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# Full scale test facilities






## for evaluation of energy and hygrothermal performances

An initiative of DYNASTEE network and INIVE EEIG
Edited by A. Janssens (UGent), S. Roels (K.U.Leuven), L. Vandaele (BBRI)

International workshop

# Full scale test facilities for evaluation of energy and hygrothermal performances

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# TABLE OF CONTENTS

# INTRODUCTION

## Workshop full scale test facilities for evaluation of energy and hygrothermal performances

Ambitious targets on transforming the building stock into a highly energy efficient and low carbon environment demand also very performing scientific tools for the evaluation of the energy performance of improved building envelopes and construction techniques. In combination with dynamic analysis and numerical simulation tools, full scale testing remains of great importance. Many test facilities of different scale are available at universities, research institutes and industrial R&D departments. New ones are under development. The capabilities of these facilities are not always well known or understood by the building industry and the broader research community. Moreover, a good operation of such facilities is challenging.

For these reasons, the network organizations DYNASTEE (www.dynastee.info) and INIVE (www.inive.org) have taken the initiative to organize a series of workshops on test and assessment methods for building performance.

The second workshop of the series focused on full scale test facilities. The workshop was organised in Brussels, Belgium on 30 and 31 March 2011. In total 74 specialists from 16 different countries participated to the workshop. They exchanged experiences with running such test facilities for the evaluation of the energy performance and hygrothermal behaviour of building components and full buildings, and they set the targets for developing new facilities.

This book compiles the descriptions of the different test facilities that were presented and discussed during the workshop. The test facilities are subdivided in four main groups, depending on the scope and scale of the testing:

1. Test facilities for evaluation of hygrothermal building envelope performances
2. Facilities for evaluation of building component energy performances
3. Testing platforms for evaluation of renewable building energy systems
4. Building integrated energy performance testing of components and systems

Within each group, facilities with a long tradition as well as recently developed platforms are described.

## Reasons for full scale testing

Despite the differences in scope and scale of the test facilities, they all have the objective in common to study the building and system performance under realistic dynamic conditions. To this purpose components, systems and buildings are tested in full scale and under varying interior and exterior

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climatic conditions. In most existing facilities this is achieved by means of a well-controlled indoor environment and by exposing components to the real climate in the field. However there are also examples of test facilities in which an artificial exterior climate is used and user behaviour is mimicked in order to obtain realistic conditions.

The dynamic behaviour and response of the test elements may be analysed either by means of comparative testing, or by quantifying specific performances based on data analysis methods.

## Common points of attention

Several authors in this book stress the importance of complementing full scale dynamic testing with other test methods, such as material property measurements and steady-state experiments (eg guarded hot box apparatus). These complementary tests are needed to improve the analysis of the dynamic test data and the reliable investigation of building performance. The results of full scale dynamic testing may also help to develop new standard test methods, for example representative accelerated ageing tests, when moisture performance and durability is the scope of the investigation.

Further the application and development of modelling and simulation methods is essential for the quality of full scale dynamic testing. Modelling plays an important role in experimental design, in dynamic data analysis, performance quantification, and in system emulation. Well documented experimental data sets from full scale test facilities allow for the validation of new numerical models. Validated simulation tools in return may be applied to extrapolate the experimental findings to long-term performance figures and to assess performances in other than the test conditions.

A common challenge in all test facilities is the reliable quantification of performances based on the experimental results. Following elements are important to consider:

- The accuracy, calibration, position, shielding and number of sensors
- The possibilities to control the indoor environment according to predefined schedules
- The management of large numbers of data
- The dynamic analysis methods for performance and error estimation

## Future needs

In view of the current environmental and energy challenges, the society is in urgent need for adequate retrofitting solutions for the existing building stock, and for concepts for nearly zero energy buildings. The existing test facilities and dynamic analysis methods have the possibilities to contribute to these developments. However, since these facilities have different scopes and scales, there is a need for collaboration within a network of excellence, such that the integral multi-physics performance of new solutions may be investigated both at component level and at the whole building level.

## About DYNASTEE

DYNASTEE stands for: "**DYN**amic **A**nalysis, **S**imulation and **T**esting applied to the **E**nergy and **E**nvironmental performance of buildings". DYNASTEE is an informal grouping of organisations actively involved in the application of tools and methodologies relative to this field. DYNASTEE functions under the auspices of the INIVE EEIG and constitutes a sustainable informal networking mechanism, which is intended for those who are involved in research and applications related to energy performance assessment of buildings. Over the years, the Grouping of Outdoor Test Centres (formerly PASLINK EEIG), has actively supported activities and initiated European research projects related to the energy performance assessment of buildings. Real experimental set-up for outdoor tesing of building components provided high quality data series for estimation of thermal characteristic parameters. The objective of DYNASTEE is to provide a multidisciplinary environment for a cohesive approach to the research work related to the energy performance assessment of buildings in relation to the Energy Performance for Buildings Directive (EPBD).

## About INIVE EEIG

INIVE EEIG (**I**nternational **N**etwork for **I**nformation on **V**entilation and **E**nergy Performance) was created in 2001 as a so-called European Economic Interest Grouping. The main reason for founding INIVE was to set up a worldwide acting network of excellence in knowledge gathering and dissemination. At present, INIVE has 11 member organisations (BBRI, CETIAT, CIMNE, CSTB, ERG, ENTPE, IBP, SINTEF, NKUA, TMT US and TNO), and there is interest in joining among other organisations. (*www.inive.org*) The original reason for creating INIVE was the availability of a strong entity able to act as the Operating Agent for the IEA' Air Infiltration and Ventilation Centre (AIVC). AIVC is the IEA Information Centre that deals with the topic of energy efficient ventilation and air tightness of buildings. Since 2001, INIVE has been the Operating Agent for the AIVC (*www.aivc.org*). As a service provider to the European Commission and the European Agency for Competitiveness and Innovation, INIVE EEIG has been coordinating the European Buildings Platform since 2006 and, since 2009, BUILD UP, which is THE European portal on Energy Efficiency (*www.buildup.eu*). INIVE aims to stimulate and contribute to the creation of new knowledge in key areas of ventilation and energy efficiency. In the ASIEPI project (*www.asiepi.eu*), which finished in March 2010 and was coordinated by INIVE, several critical areas related to energy-efficiency policies were analysed, with a whole range of new findings as a result. INIVE also wants to facilitate structured collaborations, which go beyond the duration of single projects. The best example of such collaboration is the DYNASTEE-PASLINK network (*www.dynastee.info*), which is the leading network of use and development of system identification techniques and related applications. The DYNASTEE-PASLINK network is a part of the INIVE Activities.

## Acknowledgments

Knauf Insulation (*www.knaufinsulation.com*) sponsored the organization of the workshop together with Permasteelisa Group (*www.permasteelisa.com*) .

# VLIET TEST-BUILDING K.U.LEUVEN

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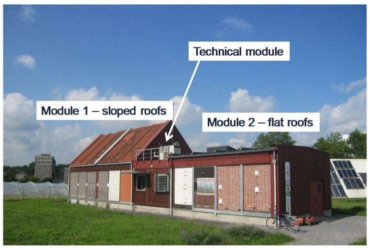
## GENERAL DESCRIPTION

### Main objective of the test facility

The VLIET-testbuilding at K.U.Leuven is a full scale test facility, constructed in 1996, for the comprehensive study of the hygrothermal behavior of well insulated building components under 'real' outside climate conditions.

The building is designed as a long box, with test walls in the longitudinal facades, facing southwest, and northeast. In this way similar test parts can be directed towards the southwest and the north east direction. In Flanders, the southwest direction is warm and wet, the north east cold and dry. If not completely air tight, building elements in the south west façade mainly show air infiltration, in the north east exfiltration. By testing the same elements in both directions, information is gained about the climatic influences on the hygrothermal behavior.



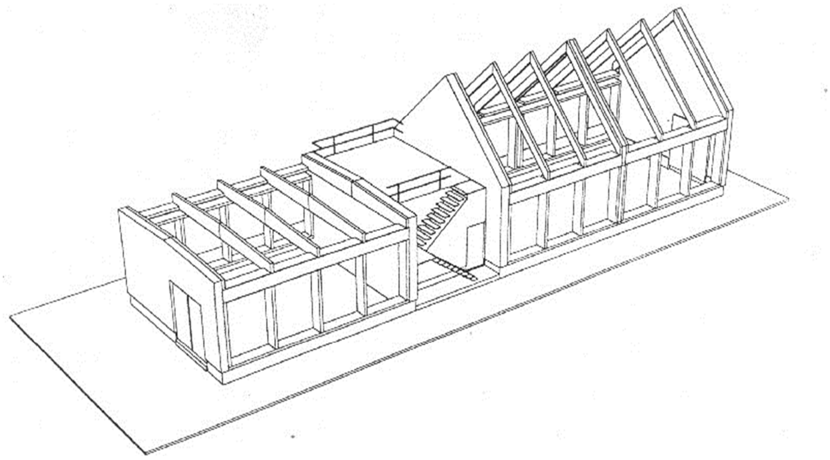

Overall view of the building with the two modules indicated.

Picture during construction of building elements: the measurement bays with fill in masonry for test walls and the construction of test roofs are visible.

Inside view; an airtightness test is performed on one of the facade elements.

## Overall lay-out

The test building is divided in two modules, in which a different inside climate can be installed. The module at the south east side contains measuring bays for 8 test walls (four at north east side, four at south west side) and for four flat roofs. The module at the north west side is larger and provides measuring bays for 12 walls (six south west, six north east) and six duo pitched roofs. In between the two modules, the room for the air conditioning and central logging is placed and a small additional testroom at the south west side for the applications of passive solar energy, solar shading devices,…



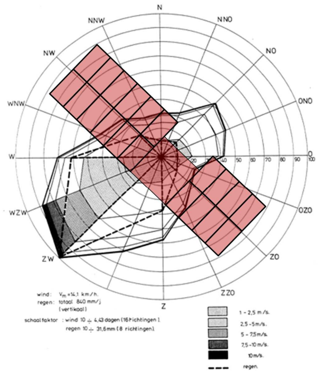
*Perspective view of the fixed structure of the test building. Metal structure + measurement bays separation in wood-PUR-wood*

The overall building size (25.2 meter long by 7.2 meter wide) is based on the dimensions of the test walls and roofs. To make the test parts representative of real envelope parts, sufficiently large measuring bays are foreseen. The width of each bay is 1.8 meter. The wall bays are one storey high (2.7 meter), the roof bays are 3 meter long in horizontal projection.

## Inside boundary conditions

Temperature, humidity and air pressure are the determining parameters for the inside climate. The HVAC-system of the test facility is designed in such a way that both residential as fully conditioned climates can be simulated. In Belgian dwellings, the installation often only adjusts the temperature through heating. Humidity and air pressure depend on the outside climate and inhabitants behavior. In offices, hospitals, factory buildings,... the installation system often controls all three parameters. In this case, the temperature is limited by heating and cooling, humidity is adjusted and an active air pressure difference is imposed between inside and outside.

The HVAC-system allows imposing different inside conditions in the two modules. This is realized by a double air conditioning system. A ventilation fan, located in the installation room, is injecting air through a duct in the axis of each module. The air consists of a mixture of outside air and recirculation air, that is heated and humidified. When dwelling conditions are simulated, the ventilation rate is fixed to a certain volume per hour. In this case, local humidifiers with constant evaporation rate within each module simulate moisture production.




The building is oriented in such a way that similar test parts can be tested southwest (warm and wet side) and north east (cold and dry)

## Outside boundary conditions

As the building is designed to study the hygrothermal behavior under real climatic conditions, the outside climate is present just as it is in real field measurements. The outside conditions are measured with a local weather station (temperature, relative humiditity and solar radiation on the roof of the installation room) and wind mast with ultrasonic anemometers in front of the building. In addition the driving rain in the free field in front of the building and at several location of the building façade is continuously logged.

Wind mast in front of building with cup anemometers at three heights and ultrasonic anemometer in order to determine the wind velocity profile.

## Special limitations / possibilities

Apart from the study of the hygrothermal performance of highly insulated building components, the VLIET-test building has also extensively been used for an in depth study of driving rain loads on buildings. To do so, the building has been equipped with a horizontal driving rain gauge in the free field in front of the building and several driving rain gauges at the façade. The measured driving rain load at the different positions has been compared with numerical predictions making use of computational fluid dynamics.

Recently a test building within the test building has been constructed that connects a measuring bay at the south west façade with a bay at the north east façade, simulating a row house. In this way the influence of the properties of one façade on the hygrothermal response of the other façade can be investigated. This is for instance of major importance when looking at air transport within the row house and through the façade elements.

Driving rain gauge at one of the facades of the test building to study the driving rain impact on buildings.

# DATA ANALYSIS

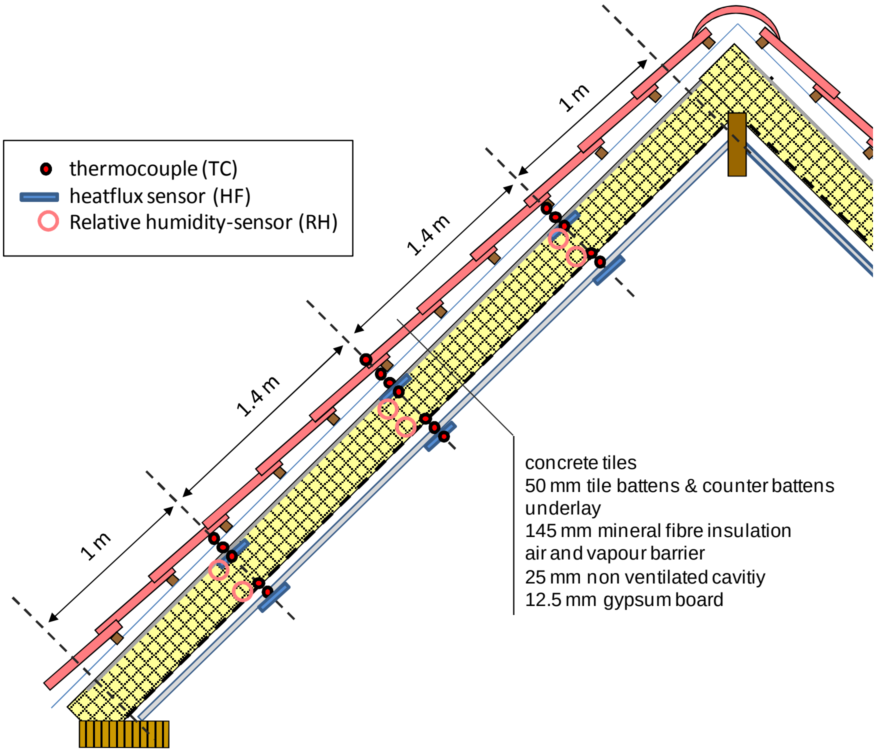
## Typical equipment within test wall

The lay-out of the measuring equipment within each test wall is always a compromise between two conflicting demands. On the one hand, enough measuring points have to be installed to all important information on the distribution of a certain variable is available, on the other hand, each additional data point leads to an increase of the costs of data and computer equipment and efforts to processing and interpretation of the data. Furthermore, too many measuring equipment may influence the hygrothermal behavior.

Measurement equipment at different heights and different interfaces in the building components.

In the VLIET-building the majority of the measurements is done by automatically and continuously logging by a computerized datalogger system. For a typical envelope part, the measuring equipment consists of the following sensors: heat flux sensors, thermocouples, relative humidity sensors and air pressure tubes.

Data logging of the building elements: all sensors are connected to the logger via plug-in-cards.




*Typical configuration of a test roof with the sensor assembly indicated on the left part: the temperatures and heat fluxes are measured at three heights along each roof.*

To achieve maximal flexibility when building components have to be adapted, the data logging of the measurement equipment is designed in such a way that all sensors are connected to plug-in-cards. The connection between the plug-in card and the logger is fixed, only the connection sensor-plug in card is changed when the walls are changed.

