International Energy Agency
Energy Conservation in Buildings and Community Systems Programme
Annex 58

Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements

Subtask 3 – Common Exercise 3b – May 2013

Revised version of CE 3

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This is a revised version of the CE 3 instruction document sent on 7/03/2013.
Three main changes occurred :
- New appendix gives further explanation on the test carried out by BBRI on the box
- A new test with dynamic heating sequence has been added (Test 3 – ROLBS sequence)
- Three corrections have been made to the data files :
- now only 1 outdoor temperature is given
- 1 time shift in the data from the main weather station has been corrected
- the heating power (W) is given instead of delivered heating energy (Wh)

1. General objectives of the round robin experiment

The global objective of the Round Robin Experiment is to perform a well controlled comparative experiment on testing and data analysis. To this extent, a test box (a scale model of a simplified building) has been built by KU Leuven. KU Leuven is the only partner within the Annex 58-project who is aware of the exact composition of the test box. After construction the box will be shipped to different partners (different climatic conditions and different acquisition equipment) with the aim to perform a full scale measurement of the test box under real climatic conditions. The obtained dynamic data is distributed to different institutes who will try to characterize the test box based on the provided experimental data. In this way, it is not a pure round robin experiment (inter-laboratory comparison performed independently by different institutes), but it is more a combination of a round robin test and data analysis comparison, somewhat comparable with e.g. the BESTEST for numerical modeling.
The aim of the experiment is first of all, within the framework of Annex 58, to

- determine the state-of-the-art on experimental design, full scale measurements and dynamic data analysis: where are we as experts at the moment?

It can be seen as a first step before moving to more complex (real) buildings. Furthermore, the well-controlled experiment allows:

- investigating the capabilities, limitations and reliability of full scale testing
- investigating the capabilities, limitations and reliability of dynamic data analysis
- investigating the influence of variables such as climatic conditions on characterisation tools

and at the same time, the experiment should

- provide a well documented data set for validation of data analysis tools.

As such, the round robin experiment (as later on other case studies in the Annex-project) links the different subtasks.

2. Aim and general description of the exercise

The global objective of this ST3_CE3b is to characterize the Round Robin Test Box based on experimental data obtained during a first measurement campaign performed by BBRI (Belgian Building Research Institute), Belgium. It must be seen as a first explorative exercise on the test box, with main objective identifying strengths and weaknesses of different practiced analysis methodologies, applied on real full scale experimental data.

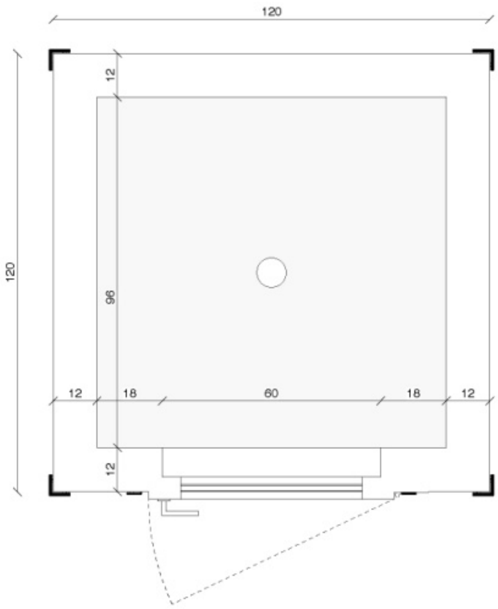
The description of the Round Robin Test Box can be found in section 3. The experiments performed at BBRI are illustrated in section 4. In Section 5, the collected data set is documented. Section 6 concludes with the expected outcomes of this common exercise.

This instruction document, together with the collected measurement data sets can be downloaded from the Annex 58 website.

Appendix 1 at the end of this document gives further information about the tests carried out by BBRI.

3. Round Robin Test Box description

The investigated test box has a cubic form, with exterior dimensions of 120x120x120 cm^3. The floor, roof and wall components are all identical and exhibit a thickness of 12cm, leaving an inner volume of 96x96x96 cm^3. One wall contains a window component with dimensions 60x60cm2, inside window frame (glazed part 52x52 cm², ouside frame 71x71cm²). A structure is provided around the box, which allows the box to remain free from the thermal influence of the ground. Hence, the box can be considered as floating in free air.



