Technical University of Denmark

Experiments and Data for Building Energy Performance Analysis

Financed by The Danish Electricity Saving Trust

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Financed by The Danish Electricity Saving Trust and Vind i Øresund - Interreg 4A

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Contents

Chapter 1

Introduction

This report documents experiments carried out in FlexHouse at Risø DTU during February and March of 2009. FlexHouse is a part of the experimental distributed energy system, Syslab. The building is controlled by one central server, where among other things it is possible to record temperature in each room, and implement control of the installed electrical heaters. Furthermore a climate station is located right next to the building. The objective of the experiments is to provide data for models of the thermal dynamics of the building. The designs of the experiments is such that the conditions are during the experiments, from conditions optimized for modelling toward more common living conditions, i.e. from high variation of the indoor temperature, toward thermostatic temperature control and human activities in the building. In total five experiments have been successfully carried out, two with PRBS signals controlling the heaters, and three with thermostatic control. The recorded data consists of:

- Temperature measurements in each room, both from sensors on the wall and from sensors hanging freely in the air
- Energy input to the house, which is mainly for heating
- State of each heater (on/off)
- Ambient temperature
- Global (solar) irradiance
- Wind speed and - direction
- State of motion, window and door sensors
- Relative humidity in each room
- Light intensity in each room
- CO2 level in each room

The data is recorded with a 10 seconds interval, except from the sensors hanging freely (they measured: temperature, humidity, light, and CO2), which is recorded with a 2.5 minutes interval. This report presents a description of the experiments, the format of the prepared data, and an exploratory analysis of the data.

1.1 Acknowledgement

The experiments would not have been possible without the people at VEA Risø DTU [1], especially Henrik Bindner and Oliver Gehrke, which apart from providing the experimental facilities, has helped all the way through the work. A very special thanks to Anders Thaulow for much help, among other things for moving many kilos of tiles. Finally the work would not have been possible without the support from the Danish Electricity Saving Trust (Elsparefonden[2]), especially Poul Erik Pedersen, and the comments and advices from the project group, especially Søren Østergaard Jensen, Bjarne W. Olesen, Carsten Rode, Henrik Aalborg Nielsen, and Kim B. Wittchen.

1.2 Outline

The Chapter 2 is a description of the building and the hardware used during the experiments. Then the design of the experiments is described in Chapter 3, and in the format of the data from the experiments is outlined in Chapter 4. The results of an exploratory analysis is given in Chapter 5, and finally the conclusions are stated in Chapter 6.

[1] http://www.risoe.dk/About_risoe/research_departments/VEA.aspx

[2] http://www.savingtrust.dk

Chapter 2

FlexHouse and Hardware

This chapter contains a description of FlexHouse and the hardware used during the experiments. For further details, see the description found in [2]. First the building is shortly characterized, together with the server system and the installed hardware. Then follows a description of the Hobo measuring equipment and finally the climate station.

2.1 The building

The outer walls of the building is constructed of wood on the outside and plasterboards on the inside, with a layer of insulation wool between, see the photos in Figure A.1 to A.11 (from page 34). The building rests on piles, leaving an air gab between the ground and the building. The roof is flat and covered with roofing felt. The interior dimensions of the building are noted on the floor plan in Figure B.1 (page 42). More information can be found in [2].

2.1.1 Windows

The building has thermo windows, which is located as shown by blue in Figure 2.3. The window in Room 3 can be seen in the photo in Figure A.9. The type of windows in the building can be seen from the photos in Figure 2.1(a) to 2.1(c). The dimensions of the windows are given in Figure B.3 Appendix B.

2.2 Installed hardware in FlexHouse

The hardware permanently installed in the building, is a system designed for running experiments with control of all installed electrical devices. The system is build around a central server, which communicate with all the devices through a network protocol.

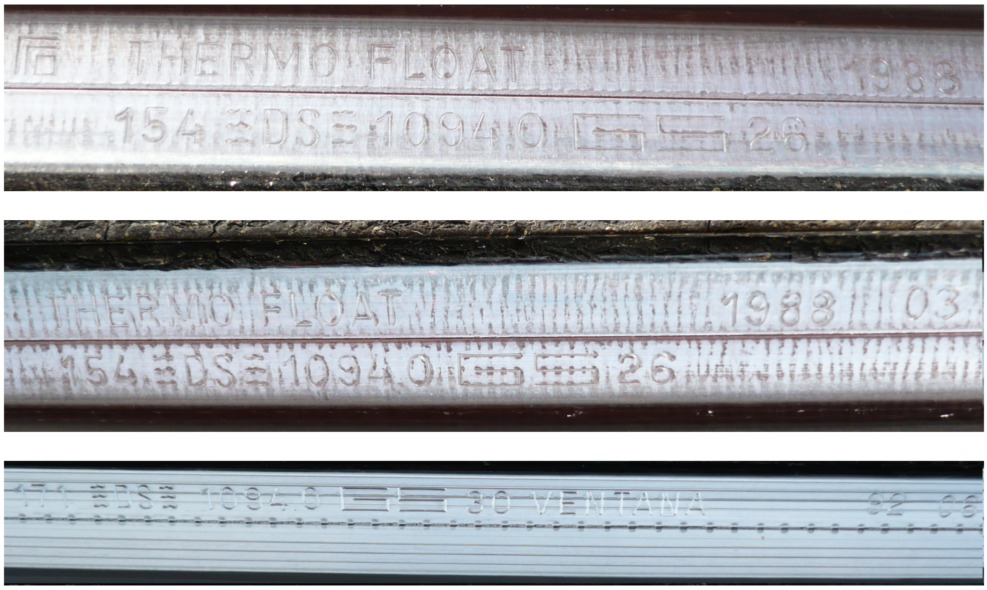

Figure 2.1: The window types in the building.

2.2.1 Server system

A central server does all the control carried out in FlexHouse. The temperature sensors send wireless to the server, which then records the values to a logfile. The server can send control messages to actuators which then switch the heaters on or off. Furthermore the state of doors, windows, and motion sensors in the house, is recorded by the server. The light is also controlled by the server. The operation of this system, was by far the most complicating factor in the implementation of the experiments. See [2] for a more detailed description.

2.2.2 Heaters

The electrical heaters in the building are manufactured by Nobö, see the photos in Figure 2.2(a) to 2.2(c). The following models are installed in the house, their positions in the house are indicated with red in Figure 2.3:

1. 750 W 230 V: `402 Type 743, GTC 07-406`
2. 1000 W 230 V: `402 Type 748, GTC 10-407`
3. 1000 W 230 V: `IP24, C4F102-067ZSCEM1NX`
4. 1250 W 230 V: `402 Type 745, GTC 12-409`

All the heaters have thermostatic control up to 30 °C. During the experiments this is set to maximum, and the power supply to the heaters is controlled by the central system.

(a) Heater in Room 5. (b) Heater in Room 5. (c) Heater in Room 0.

Figure 2.2: The electrical heaters. The type of heater shown in (a) and (b) is in Room 1-to-7, and the type of heater shown in (c) is in Room 0.

Room	Type	Nominal Effect	Setting	Working Effect
0	3	1000 W	on	1000 W
0	3	1000 W	on	1000 W
1	4	1250 W	1	625 W
2	4	750 W	off or 2	0 or 750 W
3	1	750 W	1	375 W
4	1	750 W	1	375 W
5	1	750 W	2	750 W
6	2	1000 W	1	500 W
7	4	1250 W	off	0 W
7	1	750 W	2	750 W

Table 2.1: Heater settings. Heater in Room 2 was switched off during PRBS1 and PRBS2.

Thus when the thermostatic control in a heater measures around 30 °C, it is switched off automatically, which means that this should be prevented during the experiments.

Heater types 1,2 and 4 have two settings: “1” and “2”. The heaters were set as stated in Table 2.1. This means that the effective heat input into the building, when heaters are all turned on, should be around 5.3 kW when the heater in Room 2 is swithed off or 6.1 kW when it is switched on. The energy consumption of other electrical devices in the building, such as the central server etc., is not known, but can be estimated as showed in Section 5.1. It is estimated to be around 61 W. The actual energy consumption of each heater can be found with a simple model, based on the total energy consumption and the heater control signals. An analysis is found in Section 5.1.

2.2.3 Wall mounted temperature sensors

A temperature sensor is mounted on the wall in each room. The sensors are of the type EnOcean SR-04. They have a resolution of $0.15\,K$ and an accuracy of $0.5\,K$. The temperature cannot be read directly from the sensors, but the measured temperature is transmitted

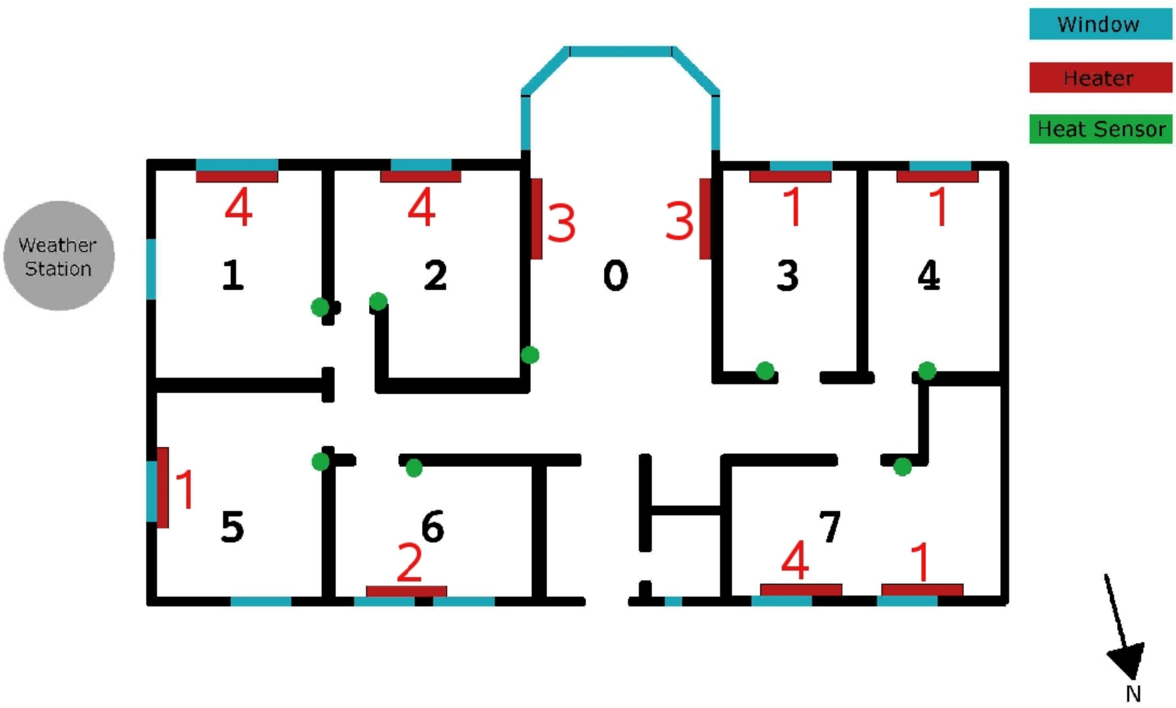

Figure 2.3: The different types of heaters installed. The numbers referer to the different types desctribed in the list at page 7.

Room	0	1	2	3	4	5	6	7
Height (m)	1.9	2.3	1.9	1.9	1.9	1.9	2.1	1.9

Table 2.2: The height of the temperature sensors.

regularly to the server. According to the datasheet for the sensors[1] temperature measurements should be transmitted every 100'th second if changes are more than 0.8 K. The location of the temperature sensors are indicated the green dots in Figure 2.3. The height of each sensor is found listed in Table 2.2.

2.2.4 Motion, window, and door sensors

Several types of sensors are installed in the building. In each room a motion sensor is located, which sends its state to the central server. Similarly every door and window in FlexHouse has a sensor attached. The plan in Figure 2.4 gives an overview of all the sensors. In Appendix C a list of all the installed sensors in the building can be found.

[1] `http://www.thermokon.de/downloads/service/44/Produktblatt_SR04_10.pdf`

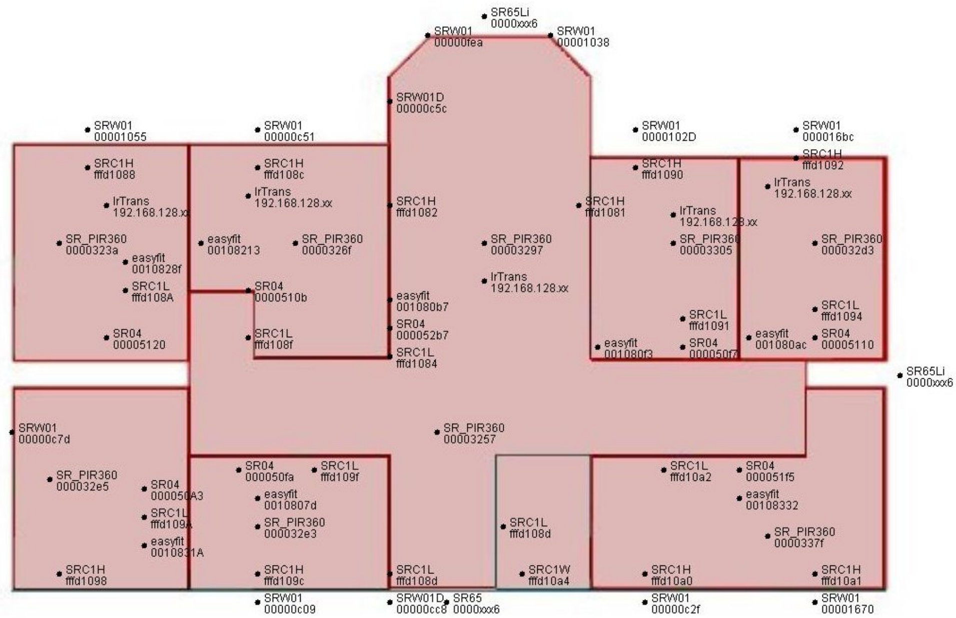

Figure 2.4: Plan over all the sensors installed in the building.

2.3 Hobo and CO2 sensors

In each room a Hobo U12-012 Temp/RH/Light/Ext sensor was hanged from the ceiling. The photo in Figure 2.5(a) show the Hobo in Room 0. Each Hobo were mounted on a piece of wood next to a Vaisala GMM20WCB CO2 sensor, calibrated to 0...5000ppm. Four of the sets can be seen in Figure 2.5(b). The Hobos measured the following with a time interval of 2.5 minutes:

- Temperature 10K Thermistor (°C). Accuracy: ± 0.35°C from 0° to 50°C
- Relative Humidity. Accuracy: ±2.5% from 10% to 90% RH (typical), to a maximum of ±3.5%
- Light Intensity (Lux)
- External channel: CO2 level (ppm). Accuracy: ± 2 mV ± 2.5% of absolute reading

The output from the CO2 sensor is 0 to 20 mA. The CO2 level is calculated by

$$L_{\mathrm{co}_2} = \frac{5000}{20} A_{\mathrm{in}}. \tag{2.1}$$

The position of the Hobos can be seen in Figure B.2 (page 43).

(a) The Hobo hanging from the ceiling in Room 0. (b) Four of the Hobo and Co2 sensors.

Figure 2.5: Photos of the Hobos and CO2 sensors.

2.4 Climate station

The climate station is located right next to the building, see the photo in Figure 2.4. The position of the climate station relative to the building is indicated in Figure 2.3 (it is denoted by Weather Station). The following instruments are installed at the climate station, the approximate height above ground is noted in paranthesis:

Temperature probe (4 meters) Vaisala HMP45AC Humidity and temperature probe.

Pyranometer (6 meters) SolData Pyranometer 80spc.

Wind vane (4 meters) Vector Instruments Windvane Type: W200P.

Cup anemometer (6 meters) Risø P2546A, 2 pulses, plastic cup.

In Appendix F specifications of the instruments can be found.

Figure 2.6: The climate station, which is located east of the building.

Chapter 3

Experiment design

Five different experiments has been carried out during the winter and early spring of 2009. The idea of the series of experiments, is to go from controlled conditions, where the heat input is a PRBS signal, i.e. optimized for modelling, toward common living conditions with thermostatic control of the temperature. The first three experiments were carried out with no activity inside the house, and the last two with activity in the house. Plots of the complete dataset can be found in Appendix D. In Table 3.1 a short overview of the five experiments is given. Note that the sequence of going from more controlled to common condition is: PRBS1, PRBS2, THERM1, THERM2, and THERM3, but that THERM1 was runned before PRBS2 due to practical reasons. The following applies to the experiments with no activity, i.e. Experiment 1,2, and 3:

- no human activity in the building,
- all windows closed,
- all doors closed, also the interior doors.

The thermostatic control is carried out by the server system in FlexHouse, such that all "on" and "off" messages sent to the heaters are logged.

3.1 PRBS - Pseudo Random Binary Sequence

The energy input from the heaters is the only input that can be controlled. It is therefore crucial to the design of the experiments, and can be designed such that optimal conditions for estimation of the system parameters are achieved. A widely used method in the time domain is to use PRBS-signals, which is a deterministic signal with white-noise properties. Moreover PRBS-signals show no correlation with other external signals, e.g. climate data. The signal shifts between two levels and may only switch from one level to the other at time $t = 0, \lambda, 2\lambda, \ldots,$ where λ is the basic period of the signal. The strength of PRBS-signals is that the signal is deterministic, therefore the signal can be designed before an experiment. PRBS-signals are periodic with period $T_0 = N\lambda$, where N is an odd integer. An example

Start to end	Length	Name	Description
05/02 to 11/02	7 days	PRBS1	A single PRBS signal controls all the heaters in the house, and the house is closed, such that the condition of the house is not changing during the experiment.
17/02 to 26/02	10 days	THERM1	Thermostatic control of the heaters, with no activity in the house.
27/02 to 05/03	6 days	PRBS2	The house is divided into three seperate areas, in which the heaters are controlled with a PRBS signal independently of the other areas.
06/03 to 19/03	13 days	THERM2	Thermostatic control of the heaters with activity in the house
23/03 to 14/04	22 days	THERM3	Thermostatic control of the heaters with activity and added thermal mass inside the house.

Table 3.1: Overview of the five experiments

of a PRBS-signal with $N = 63$ and $\lambda = 2$, and the corresponding autocorrelation function (ACF) can be seen in Figure 3.1. The ACF is the correlation between values with a constant time difference, as a function of the time difference. Hence this shows the correlation. It is noted that the ACF for lag 1, as seen in the plot, is 0.5, which is due to λ being 2, and for lags longer than 1, the PRBS has an ACF similar to white noise. One way to generate PRBS-signals is based on the maximum-length sequence for which $N = 2^n - 1$, where n is an integer. For a full description see [1]. The longest interval in the sequence where the signal is either on or off is $n\lambda$.

3.2 PRBS1

This experiment is a repetition of Experiment 6 in [2], with some modifications. The objective is to control the heat input, such that the measured data contains as much information about the system as possible. The heaters were controlled by a single PRBS signal, which is composed of two periods: a PRBS which have periods in one state between 20 minutes and 2 hours - that is Part One in Table 3.2 - and one period of a PRBS which have periods in one state between 3.5 and 20 hours, it is Part Two in the table. Note the Part One is repeated. The total length of the signal is 6.25 days. The upper plot in Figure 3.2 shows the PRBS signal that was applied. Note that the heater in Room 2 was switched off manually, but this is not reflected by the recorded heater signal, see Figure D.1. The heater was turned off because the temperature otherwise would exceed 30 °C where the heaters internal thermostatic relay switches to off.

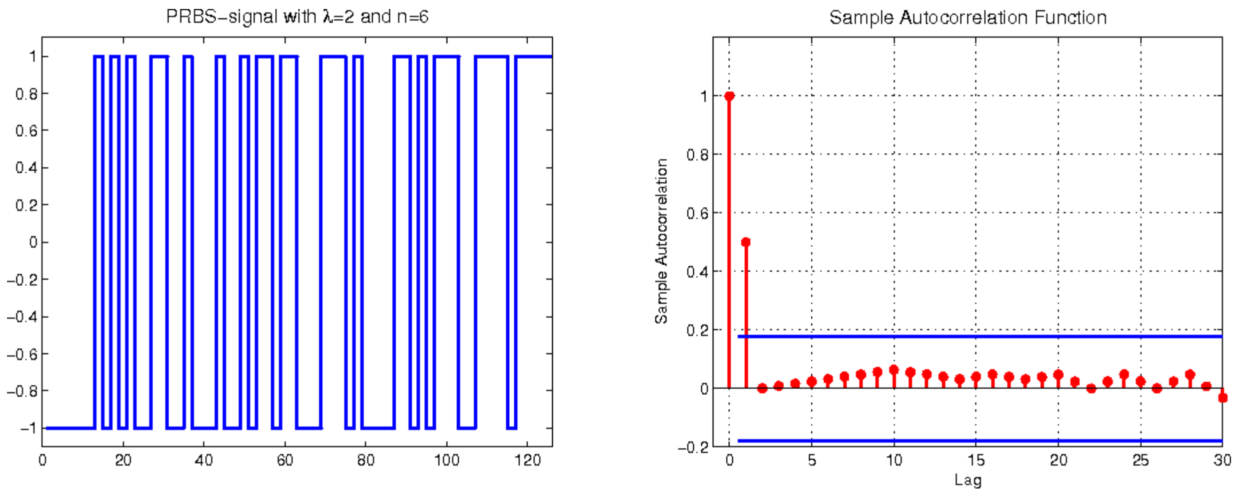

Figure 3.1: PRBS-signal and corresponding ACF.

Part	n	λ, shortest period in one state	$n\lambda$, longest period in one state	Total length
One	6	20 min	2 h	21 h
One	6	20 min	2 h	21 h
Two	5	3.5 h	20 h	108 h

Table 3.2: Parameters for the single PRBS used for all heaters in Experiment 1. Note that Part One is repeated, i.e. as stated. The total length is 150 h = 6.25 days.

3.3 PRBS2

This experiment is aimed at providing data for multiple room models, that is models where the inside of the building is not assumed to be one room. The interior of the building was divided into three areas, which are

Area 1 The rooms in the eastern part of FlexHouse, which are Room 1,2,5, and 6.

Area 2 The middle of the house, which is the Main hall.

Area 3 The rooms in the western part of the house, which are Room 3,4, and 7.

The heaters in one area was controlled by one PRBS signal, thus three seperate signals will be used. The first signal is the same as the signal used in PRBS1, and the two others are shiftet versions of that signal. See the plots in Figure 3.2. The shifts are applied such that the time, between the PRBS parts of the signals which are identical, is maximized. This means that Part One in Table 3.2, is shiftet $21/3 = 7$ hours for the second signal, and $21 \cdot 2/3 = 14$ hours for the third signal. Part Two is shiftet $108/3 = 36$ hours for the second signal, and Part Two is shiftet $108 \cdot 2/3 = 72$. The total length of the entire signal is then 6.25 days. Note that the heater in Room 2 was switched off manually, but this is not reflected by the recorded heater signal, see Figure D.3. The heater was turned off because

Figure 3.2: The three PRBS signals used is PRBS2. The upper is identical to the single PRBS used in PRBS1, and the two lower are shiftet versions.

the temperature otherwise would exceed 30 °C where the heaters internal thermostatic relay switches to off.

3.4 THERM1

The objective of this experiment is to approach real living condition, by keeping a constant indoor temperature. The heaters are therefore thermostatic controlled during this experiment. The temperature set-point is 20 °C. The thermostatic control is carried out by the central server, based on events send by the temperature sensors (as described in Section 2.2.3. When a temperature sensor sends an event, the server does either: if the temperature is below the set-point the heater in the room is turned on, and if the temperature is above the set-point the heater is switched on. This runs independently for each room.

3.5 THERM2

This experiment is identical to THERM1, except that the building is opened for human activity. Normally one or two persons work in the house, and once a week a meeting is

(a) View from Room 5 and westward into the hallway.

(b) View from the entrance and southward into Room 0.

Figure 3.3: The positioning of the concrete tiles.

held in the Main room. The amount of activity can be found from the motion sensors in each room.

3.6 THERM3

This experiment is a repetition of THERM2, except from the addition of extra thermal mass into the house. The thermal mass consisted of 140 concrete tiles of dimensions LxWxH: 50cm x 50cm x 5cm. The tiles were positioned on the floor in one layer in Room 0, including the hallway, and some stood by the wall. The tiles were taken from an experimental house at DTU BYG, so they were dry when put into the building. Ten of the tiles were weighted using a regular digital bathroom scale, and three of these tiles had notes on them, stating the weight in 1983. The result is shown in Table 3.3. The mean value of the ten tiles is 25.9 kg. Comparing with the values from 1983, which is a bit smaller, it is reasonable to believe that the bathroom scale had a small positive bias. Using a weight of 25.5 kg per tile, gives a total weight of

$$m = 140 \cdot 25.5\,\mathrm{kg} = 3570\,\mathrm{kg} \tag{3.1}$$

which is a heat capacity of

$$C = 3570\,\mathrm{kg} \cdot 1\,\frac{\mathrm{kJ}}{\mathrm{kgK}} = 3570\,\frac{\mathrm{kJ}}{\mathrm{K}} = 0.99\,\frac{\mathrm{kWh}}{\mathrm{K}}\,. \tag{3.2}$$

2009	1983	2009	1983
26.0	25.3	26.1	25.3
26.0	25.5	25.8	
25.8		26.1	
25.8		25.9	
25.9		25.8	

Table 3.3: The weight of ten of the concrete tiles (kg).