Semi Hot Box fitting a wall measurement bay in order to measure the overall U-value

In addition to the continuous logging of temperatures, relative humidity, heat fluxes, … specific measurements are performed to determine the global properties of the building elements. With an adapted blowerdoor equipment the airtightness of the building components can be evaluated and with a semi Hot Box that fits the measuring bays the overall U-value can be determined.

## Accuracy and logging resolution

The logger is connected to the central computer, measuring all sensors every 10min.

Specification and accuracy of sensors and measuring instruments:

| Instrument | Manufacturer | model | Measurement range | accuracy |
|---|---|---|---|---|
| Thermocouple (type T) | Thermo-electric Belgium | P-26-TT-IEC | Max. 105°C | ± 0.1°C |
| Relative humidity sensor | Honeywell, Belgium | HIH-4000 | 0-100 % | ± 0.5% |
| Heat flux sensor | Hukseflux Thermal sensors, The Netherlands | HFP01 | -2000 to 2000 W/m$^2$ | ± 5% of readings |
| Pressure sensor | Halstrup walcher Gmbh, Germany | P92 | 0-25Pa | ± 4% of readings |
| Velocity sensor (Hot wire anemometer) | TSI incorporated, U.S.A. | Model 8475 | 0.05-2.5m/s | ± 3% of readings |

## Analysis of the data

Data analysis is strongly depending on the investigated issue; relative humidity course, risk on interstitial condensation, moisture content of different layers,..

With respect to the thermal performance, the thermal resistance (and corresponding U-value) is based on measurements with the adapted semi hot box (see description and picture above) or determined from measured heat fluxes and temperatures. In the latter case, the concept of “local apparent thermal resistance” is introduced as the traditional thermal performance indicators (U-factor (W/(m$_2$K) and thermal resistance R-value (m$_2$K/W)) are only defined for pure heat conduction, while the measured values are also influenced by air looping, wind washing and dynamic effects. The local apparent thermal resistance is determined mainly based on simple, straightforward techniques as linear regression or averaging technique.

# EXAMPLES OF PREVIOUS STUDIES

Since 1996 the VLIET-testbuilding has been used to study the hygrothermal performance of all kind of building components; both walls and roofs. Most of the time highly insulated components have been studied, but the focus was seldom only on the thermal performance. Most of the time durability aspects (hygrothermal degradation) was part of the research. Examples of previous studies are:

- Hygrothermal behavior and corrosion of flat zinc roofs
- Study of the effect of a ventilated cavity on the durability of fibre cement cladding systems
- Robustness of highly insulated masonry cavity walls
- Analysis of the advantage/disadvantage of ventilated/vented sloped roofs
- Hygrothermal behavior of masonry walls with exterior Insulation systems and outside rendering
- The effect of reflective foils in sloped roofs
- The effect of reflective foils in light weight building walls
- Rain load and rain water penetration in glued masonry veneers
- Analysis of historic masonry walls containing salt
- Hygrothermal behavior of masonry walls renovated with interior insulation systems
- Thermal performances of double skin facades
- Shading performances of vertical and horizontal louvre systems

# MAINTENANCE / COLLABORATION

## Personnel involved

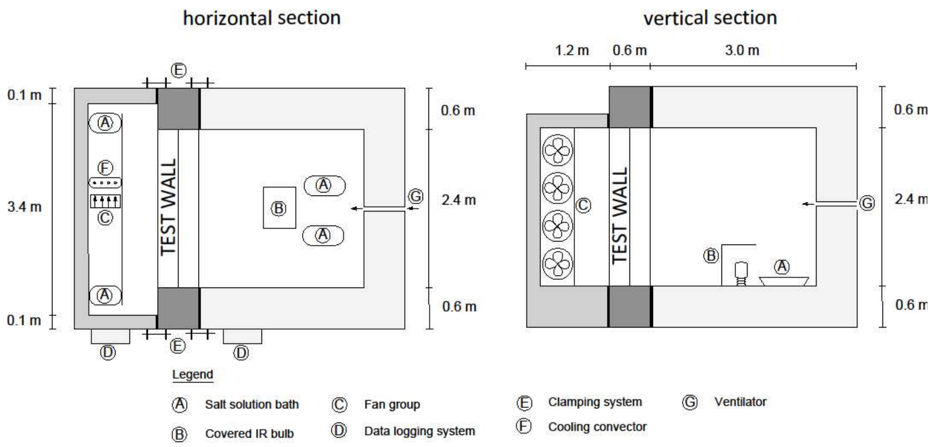
The building is maintained by the technical staff of the Building Physics Section of K.U.Leuven. They are also responsible and in charge for all adaptations, new measuring campaigns, etc. in collaboration with the responsible engineering or researcher. The latter also performs the data analysis.

## International collaboration

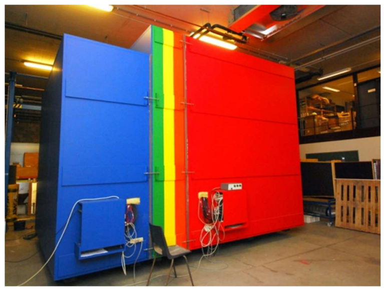
There is no specific international collaboration with respect to the device. During construction phase there has been close contact with IBP (Fraunhofer) and other institutes with similar devices.

## Link to other devices

The study of the hygrothermal behaviour of building components under ‘‘real’’ climatic conditions as performed in the VLIET-testbuilding is one element in the overall investigation of the physical behavior of heat, air and moisture-effects in highly insulated building components. In addition to the field measurements in the VLIET-building the Building Physics Section of K.U.Leuven investigates specific aspects of the hygrothermal behavior in a ‘hot-box / cold-box apparatus’.




*Overall view of the hot-box / cold-box apparatus at K.U.Leuven in addition to field measurements in the VLIET test building*



Hot Box / Cold Box apparatus to study building components under controlled boundary conditions in the laboratory.

Here, the building elements can be studied under well controlled constant or periodic boundary conditions. This provides additional insight in partial aspects, such as energy consumption, risk on interstitial condensation, effects of controlled air flow patterns,… Because of the controlled boundary conditions, hot-box / cold-box measurements are also adequate validation tools for numerical models. Once validated the numerical codes are powerful instruments to come to a better knowledge of the hygrothermal behavior of building components.

# Relevant literature

## General literature about the test facility:

Janssens A, Hens H, Roels S, VLIET-proefgebouw (VLIET-testbuilding), information document at the inauguration of the testbuilding, 1995.

Annual reports of the first four years of the VLIET testbuilding (1996-1999) according to the funding agreement with IWT VLIET/930235.

## Literature on previous measuring campaigns:

Hens H, Janssens A, Zheng R, 2003. Zinc roofs: an evaluation based on test house measurements. *Building and Environment* 38, 795-806.

Saelens D, Roels S, and Hens H, 2004, The inlet temperature as a boundary condition for multiple-skin facade modelling, *Energy and Buildings*, vol. 36, pp. 825-835.

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Abuku M, Blocken B, Roels S, 2009. Moisture response of building facades to wind-driven rain: field measurements compared with numerical simulations. *Journal of Wind Engineering and Industrial Aerodynamics* 97, 197-207.

Zheng R, Janssens A, Carmeliet J, Bogaerts W, Hens H, 2010. Performances of highly insulated compact zinc roofs under a humid-moderate climate – Part I: hygrothermal behaviour. *Journal of Building Physics* 34(2), 178-191.

Roels S, Deurinck M, 2011. The effect of a reflective underlay on the global thermal behaviour of pitched roofs. *Building and Environment* 43, 134-143.

Zeridun Desta T, Langmans J, Roels S, 2011. Experimental data set for validation of heat, air and moisture transport models of building envelopes. *Building and Environment* 46(5), 1038-1046.

# BUILDING SCIENCE – RESEARCH & TEST UNIT

## CARINTHIA UNIVERSITY OF APPLIED SCIENCES

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CARINTHIA UNIVERSITY OF APPLIED SCIENCES | FACHHOCHSCHULE KÄRNTEN

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**Exact location:**

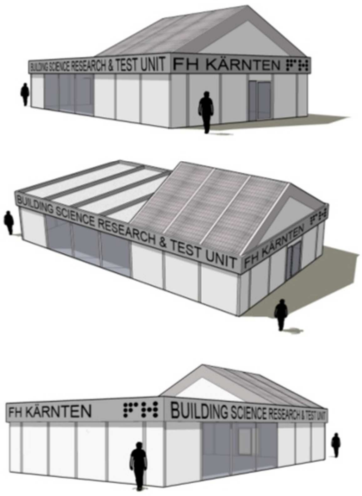
Villach, Austria
46° 36′ 53″ N, 13° 50′ 46″ E

# GENERAL DESCRIPTION

## Main objective of the test facility

The BSRTU test facility is a full scale facility based on a modular concept constructed in 2010. The test facility allows for R&D studies regarding the hygrothermal performance of full scale building assemblies under real climate conditions. The test facility is designed as a flexible, rectangular box with longitudinal façades facing to the North and South, hence building components can be tested under varying climate impacts at the same time. The western façade is used for studies regarding wind driven rain impact.

At this time the modular test facility is arranged with low-sloped roof constructions only, which are investigated during a commissional work of a business partner, but it would be possible to add statical timber elements for studies regarding sloped roofs too.




Schematic draft of test facility

Static structure of test facility

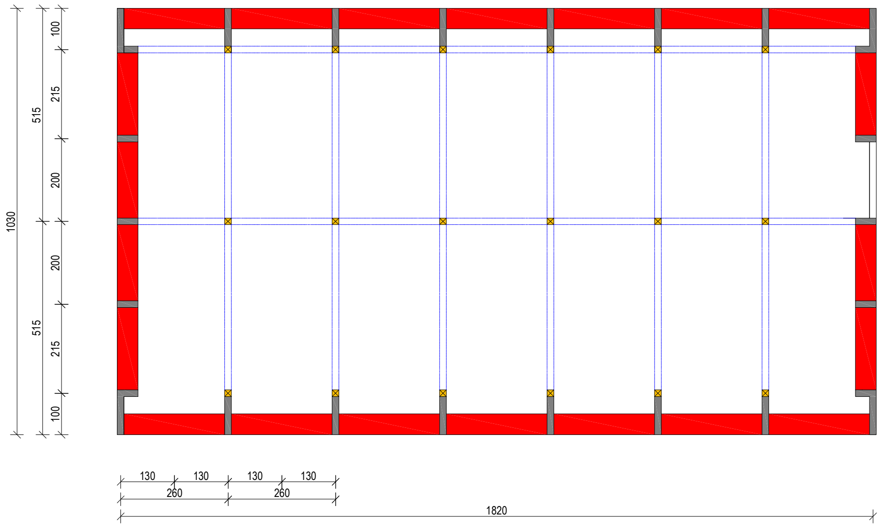
Facility during erection process

Mounting of roof assemblies

Mounting of wall assemblies

## Overall lay-out

The test facility's load-bearing static construction is made of a wooden frame structure. Various test elements like wall or roof sections can be installed into the open areas in-between the elements of this frame structure. The overall building size (~ 10,30 / 18,20m) is based on the designed dimension of the test walls and roofs. Separations in the roof area allow for testing 14 different roof assemblies of maximum dimensions of up to 2.4 / 5.0m. In addition wall or façade elements with a maximum height of 2.70m can be installed. The wall's width is variable because the single separators can easily be displaced. Static colums are placed at a distance of 1m from the wall assemblies, hence even connection and joint details, but also corners can be analyzed under real climatic conditions in a 1:1 scale.




*Schematic floor plan of the CUAS test facility (to scale)*

## Inside boundary conditions

The test facility is equipped with a double air conditioning system. The HVAC system is used for heating and cooling and can easily be adjusted. The main part of the facility, used for building enclosure tests, is executed with one single climate, varying between ~ 20-24°C and 30-50% RH depending on the season. The humidity level inside the room is adjusted by using multiple humidifying appliances.

The second room section on the western façade is equipped with a separate HVAC system. Here also translucent building materials like membrane structures, etc. can be investigated without disturbing the climate profile in main testing room. In addition, due to the modular concept of the test facility, single assemblies can also be separated from the main room and stressed with high moisture loads.

The indoor climate is monitored in a 10 minute interval with more than 20 heat / moisture sensors, placed in different sections of the test facility.

## Outside boundary conditions

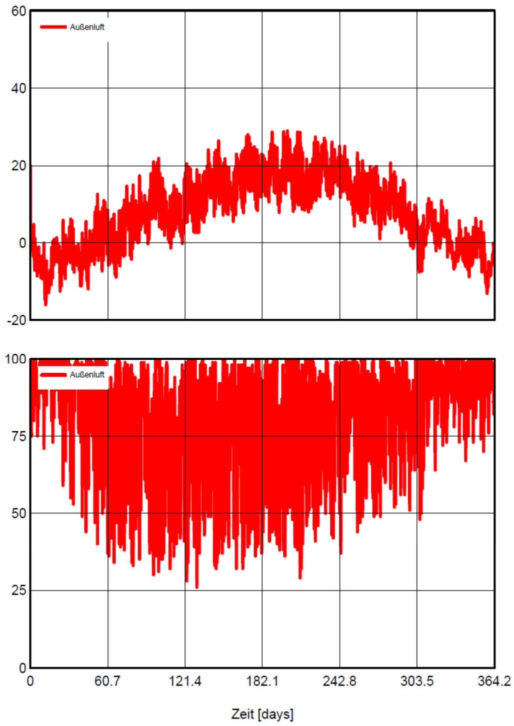
The whole test facility is exposed to the prevalent weather conditions at the location. Villach is located in Austria's most southern province Carinthia in the border triangle to Italy and Slovenia.

Location Villach:

46° 36′ 53″ N, 13° 50′ 46″ E
501 m above sea level

*Table right:*

*Overview: outside air temperature & relative humidity; location Villach*




The outside weather conditions are measured with two different weather stations (temperature, relative humidity, global solar radiation and direct solar radiation on façades and shaded and unshaded roof sections, wind velocity and direction with ultrasonic anemometers. Precipitation is measured with rainfall sensors and precipitation detectors. In addition also UVA- & UVB radiation probe heads and star pyranometers are used.

## Special limitations / possibilities

The CUAS test facility is especially used for research work regarding the hygrothermal performance of different building enclosures but also the interaction of building components with the indoor comfort conditions can be investigated.

The whole measurement data at the test facility (more than ~ 1200 different sensors) is monitored automatically and accessible to project partners over the web.

Study on different low-sloped roof assemblies (cool roofing, etc.)

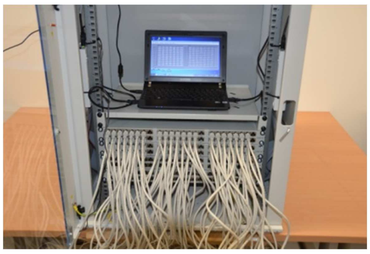
Investigation regarding roof shadings

Research regarding Façade ventilation

Research regarding building integrated PV and solar thermal panels

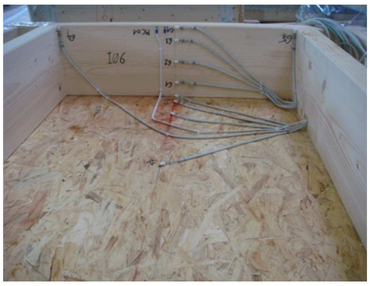
Research regarding fungi growth in building envelopes made in timber construction

Inside view of facility: Datalogging of building elements



Datalogging device

Combined heat/moisture sensors in roof assembly



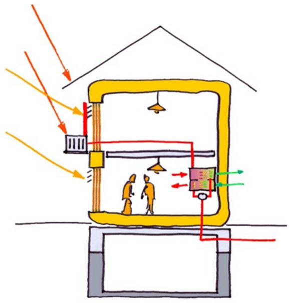
Sensor positioning in a wall assembly

Prefabrication and mounting of sensors in different building assemblies

The Building Science division @ the CUAS focuses on the following core research fields:

- Energy efficiency and durability of building enclosure systems;
- Interaction and influence of the building enclosure on the quality of the interior rooms;
- Analysis of building products and materials in due consideration of environmental influences

CUAS' objectives are to actively transfer the research knowledge to teaching by directly involving students in the development, research, and innovation activities as well as to incorporate the development, research, and innovation knowledge in teaching at the university and in advanced training for companies in the building industry, etc.



