°C in more than 30 hours. In the meeting rooms the indoor air temperature may exceed the two former two temperatures in more than 100 and 25 hours. The temperature of rooms with installations should stay between 19 and 30°C and in copy/printer rooms between 20 and 26°C.

2.4. Energy label and comfort

Figure 2.15 shows the Energy label for Tuborg Boulevard 12. The measured energy and water demand are for the period January 1, 2003 – December 31, 2003

to be continued

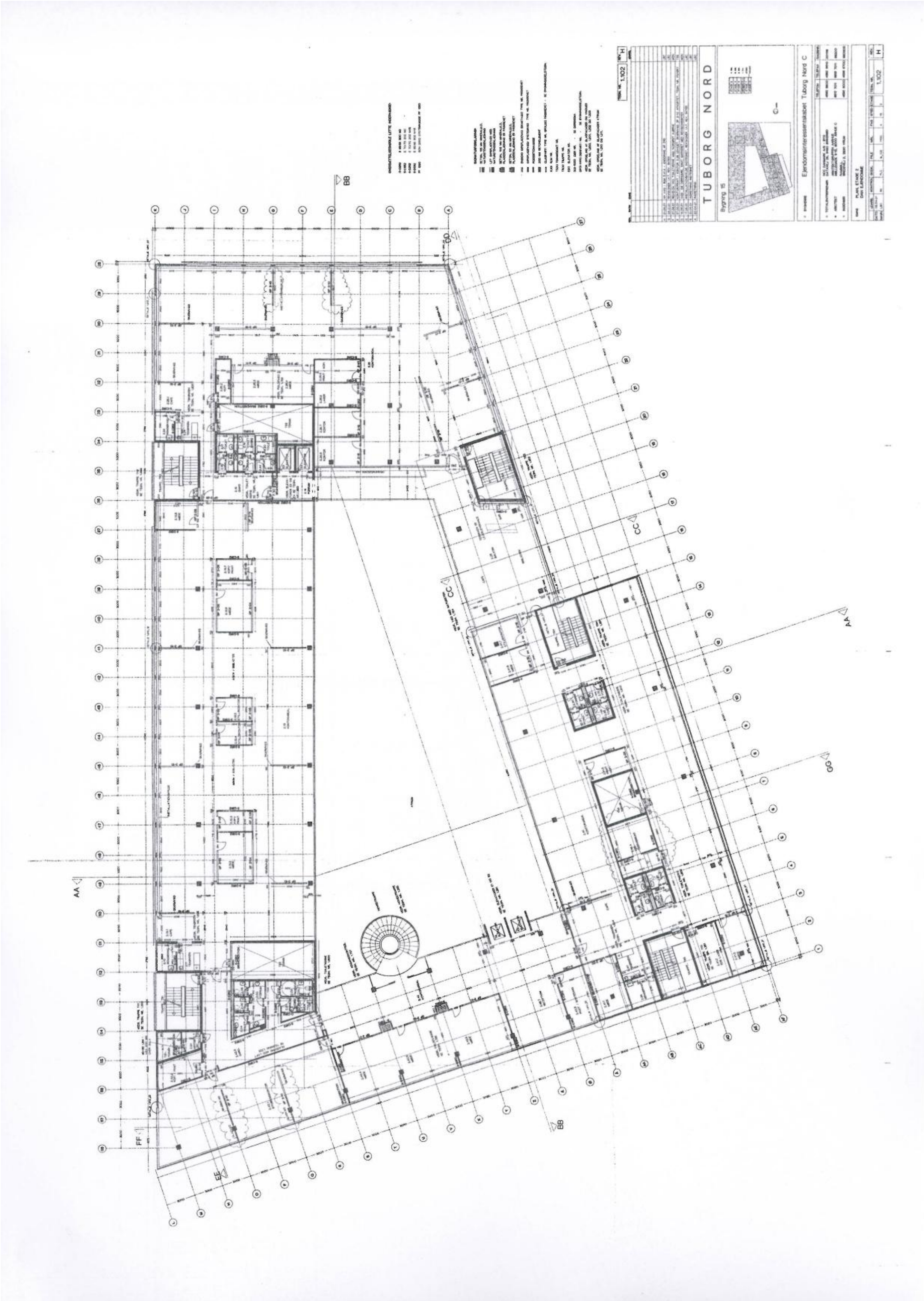


Figure 2.14. Example of floor plan with open-plan offices and few smaller offices and meeting rooms.

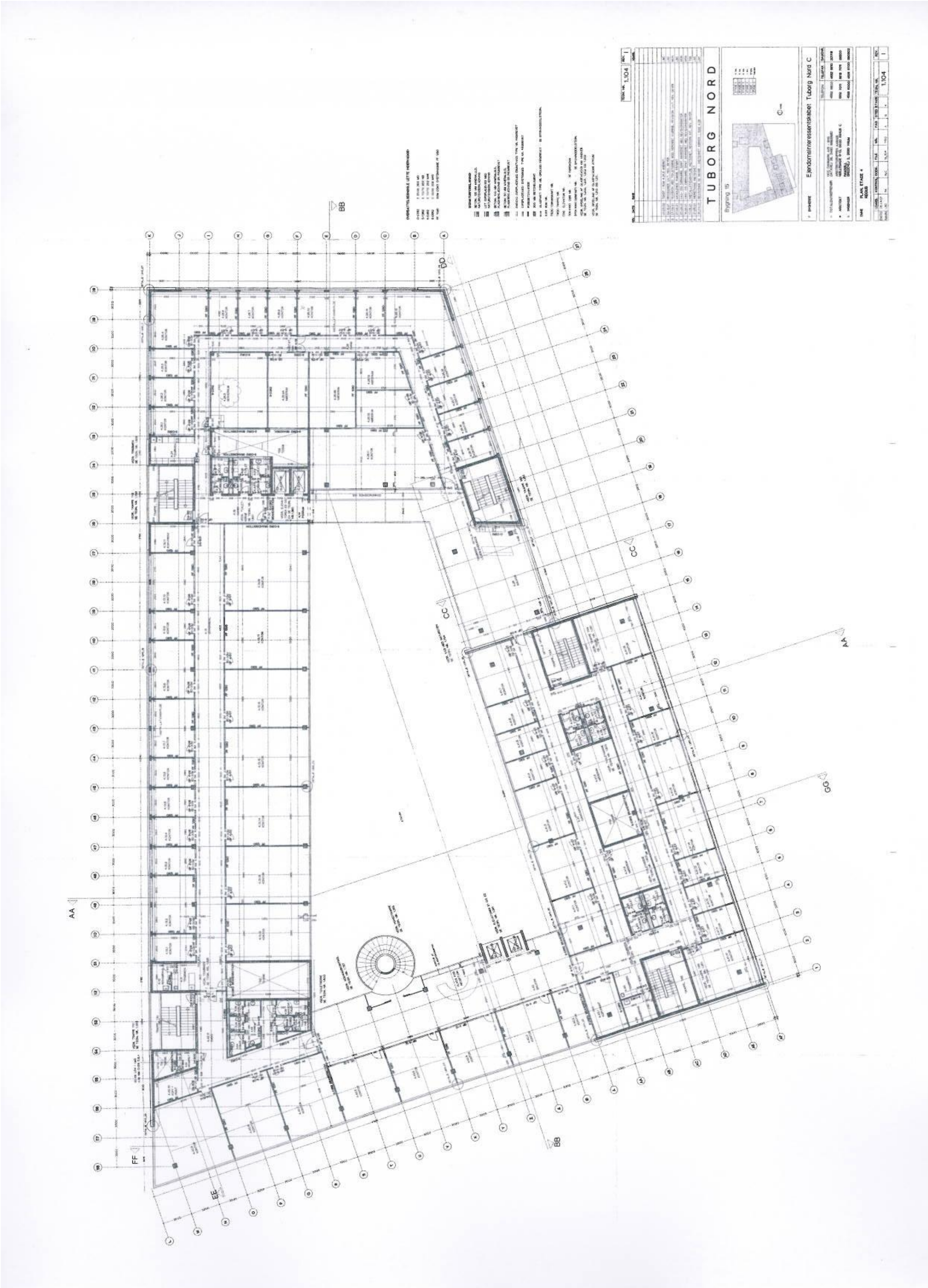


Figure 2.15. Example of floor plan with smaller offices.

Version 3.02

ENERGISTYRELSEN

Energimærke

Mærkenr : 106856

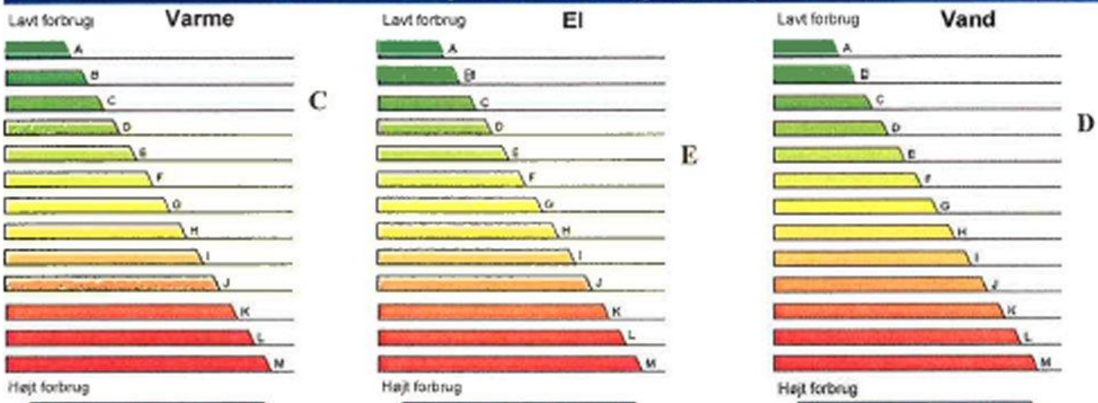
Store ejendomme

Energiledelsesordningen for store ejendomme, ELO

BBR nr: 157-296272-001
Adresse: DE+ Micro, Tuborg Boulevard 12
Post nr: 2900 By: Hellerup
Anvendelse: Anden kundebetjening (kodenr.: 5290)
BBR areal: 21.199 m² Heraf opvarmet areal: 18.726 m²
Opvarmningsform: Fjernvarme
Bygningsgennemgang: 07-05-2003
Næste bygningsgennemgang senest: 2006

Udarbejdet af: Dan-Ejendomme as
Adresse: Tuborg Boulevard 12
Post nr: 2900 By: Hellerup
Konsulent: Søren Høg
Sagsnr.: 11.176 sho
Indberettet: 25-05-2004
Underskrift:

Ejendommens årlige forbrug



72,4 kWh per m² | 34,6 kWh per m² | 0,19 m³ per m²

Markeringen på skalaen afhænger af ejendommens forbrug. Jo tættere markeringen er på A, jo lavere er ejendommens forbrug sammenlignet med andre tilsvarende ejendomme. Varmeforbrugets bidrag er klimakorrigeret.

Årlig CO_2 udledning

Markeringen på skalaen afhænger af ejendommens CO_2 udledning. Jo tættere markeringen er på A, jo lavere er ejendommens CO_2 udledning sammenlignet med andre tilsvarende ejendomme.

Samlet forbrug og CO_2 udledning

	Varme	El	Vand	I alt
Seneste års forbrug, aflæst	4.756 GJ	733.865 kWh	4.105 m³	
Opgjort periode	01-01-2003 til 31-12-2003	01-01-2003 til 31-12-2003	01-01-2003 til 31-12-2003	
Enhedspris inkl. moms og afgifter	116,13 kr. per GJ	1,48 kr. per kWh	37,87 kr. per m³	
Årets udgift inkl. moms og afgifter, dog undtaget evt. fast afgift	552.314 kr.	1.086.120 kr.	155.456 kr.	1.793.891 kr.
Årets CO_2 udledning	190 tons	437 tons		627 tons

3. Data collection

The purpose of the project was to investigate how logged values from a traditional BMS system may be utilized for generation of multi parameter sensors and controllers. For that reason a logging system was implemented in the BMS system of the building described in chapter 2. Few extra sensors were included in the BMS system and data were further obtained from DONG ENERGY and from locally placed autonomic data loggers.

In total 1050 data point were logged. The data points from the BMS system and the autonomic data loggers were logged each five minutes while the data from DONG were hourly values.

The logging started on July 1, 2007 and ended on August 31, 2008. All data are unfortunately not present for the whole period.

The logged values will be described in chapter 3.1 while the database containing the measured values will be described in chapter 3.2.

3.1. Logged data

The description of the logged data will be divided in three sections: data from the BMS system, data from DONG and data from the autonomic data loggers.

3.1.1. BMS system

972 data points in the BMS system were logged. The data from the BMS systems is divided in the following categories:

- weather station
- heating systems
- ventilations systems
- cooling systems
- offices
- roof light

Weather station

Figure 3.1 shows a screen dump of the BMS screen of the weather station. The weather station is located on another building in the area.

The following values were logged from the weather station:

- total solar radiation on horizontal
- ambient temperature
- lux
- wind speed
- wind direction

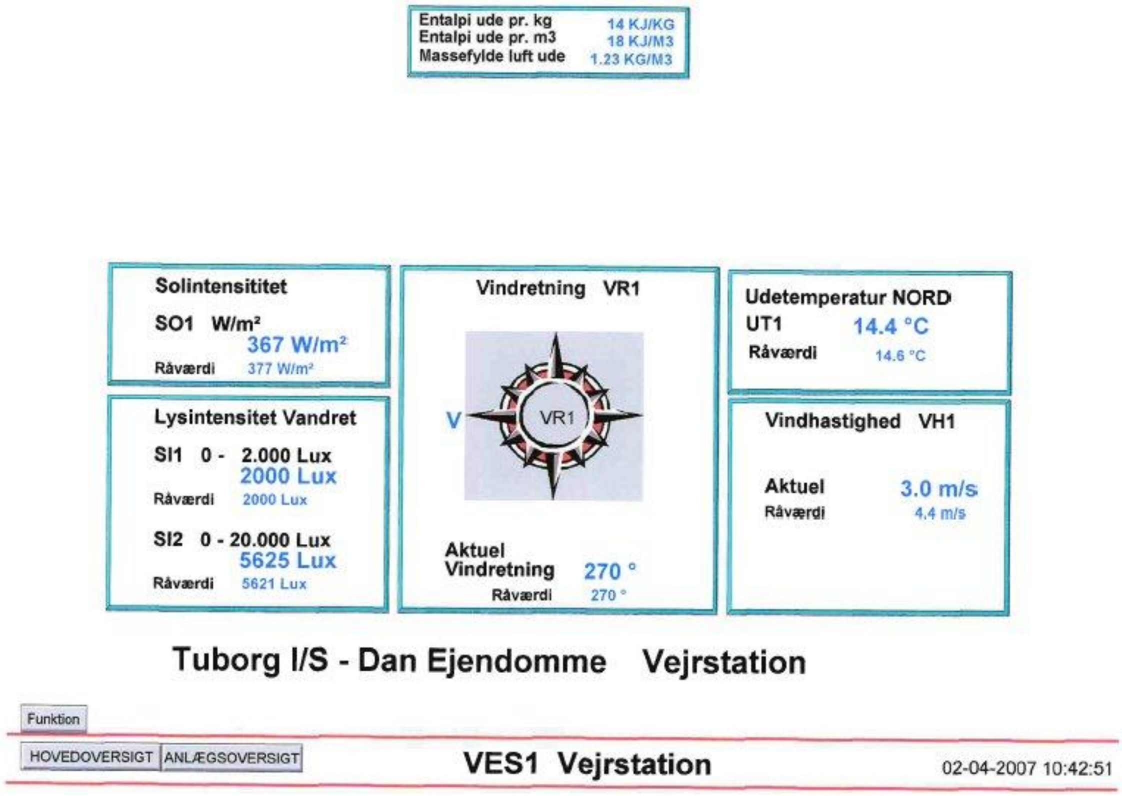


Figure 3.1. Screen dump of the BMS screen concerning the weather station (in Danish).

Heating systems

The heating systems are divided in four subsystems:

- district heating
- radiator system in the offices
- floor heating in the atrium
- ribbed heating tubes under the glazed ceiling of the atria

District heating

- energy demand from district heating

Radiator system in the offices

The following parameters were logged:

- min. room temperature in the offices – found by the BMS system
- position of the valve regulating the flow
- set point: max room temperature
- set point: min room temperature
- set point: min room temperature during the night
- calculated supply temperature to the radiators
- measured supply temperature to the radiators
- set point: ambient temperature at which the radiator system stops

Figure 3.2 shows a screen dump of the BMS screen of the radiator systems.

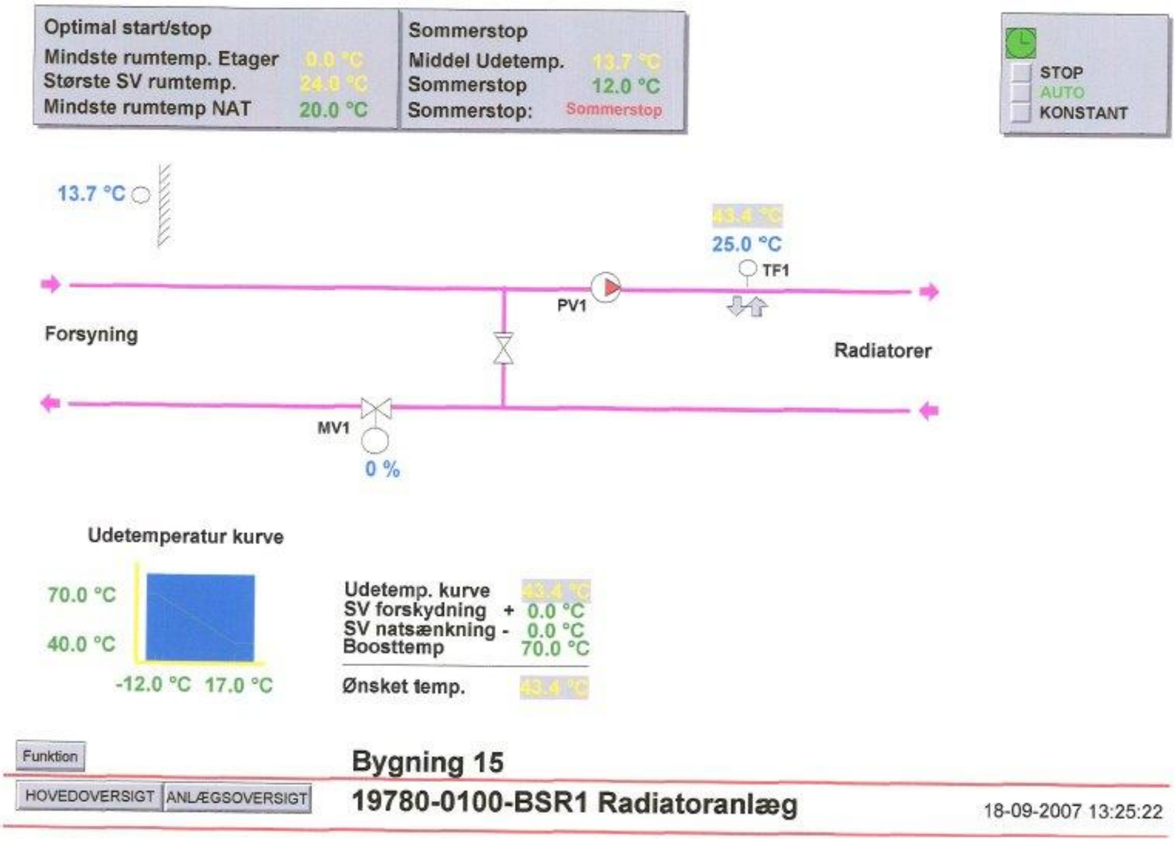


Figure 3.2. Screen dump of the BMS screen concerning the radiator system (in Danish).

Floor heating in the atrium

The following parameters were logged:

- position of the valve regulating the flow
- measured room temperature
- set point: room temperature
- calculated supply temperature to the floor heating
- measured supply temperature to the floor heating

Ribbed heating tubes under the glazed ceiling of the atria

The following parameters were logged:

- position of the valve regulating the flow
- calculated supply temperature to the ribbed tubes
- measured supply temperature to the ribbed tubes
- set point: ambient temperature at which the heating starts

Ventilations systems

Ventilations systems 1, 2, 3 and 7 has been logged. The logging was identical for ventilation system 1, 2 and 3.

Ventilations system 1, 2 and 3

The following parameters have been logged:

- CO_2 in the exhaust air – new sensor as part of the project
- dew point of the exhaust air – new sensor as part of the project
- relative humidity of the exhaust air – new sensor as part of the project
- position of the valve for cold water from cooling system 1
- position of the valve for cold water from cooling system 1 to VAV part
- position of the valve for warm water from district heating
- measured pressure in the VAV system
- set point: pressure in the VAV system
- measured pressure in the in the exhaust
- set point: pressure in the in the exhaust
- max air temperature in the rooms served by the ventilation system
- min air temperature in the rooms served by the ventilation system
- measured supply air temperature to CAV
- set point: supply air temperature to CAV
- measured supply air temperature to VAV
- set point: supply air temperature to VAV
- return air temperature from the building
- speed of the rotating heat exchanger
- speed of the fresh air fan
- speed of the exhaust fan

Figure 3.3 shows a screen dump of the BMS screen of ventilation system 1

Ventilations system 7

The following parameters have been logged:

- CO_2 in the exhaust air – new sensor as part of the project
- relative humidity of the exhaust air – new sensor as part of the project
- position of the valve for cold water from cooling system 1
- position of the valve for warm water from the district heating
- speed of the rotating heat exchanger
- measured supply air temperature to the rooms
- set point: supply air temperature to the rooms
- return air temperature

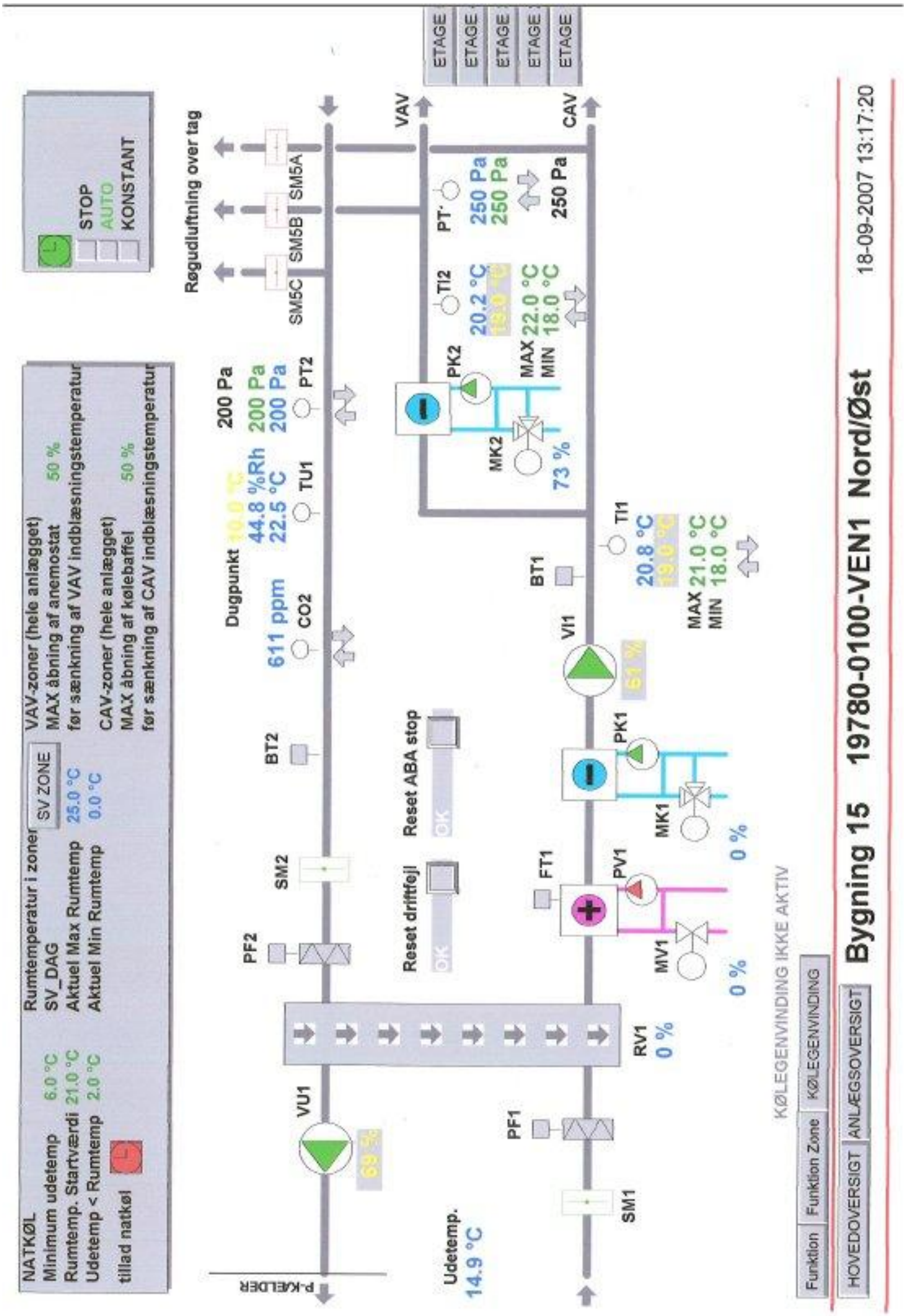


Figure 3.3. Screen dump of the BMS screen concerning ventilation system 1 (in Danish).

Cooling systems

The following parameters have been logged:

- electricity demand of cooling system 1 – not calibrated yet
- measured supply temperature for cooling system 1
- measured return temperature for cooling system 1
- electricity demand of cooling system 2 – not calibrated yet
- measured supply temperature for cooling system 2
- measured return temperature for cooling system 2

Offices

The office spaces in the buildings are divided in zones. The zones are either a room or part of an open-plan office as seen in figure 3.5.7

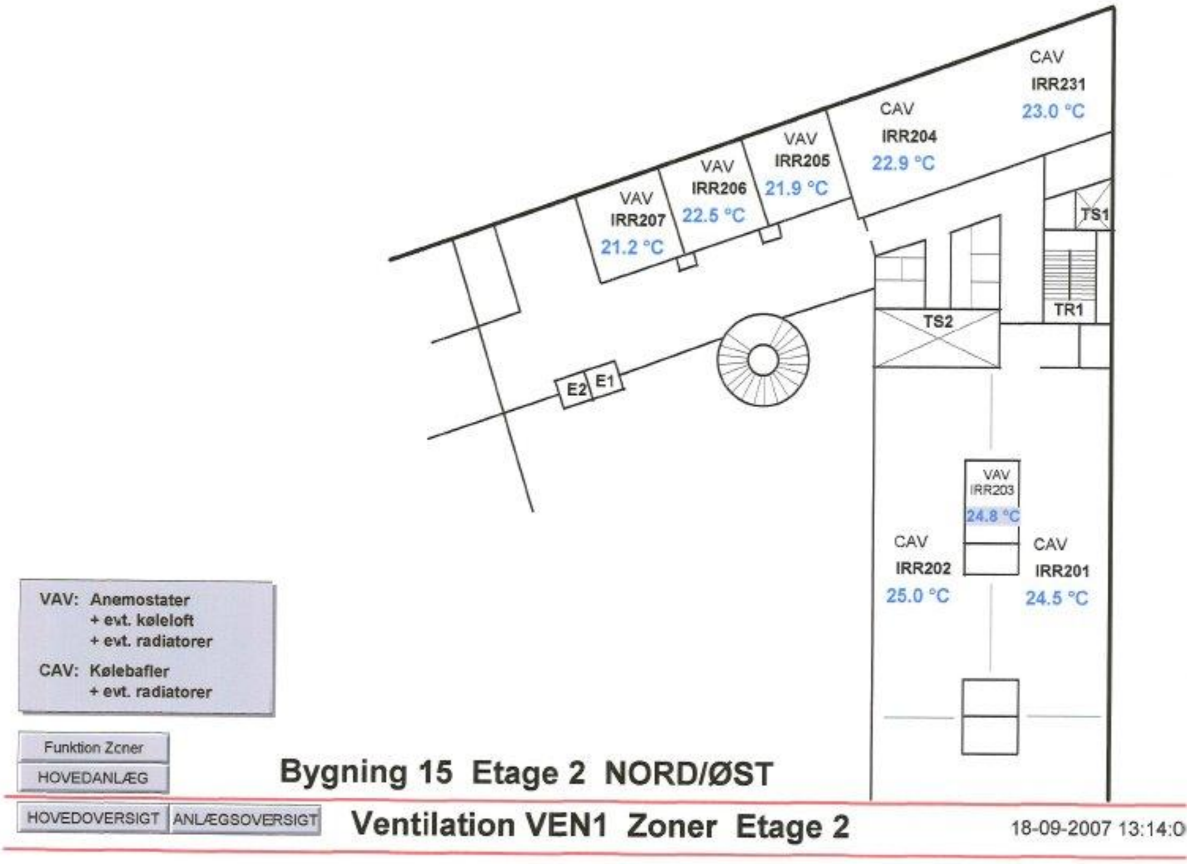


Figure 3.5. Screen dump of the BMS screen concerning zones in the office spaces (in Danish).

The following parameters have been logged for zones supplied by ventilation system 1, 2 and 3:

- the position of the valve for the cooling baffles
- the position of the valve for the radiators
- the measured room air temperature
- set point: room air temperature

Figure 3.6 shows a screen dump of the BMS screen of a zone.

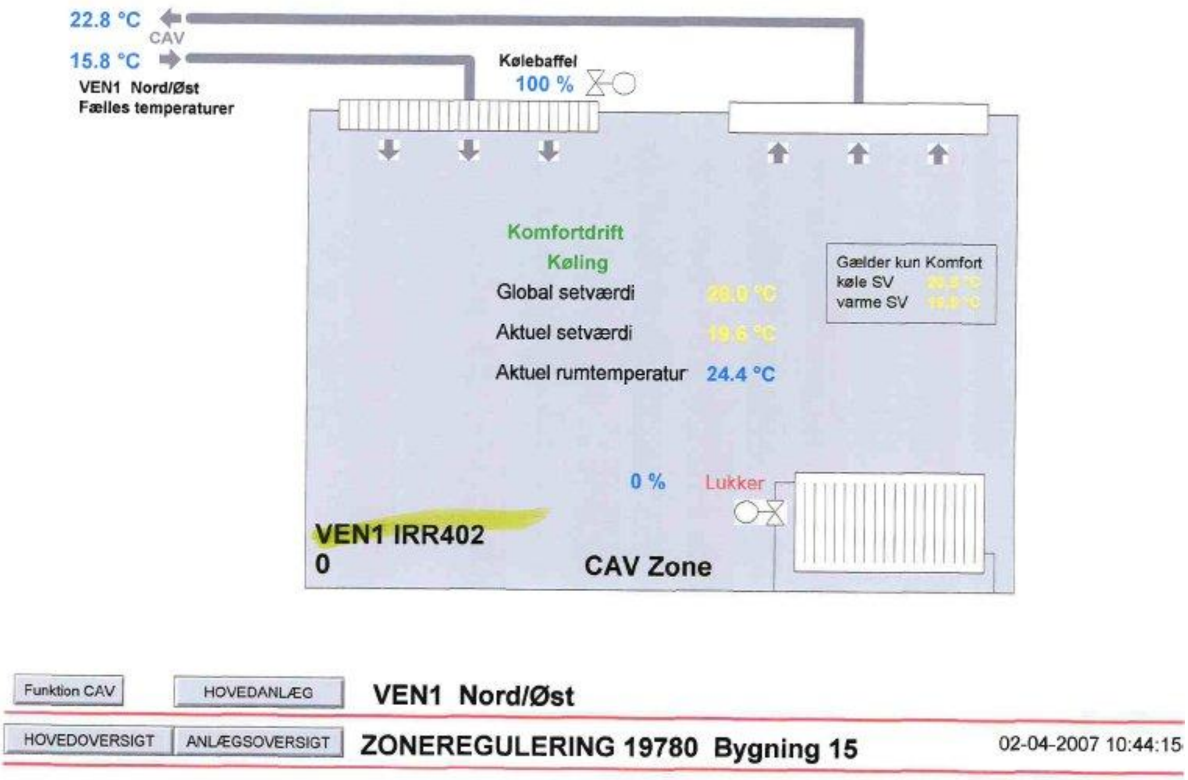


Figure 3.6. Screen dump of the BMS screen concerning zones (in Danish).

The following parameters have been logged for zones supplied by ventilation system 7.

- if the cooling baffles are active or not
- the measured room air temperature
- set point: room air temperature
- the position of the valve for the radiators

Roof light

The following parameters have been logged for the windows.

- air temperature in the atrium
- set point: air temperature in the atrium at which the windows open and close
- if the windows are open or closed

The following parameters have been logged for the solar curtains.

- if the solar curtains are for or not

Electricity to the installations

- electricity demand of the technical installations

3.1.2. Data from DONG ENERGY

Accumulated reading from seven electricity meters were received as hourly values from DONG ENERGY. The seven electricity metes measured the following demands:

- common installations – ventilation, cooling, etc.
- building management office
- Dan-ejendomme
- Microsoft ground floor and fourth floor
- Microsoft second floor
- Regus
- kitchen

3.1.3. Autonomic data loggers

In the scope of evaluation of the indoor climate in the building autonomic data loggers were located in the office spaces 17 different places. The measuring equipment is described in chapter 4. The measurements are 5 minutely values and are not continuous. The measurements comprise:

- air temperature
- relative humidity
- light level (Lux)
- CO_2 level

3.2. Database

The data is received in files from the different data providers. It is necessary to integrate the data and to make it available to different kinds of applications, e.g. statistical tools or MS Excel.

The best way to do this is to enter the data into a database. A database is a way to organize data in files in the file system in a way, which makes reading and manipulation effective. There are many commercial database systems on the market. There are also free, open source products, notably MySQL. MySQL is available for all common platforms and is highly scalable. That means it will be able to hold very large amounts of data, which is necessary in the present project. Furthermore there is a suite of GUI-tools, i.e. graphical interfaces to the database, which are conveniently used in place of the quite cumbersome standard text-based interfaces.

3.2.1 Products

The following products were used:

- MySQL Community Server
    - MySQL 5.0.51
- GUI Tools
    - MySQL Administrator 1.2.12

  - MySQL Query Browser 1.2.12
- Connectors
  - ODBC 3.51

The ODBC connector is used for connecting applications to the database, for instance MS Excel. There is a newer version than 3.51, but the old one proved more robust across platforms.

All products are downloaded from www.mysql.com.

The platforms in use were

- Windows XP and Vista
- Mac OS X Leopard 10.5
- Linux

For transforming text files between different kinds of encodings another free product was used:

- Smultron

which is very effective for that purpose.

For reporting purposes we have used

- MySQL Query Browser
- Microsoft Excel
- R

MS Excel proved inadequate for the large database. R has been the main tool and is described elsewhere in the report.

3.2.2 Handling data

The concepts used for handling data in this project are from the disciplines of Business Intelligence (BI) and datawarehousing. BI is a general term used for a reporting platform where data is collected from source systems and provided to reporting tools.

The arrows in figure 3.7 represent data flows during which transformations may take place. In BI lingo this is called ETL-processes, i.e. Extract, Transform and Load.

This concept is widely used throughout industry and business, and many dedicated tools have been developed for data handling as well as for reporting. A number of BI-suites exist for this purpose. In the present project we don't use such tools, but stay with simple SQL scripts and easily accessible reporting tools.

The reason for the success of the concepts of BI and datawarehousing is because data is gathered from different sources and are brought together in a common database in a common data structure from where it can be accessed.

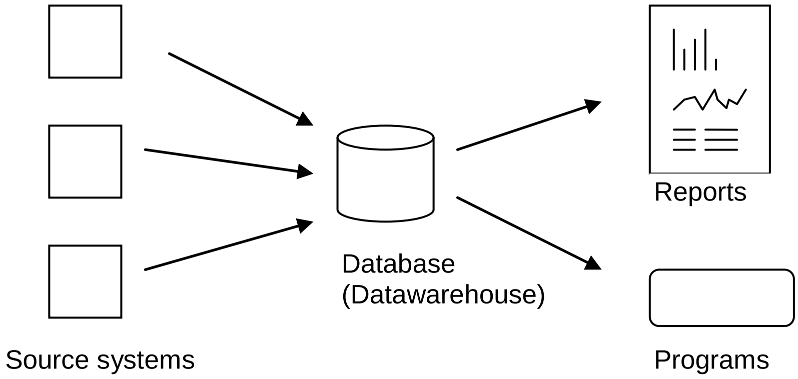


Figure 3.7.

In this project the BI scheme was implemented in the following way:

Source systems
Data was received from the source systems as text files or Excel files. When receiving files with source data from the data providers, the data was transformed into conformed formats: Text files were transformed to correct encoding (interpretation of letters in a text file), whereas data in Excel-files was extracted, encoded and stored as text files.

Database
Data was then loaded to the database, cf. below. Unlike other database systems, MySQL allows the user to select among different file formats for storing the database. The term Storage Engine is used for applications storing and accessing data in these files. In this project the classic MyISAM was user for different reasons:

1) It is highly effective for reporting purposes (in contrast to e.g. transaction handling), i.e. it is convenient for extracting data from the database.
2) Files exist in the file system for each table in the database together with files containing indexes for the tables. This very simple file structure makes exchange of data less complicated. The folder containing data and indexes can simply be copied and distributed.

When data is stored in a database such as MySQL it becomes rigid in the sense that unlike text files it can be exchanged between different operators and platforms without loosing validity and conformity.

Distribution of data
In a BI setup data are distributed to end users through dedicated channels. Typically some reporting tool is used, whish has access to the database and where user access is controlled. In our pilot project setup the situation was completely different. Here different project participants had completely different working environments, i.e. different operative systems, separate networks etc.

The distribution method adopted eventually was to copy the folder with the data files to a portable hard drive and then copy the folder with content to the local hard drive. Finally the path-variable of the database is changed to point at the new folder – this is most conveniently done with the MySQL Administrator. When working with R DTI eventually got remote access to the DTU network and database.

In the final version the files, including indexes, took up some 15 GB of storage.

3.2.3 The dimensional data model

In a database data is stored in tables. The data model of the database is the structure of the tables. As an illustration consider temperature measurements from a sensor in room 312 on the third floor. In a normalized data model each piece of information must exist only once in the database. Thus there would be a table with the floors, a table with the rooms, and a table with the temperatures:

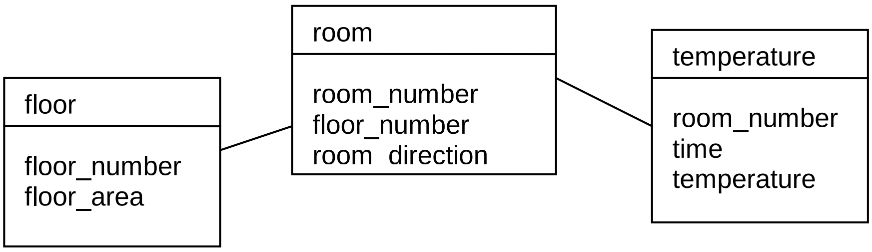


Figure 3.8.

In this example the floor table has two columns, floor_number and area. In the floor table there will be a row representing the third floor. In the room table there will be a row representing room 312, and in the temperature table, there will be a large number of rows representing measurements.

A normalized data model results in a large number of tables. For reporting purposes with massive amounts of data this is very inefficient. The star schema is another kind of data model with some redundancy:

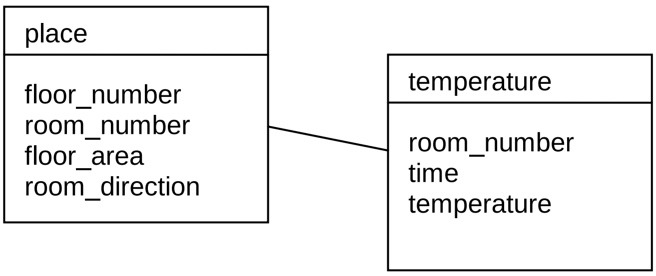


Figure 3.9.

Here the floor table and the room table have been merged. This means that the floor_area will be written in all rows. This is redundant as the floor_area is the same for all rooms on a floor. However, for each measurement in the temperature table one need only look up data in a single table to find room data as well as floor data. The redundancy pays off in performance.

Of course a complete denormalization is possible resulting in a single table:

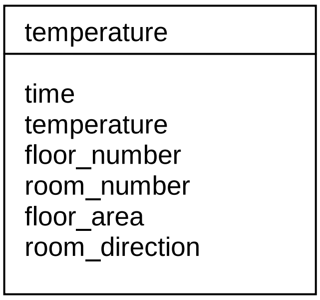


Figure 3.10.

This is the situation in a spreadsheet. It would usually not be used in a database.

In our database, the data is organized in star schemas. The following figure illustrates the star schema containing the t.a.c. data.

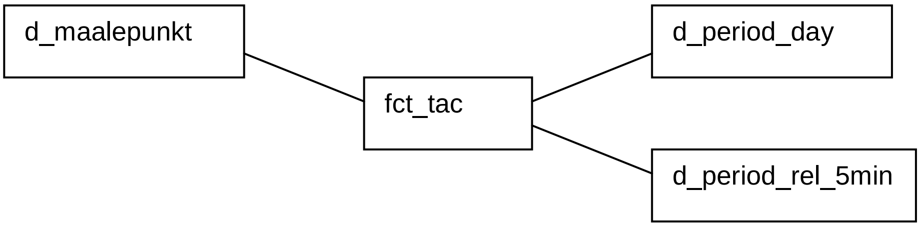


Figure 3.11.

Now it becomes more obvious why it is called a star schema. The tables are arranged around a central table. The central table is the fact table, which contains transaction data – in our case measurements. Around it are the dimension tables, which contain descriptive data. Here we have two time dimensions and a measurement type dimension. Typically the dimensions have many columns but relatively few rows, whereas the fact table is narrow with few columns but with a very large number of rows.

In a star schema the tables are usually linked by means of surrogate keys, i.e. one id-field per dimension. In the tac star schema this means three id's. The id is typically an integer. It is very convenient though, in the case of time dimensions, to use numbers, which can be interpreted directly. In this way it is not necessary to look up a date or a time in the dimensions, they can be interpreted from the id (cf. below).

In the following the fields (columns) of the tables are presented.

The fields of the tables are as follows:

d_maalepunkt: A row represents a measurement point, i.e. a timeseries for a measurement which might be a set point.

d_maalepunkt	
id_maalepunkt	Surrogate key. Id with no business information.
maalepunkt_navn	Name of the timeseries
anlaeg	System (cooling, heating, floor heating etc.)
anlaeg_besk	Description of system
maalepunkt	Type of measurement
maalepunkt_besk	Description of type of measurement
enhed	Unit (°C, %, 0/1 etc.)
SET_MAAL	Indicates if it is a set value or a measurement
rumzone	IRR### where ### is the zone number
zonenr	Zone number (three digits)
delbygning	Sub-building, indicates the section of the building
etage	Floor
facadeplacering	Front type of zone (outer, towards atrium or internal)
retning	Compass direction of front
areal	Estimated area of zone in arbitrary unit
sort	Sorting number, lists the zones in walking order

Table 3.1.

d_period_day: A row represents a date, i.e. a specific day in the calendar. The dimension was populated by means of a stored procedure.

There is a surrogate key as well as a date-like key. The latter is preferable in use, because it makes it possible conveniently to query and populate the fact table without the need to make a look-up in the dimension table.

The table has many fields, which are useful for reporting. Note that some fields are relative, e.g. *month*, which is cyclic, whereas other are absolute, e.g. *yearmonth*, are absolute.

d_period_rel_5min: The time dimension is used to indicate the time of day to which the measurement relates. As is indicated in the table name the resolution of this dimension is five minutes. This means that each row in the table identifies a time slot of five minutes by means of the start time of the interval. Example: 224000 identifies the period beginning at 22:40:00 and ending at 22:45:00.

The *id_klok* is an integer, and it is time-like. The example just mentioned, 224000, is an id. Because it is a number, it does not show preceding zeroes. Thus 20500 means 02:05:00. To have access to numbers more convenient for reporting the field *klok* is a string including preceding zeroes. *time* is a similar string showing the hour only. For all 12 rows representing the intervals within an hour this field has the same value. The field *heltime* is a flag indicating if the row is representing the beginning of the hour (1) or not (0).

d_period_day	
id_period	Surrogate key
id_period2	Date-like key (number, YYYYMMDD)
year	Year part of date (number, 4 digits)
quarter	Quarter (number 1-4)
month	Month part of date (number, 1-2 digits)
day	Day of month (number, 1-31)
date	Date (date)
week	Week number (number 1-52)
week_0_53	Week number (number, 1-53), used in Denmark
yearmonth	Absolute year-month (text, YYYY-MM)
year_week	Absolute year-week (text, YYYY-WW)
month_name_en	Name of month, English
day_name_en	Name of day, English
month_name_da	Name of month, Danish
day_name_da	Name of day, Danish
last_day	Date of the last day of the month of the day
last_day_fl	Flags if last day of month (number, 0-1)
days_in_month	Number of days in month of the day
day_of_week_en	Day number of week, English (number 1-7)
day_of_week_da	Day number of week, Danish (number 1-7)

Table 3.2.

d_period_rel_5min	
id_klok	Time-like number (number, HHMMSS, 24 hour/day, no preceding zeroes)
klok	String with time (text, HHMMSS, 24 hours, incl. preceding zeroes)
time	String with hour part of time (text, HH0000, 23 hours, incl. preceding zeroes)
heltime	Flags if row represents the first part of the hour (number, 0-1)

Table 3.3.

fct_tac	
id_maalepunkt	id determined from d_maalepunkt
id_dato	id constructed from timestamp of measurement
id_klok	id constructed from timestamp of measurement (measurement time truncated to 5 min.)
maalepunkt_navn	Is included only because it was convenient for loading the massive amounts of measurement data without the need to make a join with the dimension table. The id_maalepunkt was actually populated after load of this field.
vaerdi	Measurement value (number)

Table 3.4.

3.2.4 Populating tables

The setup for loading data used in this project is a pilot project setup. The aim was to design and populate a database applicable for the purpose of the project. In a production environment the process has to be automated.

Collecting and generating data for dimensions
The measurement type dimension, *d_maalepunkt*, was populated with data obtained from t.a.c and derived from maps of the building.

From the measurement data a selection of all measurement types present was made. Information from t.a.c. with short descriptions of the timeseries was merged with this extract. Furthermore, from maps window-direction and approximate area of each room was obtained and added to the dimension.

The process was done 'by hand'. A lot of nitty-gritty work on text files and mapping of the building was necessary. The character of the data makes it necessary to do so, and it is hardly possibly to automate the process to any degree.

The period dimensions, d_period_day and d_period_rel_5min, are much simpler to populate. This can be done by scripts, cf. Appendix 1.

Extracting and loading data to the fact tables
The following figure indicates the setup used in this project.

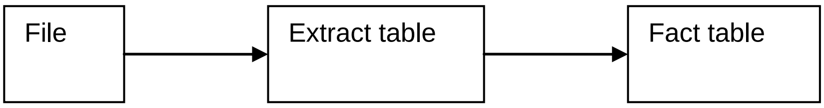


Figure 3.12.

From t.a.c. the data was received in text files, which were zipped and send by email. The files were processed something like this:

Download files	The zipped data files attached to the email were downloaded.
Unzip	The data files were unzipped. There is one file per day containing all timeseries from t.a.c.
Encode	The text files were encoded (with Smultron) to cope correctly with Danish letters.
Load to extract table	MySQL's file loader is used to load data from a text file to a database table. The data are simply read, they are not manipulated in this step.
Load of data to the fact table	Here the id's for the dimensions are determined and the data are loaded to the fact table.

Table 3.5.

This procedure was developed and used in a pilot environment. In the following section suggestions for a production setup are made.

3.2.5 Suggestions

Data model
In this project two period dimensions were used representing day level and five minutes level. Because the id's were date and time like, the id's themselves could be used in simple reporting (Excel pivot diagrams), where it was easy to study e.g. weekly and daily variation independently.

When using the database for reporting in e.g. R, data is queried and used in native format. In that case there are no benefits in having the date and time periods separated in the present way.

An alternative would be to use an hour period rather than a date period, i.e. a row would not refer to a specific day in a specific year but to a specific hour of a specific day in a specific year. The relative period dimension could define the part of the hour, i.e. in this case the five minutes interval. This dimension would be very small, only 12 rows, and it could be merged into the other period dimension leaving only one period dimension having rows defining specific five minutes intervals. This would probably be the best solution.

The reason not to choose this one could be the question of performance. On low resource systems it might lower performance, if the dimension tables are unnecessarily large.

The reason why it is better to have an hour dimension rather than a day dimension is, that it is much simpler to handle daylight saving time.

Suggestion: Merge the period dimensions to one dimension.

Loading data
In this project the data was provided and loaded by means of manual procedures. For instance: An employee of t.a.c. produced the data files, zipped them, and sent them by mail. They were received, unzipped, encoded and saved as text files. These were loaded to extract tables from where the data was loaded to the fact table.

In a production environment, the setup would be much different. There would be no manual procedures. To get there another method of getting data from source to database must be used. There are different possibilities.

Suggestion: In future projects data should be exchanged by means of FTP file transfer.

The files should be automatically generated by the data provider. A script may be scheduled or run manually, but it should be a script, which actually generates the data files and place them in the appropriate ftp-folder.

When data is received a script should copy it to an archive. If the filename does not include a timestamp, it should be added by the script. The original file to be processed should be renamed to a standard name. In that case the MySQL file load script could work with this standard name.

Data transfer	
FTP	FTP (File Transfer Protocol) is a very simple way of moving files around a network of computers, e.g. the Internet. The file is placed in a folder on a computer on a network. The computer can be addressed by other computers on the network, and the file can be manipulated, i.e. copied, moved, deleted etc. Access to files can be controlled by standard procedures for accessing networks. Because the system generating data, e.g. the t.a.c. system, simply writes data to a file in a folder, and data users simply read the file from the folder, the users never get in touch with the source system. The two are completely disconnected.
ODBC	ODBC (Open DataBase Connectivity) is a standard interface to relational databases. It makes it possible to send a query, i.e. an SQL-script, to the database and receive the query result back. Though it is an effective method for transferring data from one database to another, it is usually not recommended. If the data provider and the data receiver are two different legal subjects, the data provider would usually not allow the foreign receiver to get direct access to the production database. If, however, the two databases are both owned by the user, an ODBC solution would usually be the fastest to implement and use.
Queues	In a Queue system the data provider writes data to a queue, while data users subscribe to queues. This is done through standard interfaces. The method is used in large organisations and has many advantages, such as automatically keeping track of who got what when. But it requires special software and much setup and would hardly be of interest to projects like this.
Web services	Webservices is an interface to support interoperable machine-to-machine interaction through a network, e.g. querying data on the Internet. Usually, however, they are not designed for massive data transfer and are thus not necessarily a feasible choice for reporting porposes.

Table 3.6.

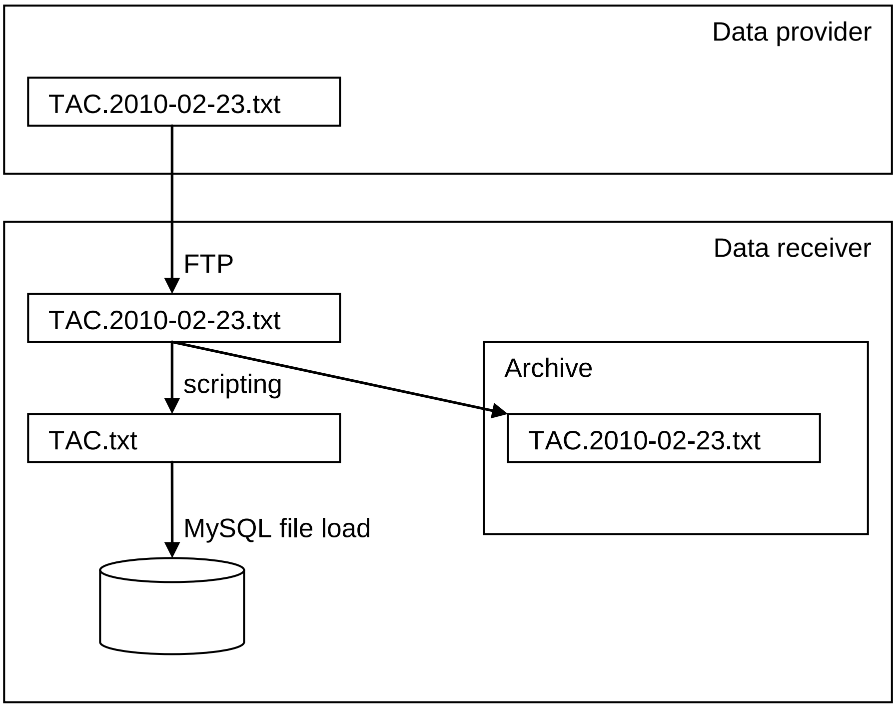


Figure 3.13

The scripting could be DOS (bat-files) on Windows or e.g. bash shell scripts in Mac OSX and Linux.

