Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 78 (2015) 1738 – 1743

Energy Procedia

6th International Building Physics Conference, IBPC 2015

Optimizing full scale dynamic testing of building components: measurement sensors and monitoring systems

A. Erkoreka[1]*, J.J. Bloem[3], C. Escudero[2], K. Martin[1], J.M. Sala[1]

[1] *ENEDI research group, Department of Thermal Engineering, University of the Basque Country (UPV/EHU), Alda. Urquijo s/n, 48013 Bilbao*
[2] *Laboratory for the Quality Control in Buildings of the Basque Government, C/ Aguirrelanda nº 10, 01013 Vitoria-Gasteiz, (Basque Country)*
[3]*European Commission DG JRC, Via E. Fermi 2749, TP 450, 21027 Ispra (VA), (Italy)*

Abstract

Experimental work to assess the thermal performance of complex building components often requires testing under real and therefore variable conditions. The PASLINK methodology developed during many years by a European network of outdoor test centres is a dynamic methodology that provides high quality data sets and makes it possible to study the thermal behaviour of tested building components.

The test methodology defines the application of a “standard” set of sensors and instruments that are fixed for all experiments carried out in this type of test cells. These minimum set of sensors are the ones described by the PASLINK network quality assurance documentation. The test procedure also includes a calibration process of the test cells. Usually the specific component to be tested is also equipped with extra sensors to obtain specific information of the thermal behaviour of the sample. An example of the sensors over a specific roof test component will be also presented. Finally the data acquisition system requirements will be presented briefly, including both data logger and the software designed for the test control and data acquisition. They must fulfil all the requirements needed for an appropriate testing strategy and a reliable data handling.

It is important to note that the requirements here expressed are valid for any type of test carried out to test the thermal behaviour of a building component under real climate but well controlled conditions. Traceability of all processes and data handling is indispensable for guaranteeing a high quality of the experimental work as well as the evaluation of the collected data by means of dynamic analysis methods.

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL

Keywords: PASLINK test cell; outdoor testing; building component; thermal characterization; dynamic testing; high quality measurements.

* Aitor Erkoreka. Tel.: +34 946017359 ; fax: +34 94 6014283
Email address: aitor.erkoreka@ehu.es

1876-6102
Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL
doi:10.1016/j.egypro.2015.11.285

1. Introduction

Dynamic testing of building components requires a very well controlled and positioned set of sensors with a correct measuring and control system that will provide high quality data sets that will be the basis for the data analysis required to obtain valuable data on the thermal performance of the tested building component. Many works have been published on dynamic data analysis starting in the 1988 with (1) and following with some other important contributions as: (2,3). But there have not been so many publications on the sensor and monitoring system. This paper will focus on describing in detail the quality requirements that during the different PASSYS and PASLINK projects have been found to perform an optimal full scale testing of a building component.

PASLINK evolved (4) from the European PASSYS Project (Passive Solar Components and Systems Testing) which began in 1985, as an endeavour to increase confidence in both the application of energy conscious and passive solar building products and the evaluation techniques used for providing practical thermal performance properties of such products. The PASSYS project was focussed on the test cell facility (5) (Fig. 1) as a means of determining the performance of passive solar building components, and providing more information regarding building design and simulation tools. The advantages of the test cells are that they provide a well-controlled, realistic room sized environment without occupancy effects.

Fig.1: (Left) Schematic of a PASSYS test cell (6). (Middle and right) Two PASLINK test cells in the Laboratory for the Quality Control of Buildings of the Basque Government, one of them also permits to test roof components.

The test methodology and analysis methods (7) in the early days of PASSYS were based around steady state evaluations. However, as the project progressed it became increasingly clear that both dynamic testing and analysis methods were required to deliver high quality performance characteristics for building components tested in real climates (8). In parallel, a programme of upgrading the original PASSYS test cells was accomplished to improve measurement accuracy (9). The test cells that were upgraded with these improvements are named as PASLINK test cells. The PASLINK Network moved away from the original philosophy of prescribed common equipment to one of agreed quality procedures for testing which includes the calibration of instrumentation and the test cells, and also data processing and analysis.

This evolution has lead to important changes in the measurement and monitoring system from the descriptions given on the published papers on PASSYS and PASLINK test cells. And what is more important, the results described in this paper are also valid for any building component or building in its whole that wants to be monitored since the focus is done in optimising the measuring and monitoring systems.

2. General description of the PASLINK measuring method

Dynamic testing of building components requires high quality data sets for model identification. These data sets are mainly the temperature in the inner side of the building component and the outdoors temperature together with the instantaneous heat flux in the inner surface of the component and the global solar radiation over the test component plane. Other variables such as diffuse and long wave radiation, wind velocity and direction, relative humidity and rain precipitation might be also important depending on the specific thermal behavior of the tested component. Test components are facing south (See Fig. 1).