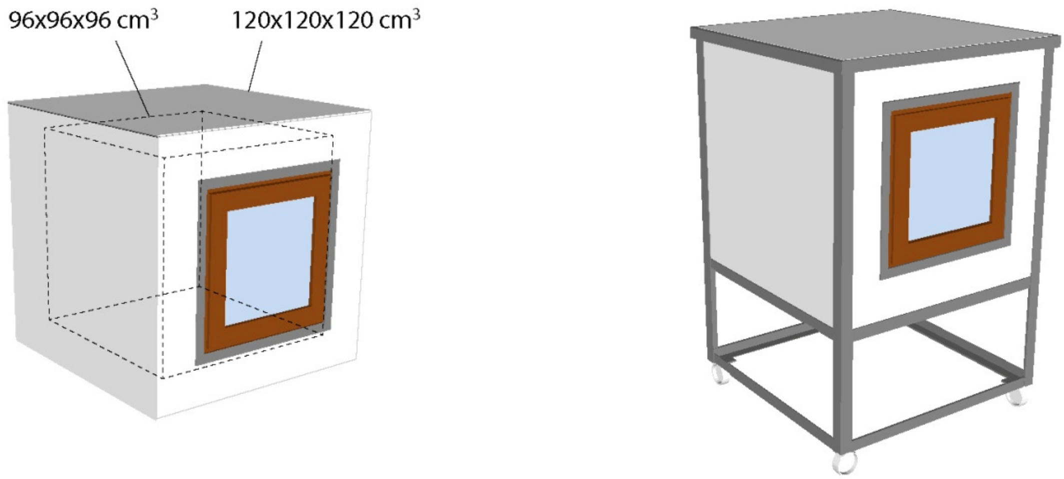


Figure 1. Top left: test box at the measuring site at BBRI, Belgium.Top right: horizontal section of test box. Bottom: overall schematic view of the round robin test box.

4. Performed experiment

4.1. Boundary conditions

The RR Test Box was tested at the premises of BBRI in Limelette, Belgium (Lat. 50°41’ N, Long. 4°31’ E). In general, the weather conditions here are temperate, consisting of mild winters and rather cool summers. It is rainy, humid and cloudy.
The experiments extended over a period of one month, starting the 25th of January 2013 and ending the 28th of February 2013.

Testing is done under real outdoor weather conditions.
The following outdoor climate sensors installed near the test box are included in the supplied data :

- air temperature (with a solar radiation shield and ventilated),
- vertical global solar radiation (parallel and next to the glazing)
- horizontal long wave radiation from the sky.

Additional meteorological sensors installed at the test site (200 m from the test box) are also included in the data sets : horizontal global solar radiation, horizontal diffuse solar radiation, vertical long wave radiation from the South direction, wind velocity, wind direction (North 0°, East 90°) and relative humidity.

4.2. Performed experiments

The following experiments have been carried out :

- Test 1 : co-heating test with constant indoor temperature of 25°C during 2 weeks
- Test 2 : free-floating temperature (with no heating power during 2 weeks)
- Test 3 : dynamic heating sequence lasting for 3.5 days (ROLBS)

5. Measurement data

The data supplied correspond to a testing period extending :

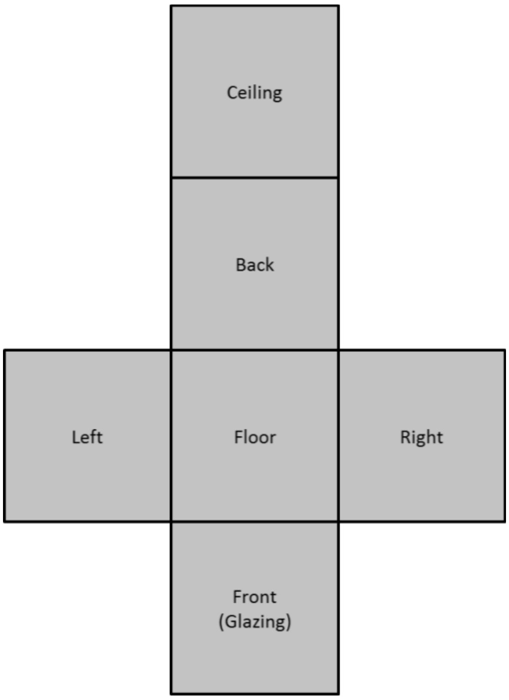
- Test 1 : from the 25th of January 2013 to the 8th of February 2013.
- Test 2 : from 8th of February 2013 to the 22th of February 2013
- Test 3 : from 25th of February 2013 to 28th of February 2013