The process could be scheduled so that the ftp-server is polled every day or every hour (or every tenth second, if that makes sense).

Data integration
When the time series data is loaded from the extract tables to the fact tales it should be converted to standard time reference, preferably UTC+1 (UTC: Universal Time, Coordinated – practically the same as Greenwich Mean Time), i.e. normal time in Denmark. By means of the period dimension the CET/CEST timestamps (Central European Time (=UTC+1) / Central European Summer Time (=UTC+2)) can be easily derived. Note that CET/CEST is not completely defining a timestamp: In the fall when returning from summer time to normal time, the day has 25 hours two of which are from 02:00 to 03:00. To completely identify this hour a flag is needed to tell if it is summer time or normal time.

Setting up a platform
A platform for reporting could be based on a multi-server setup:

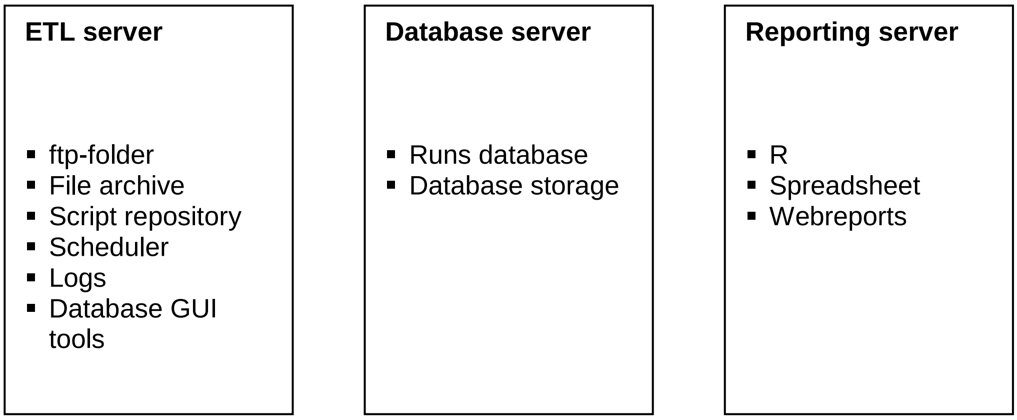


Figure 3.14.

The database server is dedicated to run the MySQL engine. It should not be accessed directly but only through either of the two other servers.

The ETL server is the back-end. Here data is received from the data providers, transformed and loaded to the database. The data files are archived to make it possible to recreate the database or e.g. load to another data model.

The reporting server is the front end, where the users get access to data. In our case this could run the R-program.

Separating functionality on different (physical) serves increases performance, which is important in reporting systems, because the user should not be required to wait long for query results.

There should be remote access to the ETL-server and the Reporting server. It might be web based, but, for instance, in Windows based systems Remote Desktop is a very convenient way to access the servers.

With remote access it is not necessary to install software on the local computer – e.g. the pc of the user. This is highly preferable to avoid problems with maintenance, software versions etc.

Such a setup would be applicable for users who are somewhat technically skilled. For a user with no required technical skills the data should be more easily accessible. A number of reporting tools are available, e.g. Targit, Business Objects and Cognos, just to mention a few. Such tools are hardly neither necessary nor convenient in an environment like the present, where a more complex software – R – is used for reporting.

4. Indoor environment

Objective measurements of physical parameters in the building and subjective responses from the occupants were used to evaluate and classify the indoor environment conditions in the building. The objective measurements comprised long-term recording of air temperature, air humidity, and CO_2 concentration in 13 selected locations and short-term measurement of air and operative temperatures, and air velocity at representative locations and on two occasions.

4.1 Thermal climate

Several standards provide guidelines for assessment of the indoor environment (DSF 3033-2009, DS 474 - 1995, ASHRAE 55-2004, ISO 7730-2005, CEN CR 1752-1998, CEN EN 15251-2007). A common approach of the standards is to define conditions in which a specified fraction of the occupants will find the environment acceptable, and the newest standards attempt to categorize the indoor environment according to its quality.

General and local thermal discomfort

Thermal dissatisfaction may be caused by a too warm or too cool overall thermal sensation. But even for a person who is thermally neutral for the body as a whole, thermal dissatisfaction may be the result of unwanted cooling or heating of local body parts (thermal asymmetry). Separate indices exist for the assessment of the different types of local thermal discomfort.

The indices Predicted Mean Vote (PMV) and Predicted Percent Dissatisfied (PPD) can be used to assess overall thermal comfort in a wide range of buildings and vehicles with differing HVAC systems as well as for different combinations of activity, clothing habits and environmental parameters. The indices are used widely for the evaluation and design of indoor thermal environments. The PMV can be determined when the personal parameters metabolic rate and the clothing insulation are estimated and the environmental parameters air temperature, mean radiant temperature, relative air velocity and air humidity are measured or estimated.

The PMV integrates the effect on the body's thermal balance of the two personal parameters and the four environmental parameters, and predicts the mean thermal sensation on a 7-point thermal sensation scale (Figure 4.1).

The PPD index predicts the number of people likely to feel uncomfortably warm or cool, i.e. those voting hot (+3), warm (+2), cool (-2) or cold (-3) on the 7-point thermal sensation scale. Typically, a 10% dissatisfaction criterion for whole-body thermal comfort is used for the determination of acceptable thermal conditions (ISO 7730-1994, ASHRAE 55-2004). This corresponds to a PMV in the range -0.5 to +0.5. It should be noted that the minimum attainable PPD is 5%, even in spite of a neutral thermal sensation (PMV = 0).

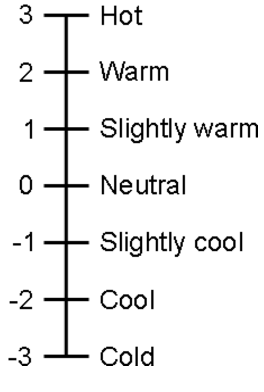


Figure 4.1. 7-point thermal sensation scale corresponding with the PMV index.

Also, local thermal discomfort due to draught, vertical temperature gradient, radiant asymmetry, or warm or cold floors may cause occupants to find the thermal conditions unacceptable. The most common cause of complaint is draught, which is defined as an unwanted, local cooling caused by air movement. Criteria to assess local thermal discomfort are given in ISO 7730-2005 and ASHRAE 55-2004 and are

reproduced here in
Table 4.1.

Category	Thermal state of the body as a whole		Local discomfort			
	Predicted Percent Dissatisfied PPD %	Predicted Mean Vote PMV	Percent dissatisfied due to draught DR %	Percent dissatisfied due to vertical air temperature difference %	Percent dissatisfied due to warm or cool floor %	Percent dissatisfied due to radiant asymmetry %
A	< 6	-0.2<PMV<+0.2	< 10	< 3	< 10	< 5
B	< 10	-0.5<PMV<+0.5	< 20	< 5	< 10	< 5
C	< 15	-0.7<PMV<+0.7	< 30	< 10	< 15	< 10

Table 4.1. Three categories of thermal environment (from ISO 7730-2005).

Each quality category prescribes a maximum percentage dissatisfied for the body as a whole (PPD) and for each of the four types of local discomfort.

Recently, a new Danish standard was proposed for the labeling of indoor climate quality (DSF 3033-2009). Currently, the standard is in a hearing phase prior to being published (as of July 2009). The new standard suggests intervals and quality classes for operative temperature and air velocity during summer and winter that as shown in
Table 4.2.

Parameter	Season	Quality class				
		A	B	C	D	E
Operative temperature (ºC)	Summer	24.5±1.0*	24.5±1.0	24.5±1.5	24.5±2.5	No limits
	Winter	22.0±1.5*	22.0±1.5	22.0±2.0	22.0±2.5	No limits
Air velocity (m/s)	Summer	0.18	0.18	0.22	0.25	>0.25
	Winter	0.15	0.15	0.18	0.21	>0.21

Table 4.2. Thermal indoor climate quality classes and corresponding parameter intervals. Adopted from DSF 3033 (2009).
*Individual control should be an option

The DSF 3033 (2009) quality classes are characterized by:

Class A: The very good indoor climate. The thermal conditions are comfortable during all year and the building offers good opportunities for individual adjustment. The concentration of unwanted pollutants in the air is low, even when the production rate is higher than normal. Light- and sound conditions are good with satisfactory opportunities for individual adjustment.

Class B: The good indoor climate with very modest health risk and sensory discomfort.

Class C: An indoor climate corresponding to the minimum requirements as specified in the building regulations. This classification is achieved by either fulfilling the requirements in the building regulations at new construction or reconstruction or as the result of measurements/observations. The risk of negative health effects is modest, but sensory discomfort may occur, e.g. as high temperatures on warm days or bad smells.

Class D: An indoor climate poorer than the minimum requirements in the building regulations. The risk of health effects is small, but a considerable fraction of the occupants will experience sensory discomfort due to temperature on warm or cold days or due to smells.

Class E: The poorest of the five quality classes. There is a risk of negative health effects and the safety margin is limited. Considerable sensory discomfort may appear.

Non-steady-state thermal environments
Fluctuations that occur due to factors not under the direct control of the individual occupant (e.g. cycling from thermostatic control) may have a negative effect on comfort. The requirements of
Table 4.3 apply to these fluctuations. The table specifies the maximum change in operative temperature allowed during a period of time. For any given time period, the most restrictive requirements apply. For example, the operative temperature may not change more than 2.2 ºC during a 1.0 hr period and it also may not change more than 1.1 ºC during any 0.25 hr period within that 1.0 hr period.

Time period	0.25 hr	0.5 hr	1.0 hr	2 hr	4 hr
Maximum operative temperature change allowed	1.1 ºC	1.7 ºC	2.2 ºC	2.8 ºC	3.3 ºC

Table 4.3. Limits on temperature drifts and ramps (from ASHRAE 55-2004).

Long-term evaluation of indoor temperatures
To evaluate the comfort conditions over time (season, year) a summation of the measured temperature can be used to calculate the number or % of hours the operative temperature is outside a specified range during the time the building is occupied (ISO 7730-2005). CEN EN 15251-2006 recommends evaluation of the time during occupancy when the measured temperature falls in the ranges shown in Table 4.4.

Category	Winter temperature range (ºC)	Summer temperature range (ºC)
I – high level of expectation	21 - 23	23.5 – 25.5
II – normal level of expectation	20 - 24	23 – 26
III – acceptable, moderate level of expectation	19 - 25	22 - 27
IV – values outside the criteria for the above categories		

Table 4.4. Temperature ranges for evaluation of the long-term measurements of indoor temperature in offices (from CEN EN 15251-2006).

Also, DS 474 recommends that the operative temperature during the time of occupancy shall not exceed 26ºC for more than 100 hours and 27ºC for more than 25 hours during a typical year.

Air quality

No common standard index for the indoor air quality exists and the indoor air quality is often expressed as the required level of ventilation or in terms of the CO_2 concentration. It is generally accepted that the indoor air quality is influenced by emissions from the occupants and their activities (bioeffluents, smoking), from the building and furnishing, and from the HVAC system itself. The latter two sources are usually called the building components. The required ventilation is based on both health and comfort criteria. In most cases, the health criteria will be met by the required ventilation for comfort (perceived air quality, odour, irritation).

To assess the air quality in an office building, DSF 3033 (2009) suggests evaluation of several parameters including air change rate and the concentrations of CO_2, radon, formaldehyde and particles. In the current study, in which the measurements were planned and completed prior to the publication of the draft standard, only the CO_2 concentration will be used to assess the level of ventilation according to
Table 4.5.

Values	Class				
	A	B	C	D	E
CO_2 (ppm)	600	800	1000	1200	>1200

Table 4.5. Quality categories corresponding to the limits of the CO_2 concentration (from DS 3030 (2009) for offices).

4.2 Measurement methods

Measurements comprised four elements:

- Continuous, long-term measurement of air temperature, air humidity and CO_2 concentration in 13 selected locations from the 5th February 2008 to the 28th October 2008.
- Detailed spot measurement of air temperature, operative temperature and air velocity on two selected days, 6th March 2008 and 11th September 2008.
- A survey of the occupants' general perception of the indoor environment in the building (background survey)
- A survey of the occupants' perception of the indoor environment on the 6th March 2008

Long term measurements

Air temperature and relative humidity were logged every 15 min with small measurement stations comprising a HOBO data logger model U12-012 with built-in temperature and humidity sensors and a Vaisala CO_2 transducer model GMW22. The accuracy of the HOBO loggers were ± 0.4ºC at

Figure 4.2. Measurement station.

25 ºC for temperature and ± 2.5% from 10%-90% RH (www.onsetcomp.com 2009). The accuracy of the CO_2 transducer was ±2 % of the range + 2% of the reading. One of each device was mounted on a plywood board with the wires gathered on the back of the board, Figure 4.2.

Measurement stations were distributed on the ground floor, first floor, second floor, and fourth floor at an approximate height of 0.6-0.8 m above the floor. The location of the loggers on each floor is shown in Figure 4.3.

Figure 4.3. Location of the measurement stations on each floor.

It was attempted to distribute the loggers to represent indoor environment exposures on each floor and in sections at different orientations of the building. The office hotel on the third floor was excluded from the measurement protocol due to its configuration with many non-uniform and independent spaces. The measurement stations are identified by the last four digits of the logger serial number, which is used throughout the following presentation of the measurement results.

Spot measurements
Spot measurements were made on two days (6th March 2008 and 11th September 2008) as close as possible to the occupants and in the vicinity of the measurement stations. Air and operative temperature, relative humidity and air velocity were measured at three heights (0.1 m, 0.6 m and 1.1 m) representing the ankles (draught, vertical air temperature difference), the centre of gravity of the body (overall thermal comfort) and the neck height (draught, vertical air temperature difference). All parameters were measured with a Brüel & Kjær 1213 indoor climate analyzer during a period of at least three minutes.

Background questionnaire
Occupant responses were collected via an internet-based questionnaire focusing on the occupants' general impression of the indoor environment, their perception of different Indoor Environment Quality (IEQ) factors, and the prevalence of symptoms and adverse perceptions, e.g. high temperature, during the previous month. The questionnaire can be seen at https://www.ie.dtu.dk/iaqtub08 (access code: indeklima). By email, the occupants were invited to fill in the questionnaire.

Short questionnaire
Simultaneously with the spot measurements, occupants were invited to complete a shorter questionnaire on their immediate impression of the thermal indoor climate, symptom intensity, intensity of adverse perceptions, and self-assessed performance. Visual Analogue Scales (VAS) were used in these assessments. Figure 4.4 shows an example of such scales. The short questionnaire in its full length can be seen at https://www.ie.dtu.dk/iaqtub08/short (access code: indeklima).

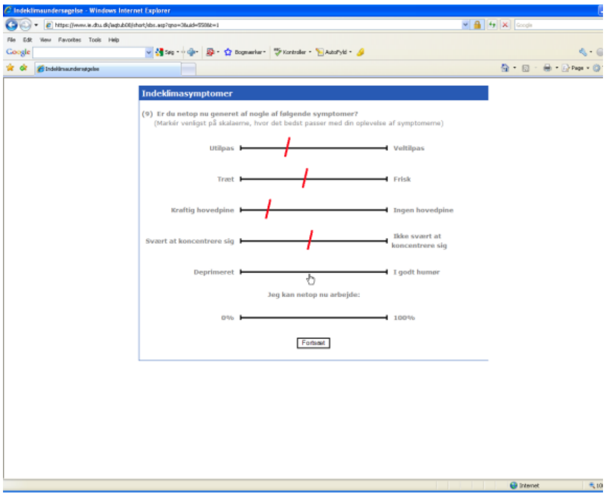


Figure 4.4. Example of a questionnaire page with VAS scales.

This questionnaire was completed during the period when the spot measurements were taken. Originally, the short questionnaire should have been completed on both the 6th March 2008 and 11th September 2008, but due to a mistake at the company with the highest response rate in the first round of measurements, the invitation email for the second round was never sent. Therefore, the short questionnaire was completed only on the 6th March.

4.3 Results

Long-term measurement of temperature and air humidity
For each month in the measurement period and for each measurement station, Appendices 1 and 2 summarize mean, median, minimum and maximum temperatures and air humidities,

respectively, during the main occupancy period, which was assumed to be from 8 – 18 hrs. Also the standard deviation of the measured temperatures and air humidities within month and measurement station is included in the appendices.

In general, the mean temperatures deviated only modestly between months from February to October indicating that the climatic system sustained nearly the same temperature regardless of the season and the changes of the outdoor temperature. The largest variation seemed to occur on the second floor in room 324 (facing west), where the monthly mean temperature varied nearly 2ºC from March to June. Some indoor climate standards recommend that the temperature in the occupied zone be kept in the range 20-24 ºC (winter) and 23-26 ºC (summer) (e.g. DS474-1995) and the measured mean temperatures suggest that the temperature during the winter season was near the upper comfort temperature limit, which may result in a too high energy consumption and sub-optimal comfort for occupants wearing heavy winter clothing. At most locations, the standard deviations of the temperature, quantifying the variability within month of the temperature measured at each location, was also very low.

Based on the data in appendix 2.1, Figure 4.5 shows that the monthly maximum temperature increased with the mean temperature indicating that high temperatures may have occurred not only at the instant when the maximum temperature was recorded, but possibly during sustained periods at that particular location and month.

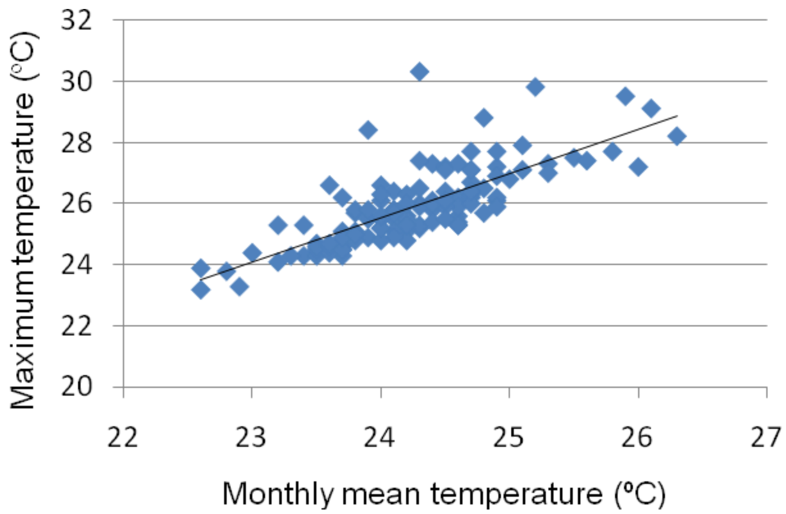


Figure 4.5. Monthly maximum temperature vs. the mean temperature at all measurement locations.

Figure 4.6 shows that there was a relation between the standard deviation of the temperature (std) and the maximum temperature (left), but not between std and the minimum temperature (right). Thus, the largest variability in the temperature also occurred where the highest temperatures were measured, whereas the minimum temperatures were not related with the temperature variability.

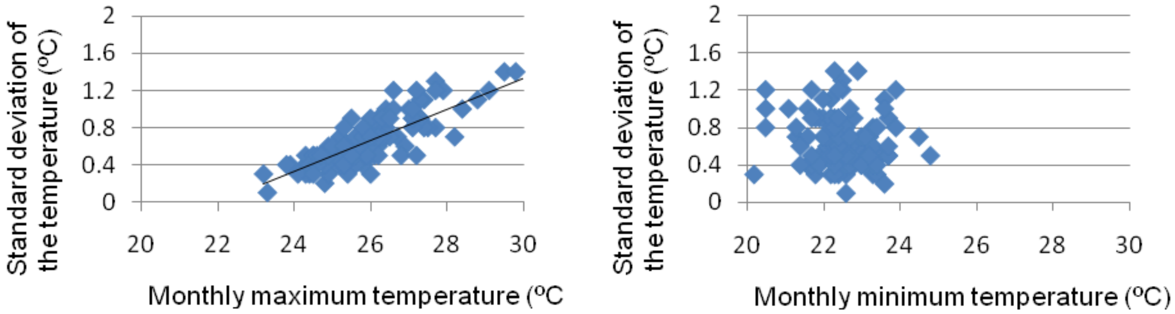


Figure 4.6. Standard deviation of the temperature within month as a function of the monthly maximum temperature (left) and the minimum temperature (right).

According to the temperature ranges recommended in the standards DSF 3033 (2009) and CEN EN 15251 (2006), Figure 4.7 shows the percent of the occupied hours (from 8:00 to 18:00 hrs) during the winter and summer seasons when the hourly mean temperature fulfilled the requirements to quality classes B to E (
Table 4.2) and with only small deviations to classes I to IV (Table 4.4). The winter season was interpreted as February, March and October and the summer season as the period from April to September (both inclusive). Since temperatures at all measurement locations deviated only modestly between seasons, and since temperatures generally were high and within the recommended summer comfort temperature range, the thermal conditions were ranked higher during the summer season. None of the recordings could be class A, since this quality class required individual control of the temperature (DSF 3033-2009).

Figure 4.7. Percent of hours when the hourly mean of the measured temperature during winter (left) and summer (right) was in the ranges recommended by or DSF 3033 (2009) and CEN EN 15251 (2006) for quality classes B, C, D, E and approximately for the classes I, II, III, and IV, respectively (
Table 4.2 and Table 4.4).

Table 4.6 shows the accumulated number of hours during the measurement period, which included the full summer season, when the temperature exceeded 26ºC and 27ºC (DS 474-1995). Also, the table shows the percent of the occupied hours when the temperature exceeded 26ºC (ISO 7730-2005). The three locations with the highest number of hours with temperatures exceeding the comfort range (3028, 3041, and 3031) were all near the west-facing façade and served by ventilation system 3 (3028 ground floor and 3031 second floor) and system 2 (3041 first floor). Logger 3046 on the second floor also exceeded the recommendation, but this logger was located in the window sill outside the occupied zone and it may have been exposed to direct sunlight. Thus, the most critical location in terms of maintaining a comfortably cool temperature was the offices facing west.

Within the comfort temperature range, air humidity has only a modest effect on the perception of comfort when the activity level is low. However, very low air humidities may result in problems with static electricity or drying of the mucous membranes, particularly in the eye, during prolonged exposure. High humidities may affect the perception of the air quality and result in the air being perceived as stuffy and uncomfortable. Typical guidelines recommend that the air humidity should be in the range 30-70% rh, but the scientific basis for assessing the effect on humans of air humidity is somewhat inconclusive. Appendix 2.2 shows that during the winter months, the measured minimum rh was below the recommended range, but the mean rh, although still below this range, was somewhat higher. As could be expected with limited indoor sources of moisture, air humidity changed mostly with the outdoor climate and reached the highest values during the summer period.

Logger	No. of hours when t > 26 ºC	No. of hours when t > 27 ºC	Percent of time when t > 26 ºC (%)
3028	391	93	25
3041	166	34	9
3034	74	8	4
3033	32	4	2
3029	8	0	0
3031	205	64	11
3036	0	0	0
3037	0	0	0
3038	0	0	0
3039	56	0	3
3040	0	0	0
3042	1	0	0
3046	116	4	9

Table 4.6. Accumulated number of hours during occupancy when the recorded hourly mean temperature was higher than 26 ºC and 27 ºC (DS 474-1995) and the percent time when the temperature was above 26 ºC (ISO 7730 – 2005).

Temperature variations with time

Standards' criteria to temporal temperature variations are based on differences in temperature calculated for 15 min, 30 min and 60 min temperature change, which will be explored here (Table 4.3), as well as differences calculated for longer intervals. For all measurement locations, Appendix 2.3 shows the running temperature difference calculated for 15 min lag, 30 min lag, and 60 min lag. As an example, Figure 4.8 shows the temperature variation at location 3031, which is one of the more critical locations in terms of temperature transients. As was the case with the highest temperatures, the largest temperature variation that frequently

exceeded the standards' recommendations was observed at locations near the west-facing façade (3028 ground floor, to some extent 3041 on the first floor, and 3031 second floor). At the end of the measurement period in October at location 3046 on the second floor (logger located in window sill at south facing façade) high temperature variation was recorded during some days. At all other locations, the temporal temperature variation was very modest and far below the criteria in
Table 4.3.

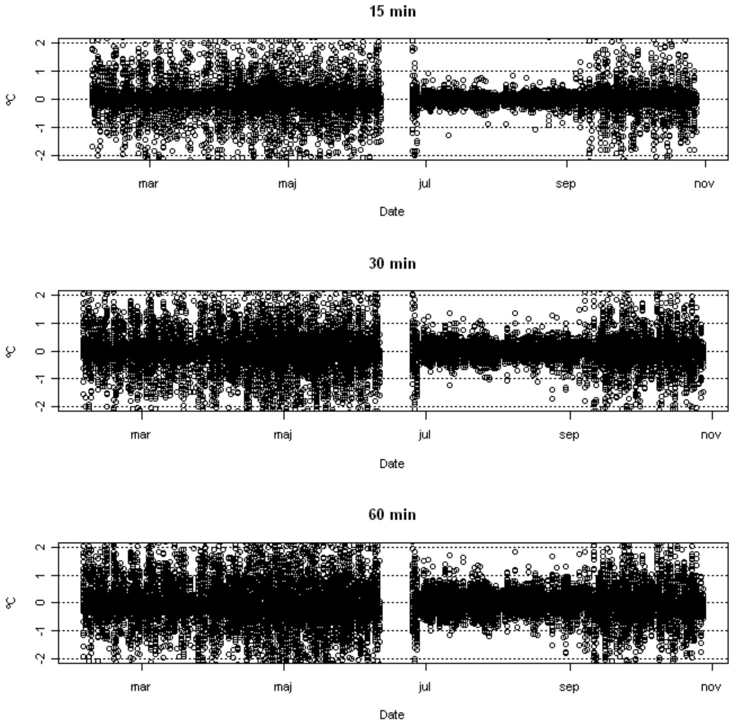


Figure 4.8. Temporal temperature difference determined for measurement location 3031 for 15 min, 30 min, and 60 min lags.

Long-term measurement of the CO_2-concentration
The CO_2 concentration was logged every 15 min together with air temperature and air humidity, but in contrast to the ta and rh measurements, the CO_2 transmitter required an external power supply, which at some locations and during some periods unfortunately was disconnected by cleaning staff or employees. Therefore, the number of recordings of CO_2 varied between 80% to 100% of the amount of ta/rh data points, pending the location.

As an example, Figure 4.9 shows the diurnal variation during April of the CO_2 concentration measured on the 4th floor in room 531 (logger 3039). The figure shows a clear increase in the concentration during the day followed by a decrease during the night, when the building was unoccupied. A similar pattern was seen at the other measurement locations. During the selected measurement period, the concentration at the selected location was never higher than what is required by the best quality class recommended by DSF 3033 (2009), reproduced here in table 4.5.

Figure 4.10 shows that the percent of occupied hours when the hourly mean CO_2 concentration fulfilled the requirements to quality class A was very high. Just in a few locations and during shorter periods the concentration corresponded to class B and was never lower (corresponding to concentrations above 800 ppm) (DSF 3033 2009). Thus, the supplied airflow rate seemed to be high in relation to the occupant density, although it should be noted that the air quality depends also on other pollution sources present in the building, e.g. the carpets, furniture or the ventilation system itself.

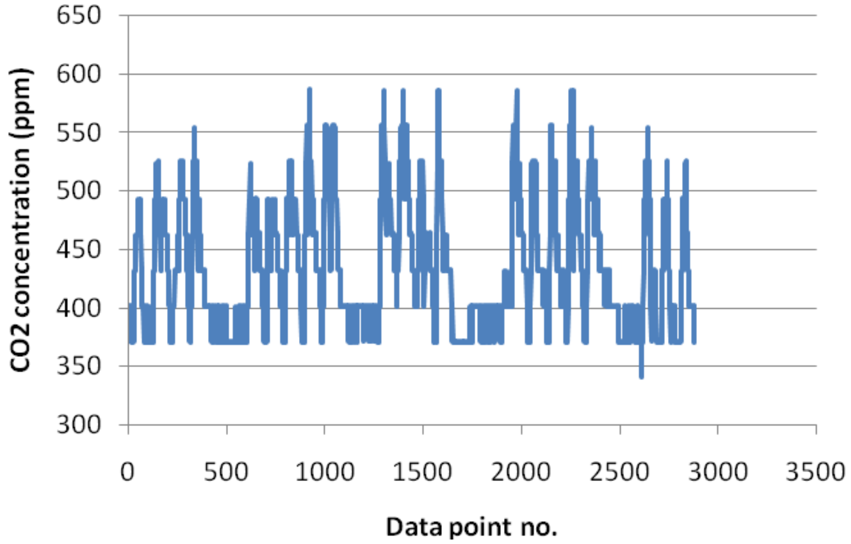


Figure 4.9. Example of the diurnal variation in CO_2 concentration (logger 3039).

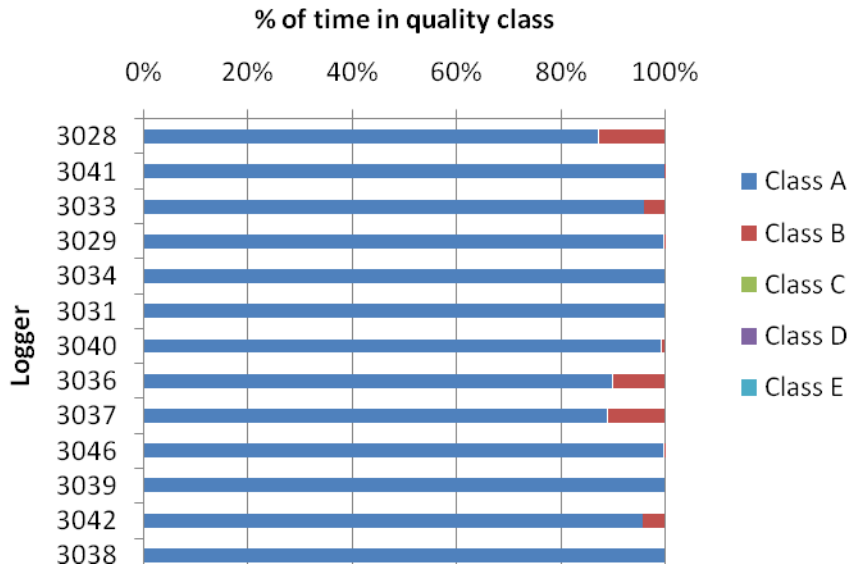


Figure 4.10. Percent of the occupied hours when the hourly mean of the measured CO_2 concentration was in the ranges recommended by DSF 3033 (2009) for quality classes A, B, C, D, and E (
Table 4.5).

Spot measurements

To assess general thermal sensation based on the PMV model and local discomfort due to draught and vertical air temperature difference, spot measurements of air temperature, operative temperature, air velocity, and turbulence intensity were carried out near the locations of the loggers thus representing the exposure in a given zone and floor. Measurements were done on the 6 March 2008 and repeated on the 11 September 2008 and the outdoor temperature on these days was 1.5 ºC and 13.2 ºC, respectively. Appendix 2.4 summarizes all physical measurements, PMV and the draught rating (DR) expressing the percent of the occupants expected to be dissatisfied due to draught. PMV was determined for an average clothing insulation of 0.75 clo (transition between summer=0.5 clo and winter =1 clo) and an activity level corresponding to 1.1 met, typical for office work.

The highest quality class in
Table 4.1 corresponding to -0.2 < PMV < 0.2 is extremely strict and it is currently being discussed whether occupants are at all able to perceive if the thermal indoor climate fulfills class A or class B (Arens et al. 2008). Nevertheless, with the estimated clothing insulation and activity level, most predictions corresponded to class A or class B indicating that the operative temperature on the measurement days was satisfying.

The measured air velocity was generally low and therefore the predicted draught rating was also rather moderate, except in a few locations. Air velocities were measured both directly under and between the air supply units, close to the employees desks, in the perimeter, middle and inner zones near the atrium glass partition, but no systematic pattern was detected that could indicate where the high velocities typically occurred. Fifty percent of the predictions of draught rating corresponded to quality class A (DR < 10%), 42 % to class B (10% > DR < 20%), and 8 % to class C (20% > DR < 30%). The air velocity measurements were carried out on days when the building cooling load presumably was lower than on a hot summer day, when it could be expected that the supply air temperature would be much lower. On such days, downdraught from the air terminal devices may cause higher air velocities in some areas. During the study period, however, air temperatures generally were rather high and air velocities low and as a result, the predicted draught rating did not indicate serious draught problems.

At all measurement locations, the operative temperature was almost equal to the air temperature indicating that there was no high intensity radiant sources or cold surfaces that caused thermal asymmetries. Also, the largest measured vertical air temperature difference between head and ankles was 0.4^{o}C, far below the standards' criteria.

Subjective data – background questionnaire
The background questionnaire was completed by 192 occupants (113 females and 80 males); 38 on the ground floor, 124 on the first floor, 14 on the second floor and 16 on the fourth floor.

The main outcome of the questionnaire study was the prevalence of building related symptoms and adverse perceptions. Both prevalences will be compared with statistics obtained in a large and somewhat representative number of Danish office buildings (CIS 2000).

Table 4.7 shows the prevalence of building related symptoms, the prevalence of symptoms regardless of these being building related and the median and 90% percentile for corresponding prevalences in the reference material in the Glostrup questionnaire on which the applied background questionnaire was based (CIS 2000). Symptoms are called building related when the intensity of the symptom is reduced when the occupant leaves the building. The symptom prevalences in

Table 4.7 correspond to the symptom being present often (weekly) or daily. For example, 41% of the occupants felt lethargy on a weekly or daily basis, while 29% felt lethargy while being in the building, but it improved when they left the building.

The comparable reference material (Glostrup) was recorded in 41 randomly selected buildings distributed equally in Denmark. Around 2/3 of the responses were obtained from women, which was compatible with the current survey. The median indicates that for a certain symptom 50% of the buildings had prevalences below the value indicated in the table, i.e. in 50% of the buildings studied in the Glostrup survey up to 12% of the occupants reported they suffered from lethargy. Likewise, the 90% percentile indicates that 90% of the buildings had prevalences below the value in the table, i.e. in 90% of the studied buildings the prevalence of lethargy was below 19%. As a guideline, the currently observed symptom prevalences shown in table 4.7 should not be above the Glostrup 90% percentile, but if a high indoor environment quality is desired, a value below the Glostrup median should be aimed at (CIS 2000).

The observed prevalences of specific (eyes, nose, throat, skin) and general (lethargy, headache, concentration difficulties) were generally higher than the values in the reference material.

Symptom	Building related prevalence (%)	Prevalence (%)	Glostrup median (%)	Glostrup 90% percentile (%)
Lethargy	29	41	12	19
Heavy head	33	41		
Headache	13	18	11	17
Concentration difficulties	28	29	4	10
Problems focusing	7	10		
Itch or irritation in the eyes	22	26	6	16
Irritated, stuffy or runny nose	19	23	12	16
Hoarse, dry throat	13	13	3	7
Cough	3	6	7	10
Dry, itchy head or skin on the ears	7	14		
Dry, itchy skin on the hands	12	18		
Other*	4	4		

Table 4.7. Prevalence of symptoms that were present weekly or daily during the month prior to completion of the questionnaire.
*"Other" comprises other symptoms with focus on noise and mucous membranes.

Symptoms with the highest prevalence were distributed on the floors as shown in Table 4.8.

Symptom	Ground floor (%)	First floor (%)	Second floor (%)	Fourth floor (%)
Lethargy	39	29	21	13
Heavy head	53	28	36	25
Concentration difficulties	34	35	14	6
Itchy or irritated eyes	8	26	0	6
Irritated, stuffy or runny nose	16	21	50	25

Table 4.8. Distribution on floors of selected, building related symptoms.

In particular, occupants on the ground floor and second floor complained of a high prevalence of general symptoms and somewhat lower prevalence of eye and nose symptoms. On the second and fourth floors, the prevalences were based on responses from only 14 and 16 occupants, respectively, and therefore may not represent well all occupants on these floors.

Table 4.9 shows the prevalence of adverse perceptions present weekly or daily during a recall period of one month as stated in the question. The occupants completed the questionnaire in early March, and the responses thus represent their impression of the indoor climate in February and early March.

Adverse perception	Prevalence (%)	Glostrup median (%)	Glostrup 90% percentile (%)
High temperature	46	10	20
Varying temperature	56	16	30
Low temperature	31	9	18
Draught	28	15	29
Stuffy air	64	17	27
Dry air	61	23	39
Noise	69	28	42
Lighting	33	10	20

Table 4.9. Prevalence of adverse perceptions present weekly or daily during the previous month.

Even though larger temperature variation was recorded at the west-facing façade, the prevalence of high or varying temperature among occupants in this section of the building was not higher than in the other sections. Complaints of dry air were rather prevalent, but even though measured air humidities periodically were lower than recommended by indoor environment guidelines other factors, such as e.g. irritants in the air may exacerbate the perception of dry air.

The prevalence of almost all adverse perceptions exceeded the 90% percentile in the reference material indicating that the occupants were rather annoyed with the indoor environment. Even though the survey was completed in March, the prevalence of complaints of high temperature was higher than for low temperature. This corresponds well with long-term measurements of temperature, which showed a relatively constant and high temperature level regardless of the season (Figure 4.7). Thus, some adjustment of the indoor temperature with the season may reduce the prevalence of some of the complaints.

The prevalence of the perception of stuffy air was high despite the high ventilation airflow indicating that other sources than humans may have a dominant effect on the indoor air quality, e.g. the building interior or the ventilation system. Also, noise is a prevalent adverse perception, however not uncommon in high-occupancy open-plan offices as found especially on the ground and first floors.

Table 4.10 shows the prevalence of adverse perceptions, but distributed on the individual floors. On the ground floor where the occupant density was rather high, adverse perceptions such as stuffy air, noise, and varying temperature were particularly high. Draught is one of the most frequent causes of complaints in office buildings, but especially on the second and fourth floors, there were only few complaints of draught, possibly because the occupant density and the cooling load may have been low, leading to a higher supply air temperature. However, only few occupants on the second and fourth floor completed the questionnaire.

Adverse perception	Ground floor (%)	First floor (%)	Second floor (%)	Fourth floor (%)
High temperature	63	45	36	25
Varying temperature	74	51	43	56
Low temperature	39	28	36	38
Draught	39	30	14	19
Stuffy air	82	59	50	69
Dry air	66	59	57	63
Noise	79	66	43	75
Lighting	53	25	29	38

Table 4.10. Prevalence of daily or weekly adverse perceptions distributed on floors.

The distribution of the number of responses to the question ”How satisfied are you with the indoor envionment in the building” can be seen in
Table 4.11.

	Clearly dissatisfied (%)	Just dissatisfied (%)	Just satisfied (%)	Clearly satisfied (%)	N
Ground floor	54	35	11	0	37
1st	27	37	33	3	123
2nd	23	54	23	0	13
4th	31	31	38	0	16

Table 4.11. Distribution of responses describing the general satisfaction with the indoor environment in the building.

A majority of the occupants were generally dissatisfied with the indoor environment in the building, in particular on the ground floor and first floor where 89% and 64% of the occupants, respectively, were dissatisfied. On the second and fourth floors, the number of responses was too low to be representative.

The occupants also had the opportunity to comment on the indoor environment in the building, and the comments are summarized in Appendix 2.5 (in Danish). Most comments concern the indoor environment on the ground and first floors and only few relate to the second and fourth floors. Generally, comments focus on the temperature being too high, low, or varying during the day, on too much noise in the open-plan offices, particularly from phone conversation, on draught, and to some degree on stuffy and unacceptable indoor air quality. Thus, the comments agreed well with the adverse perceptions with highest prevalence.

Subjective data – short questionnaire
The short questionnaire used VAS scales to assess the intensity of adverse perceptions and symptoms. These scales only have semantic end points and no indications grading the intensity between the end points. Votes cast on VAS scales therefore vary widely between individuals and the scales are used mostly to assess differences in occupant perceptions with repeated exposures and measurements, where each individual can act as his/her own control. As mentioned earlier, the short questionnaire was completed only once and it was therefore not possible to compare perceptions between the measurements carried out in March and those carried out in September. Instead, data from the measurement in March will be presented in rather condensed form.

The short questionnaire was completed by a total of 111 occupants divided between floors with 23 responses on the ground floor, 70 on the first floor, 6 on the second floor and 11 on the fourth floor (one occupant did not report on which floor he/she was located at).

For each floor, Table 4.12 compares observed and predicted average thermal sensation. Although not perfect, the correspondence between the observed and predicted values was acceptable, which may indicate that the clothing insulation and activity level estimated to predict the PMV were appropriate for the occupants on the 6 March. Also, the table shows the distribution of the observed thermal sensation votes corresponding to the ISO 7730 (2005) quality classes.

Floor	Observed average thermal sensation (± standard deviation)	N	PMV	Quality classes		
				A (%)	B (%)	C (%)
Ground	-0.4 ± 0.8	23	0.1	45	15	0
1st	-0.1 ± 1.1	70	0.2	41	6	1
2nd	0.3 ± 1.0	6	0	25	0	0
4th	-0.1 ± 0.8	11	0.1	50	10	10

Table 4.12. Observed thermal sensation, PMV calculated with averages of physical measurements on each floor and the distribution of the thermal sensation votes in the ISO 7730 (2005) quality classes.

Table 4.13 shows the percent of the occupants who on the 6 March found the general indoor environment as being comfortable and the temperature as being acceptable. On the ground and 1st floors a rather significant percentage of the occupants were not comfortable, whereas the general comfort conditions seemed to be better on the 2nd and 4th floors where the occupant density was lower. However, on these floors the number of responses was too low to represent the total population.

Floor	Comfortable occupants (%)	Occupants finding the temperature acceptable (%)
Ground	61	65
1st	51	65
2nd	83	67
4th	82	73

Table 4.13. Percent of the occupants who found the indoor environment comfortable and who found the temperature as being acceptable.

Table 4.14 shows that particularly on the ground floor the air quality was not perceived as being good. Also, noise was rated to be somewhat high on all floors. The perception of the cleanliness in the offices seemed rather low on the ground floor, but slightly better on the other floors.

Factor	Floor			
	Ground	1st	2nd	4th
Air quality (0: poor - 100: good)	29 ± 18	38 ± 10	40 ± 10	52 ± 26
Lighting (0: too dark - 100: too bright)	44 ± 17	40 ± 18	51 ± 20	42 ± 16
Noise (0: too quiet – 100: too noisy)	66 ± 19	66 ± 19	65 ± 27	64 ± 21
Air humidity (0: air too dry - 100: air too humid)	71 ± 20	71 ± 20	59 ± 10	61 ± 19
Cleanliness (0: dirty - 100: clean)	36 ± 21	43 ± 17	44 ± 22	51 ± 18

Table 4.14. Intensity of adverse perceptions and occupants' perception of the cleaning standard (mean ± std.).

Table 4.15 indicates that the intensity of selected specific symptoms (nose, mouth, skin, eyes) seemed to be lower on the 2nd and 4th floors than on the ground and 1st floors. With the general symptoms there seemed to be no difference in the intensity between the floors. Self-assessed performance was rated rather high on all floors indicating that the employees did not feel the indoor environment impaired their work performance.

Symptom	Floor			
	Ground	1st	2nd	4th
Nose (0: dry – 100: not dry)	40 ± 28	42 ± 29	56 ± 43	62 ± 30
Mouth (0: dry – 100: not dry)	39 ± 32	50 ± 31	89 ± 19	63 ± 30
Skin (0: dry – 100: not dry)	33 ± 30	33 ± 23	43 ± 33	42 ± 32
Eyes (0: dry – 100: not dry)	34 ± 32	40 ± 28	61 ± 35	60 ± 28
Eyes (0: irritated - 100: not irritated)	34 ± 31	37 ± 28	67 ± 33	61 ± 30
Lethargy (0: tired - 100: rested)	44 ± 26	50 ± 26	55 ± 29	39 ± 25
Headache (0: severe – 100: no)	69 ± 26	77 ± 25	77 ± 31	77 ± 28
Concentration (0: difficult – 100: easy)	58 ± 29	57 ± 29	63 ± 27	64 ± 31
Right now I'm able to work (0% - 100%)	83± 13	81 ± 18	85 ± 15	78 ± 17

Table 4.15. Intensity of selected symptoms and self-assessed performance (mean ± std.).

4.4 Summary of main findings

In particular during the winter season, the measured temperatures seemed higher than recommended by the standards, which may cause too high energy consumption and sub-optimal thermal comfort. Comments from the occupants also emphasize on too high temperatures. Also, temperatures varied only little between seasons. Adaptation of the system set-points to the season may promote lower energy consumption and improved thermal comfort. Highest temperatures and largest daily temperature variation was measured in offices facing west and served by ventilation system no. 3.

The CO_2 concentration was low indicating high ventilation airflow rate in relation to the occupant density. However, a high percentage of the occupants found the air quality unacceptable indicating that other sources, such as processes in the building, interior surfaces or the ventilation system itself were dominant sources.

The prevalence among the occupants of symptoms and adverse perceptions was very high as compared with a representative average of Danish office buildings. Dissatisfaction was mostly caused by noise, unacceptable temperatures, and poor air quality.

High temperatures are known to aggravate the intensity of several indoor climate related symptoms and the perception of poor air quality. Better control of the temperature in the building would thus be an obvious means to improve the thermal conditions and the perceived air quality and reduce the prevalence of symptoms. Although the measurements generally did not confirm high air velocities in the building, complaints of discomfort due to draught were rather prevalent. A more detailed study of the airflow pattern near the supply openings may reveal problematic air velocities when the system operates at highest airflow rate and lowest supply air temperature.

5. Visual investigation of the measurements

The main purpose of the project was to investigate the types of mulitparameter sensors which can be generated based on the logged values from the BMS system. This will be dealt with in the next chapter. However, another aim was to investigate how the availability of logged times series may enhance the traditional inspection of a building and installations. This will be done in the present chapter.

The visual investigations of more than 1000 data point logged over 14 is a major task and it is further difficult to explain the findings if the work was not broken down into smaller areas and illustrated only by well chosen examples.

The inspection of the measured data is therefore divided in the following areas:

- selection of two representative one week periods
- comparison with the findings from the previous chapter
- the electricity demand of the building
- the ventilation systems
- the cooling systems
- temperatures in the rooms
- the atrium

5.1. Selection of two representative one week periods

Displaying the data for the whole measuring period is beneficial for some purposes – eg in order to show the dependency on the time of the year, but in order to illustrate how the systems function this is not appropriate. Then there is a need for representative shorter periods. It was, therefore, decided to choose one winter week and one summer week – but which. Figure 5.1 show the measured ambient temperature and the measured global radiation for the whole measuring period.

There is as seen four holes of 7-14 days in the time series for the ambient temperature – and three outliers. Some problems is also seen in the start of the measuring period. The same holes in the measurements are seen for the global radiation – and unfortunately the measurements stop for the solar radiation during the first part of May 2008.

The BMS system was not prepared to log measurements. This should be implemented at the start of the project and as there was no facility for automatically export of the logged data, this had to be done by hand. This of course facilitates errors. In spite of missing data - more for some values than others (later it is stated, that over 80% of the room temperatures has been logged) – the outcome of this first attempt to log on such a large system is therefore acceptable.

Due to missing data after the beginning of May 2008 it has not been possible to choose a period with higher ambient temperatures than the wished indoor temperature, however, as the building starts to call for cooling at ambient temperatures close to zero degree this is not regarded as a major problem. The two chosen periods is February 12-19 and April 30-May 6 both in 2008. The ambient temperature and global radiation for these two periods are shown in figure 5.2.

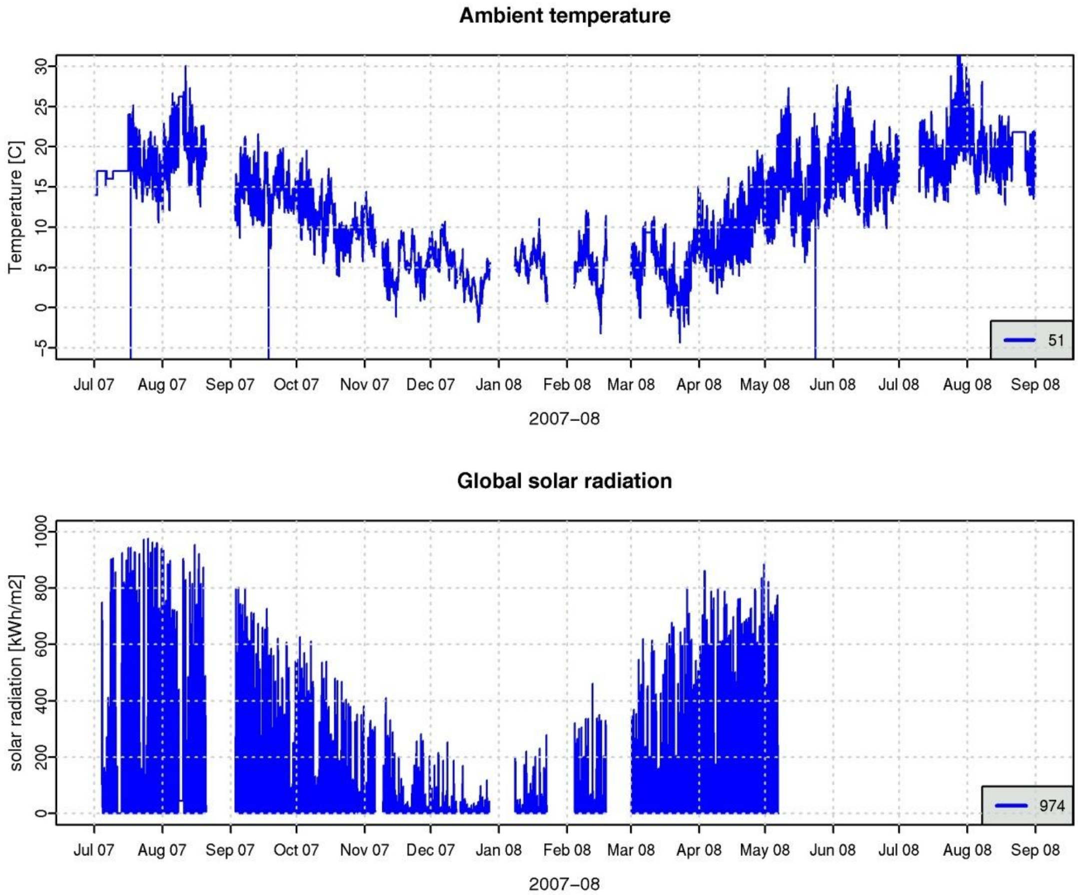


Figure 5.1. Available ambient temperature and global radiation for the measuring period July 1, 2007-August 31, 2008.

The winter period February 12-18 is characterized by low ambient temperatures: -5-12°C and a mix of clear sky, overcast and cloudy conditions.

The spring period April 30-May 6 is characterized by moderate ambient temperatures: 5-18°C and a again a mix of clear sky, overcast and cloudy conditions.

5.2. Comparison with the findings from the previous chapter

In the previous chapter the indoor climate was measured by special purpose sensorss where small data loggers - logging temperature, relative humidity and CO_2 - was located close to the users in order to measure the climate the user of the building sense. However how do this comply with the indoor climate measured by the BMS system with its temperature sensor in the zones and the mean relative humidity and CO_2 measured in the exhaust of each ventilation system.