# Data analysis

## Typical equipment within test wall

In the BSRTU test facility the typical measurement equipment for a single assembly consists of thermocouples, relative humidity sensors and dewpoint/condensate detectors, which are installed at interfaces of different building materials, but also e.g. within insulation layers. Attached at their surfaces, also heat flux sensors are installed.

The number of installed sensors depends on the scope of the research work.

## Accuracy and logging resolution

| Instrument | Manufacturer | Model | Measurement Range | Accuracy |
|---|---|---|---|---|
| Dataloggers | Ahlborn | Almemo® 5690, 2890-9 | | |
| Combined relative humidity and temperature sensor | Ahlborn | Almemo® FHAD460 | 0...100%rh | ±1,8 %rh within 20...80 % rh |
| Capacitive humidity sensor | Ahlborn | Almemo® FHA646 | 0…100 %rh | ±2 %rh below 90%rh |
| Combined relative humidity and | Proprietary | | 0…100 %rh | ±2 %rh within 10 … 90 %rh |

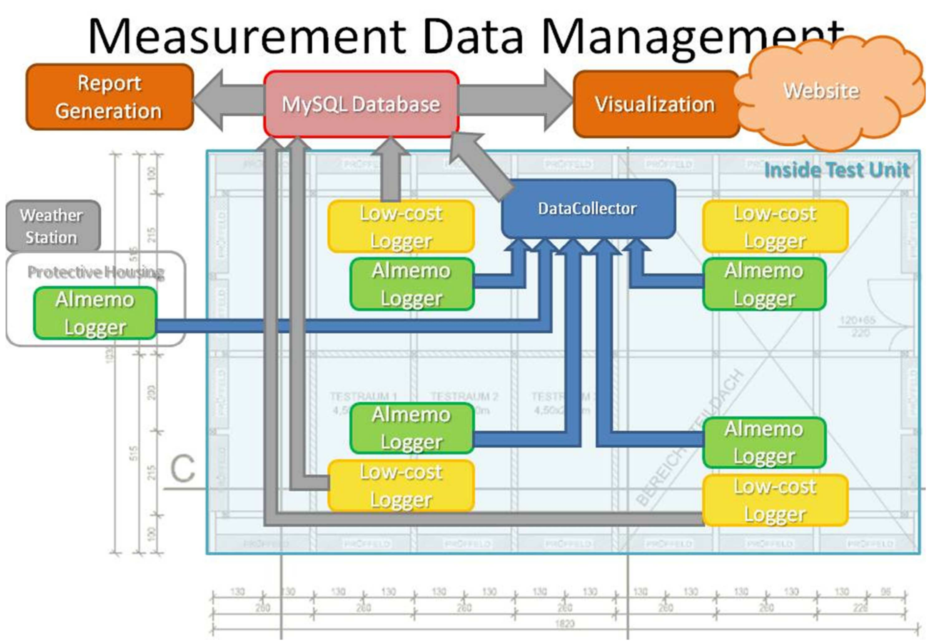
| | | | | |
|---|---|---|---|---|
| temperature sensor | | | | |
| Thermocouple | | NiCr-Ni, Type K | -200°C ...+205°C | n.a. |
| Moisture sensor | Ahlborn | Almemo® FHA636MF | 7 … 30 % moisture in wood | n.a. |
| Moisture sensor | Proprietary | | 15 … 38 % moisture in wood | n.a. |
| Dew Detector | Ahlborn | Almemo® FHA9461 | Dew/no dew | n.a. |
| Heat Flow Plates | Ahlborn | Almemo® FQA019C | n.a. | 5% @ 25°C |

Further sensor equipment: Vaisala Weather Transmitter WXT520, Almemo UVA, UVB and global radiation probe head, Almemo Star Pyranometer, E+E air velocity transmitter EE75.

Data logging is done by means of the above mentioned Almemo® devices as well as in-house developed data loggers based on hardware by National Instruments and special software developed in LabVIEW™. The common logging interval for all these devices is 10 minutes.

## Analysis of the data

The logged data of all the different devices is written to a common database on a central MySQL server. Data analysis and visualization is done by SQL queries carried out in LabVIEW™. The graphical visualization is accessible for the project partners by means of a restricted area of a web portal.



# Examples of previous studies

The BSRTU test facility is the newest technical infrastructure at the Carinthia University of Applied Sciences and was built in 2010.

Previous hygrothermal studies were done at different research buildings in cooperation with business partners.


*Further CUAS test building, operated with different partners from industry*

# Maintenance / collaboration

## Personnel involved

The BSRTU test facility is maintained by the technical staff of the Building Science Section of the Carinthia University of Applied Sciences. They are also responsible for all new adaptations, data analysis, etc.

Changes or adaptations of building components are done in cooperation with business partners.

## International collaboration

The research team at CUAS is working together with colleagues from:

- Fraunhofer Institute for Building Physics / Holzkirchen, Germany
- Technical University Dresden / Germany - Institute for Building Climatology
- Bergen University College - Høgskolen i Bergen / Norway
- Institute for Building Science & Energy Efficiency / USA

# RELEVANT LITERATURE

## Literature on previous measuring campaigns:

**Buxbaum**, C., Gallent, W., Pankratz, O., "Hygric performance of shaded and unshaded highly insulated, lightweight low-sloped roofs)", 11th International Conference on Thermal Performance of the Exterior Envelopes of Whole Buildings XI, 05 – 09.12.2010, Clearwater Beach / Tampa, USA;

**Buxbaum**, C., Gallent, W., Pankratz, O., "Thermal Rehabilitation of Existing Building Enclosures by Using VIP (Vacuum Insulation Panel) Sandwich and Timber Based Panels", 2nd BEST - Building Enclosure Science & Technology Conference, 12 – 14.04.2010, Portland / Oregon, USA

**Buxbaum**, C., „Trocknungspotential von teilweise beschatteten, unbelüfteten Flachdachkonstruktionen", Internationaler Fachkongress für Holzschutz und Bauphysik, 25 – 26.02.2010, Munich, Germany

**Buxbaum**, C., Pankratz, O., "Hygrothermal Performance of habitable Basements made in Timber constructions", 4th International Building Physics Conference, 15 – 18.06.2009, Istanbul, Turkey

**Buxbaum**, C., Pankratz, O., "Moisture performance of well-insulated timber slabs above ventilated crawlspaces in the climate of Central Europe", 12th Canadian Conference on Building Science & Technology, 06 – 08.05.2009, Montreal, Canada

**Buxbaum**, C., Pankratz, O., "Moisture performance of green flat roofs made in timber construction", Building Envelope Sustainability Symposium, 30.04 – 01.05.2009, Washington DC., USA

**Buxbaum**, C., Pankratz, O., "Drying performance of masonry walls with inside insulation exposed to different exterior climate conditions", Building Physics Symposium in honour of Prof. Hens, 29 – 31.10.2008, Leuven, Belgium

**Buxbaum**, C., et. al., "Habitable basement concepts made in timber construction –Assessment on the durability of walls and floor slabs made of solid cross-laminated timber boards", WCTE 2008 - 10th World Conference on Timber Engineering, 02 – 05.06.2008, Miyazaki, Japan

**Buxbaum**, C., Pankratz, O., "Durability of high-insulated timber-frame flat roofs", 11th DBMC - 11th International Conference on Durability of Building Materials and Components, 11 – 14.05.2008, Istanbul, Turkey

**Buxbaum**, C., et. al. "Study on the Moisture Performance of high-insulated Building Envelopes", 12th International Passive House Conference, 12 – 13. April 2008, Nuremberg, Germany

# FIELD EXPOSURE OF WALLS FACILITY

## GENERAL DESCRIPTION

NRC-IRC's Field Exposure of Walls Facility (FEWF) is located in Research House no. 3 at the NRC Montreal Road campus in Ottawa. The facility is used to assist the building industry in developing integrated solutions by providing opportunities for the characterization of the hygrothermal performance of innovative wall systems and retrofit strategies. Researchers can examine the comparative performance of different side-by-side wall assemblies exposed to naturally fluctuating outdoor climate and controlled indoor conditions of relative humidity, temperature and pressure. The data is used to benchmark hygrothermal modeling simulations using hygIRC 1D, and hygIRC-C (3D) for opaque walls. hygIRC-C is also used to assist the design, commissioning and analysis the experiments and results from the FEWF.

**Institute/organisation:**

National Research Council Canada
Institute for Research in Construction

**Contact person:**

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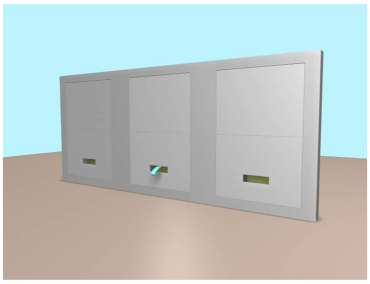
**Exact location:**

Ottawa, Canada
45°26’N, 75°37’W

## Overall lay-out

Three test bays in preparation.

Test bays nearing completion.



Slits in air barrier and wood sheathing allow exfiltration and infiltration.

Enclosure for control of interior Temperature, RH, and pressure.

The first floor of the West facade of the research house includes a test bay measuring 7.5 m wide by 3.2 m high test. It can accommodate one large specimen or several narrow specimens – typically 3 test bays per experiment – see Figure 1. Each bay is separated thermally with an insulated instrumentation cavity. Each experiment requires the full removal of the test bay and complete reconstruction, and re-instrumentation. Experiments typically last a full year. Wall specimen dimensions are not restricted to one size. Lightweight wood frame walls and massive wall specimens (e.g. insulating concrete form walls) have been studied.

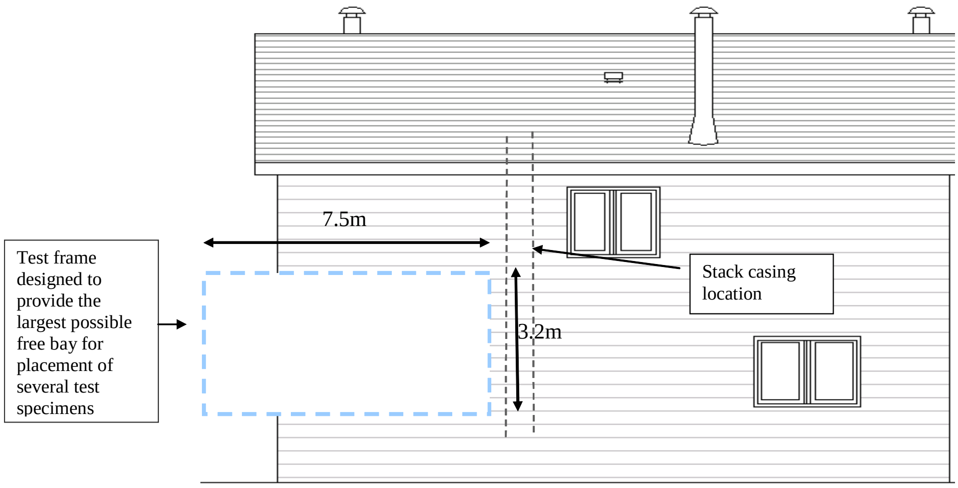



Figure 1. Schematic of the Field Exposure of Walls Facility (FEWF).

## Inside boundary conditions

To investigate the effects of an increase of indoor humidity levels on moisture content of wood-based materials, an indoor climatic chamber was constructed to introduce high humidity and increased air pressure levels on the interior side of Walls 2 and 3. Wall 1 was kept as a control wall, and exposed to uncontrolled indoor room conditions (i.e. low RH in winter). Pressure, humidity and temperature conditions were regulated and monitored throughout the field trial in the indoor climatic chamber.

As example the different walls were subjected to varying indoor conditions of relative humidity and pressure during the winter season. Four periods were selected for intensive analysis (labeled A to D respectively), as described in Table 1. To explore the potential for wetting and drying when varying the degree of air leakage across the wall assembly, the specimen air leakage characteristics were modified during testing to represent two levels of increased leakiness as compared to a perfectly airtight assembly.

| Condition | Indoor Climatic Chamber | | Opening in the air barrier system and drywall | Test period (2007) | Range of Outdoor T (°C) |
|---|---|---|---|---|---|
| | Pressure (relative to room air) | RH | | | |
| A | 0 Pa | 70% | None | 11 Feb – 18 Feb | -24.5 to -3.3 |
| B | 5 Pa | 50% | 6 X 400 mm | 22 Feb – 24 Feb | -14.3 to -4.6 |
| C | 5 Pa | ~30% | 3 X 400 mm | 16 Mar – 17 Mar | -10.0 to -4.4 |
| D | 0 Pa | 50% | 3 X 400 mm | 8 Apr – 15 Apr | -6.4 to 6.3 |

Table 1. Example of test schedule of different indoor and outdoor conditions.

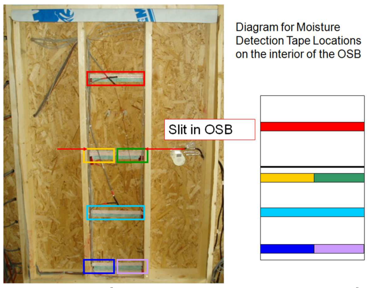
## Outside boundary conditions

A rain gauge measuring the quantity of rainwater deposition in one area of the exterior face of the exterior siding is in place as well. Ambient outdoor parameters including temperature, relative humidity, wind speed and direction are measured by means of a weather station located 30 m from the research house.

## Special limitations / possibilities

This flexible state-of-art research house enables not only evaluate the in-situ hygrothermal performance of exterior wall assemblies that have different wall assembly techniques, insulation systems and air and vapour barrier approaches, but enables as well comparison of various heating and ventilation strategies while evaluating energy usage and the quality of the resulting indoor environment. It also allows side-by-side rooms comparison in term of energy conception and thermal comfort. Automated 3-D indoor environment measurement systems (robots) are used to sample spatially distributed indoor environment parameters. The walls are exposed to the indoor conditions of the house and therefore will offer an opportunity to investigate interactions between wall moisture performance and indoor conditions produced by the various heating and ventilation systems.

# DATA ANALYSIS




Moisture detection strips to track the path of condensation at the inner surface of the wood sheathing.

## Typical equipment within test wall

Several monitoring instruments were used to characterize hygrothermal response in the different layers of the wall assembly. The middle stud cavity was designed to be the focus of the study, with the stud cavities on either side acting as a buffer zone. For this reason the majority of instrumentation was located in the middle stud of each wall, as shown in Figure 2. The instrumentation was deployed at four heights (Figure 3), with most sensors concentrated in the large area below the gap in the exterior sheathing - where it was assumed moist air exfiltration would lead to wetting.

Pressure sensors installed in the test specimens measured the differential air pressure between the pressure taps, at locations shown in Figure 2, and the ambient room pressure. Pressure taps were located in the top half of the middle stud cavity, 254 mm (10 in.) above the gap in the exterior sheathing.

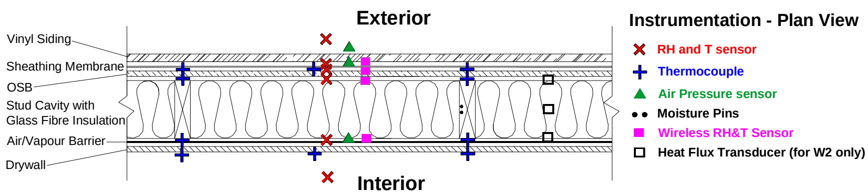
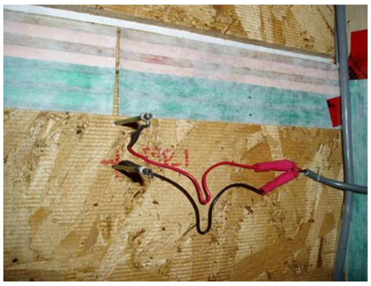



Figure 2. Plan view of wall cross section



Surface moisture detection destection strips and moisture pins.