Important to note is that there has been a problem (power cut) with the data acquisition of the main weather station at the beginning of the co-heating period (Test 1, on the 27th of January 2013) and at the beginning of *the ROLBS period (Test 3, on 25-26th of February 2013). Hence these lines are empty in the file for the channels related to the above mentioned* additional meteorological sensors.

For both tests, the face of the box equipped with the glazing is oriented to the South.
On each face of the box (5 opaque faces and 1 glazing), the following sensors have been installed:

- Internal surface temperature (in the center of the face)
- External surface temperature (in the center of the face)
- Heat flux at the internal face (in the center of the face)

The indoor temperature has been measured along the vertical symmetry axis of the box at 1/3 and 2/3 of the total height of the box.
The heating power is supplied by electrical resistances. The delivered energy is measured via a counter with a resolution of 1 Wh/impulsion and the power supplied during each timestep is given as a back-calculated value



3 data files are supplied, one for each test.

The data files are text files organized in rows and columns. Each column corresponds to a variable. The first row represents the headers of the respective columns and refers to the recorded variables as indicated in Table 1 below. Data are read and recorded in each row every 5 minutes.
The data is made available on the Annex 58 website.

n°	Name		Measurement	Unit	sensor type	Acquisition System
	Time		Time	DD/MM/AAAA hh:mm		
1	Tsi glazing			°C	thermocouple type T	HP Agilent 34970A
2	Tsi left			°C	thermocouple type T	HP Agilent 34970A
3	Tsi back		Internal surface temperature	°C	thermocouple type T	HP Agilent 34970A
4	Tsi right			°C	thermocouple type T	HP Agilent 34970A
5	Tsi ceiling			°C	thermocouple type T	HP Agilent 34970A
6	Tsi floor			°C	thermocouple type T	HP Agilent 34970A
7	Ti down		Indoor air temperature (1/3 height of the box)	°C	thermocouple type T	HP Agilent 34970A
8	Ti up		Indoor air temperature (2/3 height of the box)	°C	thermocouple type T	HP Agilent 34970A
9	Tse glazing			°C	thermocouple type T	HP Agilent 34970A
10	Tse left			°C	thermocouple type T	HP Agilent 34970A
11	Tse back		External surface temperature	°C	thermocouple type T	HP Agilent 34970A
12	Tse right			°C	thermocouple type T	HP Agilent 34970A
13	Tse ceiling			°C	thermocouple type T	HP Agilent 34970A
14	Tse floor			°C	thermocouple type T	HP Agilent 34970A
15	Te		Outdoor air temperature, shielded and ventilated	°C	thermocouple type T	HP Agilent 34970A
16	Øi glazing			W/m²	Huksflux HFP01	HP Agilent 34970A
17	Øi left			W/m²	Huksflux HFP02	HP Agilent 34970A
18	Øi back		Heat flux density at the internal face	W/m²	Huksflux HFP03	HP Agilent 34970A
19	Øi right			W/m²	Huksflux HFP04	HP Agilent 34970A
20	Øi ceiling			W/m²	Huksflux HFP05	HP Agilent 34970A
21	Øi floor			W/m²	Huksflux HFP06	HP Agilent 34970A
22	Qi (W)		Heating delivered power (Wh/h)	W	Finder Type 7E.13	Adv. ADAM 4080
23	Gv		Vertical global solar radiation (plane of the glazing)	W/m²	Kipp & Zonen CM11	HP Agilent 34970A
24	Gh		Horizontal global solar radiation	W/m²	Kipp & Zonen CM12	HP3852A
25	Gh, dif		Horizontal diffuse solar radiation	W/m²	Kipp & Zonen CM13	HP3852A
26	Glw-h		Horizontal long wave radiation from the sky	W/m²	EPLAB PIR	HP Agilent 34970A
27	Glw-v		Vertical long wave radiation from the sky	W/m²	EPLAB PIR	HP3852A
28	WD		Wind direction	°	Thies Clima 4.3129	HP3852A
29	WV		Wind velocity	m/s	Thies Clima 4.3519	HP3852A
30	RH		Relative humidity	%	Vaisala type HM70	HP3852A

