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 4 – 10th July 2013

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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_CE4 is to characterize the Round Robin Test Box based on experimental data obtained during a measurement campaign performed by CIEMAT at PSA in Almería, Spain. This campaign represents a second in a series of campaigns organised in different climatic conditions and using different acquisition equipment depending on which institute is performing the test.

This new exercise intends to continue identifying strengths and weaknesses of different practiced analysis methodologies, applied on real full scale experimental data. Particularly taking into account the weather conditions at this test site and lessons learned from previous tests at BBRI, Belgium, this exercise has the following specific objectives:

- Evaluate the capability to model and obtain accurate energy performance indicators of the test box under warm and sunny weather conditions (winter in Belgium, summer in Sapin)
- Check the consistency of results with those obtained in radically different weather conditions.
- Evaluate if implemented improvement in experiment set up and measurements lead to more accurate measurements.
- Identify potential improvements for next tests

The Round Robin Test Box is shortly described in section 3. A more elaborated description of can be found in the instructions documents corresponding to ST3_CE3b. The experiments performed at CIEMAT 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.

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 60x60cm^2, inside window frame (glazed part 52x52 cm^2, outside frame 71x71cm^2). 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. A more detailed description is included in ST3_CE3b.

4. Performed experiment

This first series of experiments carried out at CIEMAT-PSA has been designed taking as reference the previous set of experiments carried out at BBRI described in ST3_CE3b. Particular measurement devices and test conditions in these new tests are described in the following.

4.1. Boundary conditions

The RR test box was tested at the LECE laboratory at Plataforma Solar de Almeria, in the South East of Spain (37.1°N, 2.4°W). The weather at this test site is dry and extremely hot in summer and cold in winter. Temperature swings largely between day and night. Global solar radiation on the south vertical surfaces is very strong in winter, and on the horizontal surfaces it is very strong in summer. Sky is usually very clear.

The experiments extended over a period of 44 days, starting the 28th of May 2013 and ending the 10th of July 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)
- wind speed
- wind direction (North 0°, East 90°)

Additional meteorological sensors installed at the test site (80 m east from the test box) are also included in the data sets:

- horizontal global solar radiation
- beam solar radiation.
- diffuse solar radiation.
- vertical long wave radiation.

- relative humidity.

Other sensors installed at the test site (325 m north from the test box):

- horizontal long wave radiation from the sky.
- vertical global solar radiation facing north

4.2. Measurement devices

This section describes the measurement equipment and other considerations regarding their accuracy.

The following list summarises the used measurement transducers and sensors:

- Air temperature: Platinum thermoresistance, PT100, 1/10 DIN, directly measured using a four-wire connection, with a solar radiation shield and ventilated for outdoor measurements. (Figure 5 and Figure 8).
- Surface temperature: Analogous sensors and connections as those used for air temperature. The used sensor consists in a very small sensing element embedded in a very slim semi-transparent substrate. These devices have been glued to the measured surfaces in their centre and covered with a tape of same colour of the surface, to integrate them as much as possible with the corresponding surface. (Figure 6 and Figure 7).

  The internal temperature of the glass has been measured using the same device and two additional sensors: One using other type of PT100 with a very small and slim white substrate (named as Tsi glazing2), and other using a type T thermocouple (named as Tsi glazing3).
- Average surface temperature:. Type T thermocouples class 1 according to IEC-584-1982, voltage directly measured using a differential connection, Nine sensors have been matrix distributed and glued in each internal face of the Test Box. The average of the corresponding nine sensors is given for each face.
- Heat flux density: Sensor model HFP01 manufactured by Hukseflux, accuracy of sensitivity coefficient 5%, voltage measured directly by differential connection. One of these devices has been glued to the centre of each internal face of the Box and covered with a tape of the same colour of the surface (Figure 6).
- Horizontal and vertical global solar irradiance on the horizontal and south vertical surfaces respectively: Pyranometers, model CM11 manufactured by Kipp and Zonen, secondary standard according to ISO 9060:1990, voltage directly measured using a differential connection. (Figure 8 and Figure 9).