Chapter 4

Data

The complete set of recorded data is available for each experiment in two comma seperated (.csv) files: one with all data recorded by the central server, and one with the data recorded by the Hobos. The files from the central server are named with the name of the experiment, e.g. `PRBS1.csv`, and the files from the Hobos are extended with “Hobos”, e.g. `PRBS1Hobos.csv`. All timestamps are in ”GMT”.

4.1 Data from the central server

An example of a server file (white-spaces are added here), including each different type of value:

```
"time"                 ,"type","room","value" ,"note"
2009-02-05 11:07:08.623,"P"   ,      ,5980    ,""
2009-02-05 11:07:08.920,"T"   ,3     ,18.8235 ,""
2009-02-05 11:07:11.630,"S"   ,1     ,0       ,"motion:sensor8"
2009-02-05 11:07:13.763,"G"   ,      ,0.13622 ,""
2009-02-05 11:07:13.763,"Ta"  ,      ,0.771484,""
2009-02-05 11:07:13.763,"Wd"  ,      ,196.849 ,""
2009-02-05 11:07:13.763,"Ws"  ,      ,1.33699 ,""
2009-02-05 11:07:18.607,"H"   ,4     ,1       ,""
```

The different types are

- `"T"` temperature value measured with the wall mounted sensors (°C),
- `"H"` heater control: `value=0` is off. `value=1` is on,
- `"S"` state value: `value=0` is either: no motion, or closed window or door. `value=1` is either: motion registred, or open window or open door. The state values have additionally a string in the `"note"` column. This is in the format: `type:sensor_name`. The different types are: `motion`, `window`, or `door`. The sensors can be identified by their name in the list in Appendix C and from that their position in Figure 2.4.

- `"P"` power input to the building (W).
- `"G"` global irradiance (kW/m^2)
- `"Ta"` ambient temperature (C).
- `"Ws"` wind speed (m/s).
- `"Wd"` wind direction (degree). North is 0 degrees.

All the values are sampled with a 10 seconds time interval, except from the state types, which are sampled with a longer time interval. The time intervals do vary slightly around that. Note that the heater signal from Room 2, i.e. `"H2"`, is not correct. It should be set to 0 for PRBS1 and PRBS2, since the heater was manually switched off.

4.2 Data from the Hobos

Apart from a Hobo data file with measurements from the experiments (white-spaces are added here):

```
"time"              ,"room","temperature","relH" ,"intensity","co2"
2009-02-02 17:00:00,0     ,21.628       ,27.322 ,51.2       ,6.214
2009-02-02 17:00:00,1     ,22.13        ,28.001 ,67         ,6.785
2009-02-02 17:00:00,2     ,22.011       ,28.346 ,145.8      ,6.505
2009-02-02 17:00:00,3     ,22.226       ,25.398 ,27.6       ,6.298
2009-02-02 17:00:00,4     ,22.25        ,24.68  ,27.6       ,6.273
2009-02-02 17:00:00,5     ,19.08        ,34.3   ,27.6       ,6.431
2009-02-02 17:00:00,6     ,21.056       ,30.42  ,27.6       ,6.549
2009-02-02 17:00:00,7     ,21.676       ,26.648 ,35.5       ,6.165
2009-02-02 17:02:30,0     ,21.628       ,27.286 ,35.5       ,6.209
2009-02-02 17:02:30,1     ,22.13        ,28.036 ,82.8       ,6.79
2009-02-02 17:02:30,2     ,22.011       ,28.665 ,145.8      ,6.603
```

The signals have the following properties

- `temperature` temperaure in the air (C),
- `relH` relative humidity (%),
- `intensity` light intensity (lux),
- `co2` the CO2 level (ppm).

All values are sampled with a 2.5 minutes time interval.

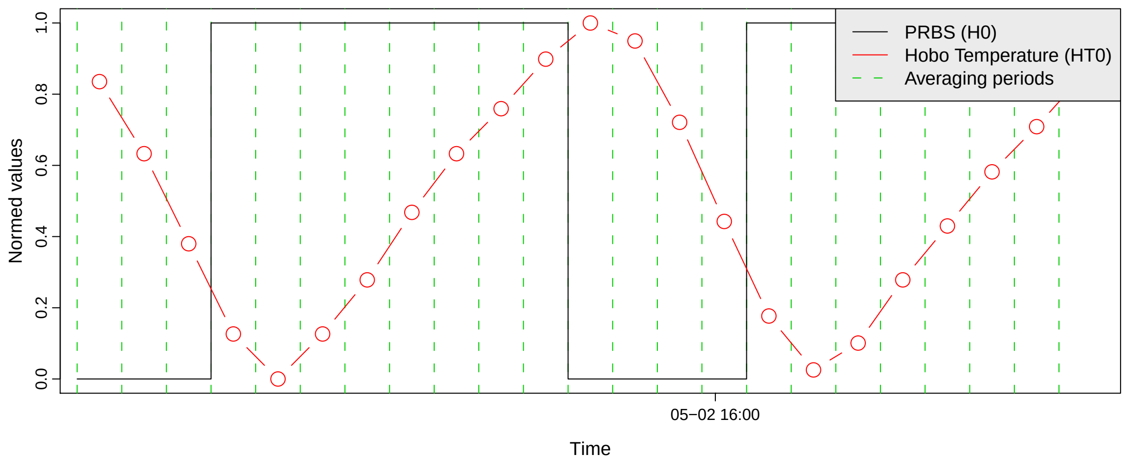

Figure 4.1: The periods over which the averaging has been calculated for the five minute values are synchronized the PRBS signal. The start- and end point of each period are marked with green lines.

4.3 Five minute values

A data set of five minute values is available in .csv files. A sample period of five mimute was chosen, since this is the shortest regularly used standard sample period for power consumption data. There is one file per experiment, they are named e.g. `5MinPRBS1.csv`. Each file is arranged as a table consisting of five minute average values of all the relevant signals. For the experiments PRBS1 and PRBS2 the time periods, over which the averaging is carried out, are synchronized to the PRBS input signal, such that the time points where the PRBS shifts state are at start- or end points of the time periods. See the plot in Figure 4.1, where start- and end points of the averaging periods are shown with the dashed green lines. Each signal is a column in the .csv file and a header is included with the names listed in the following. The included signals are:

- `"T0","T1",...,"T7"` Temperatures measured by the central server in Room $0, 1, \ldots, 7$ respectively.
- `"H0","H1",...,"H7"` Heat control signals for each room.
- `"S0","S1",...,"S7"` State values for each room.
- `"P"` Power input to the building.
- `"G"` Global irradiance.
- `"Ta"` Ambient temperature.
- `"Wd"` Wind direction.

- "Ws" Wind speed.
- "HT0","HT1",...,"HT7" Temperatures measured by the Hobos in each room respectively.
- "HRelH0","HRelH1",...,"HRelH7" Relative humidity measured by the Hobos.
- "HI0","HI1",...,"HI7" Light intensity measured by the Hobos.
- "HCo2_0","HCo2_1",...,"HCo2_7" CO2 concentration measured by the Hobos.

A reconstruction of the missing parts of the power signal in PRBS1 and PRBS2 has been carried out, see Section 5.3. Finally it is noted that in the five minute data set, the heater signal for Room 2 (i.e. "H2") during PRBS1 and PRBS2 has been corrected, i.e. it has been set to 0.

Chapter 5

Exploratory analysis

An exploratory analysis is carried to validate data. See plots of data from all the experiments in Appendix D. First it is showed that a simple model can be used to find the energy consumption of each heater, then timegaps in the series are identified, ??mangler and finally the syncronization of the series are investigated.??

5.1 Model of the energy consumption of the heaters

During the experiments with thermostatic control, each heater is switched on-off independently of each other by the system. Based on the heater on-off signals and the total energy consumption, it is possible to estimate energy consumption of each heater. The model applied is

$$\Phi_t^{\mathrm{h}} = \hat{\Phi} + \hat{\Phi}_0\, x_t^{\mathrm{r}0} + \hat{\Phi}_1\, x_t^{\mathrm{r}1} + \hat{\Phi}_2\, x_t^{\mathrm{r}2} + \hat{\Phi}_3\, x_t^{\mathrm{r}3} + \hat{\Phi}_4\, x_t^{\mathrm{r}4} + \hat{\Phi}_5\, x_t^{\mathrm{r}5} + \hat{\Phi}_6\, x_t^{\mathrm{r}6} + \hat{\Phi}_7\, x_t^{\mathrm{r}7} + \epsilon_t \quad (5.1)$$

where Φ_t^{h} is the total energy input at time t, $\hat{\Phi}$ is the energy consumption of other devices such as the central server, $x_t^{\mathrm{r}i}$ is the on-off signal to the heater in room i at time t, $\hat{\Phi}_i$ is the

Coef.	Estimate	Std. Error	t value	P(< |t|)
$\hat{\Phi}$	60.95	15.79	3.861	0.00012
$\hat{\Phi}_0$	1862.09	18.72	99.480	< 2e-16
$\hat{\Phi}_1$	713.56	17.86	39.949	< 2e-16
$\hat{\Phi}_2$	732.93	24.90	29.437	< 2e-16
$\hat{\Phi}_3$	424.31	19.08	22.241	< 2e-16
$\hat{\Phi}_4$	451.85	18.29	24.702	< 2e-16
$\hat{\Phi}_5$	425.92	17.47	24.377	< 2e-16
$\hat{\Phi}_6$	573.94	16.73	34.306	< 2e-16
$\hat{\Phi}_7$	778.77	16.41	47.458	< 2e-16

Table 5.1: Estimates of the heat consumption of each heater.

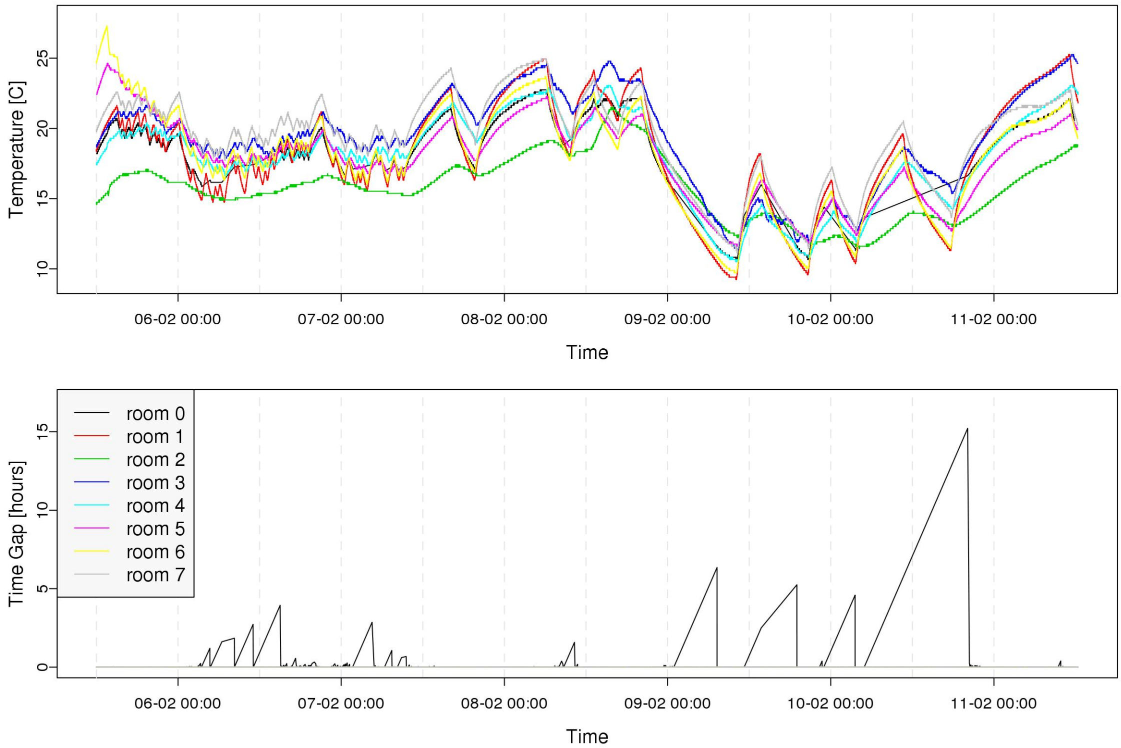

Figure 5.1: Time gaps in wall temperatures PRBS1. The upper plot shows the recorded temperature data. The lower plot shows time gaps.

estimated energy consumption of the heater in room i, and finally ϵ_t is the error at time t.

Fitting this model, by minimizing the sum of squared errors and thereby obtaining estimates of the energy consumption of each heater, is carried out on data from THERM1. A 1000 timepoints were randomly picked from the period from 2009-02-22 to 2009-02-25, and the result is shown in Table 5.1. Clearly the result seems realistic compared to the nominel values, shown in Table 2.1 (page 8). More thorough modelling of this should be carried out, in order to model the heat input in each room more precisely.

5.2 Time gaps

Time gaps in the data are identified in this section.

5.2.1 Data from the central server

Figure 5.1 shows a plot of the temperatures recorded by the central server during PRBS1. Clearly there are serious gaps in the temperature signal from Room 0. Similar plots for the remaining four experiments are found in Appendix E, which also reveal serious gaps in the temperature signal from Room 0.

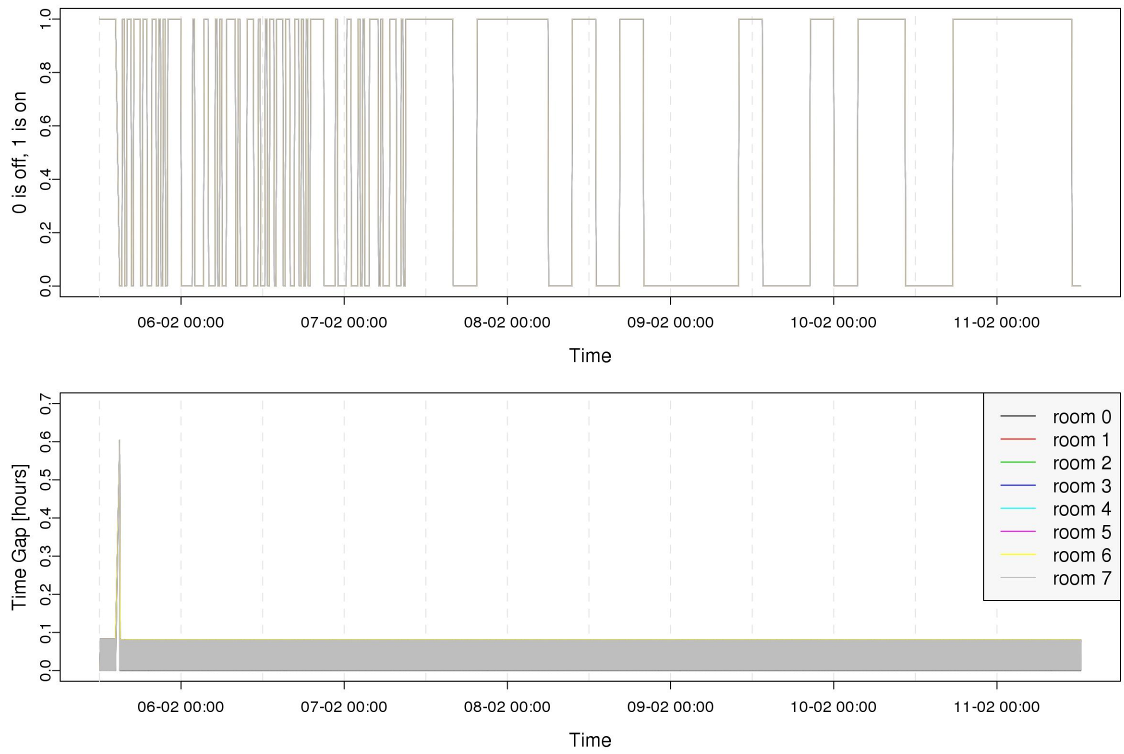

Figure 5.2: Time gaps in the heater signal. The upper plot shows the recorded heater signal. The lower plot shows time gaps.

The heater data, power data, and climate data has been checked, by visually inspecting plots similarly the plots in Figure 5.1. The following is a list of the significant time gaps found during the inspection:

PRBS1 Short time gap of 40 min. in the very beginning of the heater signals, see the plots in Figure 5.2. The power data stops from 09-02, see the plot of the power in Figure D.1 (page 48).

PRBS2 Time gap of 2 hours in the very beginning in the heater signals, see the plot in Figure D.3 (page 50). The power data has a 20 min. gap at 05-03 in the middle of the day.

THERM1 The power data starts one day later at 18-02 00:00, see the plots in Figure . There is a 2 hour gaps in the climate data, see the plots in Figure 5.3.

THERM2 No significant time gaps found.

THERM3 No significant time gaps found.

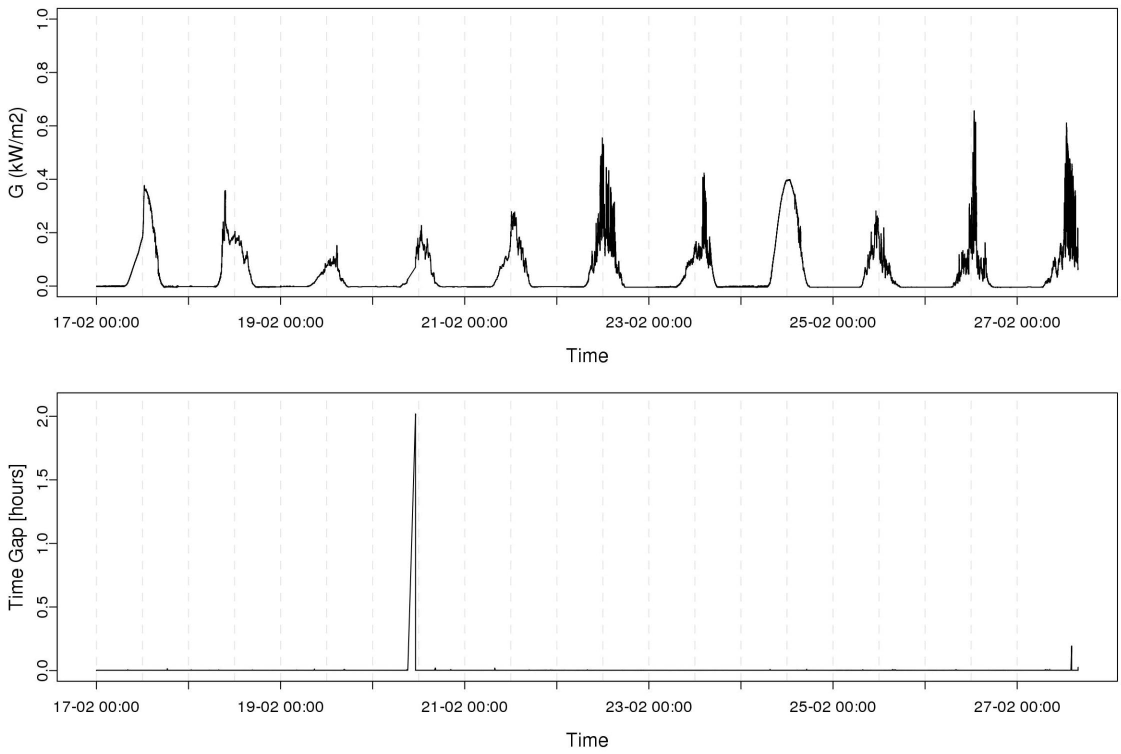

Figure 5.3: Time gaps in the climate data. The upper plot shows the recorded global irradiance data. The lower plot shows time gaps.

5.2.2 Data from the Hobos

There are no time gabs in the data from the Hobos.

5.3 Reconstruction of missing data

For the 5 min. dataset the missing parts of the power signal has been reconstructed from the heater signals. For PRBS1 it has been reconstructed from the single PRBS signal, which was used to control all the heaters. For PRBS2, in which only a short period of the power data is missing, it has been reconstructed from the three distinct PRBS signals which was used. It has also been tried to reconstruct the temperatures measured by the central server in Room 0, but without success. Consider the plots in Figure 5.4 of the temperatures measured in Room 0 by the central server and by the Hobo. The plots are over two periods, where the global irradiation increase and warms up the building, and thereafter decrease. Clearly the Hobo temperature has a faster increase, than the central server temperature, and likewise the Hobo temperature decreases faster. This can be ascribed to the position of the temperature sensors, the Hobo is closer to the real air temperature, than the central server temperature, since the Hobo was hanging in the

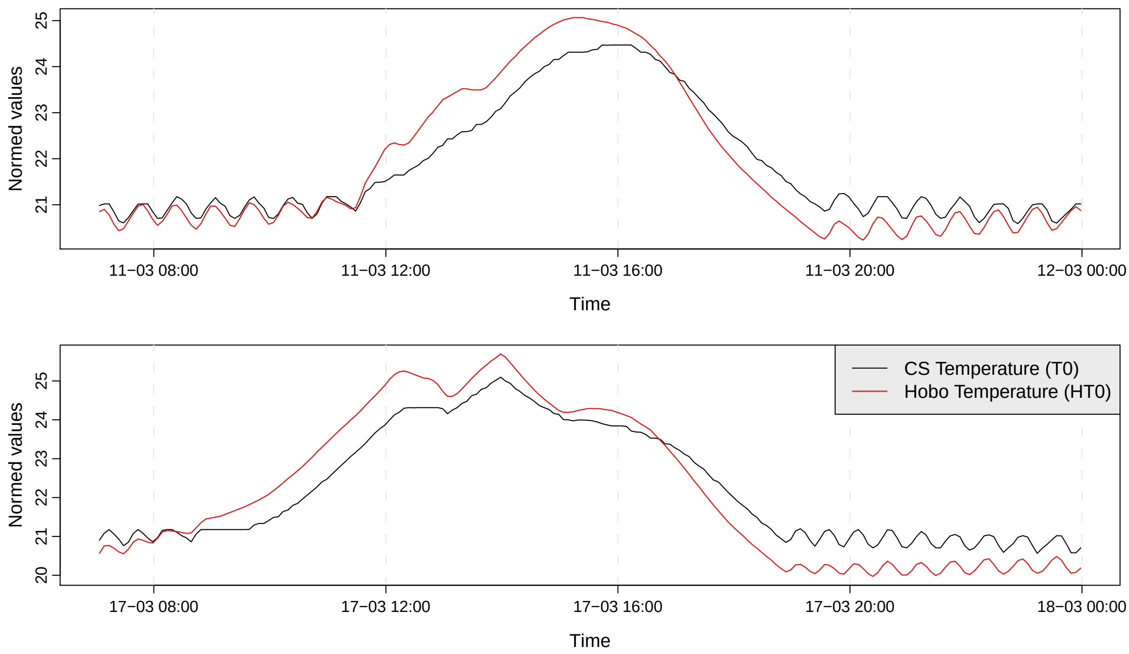

Figure 5.4: Plot of the temperature measured in Room 0 by the central server and the temperature from the Hobo.

middle of the room and the central server sensor is mounted on the wall. Because there is a difference in thermal mass between the air and the wall, and due to convection effects in the room, when the building is warmed by solar irradiance, a model of the thermal dynamics is needed for a proper reconstruction of the missing parts of the central server temperature. Since the purpose of the dataset is to develop thermal dynamical models, such models should not be used in the reconstruction of missing data. Therefore these missing parts of the data must be handled in the modelling stage.

5.4 Time synchronization

In order to verify that the data is synced correctly, relevant plots of the entire dataset have been investigated thoroughly. Examples of these plots are found in Figure 5.5 and 5.6. In Figure 5.5 the global irradiance and the light intensity measured by the Hobo in room 3 are plotted together with the cosine of the angle of incidence on a horisontal surface. Clearly the global irradiance and the light intensity is low at night time, and starts increase at sunrise and reaches back to the low level at sunset. This indicate that the time is synchronized correctly. In Figure 5.6 the temperature signal from the central server and the Hobos, are plottet over a period of 14 hours. The variation in the temperatures occurs approximately at the same points in time, again indicating that the data from the Hobos are synced correctly with the data from the central server.

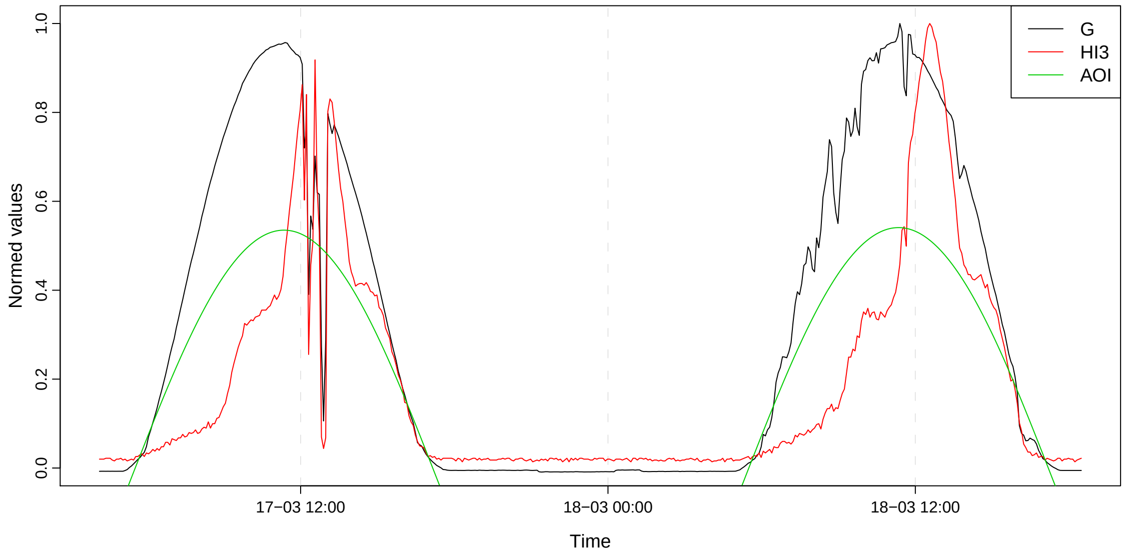

Figure 5.5: Plot of: global irradiance (G), Hobo light intensity (HI3), and cosine of the solar radiation angle of incidence on a horisontal surface (AOI), during two days.