Table 1 : nomenclature and units

All temperatures and heat flux densities are acquired with the HP Agilent 34970A acquisition system, together with the vertical global solar radiation (in the plane of the glazing) and the horizontal long wave radiation.
The other meteo datasets are acquired about 200m away from the testbox with the HP 3852A acquisition system.
The heating delivered power is acquired via a Finder module (7E.13) and then with an ADAM module (4080, pulses).
Temperature sensors are thermocouples of type T (copper-constantant) (temperature at cold junction by Pt100 sensor).
The heat flux densities sensors are Hukseflux HFP01 (shipped with individual calibration coefficient).

6. Aim of Common Exercise

Participants are given the freedom to choose what physical characteristics (overall heat loss coefficient, solar aperture, effective heat capacities, time constants, …) of the RR Box to assess. It would be good if at least one of the following performances can be analysed/characterised:

- overall heat loss (W/K) of the test box
- solar gains
- dynamic behaviour of the test box

6.1. Overall heat loss (W/K) of the test box

The overall heat losses of the box can be seen as a steady state performance. For a dynamic experiment under real climatic conditions this mainly corresponds to a kind of averaged performance. So the main aim is to investigate whether it is possible to calculate the overall heat loss coefficient based on the dynamic behaviour of the test box and the measured data of the experiment.

6.2. Solar gains

Try to characterize the performance of the box with respect to solar gains. No further prescriptions are given, so the performance can be described by a kind of averaged value (typical $g_{window}.A_{window}$) or a more dynamic value based on orientation and time, with or without taking solar irradiation on opaque elements into account. Again, the main aim is to investigate whether it is possible to deduce the solar characteristics of the box based on the dynamic measured data.

6.3. Dynamic behaviour

Apart from the overall heat losses and the solar gains, a characterisation of the dynamic behaviour of the box is aimed at. This means response of the box to changing boundary conditions (typical daily cycli of temperature, solar gains,…), capacity of the box,….

The submitted reports need to comprise a detailed description of the applied analysis and validation carried out. Try to be as clear and illustrative as possible in all steps.

7. Deadline

Interested participants are asked to submit their contribution to Mjose.jimenez@psa.es before end of June 2013.

International Energy Agency
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Annex 58

Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements

APPENDIX 1

Subtask 3 – Common Exercise 2 – Round-robin experiment on the test box

Further information on the tests carried out by BBRI

April 2013

Guillaume Lethé, Gilles Flamant

1. Introduction

The objective of this appendix is to give further information on the tests carried out by BBRI to the people participating in the CE3b. The purpose is to clarify how the test box was prepared and measured by the BBRI.

2. Initial preparation of the test box

Before installation of any of the sensors and other material, the envelope has been tested for homogeneity and air tightness. The **homogeneity** of the fabric of the box has been assessed using infrared measurements after conditioning of the box during half a day by heating the inside volume at about 10°K above the ambient temperature. Only tiny influence of the junctions between the faces was observed. Seeing neither structural element nor thermal bridge were identified in the center of the faces of the test box walls, sensors could be positioned confidently. The **air tightness** of the test box has been assessed with a special pumping equipment at several pressure differences. It showed at 50Pa an air change value very close to $1h^{-1}$. Considering the high surface-to-volume ratio of the envelope, the transmission losses could be expected to be much higher than the infiltration losses. Hence, ventilation heat losses due to the actual air change rate taking place during the experiment are considered to be negligible.