  Analogous devices used for diffuse solar irradiance but installed in a two-axis sun tracker SOLYS 2. (Figure 9).
- Beam solar irradiance: Pyrheliometer, model CHP1 manufactured by Kipp and Zonen, First Class according to ISO 9060:1990, installed in a two-axis sun tracker SOLYS 2 (Figure 9). Voltage directly measured using a differential connection.
- Horizontal and vertical long wave radiation on the horizontal and south vertical surfaces respectively: Pyrgeometers, model CGR-4 manufactured by Kipp and Zonen, voltage directly measured using a differential connection.
- Heating power: Power transducer, model SINEAX DME 440 manufactured by Camille Bauer Ltd. 4..20mA current loop directly measured.
- Wind velocity: Sensor model WindSonic manufactured by GILL INSTRUMENTS LTD. 4..20mA current loop directly measured. (Figure 8).
- Outdoors relative humidity. Sensor model HMP45A/D manufactured by VAISALA. 4..20mA current loop directly measured.

A data acquisition system with the following characteristics has been implemented: 16-bit A/D resolution, range of measurements fitting sensor output, modules distributed to minimise wiring, based in Compact Field Point modules manufactured by NATIONAL INSTRUMENTS. Particularly the following list summarises the used modules (Figure 10):

- cFP-RTD-124: Four-Wire RTD and Resistance inputs. Range –200 °C to 850 °C used for measurement of temperature.
- cFP-RTD-125: Differential thermocouple or millivolt inputs. Range –20 mV to 80 mV used for measurement of global and long wave radiation and heat flux density.

- cFP-RTD-111: Milliamp input. Range 4–20 mA used for measurement of wind velocity.
- cFP-RTD-110: Voltage or current input. Range 0–1 V used for measurement of relative humidity.

Twisted pairs and grounded shield are employed to reject noise and avoid perturbations from wiring.

4.2. Data acquisition

All data are read and recorded every minute in the GMT timeframe.

The measurements corresponding sensors in the test box and near it and in meteo 1 are collected using the same distributed data acquisition system. Measurements corresponding to Meteo 2 are recorded using an independent data acquisition system with the same characteristics as the one used for the test box. Both data acquisition systems are synchronised to the main time server at PSA.

4.2. Initial preparation of the test box

4.2.1. Heating power and its measurement

Heating power is necessary to produce a delta T high enough to produce a heat flux through walls that allow to see the phenomena to characterize.

Taking as reference the heat flux observed through opaque wall in co-heating test at BBRI (about 10W/m^2), a set point of at least 40°C is necessary to achieve an equivalent heat flux in Almeria at this time. Higher temperatures are avoided for security.

Several actions have been taken to improve the accuracy and resolution in amplitude and time of the measurement of heating power regarding previous test as explained below.

In order to improve the resolution in amplitude a very accurate measurement device, which accuracy is 0.25% of reading, has been used.

Even using a so accurate device time resolution can be very poor if temperature control is very accurate and the switching frequency is higher than the sampling frequency (see figure 13).

Switching frequency depends highly on the control dead band: dead band must be low enough to maintain stable indoor air temperature and high enough to avoid high frequency switching that can lead to low resolution measurement of heating power.

Power supplied by the heating device must be high enough to maintain the indoor air temperature set point taking into account that outdoor air temperature can vary from day to night (differences up to 20°C between day and night), and not too high to avoid indoor air stratification and also to avoid fast switching (see figures 11 and 12).

Taking all these conditions into account, several heating devices, dead bands and set points for indoor air temperature have been examined, with the final goal of achieving (see figures 11 to 15):

- A heat flux through the opaque walls high enough for identification.
- Switching frequency low enough to allow enough time resolution for accurate power measurement.
- Indoor air temperature that is stable enough and at the same time avoiding stratification.

Finally a 100W incandescent lamp has been used as heating device, with 40°C as set point and 0.5°C dead band. Indoor air temperature shows acceptable stability and low stratification, measurement of heating power has enough resolution, and heat flux through the opaque walls is high enough for identification.