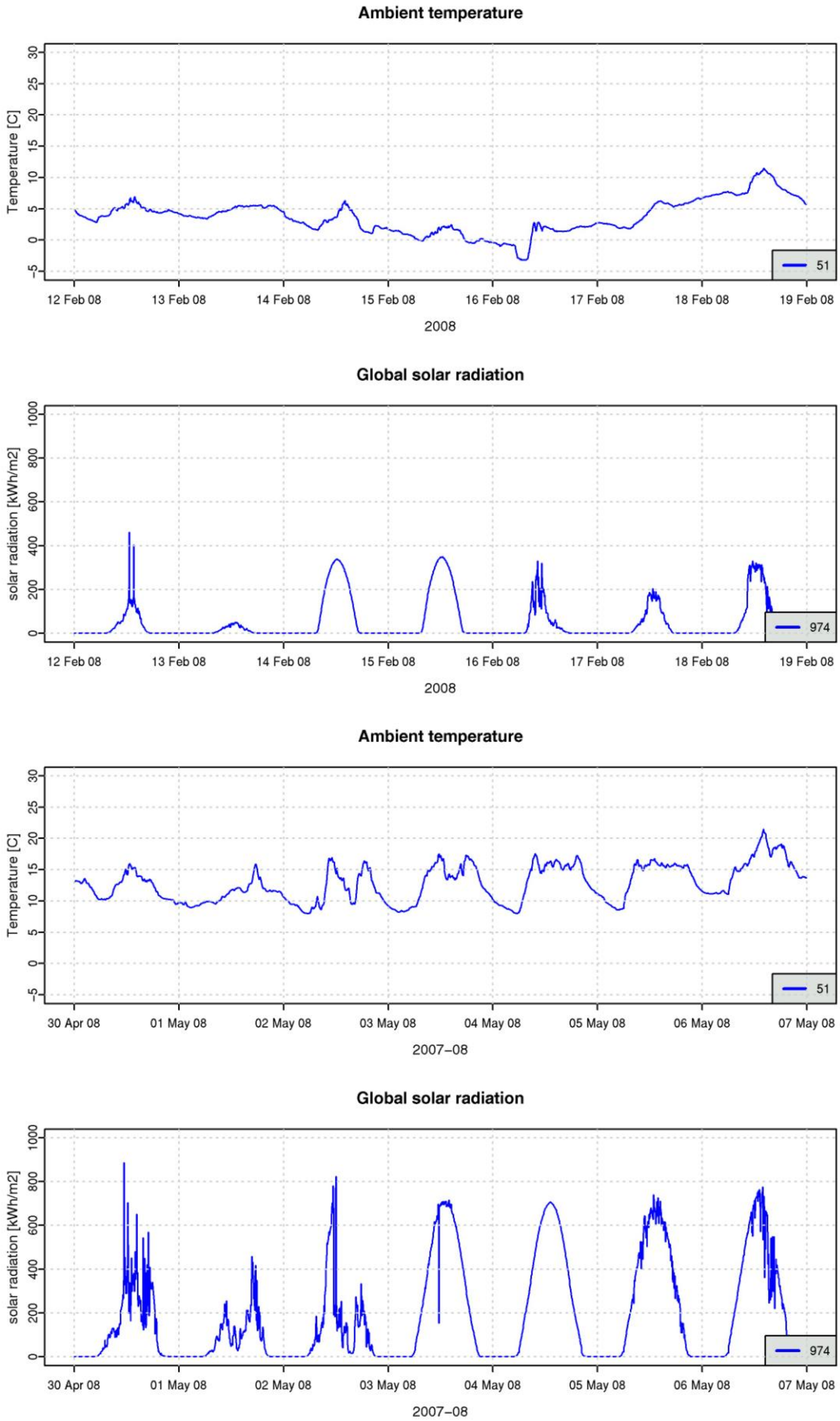


Figure 5.2. Ambient temperature and global radiation for the two chosen periods

Figure 4.3 shows the location of the special purpose indoor climate sensors. In Appendix 3 the measured air temperature of these is compared with the temperature logged by the BMS. In the case where the special purpose sensor is located between two zones the BMS temperature of both surrounding zones is shown. Graphs are both shown for the two selected periods and for the whole period with special purpose climate measurements – February-September 2008. The blue lines in appendix 3 is always the temperature measured by the special purpose indoor climate sensor.

Appendix 3 shows that the difference between the room air temperature measured with the BMS and the indoor climate data loggers is up to ±2 K. This is not bad when considering that the rooms are open space offices which easily may have a horizontal temperature stratification of ±2 K.

Appendix 3 shows that the difference is negligible for room 316 while the BMS air temperature in mean is 1-2 K lower than the special purpose measured temperature. For others eg room 322 the BMS temperature drops to at lower level than the special purpose temperature during the day.

A major part of the difference between the two temperature series may be explained by the chosen way of cooling the rooms: cooling baffles. The cooling baffles introduce as seen in figure 2.15 a cold stream of air, which just after leaving the cooling baffle is more or less parallel to the ceiling, but after a short while the cold air starts to drop towards the floor as shown in figure 5.3.

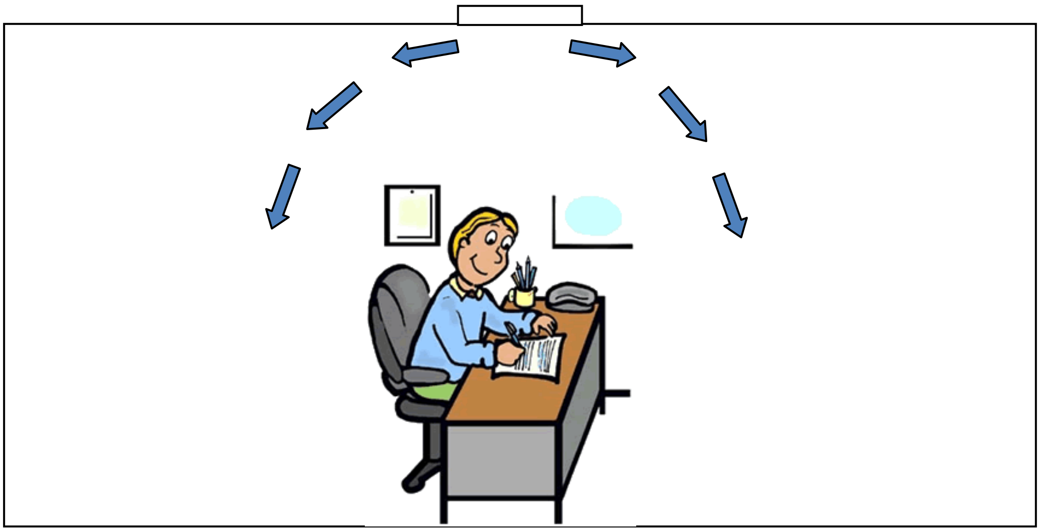


Figure 5.3. The function of the cooling baffles in a room

When visiting the offices it was noticed by inducing smoke that cold air from a cooling baffles was directly hitting the air sensors in eg room 322. Figure 5.4. shows the temperature sensor of room 322.

Does this mean that the air temperature does not well represent the air temperature in the rooms? Not necessarily – figure 5.3 shows the right location of a desk compared to the cooling baffles – ie right under the baffles as the cold air stream do not hit the working person.

However often the offices are organized in such a way that people is located right in the air stream from the cooling baffles as seen in figure 5.5.

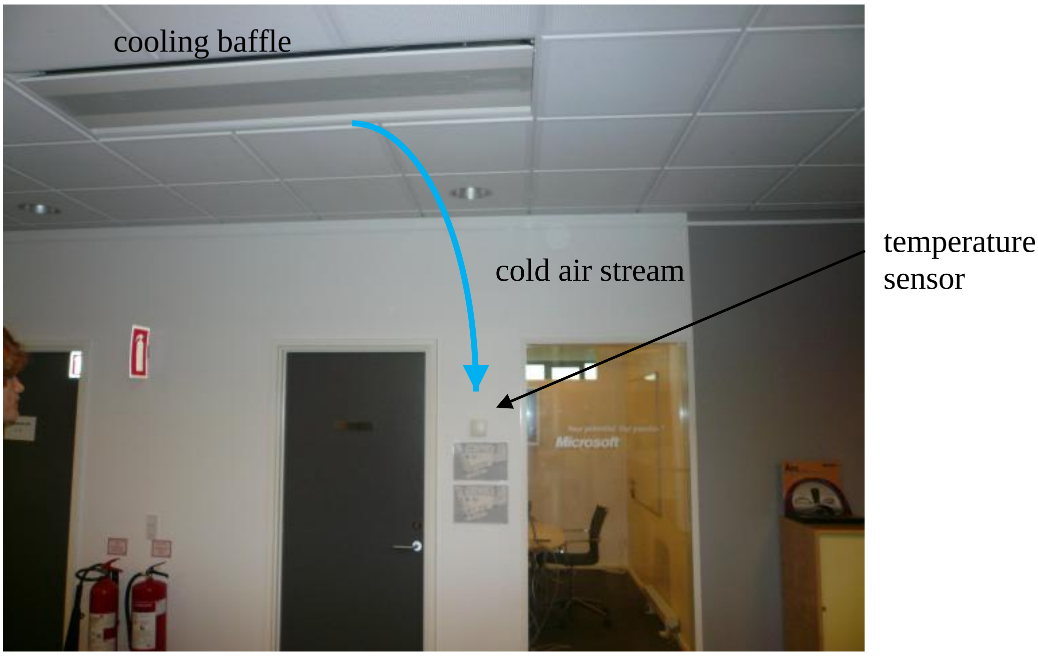


Figure 5.4. Cold air hitting the temperature sensor directly.

Figure 5.5 Problematic location of a desk.

In other rooms the location of desks is more appropriate in order to prevent draft. Figure 5.6 shows the arrangement of 4 desks in room 302 right under a cooling baffles where no draft is felt when sitting at the desks. There is in this room no complaints regarding the thermal indoor climate – however there are complaints regarding the daylight conditions as the room is facing the atrium.

Figure 5.6. Arrangement of 4 desk where there are no draft.

The arrangement regarding location of temperature sensor compared to a cooling baffle in room 316 is identical to figure 5.4, but here there is almost no difference between the BMS temperature and the special purpose temperature. An inspection showed that very little air came out of the baffle in room 316 leading to no cold air drop on the temperature sensor in this room.

Based on the investigations of the measured data and visits to the building the following may be concluded.

- cold air from the cooling baffles is often hitting the temperature sensors directly
- people are often located wrongly compared to the location of the cooling baffles. This means that the BMS temperatures may just as well represent the temperature sensed by the users as the indoor climate sensors
- the air flow through the cooling baffles need to be balanced in order to deliver the right air flow volume and thereby obtain the proper cooling capacity

5.2.1. Relative humidity and CO_2

5.3. The electricity demand of the building

Appendix 4 shows the electricity demand of the building divided in the power consumption of the installations in the building and the power consumptions of each of the companies occupying the building.

To be continued

5.4. The ventilation systems

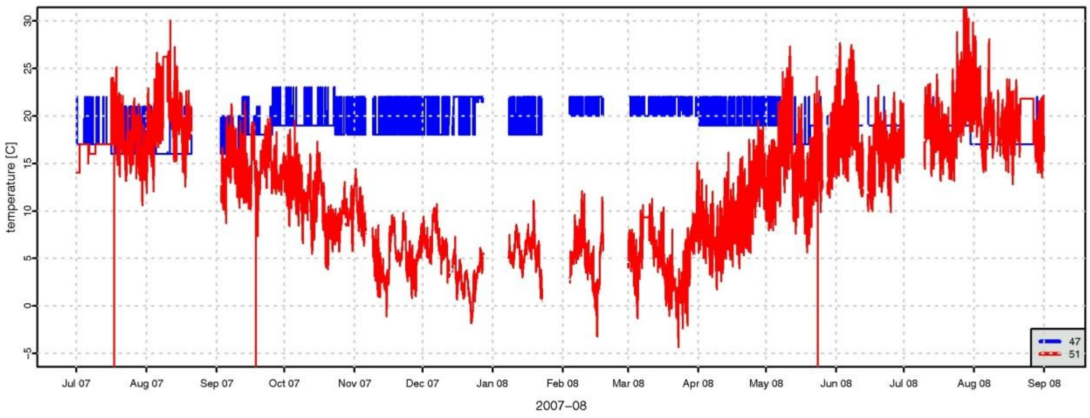
Appendix 5 shows measurements from the three main ventilation systems for the two selected periods.

Appendix 6 shows air temperatures for the rooms served by ventilation system 3. The rooms are divided on floors and type of system: CAV or VAV.

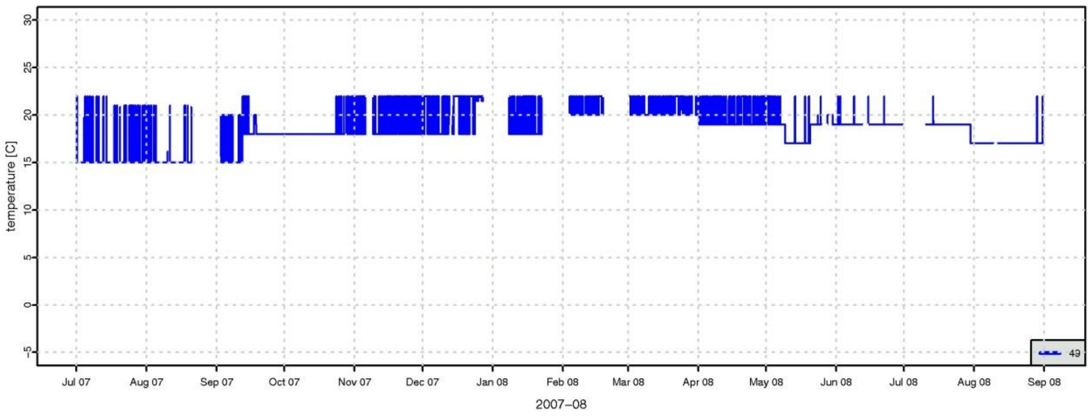
Figure 5.7 shows the set points concerning the temperature of the fresh air to the rooms.

To be continued

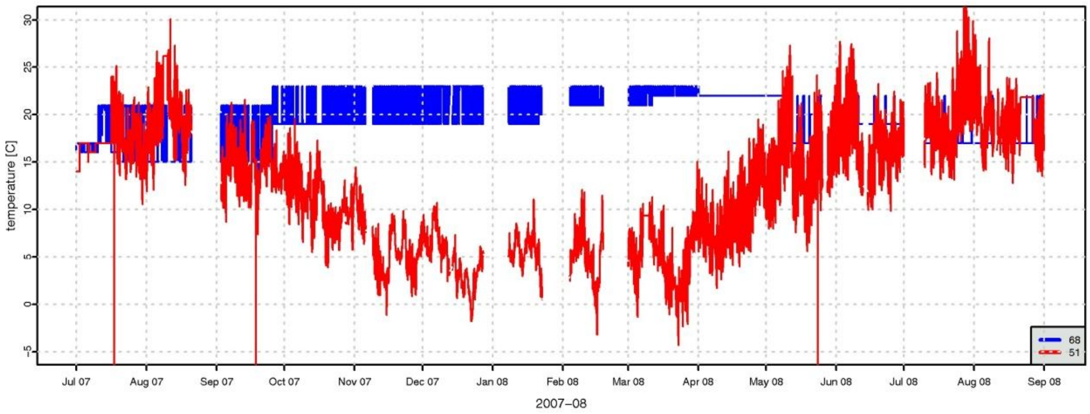
Ventilation system 1 – CAV



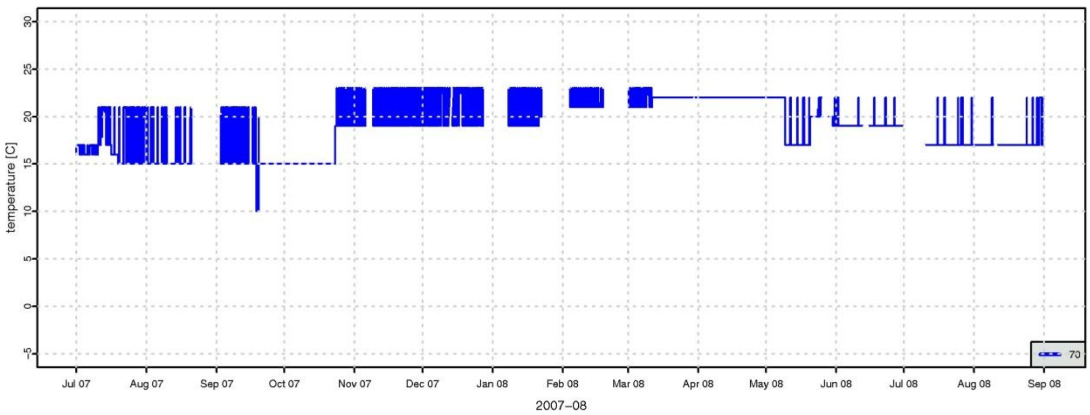
Ventilation system 1 – CAV

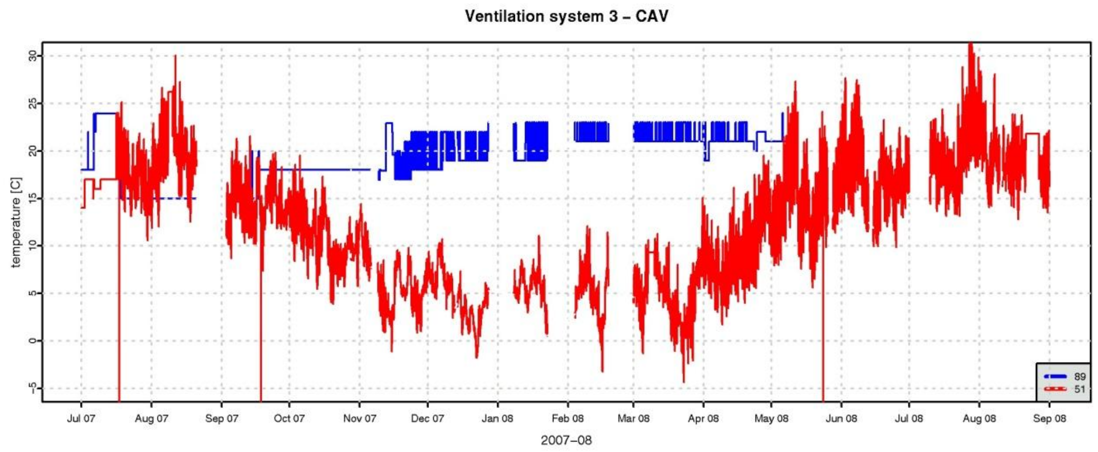


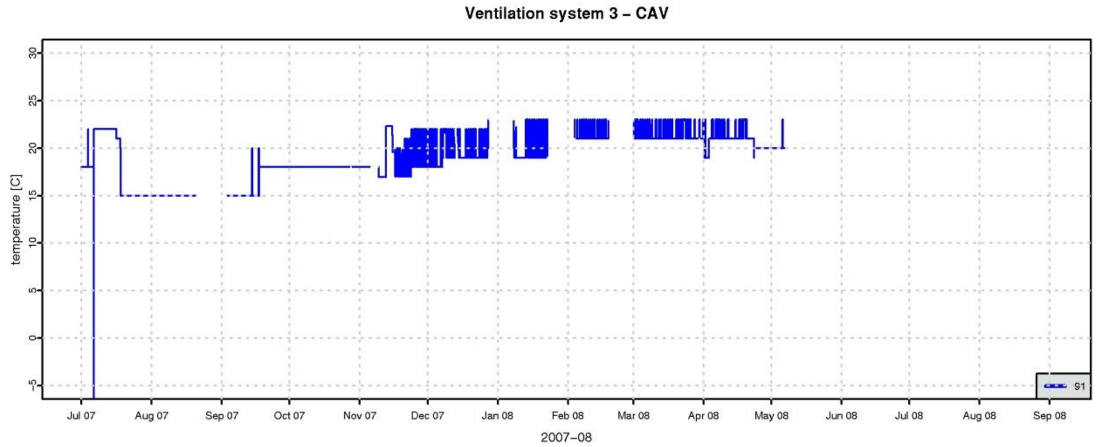
Ventilation system 2 – CAV

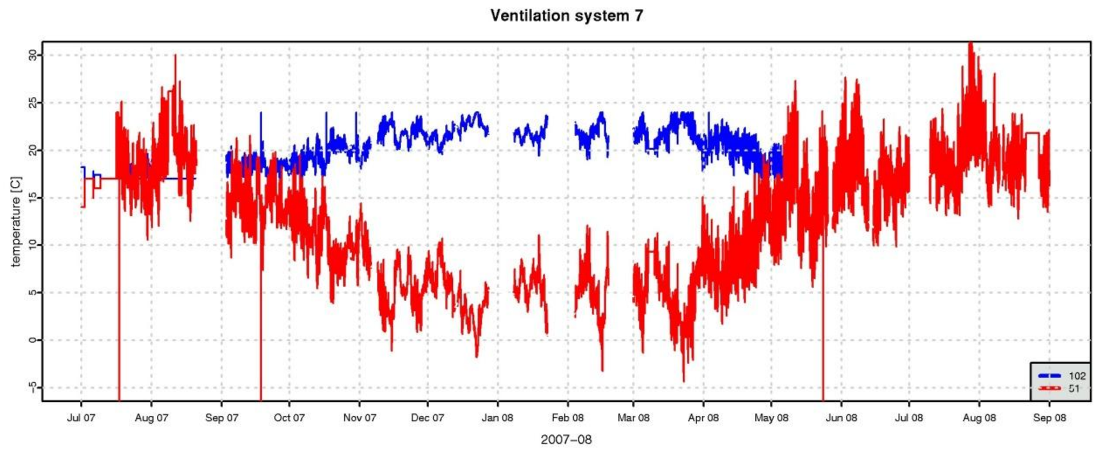


Ventilation system 2 – VAV









5.5. The cooling systems

5.6. Temperatures in the rooms

For all the rooms in the building the frequency curves of room temperatures have been generated. The curves generated are:

- *Working hours* (shown with red curves)
- *Other hours* than working hours (i.e. most data is from night time and weekends) (shown with green curves)
- *All hours*. (shown with black curves)

The working hours are defined as the time Monday to Friday between 8.00 and 17.00 pm at workdays. The measuring period is from July, 1. 2007 to August 31. 2008. The this gives a total number of days in the analysis at 428. With measurements each 5 minutes it gives a maximum of 123.264 measurements for each sensor. However there is missing data and for most of the sensors there is between 98.939 and 106.005 observations , corresponding to available data between 80 % to 86 % of the time. The working hours account for only 27% of the total hours. This is why the curves for other hours and all hours shows nearly the same appearance on the curves. In the comparisons it is therefore primarily the working hours which are compared with the other hours.

The ventilation system is supposed to run in these working hours at a constant rate(??). The cooling system is supposed to be activated at if the room temperature is above the set point temperature.

There might be minor differences between the data from different rooms due to differences in missing data.

By comparing the different curves it is possible to characterize the typical indoor temperatures in the different rooms.
The aim is to give a characterization of each single room. By this characterization it is possible to extract information about it performs typical or it shows an untypical performance. If the profile deviates from other rooms it could be worthwhile to find the reason for this performance. The curves can assist to find the diagnosis in this proces.

Following parameters will have a major impact on the thermal performance:

- External climate (solar radiation, external temperatures and wind).
    - Some of the rooms are exposed to the external climate giving additional heat load from solar radiation during daytime and heat loss when there is low external temperatures.
- Internal heat sources (equipment, lightning and persons)
    - The internal heat sources gives an additional heat load
- Operation of heating, cooling, ventilation and shading system.
- Heat exchange with other rooms (ventilation or conduction through walls, floors and ceilings)
- Heat capacity of the rooms

Below a table is shown which indicates the explanation of a certain visual appearance of the curves:

	Observation from curves:	Possible explanation:	Example (room no.)
1	Working hours close to other hours	Small heat load, no cooling, large heat capacity compared to heat load	306
2	Lower part: Working hours close to other hours Upper part: Working hours lower than other hours	Heat load independent of working hours. Cooling at high temperatures.	304, 401
3	Lower part: Working hours close to other hours Upper part: Working hours higher than other hours	Heat load independent of working hours. Indication of non optimal conditions.	Not found
4	All temp. working hours lower than all temp. other hours.	No or permanent heat load. Cooling or ventilation in all working hours. Maybe heat from other rooms	301, 302, 320, 322, 325, 328, 330, 332
5	All temp. working hours larger than all temp. other hours.	Additional heat load working hours. Cooling or ventilation in all working hours might be insufficient.	313
6	Curve for temp. working hours crosses curve for temp. other time (working hours lowest at upper part of curve)	Significant heat load at working hours. Cooling of rooms at working hours when temperature is higher than a certain level. At the lower part of the curves will the horizontal difference between working and other hours indicate the level of thermal load. At the upper part of the curves will the horizontal difference between working and other hours indicate the level of cooling load.	307, 309, 316, 317, 318, 324, 329
7	Curve for temp. working hours crosses curve for temp. other time (working hours higest at upper part of curve)	Small heat load at a large part of the working hours but some additional heat load from intermediate sources as eg solar gain or many persons at certain times. Cooling or ventilation at all working hours. The cooling or ventilation load is insufficient to cool down the temperatures of rooms at working hours when temperature is higher than a certain level.	327

8	Low temperature, other hours	Large heat loss from the room or small heating capacity. Maybe ventilation or cooling at night.	231, 313
9	High temperatures at other hours	Large heat load either permanent or from ambient.	Many examples, 321
10	Steep curve, normal temperature level	Small heat load or good control function of heating, ventilation or cooling.	Atrium, 312
11	Steep curve, high temperature level	Small or constant internal load. Maybe a large cooling capacity.	322, 332
12	Moderate slope	Large heat load	316, 323, 324

Suggestions for possible actions to be taken.
A set of curves likes the ones presented could be produced at certain intervals e.g. twice a year. The main purpose is to see whether the comfort level in each of the rooms are acceptable in general or if any parameters should be modified either to improve the comfort level or in order to save energy.

The first concern from the curves is if the temperature level is in an acceptable range. Some of the rooms have temperature levels which not are acceptable with regard to human thermal comfort but there might be server rooms and other rooms with a specialized usage. These rooms should be taken out of the evaluation unless the rooms are expected to influence the temperatures of other rooms significantly or the heat load in the rooms is evaluated.

The rest of the rooms selected are then evaluated in terms of thermal comfort.
In the next section (5.6.1) is illustrated in which of the rooms there from the CTS-system has been identified higher temperatures than normally accepted.

These rooms should be given a high priority in the evaluation. The curve for the rooms should be characterized in relation to the table elaborated above. This will give some information about the possible reason for the not acceptable temperature levels. Also rooms with acceptable temperature levels should be classified according to the table in order to identify if energy savings might be possible.

Below are some considerations concerning possible actions to be taken made for each of the cases in the table above.

		Thermal comfort acceptable	Thermal comfort not acceptable
1	Working hours close to other hours	Ok.	Cooling or increased ventilæation could be applied
2	Lower part: Working hours close to other hours	Consider if there is too much cooling or ventila-	Increased cooling or ventilation or reduc-

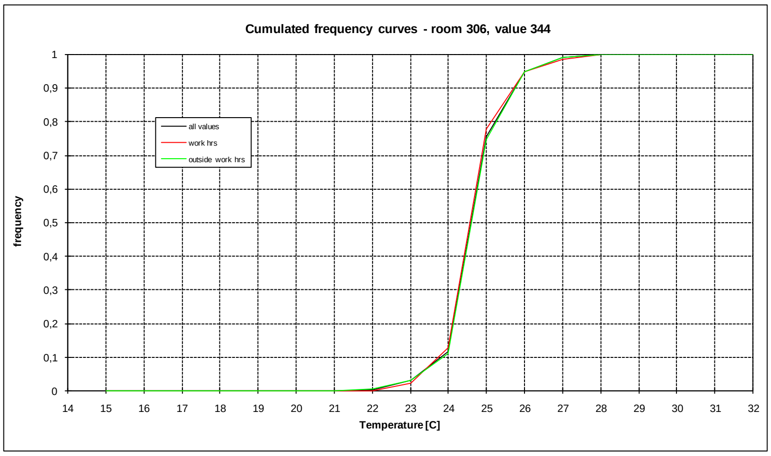
	Upper part: Working hours lower than other hours	tion.	tion of heat load
3	Lower part: Working hours close to other hours Upper part: Working hours higher than other hours	Ok.	Increased cooling or ventilation or reduction of heat load
4	All temp. working hours lower than all temp. other hours.	Consider if there is too much cooling or ventilation	Increased cooling or ventilation or reduction of heat load
5	All temp. working hours larger than all temp. other hours.	Ok.	Increased cooling or ventilation or reduction of heat load
6	Curve for temp. working hours crosses curve for temp. other time (working hours lowest at upper part of curve)	Consider if there is too much cooling or ventilation	Increased cooling or ventilation or reduction of heat load
7	Curve for temp. working hours crosses curve for temp. other time (working hours higest at upper part of curve)	Ok.	Increased cooling or ventilation or reduction of heat load
8	Low temperature, other hours	Consider if there is to large heat losses from the room	Increased heating and also consider if there is to large heat losses from the room
9	High temperatures at other hours	Consider if the heat load can be reduced.	Consider if the heat load can be reduced
10	Steep curve, normal temperature level	Consider if there is too much cooling or ventilation	Consider if the heat load can be reduced
11	??Steep curve, high temperature level	Consider if there is too much cooling or ventilation	Consider if there is too much cooling or ventilation
12	Moderate slope	Consider if the heat load can be reduced.	Consider if the heat load can be reduced

In all cases it could be considered if the set point outside some of the working hours could be lowered or if this will provide problems.

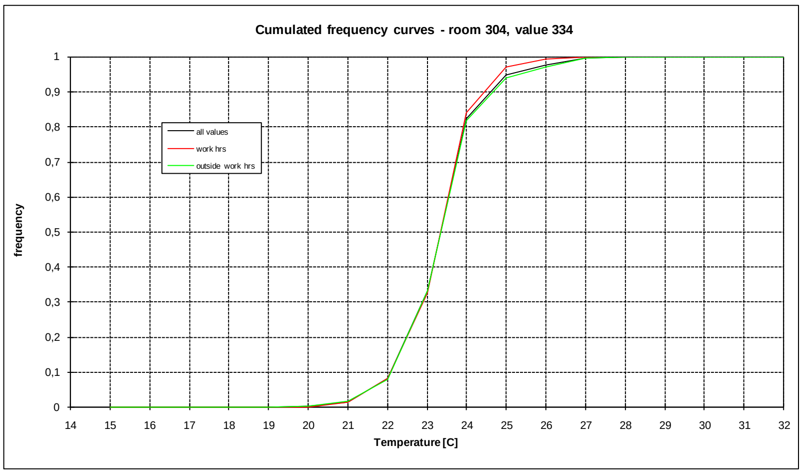
Individual comments on some of the rooms

Temperature of *atrium*. Remarks. The profile for workings hours is the same as in other hours. The slopes of the curves are steep. This leads to the consideration that the atrium is very well regulated in terms of comfort. But an atrium has an energy consumption due to floor heating and due to heating beneath the roof in order to prevent cold draughts. Maybe energy savings could be obtained by running and controlling the system with a differentiating between the working hours and other periods (e.g. weekends) where there not is a need for a constant comfortable indoor climate.

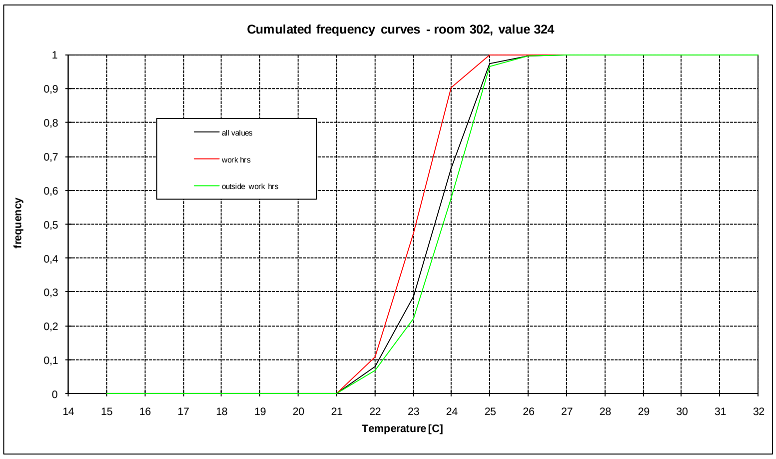
When all the curves from the *three ventilation systems* are compared it is obvious from a visual inspection that the temperatures in ventilation system 3 are considerably larger for a large number of hours in many rooms.



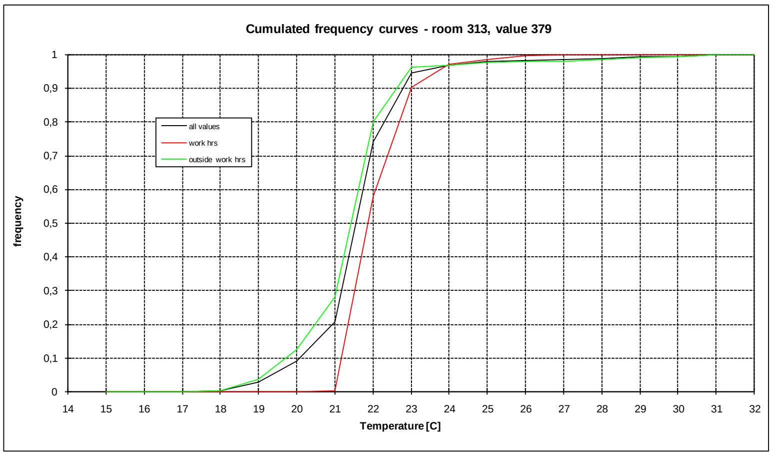
Category 1. Room 304.



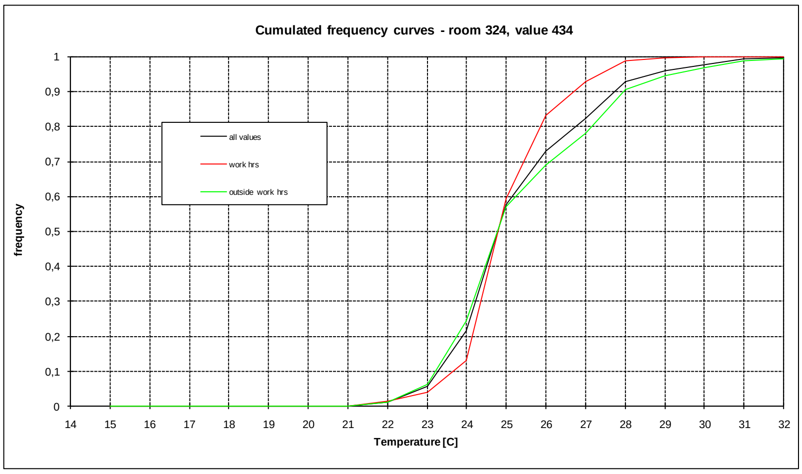
Category 2, room 304.



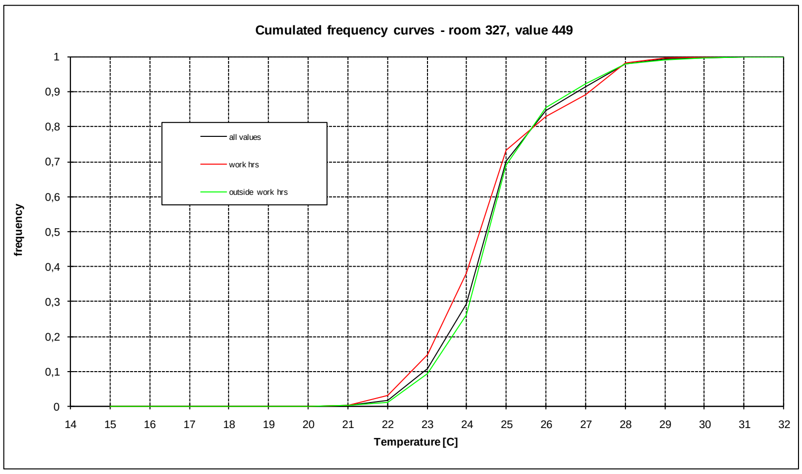
Category 4, Room 302.



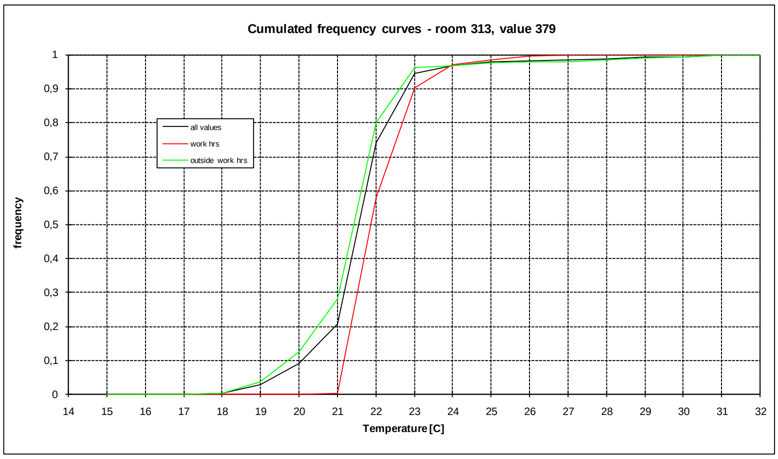
Category 5, room 313.



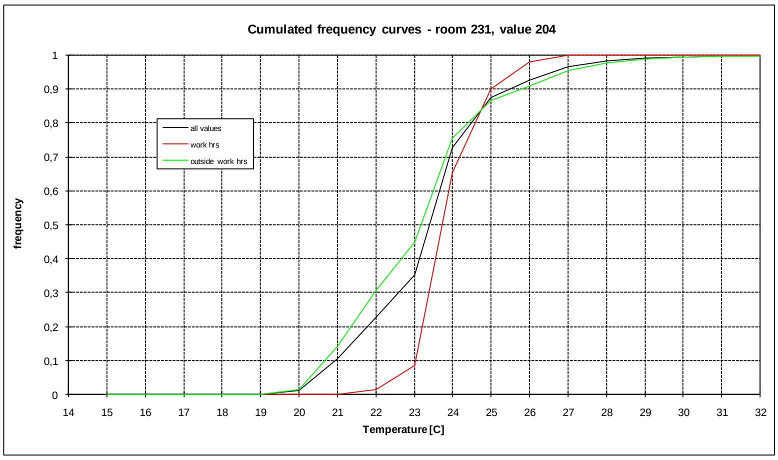
Category 6, room 324.



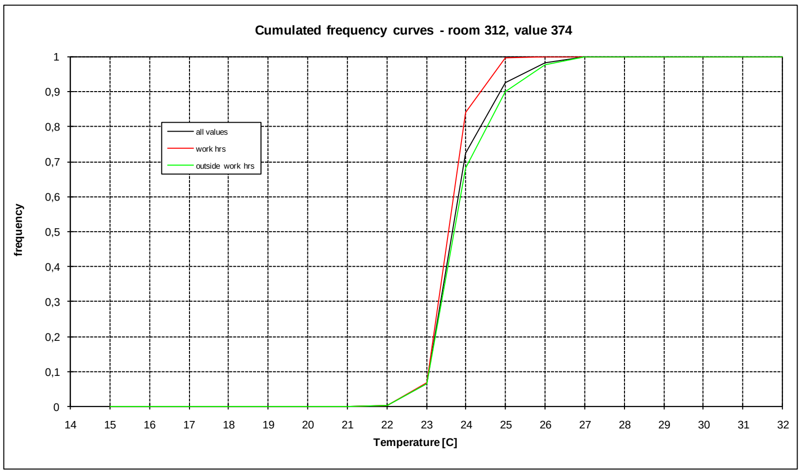
Category 7, room 327.



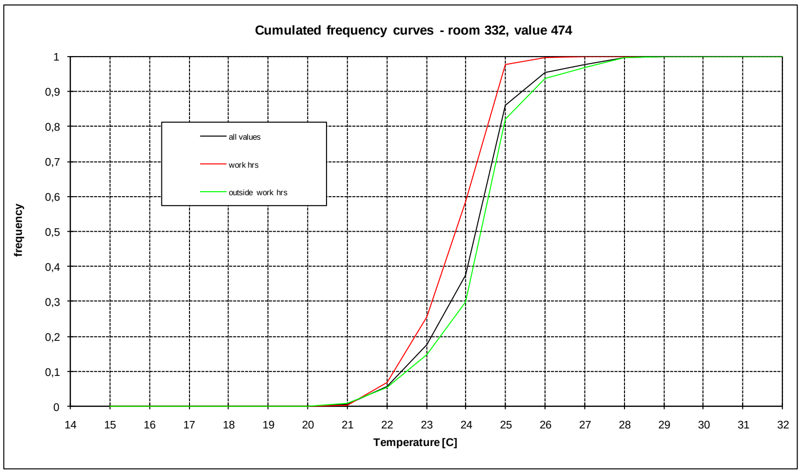
Category 8, room 313.



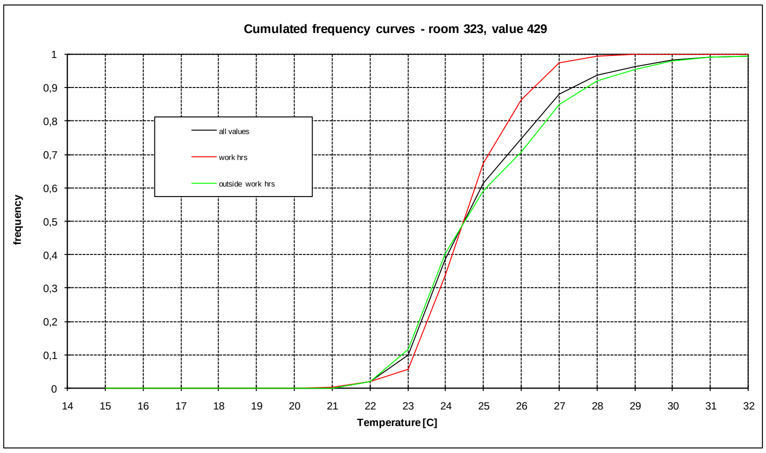
Category 9, room 231.



Category 10, room 312.



Category 11, room 322.



Category 12, room 323.

5.6.1. Temperature distribution for the rooms

According to the Indeklimahåndbogen the temperatures in workspaces during one year must not exceed 26°C in more than 100 hours and only exceed 27°C in 25 hours.
It must be noted that even if the measured temperatures are within these limits it is not necessarily synonymous with an acceptable indoor climate. Considerations are not taken to local temperature variations, temperature gradients and draught problems.

The project group has analyzed frequency curves for all the rooms registered in the CTS system and screened which rooms that don't fulfill the demands in the Indeklimahåndbogen. The analysis has also been divided in the main ventilation systems that serve the room with temperature problems.

In the table below is the result of the frequency analysis shown:

	Total number	Temp ok number	Temp problem number	VENT1 with problems	VENT2 with problems	VENT3 with problems
etage 1, stuen	11	10	1	0	1	0
etage 2, 1. sal	31	27	4	0	0	4
etage 3, 2. sal	33	26	7	1	0	6
etage 4, 3. sal	62	40	22	5	8	9
etage 5, 4. sal	33	30	3	0	2	1
Total	**170**	**133**	**37**	**6**	**11**	**20**

Table x.1 Number of rooms with problems which means that the temperatures are above the limits. The distribution on floors and ventilation systems is shown.

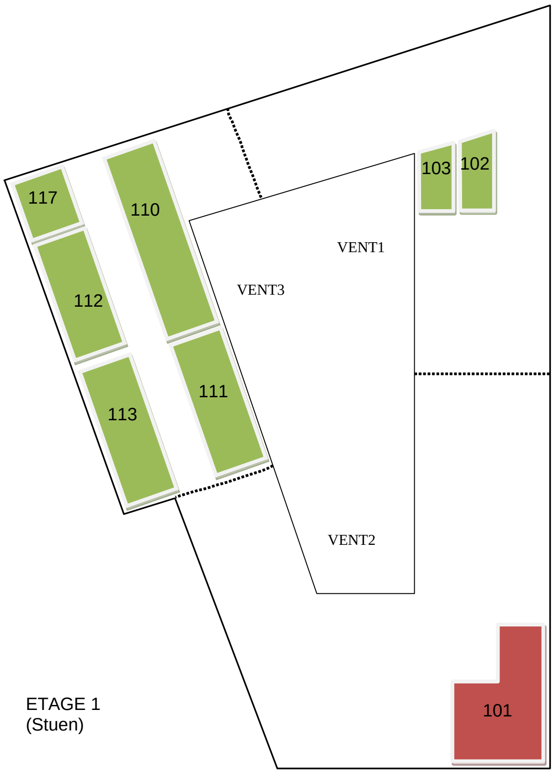
The table x.1 shows 37 of the 170 rooms don't fulfill the described temperature demands.

Of the general tendencies it can be seen that:

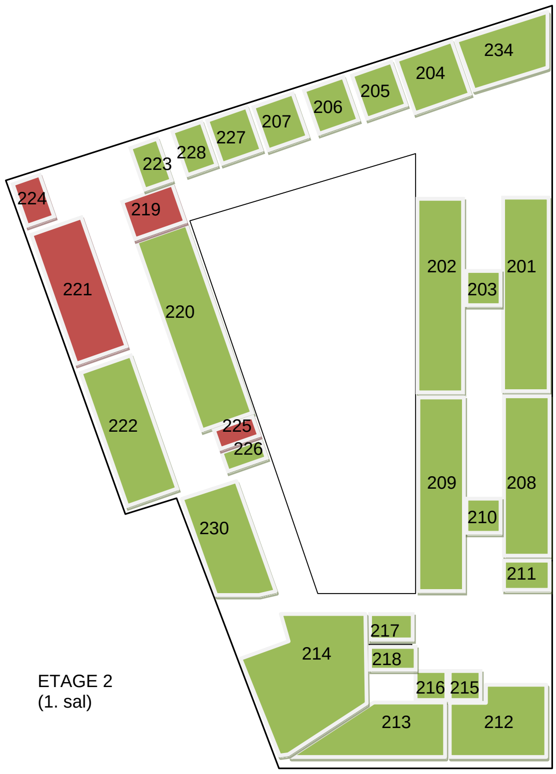
1. The largest areas with problems are located in the north western part which are served by ventilation system 3.
2. The problems are larges ton floor 4, (3. Sal)
3. Ventilation system 3 has problems with keeping the temperature down at all floors except at the ground floor (etage 1, stuen)
4. Ventilation system 2 has only significant problems with at keeping an acceptable temperature on floor 4 (3. Sal).
5. A large part of the rooms with problems are located along the facades, primarily the vest and east facades.

An survey of the result of the frequency analysis of the room temperatures is shown on the following pages. All rooms have been assigned a color according to the following criteria's:

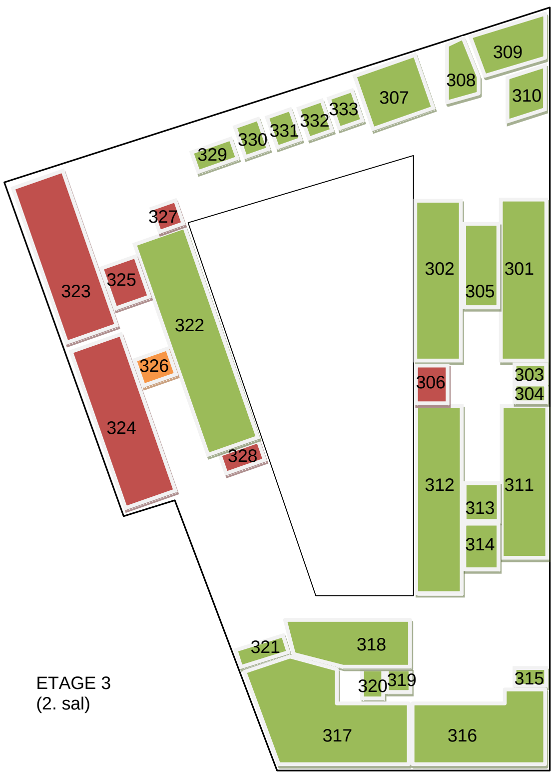
GREEN: Room temperatures exceed 26^{o}C *less* than 100 hours *and* exceed 27^{o}C *less* than 25 hours.
ORANGE: Room temperatures exceed 26^{o}C *more* than 100 hours *or* exceed 27^{o}C *more* than 25 hours.
RED: Room temperatures both exceed 26^{o}C *more* than 100 hours *and* exceed 27^{o}C *more* than 25 hours.