After these first checks, inside and outside thermocouples were taped on each face of the test box and air temperature sensors were added (air thermocouples are shielded and naturally ventilated). The heating system is constructed using 4 resistances (tubes with fins, see Figure 1) of 66.5 Ohm (760W at 225V) connected in series, yielding a total maximum power of 190W. The installed power allowed reaching a temperature gradient higher than 40K, which is expected to be able to keep the inside temperature close to 25°C even when outside temperatures reach -15°C.

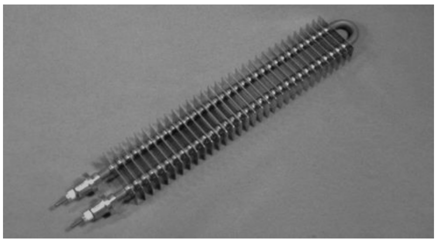
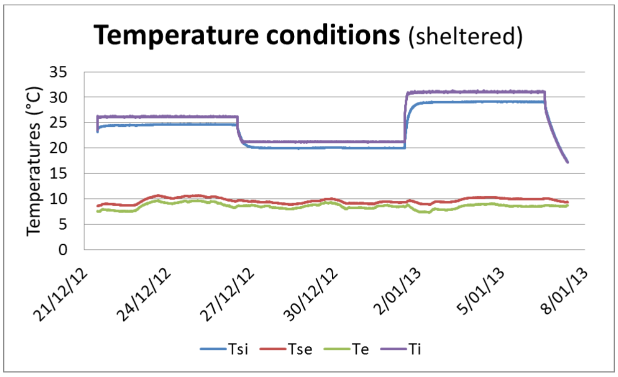


Figure 1: one of the four serial component resistances providing 188W all together

The heating system is PID-controlled in time (cut-in/cut-out) such that the heating power is always balancing from the low and high power levels and can virtually reach any power between these limits when integration is done for a certain period of time.

A **first preparation measurement** (see Figure 2) was done in December 2012, with the target indoor temperature set to 25, then 20 and finally 30°C. The total measurement period covered about two weeks during which the box was standing in an un-heated storage hall, in the lee of wind, sun and longwave radiation.



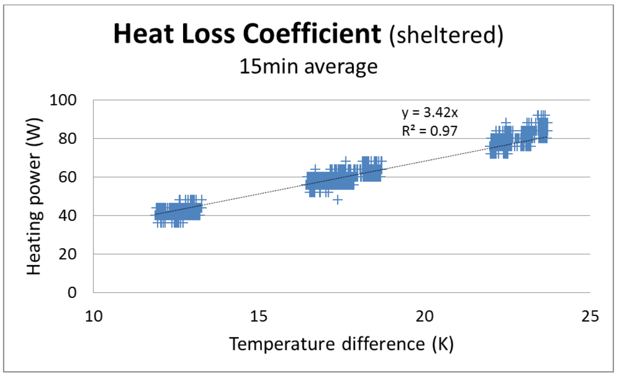


Figure 2: preparation measurement: external and internal temperature conditions (left side : index 'i' for 'internal', 'e' for external, 's' for surface) and linear regressions between heating power and temperature difference using the 15 minute centered-average data (right side)

This measurement allowed checking the stability of the acquisition system, and obtaining a first estimate of the Heat Loss Coefficient (about 3.5 W/K). The latter confirmed that infiltrations losses were not meaningful to be measured (high uncertainty on negligible term). It also helped us adjusting the total installed power such that a ROLBS experiment with reasonable temperature gradient could eventually be run by means of a simple timer.
Therefore we added an extra (by-passable) resistance (253 Ohms) in serie with the 4 others to reach a total installed power of 97W (assuming a tension of 225V), yielding achievable temperature gradients of about 25K (excluding the effects of solar radiation…).

We also noticed that the resolution of the electric energy meter (one pulse per Wh consumed, fine enough for a conventional use) was rather coarse for an experiment within the test box. Unhappily, no time was left at this point to order and install a finer energy meter and it was decided to proceed with this known limitation. 15 minute averages are required in order to find continuous heating power values, where the raw data (one recording every 5 minutes) yield quite discrete heating power values. This means that the identification of parameters related to short time constants is not compromised, but their estimation uncertainty is larger. The assessment of lower frequency behaviour is expected to be unaffected.