5.5 Temperature sensor calibration and comparison

A calibration of the Hobo temperature sensors was carried out at DTU BYG test facilities. Secondly each Hobo was hanged next to each of the wall mounted temperature sensors in the building, as shown on in Figure 5.7.

5.5.1 Calibration of the Hobo temperature sensors

A calibration of the Hobos was carried out at DTU Byg test facilities. The temperature reading of the Hobos were compared to an accurate thermometer at three different temperatures. A regression line has also been calculated in order to give an estimate of the error in an extrapolated range. The results are listed in Table 5.2. The errors of all temperature readings from the Hobos are within the limit of the accuracy of ± 0.35°C (see p.10). The error at zero degrees is estimated by the intercept of the regression lines, and these are similarly within the specified accuracy. Hence it is found that the temperature measurements from the Hobos are within ± 0.35°C in applied range.

5.5.2 Comparison between the Hobos and the wall mounted sensors

A comparison between the Hobos and the wall mounted sensors was carried out. In a period of 2 hours the temperature was measured every 1 minute, the recorded series is plotted in Figure 5.8. The measurements were carried out in middle of a day with clear

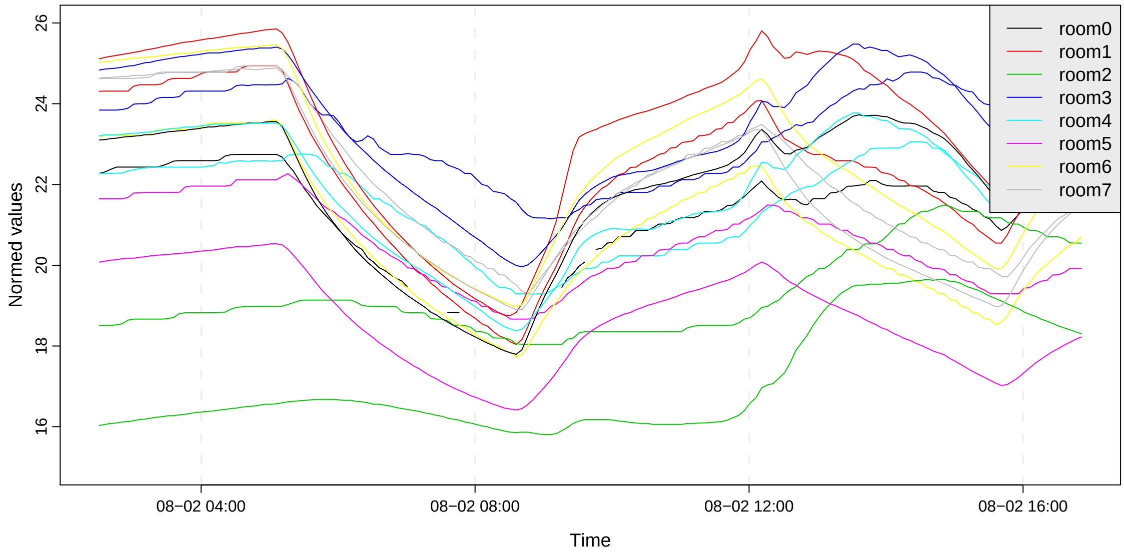

Figure 5.6: Plot of the temperatures measured in each room by both the central server sensors and the Hobos. The smoothest curves are measurements from the Hobos.

sky, which is reflected by an increasing temperature in the southward rooms, i.e. Room 0,1,2,3, and 4. The plots in Figure 5.9 are scatter plots of the Hobo temperature and the wall mounted sensor measurements, together with one-to-one function. The measurements should optimally be located on the green line. Inspecting the plots it is found that the highest difference is found in Room 0, where the difference is constantly around -1.5 °C. The other plots reveal differences in the range of -1 to 1 °C. It is apparent that the temperature range doesn't cover the range for the experiments and that the measurements cannot reveal dynamical effects of the sensors. Hence it is found, since the calibration of the Hobos showed that they are within ±0.35 °C, that the camparison indicates that the error of the wall mounted temperature sensors is found to be within the range of ± 1.5 °C.

Figure 5.7: A Hobo hanging next to a the wall mounted temperature sensor.

Set point	H0	H1	H2	H3	H4	H5	H6	H7
15.8	15.9	15.6	15.7	15.8	15.6	15.7	15.7	15.7
19.9	19.9	19.7	19.8	19.9	19.6	19.7	19.7	19.8
29.3	29.4	29.1	29.4	29.3	29.1	29.3	29.2	29.2
Error	-0.1	0.2	0.1	0.0	0.2	0.1	0.1	0.1
	0.0	0.2	0.1	0.0	0.3	0.2	0.2	0.1
	-0.1	0.2	-0.1	0.0	0.2	0.0	0.1	0.1
Slope	1.003	1.003	1.016	1.003	1.001	1.012	1.005	1.002
Intercept	-0.042	-0.303	-0.405	-0.064	-0.306	-0.408	-0.258	-0.162
RSQ	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 5.2: The results from the calibration carried out at DTU BYG. In the upper three rows the temperature readings for each Hobo at the set points are listed, and in the following three rows the errors are listed. Finally, the result of a linear regression is listed in the last three rows.

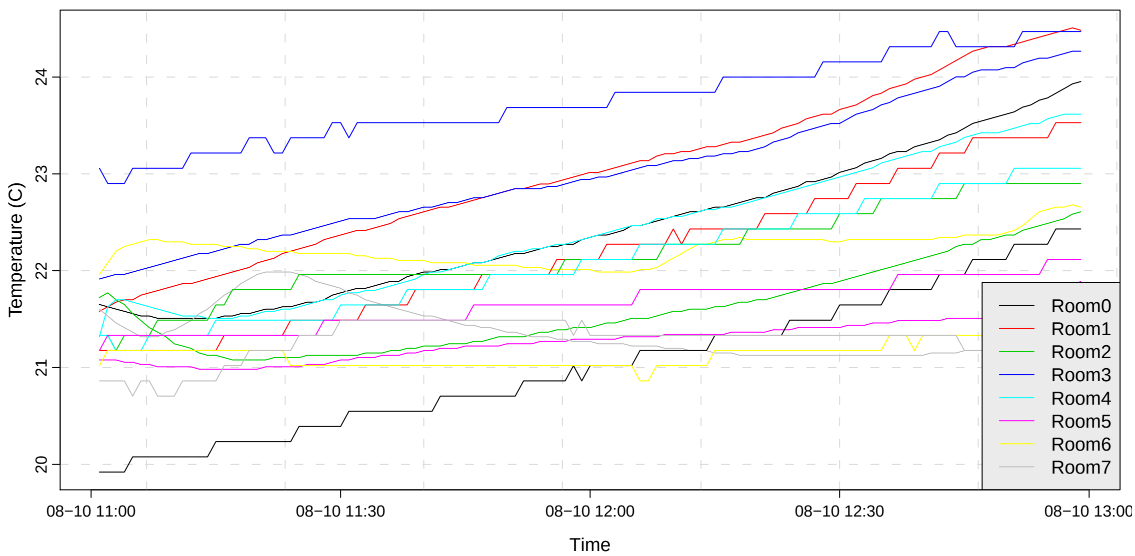

Figure 5.8: The temperature measurements from the Hobos and the wall mounted sensors hanged next to each other. The "smoothest" curves are from the Hobos.

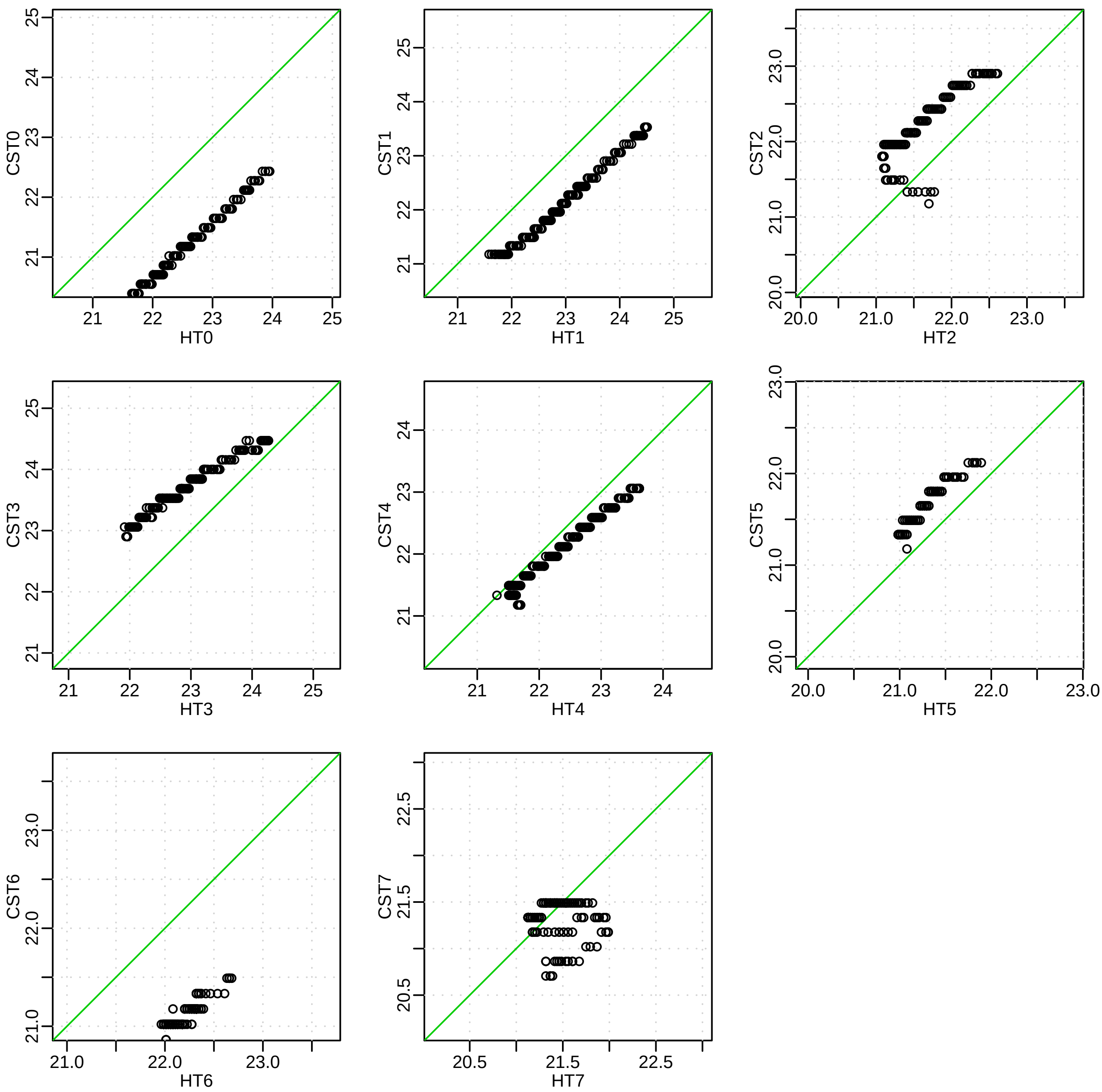

Figure 5.9: Hobo temperature (HT) versus the wall mounted temperature measurements (CST) for each room. The green lines are the one-to-one function.

Chapter 6

Conclusion

Five experiments have been successfully carried out and the collected data is prepered for modelling of the thermal dynamics of the building. The experiments follow a line from controlled conditions toward normal living conditions, providing the possibility to study model results under relevant variation of the conditions. During the fifth experiment 3500 kg of concrete was placed in the building, which is equivalent to a heat capacity of 1 kWh/K. This can be used for varification of estimated model parameters.

A thorough verification of the data has been carried out. All signals have been visually inspected for outliers and synchronization errors. Besides missing parts in the temperature signal from the wall sensor in Room 0, no substantial deficiencies has been found in the data. Regarding these missing parts it was found that dynamical models would be needed for a reconstruction, and this has therefore been left as part of the modelling. Several less important missing parts have also been identifed.

A high quality dataset of five minute average values has been prepared. It consists of all signals, which have been aligned and synchronized with the PRBS inputs. Reconstruction of missing parts of the power input signal has been carried out for this data set, and it can be applied for modelling with no additional preprocessing.

For the experiments with thermostatic control of the heaters, it has been showed how a simple model can be used to find the heat input in each seperate room. Two types of temperature sensors were applied to measure the indoor air temperature in each room of the building. A calibration of all sensors of the first type showed that their accuracy are within $\pm$ 0.35 °C in the deployed range. Finally a comparison of the two types of temperature sensors indicated that their measurement error is within a range of ± 1.5 °C. Considering that the difference from the ambient temperature to the indoor temperature mostly being in the range of 15-to-20 °C, the accuracy is found acceptable since it corresponds to an error around 10 %.

Appendix A

Photos of FlexHouse

Photos of FlexHouse are found in this chapter. The caption of each photo explain the content of the image.

Figure A.1: The east facade.

Figure A.2: The south facade.

Figure A.3: The west facade.

Figure A.4: The north facade.

Figure A.5: The main room or Room 0.

Figure A.6: The kitchen in the main room.

Figure A.7: The server hardware.

Figure A.8: Room 2. The interior consisting of a desk and some few other items, are similar in all rooms.

Figure A.9: Window in Room 3.

Figure A.10: Window in the ceiling.

Figure A.11: The air gab between the house and the ground.

Figure A.12: The air gab beneath the building.

Appendix B

Dimension and positions

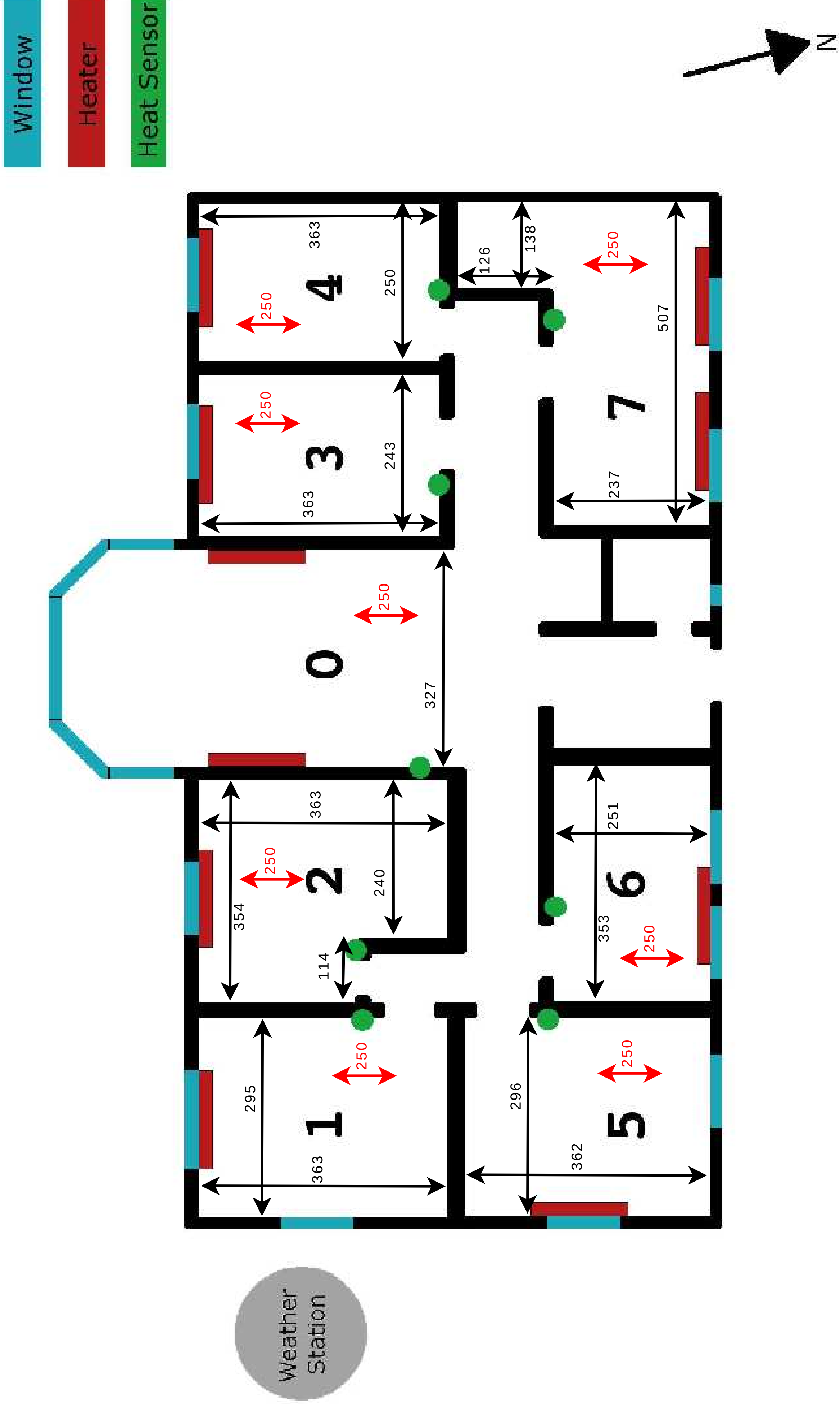

Figure B.1: The dimensions of the room. All lenghts are in centimeters. The red numbers are the heights of the room.

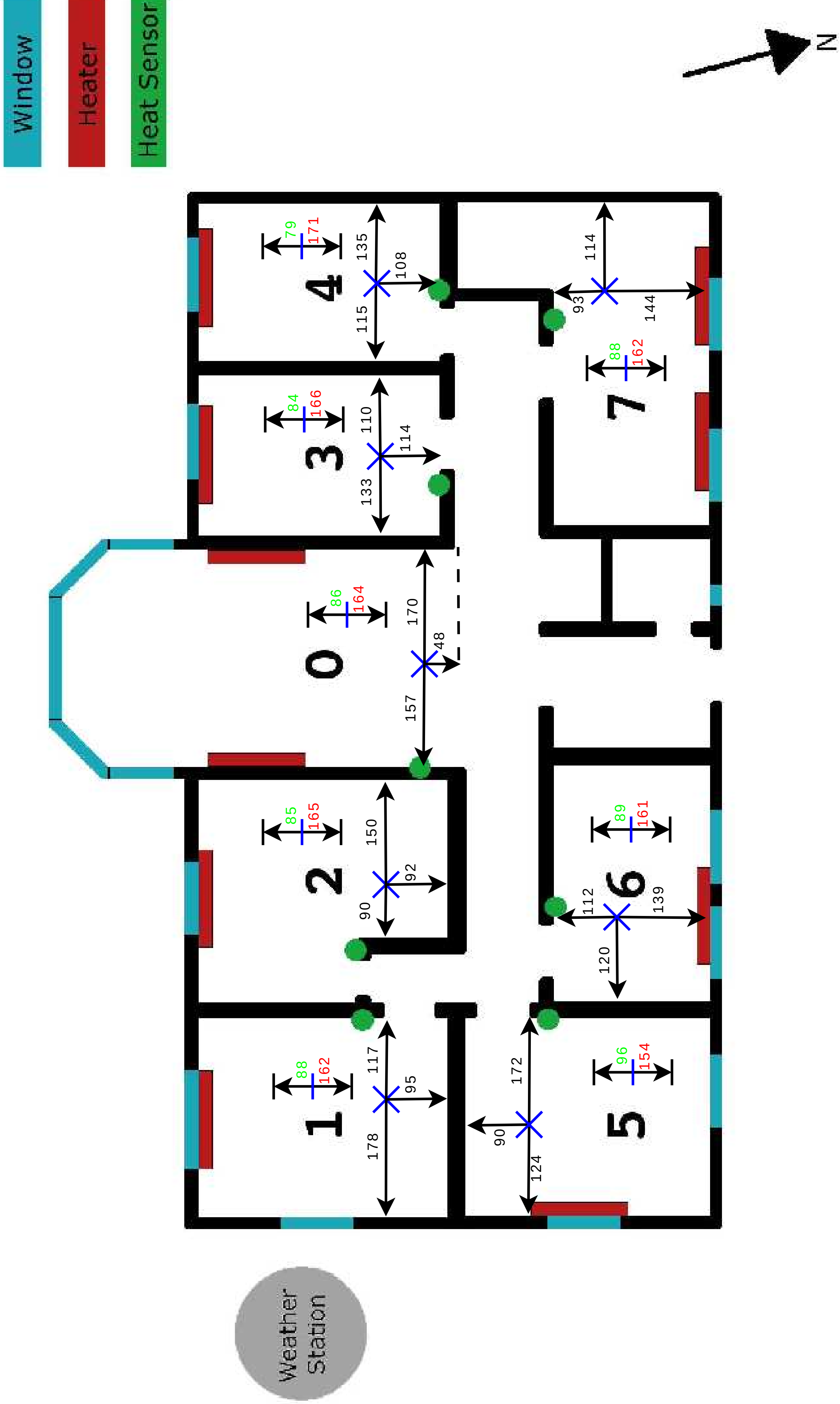

Figure B.2: The position of the Hobos. All lenghts are in centimeters. The red numbers indicate the height from the floor to the sensor, and the green number indicate the height from the sensor to the ceiling.

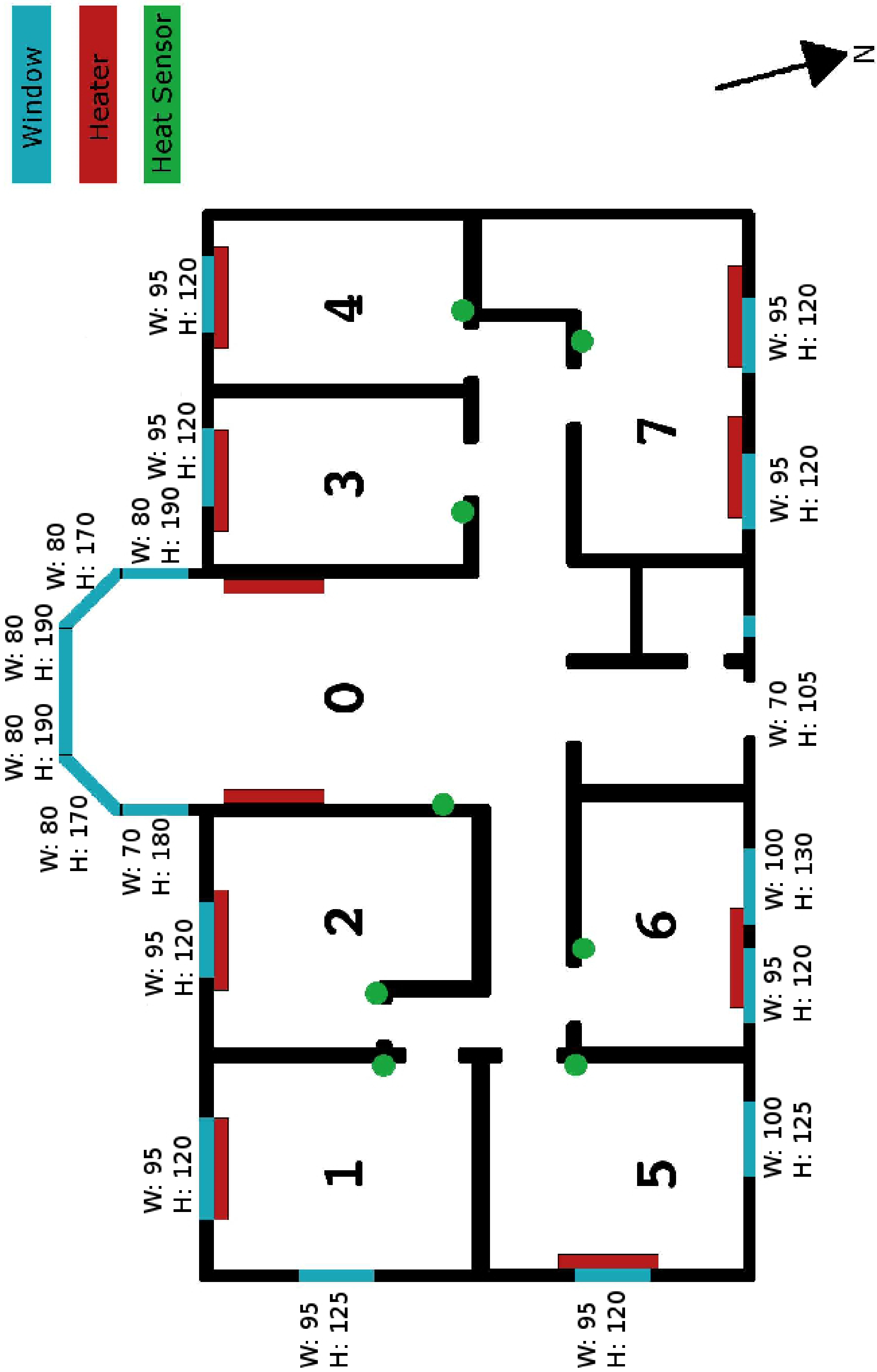

Figure B.3: The dimensions of the windows in the building. The unit dimensions are givin in centimeters.