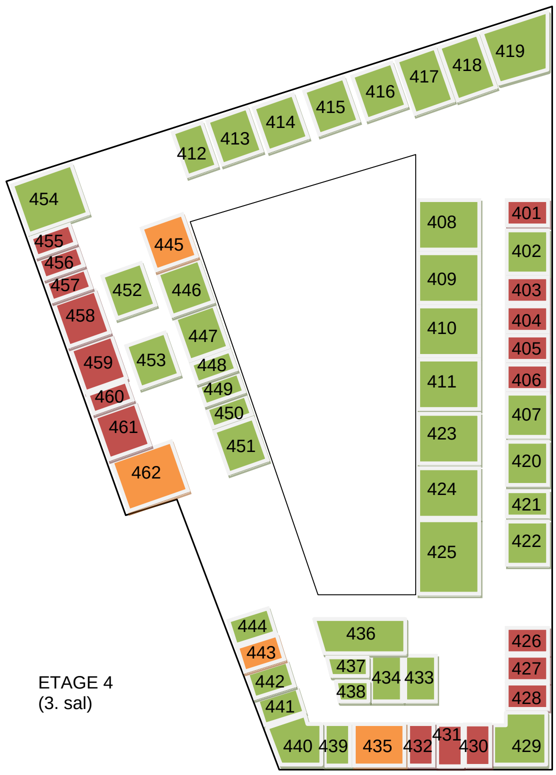
ETAGE 1
(Stuen)



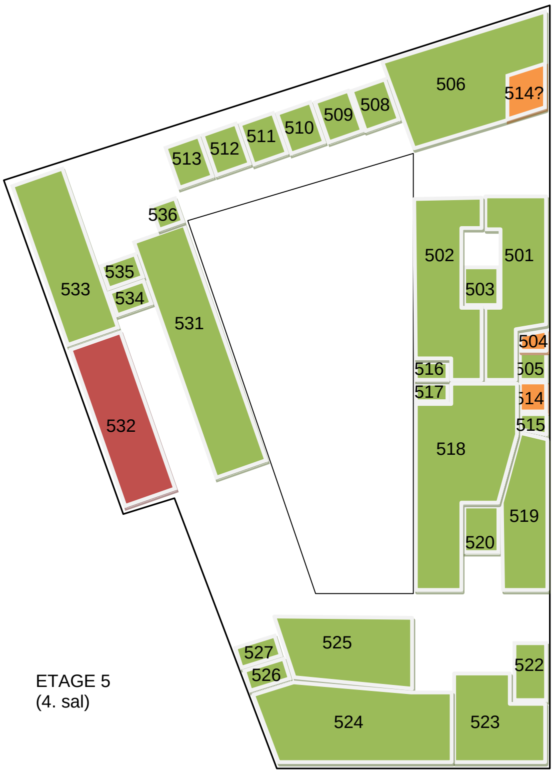
ETAGE 2
(1. sal)



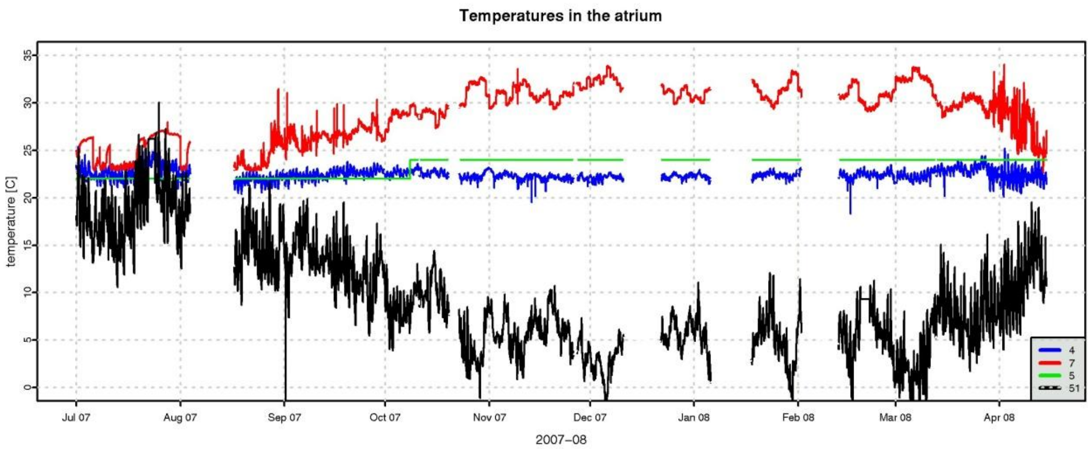
ETAGE 3
(2. sal)

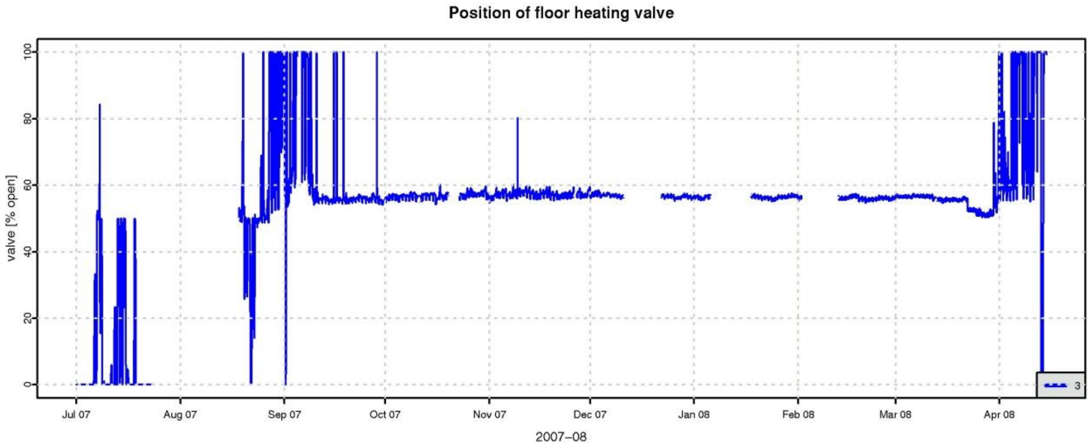


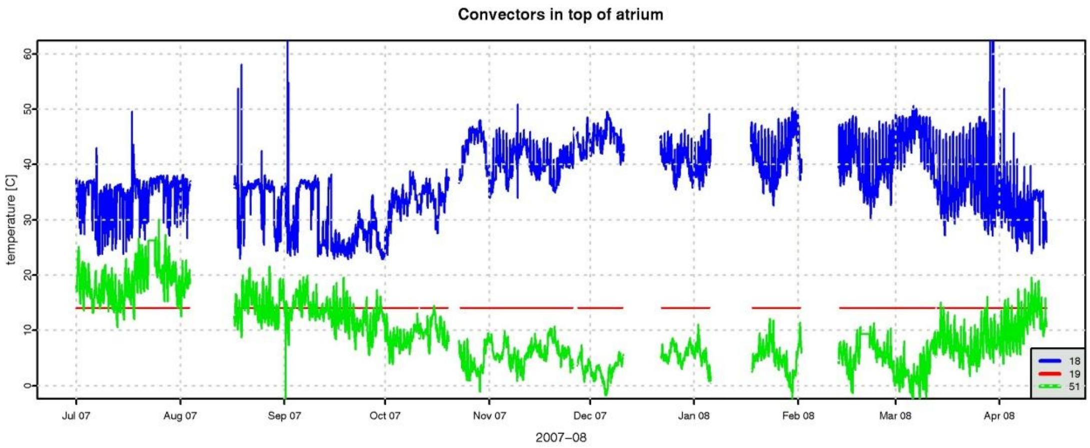
ETAGE 4
(3. sal)

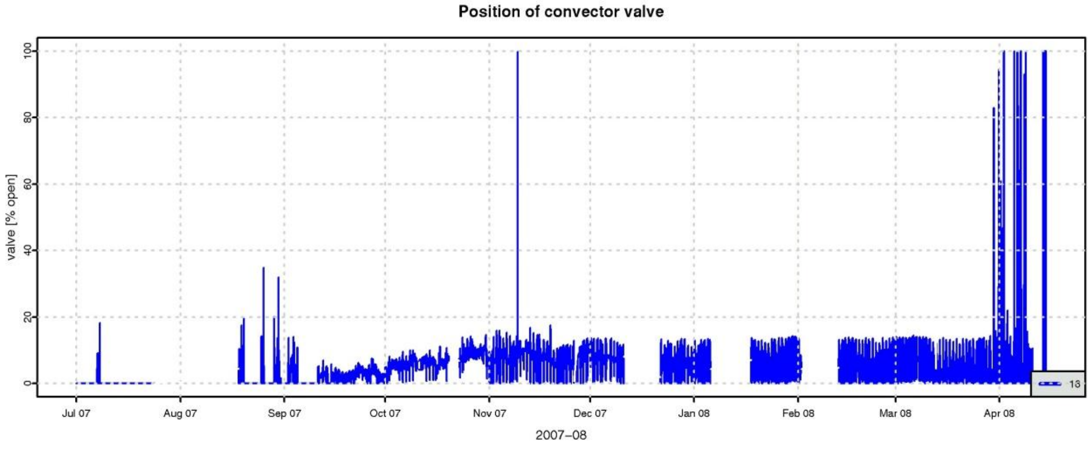


5.7. The atrium

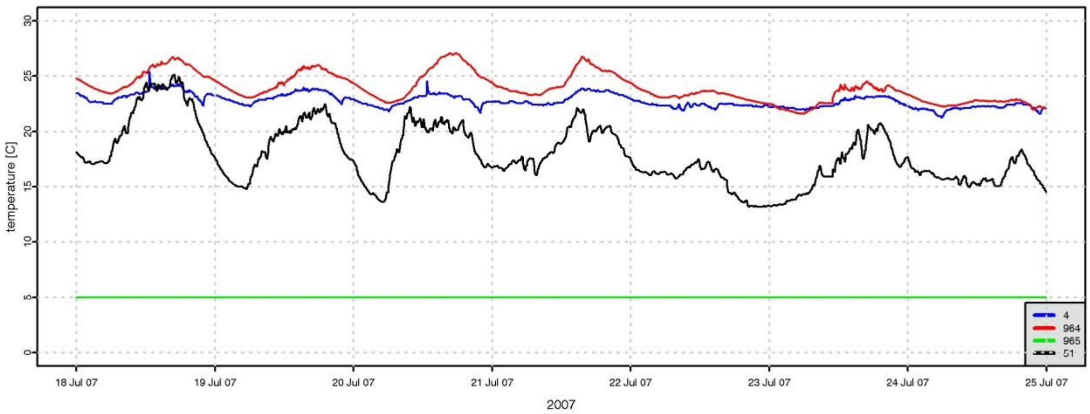

Temperatures in the atrium
temperature [C]
4
7
5
51
Jul 07
Aug 07
Sep 07
Oct 07
Nov 07
Dec 07
Jan 08
Feb 08
Mar 08
Apr 08
2007–08


Position of floor heating valve
valve [% open]
3
Jul 07
Aug 07
Sep 07
Oct 07
Nov 07
Dec 07
Jan 08
Feb 08
Mar 08
Apr 08
2007–08

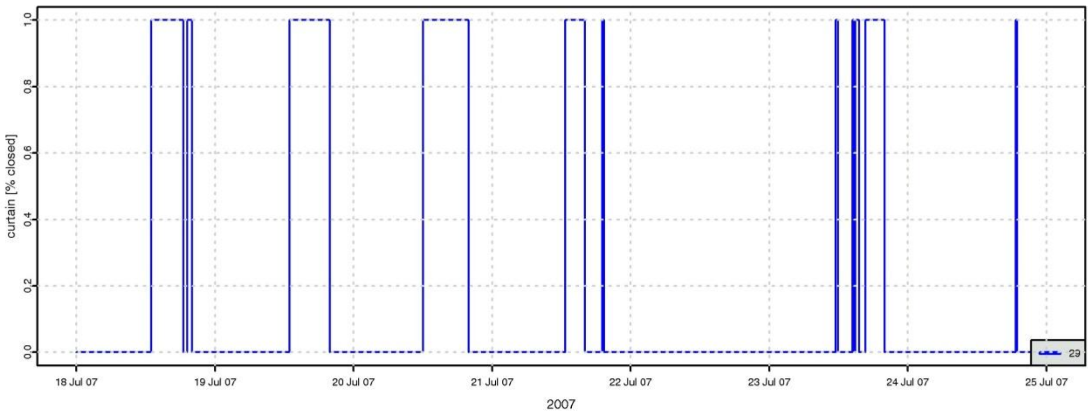

Convectors in top of atrium
temperature [C]
18
19
51
Jul 07
Aug 07
Sep 07
Oct 07
Nov 07
Dec 07
Jan 08
Feb 08
Mar 08
Apr 08
2007–08


Position of convector valve
valve [% open]
13
Jul 07
Aug 07
Sep 07
Oct 07
Nov 07
Dec 07
Jan 08
Feb 08
Mar 08
Apr 08
2007–08

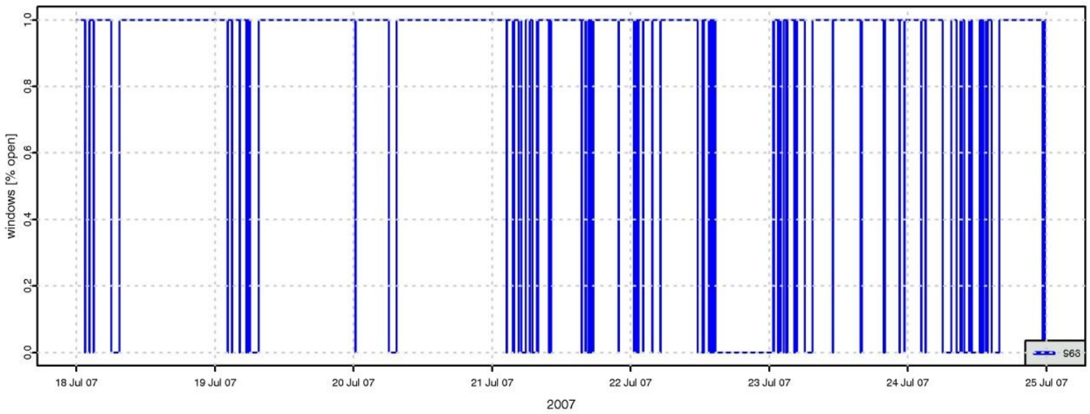
Temperature in atrium



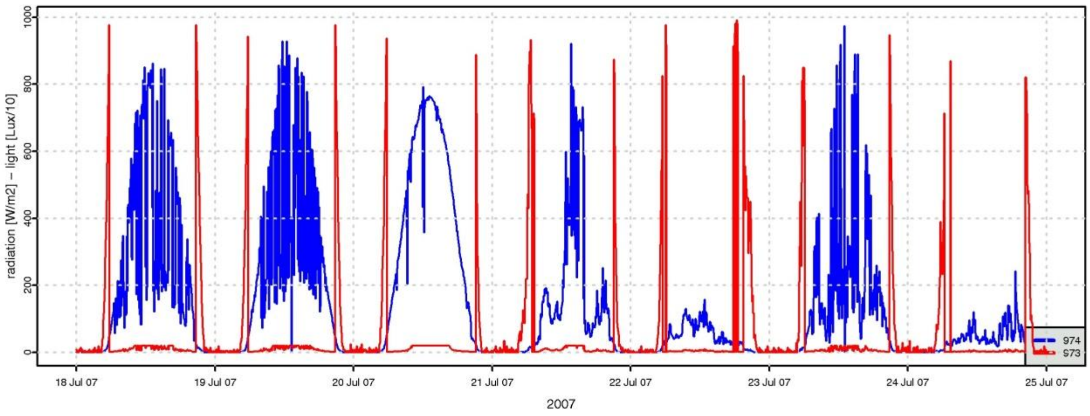
Close of curtains in atrium



Opening of windows in top of atrium



Solar radiation and light



5.8. Conclusions

6. Multiparameter sensors

7. Conclusions

8. References

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Appendixes

Appendix 1

SQL scripts

```
-- ---------------------------------------------------------------------------
-- DIMENSION TABLES
-- ---------------------------------------------------------------------------

DROP TABLE IF EXISTS `bldg_th1`.`d_maalepunkt`;
CREATE TABLE  `bldg_th1`.`d_maalepunkt` (
  `id_maalepunkt` int(11) NOT NULL auto_increment,
  `maalepunkt_navn` varchar(50) NOT NULL,
  `anlaeg` varchar(10) default NULL,
  `anlaeg_besk` varchar(100) default NULL,
  `maalepunkt` varchar(50) default NULL,
  `maalepunkt_besk` varchar(100) default NULL,
  `enhed` varchar(25) default NULL,
  `SET_MAAL` varchar(4) default NULL,
  `rumzone` varchar(10) default NULL,
  `zonenr` smallint(5) unsigned default NULL,
  `delbygning` varchar(10) default NULL,
  `etage` tinyint(3) default NULL,
  `facadeplacering` char(1) default NULL,
  `retning` varchar(2) default NULL,
  `areal` decimal(3,1) default NULL,
  `sort` smallint(5) unsigned default NULL,
  PRIMARY KEY  (`id_maalepunkt`),
  KEY `ix_maalepunkt_navn` (`maalepunkt_navn`)
) ENGINE=MyISAM AUTO_INCREMENT=1056 DEFAULT CHARSET=latin1;



DROP TABLE IF EXISTS `bldg_th1`.`d_period_day`;
CREATE TABLE  `bldg_th1`.`d_period_day` (
  `id_period` smallint(5) unsigned NOT NULL auto_increment COMMENT
'Surrogate key',
  `id_period2` int(10) unsigned NOT NULL default '0' COMMENT 'Date-like
key',
  `year` smallint(5) unsigned default '0',
  `quarter` tinyint(3) unsigned default '0',
  `month` tinyint(3) unsigned default '0',
  `day` tinyint(3) unsigned default '0',
  `date` date default '0000-00-00',
  `week` tinyint(3) unsigned default '0',
  `week_0_53` tinyint(3) unsigned default '0',
  `yearmonth` varchar(7) default NULL,
  `year_week` varchar(7) default '',
  `month_name_en` varchar(9) default '',
  `day_name_en` varchar(9) default '',
  `month_name_da` varchar(9) default '',
  `day_name_da` varchar(7) default '',
  `last_day` date default '0000-00-00',
  `last_day_fl` tinyint(1) default '0',
  `days_in_month` smallint(5) unsigned default '0',
  `day_of_week_en` tinyint(3) unsigned default NULL,
  `day_of_week_da` tinyint(3) unsigned default NULL,
  PRIMARY KEY  (`id_period`),
```

```
  UNIQUE KEY `IX_ID_PERIOD2` (`id_period2`)
) ENGINE=MyISAM AUTO_INCREMENT=733 DEFAULT CHARSET=latin1 COMMENT='Period
dimension - day';


DROP TABLE IF EXISTS `bldg_th1`.`d_period_rel_5min`;
CREATE TABLE  `bldg_th1`.`d_period_rel_5min` (
  `id_klok` int(11) default NULL,
  `klok` char(6) default NULL,
  `time` char(6) default NULL,
  `heltime` tinyint(4) default NULL,
  `dt_ins` datetime default NULL
) ENGINE=MyISAM DEFAULT CHARSET=latin1;


-- ---------------------------------------------------------------------------
-- EXTRACT TABLES
-- ---------------------------------------------------------------------------

DROP TABLE IF EXISTS `bldg_th1`.`extract_ik_log`;
CREATE TABLE  `bldg_th1`.`extract_ik_log` (
  `maalepunkt_navn` varchar(15) default NULL,
  `id_dato` int(11) default NULL,
  `id_klok` int(11) default NULL,
  `temp` decimal(10,3) default NULL,
  `rh` decimal(10,3) default NULL,
  `light` decimal(10,3) default NULL,
  `co2` decimal(10,3) default NULL,
  KEY `maalepunkt_navn` (`maalepunkt_navn`,`id_dato`,`id_klok`)
) ENGINE=MyISAM DEFAULT CHARSET=latin1;

DROP TABLE IF EXISTS `bldg_th1`.`extract_tac`;
CREATE TABLE  `bldg_th1`.`extract_tac` (
  `anl_alt` varchar(10) default NULL,
  `maalepunkt_navn` varchar(50) default NULL,
  `tidspunkt_str` char(19) default NULL,
  `tidspunkt` datetime default NULL,
  `vaerdi` decimal(10,2) default NULL,
  `extract_time` datetime default NULL,
  KEY `maalepunkt_navn` (`maalepunkt_navn`,`tidspunkt`,`vaerdi`)
) ENGINE=MyISAM DEFAULT CHARSET=latin1;

DROP TABLE IF EXISTS `bldg_th1`.`fct_dong`;
CREATE TABLE  `bldg_th1`.`fct_dong` (
  `id_maalepunkt` int(11) NOT NULL,
  `id_dato` int(11) NOT NULL,
  `id_klok` int(11) NOT NULL,
  `maalepunkt_navn` varchar(50) NOT NULL,
  `vaerdi` decimal(8,2) default NULL,
  `dt_ins` timestamp NOT NULL default CURRENT_TIMESTAMP on update CUR-
RENT_TIMESTAMP,
  PRIMARY KEY  (`maalepunkt_navn`,`id_dato`,`id_klok`),
  KEY `ix_maalepunkt_navn` (`maalepunkt_navn`),
  KEY `ix_id_dato` USING BTREE (`id_dato`)
) ENGINE=MyISAM DEFAULT CHARSET=latin1;


-- ---------------------------------------------------------------------------
```

```
-- FACT TABLES
-- ---------------------------------------------------------------------------

DROP TABLE IF EXISTS `bldg_th1`.`fct_ik_log`;
CREATE TABLE  `bldg_th1`.`fct_ik_log` (
  `id_maalepunkt` int(11) default NULL,
  `id_dato` int(11) default NULL,
  `id_klok` int(11) default NULL,
  `maalepunkt_navn` varchar(20) default NULL,
  `vaerdi` decimal(10,3) default NULL,
  KEY `maalepunkt_navn` (`maalepunkt_navn`,`id_dato`,`id_klok`)
) ENGINE=MyISAM DEFAULT CHARSET=latin1;


DROP TABLE IF EXISTS `bldg_th1`.`fct_tac`;
CREATE TABLE  `bldg_th1`.`fct_tac` (
  `id_maalepunkt` int(11) NOT NULL,
  `id_dato` int(11) NOT NULL,
  `id_klok` int(11) NOT NULL,
  `maalepunkt_navn` varchar(50) NOT NULL,
  `vaerdi` decimal(8,2) default NULL,
  `dt_ins` timestamp NOT NULL default CURRENT_TIMESTAMP on update CUR-
RENT_TIMESTAMP,
  PRIMARY KEY  (`maalepunkt_navn`,`id_dato`,`id_klok`),
  KEY `ix_maalepunkt_navn` (`maalepunkt_navn`),
  KEY `ix_id_dato` USING BTREE (`id_dato`),
  KEY `ix_id_maalepunkt` USING BTREE (`id_maalepunkt`)
) ENGINE=MyISAM DEFAULT CHARSET=latin1;


-- ---------------------------------------------------------------------------
-- REPORTING VIEW
-- ---------------------------------------------------------------------------

DROP VIEW IF EXISTS `bldg_th1`.`v_report_tac`;
CREATE ALGORITHM=UNDEFINED DEFINER=`root`@`localhost` SQL SECURITY DEFINER
VIEW  `bldg_th1`.`v_report_tac`
AS
select `f`.`id_maalepunkt` AS `id_maalepunkt`,
`f`.`id_dato` AS `id_dato`,
`f`.`id_klok` AS `id_klok`,
`f`.`maalepunkt_navn` AS `maalepunkt_navn`,
`f`.`vaerdi` AS `vaerdi`,
`dm`.`anlaeg` AS `anlaeg`,
`dm`.`anlaeg_besk` AS `anlaeg_besk`,
`dm`.`maalepunkt` AS `maalepunkt`,
`dm`.`maalepunkt_besk` AS `maalepunkt_besk`,
`dm`.`enhed` AS `enhed`,
`dm`.`SET_MAAL` AS `SET_MAAL`,
`dm`.`rumzone` AS `rumzone`,
`dm`.`zonenr` AS `zonenr`,
`dm`.`delbygning` AS `delbygning`,
`dm`.`etage` AS `etage`,
`dm`.`facadeplacering` AS `facadeplacering`,
`dm`.`retning` AS `retning`,
`dm`.`areal` AS `areal`,
`dm`.`sort` AS `sort`,
```

```
`dp`.`year` AS `year`,
`dp`.`quarter` AS `quarter`,
`dp`.`month` AS `month`,
`dp`.`day` AS `day`,
`dp`.`week` AS `week`,
`dp`.`week_0_53` AS `week_0_53`,
`dp`.`yearmonth` AS `yearmonth`,
`dp`.`year_week` AS `year_week`,
`dp`.`month_name_en` AS `month_name_en`,
`dp`.`day_name_en` AS `day_name_en`,
`dp`.`month_name_da` AS `month_name_da`,
`dp`.`day_name_da` AS `day_name_da`,
`dp`.`last_day` AS `last_day`,
`dp`.`last_day_fl` AS `last_day_fl`,
`dp`.`days_in_month` AS `days_in_month`,
`dp`.`day_of_week_en` AS `day_of_week_en`,
`dp`.`day_of_week_da` AS `day_of_week_da`,
`dk`.`klok` AS `klok`,
`dk`.`time` AS `time`,
`dk`.`heltime` AS `heltime`
from (((`fct_tac` `f`
   join `d_maalepunkt` `dm`
     on((`f`.`maalepunkt_navn` = `dm`.`maalepunkt_navn`)))
   join `d_period_day` `dp`
     on((`f`.`id_dato` = `dp`.`id_period2`)))
   join `d_period_rel_5min` `dk`
     on((`f`.`id_klok` = `dk`.`id_klok`)));



-- ----------------------------------------------------------------------------
-- STORED PROCEDURE (populating d_period_day)
-- ----------------------------------------------------------------------------

CREATE DEFINER=`root`@`localhost` PROCEDURE
`bldg_th1`.`sp_pop_d_period_day`(
    start_date                 DATETIME
   ,end_date                   DATETIME
   ,p_user                     VARCHAR(25)
   ,OUT p_sqlcode              INT
   ,OUT p_status_message       VARCHAR(100))
BEGIN

SET @date_v = start_date;

REPEAT

   INSERT INTO `bldg`.`d_period_day` VALUES (
    null,
    concat(cast(year(@date_v) as char),
           lpad(cast(month(@date_v) as char),2,'0'),
           lpad(cast(day(@date_v) as char),2,'0')),
    year(@date_v),
    quarter(@date_v),
    month(@date_v),
    day(@date_v),
    @date_v,
    week(@date_v,3),
```

```
    week(@date_v,1),
    concat(year(@date_v),'-',lpad(cast(MONTH(@date_v) as char),2,'0')),
    concat(year(@date_v),'-',lpad(cast(week(@date_v,3) as char),2,'0')),
    monthname(@date_v),
    dayname(@date_v),
    case monthname(@date_v)
         when 'January' then 'Januar'
         when 'February' then 'Februar'
         when 'March' then 'Marts'
         when 'April' then 'April'
         when 'May' then 'Maj'
         when 'June' then 'Juni'
         when 'July' then 'Juli'
         when 'August' then 'August'
         when 'September' then 'September'
         when 'October' then 'Oktober'
         when 'November' then 'November'
         when 'December' then 'December'
    end,
    case dayname(@date_v)
         when 'Monday' then 'Mandag'
         when 'Tuesday' then 'Tirsdag'
         when 'Wednesday' then 'Onsdag'
         when 'Thursday' then 'Torsdag'
         when 'Friday' then 'Fredag'
         when 'Saturday' then 'Lørdag'
         when 'Sunday' then 'Søndag'
    end,
    last_day(@date_v),
    last_day(@date_v)=date,
    day(last_day(@date_v)),
    weekday(@date_v)+1,
    dayofweek(@date_v));

    SET @date_v = DATE_ADD(@date_v,INTERVAL 1 day);

UNTIL @date_v > end_date

END REPEAT;

SET p_sqlcode=0;
SET p_status_message='aaa';

END


-- -------------------------------------------------------------------------
-- DECODE TIMESERIES NAMES
-- -------------------------------------------------------------------------

-- -------------------------------------------------------------------------
--  Create VIEW: Time series ID's in source (SELECT DISTINCT)
-- -------------------------------------------------------------------------
CREATE OR REPLACE VIEW `bldg_th1`.`v_tac_maalepunkt_navn_distinct`
(maalepunkt_navn)
AS
SELECT DISTINCT `extract_tac`.`maalepunkt_navn` AS `maalepunkt_navn`
FROM `bldg_th1`.`extract_tac`;
```

```
-- ----------------------------------------------------------------------------
--  Create VIEW: Decode time series ID's
-- ----------------------------------------------------------------------------
CREATE OR REPLACE VIEW `bldg_th1`.`v_tac_maalepunkt_navn_decode`
(maalepunkt_navn,lokation,bygning,etage,anlaeg,rumzone,maalepunkt)
AS
SELECT maalepunkt_navn,
SUBSTRING_INDEX(maalepunkt_navn,'-',1),
SUBSTR(maalepunkt_navn,INSTR(maalepunkt_navn,'-')+1,2),
SUBSTR(maalepunkt_navn,INSTR(maalepunkt_navn,'-')+3,2),
SUBSTRING_INDEX(SUBSTRING_INDEX(maalepunkt_navn,'-',3),'-',-1),
CASE WHEN INSTR(SUBSTRING_INDEX(SUBSTRING_INDEX(maalepunkt_navn,'-',4),'-
',-1),'IRR')>0
     THEN INSTR(SUBSTRING_INDEX(SUBSTRING_INDEX(maalepunkt_navn,'-',4),'-
',-1),'IRR')
     ELSE '-' END,
TRIM(TRAILING '_LOG_X' FROM SUBSTRING_INDEX(maalepunkt_navn,'-',-1))
FROM `bldg_th1`.`v_tac_maalepunkt_navn_distinct`;
```

```
-- ----------------------------------------------------------------------------
-- extract_tac_logfil
-- ----------------------------------------------------------------------------


LOAD DATA INFILE '@PATH/tac_log.txt'
IGNORE INTO TABLE `bldg_th1`.`fct_tac`
FIELDS TERMINATED BY '\t' LINES TERMINATED BY '\r\n'
(@anl_alt,@maalepunkt_navn,@tidspunkt,@vaerdi)
SET `maalepunkt_navn` = @maalepunkt_navn,
    `id_dato` = CAST(
        CONCAT(substring(@tidspunkt,7,4),
               substring(@tidspunkt,4,2),
               substring(@tidspunkt,1,2))
                AS UNSIGNED INTEGER),
    `id_klok` = CAST(
        CONCAT(substring(@tidspunkt,12,2),
               substring(@tidspunkt,15,1),
               case when CAST(substring(@tidspunkt,16,1)
                         AS UNSIGNED INTEGER)<5
                    then '0'
                    else '5'
               end,'00')
                AS UNSIGNED INTEGER),
    `vaerdi` = 0 + @vaerdi;
```

Appendix 2.1 Monthly aggregated temperatures at each measurement location

Logger	Month	Mean	Median	Var	Std	Min	Max
3028	3	24.2	24.2	0.1	0.4	23	25.1
	4	24.3	24.2	0.1	0.3	23.3	26
	5	24.1	24	0.4	0.6	22.6	25.8
	6	25.3	25.2	0.7	0.9	23.7	27.3
	7	26.1	25.9	1.4	1.2	23.9	29.1
	8	26.3	26.2	0.5	0.7	24.5	28.2
	9	25.8	25.8	0.6	0.8	23.3	27.7
	10	24.9	24.8	0.8	0.9	22.8	27.2
3029	2	23.5	23.5	0.1	0.3	22.6	24.4
	3	23.6	23.7	0.2	0.4	22.4	24.5
	4	24.2	24.3	0.2	0.4	22.8	25.3
	5	23.9	24	0.3	0.6	22.4	24.9
	6	24.6	24.7	0.4	0.6	23.1	26.2
	7	24.5	24.5	0.5	0.7	22.7	26.4
	8	24.1	24.1	0.2	0.5	22.5	25.8
	9	23.5	23.5	0.2	0.5	21.9	24.7
	10	23.4	23.4	0.1	0.4	22.4	24.3
3033	2	24.4	24.5	0.1	0.4	23.2	25.8
	3	24.4	24.5	0.5	0.7	22.1	26.1
	4	24.6	24.6	0.3	0.5	23	26
	5	24.6	24.8	0.6	0.8	22.3	26.1
	6	25.5	25.5	0.6	0.8	23.9	27.5
	7	24.7	24.6	0.5	0.7	23.2	26.7
	8	24.2	24.2	0.2	0.4	23	25.6
	9	24.6	24.6	0.2	0.5	23.2	25.6
	10	24.6	24.6	0.1	0.3	23.4	25.4
3034	2	24	24	0.2	0.4	22.5	25.2
	3	24.6	24.7	0.4	0.6	22.8	25.9
	4	24.9	24.9	0.3	0.6	23.2	26.9
	5	24.7	24.9	0.8	0.9	22.2	26.2
	6	25.6	26	1.3	1.1	23.6	27.4
	7	25	25	0.3	0.5	23.7	26.8
	8	24.9	24.9	0.2	0.5	23.5	26.1
	9	24.3	24.3	0.1	0.4	23.3	25.2
	10	24.2	24.2	0	0.2	23.6	24.8

Logger	Month	Mean	Median	Var	Std	Min	Max
3041	2	24.8	24.8	0.5	0.7	23.2	26.5
	3	24.1	24	1.1	1	21.6	26.4
	4	24.7	24.8	0.8	0.9	21.9	26.3
	5	23.6	23.4	1.4	1.2	21.7	26.6
	6	24.7	24.6	1.7	1.3	22.5	27.7
	7	25.1	25	1.5	1.2	22.5	27.9
	8	24.4	24.4	1.2	1.1	22.2	27.3
	9	24.9	24.9	1.3	1.2	22.4	27.7
	10	24.7	24.7	0.8	0.9	22.3	27.1
3031	2	24.3	24.3	0.7	0.8	20.5	27.4
	3	24	24.1	1.1	1	21.1	26.6
	4	24.8	24.8	1.2	1.1	22	28.8
	5	24.5	24.5	1.5	1.2	20.5	27.2
	6	25.9	26	1.9	1.4	22.9	29.5
	7	25.2	25	2	1.4	22.3	29.8
	8	24.6	24.5	0.9	0.9	22.4	27.3
	9	24.5	24.4	0.6	0.8	22.6	27.1
	10	24	23.9	0.6	0.8	19.4	26.1
3036	2	23.3	23.3	0.1	0.4	21.6	24.3
	3	23.5	23.6	0.2	0.5	22.3	24.3
	4	24.3	24.4	0.2	0.4	22.7	25.3
	5	23.5	23.7	0.2	0.5	22.2	24.5
	6	24.5	24.6	0.3	0.5	23.4	25.9
	9	22.6	22.5	0.1	0.4	21.6	23.9
	10	22.6	22.6	0.1	0.3	21.8	23.2
3037	2	23.7	23.7	0.1	0.4	21.7	24.6
	3	23.7	23.8	0.3	0.5	22.3	24.5
	4	24.6	24.7	0.1	0.4	23.1	25.3
	5	23.7	23.6	0.2	0.5	22.1	24.8
	6	24.1	24.2	0.4	0.6	22.7	25.5
	7	24.3	24.2	0.4	0.6	22.9	25.9
	8	24.2	24.2	0.4	0.6	22.1	25.5
	9	23	22.9	0.2	0.4	21.9	24.4
	10	22.9	22.9	0	0.1	22.6	23.3

Logger	Month	Mean	Median	Var	Std	Min	Max
3038	2	23.7	23.8	0.1	0.3	22.4	24.3
	3	23.6	23.7	0.2	0.4	22.6	24.4
	4	24.1	24.2	0.2	0.4	22.7	25.1
	5	23.5	23.5	0.3	0.5	21.7	24.6
	6	24.4	24.2	0.4	0.6	23.3	26
	7	23.9	24.2	0.8	0.9	22	25.5
	8	23.7	23.7	0.3	0.5	22.3	25.1
	9	23.2	23.2	0.1	0.3	22.2	24.1
	10	22.8	22.8	0.2	0.4	21.4	23.8
3039	2	24.1	24.1	0.1	0.3	22.3	24.9
	3	24	24	0.2	0.4	23	24.8
	4	24.9	24.9	0.3	0.5	23.7	26.2
	5	24.4	24.5	0.3	0.6	22.7	25.4
	6	25.3	25.1	0.9	1	23.6	27
	7	24.7	24.8	0.6	0.8	23.4	26.4
	8	24.2	24.2	0.4	0.7	23	26.3
	9	23.8	23.8	0.3	0.5	22.7	24.8
	10	23.6	23.6	0.2	0.4	22.3	24.6
3040	2	23.7	23.7	0.1	0.3	20.2	24.5
	3	23.7	23.8	0.2	0.5	22.6	24.9
	4	24.9	24.9	0.3	0.5	23.2	25.9
	5	23.8	23.7	0.3	0.6	22.5	25.7
	6	24.8	24.8	0.3	0.6	23.7	25.7
	9	24.6	24.7	0.2	0.4	23.4	25.3
	10	24.5	24.6	0.2	0.5	23.2	25.5
3042	2	24	24	0.2	0.5	22.2	25.5
	3	23.8	23.9	0.3	0.6	22.3	25.1
	4	24.2	24.3	0.3	0.6	22.4	25.3
	5	24	24.1	0.5	0.7	22.1	25.2
	6	24.5	24.4	0.5	0.7	23.1	26.1
	7	24.2	24.1	0.8	0.9	22.2	26
	8	24.1	24.1	0.5	0.7	22	25.7
	9	23.8	23.9	0.4	0.6	22.4	25
	10	23.6	23.7	0.3	0.5	22.3	24.7
3046	2	23.2	23	0.3	0.6	21.4	25.3
	3	23.4	23.4	0.7	0.8	21.3	25.3
	4	25.1	25.2	0.8	0.9	22.4	27.1
	5	24.3	24.4	0.8	0.9	21.7	26.5
	6	26	26	0.3	0.5	24.8	27.2
	9	24.7	24.5	1.1	1	22.7	27.1
	10	23.9	23.7	0.9	1	20.5	28.4

Appendix 2.2 Monthly aggregated relative air humidity at each measurement location

Logger	month	mean	median	var	std	min	max
3028	3	22.3	21.4	18.5	4.3	15.3	29.9
	4	25.8	25.9	10.1	3.2	19.9	34.3
	5	31.1	31.5	19.1	4.4	21.2	41.8
	6	36.8	36.8	8.3	2.9	30.6	42.4
	7	39.9	40.1	12	3.5	32.9	51.9
	8	44.8	44	20.5	4.5	33.2	54.4
	9	37.2	37.1	28.4	5.3	27.1	49.2
	10	34.3	33.8	8.4	2.9	28.6	42.2
3029	2	26.5	27.2	12.2	3.5	14.9	32.2
	3	23	22	17.2	4.1	15.8	29.9
	4	26.3	26.6	9.2	3	20.5	34.7
	5	31.4	31.9	18.3	4.3	22.3	39.4
	6	37.9	37	7.9	2.8	31.4	43.7
	7	43.9	43.2	13.7	3.7	37.3	55.8
	8	50.4	49.7	16.8	4.1	40.5	59.3
	9	43.1	42.6	34.5	5.9	31.9	56
	10	38.6	38.5	9.4	3.1	32.5	46.2
3033	2	24.3	25.2	12.2	3.5	13.5	29.9
	3	21.3	20.6	16.4	4	14.2	28.6
	4	24.8	24.7	10.5	3.2	19.1	34.1
	5	29.7	29.8	21.4	4.6	19.5	39
	6	35.2	34.9	9.9	3.1	29.4	41.7
	7	42.8	42.1	19.4	4.4	33.9	53.8
	8	49.9	49.1	22.2	4.7	36.8	59
	9	39.7	38	47.2	6.9	28.2	54.5
	10	34.6	34.7	1.3	1.1	32.1	37
3034	2	25.4	26.3	14.7	3.8	13.4	32.1
	3	21.2	20.2	15.1	3.9	14.5	27.9
	4	24.3	24.3	9.6	3.1	18.6	32.6
	5	29.3	29.3	20.8	4.6	20.6	38.6
	6	35.1	34.4	11.7	3.4	28.9	42.7
	7	41.2	40.7	13	3.6	33.7	51.5
	8	47.4	46.4	20.8	4.6	37.3	57.5
	9	39.5	38.1	40.3	6.4	26.5	52.8
	10	34.9	34.6	7.7	2.8	29.4	42.3

Logger	month	mean	median	var	std	min	max
	2	23.9	24.8	12.5	3.5	12.9	30.5
	3	21.4	20.7	15.9	4	13.7	28
	4	24.8	24.1	12.4	3.5	19	35.9
	5	32.4	33	25.1	5	21.3	43.9
3041	6	38.4	38.4	18	4.2	30.3	48.1
	7	42.7	42.2	22.4	4.7	33	58
	8	49.9	49.5	29.3	5.4	36	61.5
	9	39.3	37.3	55.2	7.4	26.5	57
	10	35.2	34.8	7.4	2.7	30.4	42.6
	2	24.7	25.8	16.5	4.1	11.8	33.1
	3	22.1	21.1	19.5	4.4	13.4	30.2
	4	24.7	24.9	12.5	3.5	17.8	34.2
	5	30.1	30.7	25.3	5	17.3	39.4
3031	6	35.4	35.9	19.4	4.4	26.5	46.4
	7	41.5	40.8	22.7	4.8	29	60.4
	8	49.1	48.4	31.1	5.6	33.8	61.3
	9	39.2	38.5	40.9	6.4	26.9	53.9
	10	36	35.4	10.5	3.2	29.2	46.1
	2	24	25	15.1	3.9	11.8	30.5
	3	21.1	20	16.1	4	14	27.6
	4	24.4	24.2	9.4	3.1	19.5	33.1
3036	5	31.1	31.6	20.2	4.5	22.2	39.9
	6	37.9	37.2	4.3	2.1	32.7	42.8
	9	39.3	39.1	15.3	3.9	31.4	53.6
	10	38.3	37.9	10.3	3.2	31.9	46.6
	2	24.2	25	14.3	3.8	12.5	30.5
	3	21.3	20.7	17.1	4.1	14.2	28.6
	4	24.3	24.1	9.9	3.1	18.5	33
	5	31	31.4	18.6	4.3	22.5	40.2
3037	6	39	37.9	9	3	31.6	45.1
	7	43.8	43.2	16.5	4.1	36.6	54.4
	8	50.5	50	20	4.5	39	60.6
	9	43.7	41.9	50.3	7.1	30.6	59.5
	10	38.1	38.2	6.7	2.6	32.9	44.3

Logger	month	mean	median	var	std	min	max
3038	2	24.6	25.4	13.8	3.7	13.1	30.5
	3	21.8	20.9	17.3	4.2	14.6	28.7
	4	25.3	24.9	11	3.3	19.9	34.8
	5	31.4	31.9	23.9	4.9	20.8	41.8
	6	37.8	37.2	8.5	2.9	30.6	43.4
	7	43.8	43.5	23.4	4.8	33.5	55
	8	50.5	49.9	21.6	4.6	40.1	60.3
	9	42.4	42.1	37	6.1	30.4	55.3
	10	39.3	38.9	9.3	3.1	33.9	47
3039	2	23.7	24.5	12.9	3.6	13.4	29.1
	3	21	20.1	15.9	4	14.4	28
	4	23.6	23.6	9.3	3.1	18.8	32.5
	5	29	29.3	19.5	4.4	20.2	37
	6	35.4	34.7	7.7	2.8	28.5	41.2
	7	41.4	40.6	14.5	3.8	35.1	51.2
	8	48.7	47.8	21.8	4.7	38	59.1
	9	39.9	39.3	43.8	6.6	28.1	54.1
	10	35.6	35.4	9.3	3.1	29.5	44
3040	2	24.7	25.5	15.9	4	12.8	31.8
	3	21.5	20.5	18.8	4.3	14.1	29.1
	4	23.8	23.8	10.4	3.2	18.2	32.6
	5	29.7	30.6	23	4.8	19.3	39.4
	6	36.3	35.9	6.2	2.5	31.5	42.5
	9	34.1	33.9	16.4	4.1	25.4	47.1
	10	33.8	33.5	9.7	3.1	28	42
3042	2	25	26	14.6	3.8	13.4	31.6
	3	22.4	21.9	17.1	4.1	15.3	29.6
	4	25.9	25.9	11.4	3.4	19.9	35.4
	5	31	31.6	24.6	5	19.7	41
	6	38	37.6	9.2	3	31.4	44.6
	7	44	43.7	20.4	4.5	35.9	55.6
	8	49.9	49	22.3	4.7	36.7	59.9
	9	41.7	40.5	48.3	7	29.8	57.7
	10	37.9	37.5	9.6	3.1	31.6	45.9
3046	2	26	27	18.8	4.3	13	33.5
	3	22.3	21.5	21.7	4.7	14.4	30.3
	4	24.3	24.8	14.4	3.8	17.4	34.5
	5	30.3	30.5	21.5	4.6	20.7	39.6
	6	34.7	33.7	7	2.6	30.8	40.6
	9	35.3	35.2	19.3	4.4	27.2	49.6
	10	36.9	36.4	11.5	3.4	28.5	45.7

Appendix 2.3 Temporal temperature difference based on 15 min, 30 min and 60 min time lags

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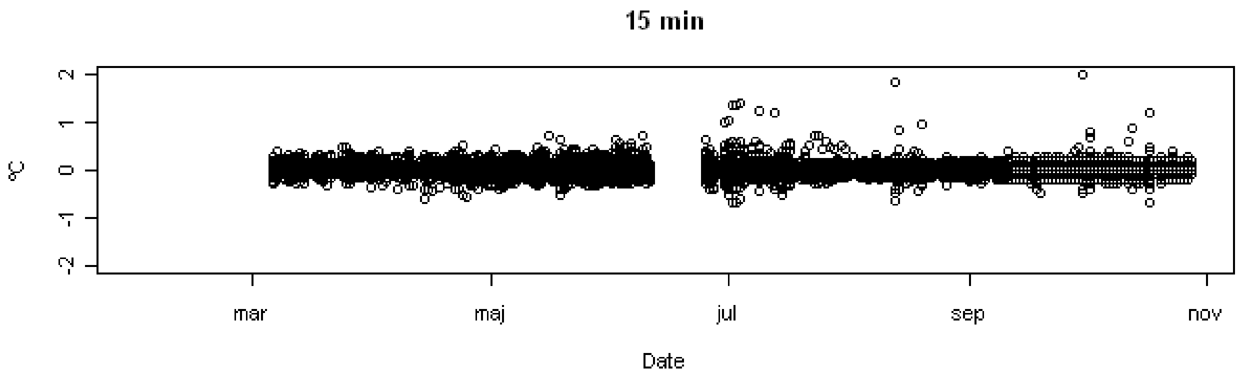

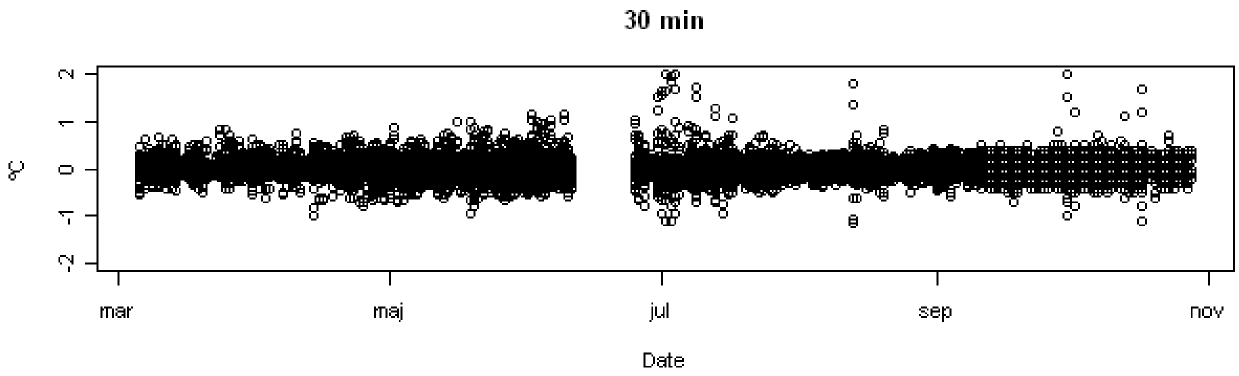

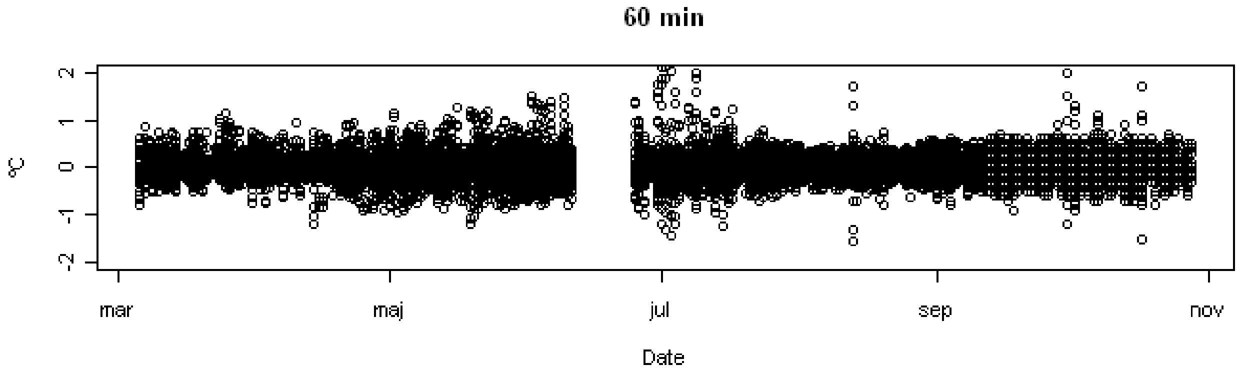

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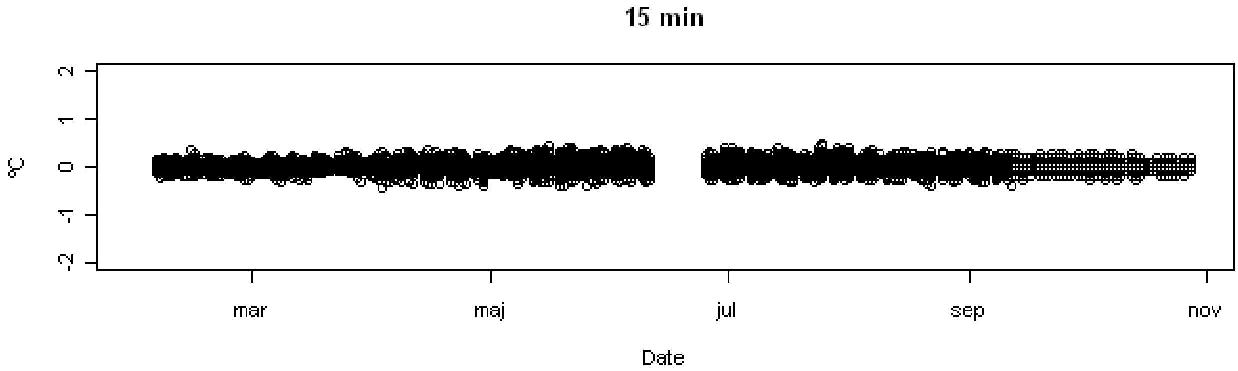
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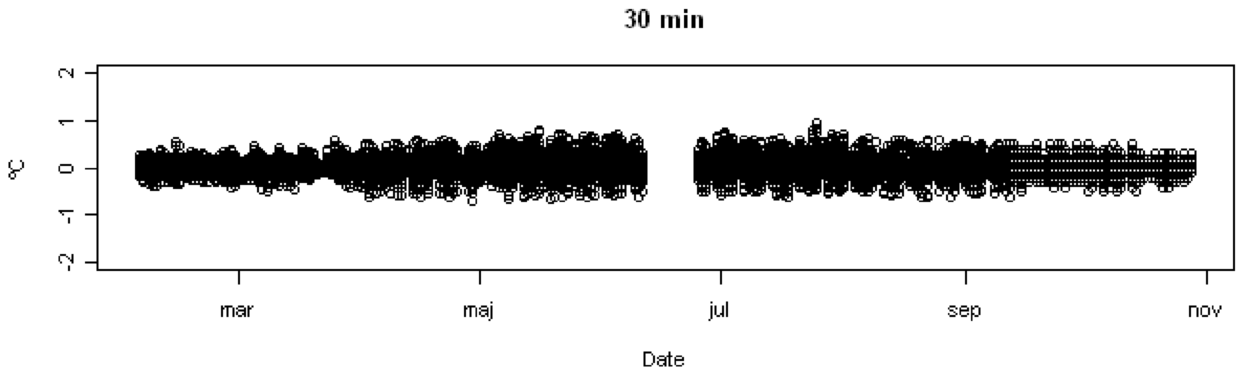
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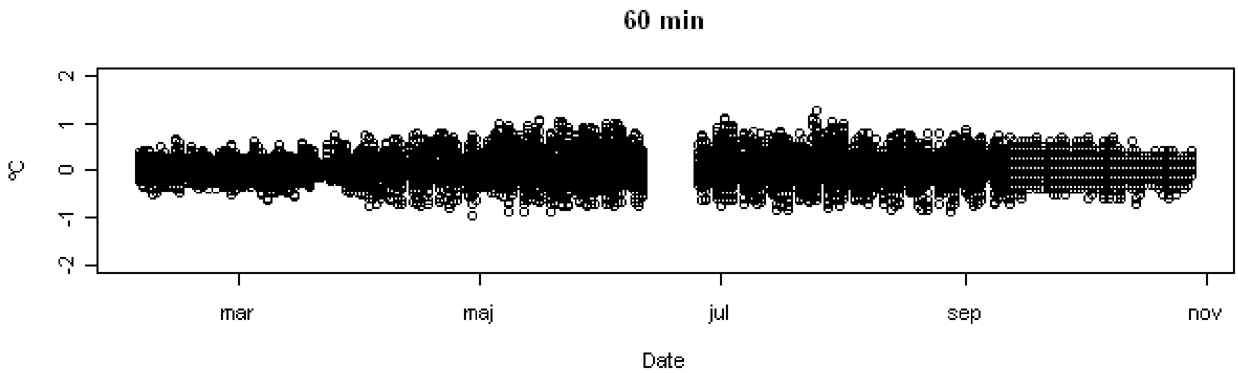
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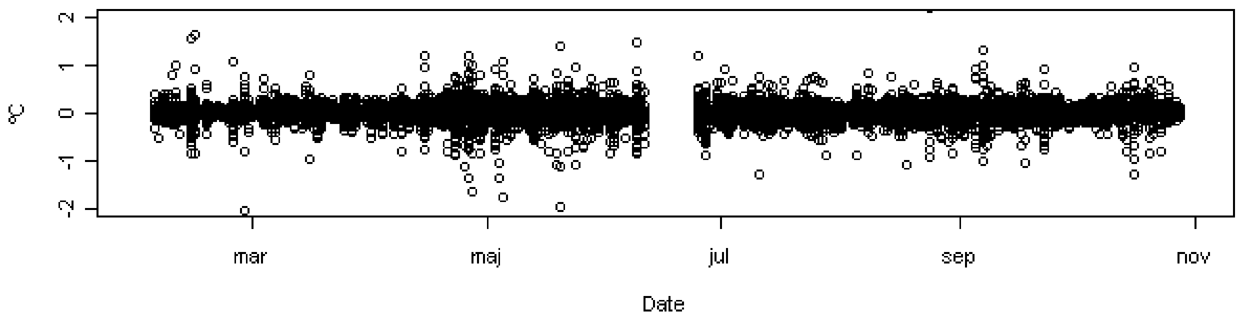