After this first measurement, the **test box was equipped with the remaining sensors**.

More thermocouples and heat flux meters have been installed on the surfaces of the test box. In order to reduce the temperature stratification within the box, a small fan (8.3W) blowing in the top-down direction was added inside the box. The stratification happened to be quite small (0.2K, box in an unheated storage hall).

Two additional sensors have been appended to the test box. The horizontal long wave radiation from the sky is measured using a pyrgeometer that stands on the back-left corner of the ceiling and that is ventilated mechanically. The vertical global solar radiation is measured with a pyranometer that is fixed to the test box frame in alignment to the plane of the window. The test box has been aligned to the South as much as possible. After analysis, the resulting orientation appears to be a little to the West, exactly 3.75° ± 0.5° to the West, according to a comparison with radiation from the horizontal direction (acquired from the main weather station).

Other provided weather data come from the **main weather station of the experimental station** of the BBRI in Limelette (see Figure 3), and are exposed to the environment in a similar way (no obstacles to sun radiation) a few hundred meters away. The testing site is located 4°31' East from the Greenwich meridian and 50°41' North.

Figure 3: location of the test box (red triangle) and the main weather station (blue square) at the experimental station of the BBRI (Limelette)

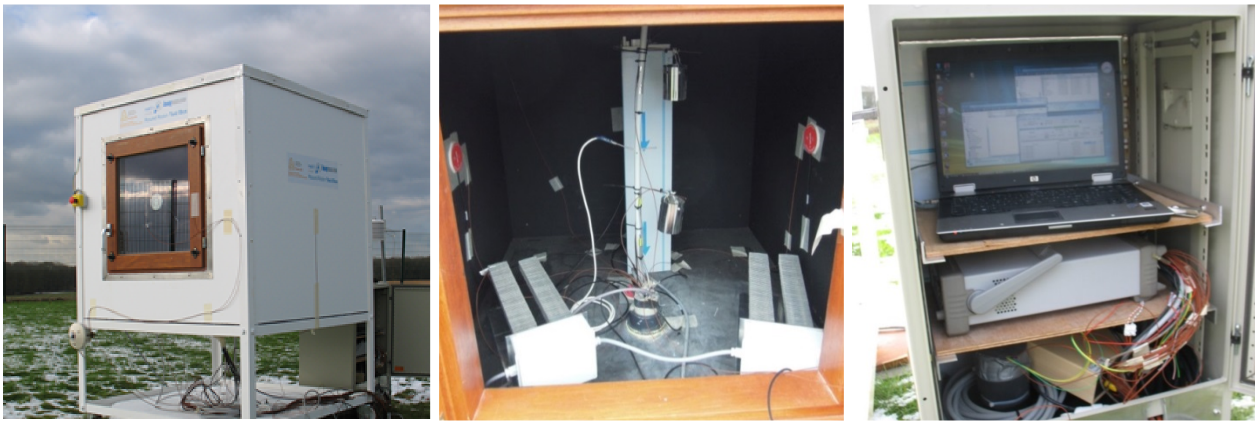


Figure 4: the South-facing window of the test box (left), the inside equipment (middle) and part of the acquisition system (right)

3. Data acquisition

The recording of the portable acquisition (near the test box) occurs punctually every 5 minutes only. Data have been corrected to GMT timeframe. The energy consumption is measured by means of a cumulative counter that is incremented each time 1Wh is consumed. In the provided data files, this consumption is converted to Watts. The other data (temperatures, heat fluxes, solar vertical radiation, long wave horizontal radiation) are recorded in parallel.

The recording of the main weather station is every minute in the GMT timeframe.

In order to consolidate the data, the weather station data have been averaged with a 5 minutes interval. The averaging for the wind direction is done in a vectorial form such that no loss of accuracy occurs if the wind is oscillating around the 0-360° (North) orientation.