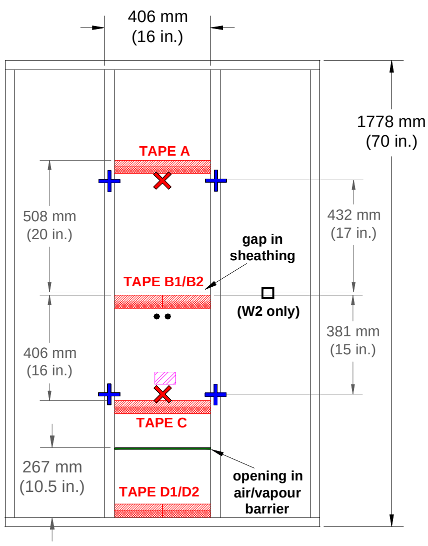



Figure 3. Liquid moisture detection strips.

Additionally, researchers deploy sensors of moisture content of wood-based materials and liquid moisture detectors on the surface of building materials in different internal layers of the wall specimens.

Heat flux transducers.

## Accuracy and logging resolution

All sensor data is recorded at a 15-minute interval. Temperature was measured with an accuracy of ±0.1°C, while relative humidity measurements were accurate to ±0.5%. The uncertainty of the heat flux measurements was ± 5%.

| **Instrument** | **Manufacturer** | **Model** | **Measurement Range** | **Accuracy** |
|---|---|---|---|---|
| Thermocouple (Type T) | Omega | TT-T-24-SLE | Max 200°C | ±0.1°C |
| Relative Humdity | HoneyWell | HIH 3602C | 0-100% | ±0.5% |
| Heat Flux | HukselfluxUSA Thermal Sensors | PU11-T & PU32-T | -2000 to 2000 $w/m^2$ | ±5% of readings |
| Pressure Sensors | Setra | 0.25"WC and 2.5"WC | Max 0.25" WC and 2.5"WC | ±1% full scale |

Table 2. Instrumentation accuracy.

## Analysis of the data

The experimental methodology and instrumentation provided substantial insight into the hygrothermal performance of wall assemblies under varying conditions. The deployment of water detection tape proved valuable in confirming or not the presence of surface water at different layers through the wall when temperature and humidity conditions were favorable for condensation. The resulting wealth of data will aid in benchmarking numerical models, and in characterizing the response of the exterior walls to heat, air and moisture transfer.

# EXAMPLES OF PREVIOUS STUDIES

Since 2006 the FEWF has been used to study side-by-side hygrothermal performance of wall assemblies. The most of the study focused on the effects of the different envelope characteristics on interstitial moisture accumulation. Examples of previous studies are:

1. Year 1 (2006-2007) Commission the facility by monitoring three identical test specimens of traditional construction (2x6) through Fall, Winter and Spring.
2. Year 2 (2007-2008) Partnership with Canada Mortgage and Housing Corporation (CMHC) and Natural Resources Canada (NRCan) to investigate the effects of two energy retrofit strategies on the wetting and drying potential of wall assemblies.
3. Year 3 (2008-2009) Partnership with FPInnovation (Forintek) to investigate the effects of the interior air/vapour barrier polyethylene membrane on the wetting and drying potential of wall assemblies and extending the project with CMHC & NRCan for one retrofit strategy.

4. Year 4 (2009-2010) Partnership with CMHC & NRCan to investigate the dynamic heat transmission characteristics through Insulated Concrete Form (ICF) wall assemblies over a full year cycle of weather exposure.
5. Year 5 (2010-2011) Project to Test the Next Generation Envelope Systems (i.e. Vacuum Insulated Panel) in partnership with CMHC and NRCan.

6. Year 6 and beyond Investigate the performance of wall specimens of different innovative designs based on industrial collaboration/partnership.

# MAINTENANCE / COLLABORATION

## Personnel involved

The Research House is maintained by Technical staff and Managed by Research Officers of the National Research Council Canada's Institute for Research in Construction (NRC-IRC) from two programs: Indoor Environment (IE) and Building Envelope and Structures (BES).

## International collaboration

There is currently no specific international collaboration. The facility is currently used in partnership with industry and with other Canadian Government Agencies.

## Link to other devices

The study of hygrothermal behaviour of building envelopes under real climatic conditions as performed in the FEWF is one of the facilities of the Heat, air and Moisture Performance of Envelope (HMPE) group. In addition to the field measurements HMPE investigates specific aspects of thermal behaviour of wall systems in the Guarded Hot Box apparatus as well at the Environmental Exposure Envelope Facility (EEEF) climatic chamber and Dynamic Wall Test Facility (DWTF) for water penetrations. In these facilities, the building envelope is subjected to controlled boundary conditions (Interior and Exterior). This will give better insight of the interstitial condensation and hygrothermal performance. The measurements are used to benchmark the State-of-The-Art hygrothermal CFD package tool hygIRC-C developed by NRC-IRC. For whole-house energy and moisture assessment studies, the team also collaborates with the Canadian Centre for Housing Technology (CCHT), operated as a partnership between National Research Council Canada, Canada Mortgage and Housing Corporation and Natural Resources Canada.

Envelope Environmental Exposure Facility (EEEF)

Twin Houses at the Canadian Centre for Housing Technology

# RELEVANT LITERATURE

## General literature about the test facility:


- Client Report “Evaluating The effects of Two Energy Retrofit Strategies For Housing on The Wetting and Drying Potential of Wall Assemblies”, W. Maref, M. Rousseau, M.A. Armstrong, W. Lei, M. Leroux and M. Nicholls, Nov 2009, PP 1-118.
- Client Report “The dynamic heat transmission characteristics through Insulated Concrete Form (ICF) wall assemblies over a full year cycle of weather exposure”, W. Maref, H. Saber, M.A. Armstrong, M.Z. Rousseau, C. Thivierge, G. Ganapathy, M. Nicholls, F. Lalumiere and K. Abdulghani, 2011.
- Client report “Effects of the Interior Air/Vapour Barrier Polyethylene Membrane on the Wetting and Drying Potential of Wall Assemblies”, W. Maref, M.Z. Rousseau, M.A. Armstrong, C. Thivierge, G. Ganapathy, M. Nicholls, F. Lalumiere and K. Abdulghani, 2011, PP 1-100


## Literature on previous measuring campaigns:


- Field Monitoring of Wetting and Drying in Wood-Frame Walls of Different Interior and Exterior Heat, Air and Vapour Transmission Characteristics for a Cold Climate Windows, W. Maref, M. Armstrong, M.Z. Rousseau, C. Thivierge, M. Nicholls, G. Ganapathy and W. Lei, Submitted to ASTM Journal, 2010.
- Hygrothermal Response of Different Wall Assemblies to Water Ingress, C. Thivierge, W. Maref, M. Armstrong, G. Ganapathy, M. Nicholls and M.Z. Rousseau, Submitted to 13th Canadian Conference of Building Science and Technology, May 2011, Winnipeg, Canada.
- Field Monitoring of Wetting and Drying in Wood Frame Wall Assemblies in Cold Climate, W. Maref, M. Armstrong, M.Z. Rousseau, C. Thivierge, M. Nicholls and W. Lei, Submitted to 13th Canadian Conference of Building Science and Technology, May 2011, Winnipeg, Canada.
- Field Energy Performance of an Insulating Concrete Form (ICF) Wall, M. Armstrong, H. Saber, W. Maref, M.Z. Rousseau, G. Ganapathy and M.C. Swinton, Submitted to 13th Canadian Conference of Building Science and Technology, May 2011, Winnipeg, Canada.
- Benchmarking 3D thermal model against field measurement on the thermal response of an insulating concrete form (ICF) wall in cold climate Saber, H.H.; Maref, W.; Armstrong, M.M.; Swinton, M.C.; Rousseau, M.Z.; Ganapathy, G. Eleventh International Conference on Thermal Performance of the Exterior Envelopes of Whole Buildings XI (Clearwater, (FL), USA 2010-12-05) pp. 1-21. .
- Field monitoring of energy-retrofitted wall assembly in cold climate: impact of the vapour permeance of exterior retrofit insulation on the flow of moisture in wood-frame wall Maref, W.; Armstrong, M.M.; Rousseau, M.Z. ASHRAE Seminar no. 48 on "Solving Moisture Problems Created by Energy Efficient Design" (Albuquerque (NM) USA 2010-06-30)

- Effect of the air and vapor permeance of exterior insulation on the flow of moisture in wood frame walls in a cold climate Armstrong, M.M.; Maref, W; Rousseau, M.; Lei, W.; Nicholls, M.ICBEST 2010 - International Conference on Building Envelope Systems and Technologies (Vancouver, Canada 2010-06-27)
- A field monitoring investigation of the effect of adding different exterior thermal insulation materials on the hygrothermal response of wood-frame walls in a cold climate Maref, W.; Armstrong, M.M.; Rousseau, M.Z.; Lei, W. BEST2 Conference (Building Enclosure Science & Technology) (Portland, (OR), USA 2010-04-12) pp. 1-15.
- Workshop on Moisture Management and Energy Rating in Building Envelopes / Part II : Effects of two energy retrofit strategies on the wetting and drying potential of wall assemblies Maref, W.; Armstrong, M.M.; Rousseau, M.Z. 12th Canadian Conference of Building Science and Technology (Montreal, QC 2009-05-06)
- A field monitoring study of interstitial condensation in wood-frame walls in cold climate Armstrong, M.M.; Maref, W.; Rousseau, M.Z.; Lei, W.; Nicholls, M. 12th Canadian Conference on Building Science and Technology (Montréal, Quebec 2009-05-06) pp. 1-12.
- Effects of exterior insulation retrofit on moisture accumulation in wood-frame exterior walls (Poster) Rousseau, M.Z.; Maref, W.; Leroux, P.; Armstrong, M.M. pp. 1. 2008-10-01
- Recent experiments conducted in NRC-IRC moisture management facility Rousseau, M. Z.; Maref, W.; Armstrong, M.M.; Lei, W.; Nicholls, M. *Construction Innovation,* 13, (3), pp. 7. 2008-09-01 Complete citation
- Étude sur la performance hygrométrique des murs menée dans une installation d'essais à l'IRC-CNRC Rousseau, M. Z.; Maref, W.; Armstrong, M.M.; Lei, W.; Nicholls, M. *Innovation en construction,* 13, (3), pp. 7. 2008-09-01
- Characterization of the hygrothermal performance of wall systems Maref, W.; Manning, M.M.; Rousseau, M.Z.; Lei, W. ASHRAE Seminar 29 - Moisture Management Concerns in Commercial and Residential Buildings (New York, USA 2008-01-21) pp. 1-83. 2008-01-21
- Ventilation and wall research house Maref, W.; Ouazia, B.; Reardon, J.T.; Rousseau, M.Z. Performance of Exterior Envelope of Whole Buildings X Conference (Clearwater, Florida 2007-12-01) pp. 1-8. 2007-12-01
- New field testing facility at NRC-IRC offers opportunities for wall performance assessment Maref, W.; Rousseau, M.Z. *Solplan Review,* (135), pp. 18-19. 2007-07-01
- Hygrothermal performance of wall assemblies Maref, W.; Rousseau, M.Z.; Lei, W.; Manning, M.M.; Nicholls, M.; Nunes, S.C. *Construction Innovation,* 11, (4), pp. 5. 2006-12-01

# OUTDOOR TESTING SITE

**Institute/organisation:**

Fraunhofer IBP

Fraunhofer Institute
for Building Physics

**Contact person:**

Theo Großkinsky
Fraunhoferstraße 10
83626 Valley
tel: +498024643223
e-mail:
theo.grosskinsky@ibp.fraunhofer.de

**Exact location:**

Valley, Germany
°N, °E
47°52', 11°44'

## GENERAL DESCRIPTION

### Main objective of the test facility

The outdoor testing site in Holzkirchen is the largest site in the world to investigate building structures on a 1:1 scale. Building components and building materials as well as system components for heating, ventilation and energy systems are tested under real climatic and application conditions.

### Overall lay-out

On an area of about 30.000 m² 27 test-houses and 7 office and laboratory buildings are located which are partly used for outdoor tests, too. Additionally more than 700 small specimens made of different ETICS, roof tiles or with painted surfaces as well as complex shaped specimen made of sandstone like the "Asterixe" are exposed for weathering. Building structures, building

components, building materials and system components are analyzed with regard to weathering protection and durability. In cooperation with industrial partners various building components are investigated to identify their functionality and to develop suggestions for improvement. Wall systems, roofs, basements as well as floor plates can be tested. With a special examination hall it is possible to investigate wall sections, too. Two specific test facilities are described more in detail below: the half-timbered building and the adaptable roof test facility.

### Inside boundary conditions

The course of inside air temperatures and humidities can be controlled for most of the test houses depending on the aim of the investigations.

### Outside boundary conditions

Climatic conditions of Holzkirchen, located near the Alps. Cold winters and high radiation in summer as well as a high amount of driving rain- the prevailing extreme climate is especially suitable for this kind of testing. Since 1950 an own weather station is measuring and recording the climatic data on the test site. These data are necessary for the interpretation of the test results and are used as datasets for hygrothermal calculations.

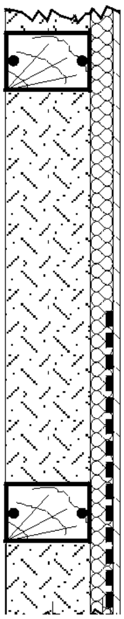
## HALF-TIMBERED BUILDING

### Main objective of the test facility

The aim of the test facility is to investigate hygrothermal problems with a half-timbered building and especially concerning the energetic improvement of this type of buildings.

### Overall lay-out

The building has more than 80 rectangular elements with dimensions of 1m by 1m mostly built with spruce. The infills can be varied. At the moment some elements are filled with solid brick, lime silica brick, aerated concrete and in one case with mineral wool. The outer dimensions of the building are 9.9 m by 6.6 m. The eaves height is 3.35 m. The slope of the roof is 24°.



*Wall section with inside insulation*

### Inside boundary conditions

The inside temperature is controlled by a floor heating system and the inside humidity by acoustic evaporators.

## Special limitations / possibilities

It is possible to change the infills, insulation systems and indoor climatic conditions. Because of the rectangular elements the air tightness can be measured with special equipment.

# ADAPTABLE ROOF FACILITY

## Main objective of the test facility

This innovative test facility provides the unique option of investigating the hygrothermal performance of an attic construction with varied roof inclinations by gradually modifying the roof slope in steps. For the first time it is possible to examine angle-dependent effects without changing the roof construction. This is quite an interesting option, particularly when examining issues concerning the impact of defects/ blemishes due to settlement of insulating material or the effect of thermally induced convection in attic voids. It is possible to install several roof constructions side by side, in north and south orientations. This enables to compare directly different roof variations under the same boundary conditions. Replacing the various building components takes only a very short set-up time. It is no longer necessary to establish completely new roof constructions or even raise an entire new building just to perform tests of the attic construction.

## Overall lay-out

Situated below the actual roof test surfaces, there are four separate test rooms. Special care was taken in finishing the adiabatic construction of the enclosing surfaces. This was achieved by two measures, namely by applying high-quality thermal insulation to the external surfaces and by placing a controllable panel heating device in the curvature of the test room. These heating surfaces and the warm-air heating ensure a (largely) homogeneous temperature distribution in the chambers. The panel heating is used to establish the base temperature; the warm-air heating is used to compensate short-term temperature fluctuations. The ventilation device can be alternatively operated with recirculated air or with fresh supply air. The outdoor air change rate may be adjusted between a range from 0 to 5. The air in the test room is distributed through so-called 'Piccolo Ducts'. These ducts allow the air to flow into the room in a particularly uniform manner, spread across the entire width of the test room.

## Inside boundary conditions

Each test room can be individually heated, humidified, and ventilated in a different way. Ultrasonic humidifiers are used, which were selected for this purpose on account of their low energy consumption. In this way it is possible to establish an individual humidity profile in each chamber, which may be adapted to different, typical usage scenarios.