Appendix C

List of devices in FlexHouse

```
1;sensor1;00003297;motion;SR_PIR360;320;170;f;main_hall;eventEnOceanSensor;;;;
2;sensor2;00003257;motion;SR_PIR360;295;270;f;main_hall;eventEnOceanSensor;;;;
3;sensor3;00000cc8;door;SRW01D;270;360;f;main_hall;eventEnOceanSensor;;;;
4;sensor4;00000c5c;door;SRW01D;270;95;f;main_hall;eventEnOceanSensor;;;;
5;sensor5;00000fea;window;SRW01;290;60;f;main_hall;eventEnOceanSensor;;;;
6;sensor6;00001038;window;SRW01;355;60;f;main_hall;eventEnOceanSensor;;;;
7;sensor7;000052b7;temperature;SR04;270;215;f;main_hall;dataEnOceanSensor;;;;
8;actuator1_ch1;fffd1081;radiator_P1000W;SRC1H;370;150;f;main_hall;enOceanActuator;;;1000;w
9;actuator2_ch1;fffd1089;radiator_P1000W;SRC1H;270;150;f;main_hall;enOceanActuator;;;1000;w
10;actuator3;fffd1084;light_P1000W;SRC1L;270;230;f;main_hall;enOceanActuator;;;1000;w
11;actuator26;fffd108d;light_P1000W;SRC1L;270;345;f;main_hall;enOceanActuator;;;1000;w
12;actuator4;192.168.128.xx;aircondition_P3000W;IrTrans;320;190;f;main_hall;enOceanActuator;;;2000;w
13;switch1_ch1;001080b7;2channel;easyfit;270;200;f;main_hall;enOceanActuator;;actuator3;;
14;switch1_ch2;001080b7;2channel;easyfit;270;200;f;main_hall;enOceanActuator;;actuator26;;
15;sensor8;0000323a;motion;SR_PIR360;95;170;f;room1;eventEnOceanSensor;;;;
16;sensor9;00001055;window;SRW01;110;110;f;room1;eventEnOceanSensor;;;;
17;sensor30;00001a7e;door;SRW01D;20;95;f;room1;eventEnOceanSensor;;;;
18;sensor10;00005120;temperature;SR04;120;220;f;room1;dataEnOceanSensor;;;;
19;actuator5_ch1;fffd1088;radiator_P1000W;SRC1H;110;130;f;room1;enOceanActuator;;;1000;w
20;actuator6;fffd108a;light_P1000W;SRC1L;130;195;f;room1;enOceanActuator;;;1000;w
21;actuator7;192.168.128.xx;aircondition_P3000W;IrTrans;120;150;f;room1;enOceanActuator;;;2000;w
22;switch2_ch1;0010828f;2channel;easyfit;130;180;f;room1;enOceanActuator;;actuator6;;
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24;sensor11;0000326f;motion;SR_PIR360;220;170;f;room2;eventEnOceanSensor;;;;
25;sensor12;00000c51;window;SRW01;200;110;f;room2;eventEnOceanSensor;;;;
26;sensor31;00001ada;door;SRW01D;40;105;f;room2;eventEnOceanSensor;;;;
27;sensor13;0000510b;temperature;SR04;195;195;f;room2;dataEnOceanSensor;;;;
28;actuator8_ch1;fffd108c;radiator_P1000W;SRC1H;200;130;f;room2;enOceanActuator;;;1000;w
29;actuator9;fffd108f;light_P1000W;SRC1L;195;220;f;room2;enOceanActuator;;;1000;w
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33;sensor14;00003305;motion;SR_PIR360;420;170;f;room3;eventEnOceanSensor;;;;
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35;sensor32;00001b3c;door;SRW01D;140;80;f;room3;eventEnOceanSensor;;;;
36;sensor16;000050f7;temperature;SR04;425;225;f;room3;dataEnOceanSensor;;;;
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37;actuator11_ch1;fffd1090;radiator_P1000W;SRC1H;400;130;f;room3;enOceanActuator;;;1000;w
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42;sensor17;000032d3;motion;SR_PIR360;495;170;f;room4;eventEnOceanSensor;;;;
43;sensor18;000016bc;window;SRW01;485;110;f;room4;eventEnOceanSensor;;;;
44;sensor33;00001b1d;door;SRW01D;180;80;f;room4;eventEnOceanSensor;;;;
45;sensor19;00005110;temperature;SR04;495;220;f;room4;dataEnOceanSensor;;;;
46;actuator14_ch1;fffd1092;radiator_P1000W ;SRC1H;485;125;f;room4;enOceanActuator;;;1000;w
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68;sensor27;00001670;window;SRW01;495;360;f;room7;eventEnOceanSensor;;;;
69;sensor28;00000c2f;window;SRW01;405;360;f;room7;eventEnOceanSensor;;;;
70;sensor36;000062aa;door;SRW01D;180;40;f;room7;eventEnOceanSensor;;;;
71;sensor29;000051f5;temperature;SR04;455;290;f;room7;dataEnOceanSensor;;;;
72;actuator21_ch1;fffd10a0;radiator_P1000W ;SRC1H;405;345;f;room7;enOceanActuator;;;1000;w
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74;actuator23;fffd10a2;light_P1000W ;SRC1L;415;290;f;room7;enOceanActuator;;;1000;w
75;switch8_ch1;00108332;2channel;easyfit;455;305;f;room7;enOceanActuator;;actuator23;;
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77;actuator24_ch1;fffd10a4;WaterHeater_P1000W ;SRC1W;340;345;f;wc;enOceanActuator;;;3400;w
78;actuator25_ch1;fffd10a5;light_P1000W ;SRC1L;330;320;f;wc;enOceanActuator;;;1000;w
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80;sensor38;0000a265;EnO_OutsideIns ;SR65Li;320;50;f;outside;dataEnOceanSensor;;;;
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82;sensor40;0000xxx7;EnO_OutsideTemp;SR65;300;360;f;outside;dataEnOceanSensor;;;;
83;Pyranometer;0000xxx1;Outside_Solar_Radiation;80spc;321;51;f;outside;analogSensor;;;;
84;rh_t_probe;0000xxx2;Outside_Temp;F2920A;322;52;f;outside;analogSensor;;;;
85;Windvane;0000xxx3;wind_Direction;W200P;323;53;f;outside;analogSensor;;;;
86;anemometer;0000xxx4;wind_anemometer;P2546A;324;54;f;outside;analogSensor;;;;
```

Appendix D

Data plots

This appendix contains plots of the entire datasets. For each experiment both plots of the data recorded by the central server, and plots of the data from the Hobos are shown.

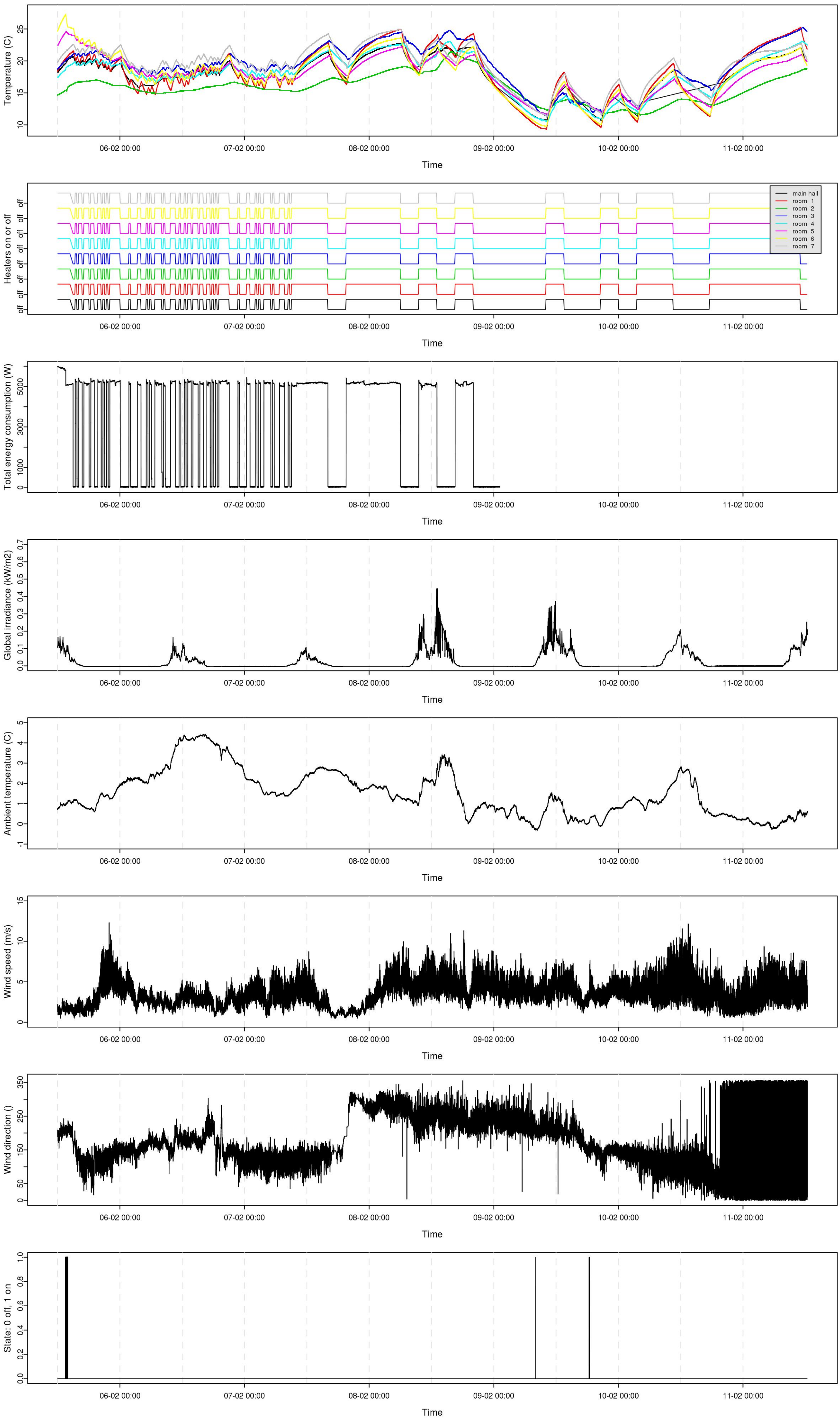


Figure D.1: PRBS1 data from the central server. Note that the heater in Room 2 was switched off manually, thus the signal should be set to 0 during the period.

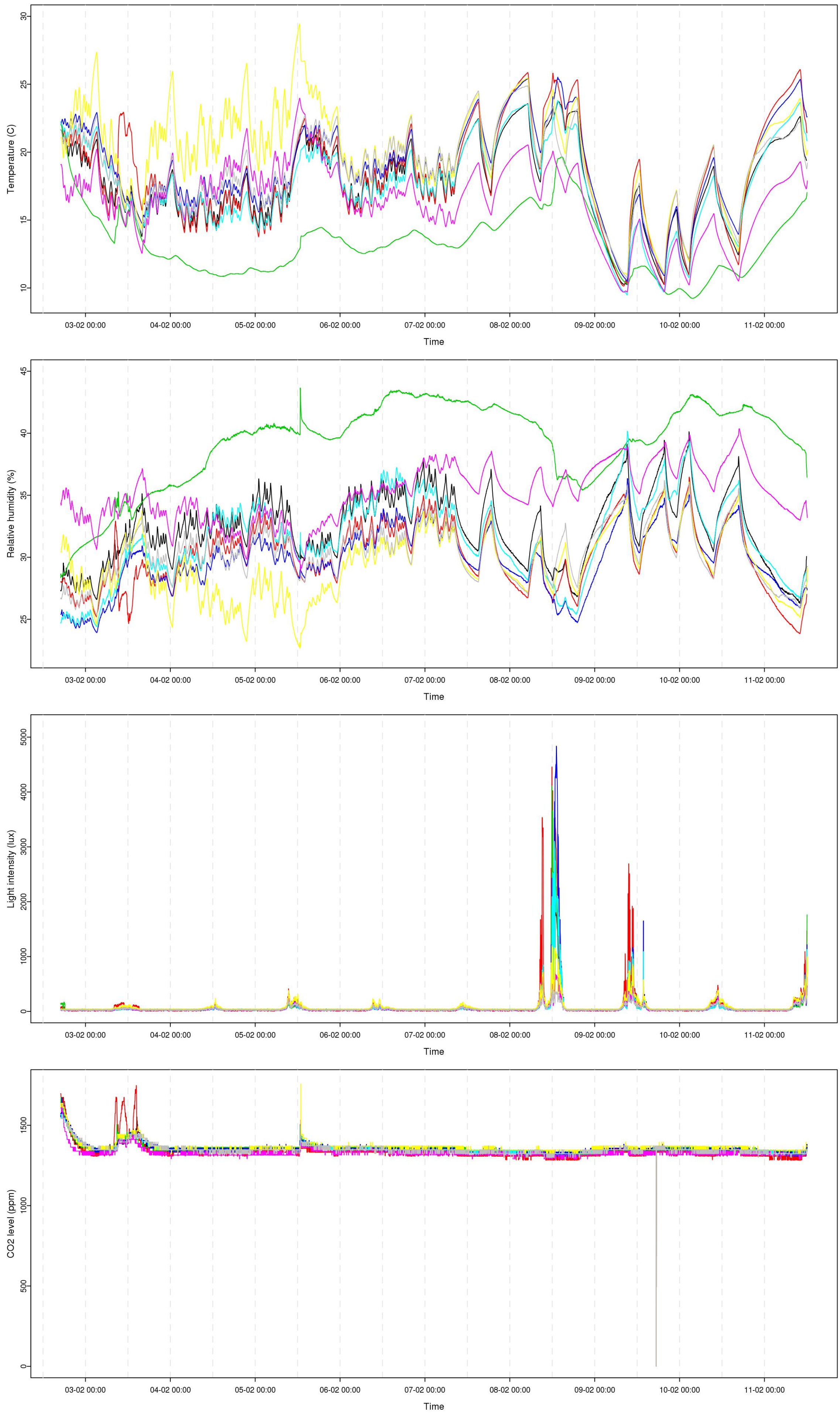


Figure D.2: PRBS1 data from the Hobos.

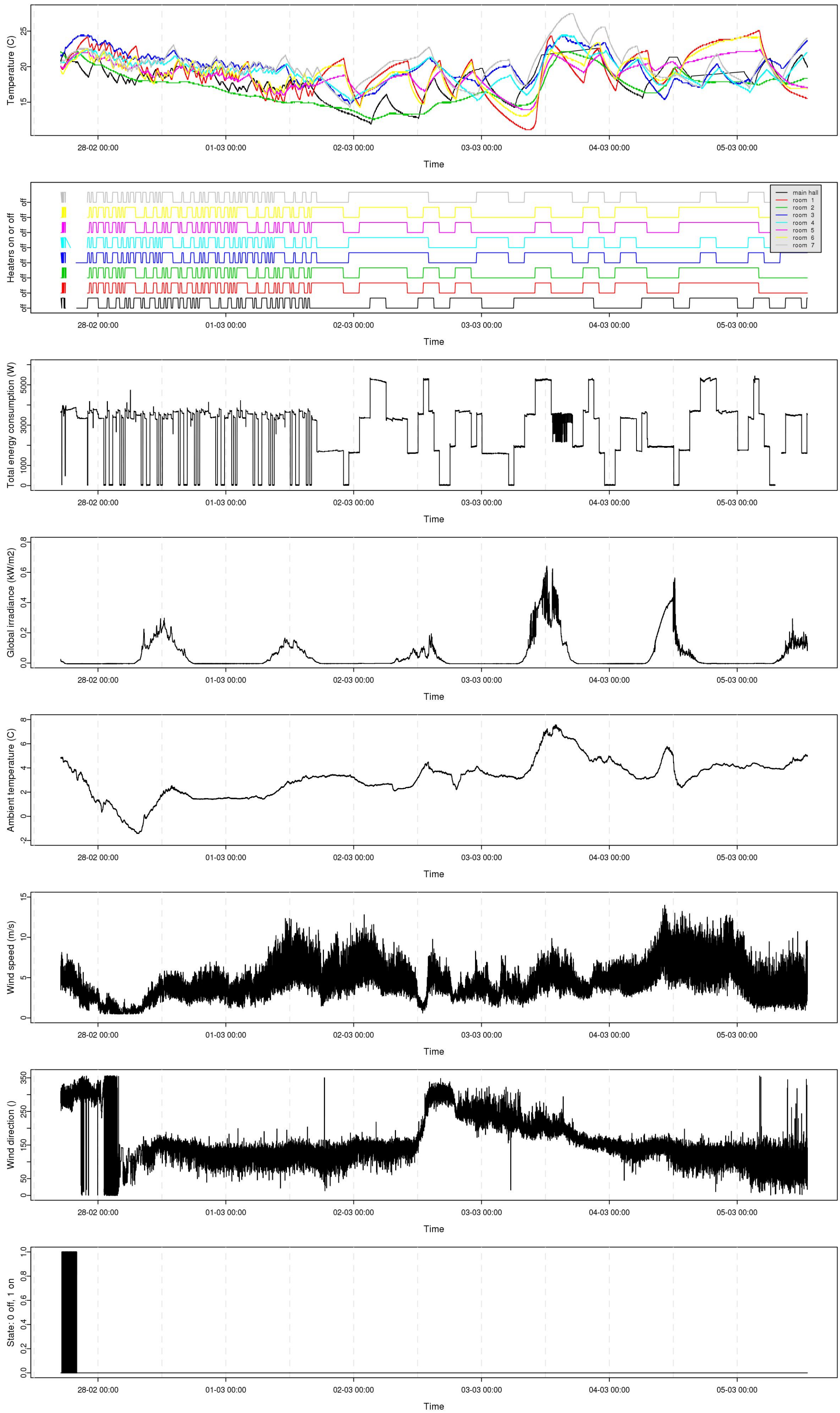


Figure D.3: PRBS2 data from the central server. Note that the heater in Room 2 was switched off manually, thus the signal should be set to 0 during the period.

Figure D.4: PRBS2 data from the Hobos.

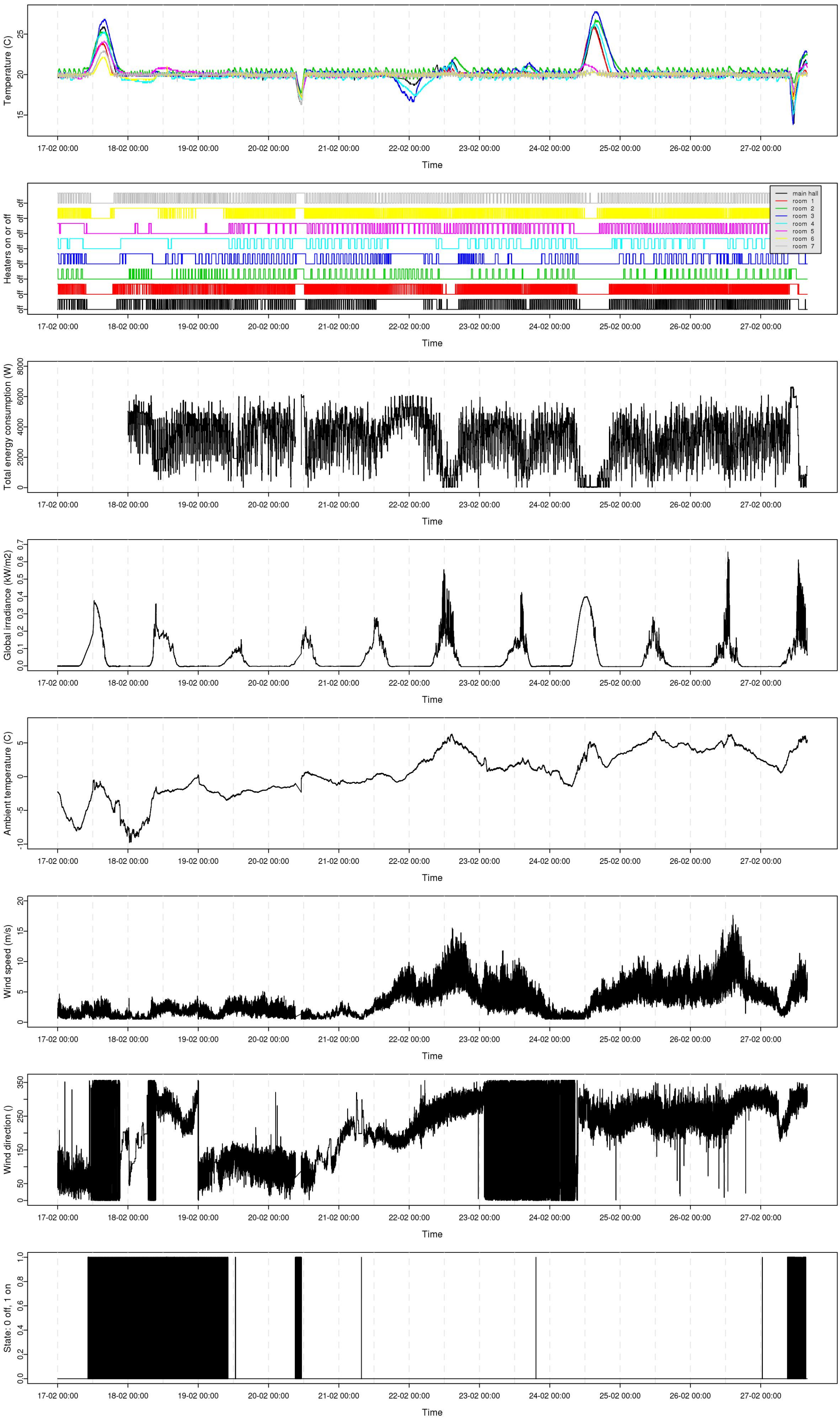


Figure D.5: THERM1 data from the central server.

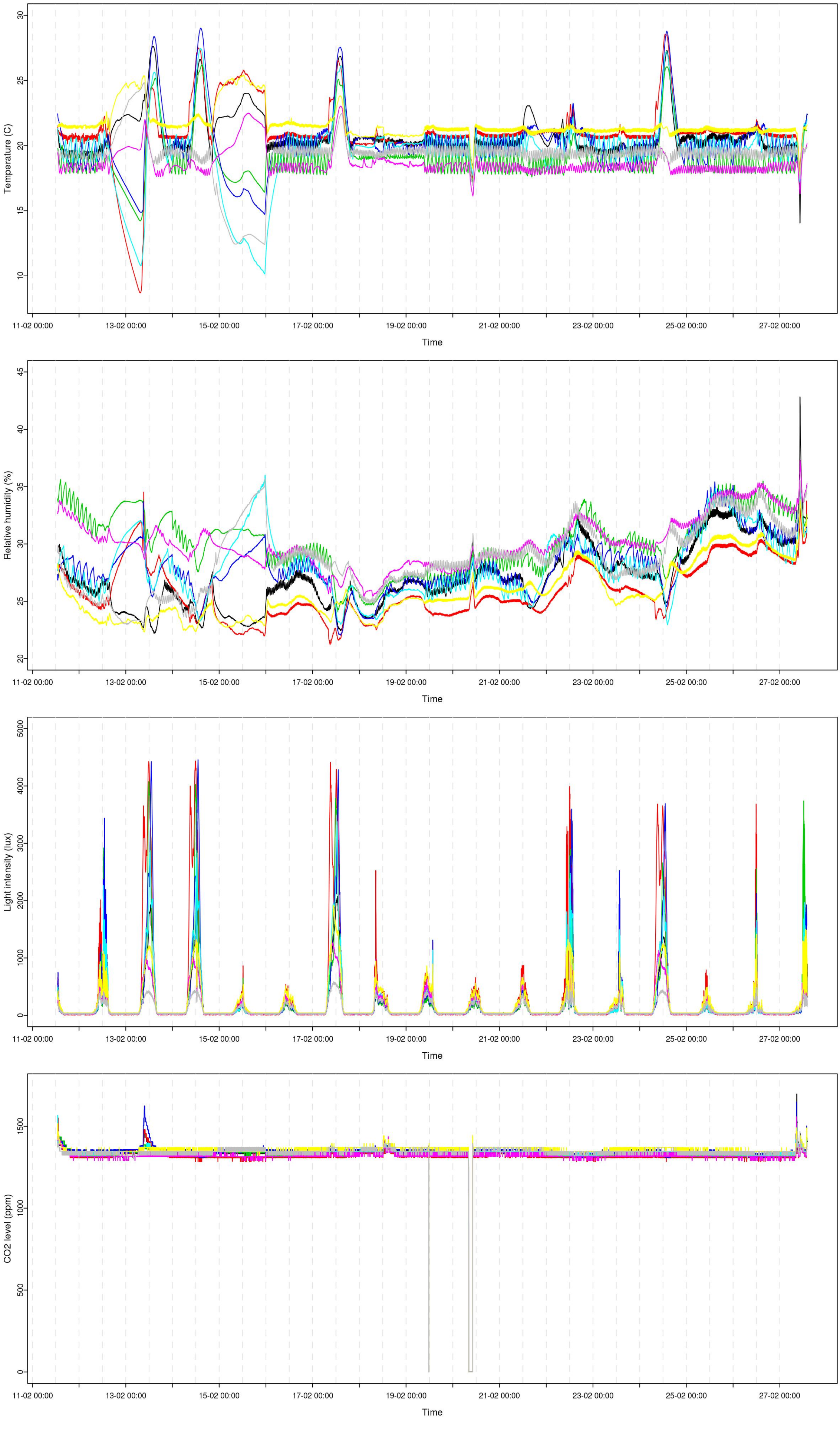


Figure D.6: THERM1 data from the Hobos.