4. Performed experiments

The following experiments have been carried out :

- Test 1 : co-heating test with constant indoor temperature (25°C during 2 weeks)
- Test 2 : free-floating indoor air temperature (no heating power during 2 weeks)
- Test 3 : dynamic test sequence (ROLBS) (3.5 days)

	Fan status	**Min. Power**	**Max. Power**
Co-heating	On	8.3W	~198W
Free floating	Off	0W	0W
ROLBS	On	8.3W	~106W

The actual instantaneous power depends on the network tension which is expected to be close to 225W (values in the table above are based on that assumption).

The ROLBS experiment (see Figure 5) has been run after the free floating sequence. It is composed of the following symmetric *number of segments* arranged randomly at both the power levels: 0.5h (2*16 occurrences), 1h (2*6 occurrences), 2.5h (2*2 occurrences), 6.5h (2*1 occurrence), 16.5h (2*1 occurrences). No extra validation sequence of the ROLBS type is available. Nevertheless, the two other data sets could also be used for validation.

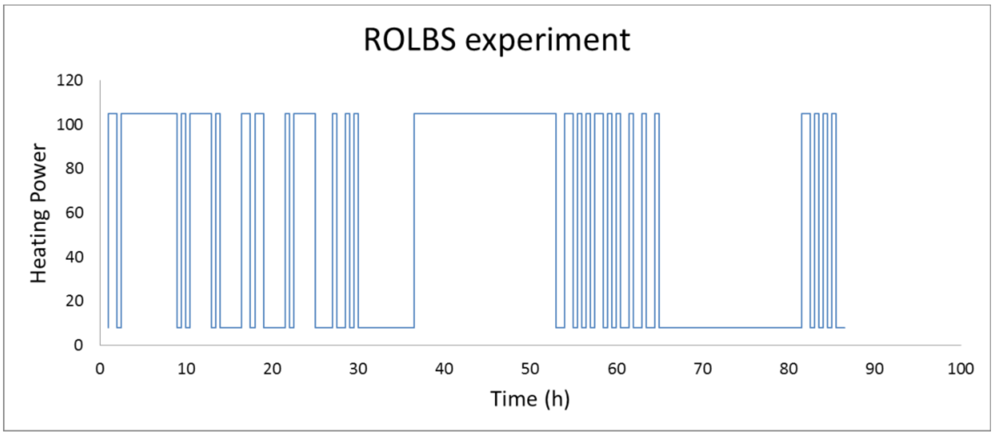


Figure 5 : Heating power, oscillating between low and high power levels, during the ROLBS experiment (3.5 days)

Because of the low resolution of the energymeter, and in order to facilitate the inter-comparison of results, synthetic data is supplied for the heating power of the ROLBS experiment. Low and high power levels have been assumed to be constant (stable network tension assumed) and are determined based on the average power during the two sequences of 16.5h. The Low level power is set to 8.3W and the High power level to 105.8W.

During the measurements, power cuts (see Figure 6) at the main weather station unfortunately occurred at the beginning of the co-heating set and at the beginning of the ROLBS set. This has been left as it is since main variables are still available from the test box acquisition (global vertical solar radiation in the plane of the glazing of the Testbox and the horizontal long wave radiation).

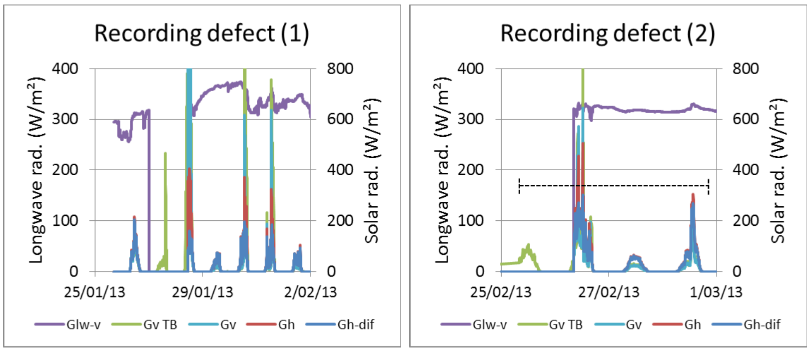


Figure 6 : power cut at the beginning of the co-heating data set (left) and at the beginning of the ROLBS data set (right)