## Special limitations / possibilities

The test facility enables researchers to examine the attic components with regard to heat flows, air tightness, moisture behaviour and surface temperatures. To perform measurements of heat flow, temperature and moisture in building components and outdoor climatic boundary conditions, sophisticated measurement technology and equipment have been provided. The test facility has been equipped with a data logging system that stores the measured data in a data base, providing data for evaluation and analyses. Real-time visualization of current data (on-line) and remote access (if requested by the client) are both possible.

# Data analysis

## Typical equipment within test wall

Temperature sensors (pt100); RH-Sensors (capacitive); wood moisture sensors (resistance measurement), air flow sensors, heat flux sensors etc. are used, all of them from different manufacturers. The place, number and positions of the sensors are strongly dependent on the aim of the investigations.

## Accuracy and logging resolution

The temperature sensors have an accuracy of 0.1 K; the RH-Sensors of about 1 to 2 % r.H.; the accuracy of the heat flux sensors are about 5 % and that of the wood moisture sensors are depending on the moisture range. The logging resolution varies from seconds to 1 hour or in case of wood moisture 1 day, dependant on the aim of the investigations

## Analysis of the data

The analysis of the data is strongly dependent on the quite different type of investigations.

# EXAMPLES OF PREVIOUS STUDIES

- Evaluation of energetic performance
- Evaluation of hygric performance
- Durability of plaster and renderings
- Microbial growth on facades
- Indoor climate
- Investigations on thermal comfort
- Interior insulation with different material
- Airing systems and airtightness
- Cultural heritage
- Influence of the infills on the moisture in wooden beams
- Smart vapour retarder
- Capillary active insulation

# MAINTENANCE / COLLABORATION

## Personnel involved

The maintenance of the test site and the investigations are conducted by a staff of several employees of two different departments within the IBP, deployed depending on the aims of the investigations.

## International collaboration

Different collaborations mostly within IEA and EU-programs

# Relevant literature

## Literature on previous measuring campaigns:

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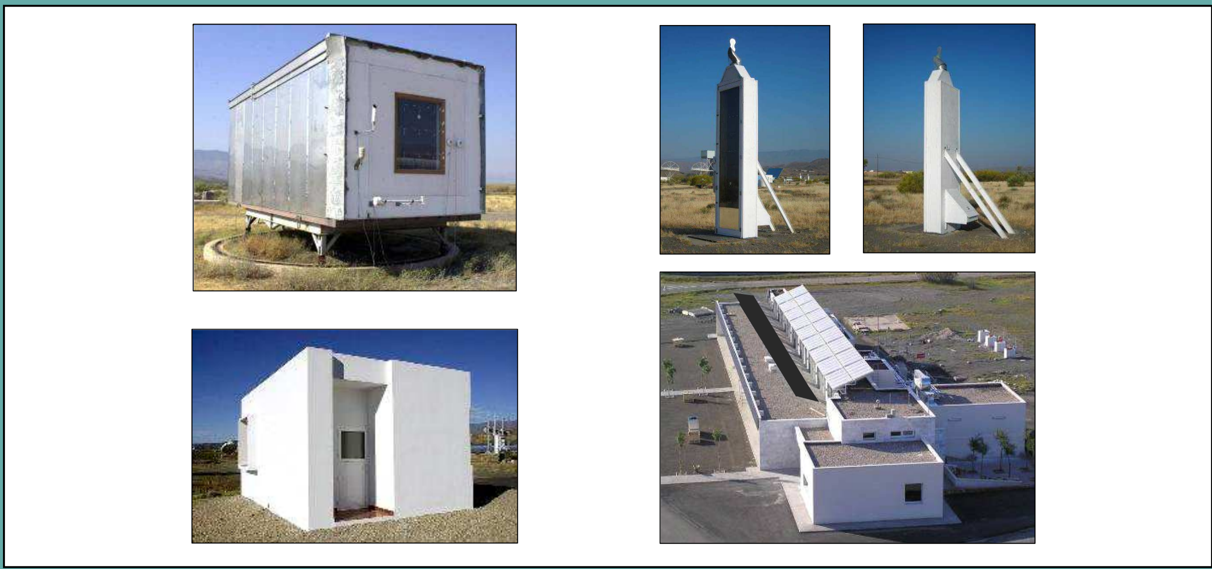
and numerous more

# LECE-UiE3-CIEMAT



## GENERAL DESCRIPTION

### Main objective of the test facility

The Building Component Energy Test Laboratory (LECE), one of the facilities at the "*Plataforma Solar de Almería*" (PSA), is part of the Energy Efficiency in Building R&D Unit (UiE3) in the CIEMAT Energy Department's Renewable Energies Division.

The UiE3 carries out R&D in integral energy analysis of buildings, integrating passive and active solar thermal systems to reduce the heating and cooling demand. This unit is organised in three lines of research focusing on: 1.-Energetic Analysis of Buildings by simulation, 2.-Study of Passive Systems in Buildings and Urbanism, and 3.-Experimental Energy Evaluation under Real Conditions. The test facilities described are under the last of these.

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The Group's activities are largely experimental, focusing in energy performance assessment of buildings, and building components

These activities are carried out in the LECE's Outdoor Laboratory at the Plataforma Solar de Almería (PSA) and the PSE ARFRISOL Research Energy Demonstrator Office Building Prototypes (C-DdI), one of which is also at the PSA.

The LECE has several systems for studying actual-size construction systems experimentally under real weather conditions, using data analysis, system-identification and time-series-analysis techniques. These experimental systems are the PASLINK and other test cells, the Solar Chimney, and Monozone Building.

In addition, the LECE infrastructure is prepared for the integration of new experimental prototypes that can be incorporated according to the needs of the Group's future research projects.

LECE activities may be classified as:

- Experiments in the CIEMAT Energy Efficiency in Building R&D Unit's research projects.
- Collaboration with and services for building materials and component manufacturers.
- Experimental support for preparation of standards and regulations.

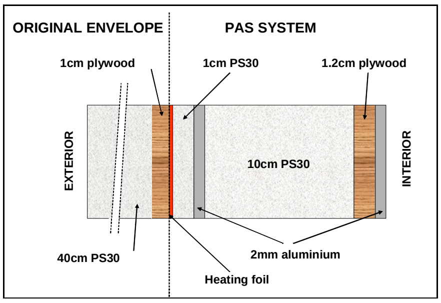
## Overall layout

The test facility integrates several devices with different capabilities as summarised below:

**Test cells:** The LECE has four test cells, each of them made up of a high-thermal-insulation test room and an auxiliary room. The test room's original south wall can be exchanged for a new wall to be tested. This makes experimental characterisation of any conventional or new building envelope possible.

CIEMAT's PASLINK test cell.

**PASLINK Test cell:** The Spanish PASLINK test cell incorporates the Pseudo-Adiabatic Shell (PAS) Concept. This system detects heat flux through the test cell envelope by means of a thermopile system, and compensates it by a heating foil device. The inner surface in the test room consists of an aluminium sheet which makes it uniform to avoid thermal bridging. It also has a removable roof that enables horizontal components to be tested. The cell is installed on a rotating device for testing in different orientations.




*Schematic drawing of the PAS system*

*Detail of the rotating device*

Solar Chimney.

**Solar Chimney:** This was constructed for empirical modelling experiments and validating theoretical models. Its absorber wall is 4.5 m high, 1.0 m wide and 0.15 m thick, with a 0.3-m-deep air channel and 0.004-m-thick glass cover. A louvered panel in the chimney air outlet protects it from rodents and birds. The air inlet is protected by a plywood box to avoid high turbulences from wind. The inlet air flow is collimated by a laminated array so that the speed component is in the x-direction only.

**Monozone building:** This is a small 31.83 $m^2$ by 3.65 m high simple monozone building built in an area free of other buildings or obstacles around it that could shade it except for a twin building located 2 m from its east wall. Its simplicity facilitates detailed, exhaustive monitoring and setting specific air conditioning sequences that simplify its analysis for in-depth development and improving energy evaluation methodologies for experimental buildings.

Reference monozone building.

**The PSE ARFRISOL C-DdIs** are fully instrumented Energy Research Demonstrator Office Building Prototypes which are in use and monitored continuously by a data acquisition system. The CIEMAT owns 3 of 5 of these “Contenedores Demostradores de Investigación, C-DdIs” (Research Energy Demonstrators Building Prototypes), built under the ARFRISOL Project. Each of them is an office building with approximately 1000 $m^2$ built area. One of them is also at the PSA and the others in different locations representative of Spanish climates. These C-DdIs are designed to minimize energy consumption by heating and air-conditioning, whilst maintaining optimal comfort levels. They therefore include passive energy saving strategies based on architectural and construction design, have active solar systems that supply most of the energy demand (already low), and finally, conventional auxiliary systems to supply the very low demand that can not be supplied with solar energy, using renewable energy resources, such as biomass insofar as possible.

These prototypes were built for high-quality measurements recorded during monitoring to support research activities on thermal comfort, building energy evaluation and both active and passive systems integrated in the buildings.

Office building in use.

## Inside boundary conditions

Different devices measuring outdoor air temperature, using natural and forced ventilation.

In the **test cells**, tests are carried out with a preset heating regime, including high power, low power, and dynamic power subsequences, according to a Randomly Ordered Logarithmically distributed Binary Sequence (ROLBS). This sequence provides test conditions such as a high enough temperature difference across the test specimen, avoiding correlation with diurnal incident solar radiation swings, and sufficient dynamic information. In these conditions tests in short periods are possible, typically two weeks long.

The test cell is carefully sealed before each test to eliminate infiltrations. Airtightness is checked by pressurisation tests before and after each test. Tracer gas measurements are also taken during the test, but only to estimate the contribution to the uncertainty budget.

In **real buildings,** testing is done simultaneously with its normal use. Indoor conditions are usually within the comfort limits and longer periods of analysis are considered.

## Outside boundary conditions

Testing is done under outdoor weather conditions. Meteorological sensors are installed at the test site. Some of the main physical quantities are measured with redundancies for good representation.

Device measuring solar global and diffuse, and longwave radiation.

The following meteorological sensors are installed: Global, horizontal, and south vertical solar radiation, air temperature, longwave radiation, wind speed and direction, relative humidity and concentration of $CO_2$.

## Special limitations / possibilities

In principle, tests of thermal performance of building components are tested in the PASLINK test cell. Some restricted tests of opaque and homogeneous walls which allow installation of heat flux sensors on the inner surface are carried out using the original PASSYS test cell or the Spanish CESPA test cells (similar).

In PASLINK test cells, due to the particular climate conditions at the test site, usually sunny with cold winters and warm summers, some of the usual analysis assumptions cannot be applied, and special considerations are necessary. One of the effects which requires special hypotheses to achieve satisfactory results is longwave heat exchange on inner surfaces heated by solar radiation. Advanced tools for dynamic analysis and nonlinear models have been applied to solve such problems, and lessons learned have since been very useful in the analysis of other systems where energy saving in warm and sunny climates is of great interest.

Ultrasonic device measuring wind speed and direction.

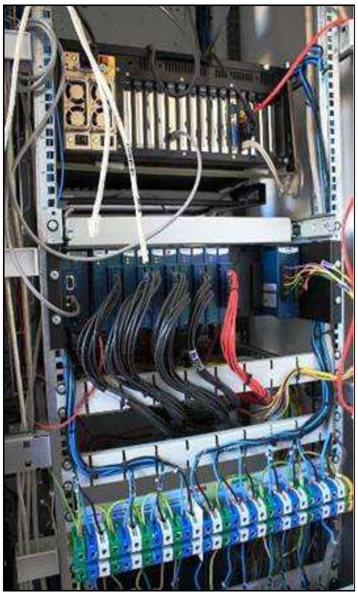
Other devices have been added to the test site to fit the requirements of the research projects being carried out by the group. One of the main topics is the analysis of natural heating and cooling techniques. An experimental solar chimney, tests of ventilated façades, and a new test cell to test roofs, have been built for this purpose. The design of this new test cell is intended to solve some practical aspects related to roof testing, such as accessibility and structural resistance. An underground test room allowing easy access to the test component is used for this.

*Views of the new roof test cell, presently under construction.*

Ceramic ventilated façade being tested in a CESPA test cell.

Another of the main topics of research of this group is experimental energy analysis of buildings. The elements of the test site that support this activity are a monozone building (30 $m^2$) and an office building prototype which is in use (1000$m^2$).

# DATA ANALYSIS



Data acquisition system in the service room of a test cell.

## Typical equipment inside the test wall

The following measurements are necessary in the test cells: a sensor arrangement measures indoor air temperature, and the energy supplied for heating and cooling. If the longwave radiation effect is not negligible then outdoor surface temperatures must also be known.

In other kinds of tests, special measurement points are decided for each particular case, according to the characteristics of the component and the purpose of the test, in line with the general idea that all physical quantities that contribute to the heat exchange in the test system must be quantified.

## Accuracy and logging resolution

The following aspects have been considered to achieve the required measurement accuracy:

- Accuracy of the measurement transducers.
- Sensor position (and distribution if necessary), installation and accessories, for good representation of the measurand.
- Data acquisition system: 16-bit A/D resolution, range of measurements fitting sensor output, modules distributed to minimise wiring.
- Twisted pairs and grounded shield are employed to reject noise and avoiding perturbations from wiring.

Rack mounted computer and data acquisition system in the service room of a test cell.

Although a wider range of measurements are carried out in the context of research, some of them have been identified as most influencing the final results in the most common tests assessing thermal performance of building components. The following list summarises the instrumentation used for these measurements.

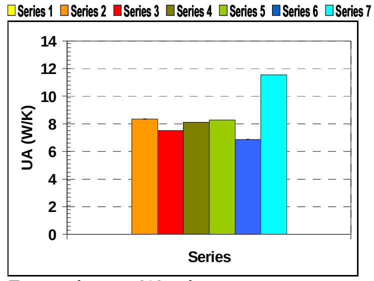
- Air temperature: Platinum thermoresistance, PT100, 1/10 DIN, directly measured using a four-wire connection, with a solar radiation shield and ventilated for outdoor measurements.
- Global Solar Irradiance: Pyranometer, model CM11 manufactured by Kipp and Zonen, secondary standard according ISO 9060:1990, voltage directly measured using a differential connection.

- Heating power: Vatimeter model SINEAX DME 440 manufactured by Camille Bauer, class 0.25 to IEC 688:1992, 4.20mA output directly measured.
- Heat flux density: Sensor model HFP01 manufactured by Hukseflux, accuracy of sensitivity coefficient 5%, voltage measured directly by differential connection.

Data are recorded every 10 minutes, although other recording intervals are available.

## Analysis of the data

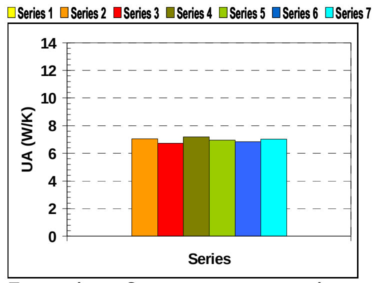
Applied analysis depends strongly on the purpose of the tests and also on the characteristics of the test object, ranging from averaging methods to dynamic approaches traditionally considering linear and time invariant parameters, and more recently including nonlinear and time-dependent parameters. In all cases, validation of results takes physical coherence of results into account.




Example: Window component tested in a test cell. Test conditions in series: 1 to 5 in summer, 6 and 7 in winter. 2 to 6 with test cell facing north. 1 and 7 with test cell facing south. Results assuming heat exchange through the test cell envelope negligible.

Averaging methods are restricted to quite simple components or simplified test conditions (example: using a shading screen to avoid solar radiation incident on the component). These methods usually require a very long period of testing. In some cases, this is because high thermal inertia leads to a long period of integration. In other cases, in components with less thermal inertia, effects such as wind speed, longwave radiation, or solar irradiance in sunny weather, may become non-negligible, and make necessary the use of multi-linear regressions in which the increase in the number of inputs leads to longer test periods in order for there to be enough degrees of freedom for regression.