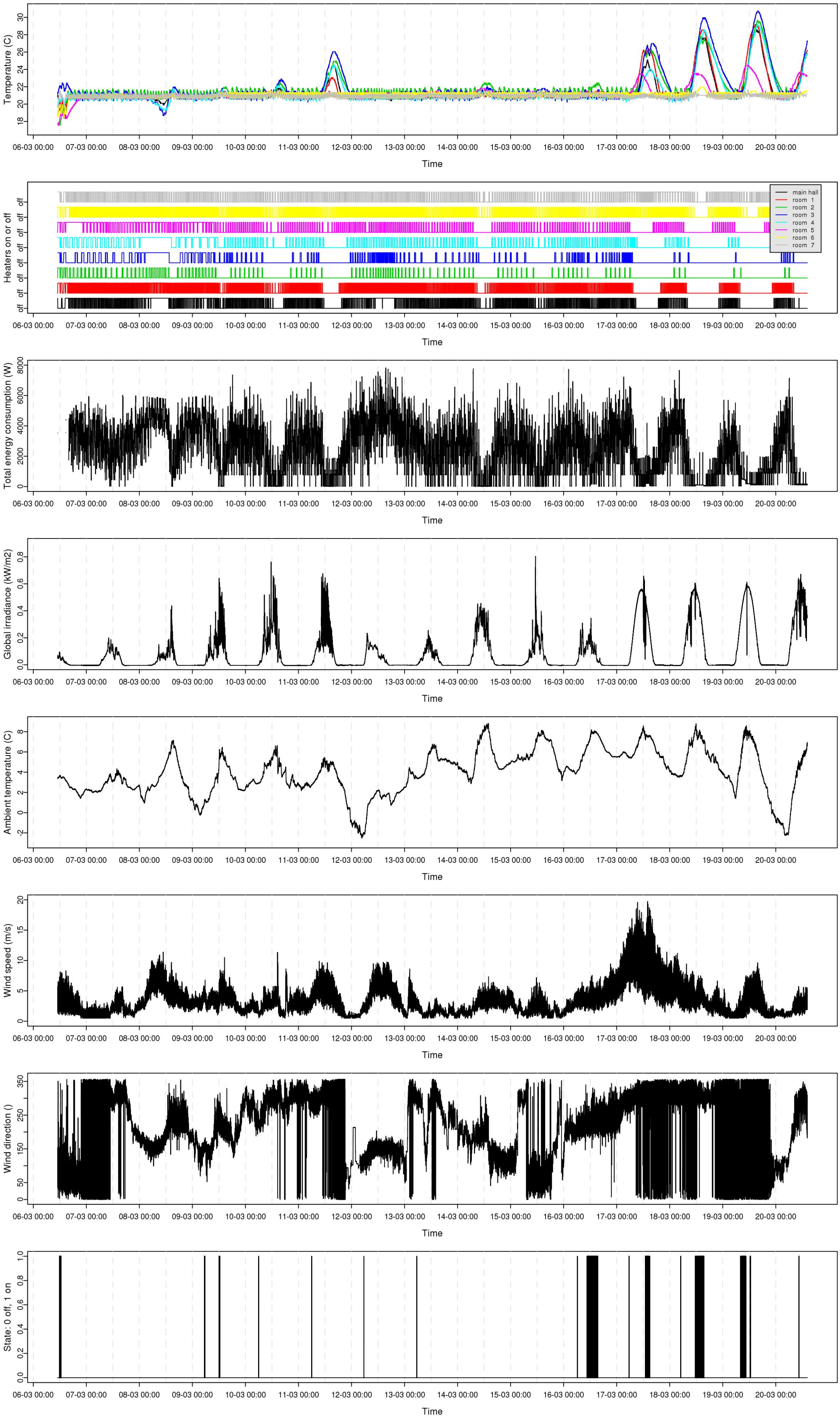


Figure D.7: THERM2 data from the central server.

Figure D.8: THERM2 data from the Hobos.

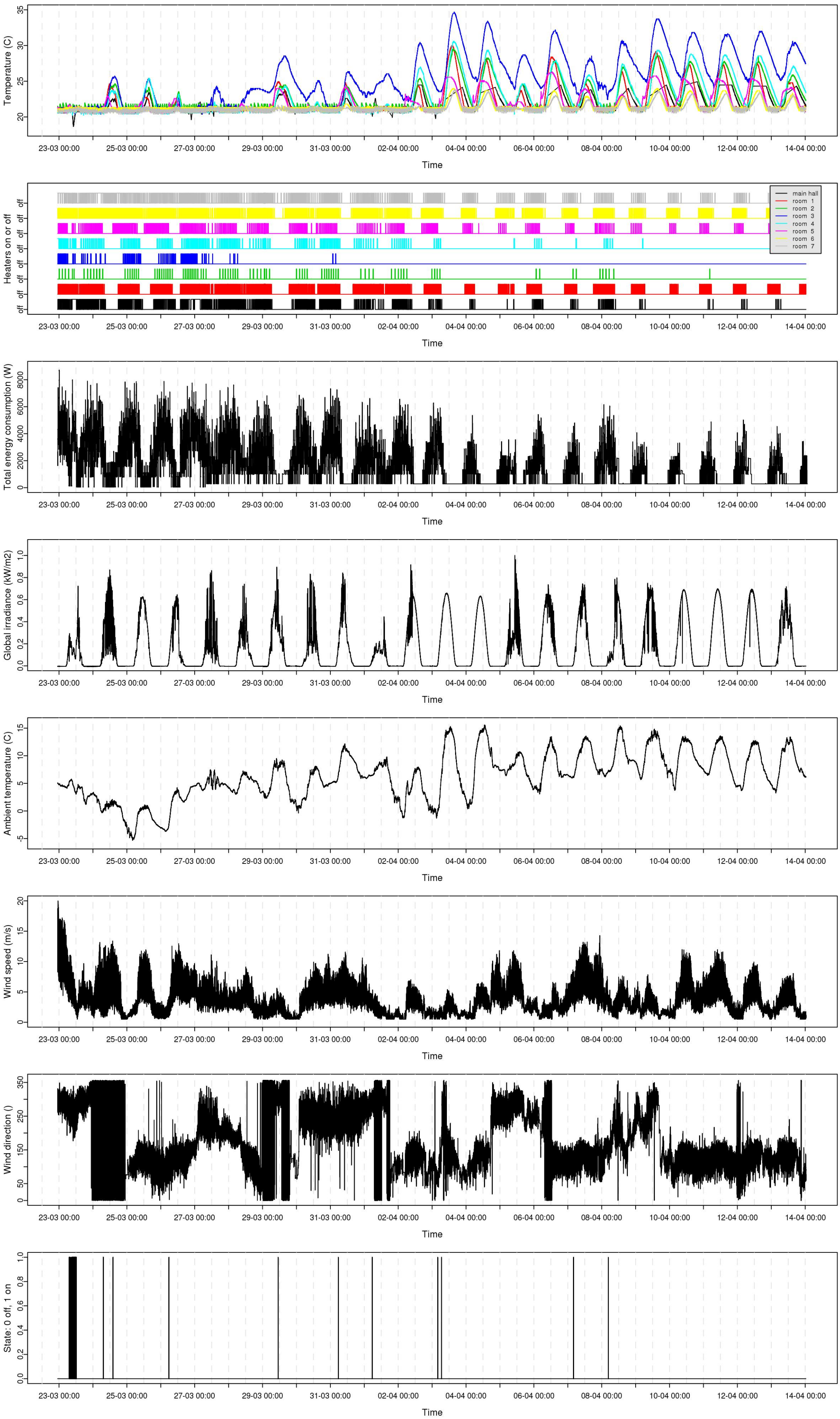


Figure D.9: THERM3 data from the central server.

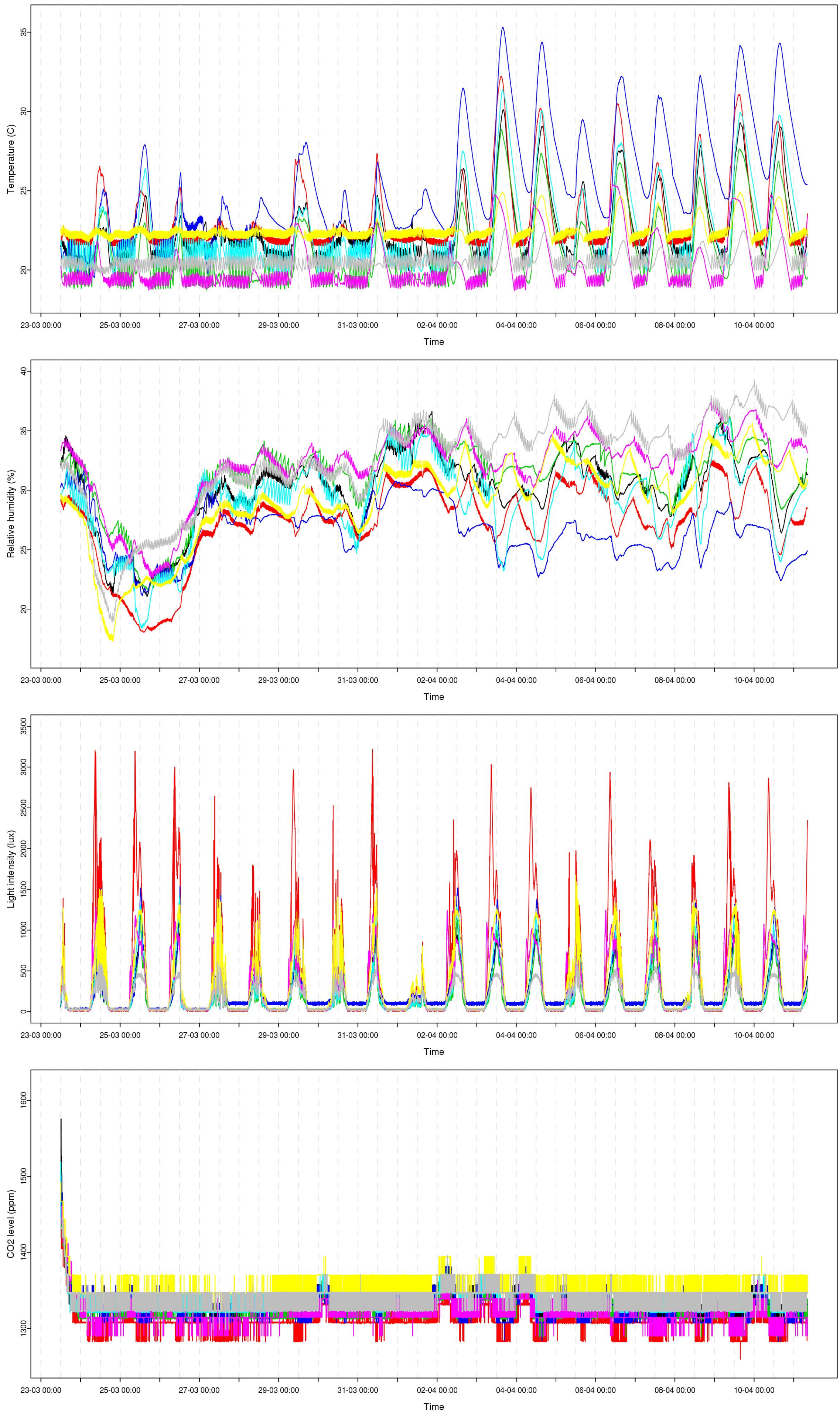


Figure D.10: THERM3 data from the Hobos.

Appendix E

Time gap plots

The chapter contain plots of the identification of time gaps in the data from the temperature sensors mounted on the walls, and recorded by the central server.

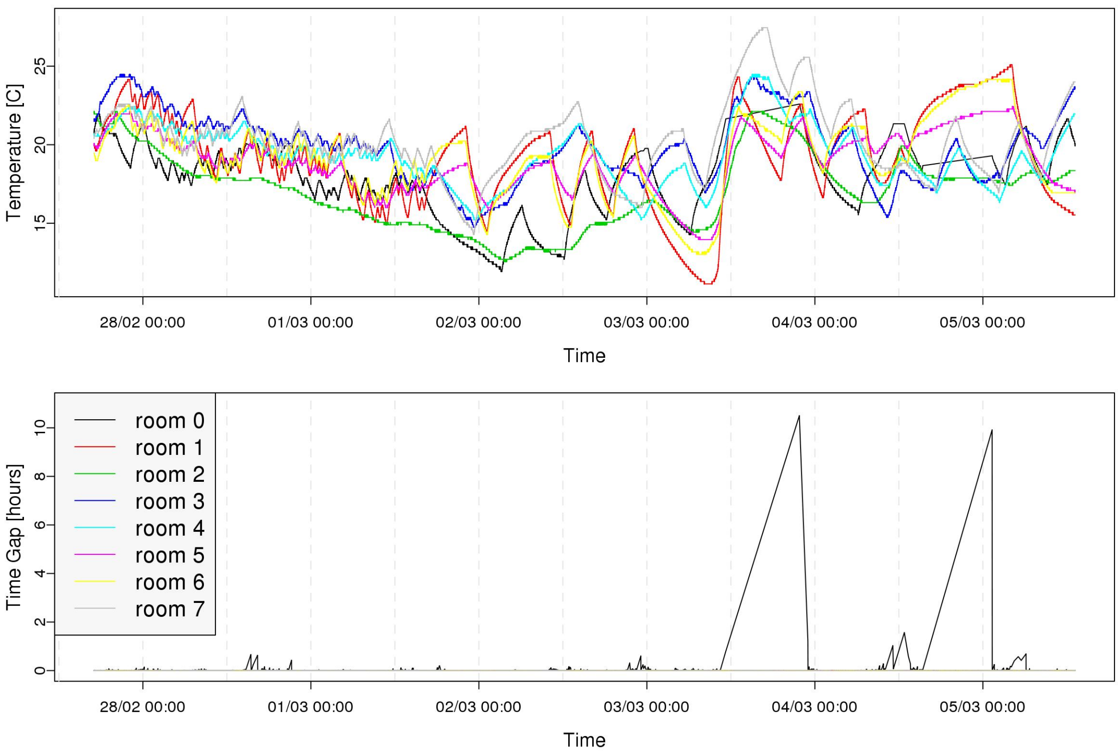


Figure E.1: Time gaps in wall temperatures PRBS2.

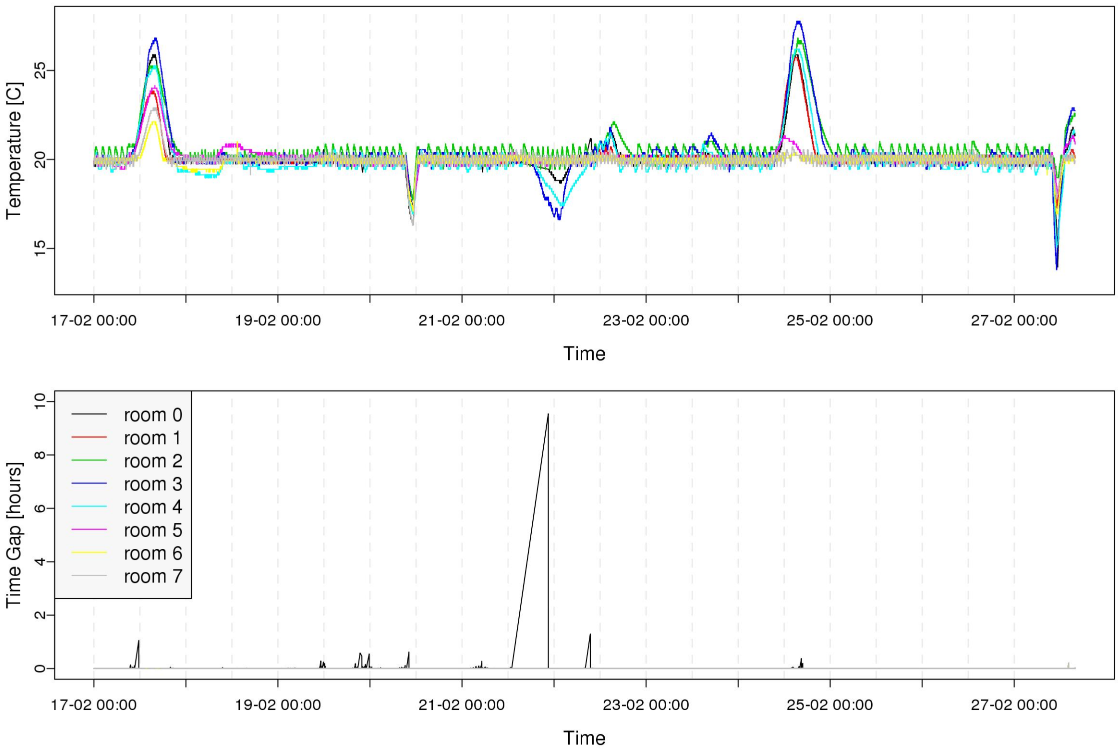


Figure E.2: Time gaps in wall temperatures THERM1.

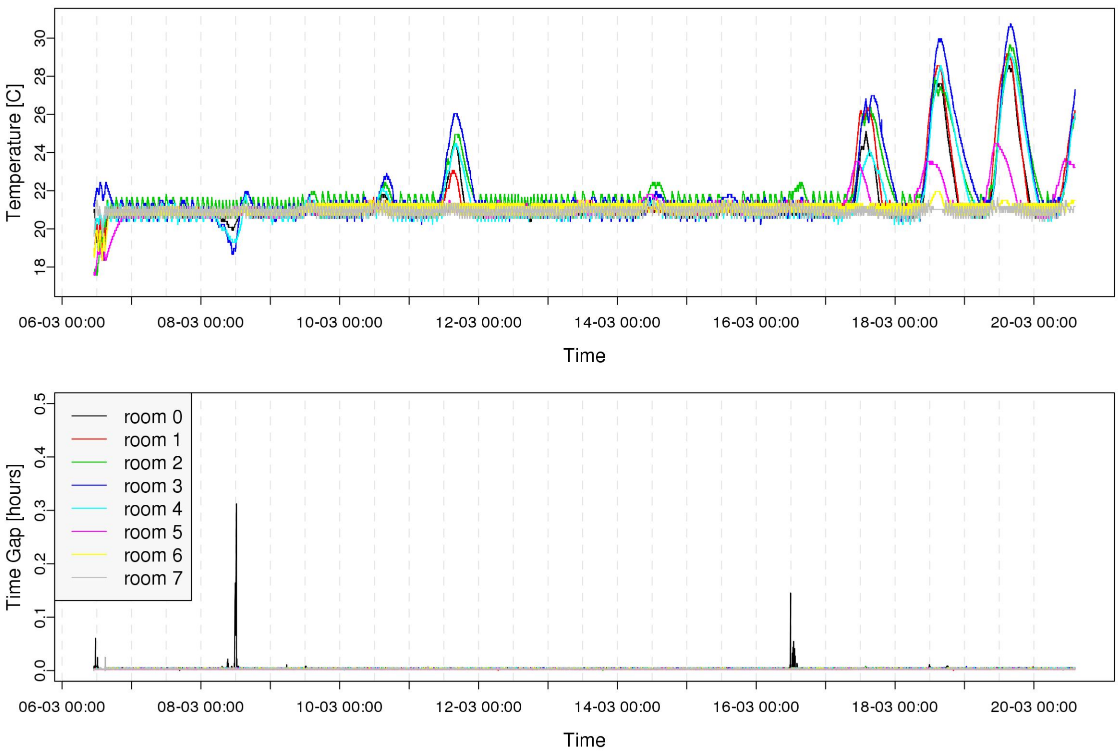


Figure E.3: Time gaps in wall temperatures THERM2.

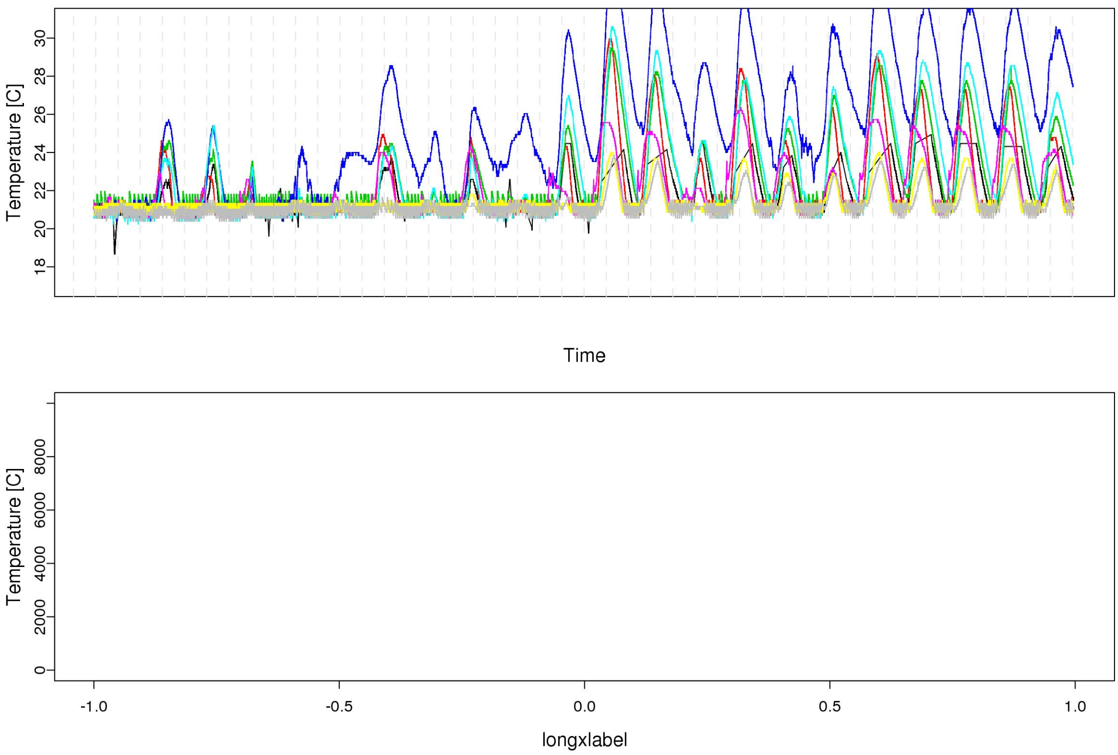


Figure E.4: Time gaps in wall temperatures THERM3.

Appendix F

Specifications for the instruments at the climate station

VAISALA

Certificate report nr. H09-05060057

CALIBRATION CERTIFICATE

Instrument	HMP45AC Humidity and temperature probe
Serial number	A0640007
Manufacturer	Vaisala Oyj, Finland
Calibration date	10th February 2005
Test procedure	Doc210426-A

The above instrument was calibrated by comparing the relative humidity and temperature readings to two HMP233 factory working standards. At the time of shipment, the instrument described above met its operating specifications.

The relative humidity readings of the two HMP233 factory working standards have been calibrated at the Vaisala factory by using Hygro M-3 dewpoint meter. Hygro M-3 dewpoint meter has been calibrated at Vaisala Measurement Standards Laboratory (MSL) by using the MSL primary standard traceable to the NIST. The temperature readings of the two HMP233 factory working standards have been calibrated at MSL by using the MSL working standard traceable to the NIST. The temperature calibration at MSL has been accredited by the FINAS according to the ISO/IEC 17025.

Calibration results

Reference humidity* % RH	Observed humidity % RH	Difference %RH	Permissible difference %RH
0.5	1.4	+ 0.9	±2.0
41.6	41.2	- 0.4	±2.0
68.6	69.3	+ 0.7	± 2.0
Reference temperature* °C	**Observed temperature** °C	**Difference** °C	**Permissible difference** °C
+ 22.77	+22.65	- 0.12	± 0.2

*Average of two references.

Equipment used in calibration

Type	Serial number	Calibration date	Certificate number
HMP233 / RH	623114	2005-01-11	H09-05020022
HMP233 / RH	P1740018	2005-01-11	H09-05020023
Vaisala HMP233 / T	623114	2004-02-16	K008-M00235
Vaisala HMP233 / T	P1740018	2004-02-16	K008-M00236
HYGRO M-3	361095	2005-01-26	N00160
HP 34401A	3146A47883	2004-08-31	K004-04S486

Uncertainties (95 % confidence level, k=2)
Humidity ±1.0%RH @ 0..15%RH, ±1.5%RH @ 15..78%RH
Temperature ± 0.13 °C
Ambient conditions / Humidity 39 ± 5%RH, Temperature 22 ± 1 °C, Pressure 1013 ± 1 hPa.

For Vaisala Oyj

Birgitta Pennanen

Vaisala Oyj
Vanha Nurmijärventie 21
FIN-01670 Vantaa, Finland

Tel. (+ 358 9) 8949 2658
Fax (+ 358 9) 8949 2295
http://www.vaisala.com

Domicile Vantaa, Finland
Trade Reg. No. 96.607

EQUIPMENT USED

Serial number	Description
-	Boundary layer wind tunnel.
1255	Control cup anemometer.
-	Mounting tube, D = 25 mm
t3	PT100 temperature sensor, wind tunnel.
t4	PT100 temperature sensor, control room.
950610	PPC500 Furness pressure manometer
Z0420014	HMW71U Humidity transmitter
U4220037	PTB100AVaisala analogue barometer.
P11	Pitot tube
001551	Computer Board. 16 bit A/D data acquisition board.
-	PC dedicated to data acquisition.