To obtain reliable data sets for data analysis, there must be an average temperature difference of about 20ºC between interior and exterior of the building component to make the measurement error small compared to the errors of the temperature measurements. A 0.5ºC accumulated error in the interior to exterior temperature difference makes a 2.5% error on a 20ºC temperature difference. When generating the 20ºC temperature difference between interior and exterior ambient, the heating or cooling signals generated inside the test room (See Fig. 1) must not be correlated to the exterior temperature (controlling the interior temperature to be constant or making temperature difference constant will generate correlated data sets), otherwise when analyzing the measured dynamic data, the data analysis techniques will not be able to correctly characterize the tested building component thermal behavior. That is why PRBS (Pseudo Random Binary Sequence) or ROLBS (Randomly Ordered Logarithmically Binary Sequence) (2) type signals must be used as heating or cooling signals during tests.

Measuring the inner surface heat flux [W/m^2] with accuracy better than a 5% is the other main issue. When opaque elements are measured in the PASLINK test cells, it has been proven by (10) in section 6.2.4 that direct heat flux measurement in the center of the inner surface of the test component can produce reliable heat flux data sets. When measuring the inner surface heat flux of a semitransparent element, the process becomes complex since the heat flux must be measured in an indirect way. This indirect method consists on making an energy balance in the test room by means of measuring accurately the generated heating or cooling signal together with the heat flow through all the inner opaque surfaces (HFS Tile method (11)) except of the heat flow through the sample. These indirect methods require for in situ calibration and modeling procedures previous to testing the building component to previously characterize the border effects, air infiltrations and other possible effects on the test cell energy balance. A detailed example on how to calibrate and model an indirect heat flow measurement case is explained in section 5.3.3 of (10).

All sensors must be calibrated before being installed. Sensors must be traceable from measurement data sheets to reality and vice versa.

3. Standard sensors for a PASLINK test cell

This section summarizes the PASLINK sensor and data acquisition requirements (12). All sensors have a different 5 alphanumeric code, such as 2STI01 see coding specifications in (12).

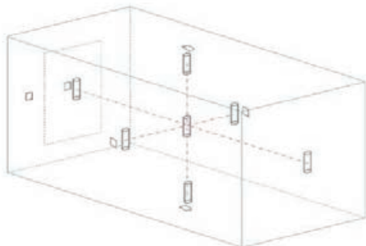

Fig.2: left: front view of the test cell without the south wall (test component). All radiation shielded air temperature sensors can be seen. The green box holds for the electrical resistance for heating by means of exciting signal production and the axial ventilator to avoid temperature stratifications. Right: schematic of the distribution of the temperature sensors inside the test room.

3.1. Internal air temperature measurements

The high insulation of the test room envelope allows for very controlled and homogeneous conditions in relation to the air temperature of the test room. Thanks to the axial ventilator located inside the test room the stratification of air is avoided. Fig. 2 shows the temperature sensors used to record the internal test room air conditions. There are seven air temperature sensors protected against radiation positioned as in Fig. 2. All the air temperature sensors used in the test room are platinum thermoresistances (PT100) with an accuracy of ± 0.1 °C. The PASLINK network test requires the maximum differences of indoor air temperatures must be under 0.5 °C. Actually the average of those seven sensors is used as the internal air temperature. This permits to work with a single value of air temperature inside the test room. As a control signal, the blackbody temperature is also measured in the centre of the test room with a platinum thermoresistance (PT100) with an accuracy of ± 0.1 °C.

3.2. Internal surface temperature measurements

Fig. 2 (small squares on the right figure) shows the temperature sensors used to record the internal test room surface temperature. There are seven surface temperature sensors. All the surface temperature sensors used in the test room are surface platinum thermoresistances (PT100) with an accuracy of ± 0.1 °C. The maximum deviation between sensors is reduced to around 0.5ºC. This permits to work with a single value of surface temperature inside the test room, obtained by averaging.

It is important to note that the maximum difference between average surface and average air temperatures is in practice under 0.6ºC. This fact makes negligible the long wave radiation effects inside the test room. This assumption assures that the surface Heat Flux meters in the internal surface of the test sample are not affected by the different emissivity between the sensor outermost surface and the sample inner surface (13).

3.3. Outdoors temperature measurements

Outdoors temperatures are recorded in several places, see Table 1 for description and location of each of the sensors. During sunny hours the temperature increases more in the roof, south and Meteorological station (located at 10 m high) rather than below the test cell. This is logical since the air temperature below the test cell is cooler during daytime in such a shadowed place. However, this relationship is reversed during the night due to the thermal inertia of the land and the protection to sky radiation exchange by the test cell itself. This way the temperature below the test cell is maintained highest during the night.