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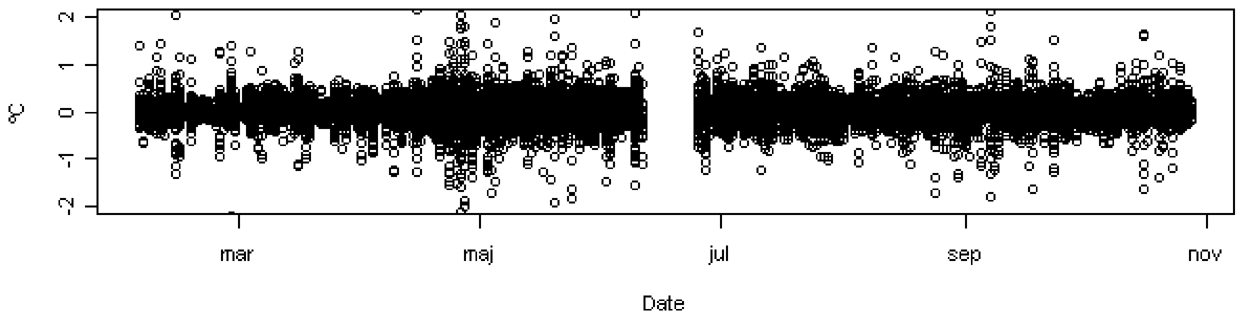

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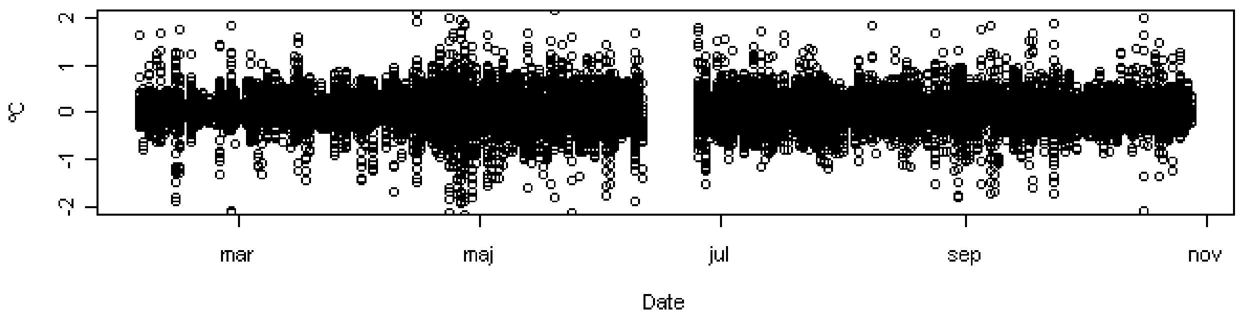

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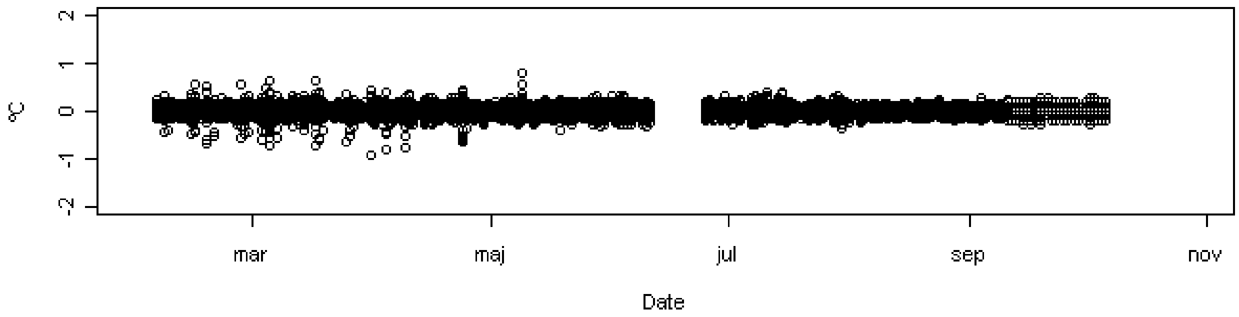

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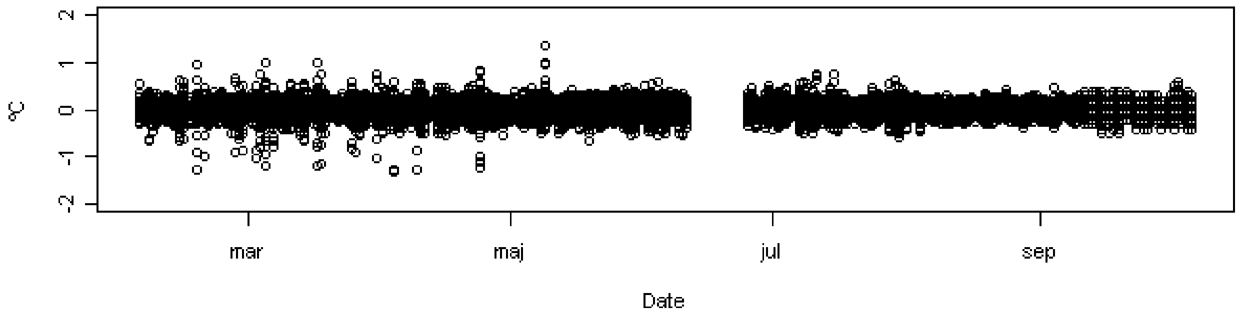

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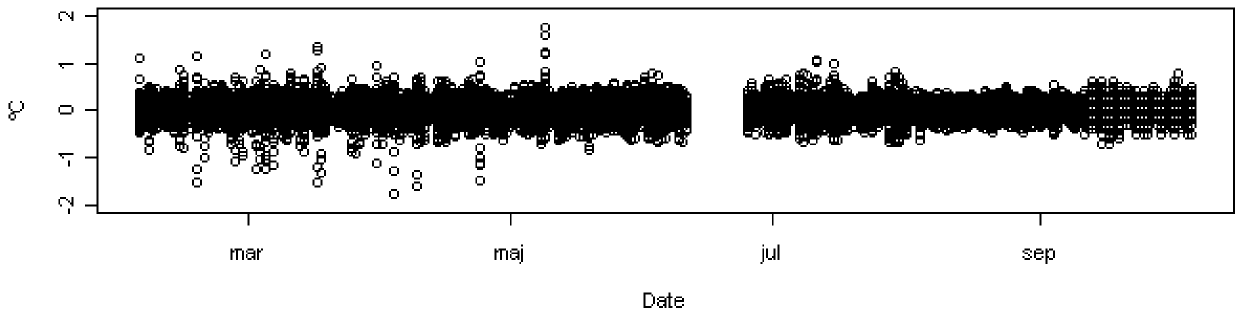

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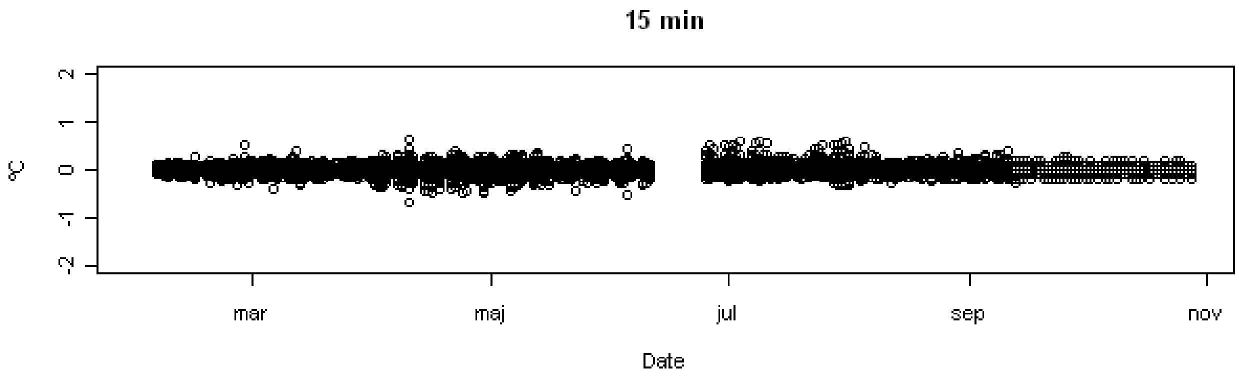
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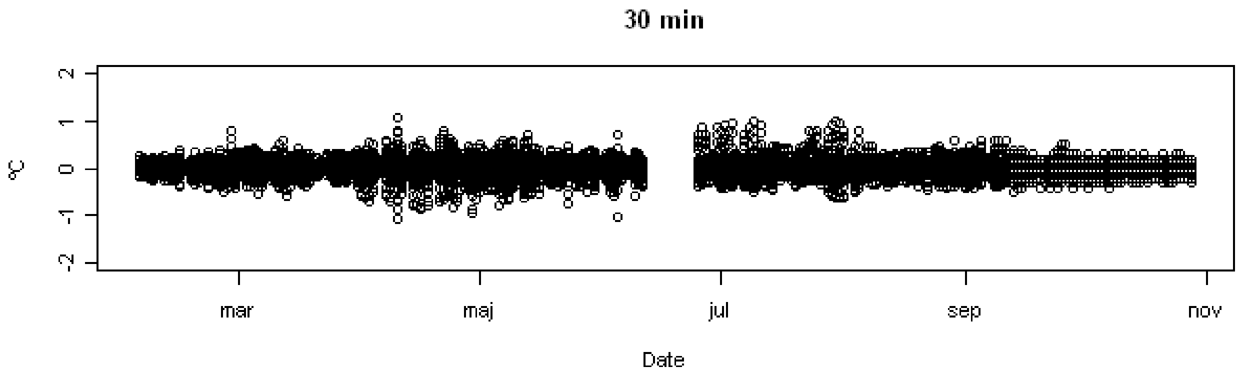
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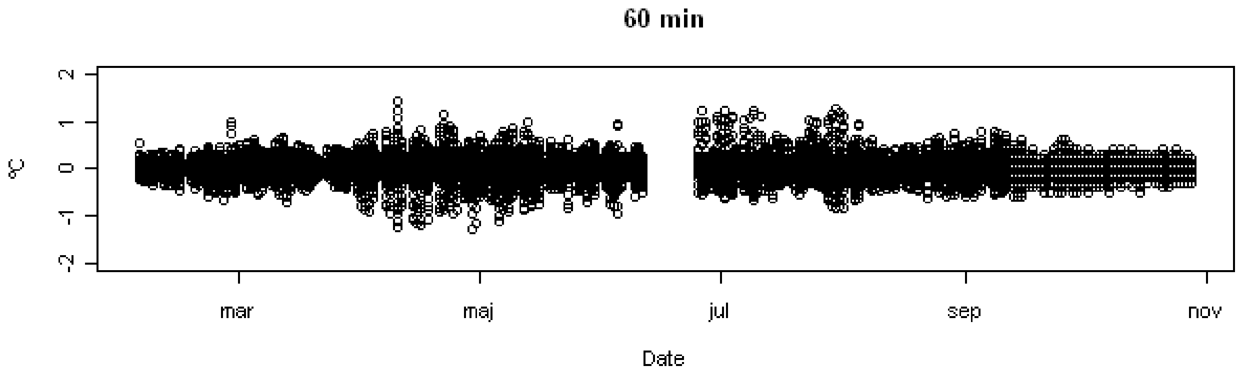
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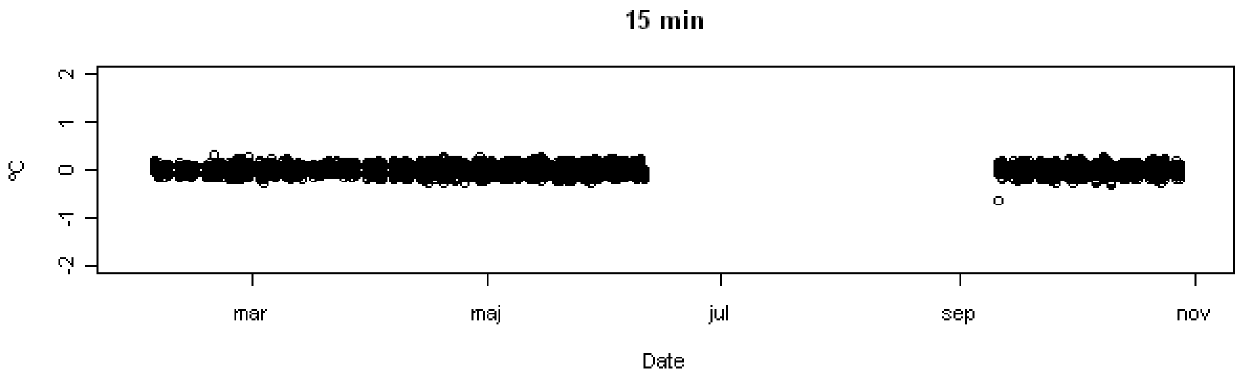
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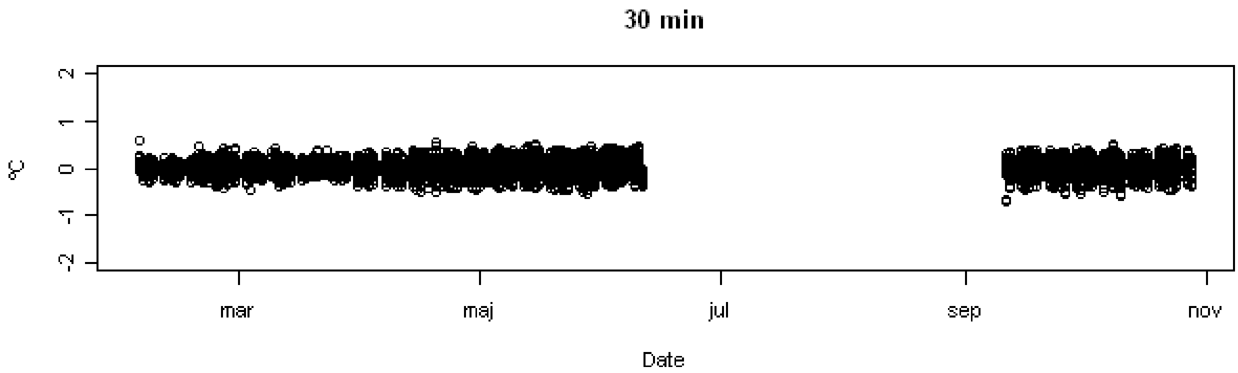
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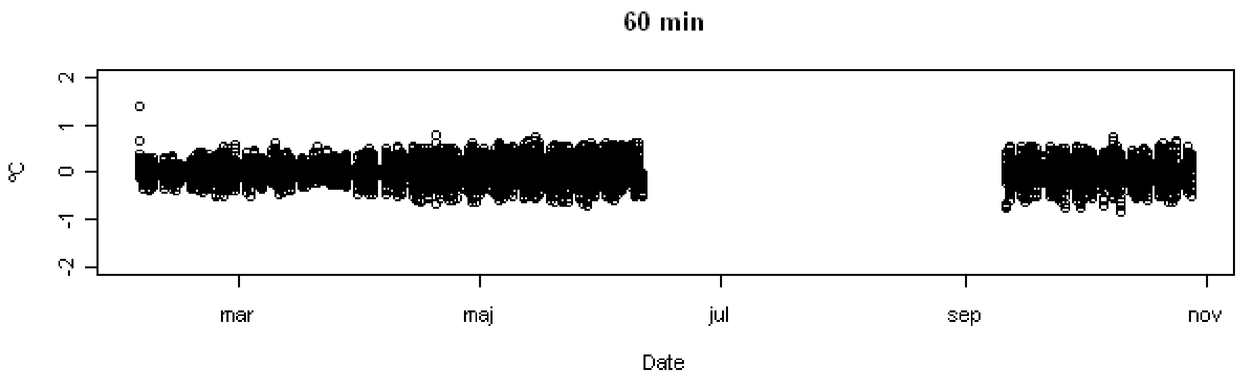
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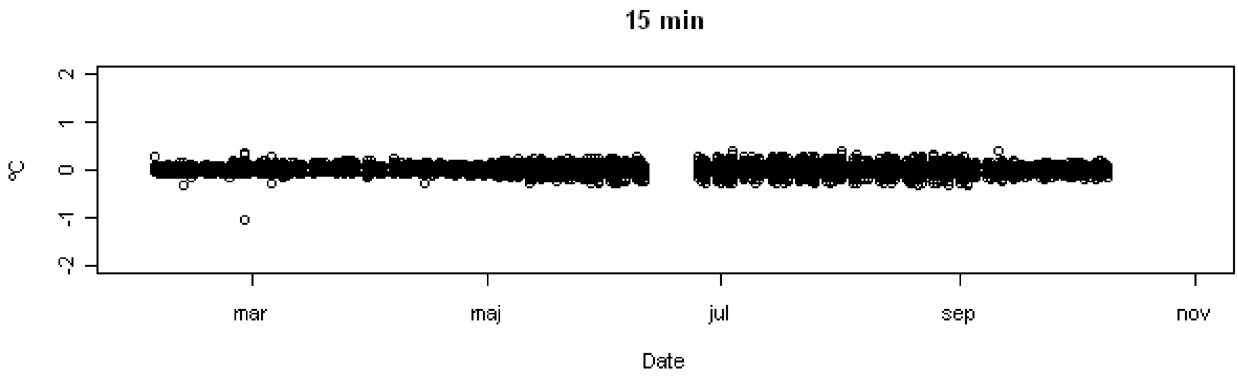
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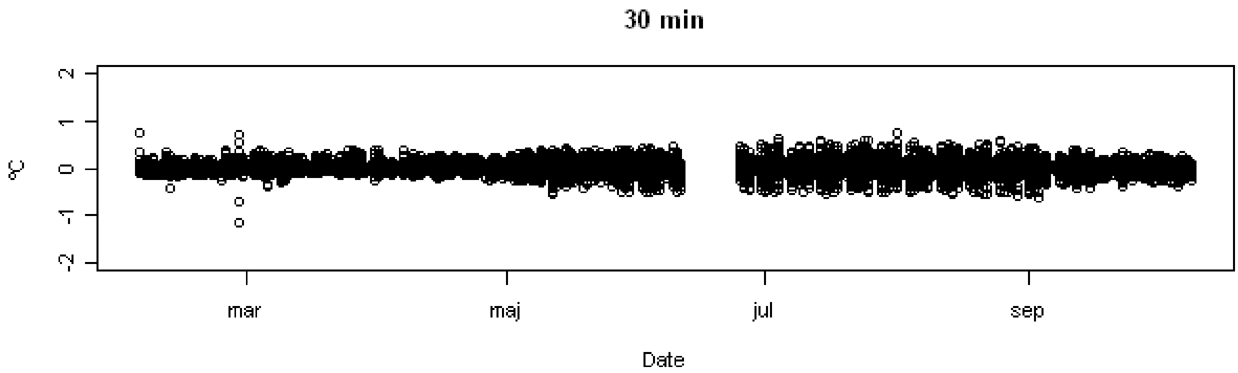
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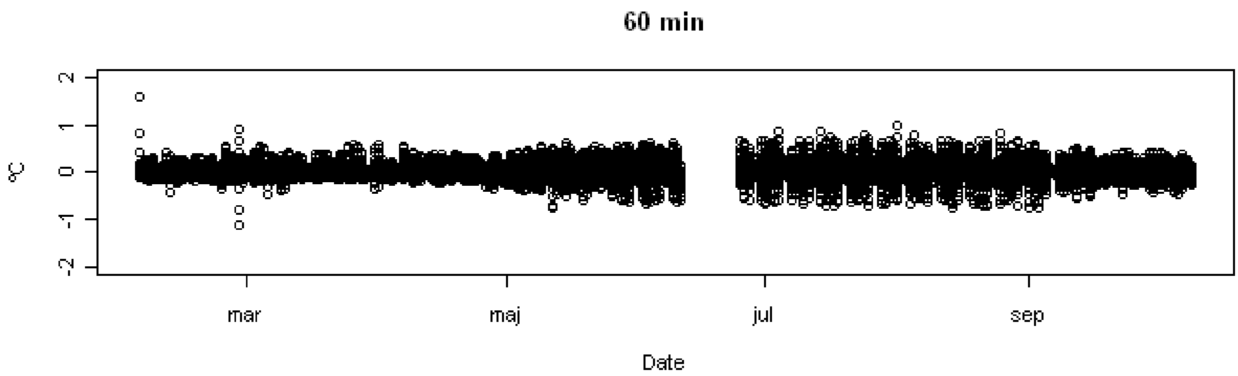
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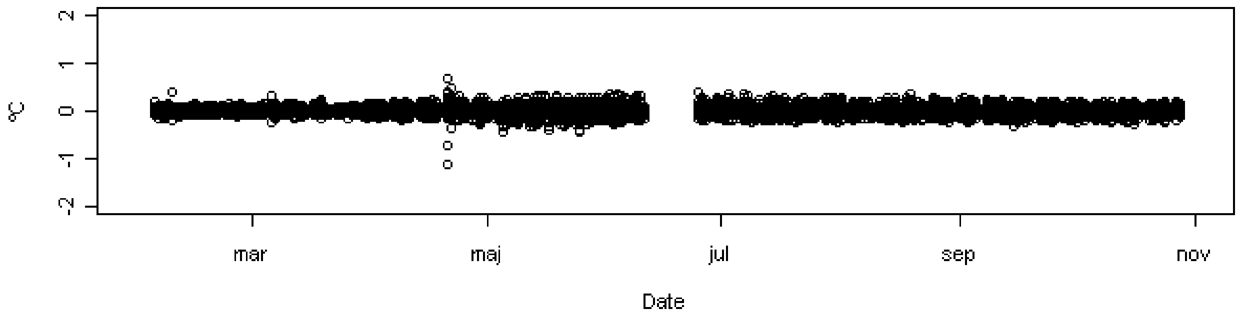

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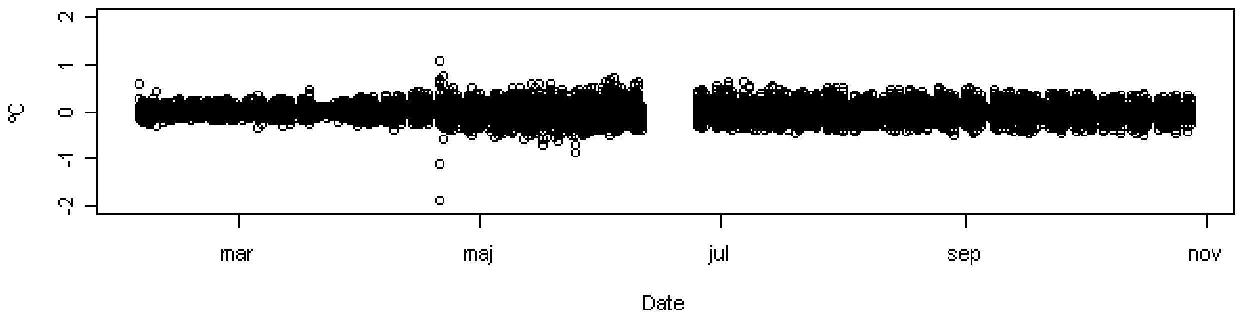

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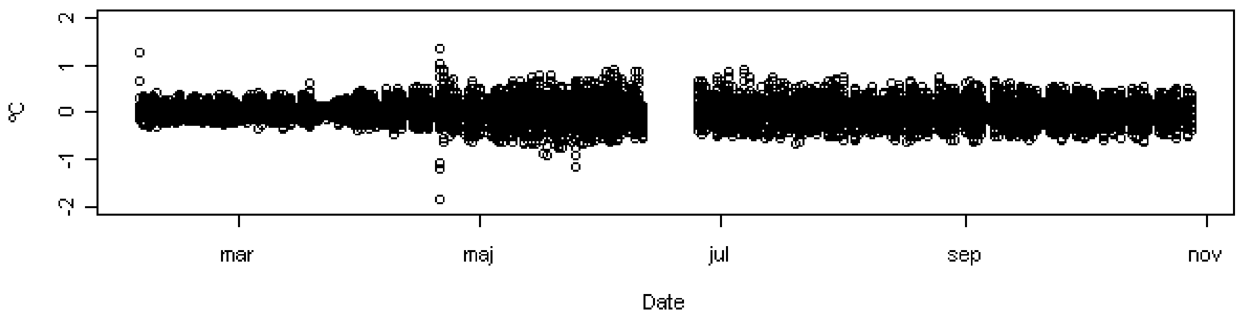

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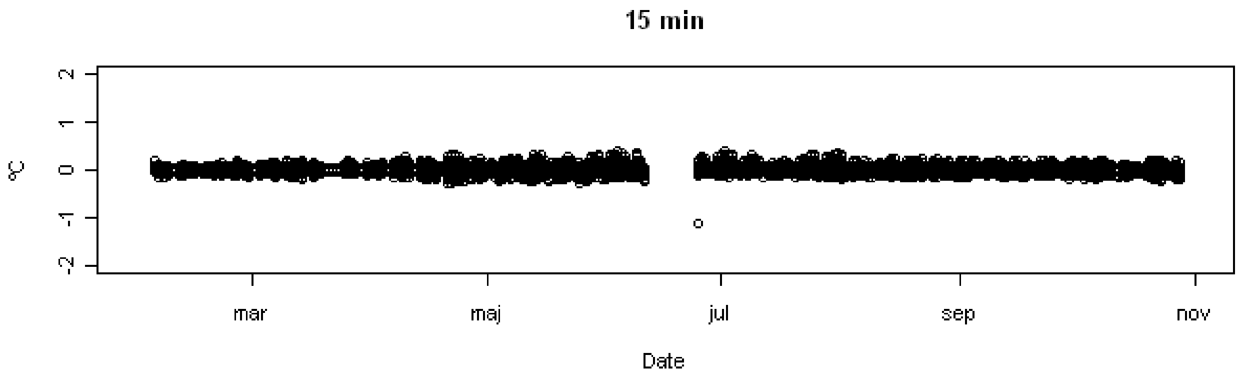
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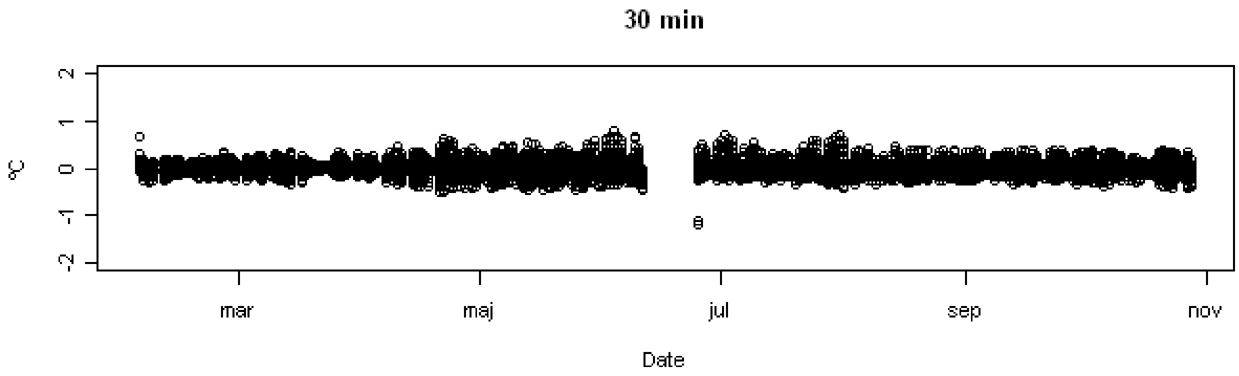
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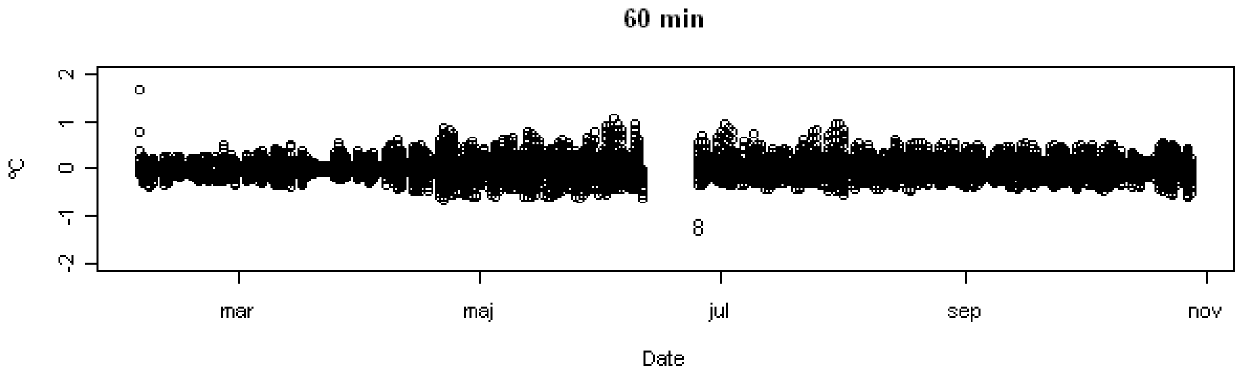
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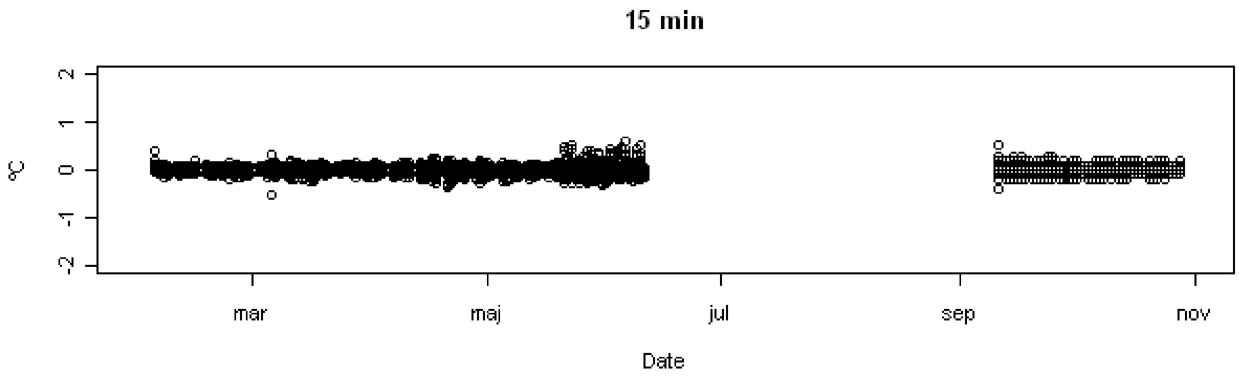
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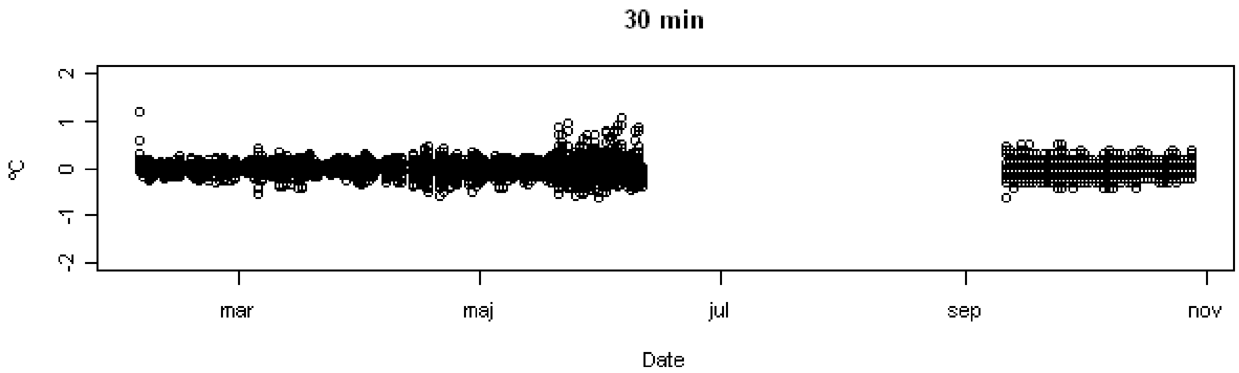
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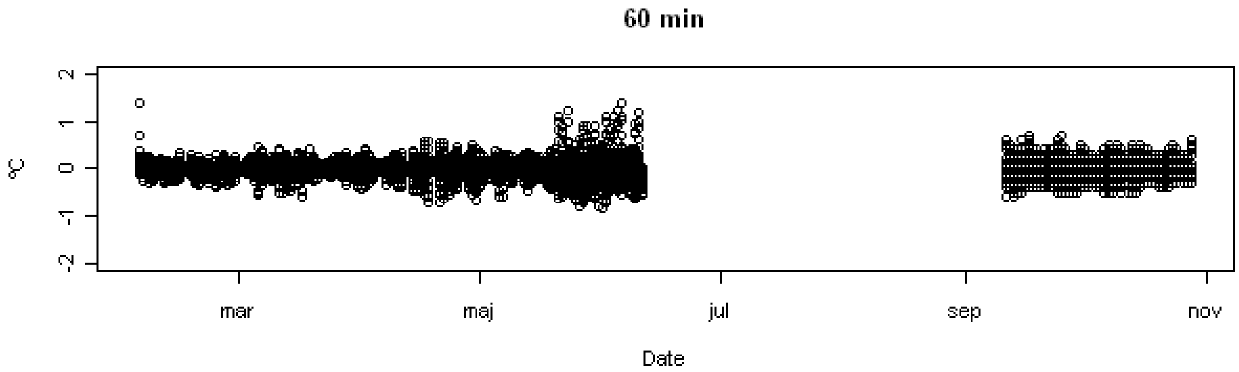
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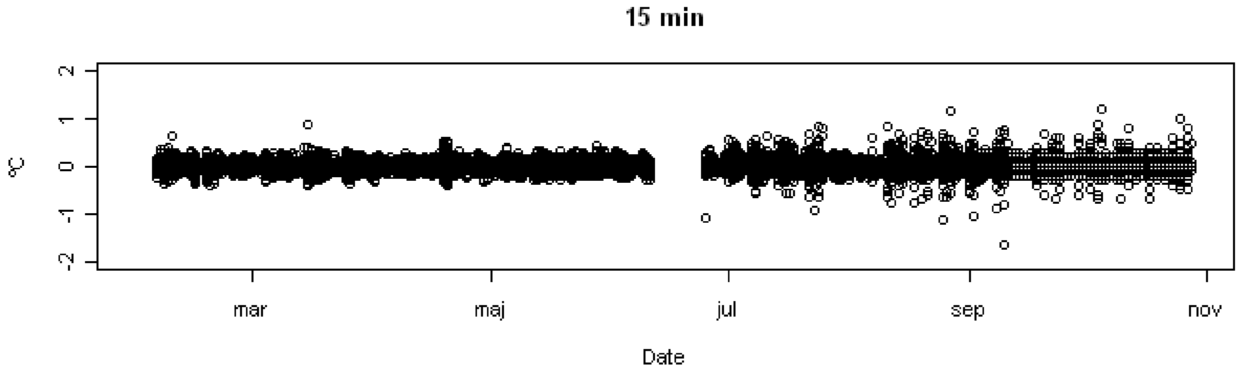
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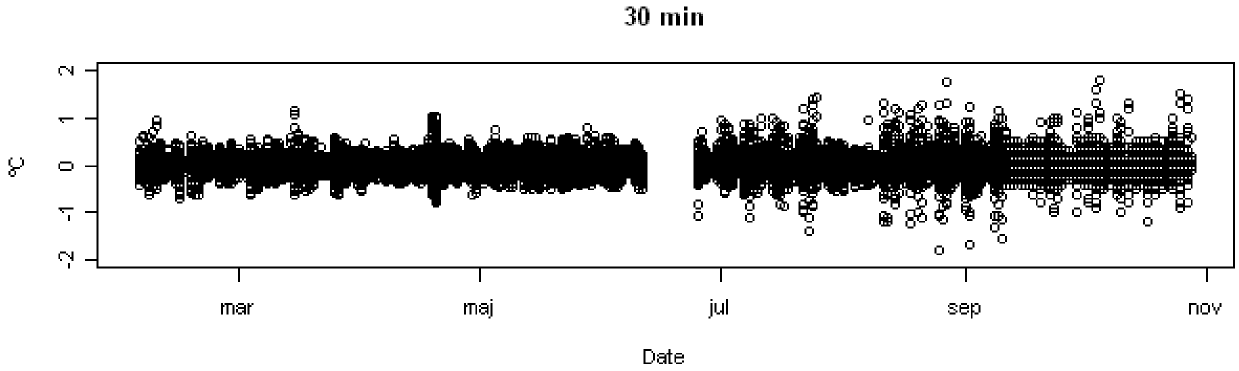
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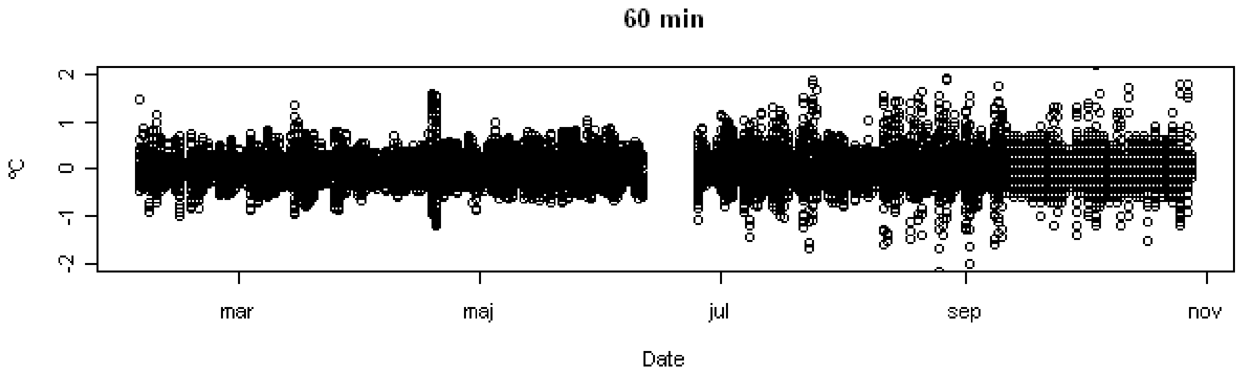
Date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1
0
-1
-2
°C
mar
maj
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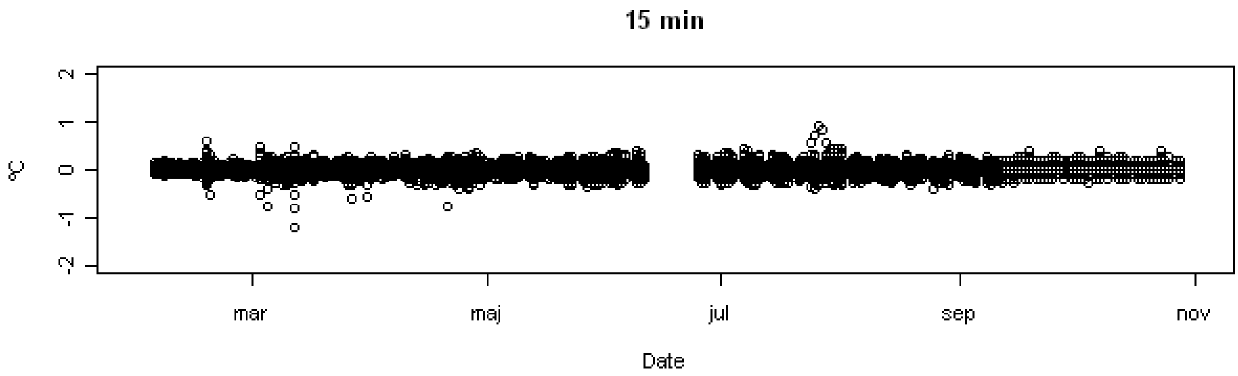
nov
Date

3042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2
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mar
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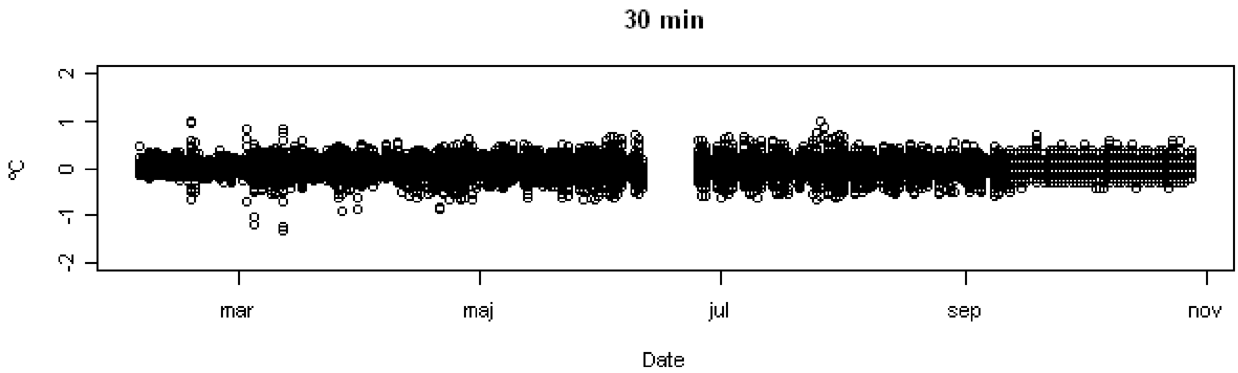
Date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1
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-2
mar
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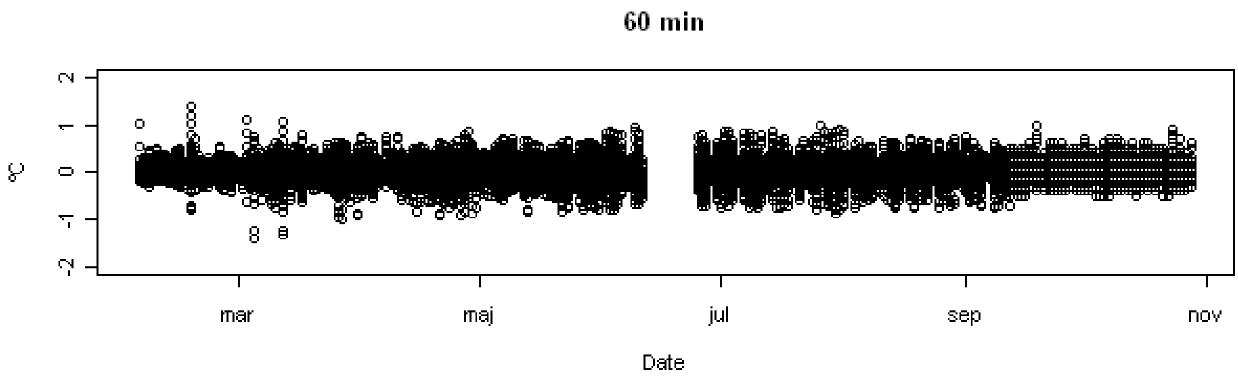
jul
sep
nov
Date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°C
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1
0
-1
-2
mar
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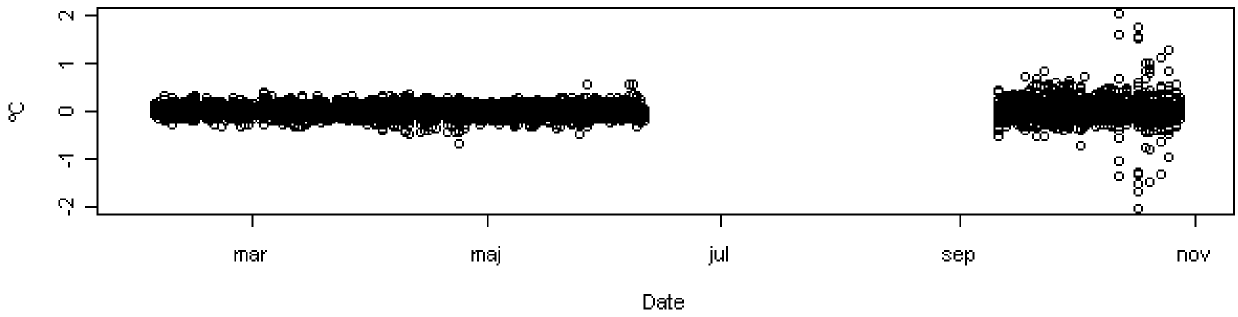
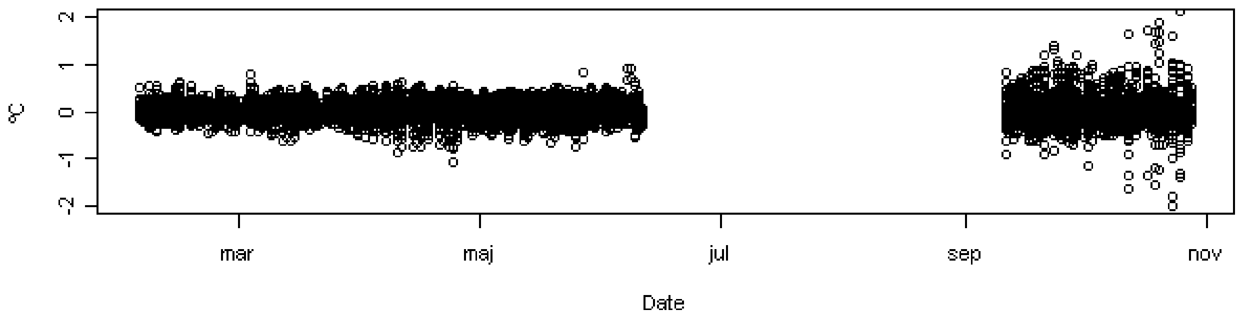
nov
Date

3046

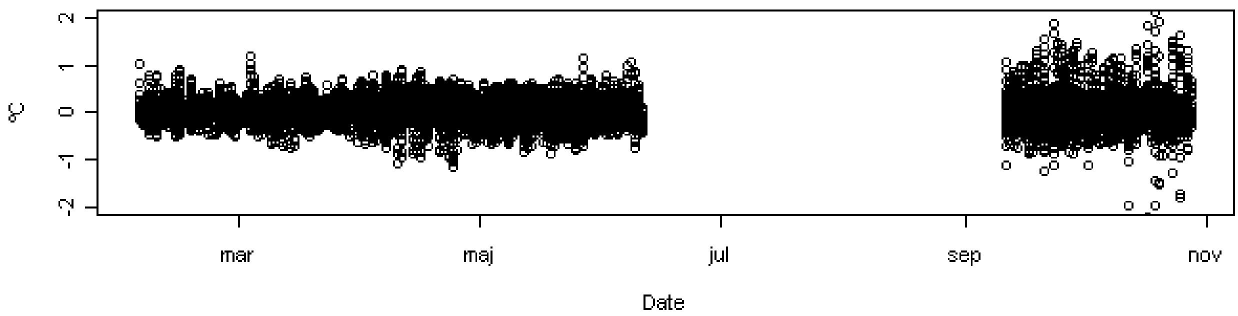
15 min



30 min



60 min



Appendix 2.4a-b Summary of spot measurements on the 6 March 2008

Nearest logger	Floor	Zone	Height	Air temp. (ºC)	Op. temp. (ºC)	Air vel. (m/s)	Turbulence intensity (%)	DR	PMV	PPD
3028	0	Y1	0.1	23.3	22.8	0.16	50	17		
3028	0	Y1	0.6	23.3	22.9	0.15	47		0.1	5
3028	0	Y1	1.1	23.4	22.8	0.16	75	20		
3032	1	A1	0.1	23.5	22.9	0.11	73	11		
3032	1	A1	0.6	23.4	23	0.12	50		0.2	5
3032	1	A1	1.1	23.5	23	0.1	70	9		
3029	1	I3	0.1	22.7	22.6	0.1	50	9		
3029	1	I3	0.6	23	22.8	0.1	40		0.1	5
3029	1	I3	1.1	23.1	22.6	0.11	36	9		
3041	1	I4	0.1	23.4	22.6	0.13	38	11		
3033	1	I4	0.1	24.1	23.6	0.12	42	9		
3041	1	I4	0.6	23.1	22.4	0.09	67		0.1	5
3033	1	I4	0.6	24.1	23.4	0.11	82		0.4	8
3041	1	I4	1.1	23.8	22.8	0.07	71	5		
3033	1	I4	1.1	24.4	23.7	0.11	45	8		
3040	2	A1	0.1	22.8	22	0.12	83	15		
3040	2	A1	0.6	22.7	21.5	0.11	45		0.0	5
3040	2	A1	1.1	22.8	21.8	0.11	36	9		
3036	2	A3	0.1	23.1	22.7	0.11	100	14		
3036	2	A3	0.6	22.9	22.5	0.12	58		0.0	5
3036	2	A3	1.1	23	22.6	0.1	80	10		
3037	2	I3	0.1	22.9	22.6	0.16	50	17		
3037	2	I3	0.6	23.1	22.6	0.12	50		0.1	5
3037	2	I3	1.1	23.2	22.6	0.14	64	16		
3031	2	Y1	0.1	22.8	22.2	0.1	80	11		
3031	2	Y1	0.6	22.7	22	0.13	46		-0.1	5
3031	2	Y1	1.1	22.5	22	0.11	109	15		
3046	2	Y4	0.1	22.8	22.3	0.13	77	16		
3046	2	Y4	0.6	22.9	22.4	0.12	42		0.0	5
3046	2	Y4	1.1	23.1	22.4	0.08	50	6		
3039	4	A1	0.1	22.7	22.2	0.1	30	7		
3039	4	A1	0.6	22.6	22.3	0.09	111		0.0	5
3039	4	A1	1.1	22.7	22.2	0.16	75	22		
3038	4	I3	0.1	23.2	22.7	0.12	50	11		
3038	4	I3	0.6	23.2	22.6	0.11	55		0.1	5
3038	4	I3	1.1	23.3	22.7	0.12	75	13		
3042	4	Y4	0.1	23.1	22.5	0.07	14	3		
3042	4	Y4	0.6	23	22.4	0.08	88		0.1	5
3042	4	Y4	1.1	23.2	22.6	0.09	67	8		

Nearest logger	Floor	Zone	Height	Air temp. (ºC)	Op. temp. (ºC)	Air vel. (m/s)	Turbulence intensity (%)	DR	PMV	PPD
	0	A1	0.1	23.5		0.09	56	7		
	0	A1	0.6	23.7	23.4	0.09	44		-0.1	13
	0	A1	1.1	23.7		0.11	27	8		
3028	0	Y1	0.1	25.2		0.12	50	9		
3028	0	Y1	0.6	25.1	24.4	0.14	71		0.0	5
3028	0	Y1	1.1	25.2		0.1	70	8		
3032	1	A1	0.1	22.4		0.2	45	23		
3032	1	A1	0.6	22.4	22	0.21	48		-0.7	15
3032	1	A1	1.1	22.5		0.18	72	26		
	1	A3	0.1	23		0.12	58	12		
	1	A3	0.6	23.2	22.8	0.08	38		-0.3	7
	1	A3	1.1	23.3		0.07	43	4		
3029	1	I3	0.1	22.9		0.18	50	20		
3029	1	I3	0.6	23.3	23	0.16	69		-0.7	15
3029	1	I3	1.1	23.3		0.13	46	12		
3041	1	I4	0.1	22.2		0.1	50	9		
3033	1	I4	0.1	23.7		0.08	50	5		
3041	1	I4	0.6	22.3	22	0.15	40		-0.7	15
3033	1	I4	0.6	23.8	23.3	0.1	40		-0.2	6
3041	1	I4	1.1	22.3		0.13	54	14		
3033	1	I4	1.1	23.9		0.07	71	4		
3040	2	A1	0.1	23.4		0.12	50	11		
3040	2	A1	0.6	23.4	23	0.08	50		-0.3	6
3040	2	A1	1.1	23.4		0.09	56	7		
3037	2	I3	0.1	22.7		0.14	36	13		
3037	2	I3	0.6	22.7	22.4	0.14	43		-0.5	11
3037	2	I3	1.1	22.7		0.08	88	7		
3031	2	Y1	0.1	23.6		0.15	47	14		
3031	2	Y1	0.6	23.7	23.3	0.09	67		-0.2	6
3031	2	Y1	1.1	23.7		0.06	67	3		
3046	2	Y4	0.1	23.3		0.11	55	10		
3046	2	Y4	0.6	23.1	22.9	0.13	46		-0.4	8
3046	2	Y4	1.1	23.2		0.09	78	8		
3039	4	A1	0.1	22.7		0.1	50	9		
3039	4	A1	0.6	22.8	22.5	0.05	80		-0.4	8
3039	4	A1	1.1	22.8		0.05	80	0		
3038	4	I3	0.1	23.1		0.06	67	3		
3038	4	I3	0.6	23.2	22.6	0.08	63		-0.4	8
3038	4	I3	1.1	23.2		0.08	63	6		
3042	4	I4	0.1	22.3		0.1	50	9		
3042	4	I4	0.6	22.5	22.1	0.09	78		-0.5	10
3042	4	I4	1.1	22.6		0.12	75	14		

Appendix 2.5 Comments from the occupants on the indoor environment

Her er skiftende koldt/varmt, dårlig luft, meget støjende (eftersom man sidder i åbent miljø). Man får røde og irriterede øjne hen over middag samt ofte hovedpine og bliver utilpas.