A real-time analysis module within the data acquisition software detects pulse frequency.

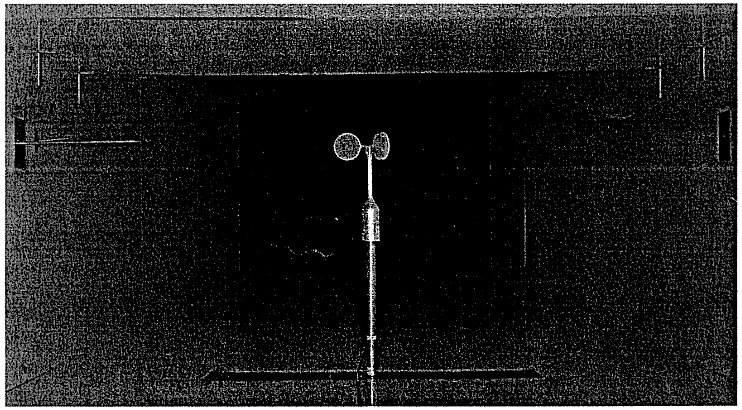


Photo of a cup anemometer in the wind tunnel. The shown anemometer is of the same type as the calibrated one.

UNCERTAINTIES

The documented uncertainty is the total combined uncertainty at 95% confidence level (k=2) in accordance with EA-4/02. The uncertainty at 10 m/s comply with the requirements in the MEASNET procedure that prescribes an absolute uncertainty less than 0.1 m/s at a mean wind velocity of 10 m/s, that is 1%. See Document 97.00.004 "MEASNET-Test report on the calibration campaign" for further details.

SolData Pyranometer 80spc

USER'S GUIDE

pyrano 80spc - UK-oki.wpd

Purpose

The purpose of the instrument is to measure *global irradiance*, i.e. *diffuse* plus *direct* solar irradiance. The pyranometer can be mounted on a horizontal surface or in the same plane as a solar heat collector or photovoltaic (PV) panel when the global irradiation on these surfaces is of interest.

Calibration factor

A typical calibration factor K can be expressed as:

$$K = 160\ mV/(kW/m^2) \qquad (1)$$

This value means that when the solar irradiance S is 1 kW/m^2 (typical for a clear, sunny day around noon) the pyranometer will provide an output voltage around 160 mV. If the output voltage is found to be 80 mV, this indicates that the solar irradiance is about 0.5 kW/m^2 = 500 W/m^2. Thus:

$$S = U / K \qquad (2)$$

where U is the signal voltage in millivolts and S is measured in kW/m^2. Note that forward scattering from clouds may cause values 10-20% higher under extreme conditions.

Cable connections

The 80Spc is supplied with an integral three meter long cable connection. The electrical connections are:

blue - voltage plus (0-200 mV)
black - signal ground

Experience has shown that cable length is non-critical, and cable lengths of up to 30 meters can be used successfully. Atmospheric disturbances such as lightning can of course affect measurements, so it is wise to protect long cables from exposure by burial or by running cables indoors.

Shielded cable is not essential unless a high electrical noise environment is anticipated. Connect the end of the 3 meter cable supplied directly to your datalogger or connect it via an extension using a weather-proof electrical housing.

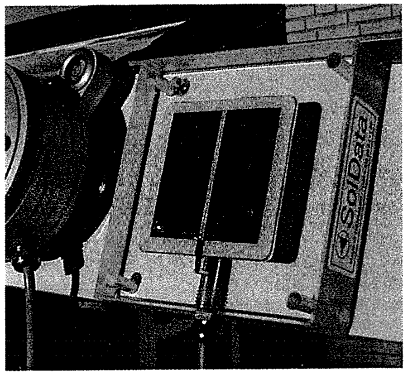


Figure 1: *The SolData 80Spc pyranometer is supplied with a 3 meter long cable and a weather-proof IP54 connection to the instrument.*

Applications

SolData pyranometers have been used to measure solar irradiance from as far north at Thule in northern Greenland to the Palmer peninsula in Antarctica.

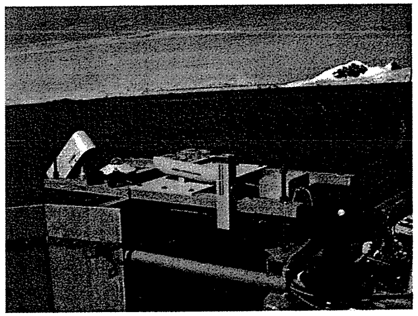


Figure 2: *Two SolData pyranometers performed measurements during the Danish Galathea 3 Expedition 2006-07 here shown near the Palmer Peninsula.*

SolData pyranometers have been chosen for use in Nepal high in the Himalayas. At the other temperature extreme the instruments are used at very warm locations in Australia. Each instrument is temperature compensated for use from -10 °to +50 °C.

During the Galathea 3 research voyage calibration checks were made continuously against a Kipp-Zonen CM11 meteorological pyranometer. Sample calibration check results are shown in Figure 3.

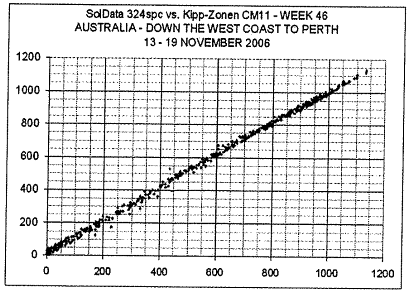


Figure 3: *Calibration check of 80spc against Kipp-Zonen CM11.*

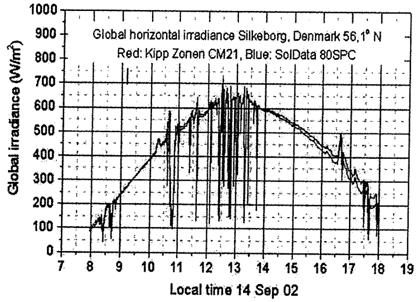


Figure 4: *Global radiation data collected using a 80spc and a Kipp-Zonen CM21 around the spring equinox in Denmark.*

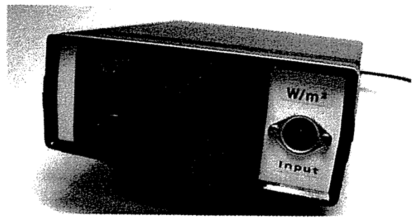


Figure 5: *Continuous display of irradiance in W/m^2 can be achieved using a SolData DM-PYR. Options include relays and 0-20mA current loop output signal.*

Signal integration

In order to measure the *total* solar energy striking each square meter of a particular surface, e.g. a solar collector, a number of options are available.

Datalogger or digital readout module:
The data shown in Figure 4 were collected using a Grant datalogger. Data was recorded every 30 seconds. These data were later downloaded to a PC and transferred to an *Excel* spreadsheet. Using *Excel* the user can define a column which converts the raw voltage values to the irradiance in watts per square meter using Equation 2. By summing up this column and multiplying by the measurement interval in seconds, a numerical integration is performed of the irradiance over time.

In connection with scientific studies of solar heating (or solar photovoltaic) energy systems it is often of considerable interest to compare the global irradiance on the collector with the total energy supplied by the system during the same period. This can for example be done by regarding the heat storage tank as a calorimeter.

PC datalogging:
Modern data acquisition systems can transform an input voltage e.g. from a pyranometer to digital form for computer processing. Equation 2 can be used in the program along with the calibration constant provided with our instrument to continuously record the momentary solar irradiance $S(t)$. The global radiation energy G per unit area is the time integral:

$$\int_{t_1}^{t_2} S(t)\,dt = G \approx \Sigma_i\, S(t_i)\cdot\Delta t_i \qquad (3)$$

The programmer will usually choose a time interval Δt_i in harmony with the acquisition of other quantities in the program. It is of course necessary to be careful to use correct units. kWh/m^2 or MJ/m^2 are recommended.

$$1\ kWh/m^2 = 3{,}6\ MJ/m^2$$

SolData Instruments
att: Frank Bason, Ph.D.
Linåbakken 13
DK-8600 Silkeborg, DENMARK
fax: +45-86 84 15 97
e-mail: soldata@soldata.dk
web: www.SolData.dk

Fraunhofer-Institut für Solare Energiesysteme
PV-calibration laboratory

This calibration check was performed on a SolData pyranometer (no. 109) at the Fraunhofer Institute, Freiburg, Germany. It indicates accord with our calibration to within ±3%. You can expect similar accuracy with the instrument which you now own.

report number:	19.07.91 H 1400
test object:	Si-sensor
manufacturer:	SolData, Silkeborg
type:	80-HD
serial number:	No. 109
client:	Frank Bason, SolData, Linabakken 13, DK-8600 Silkeborg
type of measurement:	secondary outdoor calibration normal to the sun on a tracking platform
reference pyranometer:	Kipp & Zonen, CM 11-3; sensitivity 5.04 $\mu VW^{-1} m^2$; last calibration by Kipp & Zonen in March 1990
Date of calibration:	10th July 1991
report sheet:	100791 K 115
total uncertainty:	3 %
result:	**144.5 mV kW^{-1} m^2** calibration constant of SolData No. 109 (ISE identification SD1PR)
further inquiry:	Fraunhofer-Institut für Solare Energiesysteme att. Dr. Klaus Heidler or Mr. Siegfried Kunzelmann Oltmannsstr. 22, D (W)-7800 Freiburg, Tel.: (+49) 761/4014-0 Telefax: (+49) 761/4014-100, Telex: 17-761-187

Freiburg, 19th July 1991

(responsible for the measurements)

(approved)

Forskningscenter Risø

SolData Instruments
Linåbakken 13
DK-8600 Silkeborg
Denmark

KALIBRERINGSRESULTATER

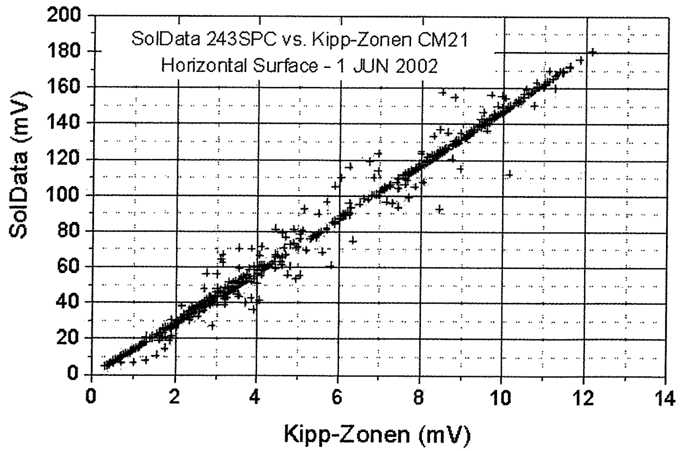
Pyranometer nr. 579SPC

Følsomhed: 158 mV/(kW/m^2)

dato: 10 FEB 2007

Instrumentets følsomhed og linearitet er blevet kontrolleret i forhold til en udendørs kalibreringsopstilling i Silkeborg (56°10'N, 9°34'Ø) med kontrolinstrumenter på en sydvendt flade. Date korrigeres på grundlag af solens elevationsvinkel til standarde luftmasse 1,5 betingelser. Kontrolinstrumenterne sammenlignes regelmæssigt med en Kipp-Zonen CM21 sekundær standard. Nedenstående figur viser sammenhængen mellem et *typisk* SolData fotoelektrisk pyranometer og Kipp-Zonen instrumentet.

Bemærk, at pyranometrets udgangssignal er tilgængeligt på tilslutningsledningen (blå-plus, sort-jord). Den maksimale spænding i meget kraftigt solskin med kumulusskyer i nærheden af indstrålingsvejen, så de giver fremadrettet Mie spredning af lyset, er max. omkring 220 mV. Følsomheden er som nævnt oplyst for AM=1,5. For AM korrektionsdata bed om *Teknisk notat 10312-01*.



Denne SolData SPC (SN 243) blev kalibreret i forhold til en Kipp-Zonen CM21 sekundær standard på en solrig dag med spredte skyer. Læg mærke til den gode linearitet hele dagen. Afvigelser skyldes bl.a. CM21'ens langsom responstid under skypassager. Også ved lave solelevationsvinkler er der god overensstemmelse.

Telephone: +45-86 84 11 96 Telefax: +45-86 84 15 97

POTENTIOMETER WINDVANE W200P

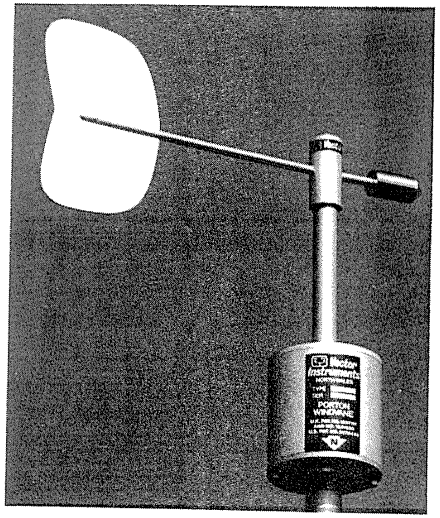
This instrument incorporates a precision wire-wound potentiometer as shaft angle transducer, enabling wind direction to be accurately determined when used in suitable electronic circuits. The potentiometer has the lowest possible torque consistent with long life and reliability, the small gap at north being filled with an insulating material to ensure smooth operation over the full 360°. The vane-arm assembly is attached by the unique Porton™ gravity fastener, allowing rapid attachment and release; thus improving portability.

Construction is from anodised aluminium alloys and stainless steels for exposed parts. Combined with the hard plastic (upper) plain bearing and precision ball races, the result is an instrument with a long service interval which is suitable for permanent exposure to the weather.

In the marine version,[#1] body/fin sealing is enhanced and a touching shaft-seal is fitted above the upper (replaceable) bearing for extra protection.

For applications where improved sensitivity is required, a larger vane version[#2] is available.

An anti-icing heater can also be fitted to extend operation by removing hoare frost around the upper bearing.



Range of Operation

Maximum Wind Speed:	Over 75m/s (150Knots, 170mph) [60m/s][#2]
Range:	360° mechanical angle, full-circle continuous rotation allowed.
Temperature range:	-50 to +70°C

Performance

Threshold:	0.6m/s (1.2Knot, 1.4mph) [0.75m/s][#1] [0.5m/s][#2] (the vane will commence movement when aligned at 45° to the flow).
Response:	Damped natural Wavelength: 3.4m [3.6m][#2] Damping Ratio: 0.2m [0.24m][#2] Recovery distance: 0.51m [0.54m][#2] Distance constant: 2.3m [2.4m][#2]
Repeatability:	±0.5° vane removed and replaced (no measurable backlash movement during use).
Life of potentiometer:	5 x 10^7 cycles (10 years typical exposure).
Service Interval:	4 to 5 years.
Accuracy:	±3° in steady winds >5m/s [6m/s][#1] [3.5m/s][#2] (±2° obtainable following calibration).

Electrical

Potentiometer resistance:	1000 Ω ±10%
Maximum dissipation:	0.5W, -50 to +20°C (de-rate linearly to 0.25W at 70°C)
Maximum wiper current:	50μA*, (20mA absolute max.)
Supply voltage:	1 to 5V*, (20V absolute max.) across terminals 1 & 3.
Case to pot. voltage:	72V max. (case or screen to any terminal on pot.)
Insulation resistance:	>50MΩ
Temperature coefficient of resistance:	±50 x 10^{-6}/°C
Electrical continuity angle:	357.7 ±1.5° (2.3° gap at north)
Electrical variation angle:	356.5 ±1.5° (3.5° dead-band)
Resolution:	±0.2°
Independent non-linearity:	±0.25% (unloaded)

*Notes: Figures marked * refer to recommended operating conditions.*
Bracketed figures marked[#1,#2] refer to parameters changed when options are fitted, (see options section overleaf).

Vector Instruments

Svend Ole Hansen ApS

SCT. JØRGENS ALLÉ 5 · DK-1615 KØBENHAVN V · DENMARK
TEL: (+45) 33 25 38 38 · FAX: (+45) 33 25 38 39 · WWW.SOHANSEN.DK

WIND ENGINEERING
FLUID DYNAMICS

CERTIFICATE FOR CALIBRATION OF CUP ANEMOMETER

Certificate number: 07.02.1156 **Date of issue:** May 19, 2007
Type: Risø P2546A, 2 pulses, plastic cup **Serial number:** 2785
Manufacturer: Risø, VEA, bygning 100, 4000 Roskilde
Client: Risø, VEA, bygning 100, 4000 Roskilde

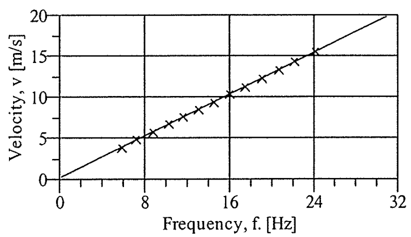
Anemometer received: May 16, 2007 **Anemometer calibrated:** May 16, 2007
Calibrated by: tmh **Calibration procedure:** MEASNET
Certificate prepared by: soh **Approved by:** soh Svend Ole Hansen

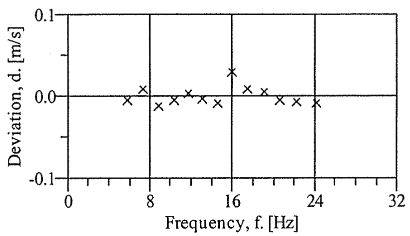
Svend Ole Hansen ApS - Wind Engineering - Denmark

Calibration equation obtained: v [m/s] = 0.63390 · f [Hz] + 0.18914
Standard uncertainty, slope: 0.00089 **Standard uncertainty, offset:** 0.04716
Covariance: -0.0000047 (m/s)²/Hz **Coefficient of correlation:** ρ = 0.999996
Absolute maximum deviation: 0.029 m/s at 10.356 m/s

Barometric pressure: 1003.0 hPa **Relative humidity:** 26.9%

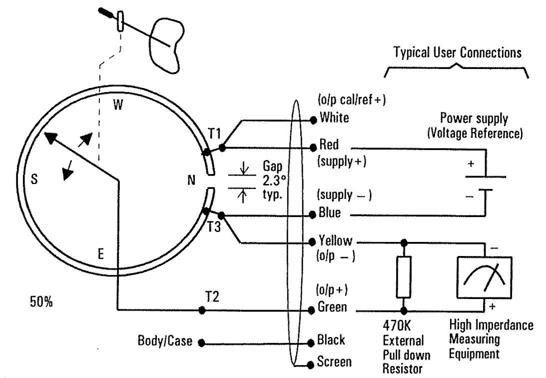
Succession	Velocity pressure, q. [Pa]	Temperature in wind tunnel [°C]	Temperature in control room [°C]	Wind velocity, v. [m/s]	Frequency, f. [Hz]	Deviation, d. [m/s]	Uncertainty u_c (k=2) [m/s]
2	8.64	27.5	21.6	3.863	5.8041	-0.006	0.043
4	13.24	27.3	21.6	4.781	7.2306	0.009	0.041
6	19.29	27.2	21.6	5.769	8.8217	-0.012	0.043
8	26.04	27.1	21.6	6.703	10.2843	-0.006	0.046
10	33.30	27.0	21.6	7.579	11.6504	0.004	0.050
12	41.27	27.0	21.6	8.436	13.0159	-0.004	0.054
13-last	51.04	26.9	21.6	9.380	14.5117	-0.008	0.059
11	62.19	27.0	21.6	10.356	15.9931	0.029	0.064
9	73.80	27.1	21.6	11.282	17.4863	0.008	0.070
7	87.50	27.2	21.6	12.286	19.0748	0.006	0.076
5	102.27	27.3	21.6	13.285	20.6659	-0.005	0.082
3	117.67	27.4	21.6	14.253	22.1958	-0.007	0.087
1-first	138.98	27.7	21.6	15.497	24.1627	-0.009	0.095

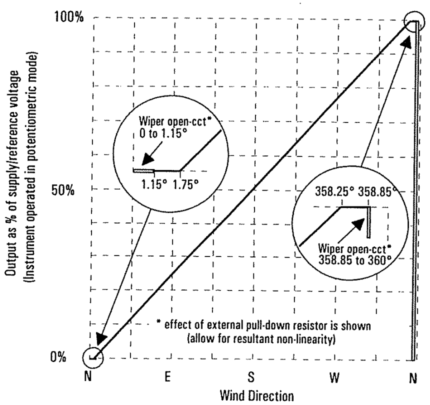




DANAK
Reg. nr. 452

Electrical (cont'd)

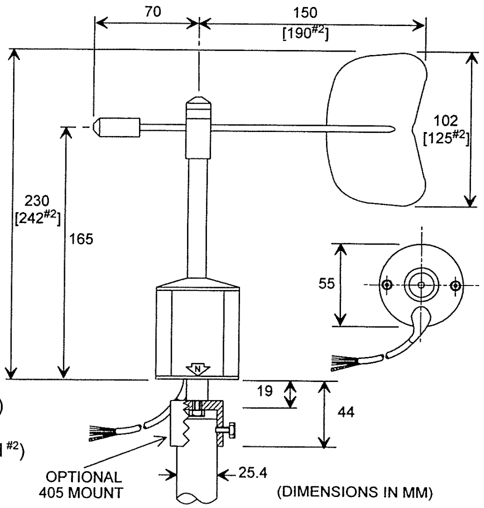




Terminations:	3 metres of 6-wire cable with overall screen: 7 x 0.2mm (≅24AWG) overall tinned copper wire braid screen and black pvc outer. Alternative standard lengths: 6m, 10m, 15m. (where extended, max. recommended overall length: 100m)
Connections:	Red, White: Terminal T1. Green (wiper): Terminal T2. Blue, Yellow: Terminal T3. Black: Sensor body. Screen: Isolated.
Rotation sense:	Direction changes from N through E,S,W to N cause the wiper to move along the track from terminal T3 to terminal T1. Note: Wind direction is North when wind is coming from the North.

Mechanical

Net weight:	310g. [350g][#2]
Packed weight:	700g. [780g][#2]
Packed dimensions:	250 x 160 x 160mm [230 x 180 x 170mm][#2] (one instrument c/w fin)
Fixing:	0.25 inch UNC/BSW screw into base, or optional mast adapter (type 405 shown). Taper fitting also available.
Materials:	Anodised aluminium alloys and stainless steels for exposed parts.



Options

/WR:- Marine version (see bracketed figures marked [#1])
/LV:- The standard F20 vane-arm/fin can be replaced with a larger F20/LV type (see bracketed figures marked [#2])
/HE-1, /HE-2:- Anti-icing heaters, 6W (12V, 24V resp.)

Also available is a selection of mounting brackets and arms, mast adaptors and spare parts; including vane, bearing, potentiometer/spindle assy. & overhaul kit.

CE

Vector Instruments

115, Marsh Road,
RHYL, N. Wales, LL18 2AB,
United Kingdom.
Tel: 01745 350700
Fax: +44 (0) 1745 344206

Vector Instrument's policy of continuous development means that this specification may be altered without notice, however new product will wherever possible remain compatible with that previously supplied.

Distributor:

Operating Instructions Contents:

CE *This instrument complies with the European CE Marking Directive (which includes ElectroMagnetic Compatibility - 'EMC') when used in accordance with these instructions provided that the recommended operating conditions are not exceeded. When used in this way, and when connected to other CE marked equipment intended to be used with this instrument, it should result in a system which also complies with the regulations (although this is not guaranteed). The instrument cable may be extended (using overall screened cable to DEF61-12 part 4 or similar with 7/0.2mm or 24AWG cores) up to 115m total length by use of junction box 2J-DS-A (2-way) or 3J-DL-A (3-way). Application circuits are available on request. OEM users and Value Added Resellers may need to make their own CE conformity declarations.*

WINDVANE TYPE: W200P

(standard product, options /DH,/LV,/WR)

OPERATING INSTRUCTIONS

CE s/n: 6501 onwards

Health & Safety:
Contains PTFE, do not dispose of by incineration.

Windvane Operating Instructions

1) Pull off the plastic protection cap and hold the instrument upright with the locator indent on the spindle turned towards you. Check last three digits of serial number match with instrument and slide on the vane-arm/fin assembly with the counterbalance pointing to your right. Press the hub firmly (twice) until positive location is obtained. ***EXCESSIVE FORCE SHOULD NOT BE USED.***
To remove the vane-arm/fin assembly, first invert the instrument. Press on the hub (approx. 7KgF) to release an internal gravity-sensitive catch, and allow to slide off.

2) Siting should be given careful consideration and our information sheet: 'General Notes on Siting Anemometers and Windvanes' 020-004 may be of assistance. Mount the windvane using a 0.25 inch BSW or UNC screw into the base, ensuring that the screw projects between 0.22 and 0.25 inches into the instrument. Various mountings are available complete with captive screw. Turn the instrument before tightening so that the N arrow on the case faces north (view label with your back to north). In relative measurement applications turn the N arrow - which corresponds to the gap in the track - so that it faces away from the sector of interest. The windvane is intended for upright mounting only.

3) Wire to base station/terminal equipment, logger etc. as per the application circuit below, or refer to the equipment instructions. The windvane cable should not run close to conductors carrying heavy currents which may be frequently switched. For lightning protection see 'Lightning Protection Guidelines' 020-001. Note that the windvane does not include signal filtering components; a suitable load resistor plus capacitor should be added at the terminal equipment end of the cable for this purpose (see overleaf).