For the test using a ROLBS power sequence a 60W incandescent lamp has been used to avoid indoor air temperature increase above 40°C.

4.2. Performed experiments

- Series 1: 31/05/2013 to 05/06/2013. One step of heating the first day, two days free running and the rest with constant heating using a 60W incandescent lamp. Missing: Tse_left, Tse_back.
- Series 2: 5/06/2013 to 10/06/2013. Controlled heating power using a 60W incandescent lamp. First day indoor air temperature set point is 40°C, afterwards it is 38°C, and dead band is 2°C..
- Series 3: 10/06/2013 to 17/06/2013: Controlled heating power using a 100W resistance. Indoor air temperature set point is 40°C, dead band is 2°C, 0.5°C and 0.8°C the first, second and third days respectively..
- Series 4: 17/06/2013 to 26/06/2013: Controlled heating power using a 100W incandescent lamp. Indoor

air temperature set point is 40°C, dead band is 0.8°C the first day and 0.5°C afterwards.

- Series 5: 28/06/2013-1/07/2013: ROLBS power sequence. Heating power using a 60W incandescent lamp.
- Series 6: 2/07/2013-10/07/2013: Free floating temperature.

5. Measurement data

For all these 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:

- Heat flux at the internal face (in the centre of the face)
- External surface temperature (in the centre of the face)
- Internal surface temperature (in the centre of the face)
- Average of the internal surface temperature (from a matrix of nine measurement points, only in opaque faces)

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.

In the initial test phase, different electrical resistances and incandescent lamps have been tried as heating device, with the objective of finding one which allows to maintain stable indoor air temperatures and at the same time exhibiting a switching frequency lower than the sampling interval to allow for accurate monitoring of heating power. Finally, a 100W incandescent lamp has been chosen.

Six 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. Data are read and recorded in each row every minute.

Nomenclature used is the same as in the previous test by BBRI (see instructions document of ST3 CE3b). The text "_1" and "_2" has been added at the end of the name of variables to indicate that these measurements correspond to Meteo 1 or Meteo 2 respectively (see Figure 2).

The text "N/A" has been used in the data files in records for which the corresponding measurement are not available.

The data is made available on the Annex 58 website.

Figure 1: the test box and meteorological devices near to it (left), indoor air temperature (right-top), heat flux and internal and external surface temperature sensors (right-bottom).

Table 1: Nomenclature and units. Variables in common to the previous experiments at BBRI.

Name	Measurement	Unit
TIME	GMT Time	DD/MM/AAAA hh:mm
Tsi glazing	Internal surface temperature	°C
Tsi left		°C
Tsi back		°C
Tsi right		°C
Tsi ceiling		°C
Tsi floor		°C
Ti down	Indoors air temperature (1/3 height of the box)	°C
Ti up	Indoors air temperature (2/3 height of the box)	°C
Tse glazing	External surface temperature	°C
Tse left		°C
Tse back		°C
Tse right		°C
Tse ceiling		°C
Tse floor		°C
Te down	Outdoors air temperature se figure below the box (Figure 1)	
Te middle	Outdoors air temperature se figure mid height of the box (Figure 1)	
Øi glazing	Heat flux density in the internal surface.	W/m^2
Øi left		W/m^2
Øi back		W/m^2
Øi right		W/m^2
Øi ceiling		W/m^2
Øi floor		W/m^2
P heating	Heating power	W
Gv	Vertical south global solar radiation (plane of the glazing).	W/m^2
Gh_1	Horizontal global solar radiation.	W/m^2
Gh, dif_1	Diffuse solar radiation	W/m^2
Glw-h_2	Horizontal long wave radiation	W/m^2
Glw-v_1	ertical south long wave radiation	W/m^2
WD	Wind direction	°
WV	Wind speed	m/s
H_1	Relative humidity	%

Table 2: Nomenclature and units. Added variables regarding the previous experiments at BBRI.