Dynamic methods, frequently with linear parameters, are very useful for overcoming some of these problems. Recent studies have shown the flexibility and usefulness of dynamic nonlinear models, particularly for dealing with problems related to warm sunny weather in this test facility. Nonlinear models have been successfully applied to such cases as ventilated photovoltaic modules, solar chimneys and also for taking the boundary conditions in a test cell into account. Models including time-dependent parameters have also been applied successfully for finding the characteristic parameters of a wall before and after energy refurbishment.




Example: Same test as above. Results considering the longwave heat exchange on inner surfaces of the test cell as boundary condition.

These results show enormous potential for the analysis of systems including cooling strategies, such as longwave radiation, natural ventilation, etc. Many of these strategies are based on nonlinear physical processes. This becomes more relevant when these effects are maximized to optimize performance in energy savings strategies, which at the same time highlight the insufficiency of linear models in such cases.

# EXAMPLES OF PREVIOUS STUDIES

The test facility has recently been used to experimentally support the following studies:

- Experimental energy analysis of empty monozone reference building applying system identification tools. The analysis focused in the effect of heat exchange with the soil. (Ph. D Thesis B. Porcar. 2009).
- Analysis of heat transfer in a Solar Chimney with turbulent air flow. The solar chimney was used to validate the proposed model. (Ph.D Thesis J. Arce. 2008).
- Analysis of heat transfer in a Solar Chimney. The solar chimney was designed and used to validate the proposed model. (Ph.D Thesis J. Martí. 2006).
- Analysis of opaque and window components tested in a test cell. Proposal for uncertainty estimation according GUM, analysis of problems related to tests in sunny weather and solution of these problems. (Ph.D Thesis M.J. Jiménez. 2005).

This facility has been in use since 1989 for CIEMAT services to external clients and funded research projects. Many of these projects deal with developing and setting up the test facilities and tests procedures. Some supported by the EU were: PASSYS II (1989-1992), COMPASS (1992-1995); PASLINK (1992-1994), PV-HYBRID-PAS (1996-1998), IQ-TEST (2000-2003), etc.

In other projects, the test facility participated by giving experimental support to research, such as PASCOOL (1992-1995) about Passive Cooling, APISCO (1996-1998) analysing the effect of plants in thermal comfort, and ARCHINT (1999-2001) on architectural integration of solar collectors.

The following projects are currently in progress:

- Experiment set up and analysis of five occupied 1000-$m^2$ fully monitored, energy demonstration and research office building prototypes. One of them is at the PSA test site. Running and 2 year's data are available in the framework of the PSE-ARFRISOL project on Bioclimatic Architecture and Solar Cooling (Supported by R&D Spanish National Plan Ministry of Science and Innovation, 2005-2012).
- Experiment set up and analysis of 2 twin empty, fully monitored, 250-$m^2$ energy demonstration and research residential building prototypes each. Installation of the monitoring system is underway. In the framework of the EDEA project (Efficient Development of Eco-Architecture: Methods and Technologies for public Social Housing Building in Extremadura, Spain). European Financial Support LIFE+97. 2009-2012.

- Experiment set up and analysis of an occupied, 5000-$m^2$ fully monitored, energy demonstration and research office building prototype. Installation of the monitoring system is underway. In the framework of the Innpacto CELSIUS Project. (Supported by PLAN E from the Spanish Ministry of Science and Innovation). 2010-2013.

# MAINTENANCE / COLLABORATION

## Personnel involved

The experimental set up, including sensors and data acquisition systems and their operation, and data analysis are done by the CIEMAT Energy Efficiency in Building Group. Test components in test cells are usually installed by the manufacturer of the component. Exceptionally large installations for monitoring actual-size buildings are contracted. Also exceptionally, other technical assistance, such as carpenters and plumbers, is contracted. Work done by such external assistance always follows CIEMAT's detailed technical specifications.

## International collaboration

CIEMAT has participated in European projects on characterisation of building components, such as PASSYS II and COMPASS, since 1989. It has been a member of PASLINK EEIG since its creation in 1995. It is presently a member of INIVE through the DYNASTEE platform. During this time it has participated actively in all these activities, mainly in those related to data analysis.

This test facility, as part of the facilities of the PSA, was included in the TMR (Training and Mobility of Researchers, 1996-1998) and IHP (Improving Human Potential, 2000-2003) programmes funded by the EU. These programmes provided access to the PSA free of charge for user groups or individuals throughout the Member States of the European Union and Associated States. Users were provided with infrastructure, logistical, technical and scientific support.

## Link to other devices

The test facility makes use of the excellent infrastructure for solar applications at the PSA, which belongs to the Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), the largest European centre for research, development and testing of concentrating solar technologies.

# RELEVANT LITERATURE

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www.arfrisol.es, in Spanish. Last viewed 28th February 2011.

M. J. Jiménez, R. Enríquez, R. Olmedo, N. Sánchez, M.R. Heras. 2010. In Spanish. “Monitorización energética de los C-DdIs del PSE-ARFRISOL. Diseño experimental”. Presented at congress: “I Congreso sobre Arquitectura Bioclimática y Frío Solar”. Aguadulce, Almería, Spain. 23-26 March 2010. ISBN: 978-84-693-5141-3.

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M. J. Jiménez, B. Porcar and M. R. Heras. “Application of different dynamic analysis approaches to estimate the U value of building components”. Building and Environment. 44(2), pp. 361-367. February-2009.

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# EGUZKI and ILARGI PASLINK TEST CELLS LCCE VITORIA-GASTEIZ

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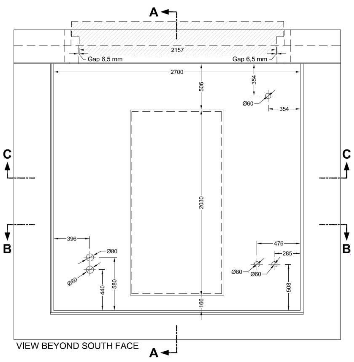
## General description

### Main objective of the test facility

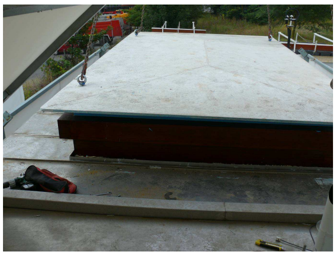
The two PASLINK test cells named EGUZKI and ILARGI are part of the equipment of the Thermal Area of the Laboratory for the Quality Control in Buildings (LCCE) of the Basque Government. The Department of Thermal Engineering at the University of the Basque Country (UPV/EHU) was appointed by the Basque Government to set up and manage the Thermal Area within the LCCE. To accomplish that goal, it was signed an agreement between both institutions.

The LCCE's Thermal Area started its activities in 1988 with thermal conductivity measurements (according to ISO 8301 and 8302). Then a guarded hot box for opaque walls (according to EN ISO 8990) was installed to measure




ILARGI drawings for roof samples.

Installing the insulation frame for roof samples in ILARGI.



Removing the calibration roof from ILARGI.

Installing the frame for roof samples in ILARGI.

thermal transmittances, and a year later a guarded hot box for windows was installed (according to EN ISO 12567).

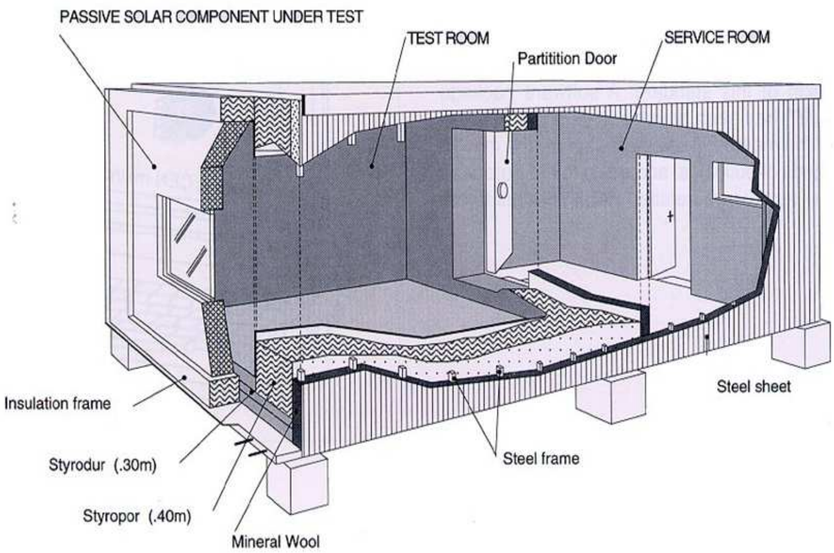
In parallel to the thermal testing, the LCCE also set up equipment for hygrothermal measurements:

- Water vapor permeability tests as per Standard UNE-EN ISO 12572:2002
- Capillary absorption tests as per Standard UNE-EN ISO 1548:2002
- Hygroscopic sorption tests as per Standard UNE-EN ISO 12571:2000
- Water absorption under vacuum tests as per Standard NBN B 24-213
- Mercury intrusion porosimenter: Micromeritichs AUTOPORE IV
- Moisture buffering Value determination as per NORDTEST protocol, as per Standard JISA 1470-1: 2002 and as per ISO 24353:2008.

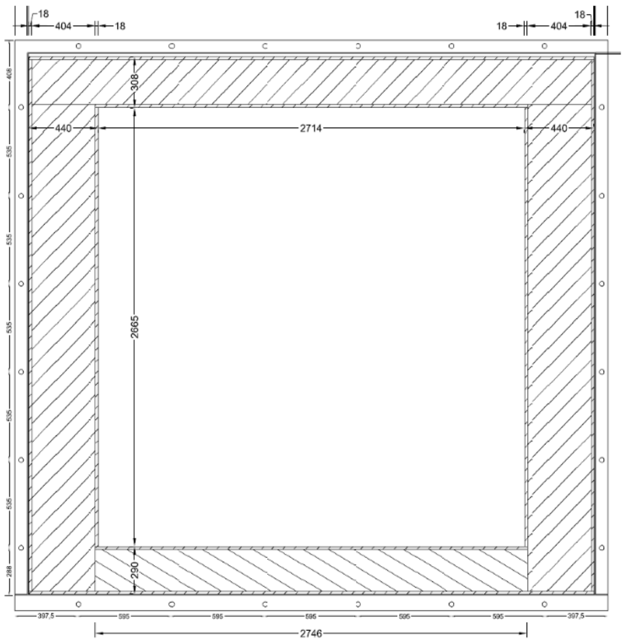
In 2007 a need for testing the hygrothermal behavior of full size samples of new developments such as ventilated façades, new roof system, PCM walls, etc. was found. After searching in the literature, the LCCE staff found PASLINK test cells was the most developed system (both: equipment and procedures) for measuring the hygrothermal performance of this type of elements under real conditions.

## Overall lay-out

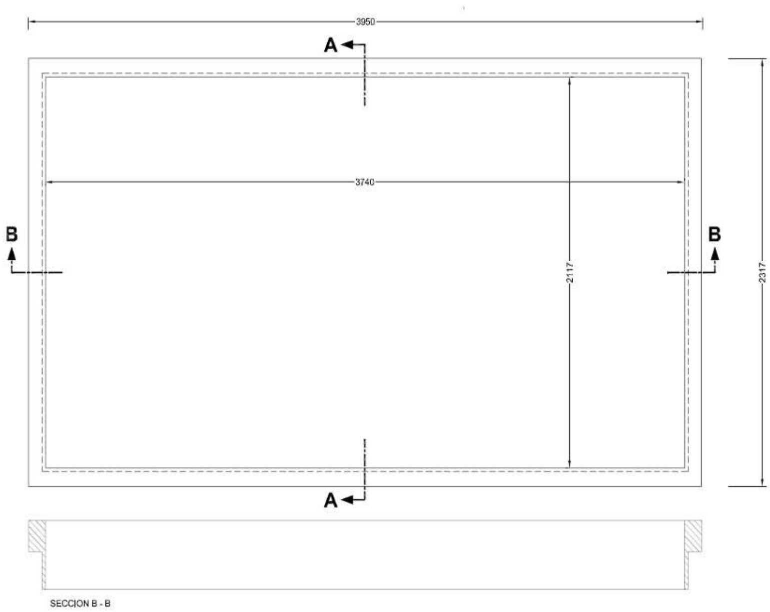
Nowadays there are two PASLINK test cells in the LCCE premises. One of them named EGUZKI can test vertical elements of 2.7 x 2.7 m while the second test cell named ILARGI can test both: vertical elements of 2.7 x 2.7 m and horizontal ones of 3.7 x 2.1 m.




*Schematic view of EGUZKI test cell. ILARGI test cell is similar but part of the roof is removable. Source: [3].*




*Drawings of the insulation frame for EGUZKI test cell vertical samples. ILARGI test cell vertical samples are of similar size.*




*ILARGI test cell frame for horizontal samples.*

Both test cells were bought to the Porto test site and before being used they have been upgraded following the indications provided by Dr. J.J. Bloem:

- All thermal bridges were removed: the front of the sample connection was metallic and was replaced by a wooden frame; the cooling water

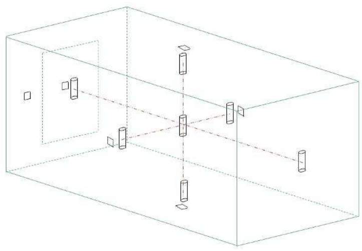
Samples are constructed under controlled conditions inside the pavilion.

The pavilion has all the required facilities to construct any type of samples with the required quality under safe conditions.

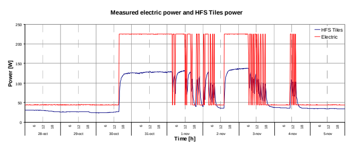
Sample being transported from pavilion to EGUZKI test cell.

Sample installed in EGUZKI.

Frontal view of EGUZKI test cell without the sample. All interior sensors of the test room can be seen: 7 air Pt100 protected against radiation, blackbody temperature, 9 surface Pt100 to measure envelope walls interior surface temperature and 230 Heat Flux Sensitive tiles (HFS Tiles) covering the whole envelope except the sample. Inside the wooden box an axial ventilator and an electrical heater are located.



Temperature sensor location schematic inside the test room.




Measured electric power (red) versus HFS Tiles heat flux (blue). Considering the thermal inertias of the test room elements the heat flux through the sample can be calculated.

tubes that connected the test room and service room were removed too; the door separating the test room and the service room had a metal frame and it was changed to wood; the two large air pipes were removed, insulated and sealed because they are not needed.

- Inner wooden lining was removed and new plastic foil was installed before new and thicker inner wooden lining was installed. Air infiltration rates have become negligible and inner surface for HFS Tiles installation was improved.
- A shadow system for solar radiation on lateral walls and roof of the test cell was installed to obtain better uniformity in the heat fluxes through the envelope excluding the test sample.
- In the second test cell, roof components can also be tested. An insulation frame for the roof components have been designed and constructed. This new development was carried out entirely by the LCCE staff. It minimizes border effects and makes it easier to manipulate roof samples although they are heavy roofs.

Both test cells are facing south. The volume of the test room (38 $m^3$) and the size of the samples are representative for real size constructions.

## Inside boundary conditions

The inside conditions are those of the test room. The interior air temperature is measured in 7 points by Pt100 sensors protected against radiation and are distributed as shown in the temperature sensor schematic. This way temperature stratification can be measured and it is maintained below 0.3ºC thanks to an axial ventilator that is placed inside the wooden box, as it can be seen in the adjoined photo. Inside the box there is also an electrical heater that can be switched ON and OFF from the data acquisition program. The power consumption of both is measured by a power transducer (± 0.5 W) very accurately. The complete envelope is covered by 230 Heat Flux Sensitive Tiles (HFS Tiles) grouped in 21 groups which measure the heat that leaves the test room through the envelope walls except through the south wall. The surface temperature of all interior walls is also measured by 9 surface Pt100 and their deviation is less than 0.9ºC.