Windvane Output

The output is proportional to the fraction of the resistance element covered by the wiper of the potentiometer, with small sections of deadband near the ends, and with a small gap in between at north (see graph on specification sheet). This instrument is intended for use in a potentiometric (or ratiometric) manner. Operation as a variable resistance can give inconsistent results and is not recommended.

When the wind blows from the south, the wiper is halfway along the potentiometer track; when the wind veers from N through E,S,W around to N, the wiper moves along the track from terminal T3 to terminal T1. The instrument is designed to have a reference voltage or current supplied by the red (R) and blue (B) wires, with the yellow (Y) wire as output negative (o/p-), the green (G) wire as the output positive (o/p+) and the white (W) wire as full-scale 'cal' output (o/p cal), although it may be used in other configurations provided the recommended operating conditions are not exceeded[#1].

Windvane Type: W200P (and W200P/DH)

Regular Maintenance / Replacement of Potentiometer (6-8 years normal exposure)

1. Switch off power, disconnect cable, remove instrument from mounting, invert and remove vane assembly by pressing on the hub and releasing. Replace spindle protection cap.

2. Clean windvane and vane assembly F20 (F202 close-fitting skirt for /WR version) using a damp cloth and soapy water (do not immerse).

3. Unscrew nuts holding base plate (18) using a 5.5mm A/F (M3) nut-driver, pull off base plate with body-tube (16) and unsolder wires from potentiometer (10).

4. Remove the 3 servo mounting clips and take out the potentiometer with the spindle (3) attached.

5. Non-marine version: Check upper bearing play does not exceed 0.4mm; if so return instrument to manufacturer for replacement. If marine /WR version, remove touching seal and check upper bearing play does not exceed 0.2mm; if so remove old bearing using a 6mm rod and fit a new brown plastic bearing (order code: 263-02). Do not fit new seal yet.

6. Insert new spindle with potentiometer, obtained as an assembly. Spindle should be concentric to within ±0.05mm (±0.002"). This can be adjusted if necessary by carefully bending (applying side force to end of spindle). Replace onto top plate (4) and tighten servo-mount clips.

7. Re-solder wires to new potentiometer*, yellow and blue to pin 11 brown, the green wire to pin 10 black (centre) and both the red and white wires to pin 12 red, observing the diagram overleaf. Note that the black wire is soldered onto the tag on the base plate and the cable screen is normally isolated.

8. Replace 'O' ring fully against flange on top-plate, push on body tube and then base plate with second 'O' ring in place, making sure wires do not touch lower projection of shaft on potentiometer (see diagram overleaf). Replace nuts to hold instrument together temporarily.

9. Replace vane assembly and rotate while using digital ohm meter to find the position of South (centre of track), mark onto case with pencil, break down instrument again and loosen servo-mount clips, rotate potentiometer the required amount and re-tighten.

10. Repeat as necessary, checking that the N mark on the body is aligned with the vane arm assembly (S = fin on the north side).

11. Remove vane assy. and check that spindle is not pressing on one side of the top bearing (2) as it rotates (it should be central for minimum friction, with slight pressure required to bend it to touch the bearing). For marine version fit a new touching seal, order code: ST-W, whether or not the top bearing was changed.

12. On final assembly, apply non-drying silicone rubber compound around the studs (6), replace washers (8), nuts (9) and wipe off excess compound.

* For W200P/DH: Wire blue to pin 11 brown, the green wire to pin 10 black (centre) and the red wire to pin 12 red, observing the diagram overleaf. Note that the yellow wire is soldered onto the tag on the base plate and the cable screen is normally isolated.

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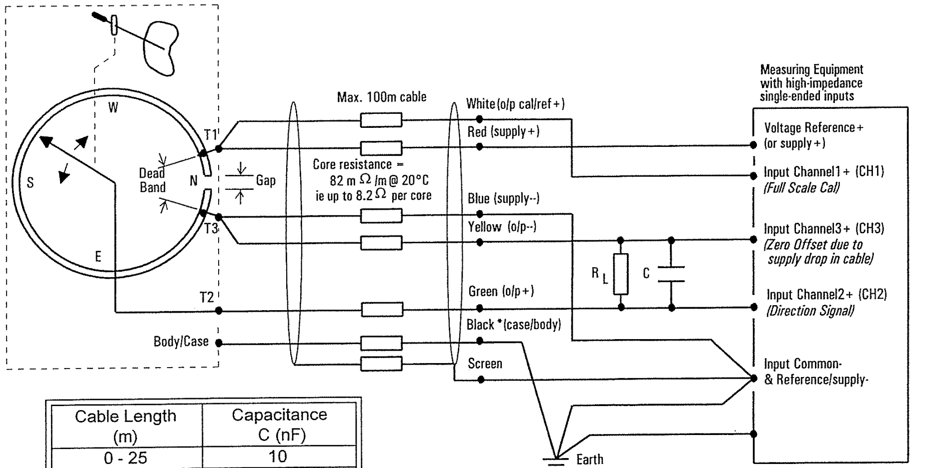
Output Loading

The output will need to be loaded (R_L) to some degree in order to avoid spurious signals when the wiper is in the gap. This loading will add a non-linearity error, the maximum occurs at 240° and is 0.53° using a 100KΩ load (0.11° with a minimum recommended load of 470KΩ). This contribution to error can be corrected if required while logging or subsequent data processing according to the formula below.

A suitable capacitor should be added to the o/p+ (= pot. wiper =green wire) line at the terminal equipment end of the cable. This will reduce possible interference pick-up, especially when the wiper is in the gap. However, the value of R_L x C should not be too large or there will be significant sampling errors when the average wind direction is near north (wiper frequently crossing the gap). To minimise this source of error, it is best to use a relatively low value of load resistance, and apply the correction as the formula below. The table shows suitable values of C for various cable lengths.

Application Circuit [#2]



Cable Length (m)	Capacitance C (nF)
0 - 25	10
26 - 50	4.7
51 - 115	2.2

(* Black to be earthed only if sensor body is not earthed via mast)

/DH version: T1=red, T2=green, T3=Blue, Body/Case=yellow

Formulae

The wind direction can be calculated according to the following formulae which can correct for non-linearity due to loading, voltage drops in the cables and potentiometer tolerances[#2].

Corrected Direction (degrees), $\theta = (360 - D)x_C + \frac{D}{2}$

Where, Corrected Potentiometer Output*, $x_C = x\left\{1 + \frac{R}{R_L}\left(x - x^2\right)\right\}$

** This correction is for the non-linearity due to loading, provided R_L is large compared to the pot. resistance R and the cable core resistance. Set x_c=x if linearity correction is not required.*

and, fraction of full potentiometer output, $x = (CH2 - CH3) \div (CH1 - CH3)$

and, R = potentiometer resistance[#3], R_L = load resistance, D = Deadband (in degrees)[#3]

and, CH1, CH2 and CH3 are measurement channel values.

Notes

[#1] See the paragraph on CE Marking overleaf. It is possible to use this instrument up to the absolute max. ratings in the spec. without damage or degradation of performance, however this is not covered by our declaration of compliance with the CE marking regulations.

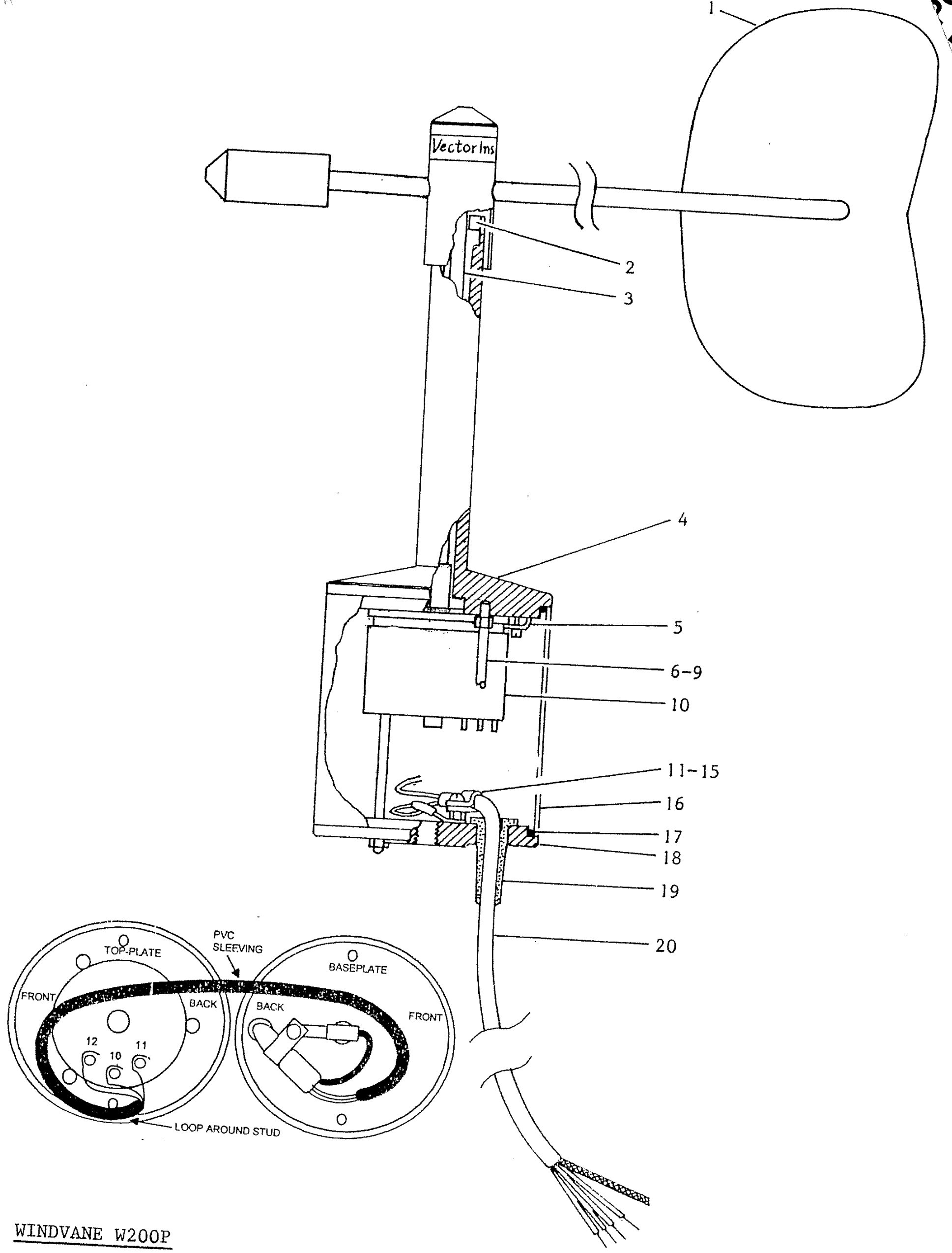
[#2] In some applications there may not be sufficient channels available to measure the three values required. In this case the measurements can be simplified (with an accompanying potential loss of accuracy) as follows:-

i) If the Voltage Reference (V_{REF}) is known (and sufficiently stable), then it need not be measured. The voltage drop in the red wire can also be assumed equal to that in the blue, permitting measurement of only two channels, CH2(potentiometer voltage) and CH3 (voltage drop / zero offset). Thus the formula for *x* becomes: $x = (CH2 - CH3) \div (V_{REF} - 2.CH3)$

ii) If short cables are in use, then the voltage drop in both the red and blue wires is small and may be assumed to be zero (it can be further reduced by paralleling the red+white and blue+yellow wire pairs). If V_{REF} is known (as above) then only CH2 need be measured and the formula for x becomes simply: $x = CH2 \div V_{REF}$.

iii) If short cables are in use, the voltage drop in the blue wire is small and may be assumed to be zero (it can be further reduced by paralleling the blue+yellow wire pair), but if V_{REF} is not known (or not stable over time/temperature etc.) and both CH1 (i.e. V_{REF}) and CH2 are measured, then the formula for x becomes simply: $x = CH2 \div CH1$.

[#3] Refer to specification sheet for nominal Deadband and Potentiometer Resistance figures. Data for individual instruments is available on request. Instruments are set up so that south corresponds to the mid point of the potentiometer resistance.



WINDVANE W200P

GENERAL ARRANGEMENT

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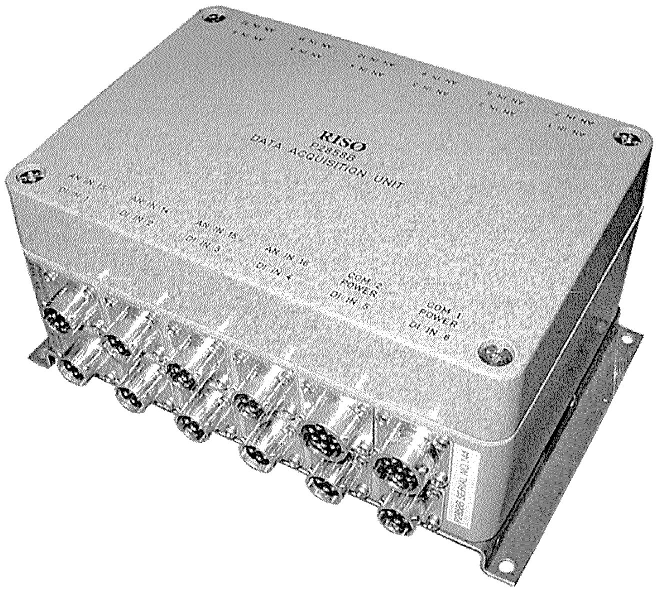
P2858B Data Acquisition Unit

User's Manual



Content

1 Introduction

1.1 Description

The P2858B Data Acquisition Unit (DAU) is a high accuracy and high stability measuring unit developed to be used in meteorological and wind turbine measurement systems. The DAU provides 16 high-resolution analog input channels and 6 general-purpose digital input channels. Data obtained from the input channels is continuously sent to a host computer through a serial interface. Built-in transient protection on all inputs and outputs makes the DAU suitable to be used in outdoor environments without the need for external circuit protection. A power distribution concept enables external sensor units to obtain the power supply from the DAU.

1.2 Features

The P2858B Data Acquisition Unit provides the following features:

- 16 high-resolution analog inputs
- 6 general purpose digital inputs
- 2 serial RS232 or RS485 serial communication interfaces
- Fibre optic option for the serial communication interfaces
- Sample rate of 35 or 70 Hz
- Transient protection on all input channels
- Wide power supply range 10 - 36 V DC
- Wide operating temperature range -40 - 60 deg. C
- Auto calibration
- Watchdog function

1.3 Applications

- Meteorological measurement stations
- Wind turbine measurement systems
- Field measurement equipment

2 General description

2.1 Functional description

After power up the DAU will start reading data from the analog and digital input channels. The data from the analog and digital input channels is formatted into a binary data telegram that is transmitted through the serial port on the DAU. The transmission is continuous at a fixed sample rate of either 35 or 70 Hz.

2.1.1 Analog input channels

The DAU has 16 analog input channels with a resolution of 16 bit. A Sigma-Delta converter with a resolution of 22 bit carries out the analog conversion process and the resolution is afterwards reduced to 16 bit in software by omitting the 6 least significant bits. Before transmission the analog input data is calibrated based on the latest auto calibration. The analog input channels have a fixed input voltage range of -5 to 5 V DC represented in the serial output as:

Input voltage	Digital representation	Hex representation
-5 V	0	0000_{HEX}
0 V	32768	8000_{HEX}
+4.9998 V	65535	$FFFF_{HEX}$

$$Input = 5 \times \frac{output - 32768}{32768}$$

2.1.2 Digital input channels

The DAU has 6 digital input channels that may be configured to one of three functions provided for the digital input channels:

1. Period time measurement (default)
2. Status measurement
3. Position measurement

Period time measurement

The period time measurement is based on a measurement of the number of clock pulses from an internal clock generator within one or more periods of the digital input signal. Two frequencies of 16 KHz or 256 KHz may be selected for the internal clock generator depending on the resolution needed. The output from the period time measurement is in the range 0 - 65535. The period time measurement is the default measurement if nothing else is specified.

For sensors having more than one count per revolution it is possible to divide the input frequency by a division factor of 1 to 31 before measuring the period time. This way the output represents the period time of the rotational frequency rather than a random selected sensor frequency.

For convenience, the rest of this chapter refers to the digital input frequency rather that the period time. The input frequency may be calculated from the DAU output as:

$$Frequency = \frac{Internal\ Clock \times Division\ Factor}{DAU\ Output}$$

Correspondingly the DAU output may be calculated as:

$$DAU\ Output = \frac{Internal\ Clock \times Division\ Factor}{Frequency}$$

As an example a frequency measurement of a 10 Hz input signal in the default configuration with an internal clock of 16 KHz and a division factor of 2 yields an output of:

$$DAU\ Output = \frac{16\ KHz \times 2}{10\ Hz} = 3200 = 0C80_{HEX}$$

The minimum allowed input frequency may be calculated as:

$$Minimum\ input\ frequency = \frac{Internal\ Clock \times Division\ Factor}{Maximum\ DAU\ Output}$$

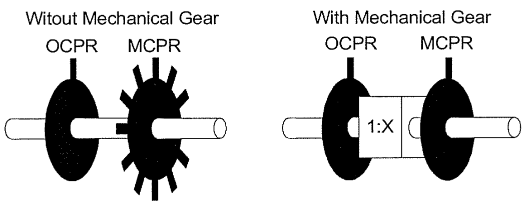
Having an internal clock of 16 KHz and a division factor of 2 the minimum input frequency becomes:

$$Minimum\ input\ frequency = \frac{16\ KHz \times 2}{65535} = 0.488\,Hz$$

Status measurement
When selecting the status measurement the status of the digital input channel is transferred as the value 0 for an open circuit (input disconnected) or the value 1 for a closed circuit (input shorted). Even though the output can only be 0 or 1 the output is still represented as a 16-bit integer. The status measurement is activated by the 'Status output' parameter

Position measurement
This function can be used to measure the angular position of a rotating axis by letting a one-count-per-revolution (OCPR) signal clear the counting of a multiple-count-per-revolution (MCPR) signal. Assuming that the MCPR pulses are uniformly distributed the counting of these pulses represents an angle relative to the OCPR position on a rotating axis. This option is tied to the digital input channels DI IN 5 and DI IN 6 in the sense that DI IN5 must always be connected to the OCPR signal and DI IN 6 must always be connected to the MCPR signal. The position measurement is activated by the 'Clear counter' parameter on DI IN 6. The 'Clear counter' parameter is not available on any of the other digital input channels.

The OCPR and MCPR signals may be established by mounting a one toothed disc and a multiple toothed disc on the same axis, by mounting a one toothed disc on each side of a mechanical gear or a combination of the two. The figure below shows the principle of mounting the toothed discs. The angular position and rotational speed can be read on the position output and the frequency output of DI IN 6 respectively. Even though DI IN 5 is used to clear the counter of DI IN 6 it will still produce its own period time or status measurement on the DI IN 5 output.



Configuration
To configure the digital input channels (FM configuration) the DAU must be brought into terminal mode as described in the configuration chapter. Also the software configuration jumper (S10) must be inserted for the configuration to take effect. Without the software configuration jumper inserted the digital inputs will all default to the period time measurement using the default configuration described below. Four parameters are used to configure the digital input channels.

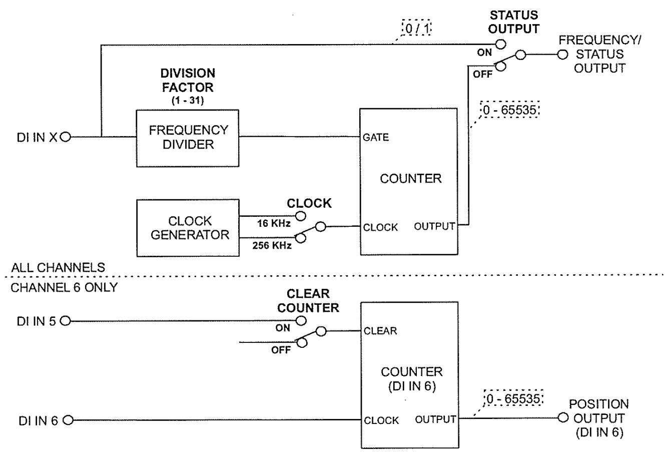
1. **Division factor** - Specifies an integer division factor for the digital input frequency on any channel. This parameter may be used to set up counts per revolution for cup anemometers etc. The parameter can be used independently of the measurement function selected. Default: **2.**

2. **Clear counter** - Used to activate the position measurement on the digital input DI IN 6. When On a signal on DI IN 5 will clear the position counter of DI IN 6. When Off the position counter of DI IN 6 will count to 65535, roll over and then start counting from 0 again. The 'Clear counter' parameter is only available on DI IN 6. Default: **Off.**

3. **Status output** - Used to activate the status measurement on any channel. When On the output will hold the status of the digital input. When Off the output holds the normal frequency measurement output. Default: **Off.**

4. **Clock** - Selects the frequency of the internal clock generator as 16 kHz or 256 kHz on any channel. This parameter may be used to increase the resolution of the frequency measurement. It should however be noticed that increasing the internal clock frequency would decrease the maximum allowed period time for the frequency measurement. Default: **16 kHz.**

The block diagram below shows the functional design of a digital input channel. The configuration parameters as well as the possible parameter settings are shown in bold face.



2.1.3 Serial interface

The serial interface on the DAU is used for transmission of analog and digital input data and for configuration of the unit. A binary data format is used for transmitting the input data and an ASCII based data format is used in the configuration mode. This chapter contains information on the binary data telegram while the configuration mode is described in a separate chapter. The DAU is provided with the two serial ports COM1 and COM2. In the default configuration COM 1 is configured for RS232 communication and COM2 is configured for RS485 communication. The COM1 and COM2 port works in 'parallel' in the sense that they are both receiving and transmitting the same data and should therefore not be used at the same time. In order to communicate with the serial port the acquisition software must use the following serial settings:

Baudrate:	38400 bps
Databit:	8
Stopbit:	1
Parity:	None
Flow control:	None

4800 Bps

The length of binary data telegram depends on the measurement mode selected due to a different number of channels in each mode. The number of data points may be calculated as the total number of channels specified in the table below.

Mode	# Analog channels	# Digital channels	# Count channels	Total # of channels	Sample rate
0	16	6	1	23	35
1	8	0	0	8	70
2	8	6	1	15	35
3	16	1	0	17	35

23+1+1 = 25

≈ 50 byte

≈ 400 bit

Each data point is represented in the binary data telegram as a 16-bit unsigned integer having the MSB (Most Significant Byte) transmitted first and the LSB (Least Significant Byte) transmitted last. The transmission of data starts with a 16-bit start word (8181_{HEX}) and ends with a 16-bit checksum.

The example below shows the binary data telegram in mode 0 including:

- 16 analog channels (AN 1 - AN 16)
- 6 digital channels (DI 1 - DI 6) and
- 1 counter channel (CT6)

$81_{hex} = 129_{10}$

$8 \times 16 + 1 = 80 + 48 + 1 = 129$

It should be noticed that the counter channel is part of the digital channel 6.

Start word A1 A2 ... A16 D1

1	2	3	4		33	34	35	
81_{HEX}	81_{HEX}	AN 1_{MSB}	AN 1_{LSB}	• • •	AN 16_{MSB}	AN 16_{LSB}	DI 1_{MSB}	⇒

D2 .. D6 Count Ch

	36		45	46	47	48	49	50
⇒	DI 1_{LSB}	• • •	DI 6_{MSB}	DI 6_{LSB}	CT 6_{MSB}	CT 6_{LSB}	CS_{MSB}	CS_{LSB}

Check Sum

The checksum is calculated as the sum of the start word and all the data values truncated to 16 bit.

In mode 0 this becomes:

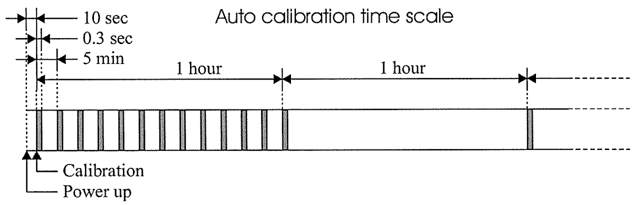
$CS_{16\text{-}BIT} = 8181_{HEX} + AN\ 1_{16\text{-}BIT} + \ldots + AN\ 16_{16\text{-}BIT} + DI\ 1_{16\text{-}BIT} + \ldots + DI\ 6_{16\text{-}BIT} + CT\ 6_{16\text{-}BIT}$

$((-128 - 127) + 128) \times 256$

2.1.4 Auto calibration

The DAU utilises auto calibration in order to increase the stability and accuracy of the analog input channels. The auto calibration is based on an internal high precision voltage reference with an ultra low temperature drift. When auto calibration is activated the analog input circuits is switched from the analog input connectors on to the internal voltage reference and further on to a short circuit of the inputs for a zero voltage reference. This operation takes approximately 300 mS due to the settling time necessary when shifting the input voltage. During the auto calibration the latest reading of the actual analog input voltage is repeated on the serial data output so that the auto calibration does not interrupt the streaming of serial output data.

After start-up the DAU will wait 10 seconds for the power supply to stabilise before making the first auto calibration. It will then make an auto calibration for every 5 minutes during the first hour after start-up to compensate for the slow self-heating of the instrument. After one hour the DAU makes an auto calibration continuously every hour. The auto calibration schedule is shown on the time-scale below.