I løbet af eftermiddagen er det klart ubehageligt at sidde to personer i det lille kontor, hvor jeg sidder, og der er ca. 25 grader om eftermiddagen, selv om der aldrig er nogen sol, der står på. Luften er også ""dårlig"", manglende ilttilførsel til rummet, og man er "godt brugt", når man går hjem. Dog ingen hovedpine, bare træt.

mht. varmen i kontoret - lige nu er her altså ret køligt og det trækker et eller andet sted fra. men ellers må jeg nok tilføje at her er for varmt det meste af tiden. Det der sådan set, er det værste for mig er, her er alt for meget lys.

De problemer jeg oplever er, alt for tit alt for varmt, det gør at jeg bliver temmelig dvask. I skrivende stund "morgen" er her én behagelig temperatur, men mod middagstid bliver den noget højere.

Ingen mulighed for at udluftning eller gennemtræk, intet normalt dagslys - kun fra ovenlys atriumgård, megen persongennemgang i kontoret, støjgener fra kolleger- adfærd omkring tale, tlf. mv bør oplyses bedre.

Dårligt. Støjende / snavset / støvet / mørkt / ubehageligt / generelt ganske utilfredsstillende

Problemet i vores lokale er ikke temperaturen, men at det trækker.

Det trækker ad h.t. især når der er trafik ud og ind af opgangen, så kommer det et sus af kold luft.

Luften er ok om morgen, men opad dagen bliver den tung, tør og varm.

Jeg har altid tørre hænder, læber, mund og hals. Det er altid enten rigtig varmt eller rigtig koldt. Det føles som om der aldrig er luftudskiftning i rummet og det får jeg let hovedpine af. Desuden lugter der altid af et eller andet ubeskriveligt i lokalet. Jeg tror lugten kommer fra kantinen, når de laver mad også når mine kolleger spiser deres medbragte mad ved bordet. Desuden sidder vi ekstremt tæt og når folk taler i telefon på samme tid, er det slet ikke til at være her for larm.

Her er generelt for varmt. Dog kan temperaturen svinge. Om sommeren er her for koldt. Det værste er støj, dårlig luft (mangel på ilt) og manglende sollys.

Jeg har netop nu været på arbejde i en halv time, og klokken er 9:20. Der er som regel rart at være tidligt på dagen. Efter frokost kommer generne (når de er der).

Jeg arbejder bedst, når her ikke er for varmt. Men når her er køligt (fordi vejret uden for er det), kan jeg tydeligt mærke, at det "kulder" ind fra mit vindue (jeg sidder med venstre side til vinduet), og det er vel en "forkert" måde, luften bevæger sig på.

Da de fleste ansatte sidder i et åbent kontorlandskab er støj og gentagne afbrydelser fra flere sider det der generer mig mest, når jeg har en opgave der kræver ekstra koncentration.

Lige nu er temperaturen okay, men f.eks. om sommeren når solen skinner så har vi mellem 25 og 27 grader om eftermiddagen, og det er meget ubehageligt.

Indeklimaet i kopirum er ekstremt dårlig. Hvis der printes /kopieres store mængder er lugten dårlig og luften tør, så døren til rummet står altid åben - med det resultat, at både dårlig lugt og støj kommer ud i rummet.

Der er typisk normal temperatur eller køligt om morgenen og det er også der jeg mærker meget træk/blæst fra ventilationen i loftet over mig. Efter frokost er her for varmt og indelukket, men der er stadigvæk træk fra ventilationen, på trods af den højere temperatur.
På vores lille kontor er problemet stillestående luft og iltmangel, dårlig og tungt indeklima, ingen luftudskiftning.

Min frustration er at jeg gerne ville have mere frisk luft, men øget cirkulation betyder mere træk, og jeg kan ikke tåle træk

For lidt luftcirkulation, for tør luft, rimeligt store temperatursvingninger så der er koldt om eftermiddagen, for lidt dagslys.

Der er meget store komfort forskelle på om man sidder tæt ved vinduer (meget dårlige forhold: for koldt når det er koldt i lokalet, for varmt når det er varmt i lokalet) og når man ikke gør.

Jeg har generelt ingen problememer med at sidde i storrum. Støj og varme generer mig sjældent. Jeg ved godt at jeg er en meget unormal kvinde.

Det er formiddag, og luften er stadig forholdsvis frisk.

Oven lyset er generelt for skarpt og der er ikke mulighed for at dæmpe lyset. Temperaturen er generelt for høj og vi åbner dagligt vinduet for at forbedre luften og temperaturen i kontoret.

Til tider svært at koncentrere sig pga. støj fra kolleger, når der tales i telefon. Vi sidder 8 kolleger (2 x 4) med mange telefoner daglig.

Det værste er, at indeklimaet ikke er konstant. Nogle dage er der alt for koldt, nogle dage alt for varmt, nogle dage al for tung luft osv.

Netop nu er klimaet ok, men over middag bliver der normalt meget varmt eller meget koldt og dårlig luft. Desuden er her generelt ikke lyst nok, hvilket gør, at man bliver lidt sløv...

Generelt synes jeg klimaet er ok - kunne være lækkert, hvis man kunne slippe for nyseri og tør næse

Det trækker jævnligt. Der bør ikke være borde i midten af lokalerne, der bør være mødelokaler e.l. Der er for mørkt og alt for meget støj. Generelt mangler der "udsmykning" /omgivelser der skaber ro, balance og energi!

Mit store problem er lys. Og så at temperaturen ændrer sig flere gange i løbet af en uge....

Jeg er ikke sikker på at temperaturen er for lav, men jeg fryser tit (skutter mig lidt). Jeg synes det er som om jeg sidder i træk. Mht hvorvidt her er snavset eller rent synes jeg umiddelbart her er pænt rent, men her roder helt vildt, og det synes jeg skaber et uroligt arbejdsklima.

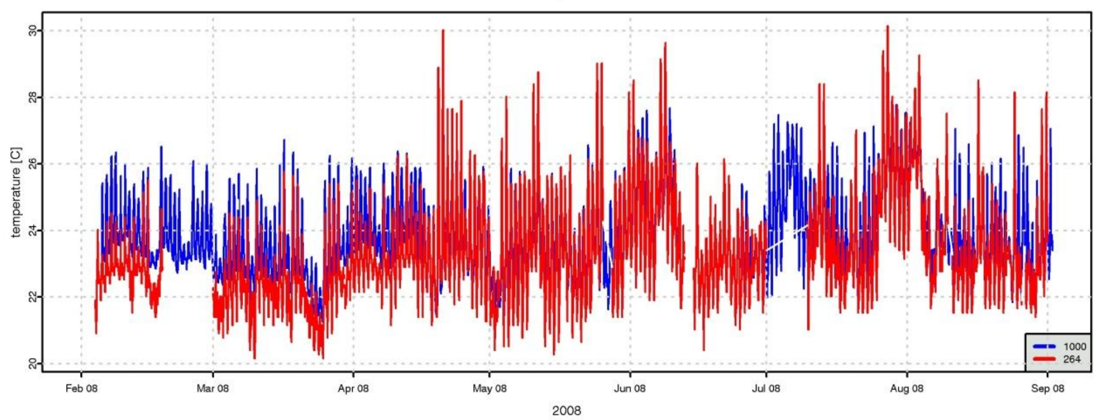
Om formiddagen er luften bedre tempereret end om eftermiddagen hvor det er nærmest uudholdeligt med tungt hoved og hævede fødder.

Det trækker med ret kold luft.

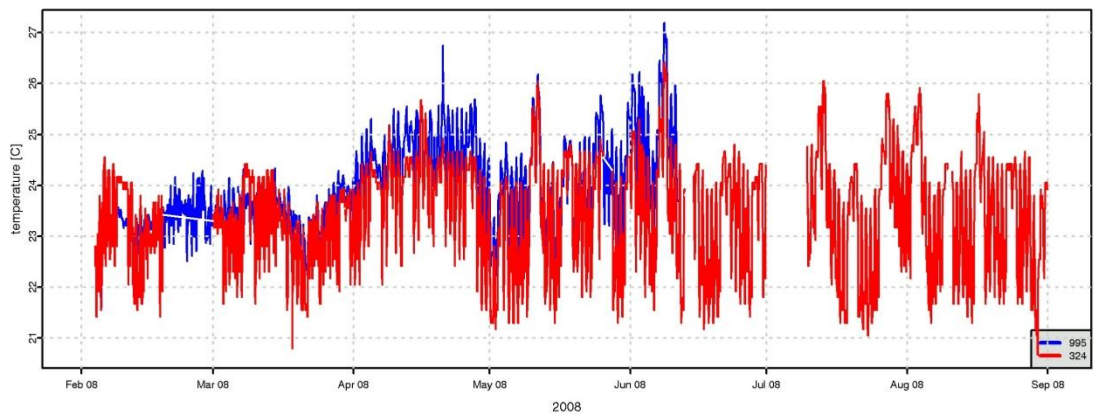
Som udgangspunkt meget tilfreds, men der kan til tider godt trække kolde vinde fra loftet

Appendix 3 Comparison between BMS and special purpose data

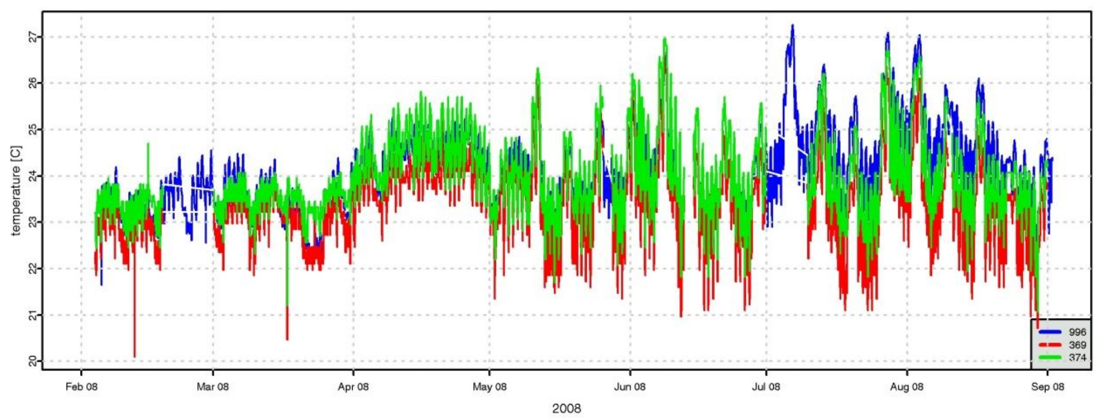
Room temperature 230



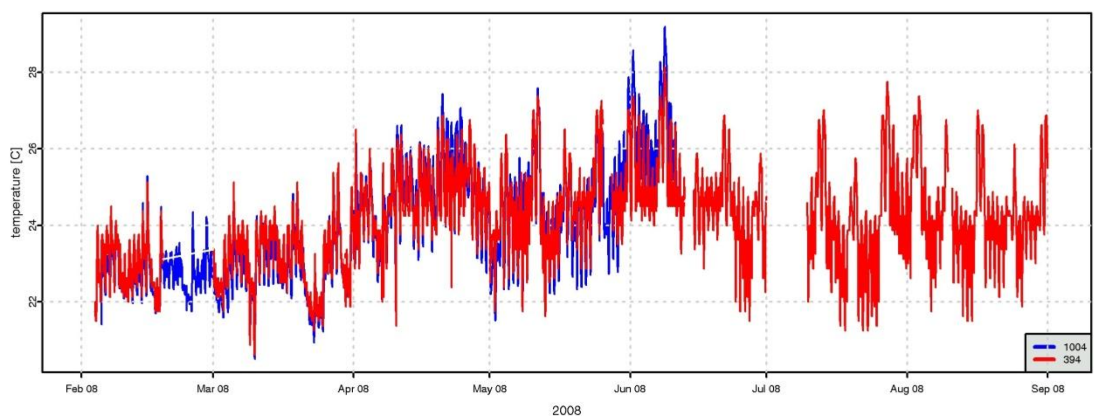
Room temperature 302



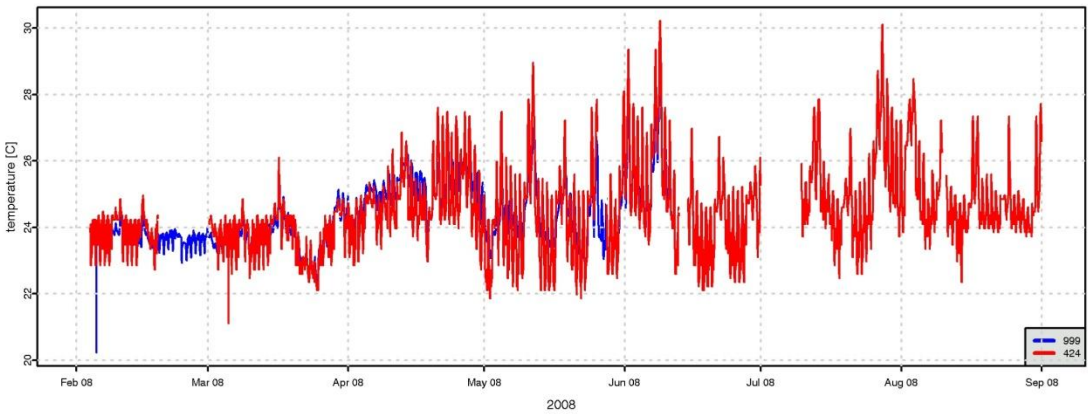
Room temperature 311–312



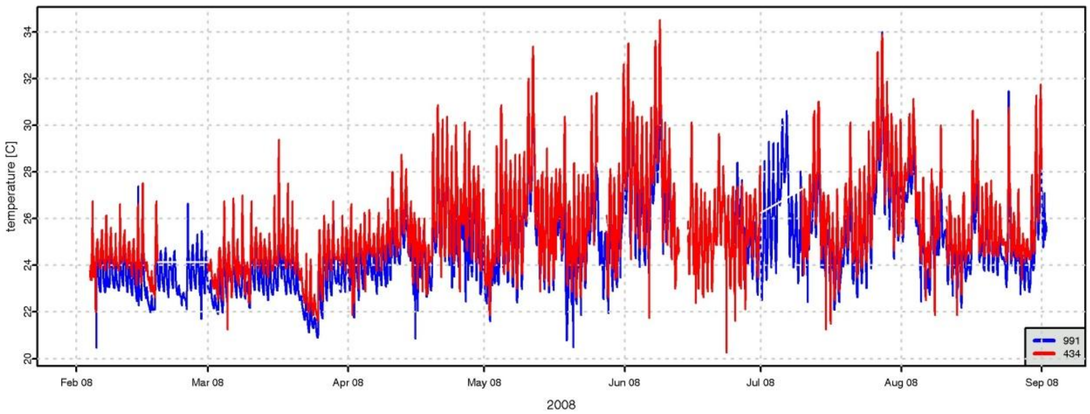
Room temperature 316



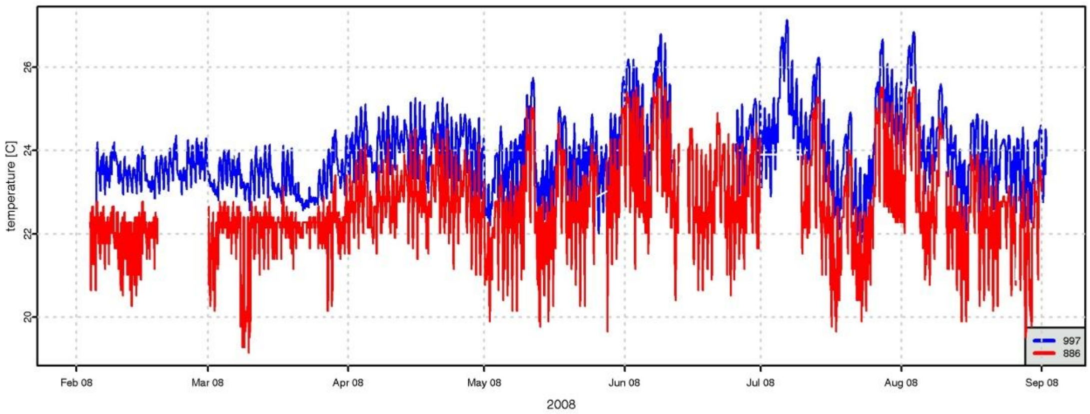
Room temperature 322



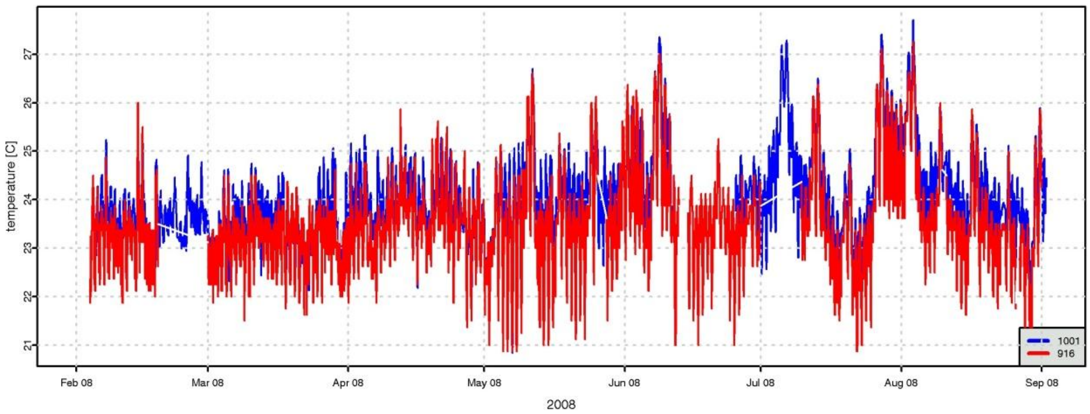
Room temperature 324

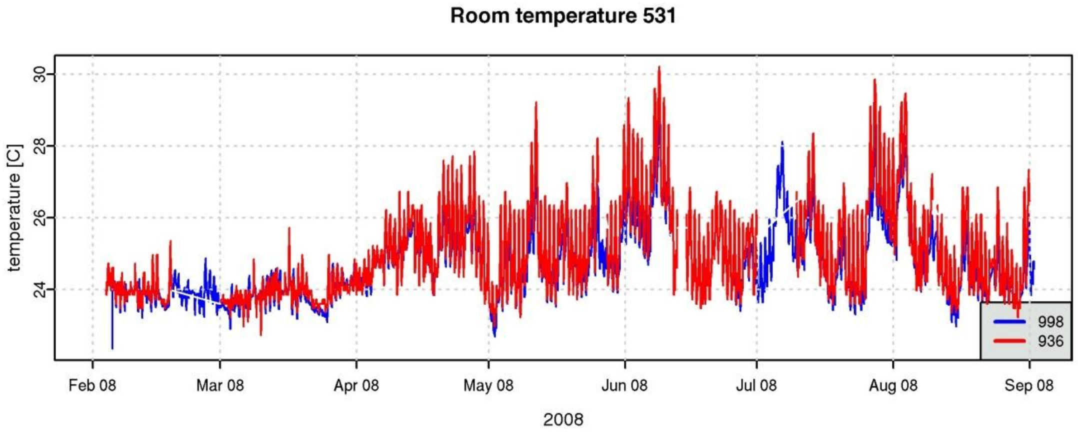


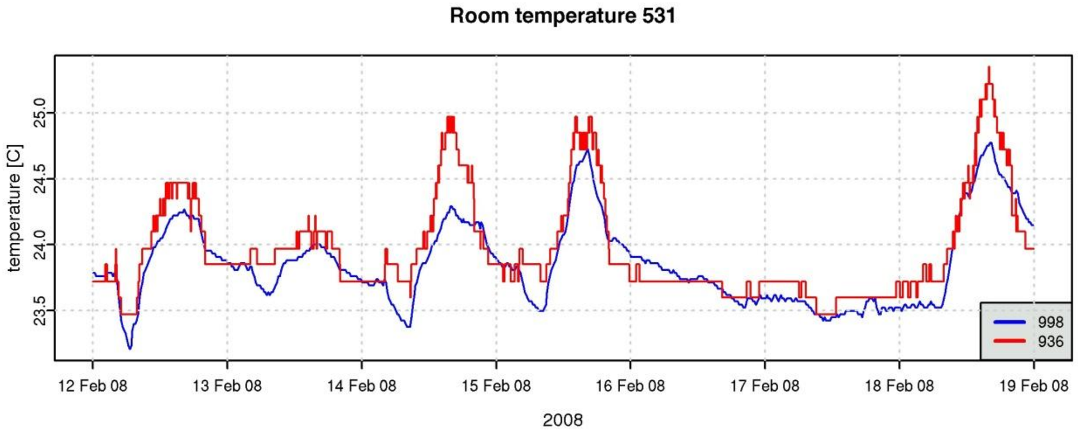
Room temperature 518

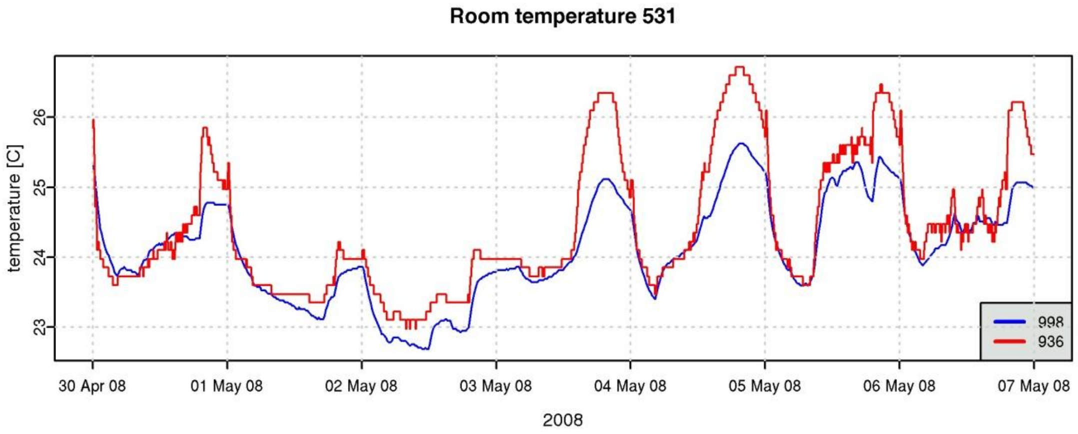


Room temperature 524

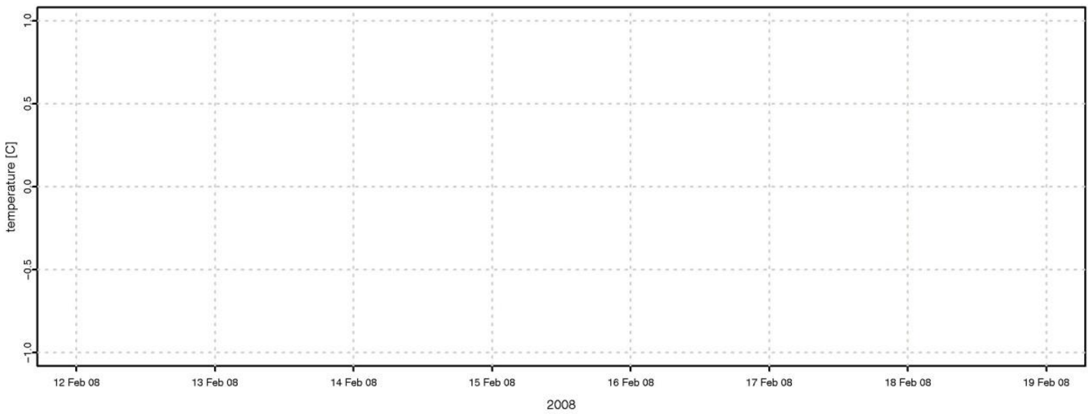



Room temperature 531
temperature [C]
30
28
26
24
998
936
Feb 08
Mar 08
Apr 08
May 08
Jun 08
Jul 08
Aug 08
Sep 08
2008

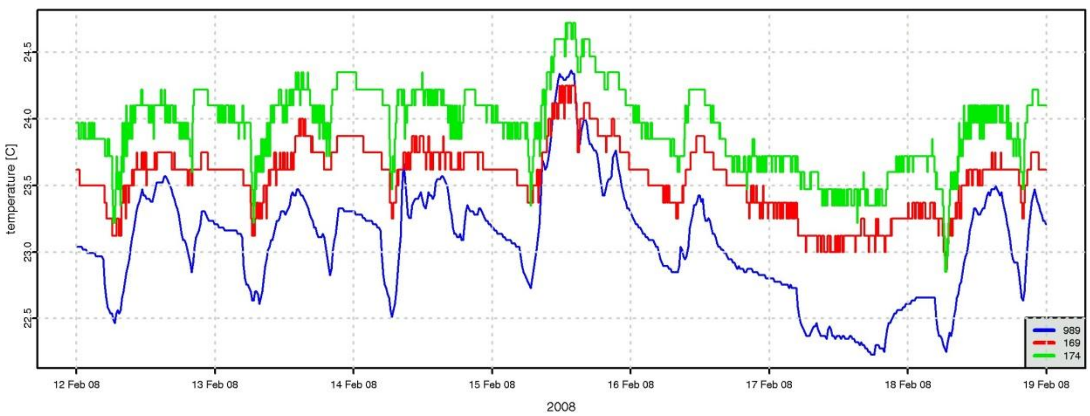

Room temperature 531
temperature [C]
25.0
24.5
24.0
23.5
998
936
12 Feb 08
13 Feb 08
14 Feb 08
15 Feb 08
16 Feb 08
17 Feb 08
18 Feb 08
19 Feb 08
2008


Room temperature 531
temperature [C]
26
25
24
23
998
936
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008

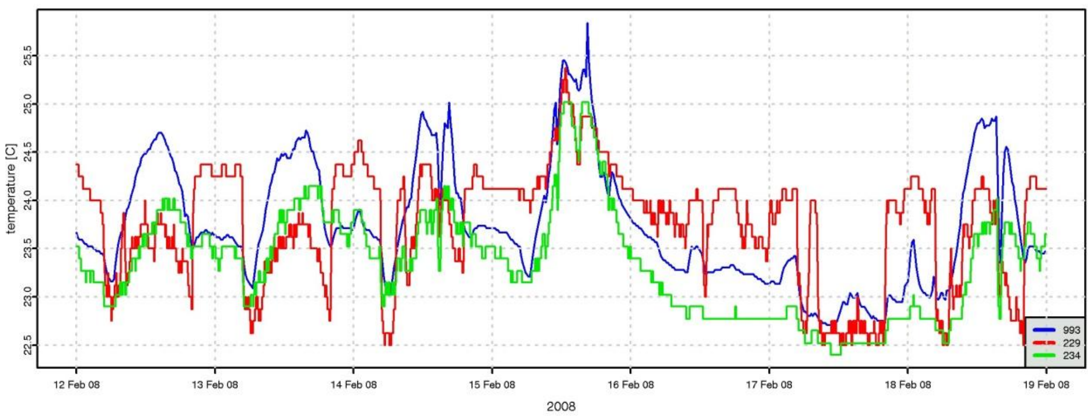
Room temperature 113



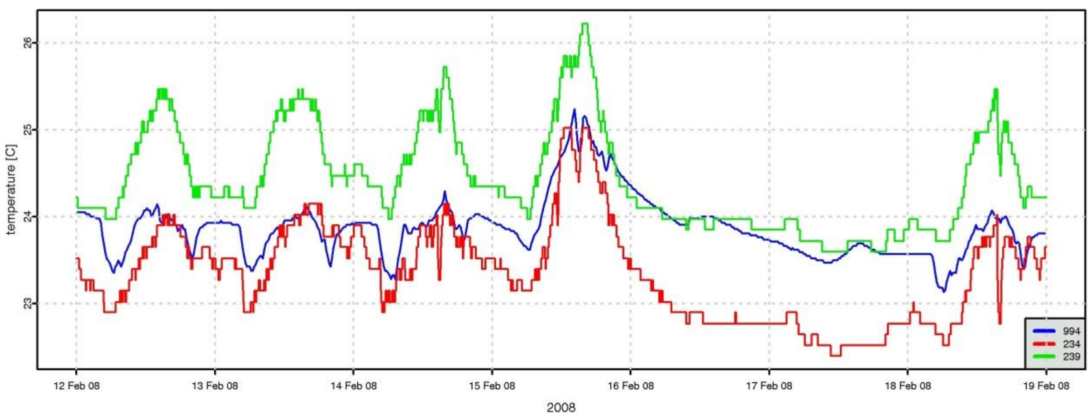
Room temperature 201−202



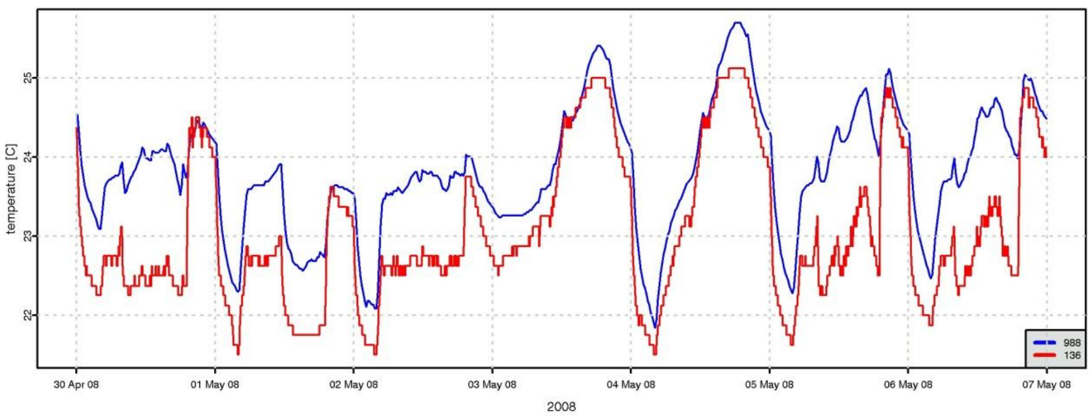
Room temperature 212−213



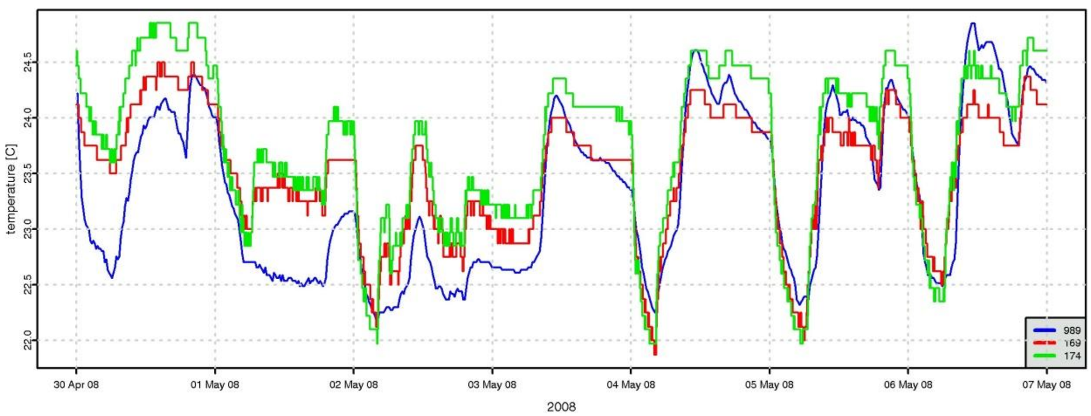
Room temperature 213−214



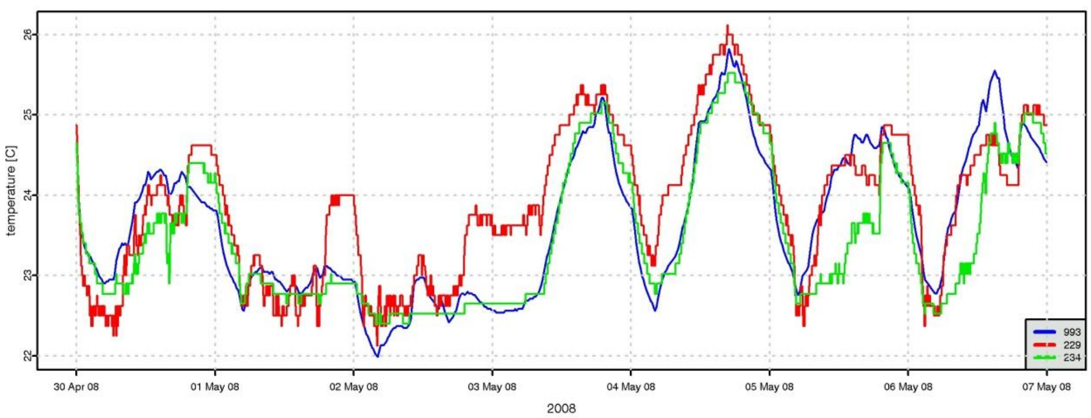
Room temperature 113



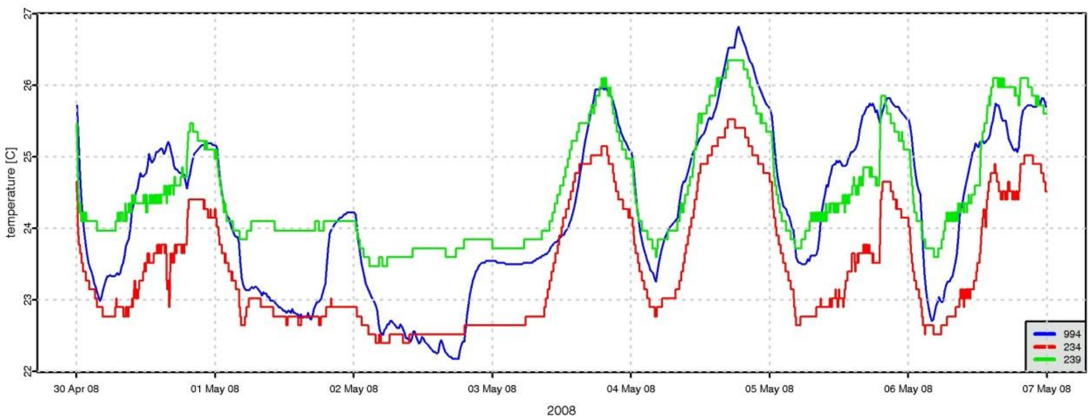
Room temperature 201–202

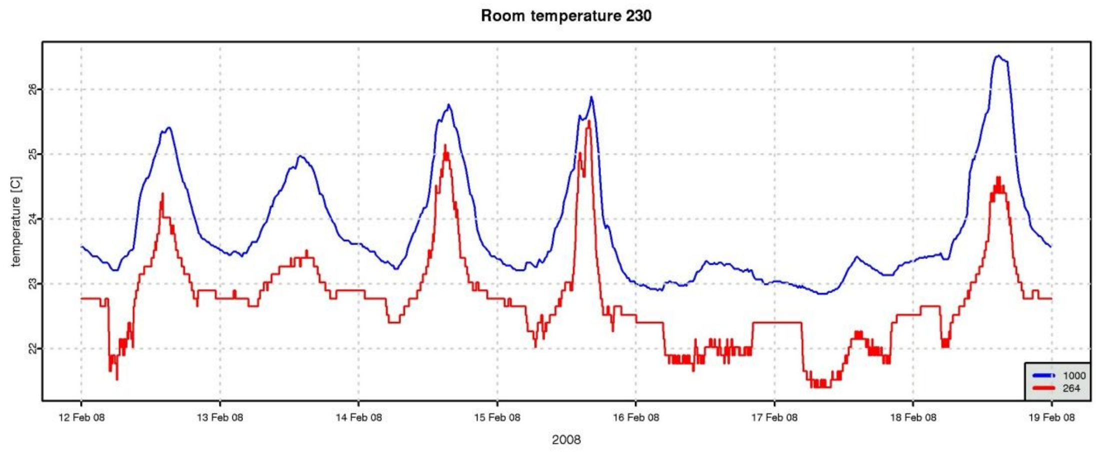


Room temperature 212–213



Room temperature 213–214




Room temperature 230
temperature [C]
22
23
24
25
26
12 Feb 08
13 Feb 08
14 Feb 08
15 Feb 08
16 Feb 08
17 Feb 08
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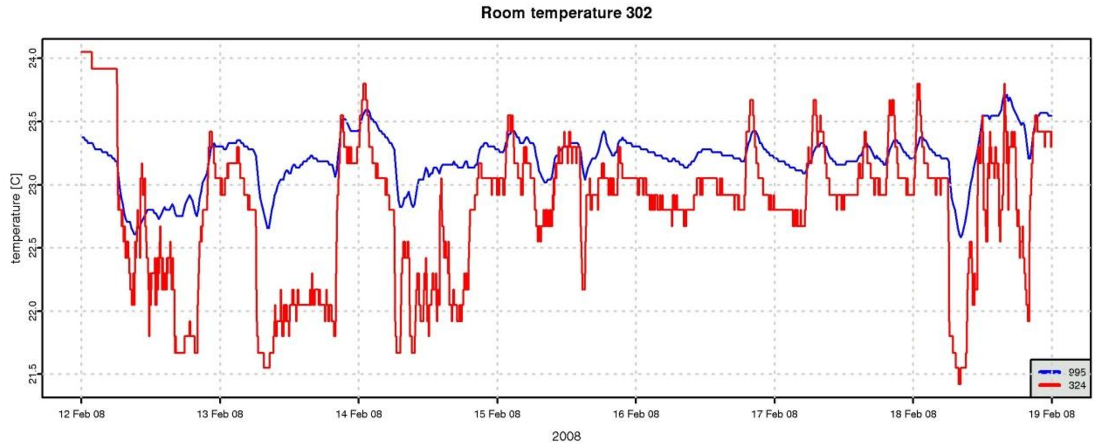
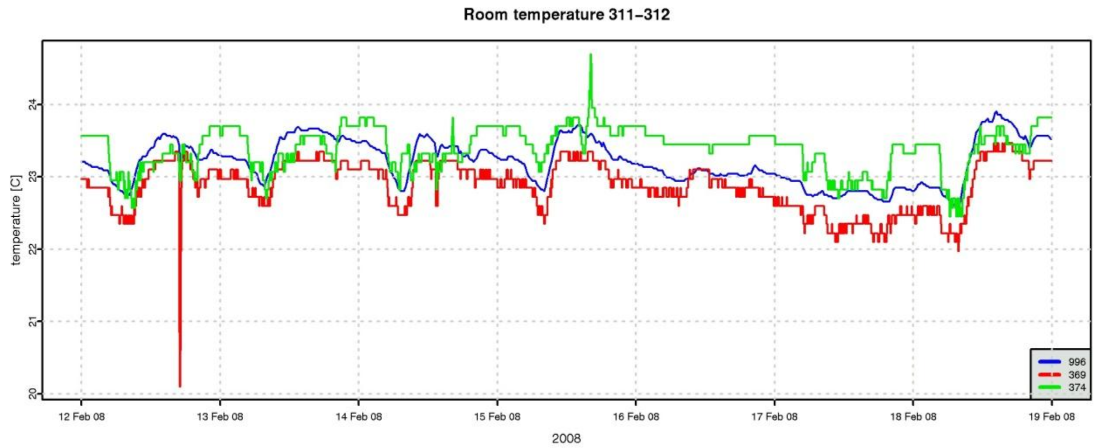
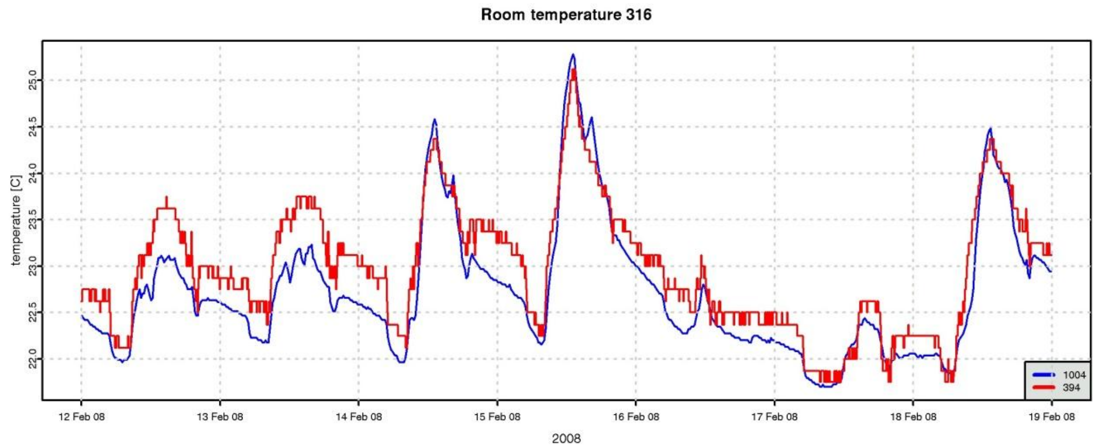
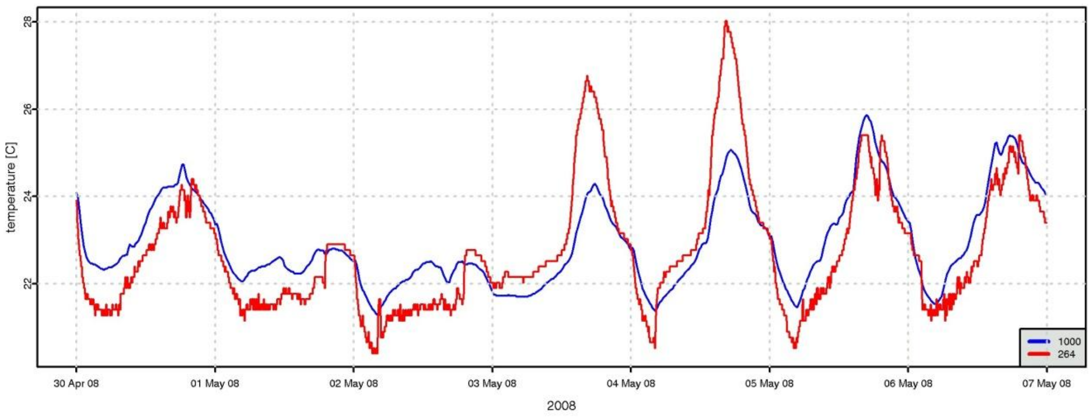
19 Feb 08
2008
1000
264


Room temperature 302
temperature [C]
21.5
22.0
22.5
23.0
23.5
24.0
12 Feb 08
13 Feb 08
14 Feb 08
15 Feb 08
16 Feb 08
17 Feb 08
18 Feb 08
19 Feb 08
2008
995
324

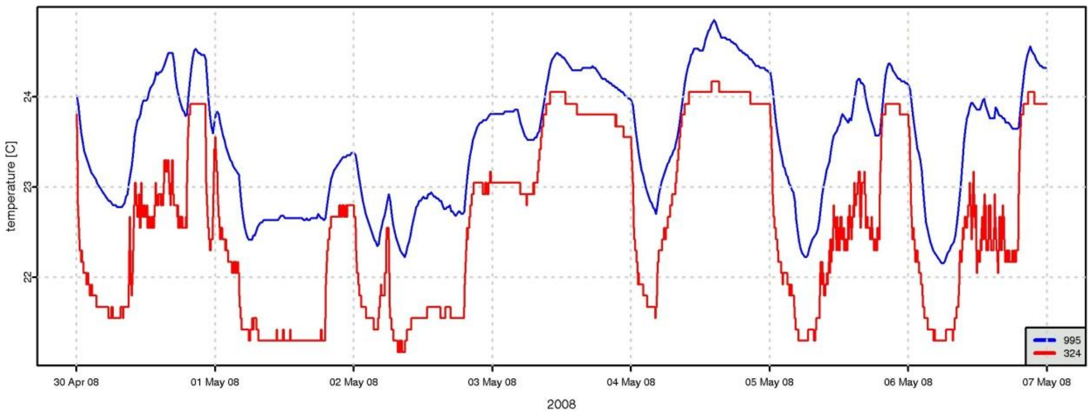

Room temperature 311−312
temperature [C]
20
21
22
23
24
12 Feb 08
13 Feb 08
14 Feb 08
15 Feb 08
16 Feb 08
17 Feb 08
18 Feb 08
19 Feb 08
2008
996
369
374


Room temperature 316
temperature [C]
22.0
22.5
23.0
23.5
24.0
24.5
25.0
12 Feb 08
13 Feb 08
14 Feb 08
15 Feb 08
16 Feb 08
17 Feb 08
18 Feb 08
19 Feb 08
2008
1004
394