Name	Measurement	Unit
Tsi glazing2	Internal glass surface temperature (small size PT100).	°C
Tsi glazing3	Internal glass surface temperature. (type T thermocouple).	°C
Tsi left avg	Average of the internal surface temperature	°C
Tsi back avg		°C
Tsi right avg		°C
Tsi ceiling avg		°C
Tsi floor avg		°C
Tsi frame avg		°C
Tsi front avg		°C
Gb_1	Beam solar radiation	W/m^2
Ggr_1	Ground reflected solar radiation	W/m^2
Gvn_2	Vertical north global solar radiation	W/m^2

6. Aim of Common Exercise

This exercise consists of two independent parts. Contributions can be to either one or both.

Series 1 to 5 must be used for part 1 and series 6 must be used for part 2. Take into account that some of the provided data may not be necessary.

6.1. Part 1: Obtain the energy performance indicators

The aim of this part is to obtain the energy performance indicators using the data recorded at CIEMAT-PSA.

As in previous exercises, participants are given the freedom to choose which physical characteristics (overall heat loss coefficient, solar aperture, effective heat capacities, time constants, …) of the RR Box to assess. However, at least one of the following performances should be extracted from the analysis:

- U value (W/m^{2}K) of each opaque wall of the test box
- overall heat loss (W/K) of the test box
- solar gains (m^2)
- dynamic behaviour of the test box

<u>Use data series 1 to 5.</u> The suitability of each data set to fit the objective must be discussed.

6.2. Part 2: Cross validation of identified models

The aim of this part is to analyse the capability of a model identified on the basis of one data set to predict the box's behaviour during another period, for which only the inputs are available. Two possibilities come forward:

- Using models identified on the basis of measurement campaigns performed by BBRI, predict the output on the basis of input data recorded at CIEMAT-PSA.
- Using models identified on the basis of data recorded at CIEMAT-PSA, predict the output during a measurement period different from the one used to identify model.

Discuss difference between predicted and simulated output in both cases.

<u>Use data series 6.</u>

6.3. Reporting

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.

The report must consider at least the following items:

- Pre-processing (Data overview, discussion about quality of data and suitability to fit objectives, etc.)
- Modelling (Hypotheses and approximation about the physics behind the model used, statistical and mathematical approach, software tools, etc.)
- Validation (statistical criteria and physical consistency).
- Clear indication of results and uncertainty in each parameter estimate
- Conclusions (about results themselves, about the experiment set up and measurement campaign, etc).

Participants are requested to:

- complete the provided .xls-file (*CE4_series6.xls*) with a prediction of the indoor air temperature T_i for CIEMAT data series 6, based on models trained on other experiment data collected by BBRI and/or CIEMAT. Rename the file to *CE4_series6_country_institute.xls.*

- provide full analysis report in a .doc-file or .pdf-file (CE4_country_institute.doc/pdf).

Please note that *CE4_series6_country_institute.xls* and *CE4_country_institute.doc/pdf* need to be renamed to the participant's actual country and institute name, as e.g. *CE4_series6_Belgium_KUL.xls*.

7. Deadline

Interested participants are asked to submit their contribution to Mjose.jimenez@psa.es and Geert.Bauwens@bwk.kuleuven.be, before 15th of September 2013.