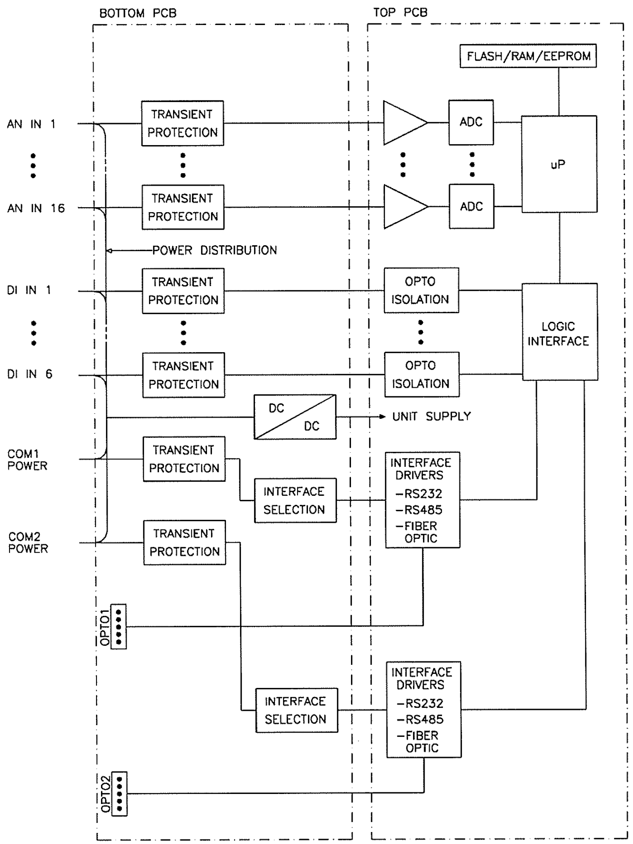


2.1.5 Watchdog

A watchdog circuit is used to supervise the software and hardware function of the DAU to prevent a permanent malfunction in case of a temporary failure. A possible cause could be a powerful noise spike influencing the function of the microprocessor. If the normal operation of the microprocessor is interrupted for more than 1.6 seconds the watchdog circuit will restart the DAU and normal operation can be regained. The parameter 'Number of restarts' found in terminal mode can be used to identify if a problem persists causing the DAU to be restarted repeatedly.

2.2 Block diagram

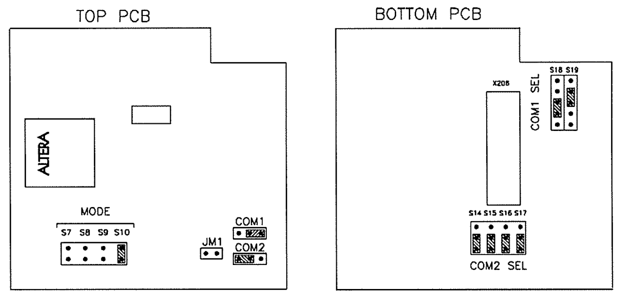
The diagram below shows the main components of the DAU indicating the dual PCB layout of the unit. The dual PCB layout isolates the transient protection and power supply components from the more sensitive electronic circuits. A microprocessor system is used to control the measuring cycle. The microprocessor system is provided with flash, ram and eeprom memory for holding the embedded software, data and configuration information. A programmable logic device is used to control the data flow and for calculating the specialised digital functions. To enable simultaneously sampling of all input channels the DAU contains 16 individual analog input circuits and 6 individual digital input circuits. Each of the two serial ports has drivers for the RS232 or RS485 serial interface and a driver circuit for a fibre optic serial link. A transient protection circuit protects the analog and digital inputs as well as the communication interfaces from lightening and other transient sources.



3 Configuration

3.1 Jumper configuration

The DAU unit may be configured using the jumpers placed on the top and on the bottom PCB. There are two groups of jumpers - one group for selecting the operating mode (MODE) and one group for selecting the interface standard for the serial communication interface (COMx/COMx SEL). The figure below shows the position of the jumpers in the default configuration scheme.

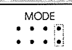
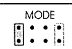
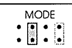
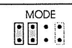


In the jumper configuration tables below the jumper text labels can be used to indicate the orientation of the jumpers.

3.1.1 Mode selection

The mode selection jumpers can be used to set an operating mode for the DAU and to select a software configuration mode for the digital inputs. The operating mode specifies the sample rate and the number of input channels and may be selected using the MODE jumpers S7 to S9. Currently only four operating modes are available. Do therefore not short S9. A jumper is ON with the plastic cap inserted over the two pins of the jumper (pins are shorted) and OFF without a plastic cap (pins are open).

The available jumper settings are:

Mode	# Analog channels	# Digital channels	# Count channels	Sample rate	Jumpers S7 - S10*
0	16	6	1	35	
1	8	0	0	70	
2	8	6	1	35	
3	16	1	0	35	

* S10 is configured as described below

The last jumper S10 may be used to select a software configuration mode for the digital inputs. In this mode it is possible to select a number of special functions for the digital inputs from software. After inserting or removing the software configuration jumper the DAU must be restarted to initialise the digital input functions. The software configuration is described in details in a separate chapter.
The available jumper settings are:

Digital input configuration	Jumpers S7 - S10*
Default configuration used	MODE
Configuration programmed by software	MODE

* S7 - S9 are configured as described above

3.1.2 Serial interface selection

Two sets of jumpers are used to select the interface standard on each of the two serial ports COM1 and COM2. One set is used to connect the serial ports of the microprocessor to the interface drivers (COM1 and COM2 jumpers) and one set is used to connect the drivers to the pins of the output connectors (COM1 SEL and COM2 SEL jumpers). Due to the dual jumper configuration of the serial ports the jumper configuration must apply with some simple rules as described in the tables below.

The COM1 jumper is used to select the interface driver for COM1.

The available jumper settings are:

COM1 interface driver selection	Jumper S13
RS485 - The serial signals are directed to the RS485 drivers. Use RS485 selection on the COM1 SEL pin output selection.	COM1
RS232 - The serial signals are directed to the RS232 drivers. Use RS485 selection on the COM1 SEL pin output selection.	COM1
Fibre optics - The serial signals are directed to the fibre optic drivers. For future use.	COM1

The COM2 jumper is used to select the interface driver for COM2.

The available jumper settings are:

COM2 interface driver selection	Jumper S12
RS485 - The serial signals are directed to the RS485 drivers. Use RS485 selection on the COM2 SEL pin output selection.	COM2
RS232 - The serial signals are directed to the RS232 drivers. Use RS485 selection on the COM2 SEL pin output selection.	COM2
Fibre optics - The serial signals are directed to the fibre optic drivers. For future use.	COM2

The COM1 SEL jumpers are used to select the output pin configuration of COM1. The output from this port is directed to the COM 1 POWER external connector.

The available jumper settings are:

COM1 SEL pin output selection	Jumpers S18-S19
RS485 - The RS485 output is directed to the COM 1 POWER external connector. Use the RS485 selection on the COM1 interface driver selection.	COM1 SEL
RS232 - The RS232 output is directed to the COM 1 POWER external connector. Use the RS232 selection on the COM1 interface driver selection.	COM1 SEL

The COM2 SEL jumpers are used to select the output pin configuration of COM2. The output from this port is directed to the COM 2 POWER external connector.

The available jumper settings are:

COM2 SEL pin output selection	Jumpers S14-S17
RS485 - The RS485 output is directed to the COM 2 POWER external connector. Use the RS485 selection on the COM2 interface driver selection.	COM2 SEL
RS232 - The RS232 output is directed to the COM 2 POWER external connector. Use the RS232 selection on the COM2 interface driver selection.	COM2 SEL

A summary of the jumper configuration is shown in appendix B.

3.2 Terminal mode

The DAU may be put into terminal mode in order to obtain various type of information about the unit and to configure the digital input channels.

First a computer must be connected to one of the serial output connectors COM1 POWER (RS232) or COM2 POWER (RS485). A terminal program must then be started using the following settings:

Baudrate:	38400 bps
Databit:	8
Stopbit:	1
Parity:	None
Flow control:	None

When entering the terminal program the binary data from the serial data transmission will be displayed on the terminal screen as nonsense characters. The character sequence **28581** (the DAU type number followed by the function code 1) is then used to bring the DAU into the terminal mode, which will stop the transmission of binary data and display a text-based menu on the terminal screen.

The menu on the terminal screen will look like this:

P2858a - Data Acquisition Unit - Terminal mode

(D)ate of fabrication
(S)erial number
(N)umber of restarts
(G)eneral description
(C)alibration constants
(V)ersion - Software
(F)M configuration
(J)umper settings
(E)xit terminal mode

By selecting a key character from one of the menu items it is possible to display the various information as one or more lines of information. The information is followed by the text:

Press any key to return to menu

When pressing a key the menu will be displayed again.

The various type of information is described in details below.

3.2.1 (D)ate of fabrication

This parameter specifies the date of fabrication for the DAU. The information is displayed as:

Date of fabrication: 2003-10-12

3.2.2 (S)erial number

This parameter specifies the serial number of the DAU. The serial number is also printed on a label on the instrument box. The information is displayed as:

Serial number: 144

3.2.3 (N)umber of restarts

This parameter specifies the total number of restarts detected by the unit over the complete lifetime. A restart is detected during the initialisation procedure in the DAU software at which point this parameter is incremented. Normally a restart is due to a power off and power on sequence but it may also indicate that the watchdog function of the DAU has initiated a restart. The information is displayed as:

Number of restarts: 31

3.2.4 (G)eneral description

This parameter can be used to identify the DAU. The information is displayed as:

General description: P2858B Data Acquisition Unit

3.2.5 (C)alibration constants

This function return the gain and the offset constants calculated during the latest auto calibration of the DAU. Auto calibration of an ideal analog circuit with no inaccuracies would result in a gain equal to 1.032 and an offset equal to 31761. The information is displayed as:

Calibration constants:
Ch: 1 Gain: 1.03408 Offset: 31675
Ch: 2 Gain: 1.03487 Offset: 31588
Ch: 3 Gain: 1.03690 Offset: 31584
...
Ch: 12 Gain: 1.03821 Offset: 31576
Ch: 13 Gain: 1.03148 Offset: 31768
Ch: 14 Gain: 1.03467 Offset: 31673
Ch: 15 Gain: 1.03467 Offset: 31683
Ch: 16 Gain: 1.03539 Offset: 31633

3.2.6 (V)ersion - Software

This parameter specifies the current software version formatted as x.x.Lyyy where x.x is the microprocessor software version and yyy is the programmable logic device version. The information is displayed as:

Software version: 1.3.L001

3.2.7 (F)M configuration

This function returns the configuration of the digital input channels (FM = frequency modulated). Five parameters are presented for each digital input channel. The information is displayed as:

FM configuration:
Ch: 1 Div: 1 Clear: - Status: Off Clock: 16K
Ch: 2 Div: 1 Clear: - Status: Off Clock: 16K
Ch: 3 Div: 1 Clear: - Status: Off Clock: 16K
Ch: 4 Div: 1 Clear: - Status: Off Clock: 16K
Ch: 5 Div: 1 Clear: - Status: Off Clock: 16K
Ch: 6 Div: 1 Clear: Off Status: Off Clock: 16K

Note: Div = Division factor, Clear = Clear counter, Status = Status output, Clock = Clock

For a description of the FM configuration parameters please refer to the functional description of the digital input channels.

3.2.8 (J)umper settings

This function returns the setting of the hardware jumpers S7 to S10. When a jumper is inserted the status is 'On' and when the jumper has been removed the status is 'Off'.

Jumper settings: S7 = Off, S8 = Off, S9 = Off, S10 = On

3.2.9 (E)xit terminal mode

Selecting this menu item will bring the DAU into the binary transmission mode again.

3.2.10 Changing the software configuration

It is possible to change some of the software configuration parameters describe above by entering the character sequence **2858** (the DAU type number) before selecting one of the key characters from the menu items. The parameters that may be changed are:

- (D)ate of fabrication (max 32 characters)
- (S)erial number (32 bit number)
- (N)umber of restarts (32 bit number)
- (G)eneral description (max 32 characters)
- (F)M configuration (32 bit numbers)

If e.g. the FM configuration is to be changed the character sequence **2858F** must be entered on the terminal screen and the DAU will prompt for the information needed. The display will look like this:

FM configuration:
Ch: 1 Div: 0 Update: Full Clear: - Status: Off Clock: 16K
Ch: 2 Div: 0 Update: Full Clear: - Status: Off Clock: 16K
Ch: 3 Div: 0 Update: Full Clear: - Status: Off Clock: 16K
Ch: 4 Div: 0 Update: Full Clear: - Status: Off Clock: 16K
Ch: 5 Div: 0 Update: Full Clear: - Status: Off Clock: 16K
Ch: 6 Div: 0 Update: Full Clear: Off Status: Off Clock: 16K
New FM configuration (one channel only):
Channel no (1..6):

It is now possible to enter the configuration parameters one by one. For the FM configuration only one channel is configured at a time. If an illegal input is entered the function will abort without any changes and display the message:

Illegal input - No changes made

Press any key to return to menu

For more information on configuring the digital input channels (FM configuration) please refer to chapter 2.

4 Operation

4.1 Connector pin assignment

The DAU has 24 connectors accessible from the two sides of the instrument box each having 12 connectors. Two connectors COM 1 POWER and COM 2 POWER can be used for powering the DAU and for transmission of serial data. The 16 connectors AN IN x are used for the analog input channels and the 6 connectors DI IN x are used for the digital input channels. Labels identifying the individual connectors are positioned on top of the instrument box.

The connector pin assignment is described in the table below.

Pin	COM 1 POWER		COM 2 POWER		AN IN x	DI IN x
	RS232	RS485	RS232	RS485		
A	TXD	TXD+	TXD	TXD+	HIGH (V+)	HIGH (V_{EXC})
B	*NC**	TXD-	*NC**	TXD-	LOW (V-)	LOW (0V)
C	RXD	RXD+	RXD	RXD+	24 V	24 V
D	*NC**	RXD-	*NC**	RXD-	0V	0V
E	24 V	24 V	24 V	24 V	-	-
F	0V	0V	0V	0V	-	-
G	GND	GND	GND	GND	-	-
H	SHIELD	SHIELD	SHIELD	SHIELD	-	-

*NC = No Connection.

Appendix C shows the position of pins in the connectors.

4.2 Power distribution

Internal power distribution in the DAU can be used to simplify the task of connecting external sensor units requiring a power supply. The power distribution connections passes the DAU power supply on to the analog and digital input connectors allowing the external sensor units to be supplied directly from the DAU.

As shown in appendix C the power supply pins E and F are connected directly between the connectors COM 1 POWER and COM 2 POWER. From here the power supply is connected to pin C and D of the input connectors through a PTC resistor protecting the power supply from a malfunction in an analog or digital sensor unit. Care must be taken not to exceed the current limit of the PTC when supplying external sensor units from the DAU. A separate PTC resistor is used to protect the power supply from a malfunction in the DAU.

4.3 Installation

In a normal installation the COM 1 POWER or COM 2 POWER connectors should be used to connect the DAU to a power supply and a computer holding the data acquisition software. If required the power supply and the serial communication can be split up into two separate cables using both COM 1 POWER and COM 2 POWER. The connectors AN IN 1 to AN IN 16 may be used to connect analog input sensors while the connectors DI IN 1 to DI IN 6 may be used to connect digital input sensors. Unused analog input channels should be terminated by a short circuit and not left open.

A typical system setup containing one analog sensor unit and three different types of digital sensor units is shown in Appendix D.

Care must be taken to prevent the excessive start-up current from damaging the power supply and from activating an automatic current limitation when powering up the DAU.

After power up the DAU should automatically start transmitting data on the serial port connection according to the configuration.

A Specifications

Power supply

Supply voltage:	10 – 36 V DC
Operating current:	150 mA @ 24 V DC
Start-up current:	Approx. 0.5A @ 24 V DC
Internal PTC:	Rated current, hold: 0.9A, trip: 1.8A
Inputs PTC:	Rated current, hold: 2.5A, trip: 5.0A

Serial interface

Interface types:	RS232-C, RS485
Baudrate:	38400 bps
Databit:	8
Stopbit:	1
Parity:	None

Analog inputs

Input voltage:	-5 to +5V DC
Resolution:	16 bit = 0.153 mV
Input impedance:	1 Mohm
Analog accuracy:	
Absolute accuracy[1]:	±2.3 mV @ FSR (-40 to 60°C)
Gain error:	±2 mV @ FSR (25°C)
Offset error:	±0.23 mV
Linearity error:	±0.3 mV
Drift:	±0.015 mV/°C @ FSR
Calibrated gain drift[2]:	±0.19 mV/°C @ FSR
Calibrated offset drift[2]:	±0.008 mV/°C

Digital inputs

Sensor types:	Contact Closure, Namur Sensor, Open collector NPN transistor
Functions:	Status, Frequency, Special speed and position
Exitation voltage:	12 V DC through a 3 Kohm resistor
Resolution:	16 bit on frequency, speed and position measurement
Clock accuracy:	±100 ppm (-40 to 60°C)
Minimum Frequency:	0.244 Hz @ 16 KHz clock 3.9 Hz @ 256 KHz clock

Environmental conditions

Temperature:	-40 to 60 deg. C
Humidity:	0 to 100 %
Enclosure:	IP65

Dimensions

Width x Depth x Height:	200 x 140 x 91 (200 x 168 x 91 including connectors)
Weight:	Approx. 2200 g (without mounting bracket)

Note 1: Absolute accuracy at FSR (Full Scale Range) including Gain error, Offset error, Linearity error and Drift.
Note 2: Calibrated gain and offset drift apply to the temperature drift between calibrations only. Right after calibration these errors are compensated for and are therefore not included in the absolute accuracy.

B Jumper configuration

The tables below show the jumper configuration of the DAU. Please refer to chapter 3 for more information on the jumper configuration.

B.1 Mode selection

Mode	# Analog channels	# Digital channels	# Count channels	Sample rate	Jumpers S7 - S10*
0	16	6	1	35	MODE
1	8	0	0	70	MODE
2	8	6	1	35	MODE
3	16	1	0	35	MODE
Default digital input configuration used					MODE
Digital input configuration programmed by software					MODE

B.2 Interface driver selection

COM1	Jumper S13
RS485	COM1
RS232	COM1
Fibre optics (for future use)	COM1

COM2	Jumper S12
RS485	COM2
RS232	COM2
Fibre optics (for future use)	COM2

B.3 Pin output selection

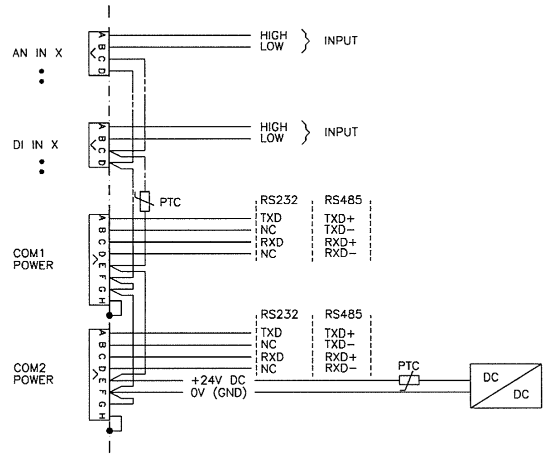
COM1 SEL	Jumpers S18-S19
RS485	COM1 SEL
RS232	COM1 SEL

COM2 SEL	Jumpers S14-S17
RS485	COM2 SEL
RS232	COM2 SEL

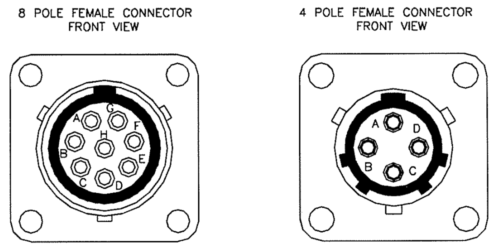
C Connector pin assignment

The figures below show the connector pin assignments and a front view of the male and female input connectors. Please refer to chapter 4 for more information on connecting the DAU.

C.1 Inputs and power distribution

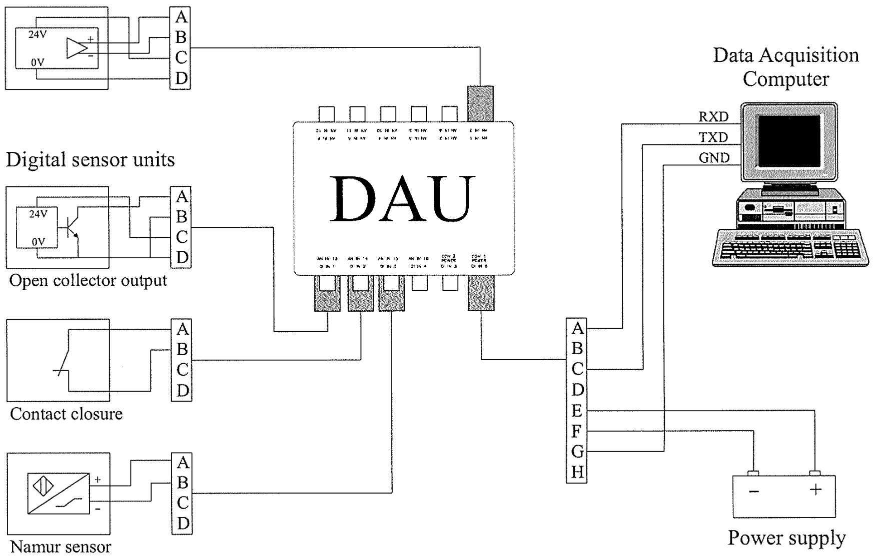


C.2 Connectors front view



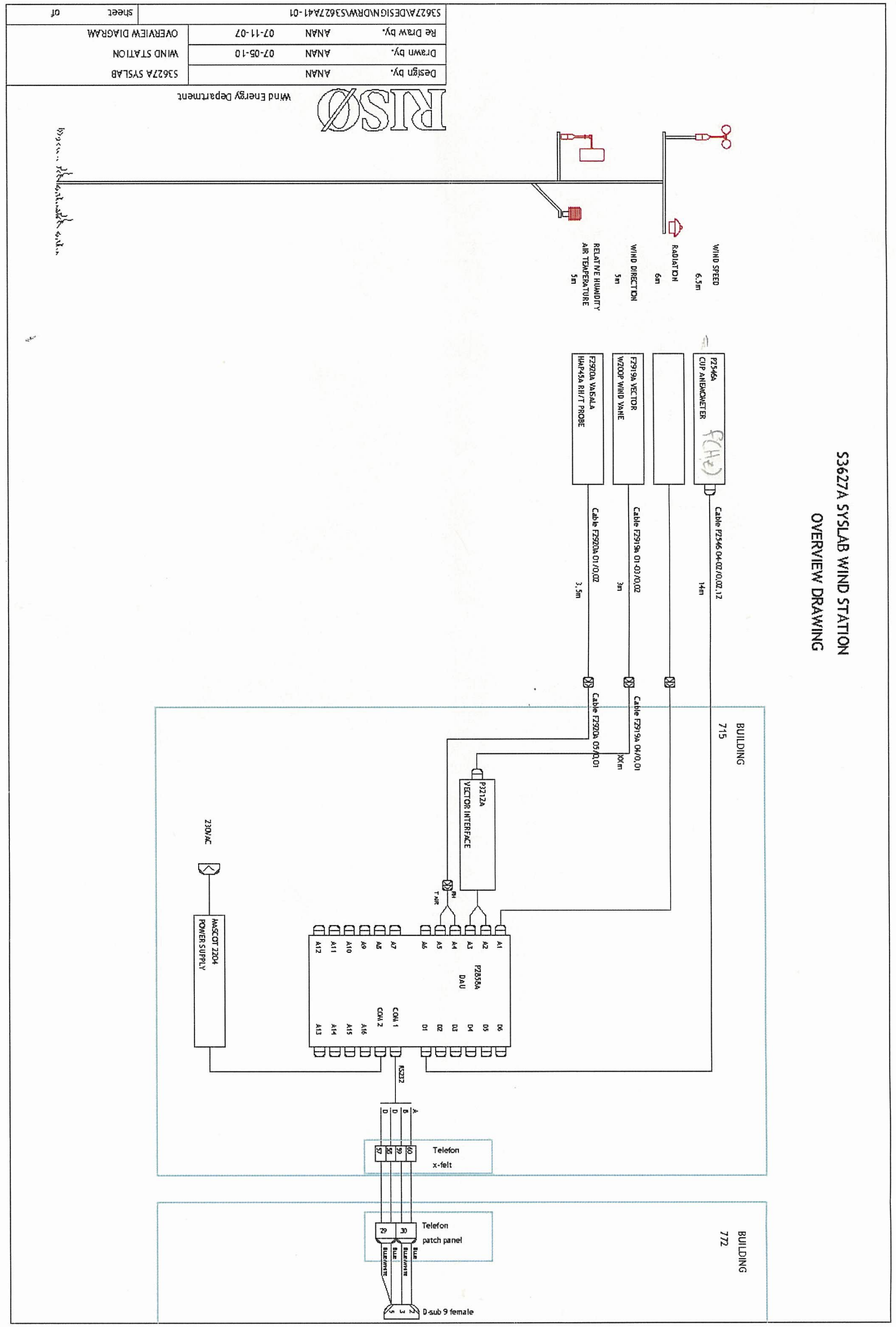
D Typical system setup

The figure below shows a typical DAU system set up. In this example the DAU is used for RS232 serial communication on the COM 1 POWER connector.



The table below shows the connections for a standard pc 9-way and 25-way RS232 serial COM port.

PC Signal	Description	PC 9-pin	PC 25-pin	DAU
RXD	Receive data	2	3	A (TXD)
TXD	Transmit data	3	2	C (RXD)
GND	Signal ground	5	7	G (GND)



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