The test room is very airtight. After installing the sample a pressurization test is carried out and if the air renovation rate is below 0.5 $h^{-1}$ under a 50 Pa pressure difference between interior and exterior it means the air infiltration rates are negligible during the test. The pressurization test is repeated after the test procedures have been finished. If all the conditions mentioned above are accomplished, by means of an energy balance between the power transducer signal and the HFS tiles signal, we can accurately obtain the heat flux through the sample. This indirect way of measuring the heat flux through the sample makes possible to install any type of semitransparent elements in the south wall and both whole-element thermal transmittance (UA) and solar aperture (gA-value) can be calculated.

## Outside boundary conditions

Outside boundary conditions are the ones of the exterior conditions in the location of Vitoria-Gasteiz. There is a meteorological station in the site measuring air temperature protected against radiation, wind direction, wind velocity, barometric pressure, relative humidity and rain precipitation at 10m height. All these measurements are carried out by a VAISALA weather transmitter WXT510 meteorological station.

In front of the sample the air temperature is measured accurately by a Pt100 shielded against radiation and ventilated. Wind direction and wind velocity are also measured in front of the sample. There is a Kipp & Zonen CMP11 pyranometer for measuring the global solar radiation in the plane of the sample, for both vertical and horizontal samples. Apart from these pyranometers there are also two CMP11 pyranometers that measure the global horizontal and the diffuse horizontal radiation in the test site. For checking issues there are also two air Pt100 temperature sensors shielded against radiation in each test cell, one placed below the test cell and the other one in the roof under the solar shielding.

EGUZKI without sample and protected with a tarpaulin. Meteorological station is located 10 m high. Air temperature, velocity and direction in front of the sample.

## Special limitations / possibilities

The way of measuring the heat flux through the sample in an indirect one, making it possible to test any type of vertical enclosure within the dimensions of the frame. This includes any type of semitransparent element, ventilated façades, façades using PCM… The height of one story is 2.7 m and is the maximum sample height. There was a need for calculating the thermal behaviour of a 4 story ventilated façade, so the test cell was used for calibrating a CFD model for a 2.7 m height case and that model was used thereafter for optimising the air chamber for the real size building.

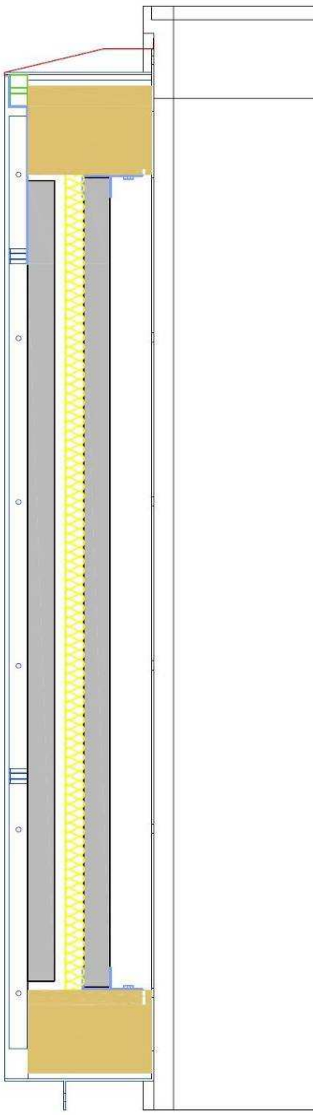
ILARGI air temperature, velocity and direction in the height of the roof.

The most important improvement made by the laboratory Thermal Area staff on the test cells has been the roof testing system. The original test cells were designed to remove the whole roof. In this way the roof sample installed has no insulating frame whereas the vertical samples do have. A fixed insulating frame was designed and constructed within the original roof making possible to test horizontal roof samples as accurately as vertical walls are tested. The size is not as big as to test an inclined roof so the roof testing has been limited to horizontal or very low tilted roofs. A calibration roof was also constructed in the same way as it is made for vertical samples.

Global solar radiation in the plane of the sample.

Global and diffuse horizontal radiation.

# DATA ANALYSIS



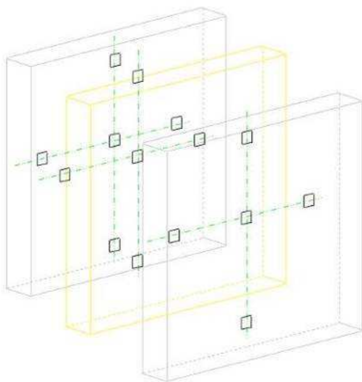
Vertical section of one ventilated façade tested in EGUZKI test cell. Left side is facing exterior and right side is facing test room. From inside to outside is composed by 4 layers: 8,5 cm concrete slab, 6 cm of mineral wool, 3.5 cm of ventilated air chamber and 8.5 cm exterior concrete slab.

## Typical equipment within test wall

The sensors to measure the inside boundary conditions and the ones for outside are fixed for all tests and they are described in [1], [2] and [3]. Besides all those fixed sensors, the sample to be tested is usually equipped with Pt100 temperature sensors (air and surface), heat flux sensors, thermopiles, pressure tubes, relative humidity sensor, thermoanemometers and air flowmeters.

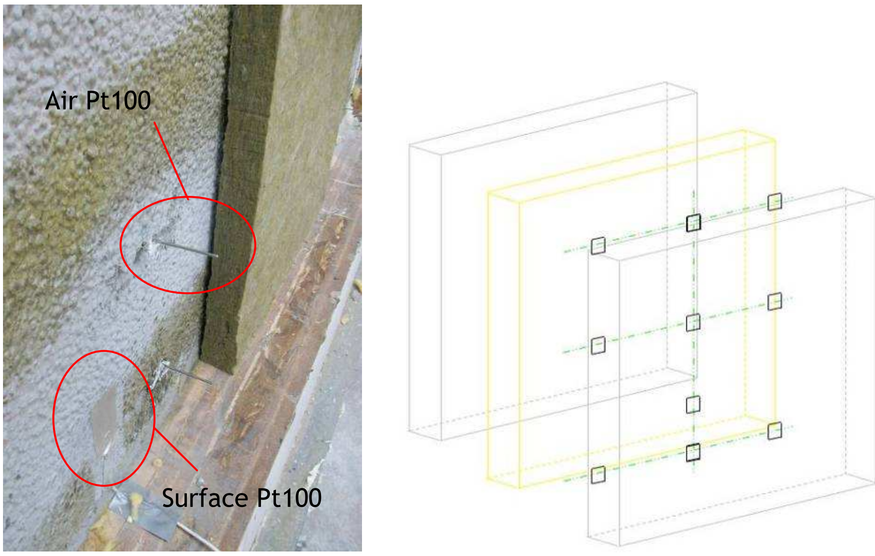
Depending on the sample to be tested and also on the aim of the test, the sensor types and positions are defined before the sample is constructed. The construction of the sample is done inside the laboratory pavilion. Some sensors are usually wrapped up inside the sample and they must be installed during construction.

For example a ventilated façade was tested for a modular housing company; it can be seen schematically in the adjoining column.



*15 Pt100 for surface temperature installed in the three interior interfaces: in both layers of insulation and in the concrete surface of the air chamber.*

For this sample the air chamber was the most important part of the test, since the test results were used to calibrate a CFD model. That is why 10 air Pt100, a thermopile and 4 thermoanemometers were installed inside the air chamber to measure the evolution of temperatures in the air as well as the mass flow in the air chamber.




*Left: Pt100 for air chamber and surface Pt100 installed below the insulation layer. Right: Distribution of air Pt100 in the air chamber.*

Hot wire anemometers to measure the air chamber air velocities in the central vertical axis in two different levels.

Closing the air chamber, wooden separators to maintain the air gap uniform. Thermopile cables in green.

The air chamber was also equipped with air velocity sensors and relative pressure sensors as listed below.

| Name | Description | Accuracy |
|---|---|---|
| 1AVT01 | Air velocity inside the air chamber. Central vertical axis (226 cm). | ± 0.01 m/s |
| 1AVT02 | Air velocity inside the air chamber. Central vertical axis (123 cm). | |
| 1AVT03 | Air velocity inside the air chamber. Central vertical axis (33 cm). | |
| 1AVT04 | Air velocity inside the air chamber. Central vertical axis (0 cm). | |
| 1PRT01 | Relative pressure between the atmospheric pressure (protected against wind) and the air chamber top level static pressure. | ± 0.5 Pa |
| 1PRT02 | Relative pressure between the lower level static pressure of air chamber and the air chamber top level static pressure. | |
| 1PRT03 | Relative pressure between the lower level static pressure of air chamber and the atmospheric pressure (protected against wind). | |

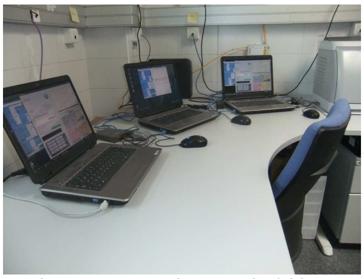
## Accuracy and logging resolution

The data acquisition and control of each test cell is done by a HP Agilent 34980A which can accommodate up to 8 plug-in modules for different purposes (in our case 5 multiplexer 34921A and 1 control 34951A module). This acquisition system is placed in the service room 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. The software used to communicate with the HP Agilent 34980A has been developed by the LCCE laboratory staff in collaboration with a programmer who has done the program to fit the needs for data collecting and controlling of the test cell.

HP Agilent 34980A data acquisition system for logging and controlling the PASLINK tests.

The most common and important measurements of the tests are usually the temperatures. PT100 class A 1/5DIN four wire connection are used, having different configurations depending if they are measuring air or surface temperature. In those samples where the temperature measurement must be done inside mortar layers, T Type thermocouples are employed since they are more robust. To measure differential temperatures self made and self calibrated thermopiles are used from T Type thermocouple wires. Some of the temperature instrumentation is manufactured specifically for the LCCE. These temperature sensors are calibrated in-situ using a controlled bath with an internationally traceable pattern. The measuring range is the one used in the calibration.

| Instrument | Manufacturer | Model | Range | Accuracy |
|---|---|---|---|---|
| PT100 class A 1/5 DIN | TC S.A. Measure and Control of Temperature Spain | F217-5/SPEC-RT47-F9/CU 16-1-30-CE2L-RT47-F9/CU | -20 to 60°C | ±0.2°C |
| Thermocouple Type T | TC S.A. Measure and Control of Temperature Spain | A14-KT-1-0.8-20.0.5 | -20 to 60°C | ±0.4°C |
| Heat flux sensors | AHLBORN S.L. German | FQA0801H | < 80 W/m$^2$ | 5% at 25°C |
| Air velocity sensor (thermoanemometer) | AHLBORN S.L. German | FVA605TA1 | 0.01 to 1 m/s | ±0.01 m/s |
| Humidity sensor | AHLBORN S.L. German | FHA6461 | 5 to 98% rH | ± 2 % |
| Differential Pressure sensor | AHLBORN S.L. German | OD 8612P05 | 0 to 50 Pa | ± 0.2 Pa |



Each HP Agilent 34982A is connected to a computer where the data is stored and sent by email in “dayfiles” format. The third one is for the meteorological station that passes the information to the other two computers.

The data acquisition system is very flexible and can hold most of the possible instruments needed for any specific sample. All the elements in the PASLINK test cells are connected to an UPS system located in the test room to permit a 2 hour electrical grid failure, the batteries of the computers have also 2 hour autonomy. This way the test can keep running if the electrical failure is under 2 hours.

This is the interface of the developed program for logging and controlling the PASLINK tests.

## Analysis of the data

Data analysis is different depending on the tested element. In any case the installations, data acquisition system and control system have been designed and constructed to make possible the use of the PASLINK data analysis methodology. This data analysis methodology is developed in [1], [2] and [3] and makes possible to obtain the UA and gA values of the tested element under real conditions. It also allows to evaluate the “apparent thermal transmittance” of elements that are performing under real conditions in which air cavities can have ventilation, where dynamic behaviour is important due to the thermal inertias of the element, solar energy can be stored, etc.

Calibrating temperature sensors in a controlled bath in the LCCE premises.

LORD and CTSM are the software that have been used for most of the cases when PASLINK methodology has been applied. Nevertheless, the flexibility of the test cells is very wide and has been demonstrated with several projects carried out by different members of the PASLINK network. Depending on the specific sensors installed inside the specific tested element, different goals can be achieved. Among the tested elements, apart from the thermal behaviour, the air movement on ventilated chambers has been studied. A CFD model has been calibrated for an industrialised ventilated façade: the cavity width has been optimised taking into consideration their mechanical and acoustic restrictions. Also a model (using software for hygrothermal simulation) has been calibrated to study the hygrothermal behaviour of a flat roof: the possibilities of condensation have been measured and simulated.

Active ventilated façade for non-residential buildings.

# EXAMPLES OF PREVIOUS STUDIES

The setting up of the two test cells started on 2007 and it was not until June 2009 when the first test cell (EGUZKI) was calibrated. Most of the testing works have been done in this test cell:

- Active ventilated façade was tested to study the energy savings that could be obtained for non-residential buildings. The ventilated cavity was the focus of the study and the data were used for calibrating a CFD model. This work was developed as part of a coordinated R+D project funded by the Spanish Government.

- A ventilated façade with the outer skin filled with PCM material was tested, both in summer and winter, to study the behaviour of the PCM under real conditions. Also the air chamber was monitored to study its performance. This work was developed as a R+D project funded by Biscay council.

- A company that has designed a system to construct modular houses has used the test cell for testing their ventilated façade design (referred above). The aim was to evaluate the thermal behaviour of the ventilated façade and also to optimize the air cavity width. The optimization was done via a CFD model that previously had been calibrated with the test results.

- A construction material company has tested the dynamic behaviour of one of his insulating mortar. This mortar has been used as an insulating material in a traditional façade and the “apparent U value” under real conditions has been calculated. Thermal inertias of the different layers have been calculated.

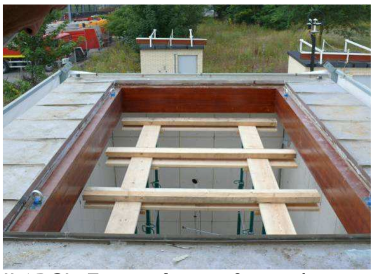
Ventilated façade with outer skin filled by PCM.

Insulating mortar projection.

Window system with solar energy accumulator.

IQ-TEST opaque wall.

IQ-TEST window.



ILARGI: Frame for roof samples.

ILARGI: installing the roof covered by gravel to be tested inside the frame.

- The University of Navarre has contracted the LCCE to test a window system with solar energy accumulator in the EGUZKI test cell. This development was obtained as the result of a R+D project. We have tested their element in different seasons and in different operational modes, obtaining UA value and gA values for these different operational modes.

- Apart from the calibration of the test cell, the IQ-TEST round robin test has been carried out in the EGUZKI test cell to evaluate if the test cell and the data analysis have been implemented properly in the test site. IQ-TEST description on [9] and [10].

The second test cell (ILARGI) has been calibrated by the end of June 2010. Only one test has been carried out in this cell. The calibration roof has been replaced by a flat roof sample designed by the same company that tested the ventilated façade for modular houses. A roof covered with gravel has been tested and the U value and the thermal capacity of the roof have been obtained. A Wufi model has been calibrated with the test data and used to advise for the need of vapour barriers and their optimal placement. Also the hourly annual energy demand per $m^2$ of roof has been calculated for the several zones considered in the Spanish Technical Building Code. As a next step the gravel cover will be substituted by a green roof and its thermal behaviour will be studied during 2011.

# MAINTENANCE / COLLABORATION

## Personnel involved

The Thermal Area staff of the LCCE is responsible of the test site. The full time members of the staff are engineers and technicians. There are also part-time members of the staff who are researchers from the Department of Thermal Engineering at the University of the Basque Country.

The technicians are the ones that make the control during the sample construction and testing. They are responsible for the quality during the construction of samples and they are also in charge of installing all the instrumentation on them. Calibration of sensors and supervision of the measuring and control system is also their responsibility. Common maintenance work is their responsibility but always guided by the engineers.