Table 1: codes, description and accuracy of the outdoors temperature sensors.

Name	Description	Accuracy
2ATE01	Outdoors air temperature. This sensor is placed in front of the south wall at the test sample height, protected against radiation and YES mechanically ventilated.	± 0.1ºC
2ATE02	Outdoors air temperature. This sensor is placed below the test cell, protected against radiation and NOT mechanically ventilated.	± 0.1ºC
2ATE03	Outdoors air temperature. This sensor is placed over the test cell but under the sun screen, protected against radiation and NOT mechanically ventilated.	± 0.1ºC
2ATI09	Service room air temperature. It is located in the centre of the test room protected against radiation and NOT mechanically ventilated.	± 0.1ºC
2STI08	Service room surface temperature. Over the surface of the partition wall.	± 0.1ºC
0ATE04	Outdoors air temperature. This sensor is part of the VAISALA meteorological station (ME) of the test site located at 10 [m] height. Protected against radiation NOT mechanically ventilated.	± 0.2ºC

The NOT mechanically ventilated 2ATE03 temperature deviates considerably from the mechanically ventilated 2ATE01 temperature when the solar radiation is high. In hot and sunny days the deviation between the ventilated and not ventilated temperatures is considerable (up to 5ºC). This effect is because the natural ventilation is not enough to evacuate the solar radiation reaching the shield.

The other outdoor air temperatures are mainly used for controlling if there is something strange in the 2ATE01 signal. During daytime of sunny days the 2ATE01 should be above 2ATE02 signal and under 2ATE03 signal. During cold and clear nights, the 2ATE01 should be below 2ATE02 signal and above 2ATE03 signal. During cloudy and warm days the three signals should be nearly the same. These checks are very important since the 2ATE01 signal will be used as a direct input for most of the models.

3.4. Solar radiation measurements

Global solar radiation on the building component plane and the outdoors temperature are the most important environmental variables. The radiation flux will participate in the overall balance of heat exchange of the test sample and the test cell itself. This data must be measured by pyranometers (3% accuracy) which record the global vertical (or horizontal) radiation over the plane of the tested sample. Diffuse horizontal solar radiation (3% accuracy) and longwave radiation (5% accuracy) are also recommended although not used in some modeling approaches.

3.5. Other meteorological variables measurements

Wind velocity and wind direction are other important variables during the tests. They can be introduced in the models if external convective coefficients are assumed wind dependant. The outdoors air relative humidity and rain precipitation are usually important for building components hygrothermal behavior characterization. Although it is rarely used in the data analysis, the atmospheric pressure is measured at the test site meteorological station. All the sensors presented in this paragraph are listed in table 2 with the corresponding code, description and accuracy.

Table 2: codes, description and accuracy of the other meteorological sensors.

Name	Description	Accuracy
2AVE01	Anemometer. Wind velocity measurement in the same height of the sample.	± 1%
0AVE02	Anemometer. Measured in the VAISALA meteorological station 10 [m] height.	± 1%
2ADE01	Wind direction. Wind direction measurement in the same height of the sample.	± 10º
0ADE02	Wind direction. Measured in the VAISALA meteorological station 10 [m] height.	± 10º
0RHE01	Relative humidity of outdoors air. Measured in the VAISALA meteorological station 10 [m] height.	± 3%
0APE01	Atmospheric pressure. Measured in the VAISALA meteorological station 10 [m] height.	± 10 Pa
0RPE01	Rain precipitation. Measured in the VAISALA meteorological station 10 [m] height.	-

3.6. Heat Flux Sensitive Tiles (HFS Tiles) and power transducer for heat balance on the test room

The HFS Tiles are the heart of the PASLINK test cells; see inner surface lining of Fig. 2. The HFS tiles permit to calculate the heat flux through the tested sample in an indirect way. For doing the energy balance, the heating (or cooling) signals generated inside the test room are measured by means of a power transducer with accuracy better than a 0.25%. After calibration of the whole test cell (calibration example in (10)) the error of the inner surface heat flux measurement through the test sample should be better than a 5%.

4. Example of sensors on a test component

As an example the sensor set installed in a roof test sample covered by vegetation with a set of 38 sensors will be briefly presented (see Fig. 3). 31 surface temperatures are measured, 5 per layer (see Fig. 3) plus some extra ones in the soil layer; all embedded temperature sensors are thermocouples (accuracy 0.3ºC) and the rest are Pt100 (accuracy 0.1ºC). Average temperature of each layer five sensors is used for modeling. There is one heat flux in the centre of each layer (accuracy 5%), in total 4 sensors. For hygrothermal analysis three relative humidity sensors (accuracy 3%) at different layers of the sample have been installed. The experimental design have been done in order to achieve two primary objectives: experimental characterization of the thermal behaviour of the sample by means of identification (thermal transmittance and thermal capacity) and validation of a numerical model developed to study the green cover effect. For detailed description of the described test component sensors see (10).