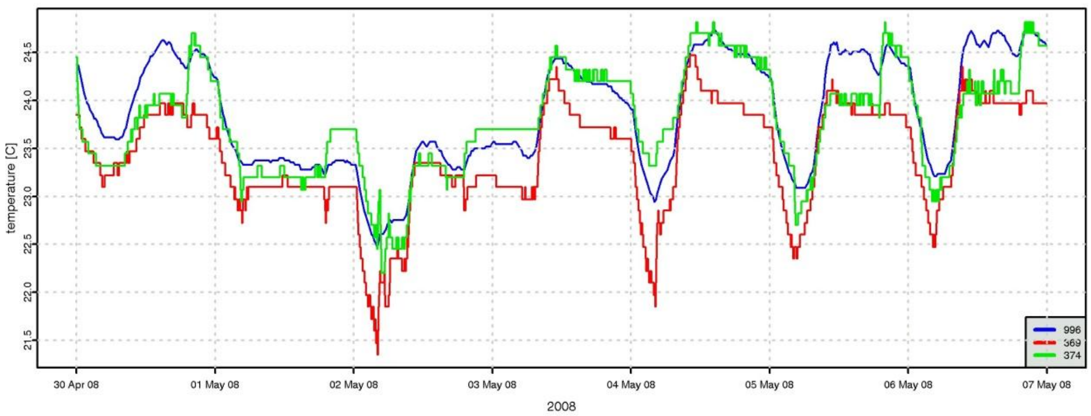
Room temperature 230



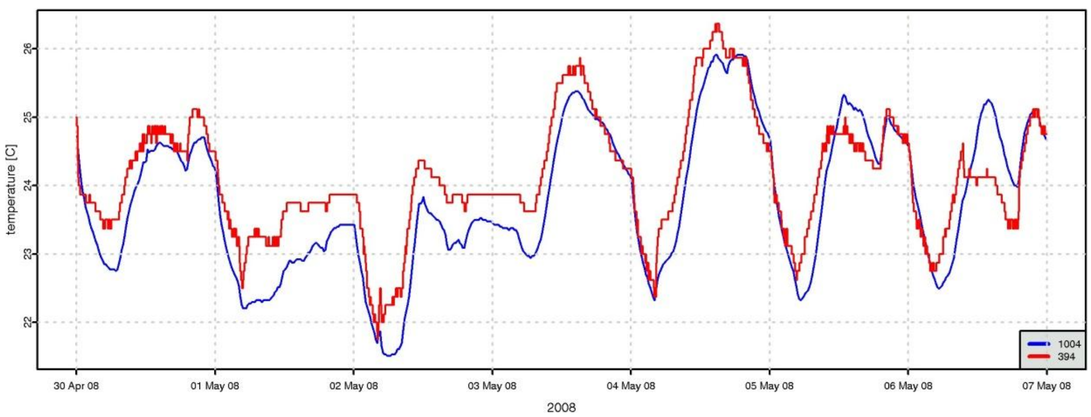
Room temperature 302



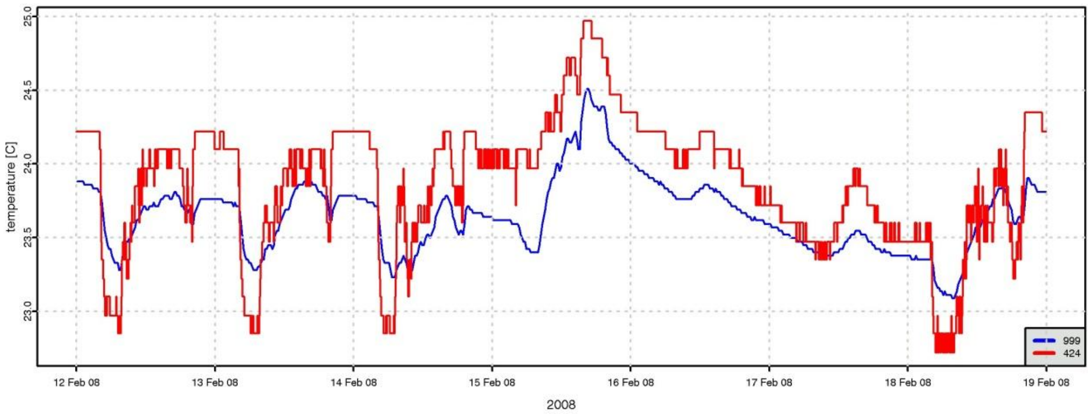
Room temperature 311−312



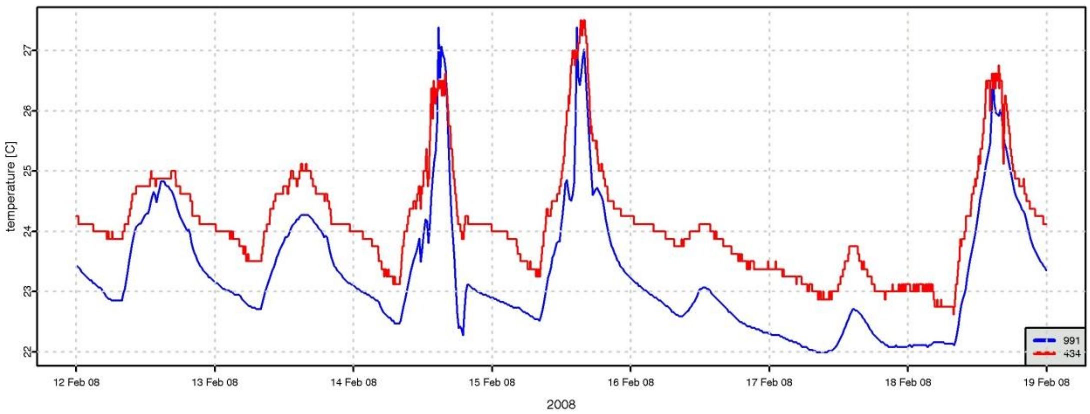
Room temperature 316



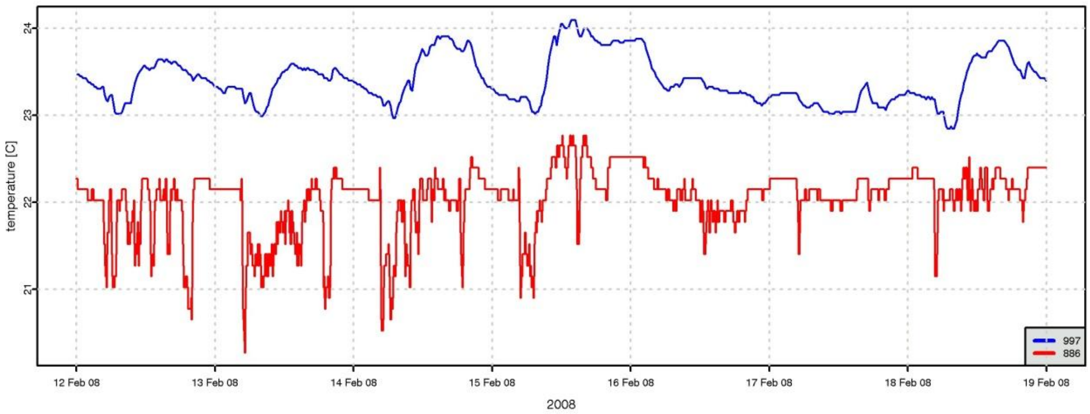
Room temperature 322



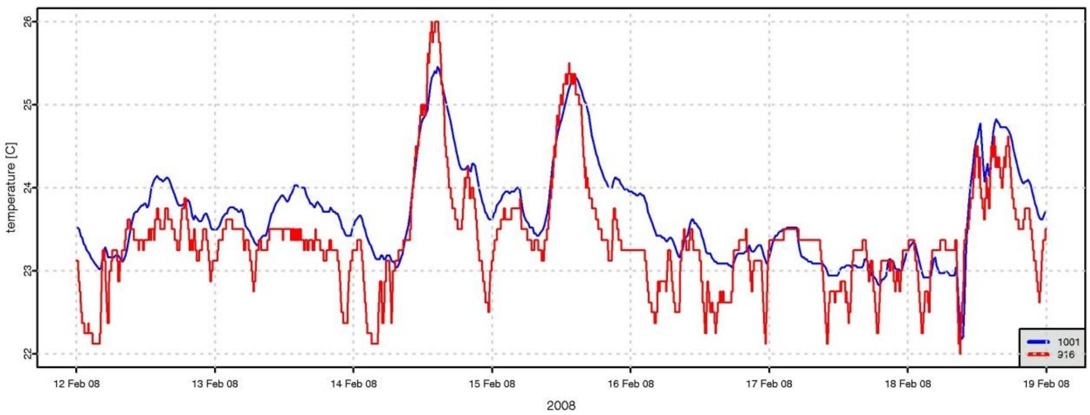
Room temperature 324

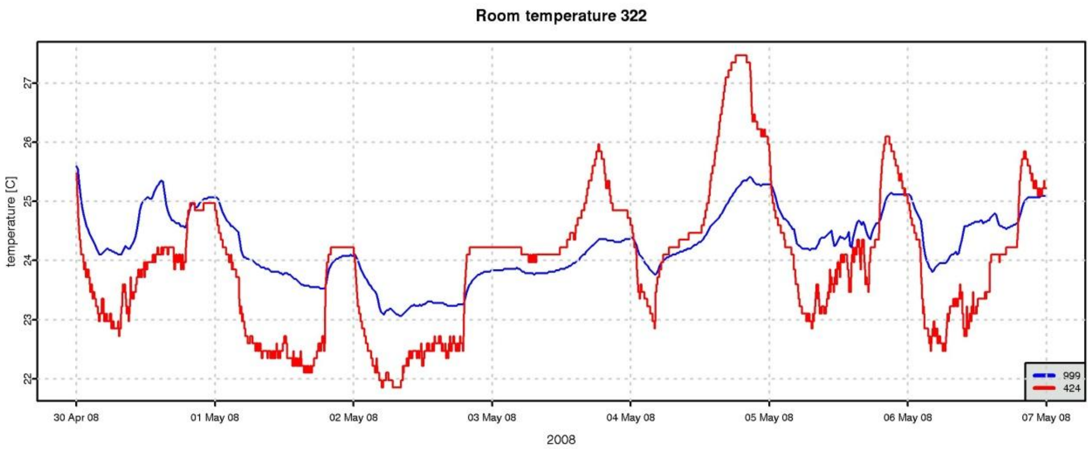


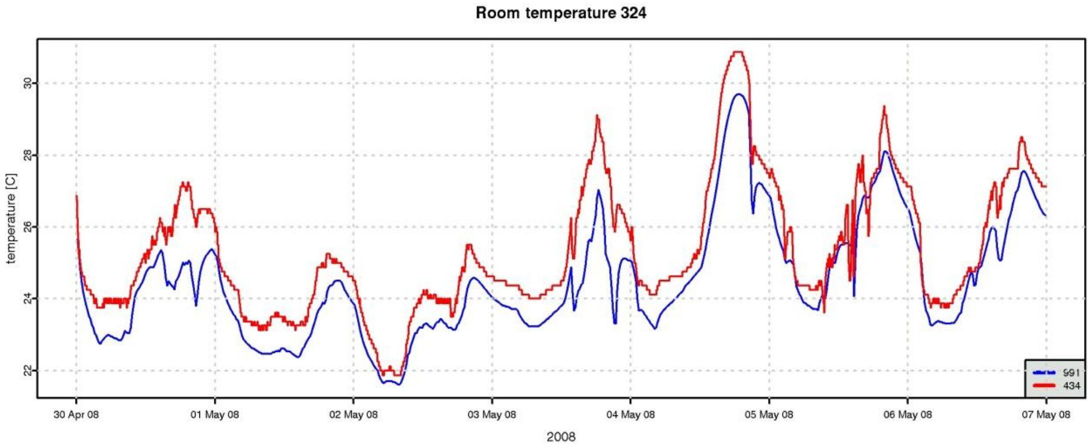
Room temperature 518

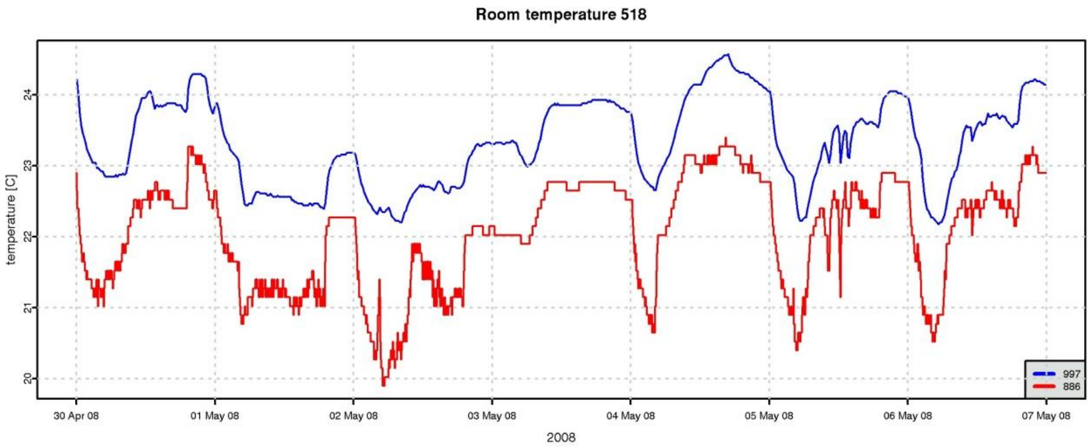


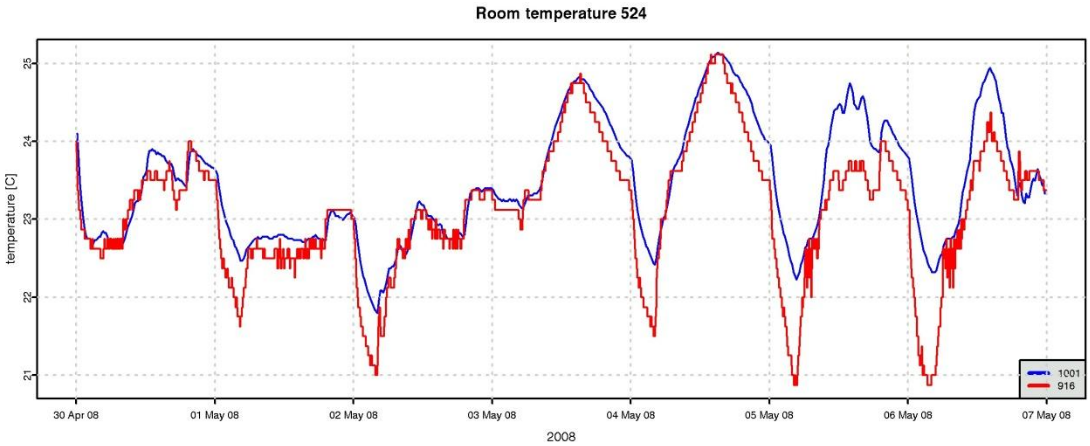
Room temperature 524



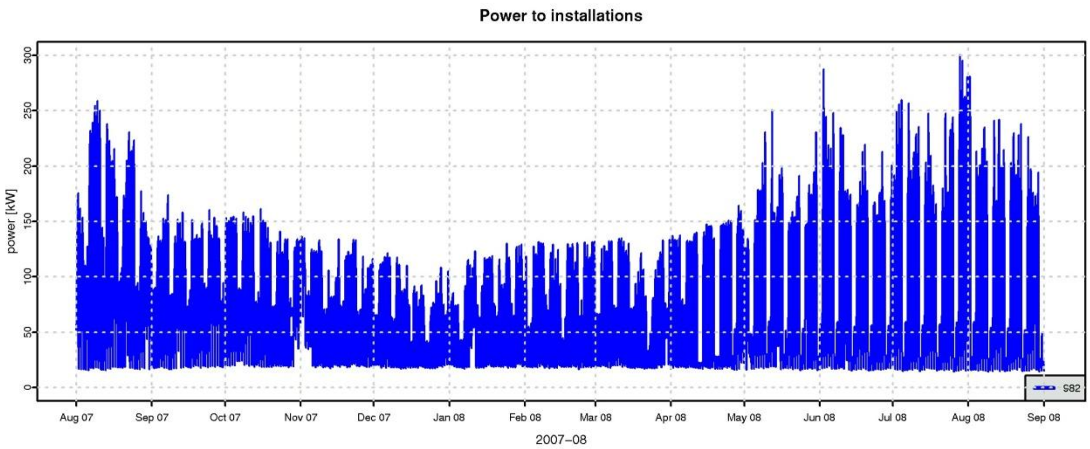

Room temperature 322
temperature [C]
999
424
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008

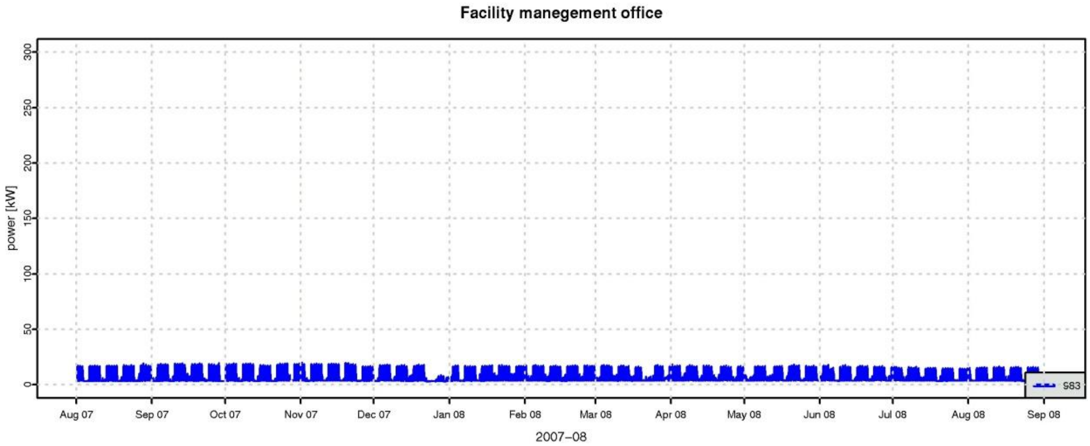

Room temperature 324
temperature [C]
991
434
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008

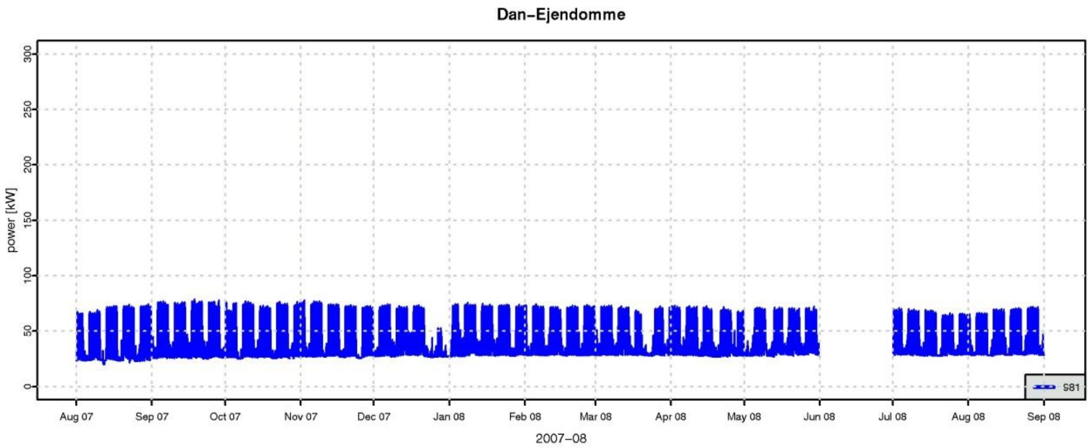

Room temperature 518
temperature [C]
997
886
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008

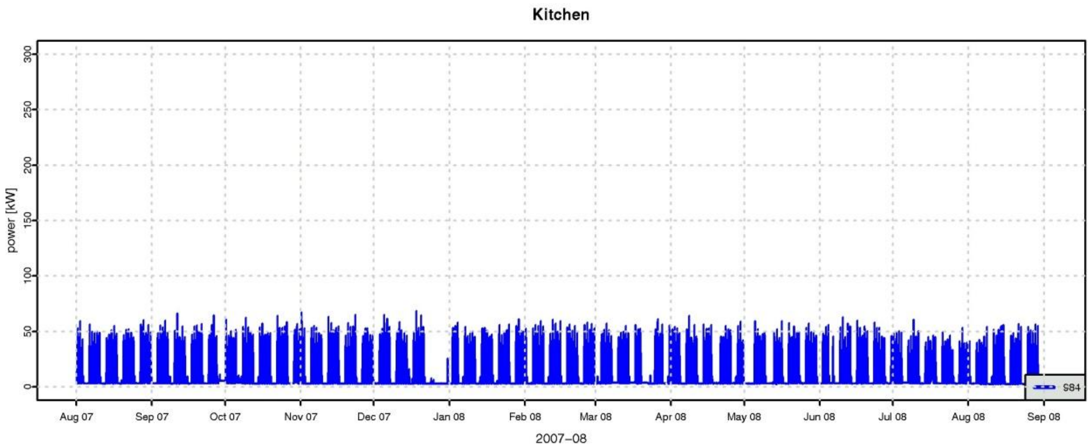

Room temperature 524
temperature [C]
1001
916
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008

Appendix 4 Electricity demand

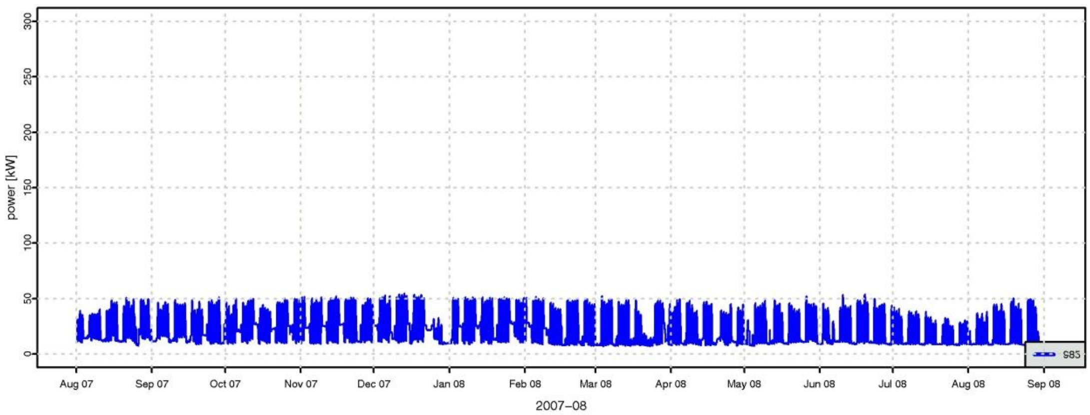




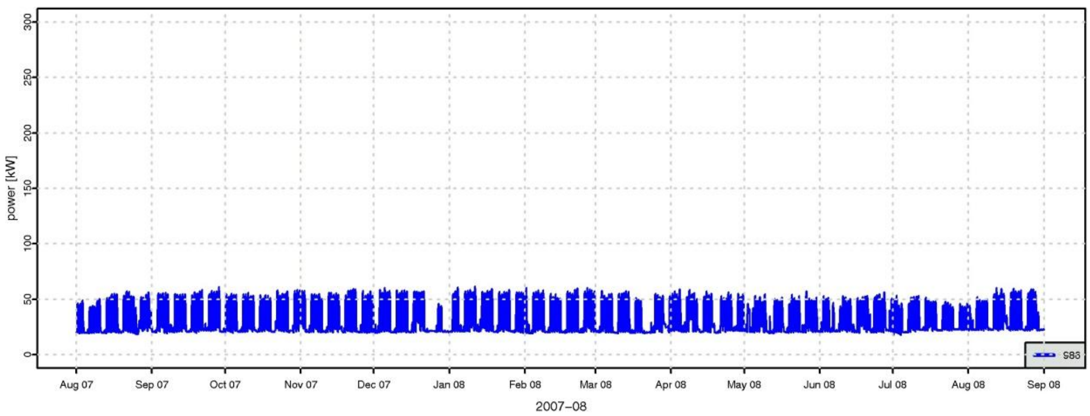




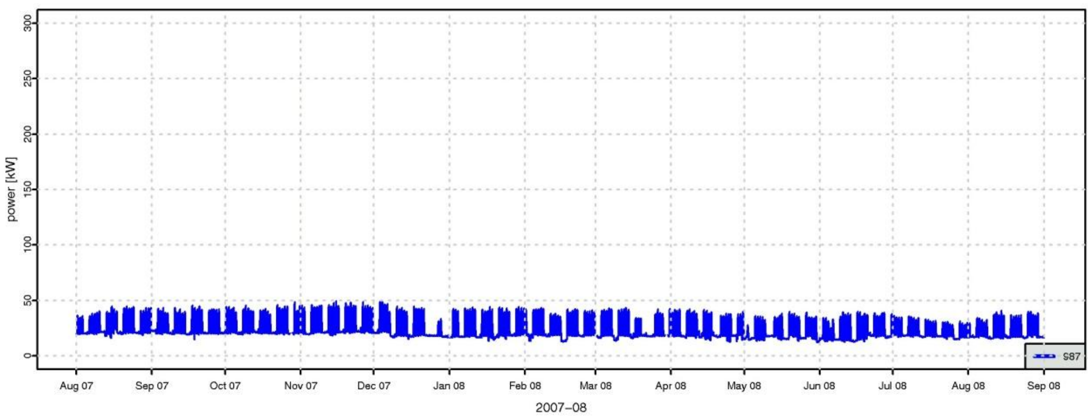
MicroSoft 1st and 4th floor



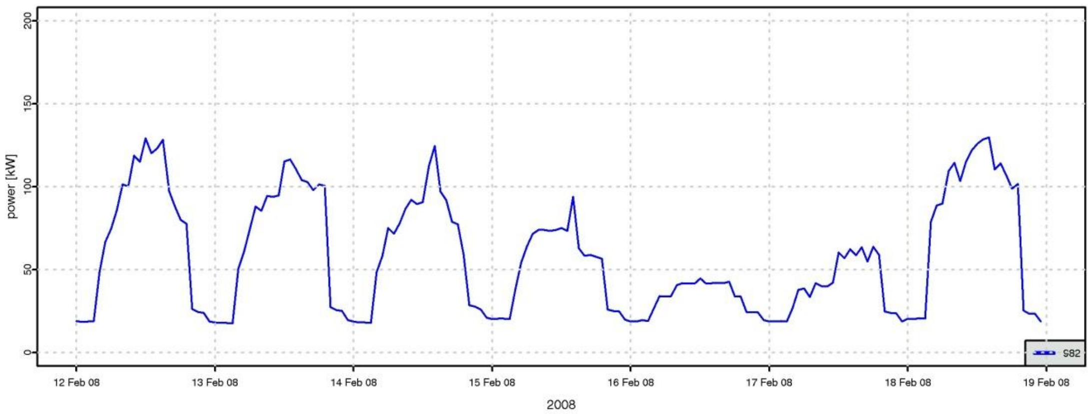
MicroSoft 2nd floor



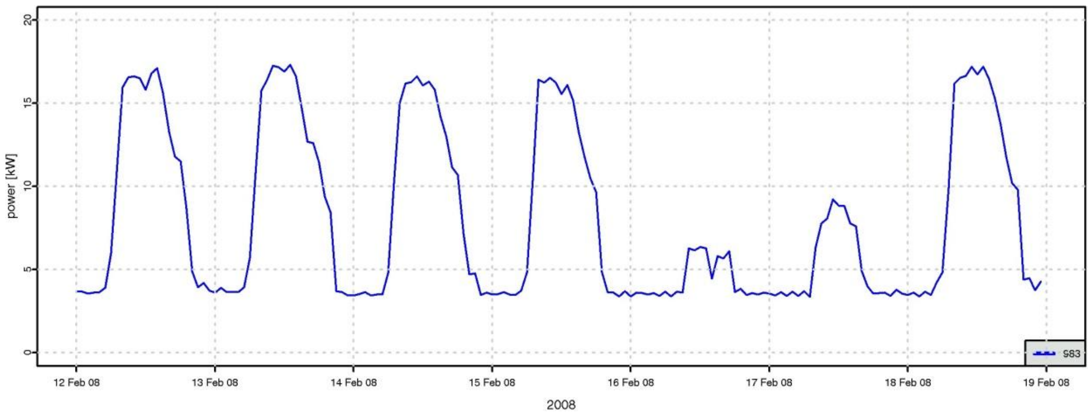
Regus



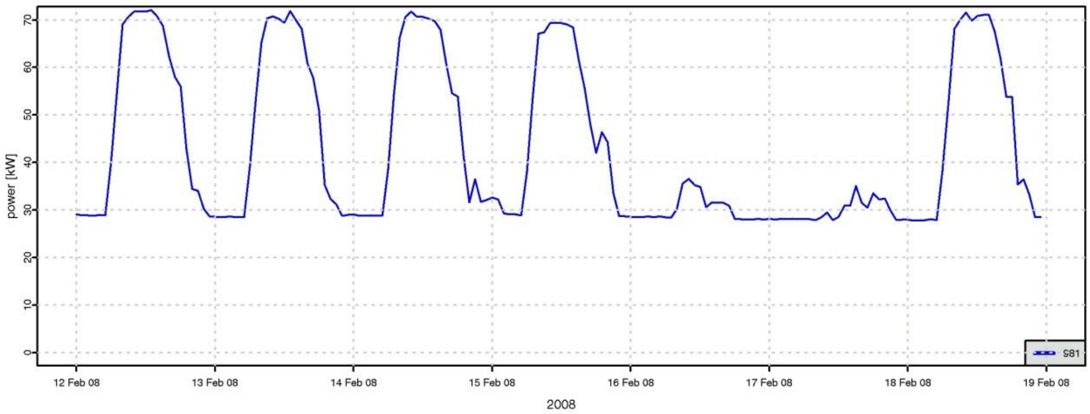
Power to installations



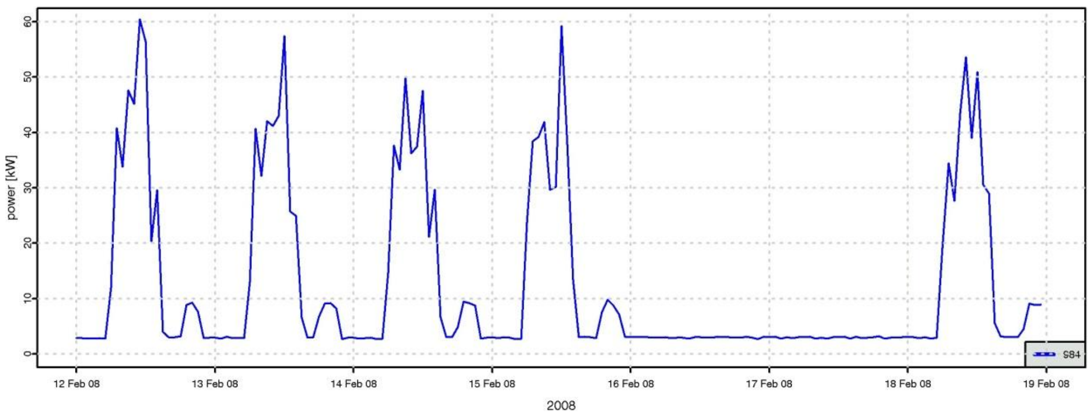
Facility manegement office

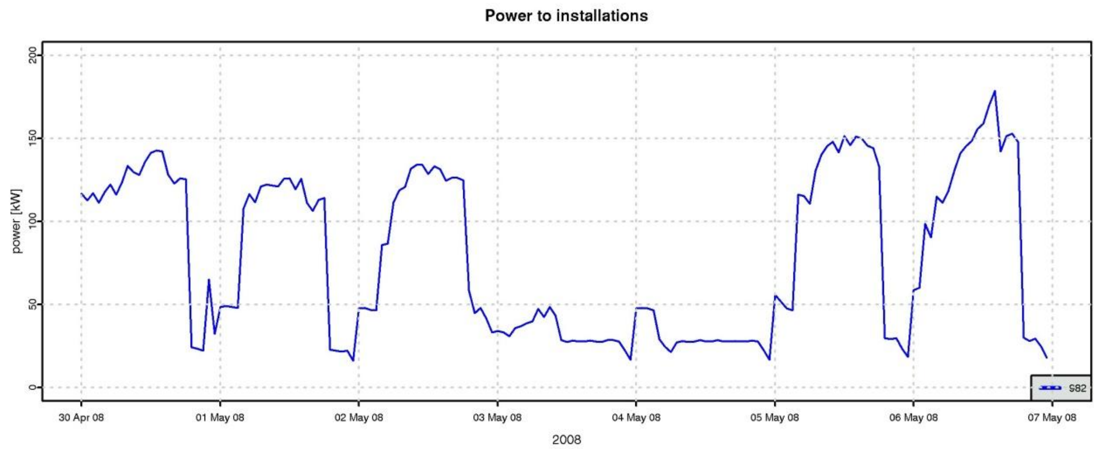


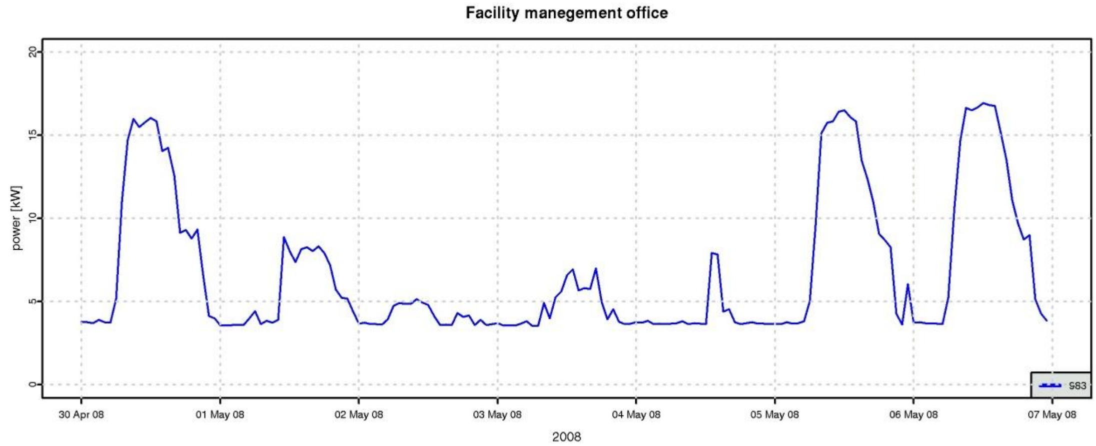
Dan−Ejendomme

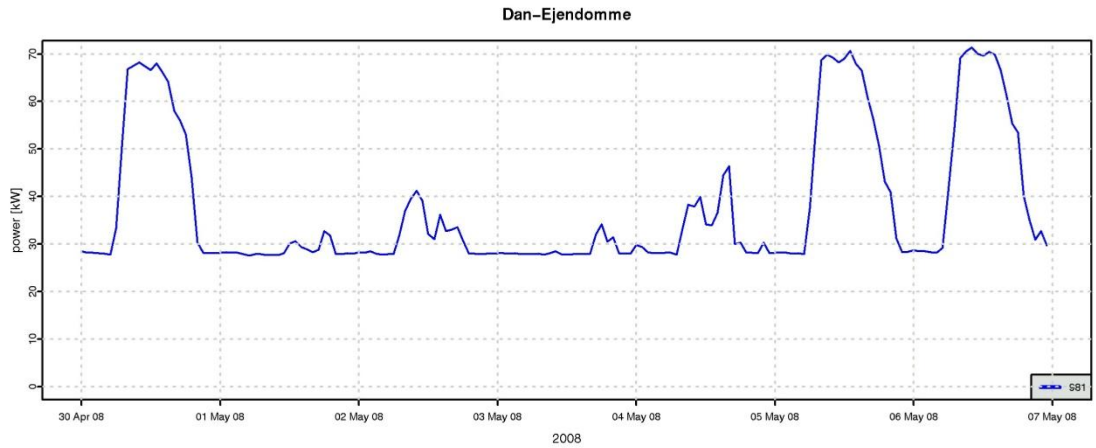


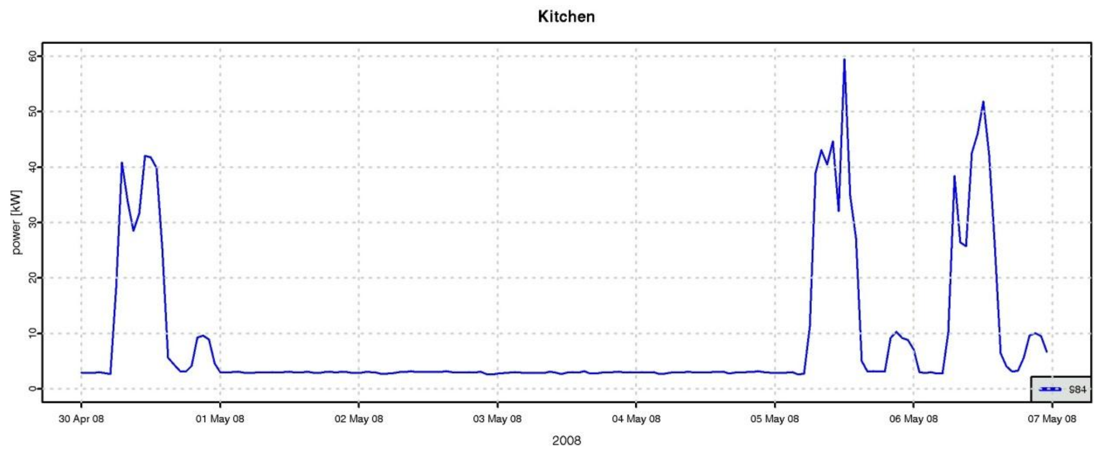
Kitchen

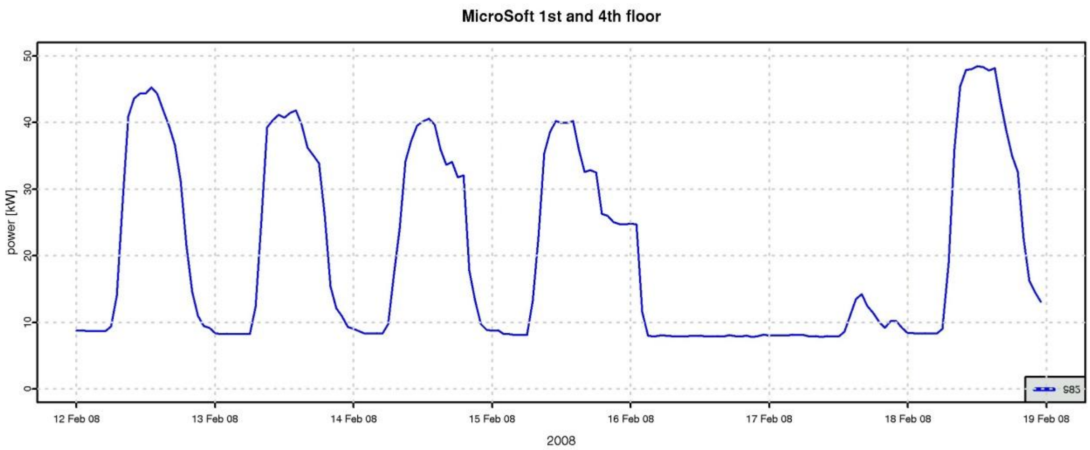


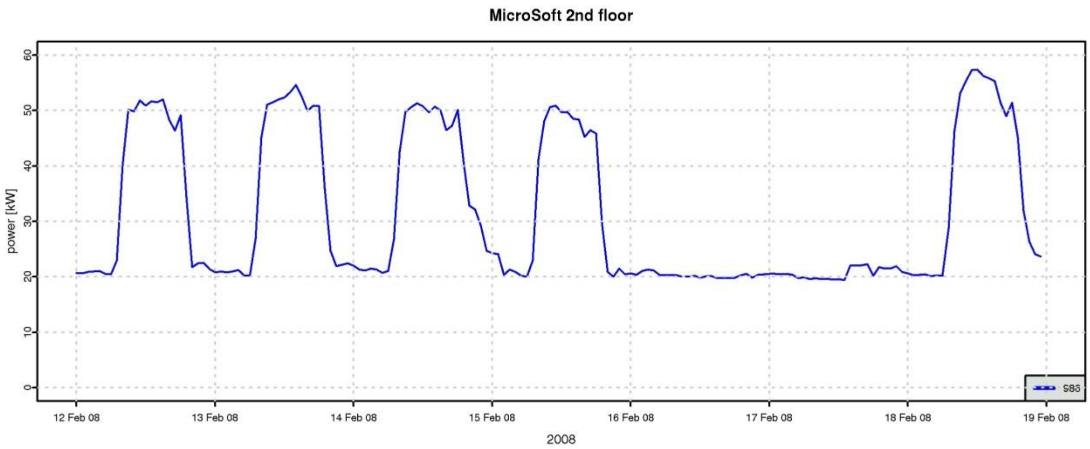

Power to installations
power [kW]
0
50
100
150
200
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008
S82

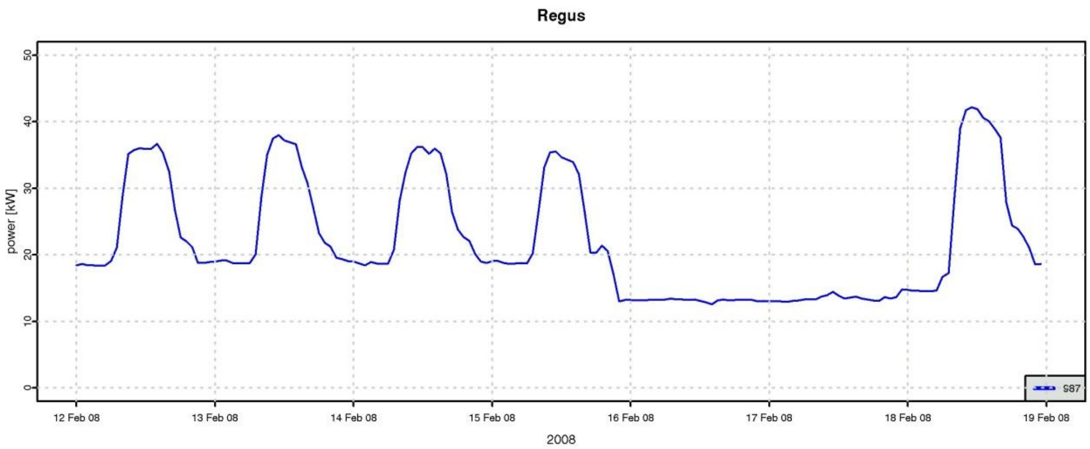

Facility manegement office
power [kW]
0
5
10
15
20
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008
S83

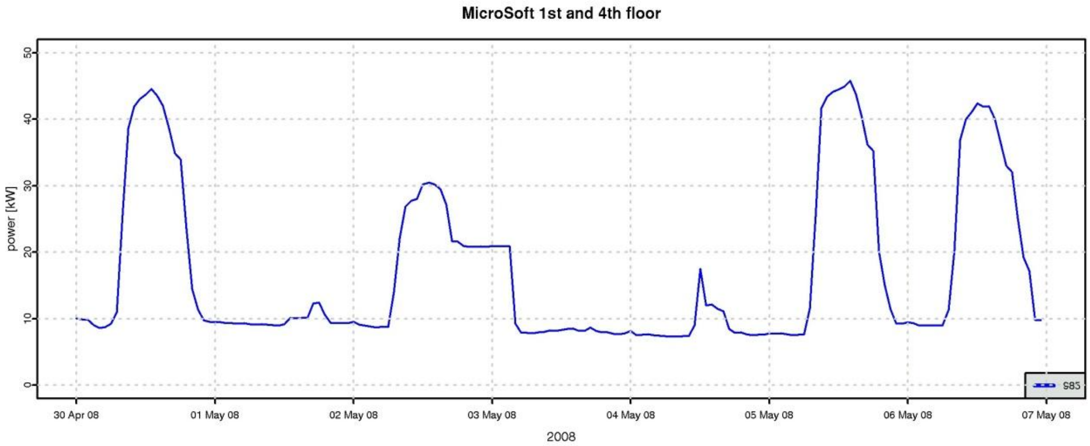

Dan−Ejendomme
power [kW]
0
10
20
30
40
50
60
70
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008
S81

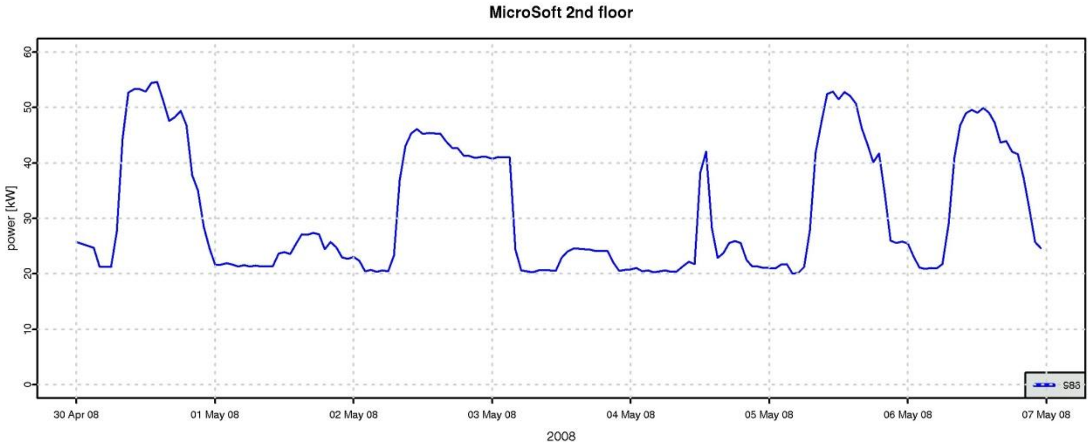

Kitchen
power [kW]
0
10
20
30
40
50
60
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008
S84

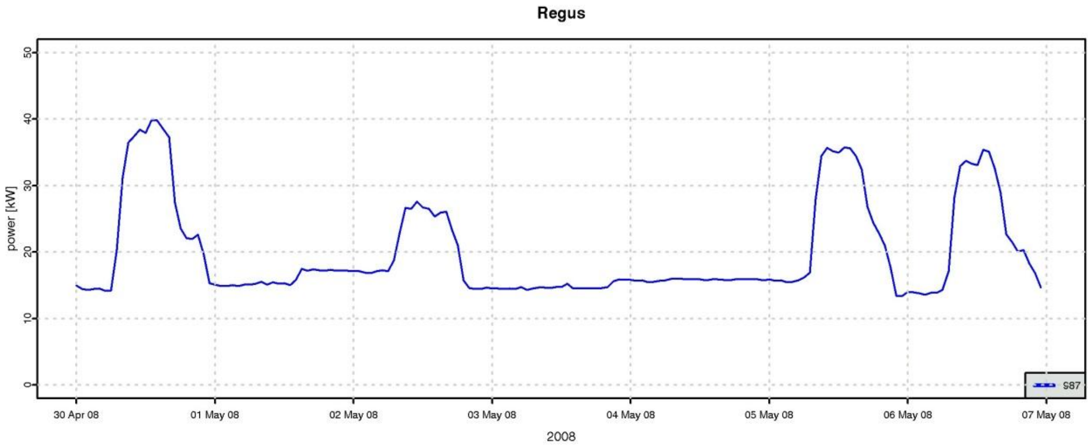

MicroSoft 1st and 4th floor
power [kW]
0
10
20
30
40
50
S85
12 Feb 08
13 Feb 08
14 Feb 08
15 Feb 08
16 Feb 08
17 Feb 08
18 Feb 08
19 Feb 08
2008


MicroSoft 2nd floor
power [kW]
0
10
20
30
40
50
60
S83
12 Feb 08
13 Feb 08
14 Feb 08
15 Feb 08
16 Feb 08
17 Feb 08
18 Feb 08
19 Feb 08
2008

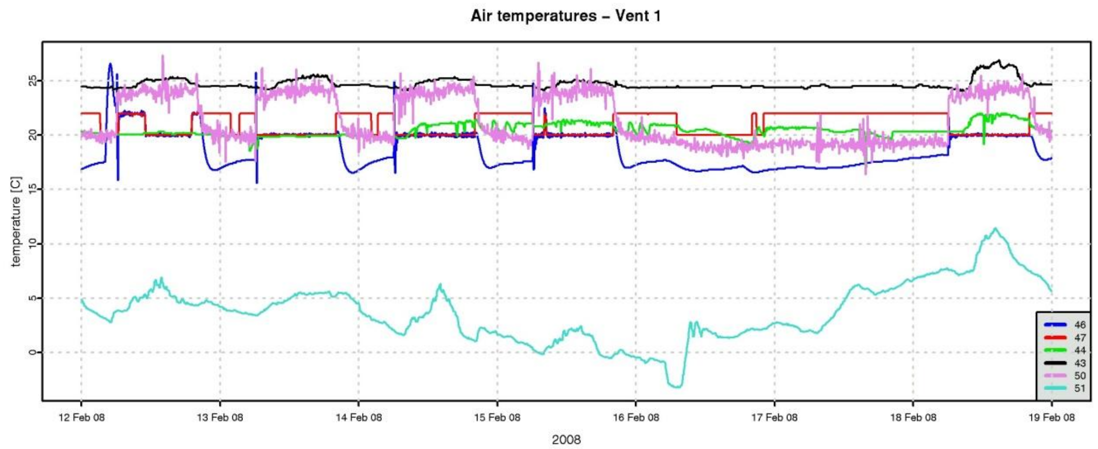

Regus
power [kW]
0
10
20
30
40
50
S87
12 Feb 08
13 Feb 08
14 Feb 08
15 Feb 08
16 Feb 08
17 Feb 08
18 Feb 08
19 Feb 08
2008

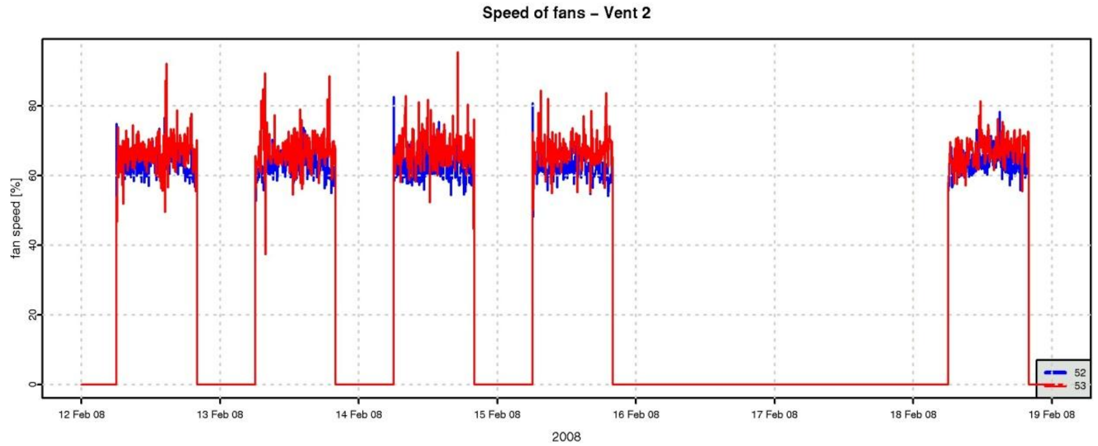

MicroSoft 1st and 4th floor
power [kW]
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008

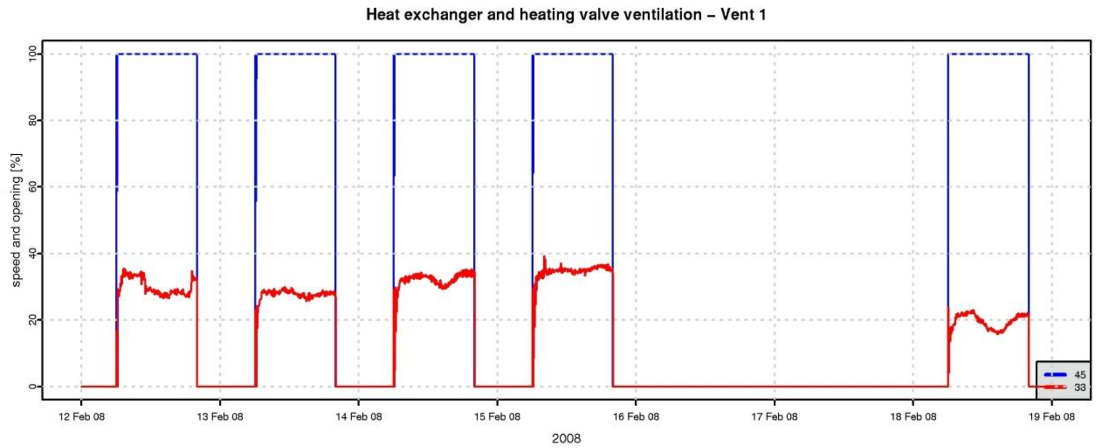

MicroSoft 2nd floor
power [kW]
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008

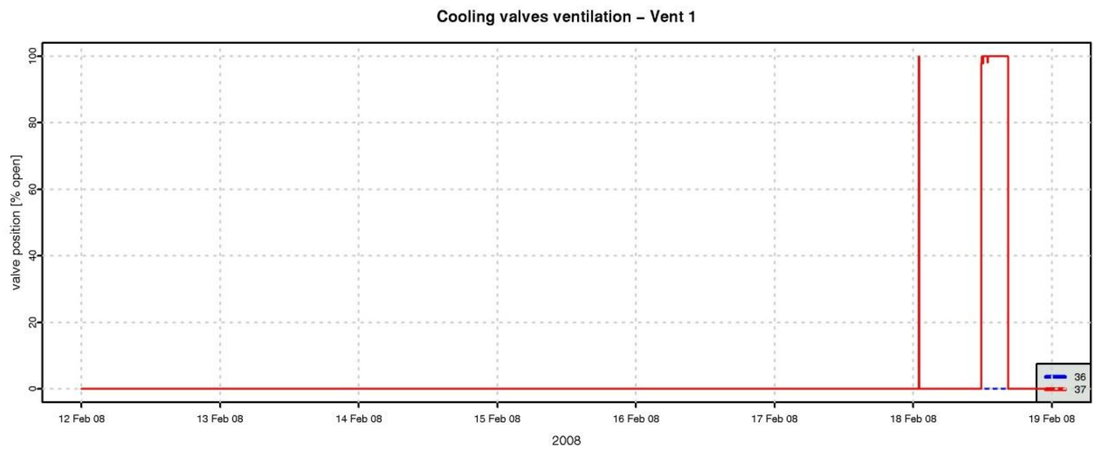

Regus
power [kW]
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008

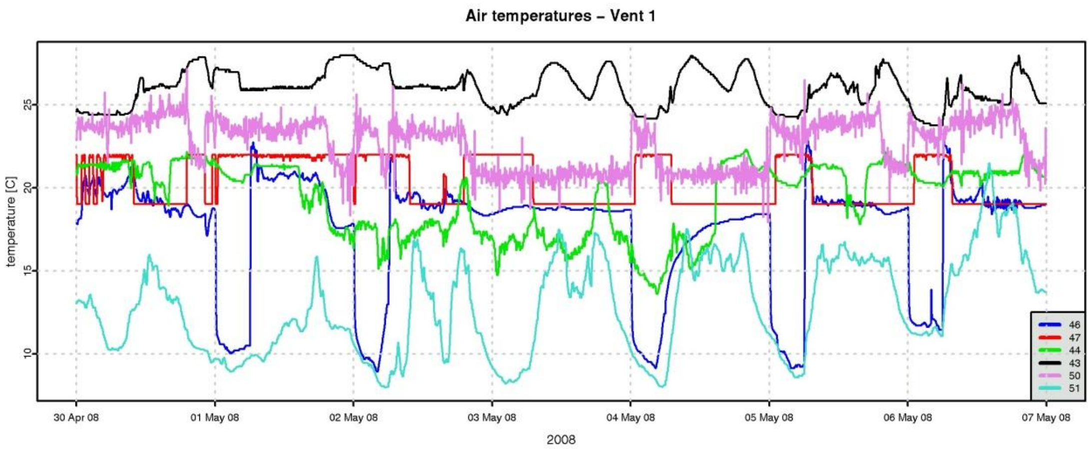
Appendix 5 Ventilation system 1-3

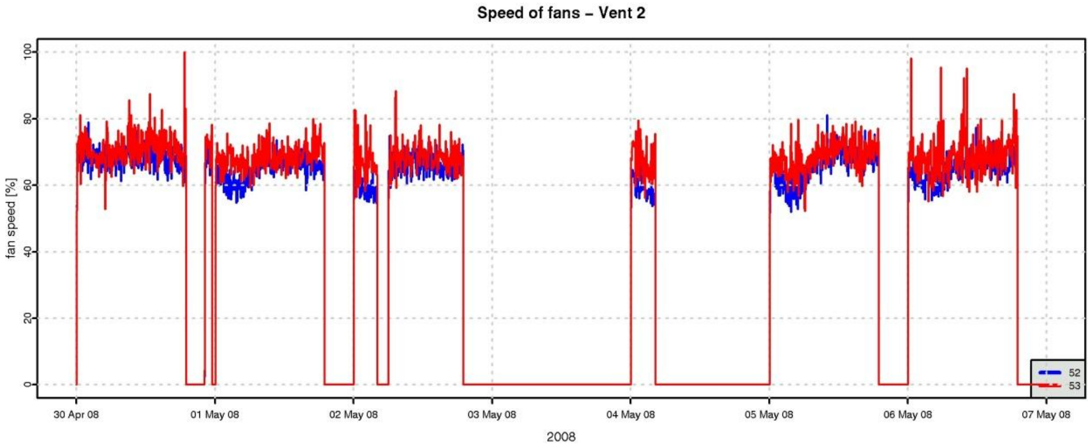


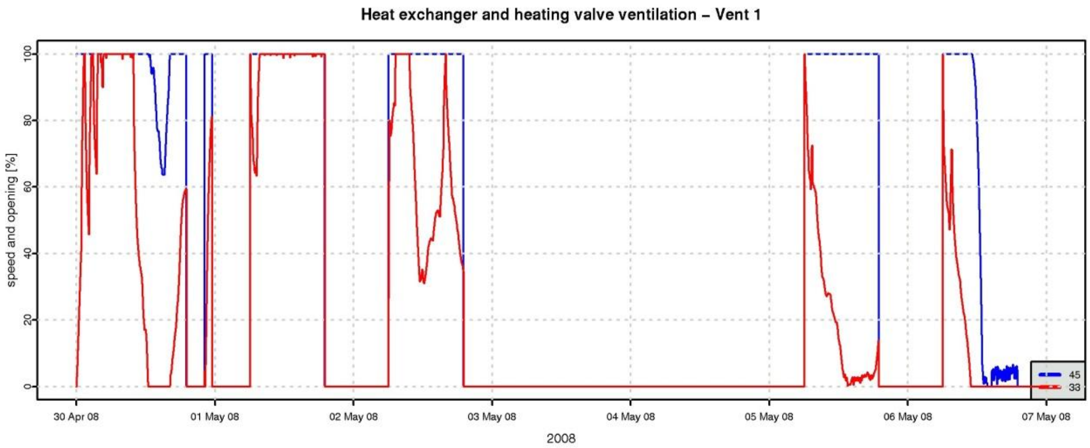


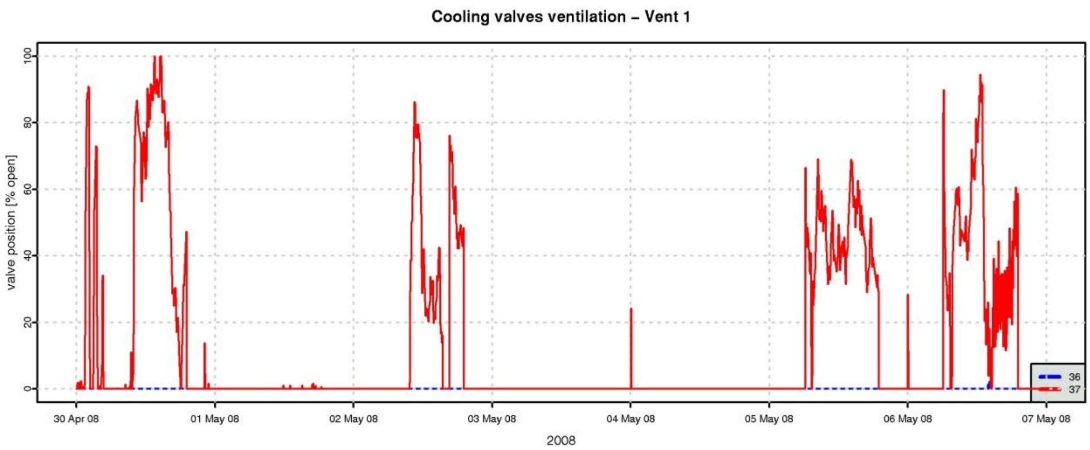




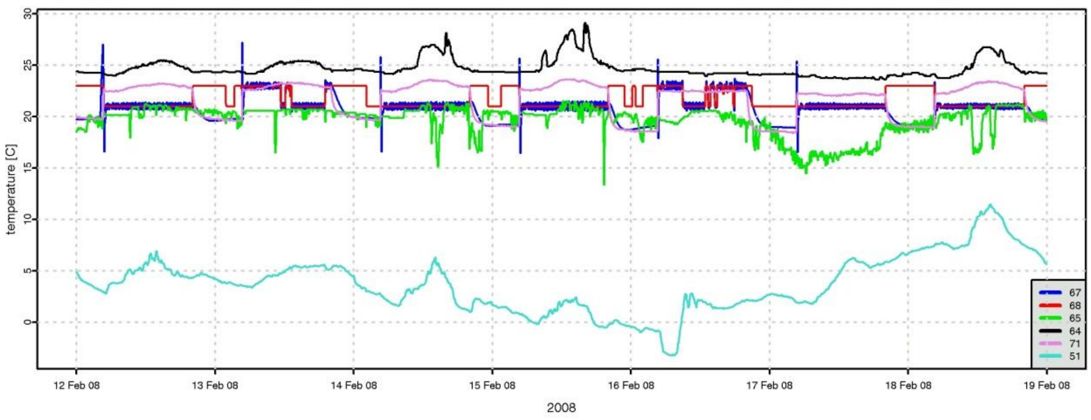

Air temperatures – Vent 1
temperature [C]
10
15
20
25
46
47
44
43
50
51
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008