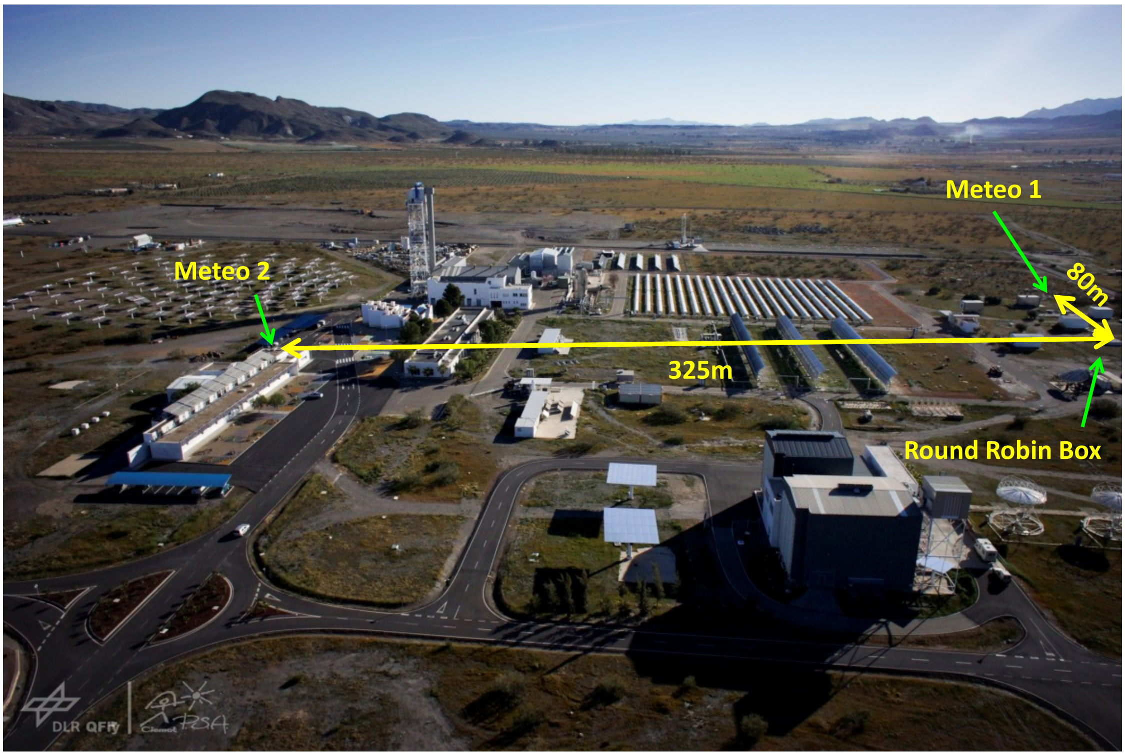

Figure 2: Location of the test box and the other meteorological devices at Plataforma Solar de Almería (PSA).

Figure 3: Placement. Facing south in an open area.

Figure 4: Anchoring additional to the brakes, to prevent damage due to strong winds which are very frequent in the test site

Figure 5: Indoors air temperature and shielding devices

Figure 6: Installation of internal heat flux density and surface temperature sensors. First glued to the internal surfaces and then covered with a tape of same colour of the internal surface.

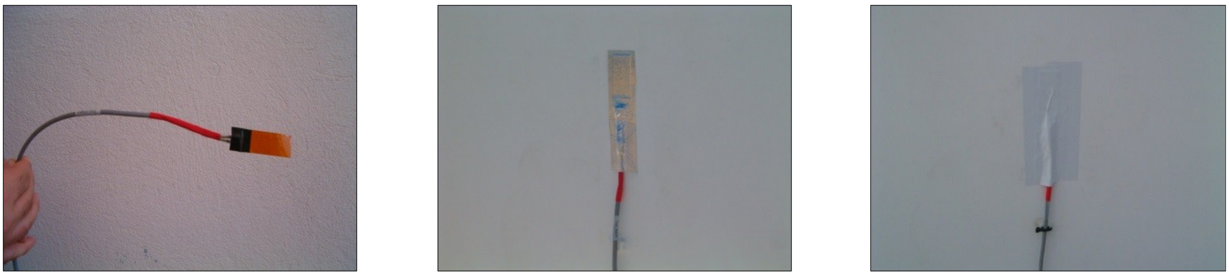

Figure 7: Installation of external surface temperature. First glued to the internal surfaces and then covered with a tape of same colour of the internal surface.

Figure 8: Meteorological sensors near the test box: Outdoors air temperature, global vertical solar radiation, wind speed and direction.

Figure 9: The test box and meteorological devices near to it (left), meteorological devices at meteo 1 (right)

Figure 10: Data acquisition modules