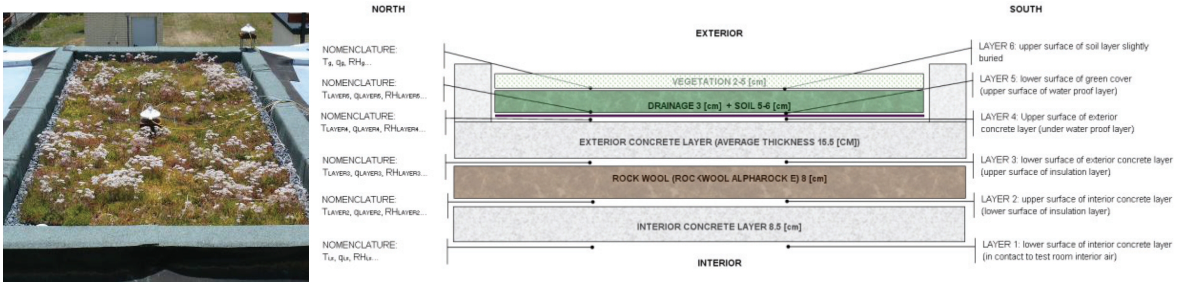

Fig.3: left: front view of the green roof test sample installed on top of the test cell. Right: Schematic view of the test sample covered by vegetation. Each layer is numbered and described. Also the nomenclature to refer to each layer variables can be seen.

5. Data acquisition system

The acquisition system is placed in the service room (Fig. 1) of the test cells and all the measuring and control signals are connected to it. There is cable connection from this device to the control room where a computer stores all the data in some "dayfiles" that keep every signal recorded each minute. Before starting the model identification and validation analysis this "dayflies" are processed. The processing consist mainly in calibrating the signals by means of the calibration factor for each of the sensors and averaging each signal into a 10 [min] basis (or other).

6. Discussion and conclusions

This paper describes and discusses the way sensors should be installed to provide for high quality data sets that will be used for analyzing the real thermal performance of a complex building component such a green roof. The quality assurance is based in the PASLINK method including most of the improvements made during the PASSYS and PASLINK projects. These set of signals, with the described accuracies, have been proven to provide reliable data sets for dynamic data analyzing.

References

(1) Hammarsten S, van Hattem D, Bloem H, Colombo R. Passive solar component testing with identification methods. Solar Energy 1988;41(1):5-13.
(2) Norlén U. Estimating thermal parameters of outdoor test cells. Build Environ 1990;25(1):17-24.
(3) Madsen H, Holst J. Estimation of continuous-time models for the heat dynamics of a building. Energy Build 1995 3;22(1):67-79.
(4) Owen JL. Solar building—European Union Research and Development Programmes. Solar Energy 1996 0;58(1–3):127-135.
(5) Wouters P, Vandaele L, Voit P, Fisch N. The use of outdoor test cells for thermal and solar building research within the PASSYS project. Build Environ 1993 4;28(2):107-113.
(6) Vandaele L, Wouters P. *The PASSYS Services: Summary report*. BBRI & European Commission – Directorate - General XII, EUR 15113 EN, Brussels, 1994. .
(7) Van Dijk HAL, Van der Linden GP. The PASSYS method for testing passive solar components. Build Environ 1993 4;28(2):115-126.
(8) Development of the PASSYS Test Method, Research Report PASSYS Subgroup Test Methodologies. Ed. H.A.L. van Dick, TNO Building and Construction Research. CEC DG XII Brussels, 1993. EUR 15114 EN.
(9) Hahne E, Pfluger R. Improvements on PASSYS test cells. Solar Energy 1996 0;58(4–6):239-246.
(10) A. Erkoreka. Phd: Modelling and testing of green roof using the PASLINK methodology for characterization of its energy behaviour; Bilbao, 2012.
(11) COMPASS Installation guide HFS Tiles for the PASSYS Test cells. G.P. van der Linden, H.A.L. van Dijk, A.J. Lock, F. van der Graaf, TNO. JOULE2 Programme, Brussels, 1995.
(12) COMPASS Measurement and data analysis procedures, H. A. L . van Dijk, TNO Building and Construction Research, F. Tellez , CIEMAT. EC DG XII, Brussels, December 1995 (These procedures replace the PASLINK Calibration and Component Test Procedures).
(13) Cesaratto PG, De Carli M, Marinetti S. Effect of different parameters on the in situ thermal conductance evaluation. Energy Build 2011 7;43(7):1792-1801.