Speed of fans – Vent 2
fan speed [%]
0
20
40
60
80
100
52
53
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008

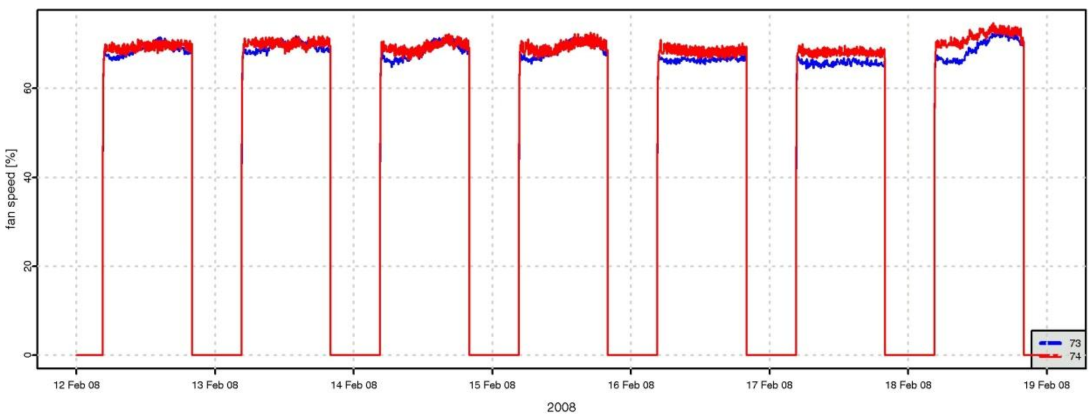

Heat exchanger and heating valve ventilation – Vent 1
speed and opening [%]
0
20
40
60
80
100
45
33
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008


Cooling valves ventilation – Vent 1
valve position [% open]
0
20
40
60
80
100
36
37
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008

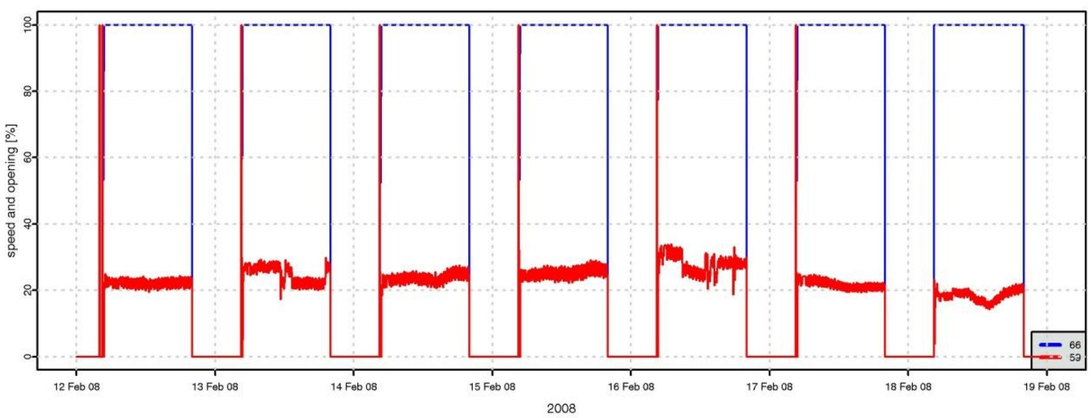
Air temperatures – Vent 2



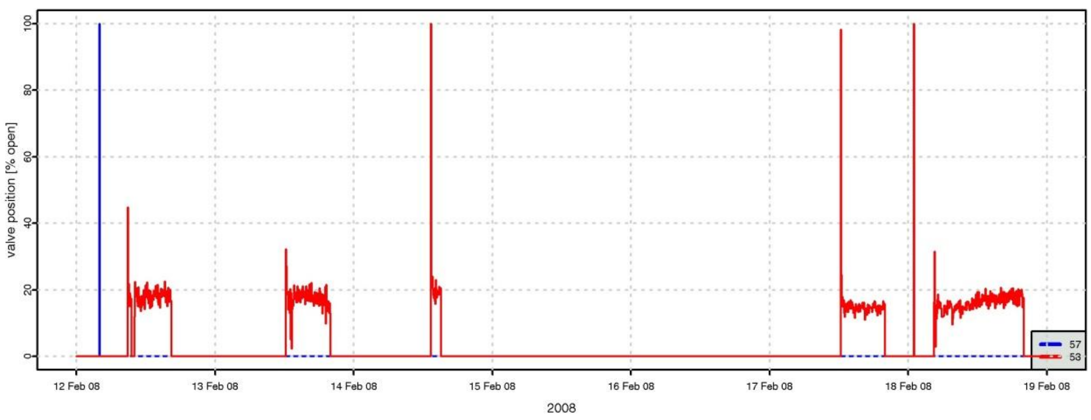
Speed of fans – Vent 2

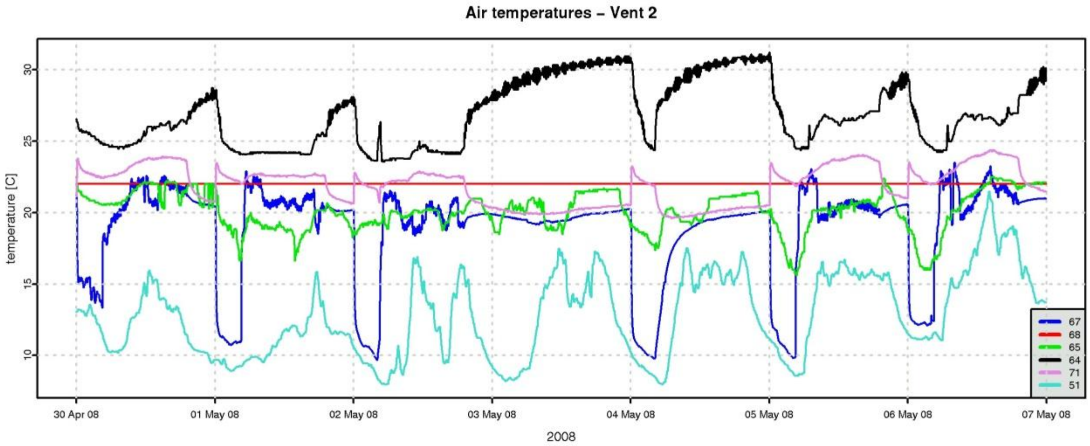


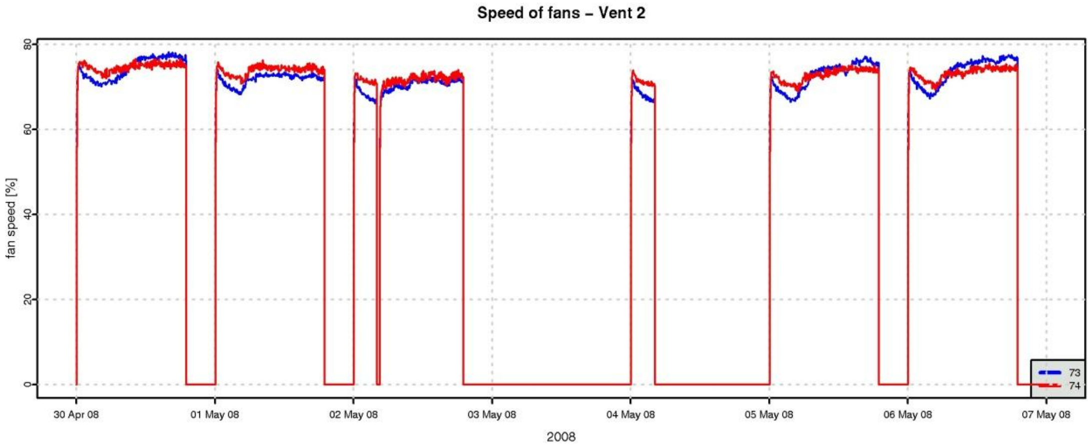
Heat exchanger and heating valve ventilation – Vent 2

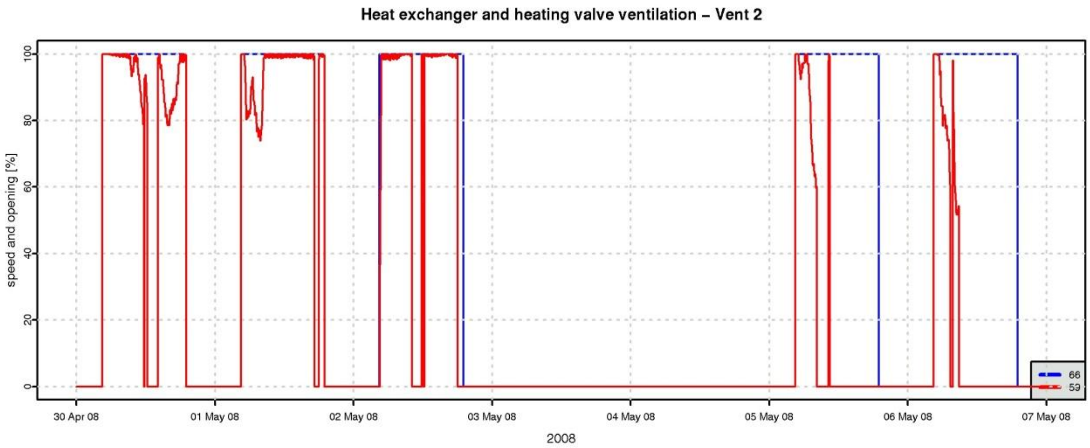


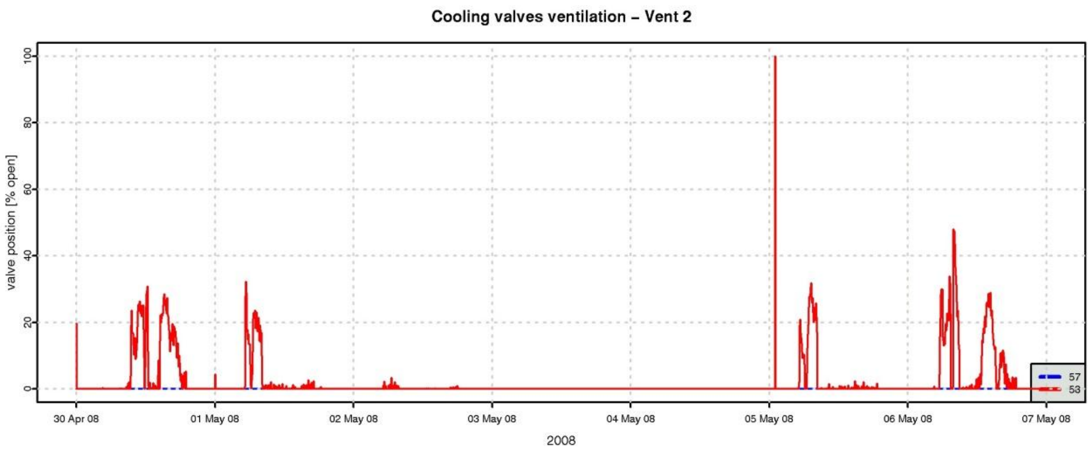
Cooling valves ventilation – Vent 2

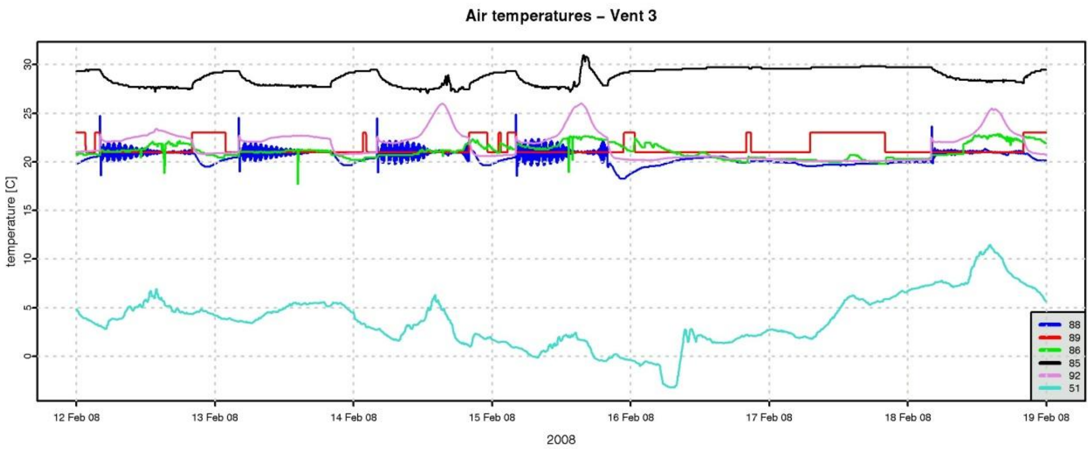


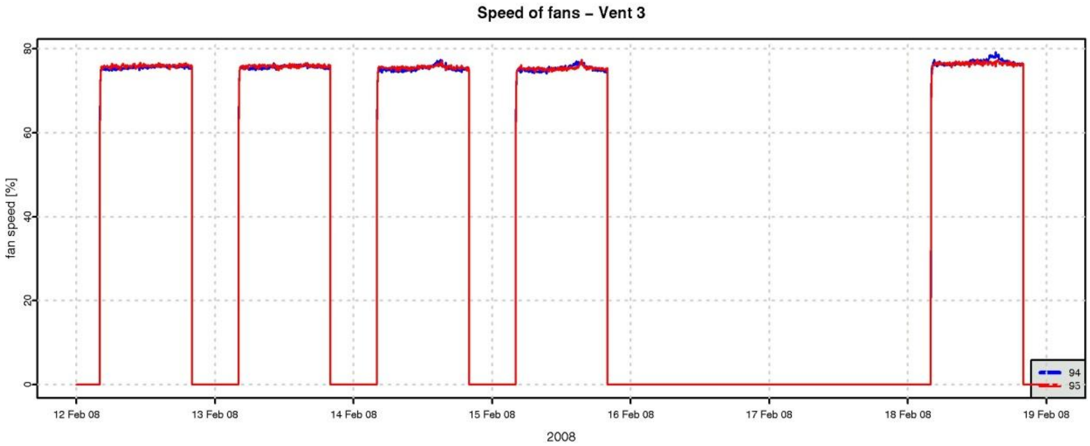

Air temperatures – Vent 2
temperature [C]
10
15
20
25
30
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008
67
68
65
64
71
51

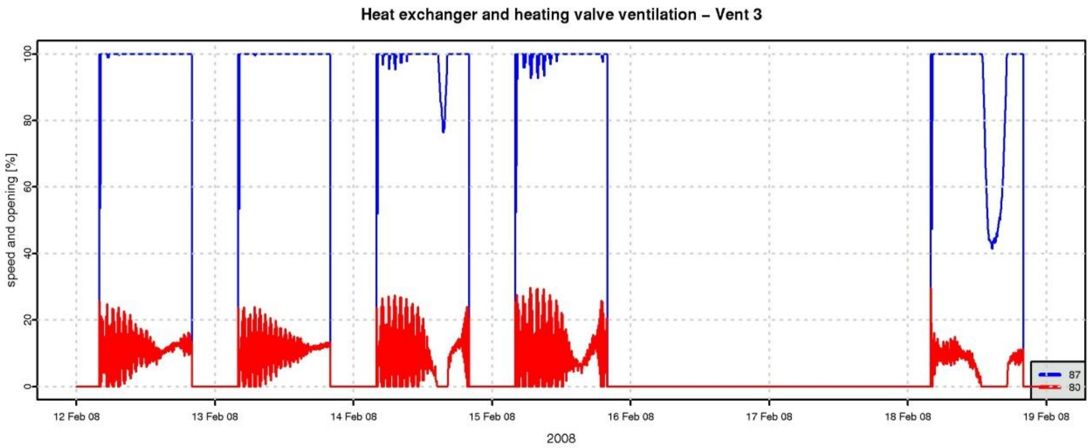

Speed of fans – Vent 2
fan speed [%]
0
20
40
60
80
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008
73
74

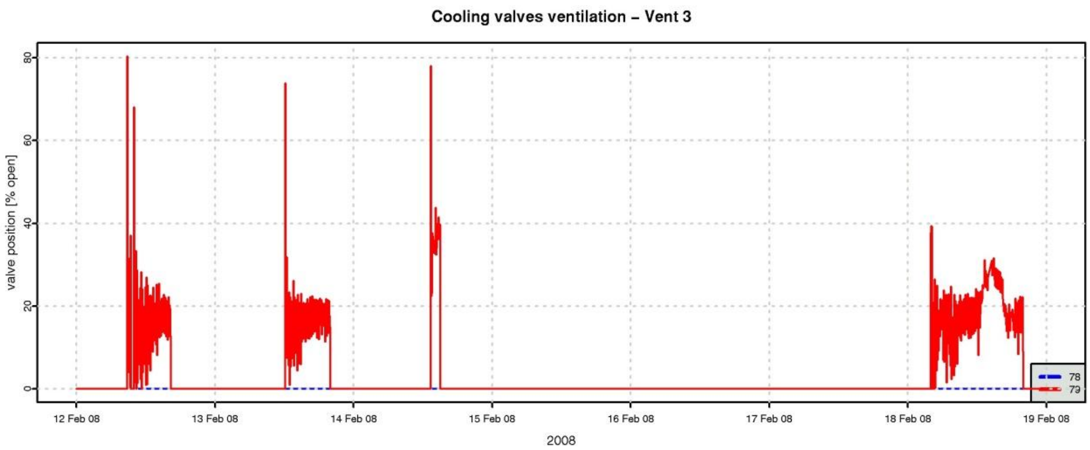

Heat exchanger and heating valve ventilation – Vent 2
speed and opening [%]
0
20
40
60
80
100
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008
66
59

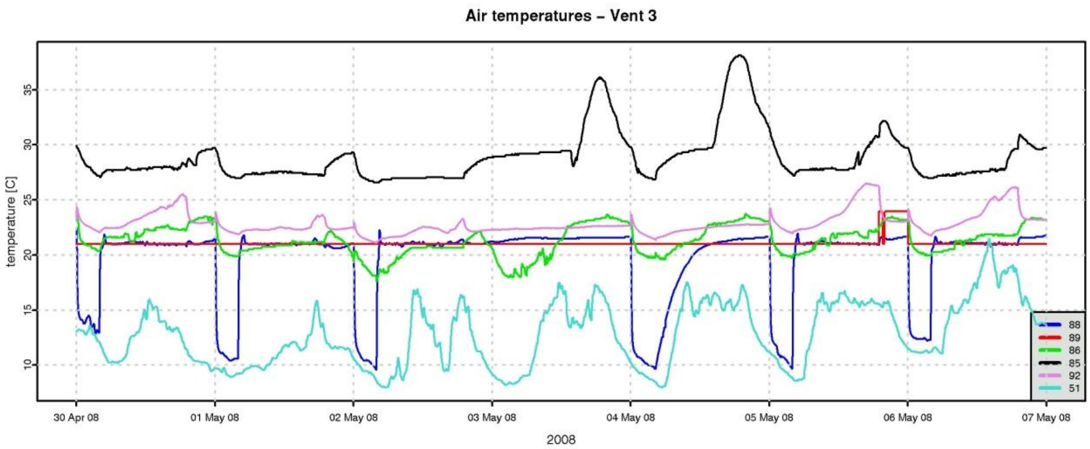

Cooling valves ventilation – Vent 2
valve position [% open]
0
20
40
60
80
100
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008
57
58

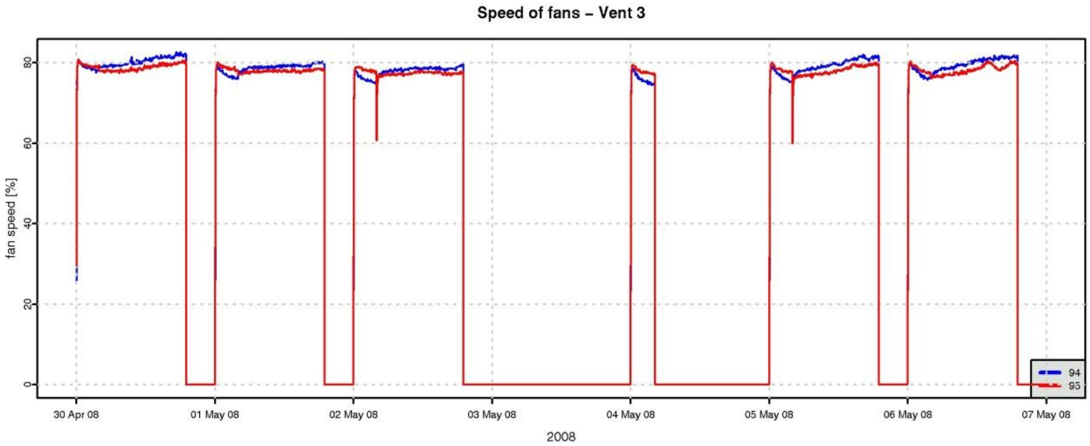

Air temperatures – Vent 3
temperature [C]
0
5
10
15
20
25
30
88
89
86
85
92
51
12 Feb 08
13 Feb 08
14 Feb 08
15 Feb 08
16 Feb 08
17 Feb 08
18 Feb 08
19 Feb 08
2008

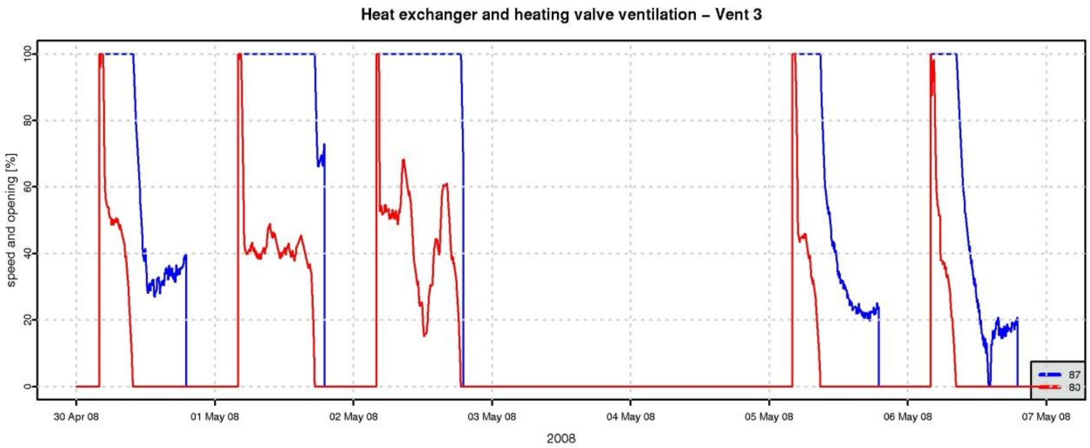

Speed of fans – Vent 3
fan speed [%]
0
20
40
60
80
94
93
12 Feb 08
13 Feb 08
14 Feb 08
15 Feb 08
16 Feb 08
17 Feb 08
18 Feb 08
19 Feb 08
2008

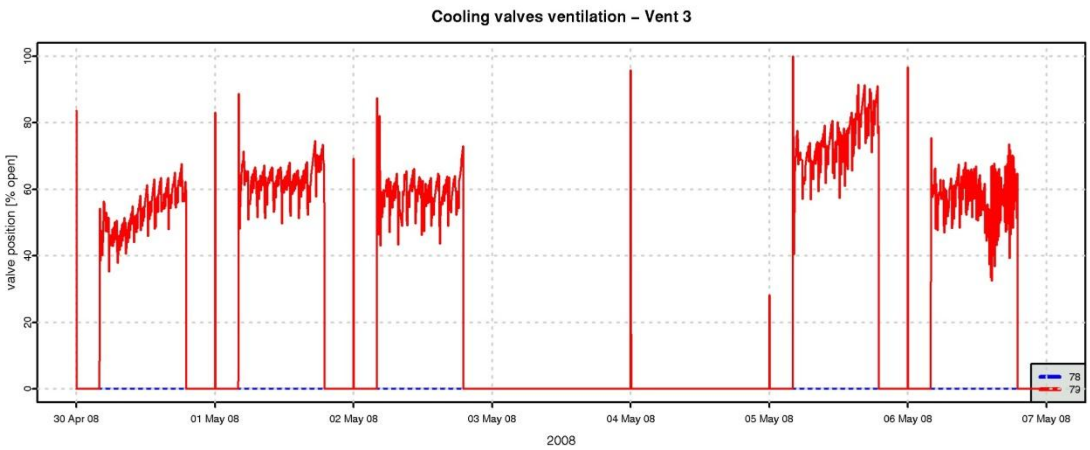

Heat exchanger and heating valve ventilation – Vent 3
speed and opening [%]
0
20
40
60
80
100
87
80
12 Feb 08
13 Feb 08
14 Feb 08
15 Feb 08
16 Feb 08
17 Feb 08
18 Feb 08
19 Feb 08
2008


Cooling valves ventilation – Vent 3
valve position [% open]
0
20
40
60
80
78
79
12 Feb 08
13 Feb 08
14 Feb 08
15 Feb 08
16 Feb 08
17 Feb 08
18 Feb 08
19 Feb 08
2008

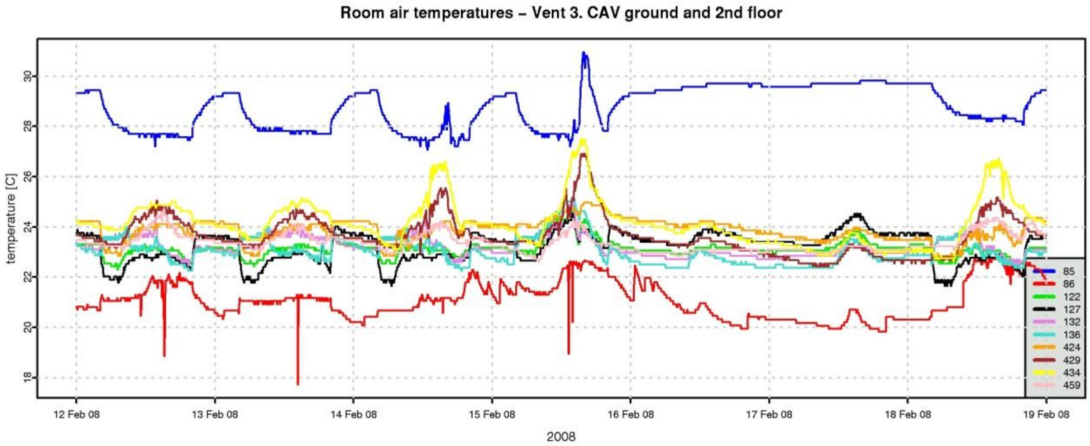

Air temperatures – Vent 3
temperature [C]
10
15
20
25
30
35
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008
88
89
86
85
92
51

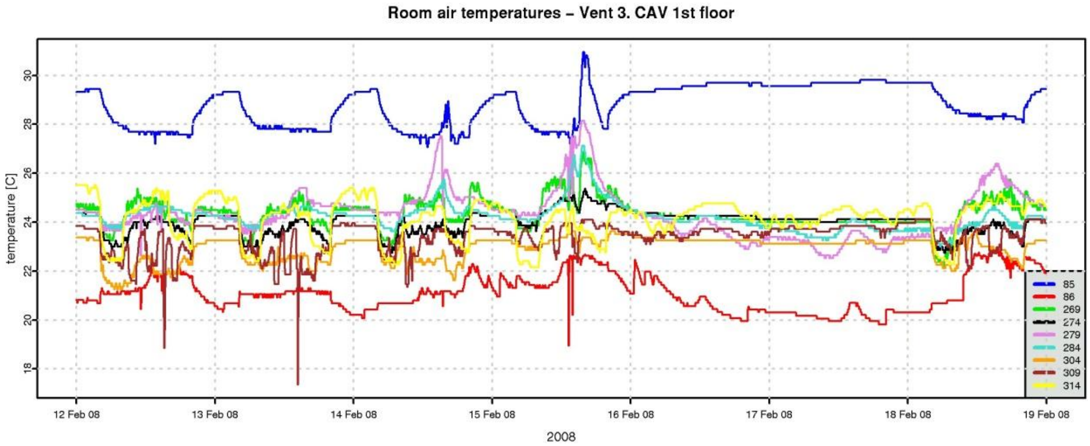

Speed of fans – Vent 3
fan speed [%]
0
20
40
60
80
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008
94
95

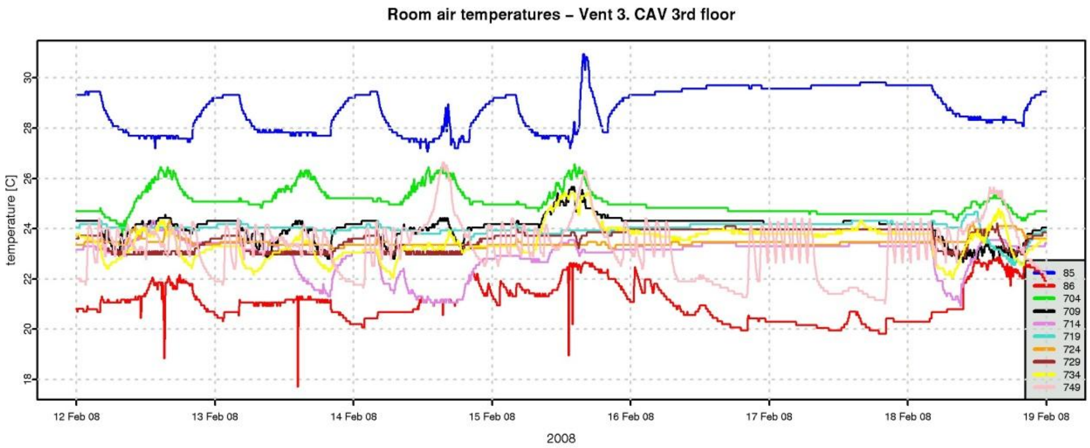

Heat exchanger and heating valve ventilation – Vent 3
speed and opening [%]
0
20
40
60
80
100
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008
87
80

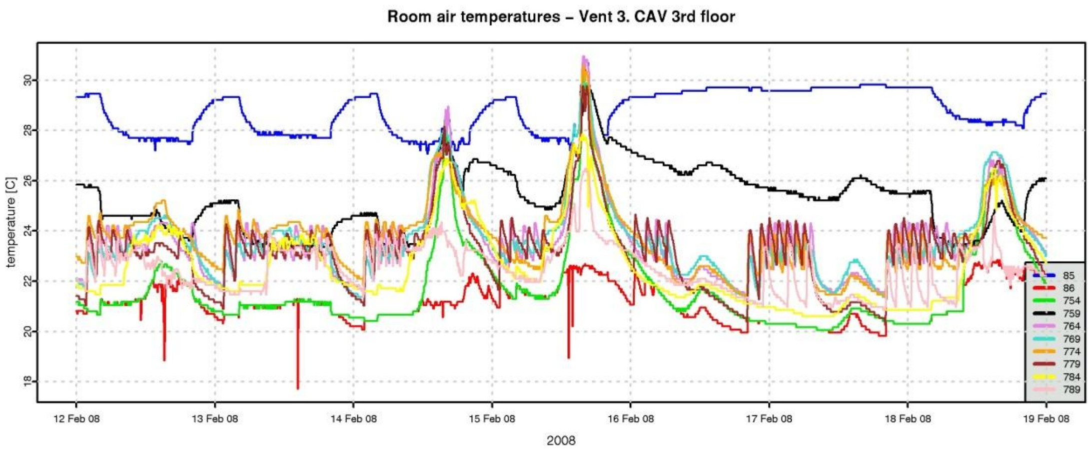

Cooling valves ventilation – Vent 3
valve position [% open]
0
20
40
60
80
100
30 Apr 08
01 May 08
02 May 08
03 May 08
04 May 08
05 May 08
06 May 08
07 May 08
2008
78
79

Appendix 6 Temperatures in the rooms served by ventilation system 3

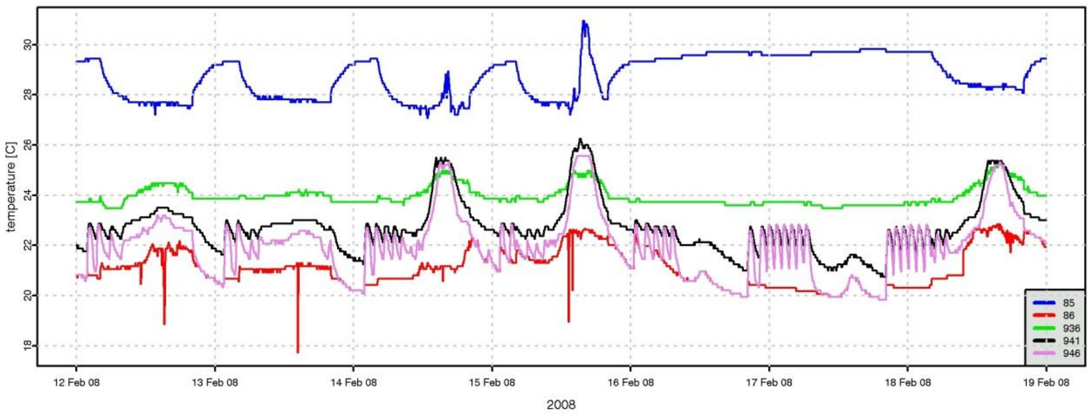




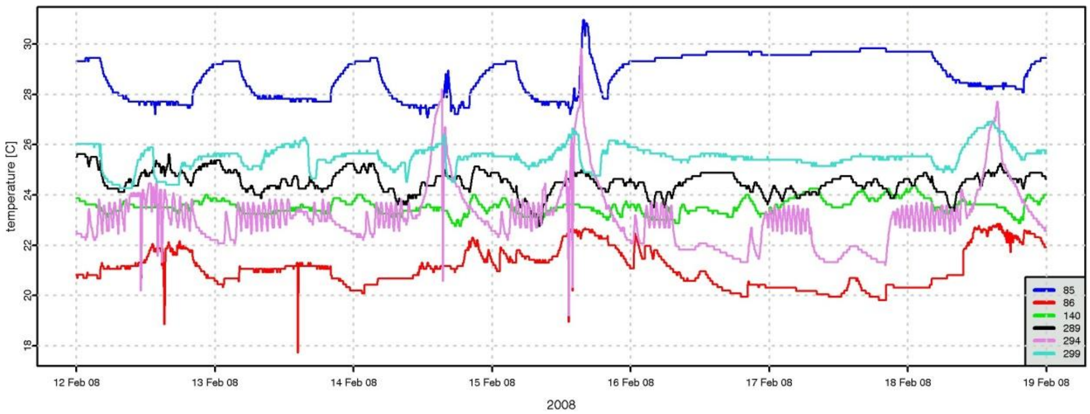




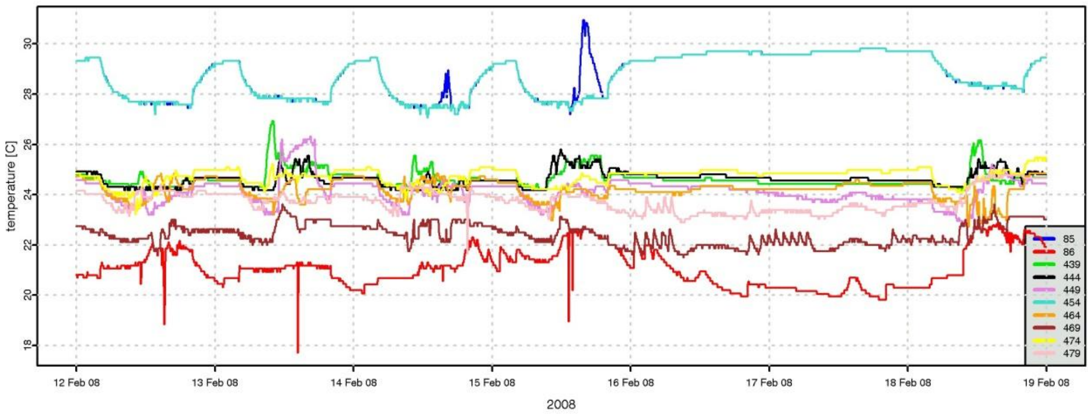
Room air temperatures – Vent 3. CAV 4th floor



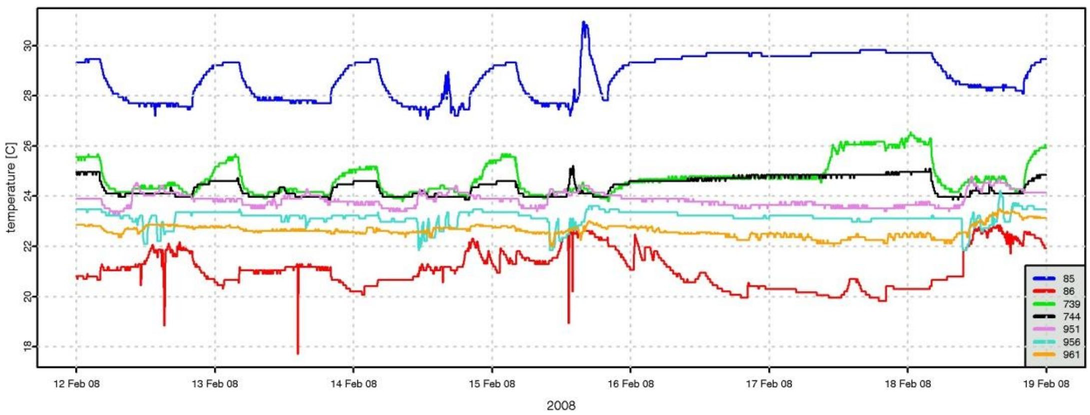
Room air temperatures – Vent 3. VAV ground and 1st floor



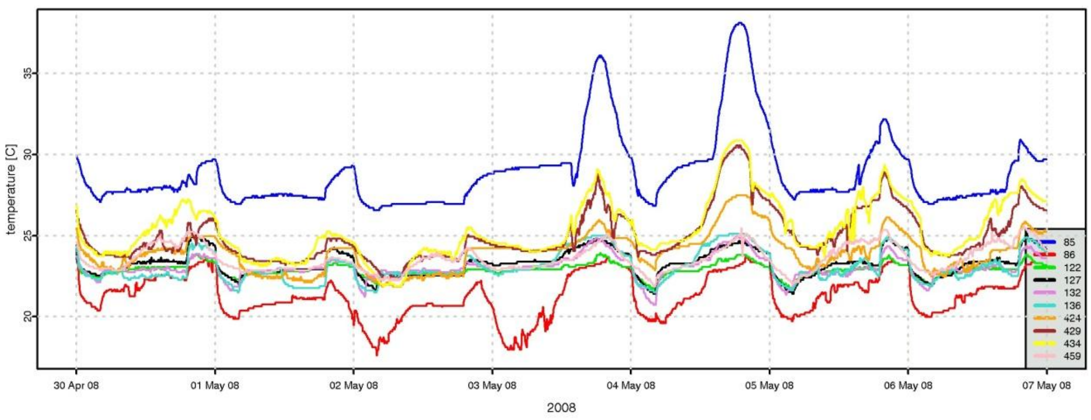
Room air temperatures – Vent 3. VAV 2nd floor



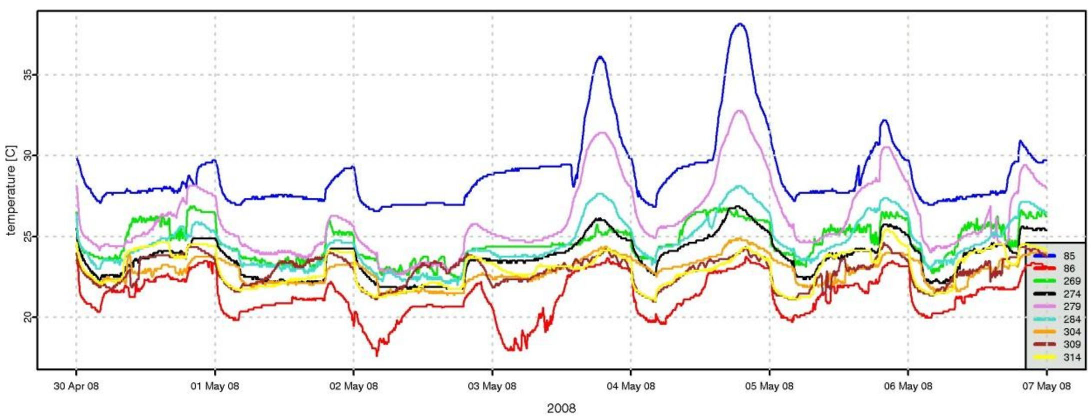
Room air temperatures – Vent 3. VAV 3rd and 4th floor



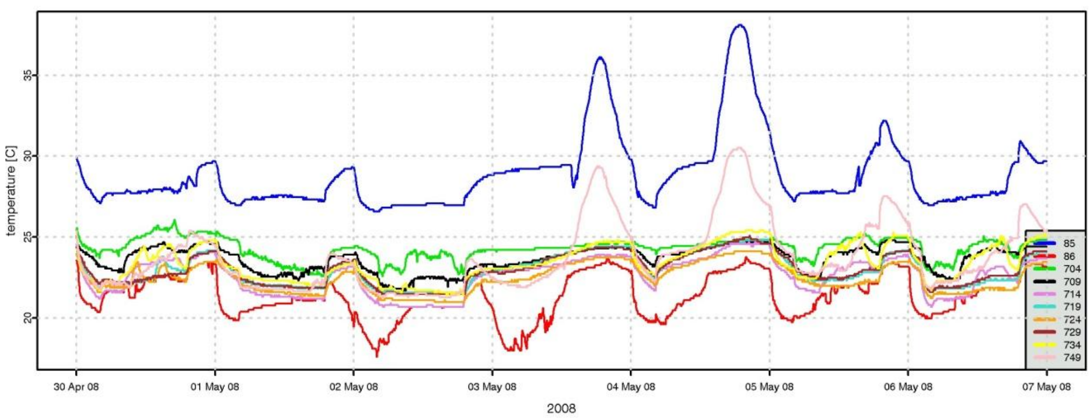
Room air temperatures – Vent 3. CAV ground and 2nd floor



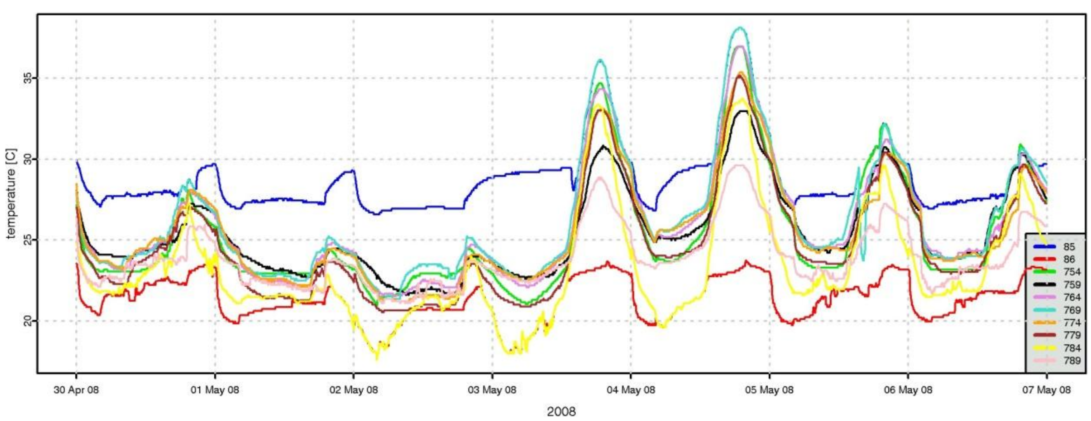
Room air temperatures – Vent 3. CAV 1st floor



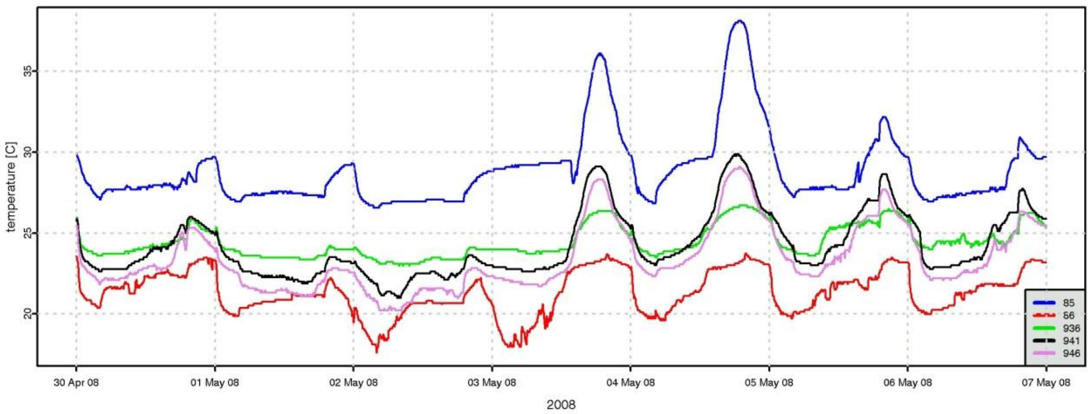
Room air temperatures – Vent 3. CAV 3rd floor



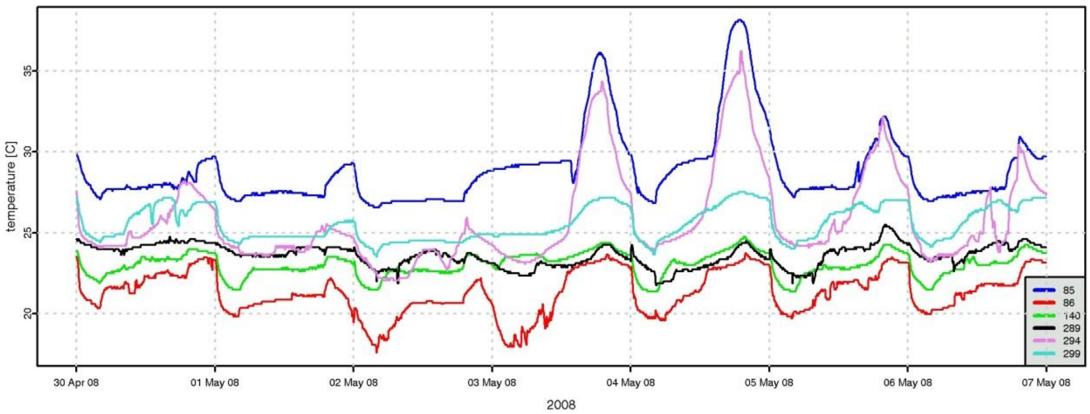
Room air temperatures – Vent 3. CAV 3rd floor



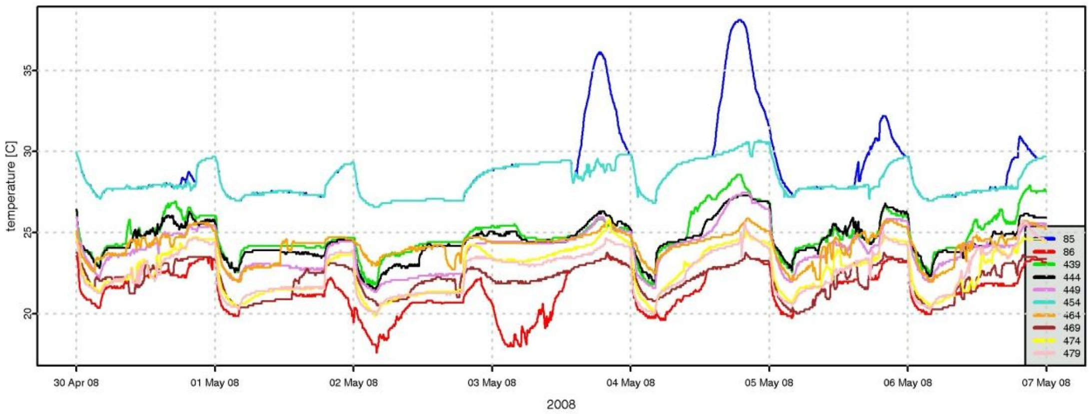
Room air temperatures – Vent 3. CAV 4th floor



Room air temperatures – Vent 3. VAV ground and 1st floor



Room air temperatures – Vent 3. VAV 2nd floor



Room air temperatures – Vent 3. VAV 3rd and 4th floor