The full time engineers of the LCCE are the ones to make the data analysis and reporting for contracted tests. The part-time staff from the University of the Basque Country is involved in the development of the test cells and data analysis for some of the research projects. Some of them are doing their PhD with projects related to these activities.

## International collaboration

Dr. J. J. Bloem from ISPRA Joint Research Centre has visited the test site several times to check the setting up of both test cells. He is the one who has guided the improvements based in his wide experience with PASLINK test cells. During the first steps of the test site no specific international collaboration with other test sites has been possible.

Heat flow meter apparatus (according to EN ISO 8301)

## Link to other devices

The PASLINK test cells have been the last step forward made by the Thermal Area of the LCCE laboratory. It has followed a logical evolution starting from the knowledge of materials (thermal conductivity) until the hygrothermal behaviour under real conditions of real size samples. The hygrothermal behaviour of specific materials can also be tested in the laboratory by the different measurements described in the first part of this document.

Guarded hot box for opaque walls (according to EN ISO 8990)

The link to the guarded hot box for windows and walls is direct. The IQ-TEST window was tested previously in the hot box apparatus and similar results for the U value were obtained in the PASLINK test cell. The same procedure was followed with a concrete opaque wall tested in both, the guarded hot box equipment and in the PASLINK test cell, obtaining similar U values. The hygrothermal measurements have been accomplished only in the roof sample and they have given us satisfactory information.

Guarded hot box for windows (according to EN ISO 12567)

# RELEVANT LITERATURE

## General literature about the test facility:

[1] Van Dijk, H.A.L. and Van Der Linden, G.P. *PASLINK Calibration and component test procedures*. TNO, Delf, 1995.

[2] Van Dijk, H.A.L. and Tellez, F. *COMPASS Measurement and data analysis procedures*, WTCB-CSTC, Brussel, 1995.

[3] Van Dijk, H.A.L. *Development of the PASSYS test Method*, BBRI & European Commission – Directorate - General XII, EUR 15113 EN, Brussels, 1994.

[4] Hahne, E. and Pfluger, R. *Improvements on PASSYS test cell. Solar Energy*, Vol. 58, n 4-6, (1996), pp. 239-246.

[5] Saxhof, B. *PASLINK calibration manual*, Technical university of Denmark, 1995.

[6] Van der Linden, G.P., Van Dijk, H.A.L., Lock, A.J., van der Graaf, F. *Installation Guide for HFS Tiles for the PASSYS test cells*, WTCB-CSTC, Brussel, 1995.

[7] Saxhof, B. *PASLINK calibration manual*, Technical university of Denmark, 1995.

[8] Van der Linden, G.P., Van Dijk, H.A.L., Lock, A.J., van der Graaf, F. *Installation Guide for HFS Tiles for the PASSYS test cells*, WTCB-CSTC, Brussel, 1995.

[9] Baker, P.H., *WP3 Spec for component – 1*.doc, 2000. (IQ-Test internal report)

[10] Heimonen, I. *Test Report on Round Robin Components*, VTT Results, WP3 IQ-Test, Finland, June 2002. (IQ-Test internal report)

## Literature on previous measuring campaigns:

[11] Escudero, C., Erkoreka, A., Garcia, C., Flores, I., Martin, K. *Puesta a punto y objetivos a cumplir de una célula de ensayos PASLINK*, VI Jornadas Nacionales de Ingeniería Termodinámica, Cordoba, June 2009.

[12] Erkoreka, A., Flores, I., Escudero, C., Martin, K., Sala, J.Mª, *Importance of testing the thermal performance of façades and roofs under real conditions,* XXIX summer courses UPV/EHU San Sebastian – XXII European Courses, June 2010.

[13] Erkoreka, A., Escudero, C., Flores, I., Garcia, C., Sala, J.M. *Upgrading and calibration of two PASLINK test cells. Evaluation through the "IQ-TEST" round-robin test*, DYNASTEE workshop on Dynamic Methods for Building Energy Assessment, October 11 – 12, 2010, BRUSSELS

[14] Erkoreka, A., Flores, I., Escudero, C., Garcia, C., Sala, J.M. *Thermal characterization of ventilated facades under real conditions using PASLINK test cells*, XXXVII IAHS World Congress on Housing, October 26 – 29, 2010, Santander, Spain

# TEST SITE UIBK INNSBRUCK

full scale test facility (view from S/W)

**Institute/organisation:**

University of Innsbruck
Unit: Energy Efficient Buildings

**Contact person:**

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A-6020 Innsbruck
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e-mail : rainer.pfluger@uibk.ac.at

**Exact location:**

Innsbruck, Austria
47° 15' N, 11°20' E

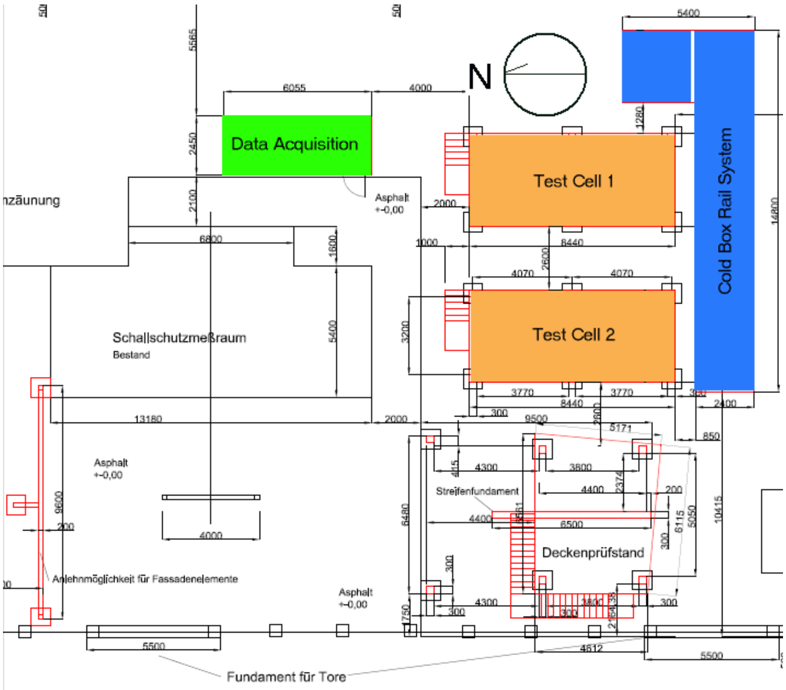
## GENERAL DESCRIPTION

### Main objective of the test facility

The major aim of the test facility at the outdoor test site of the unit is thermal and visual (Daylight and artificial light) test of building components, lighting products and control devices. It is used within several research projects with the aim of research and tests on prototypes for energy efficient buildings. Besides the two PAS/PASSYS – Test Cells, there is a test facility for measurement of sound protection of building elements (air and solid borne sound)

Besides the research on the thermo physical behaviour of building components, research on thermal and visual comfort as well physiological impacts is performed in close collaboration with medical departments.

## Overall lay-out




*Outdoor test site UIBK*

The test site consists of one PAS-Testcell and one PASSYS-Testcell, both for test elements with the size of 2,75x2,75 m. In front of both cells, a rail system was constructed for positioning of a so-called "Cold-Box", which is used to create a constant low temperature in front of the test component. This way, tests under steady state ambient conditions can be performed.

*Rail system for placement of the movable Coldbox.*

*Testcell and Coldbox in parking position.*

North to the Test Cells, the sound tests facility is located, which consists of two rooms, separated by a test component of max. 10 m². The component is put in place by a special crane facility.

At the east side of the test cells, the foundations for a test device for ceilings is already finished.

### Inside boundary conditions

The inside temperature can be controlled within the range from 5 up to 45 °C by means of a heating (electric) and cooling (hydraulic) system via air (recirculation air handler).

### Outside boundary conditions

The outside boundary conditions are ambient conditions or kept constant by Cold Box (as described above) within the temperature range of 5 up to 45 °C

### Special limitations / possibilities

The standard heating and cooling system as developed during the EU-projects PASSYS and PASLINK is supplemented by an air dryer and ambient air ventilation system, which makes it possible to perform tests under different hygro-thermal conditions. This special feature is used for component tests as well as for medical tests under controlled adverse conditions.

## DATA ANALYSIS

### Typical equipment within test wall

The test component is equipped usually with 15 additional temperature sensors (NI-CrNi thermoelements), two heat flux sensors and (depending on the component) humidity sensors.

### Accuracy and logging resolution

Calibrated thermocouples (type Ni-CrNi) and PT 100 temperature sensors for air and surface temperatures. Calibrated heat flux sensors (TUC) and air velocity (Omnisensor). The logging resolution is 10 minute interval for standard measurements (higher resolution on demand for special measurements).

### Analysis of the data

The dynamic data is analysed with the Software LORD for determination of U and g-value of the components. Moreover stationary tests with Cold-Box in front of the component is applied for accurate and fast determination of the U-value under steady state conditions.

# EXAMPLES OF PREVIOUS STUDIES

First tests on window-components with integrated shading and ventilation system were performed. At the moment the second test cell is under preparation for measurement of daylight and artificial light (integrated systems) within a national research project (K-Licht, P01).

# MAINTENANCE/ COLLABORATION

## Personnel involved

The test facility is maintained by employees of TVFA and research persons of University Innsbruck. They are also responsible for data analysis and take care of smaller adaptations. The maintenance of the heating and cooling system is done by Sparer Klima&Kältetech.

## Link to other devices

The outdoor test facility as well as the indoor climate chambers and sound measurement test devices is part of the TVFA (Technische Versuchs und Forschungsanstalt) working as an accredited laboratory of the University Innsbruck. The test cells work as a stand-alone test facility, the data acquisition is located in an office container nearby.

# RELEVANT LITERATURE

## Literature on previous measuring campaigns:

Pfluger, Rainer; Malzer, Harald; Feist, Wolfgang: Testing of a Window Device with Integrated Shading and Ventilation System with PAS-Test Cell and Coldbox, in: Bloem, Hans et al. (2010) DYNASTEE workshop on Dynamic Methods for Building Energy Assessment Centre Borchette Brussels, 11-12. October, 2010

# INCAS PLATFORM - INES

## GENERAL DESCRIPTION

### Main objective of the test facility

The Buildings Energy Laboratory (LEB) is one of the R&D teams of the National Institute for Solar Energy (INES). INES was created in 2006 close to Chambery, in the French Alps, and is composed today of more than 300 people working on various research fields related to solar energy: from silicon purification to electricity management and storage, including energy efficiency in building and transport.

The INCAS platform is a full scale test facility developed since 2008 by the LEB including 4 PASSYS test cells, 3 experimental houses (+1 coming soon) and 10 PV-integration benches.

**Institute/organisation:**

CEA – INES (National Institute for Solar Energy)
LEB (Buildings Energy Laboratory)

**Contact person:**

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**Exact location:**

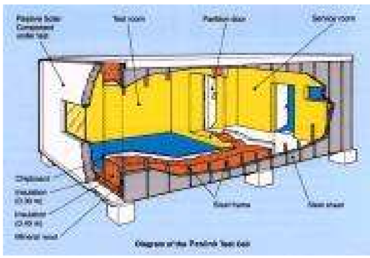
Le Bourget du Lac, France
45°38' N, 5°52' E
Altitude 235m

PV-integration benches and solar concentrador.

The 4 test cells came from Cadarache CEA research center (80's PASSYS program); 2 of them were completely refurbished in order to suit the needs of our R&D program.

The first 2 experimental houses were constructed in 2008. There are currently 3 un-inhabited 110m² houses (an additional one is under planning), with the same internal geometry, same architecture, same level of insulation, and located under the same climate, hence in particular with the same solar inputs.

*The first three experimental houses.*



Original PASSYS test facility composition.

## Overall lay-out

**PASSYS test cells**

The original composition of the test cells includes a very high insulation level. 5 out of their 6 facades are nearly fully adiabatic; therefore tests can be conducted on the 6$^{th}$ façade, which is removable and can be adapted for every project.

Two of the cells are fixed, with the test façade being oriented towards the South. The two other cells are installed on a rotational platform, allowing test under different orientations.

Airtightness test (blower door) in experimental houses.

**Experimental houses**

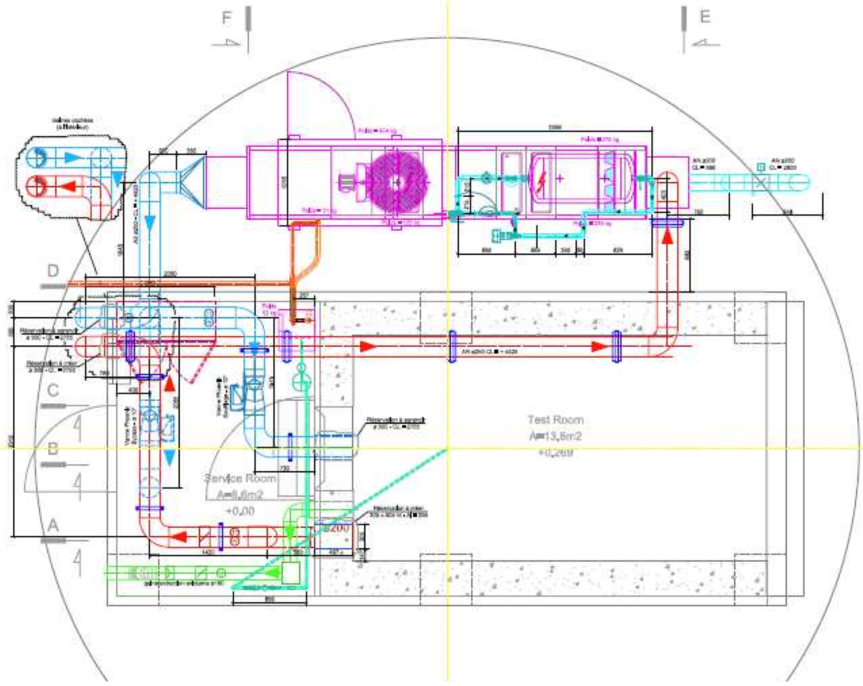
The three houses currently available are respectively made of concrete blocks (house I-DM), cast concrete (house I-BB) and timber frame (house I-OB), with insulation materials ranging from 20cm to 40cm in order to comply with the "Passivhaus" energy standard (less than 15 kWh/m² heating needs per year). First part of the research program was to carefully follow all the steps of the construction and the workmanship ; the air tightness and thermal bridge issues have been carried out with high care so that to insure very high thermal performances.

An additional house is under planning (thermal brickwork).

## Inside boundary conditions

**PASSYS test cells**

Two cells are equipped with brand new air handling units which allow a perfect control of air temperature, humidity and ventilation rate inside the test cells (15°C to 35°C, 6 to 14g/kg weight of water, until 400m3/h of fresh air). Furthermore this new installation is compliant with air quality experiments since it can integrate filtration devices.




*The new air handling unit.*

The brand new rotational platform.

The 2 South-oriented PASSYS cells.


Details of the weather station.


Radiation sensors.

The two other cells are equipped with small heating and cooling split systems, allowing to control temperature (accuracy of + or – 5°C).

**Experimental houses**

The houses are un-inhabited in order to control all the indoor boundary conditions. Human presence can be simulated (heat, humidity and $CO_2$) according to usage schedules (different types of family lifestyle); thus allowing to represent occupants' behaviour in terms of energy and IEQ.

The houses are fitted with the latest energy systems. The ventilation is carried out by a heat recovery system, whereas heating and DHW can be connected to solar thermal panels. The roof is covered by a 5kWc PV system and local electricity storage can be performed.

A multipurpose control system is being developed to master all the appliances and will allow to test a wide range of heating, cooling, ventilation or solar inputs control strategies.

## Outside boundary conditions

A major interest of the INCAS platform is the ability to carry out the tests under real dynamic outdoor climate. The cells and the houses are located within an experimental area, where weather conditions are fully monitored, and where no undesired shading is observed.

Local weather conditions are measured through a weather station (temperature, humidity, wind speed and direction, rainfall) on a 5-meter high mast close to the site. The solar resource is very well characterised by various radiation sensors, on a platform placed 15m above the ground: pyrheliometer on a suntracker, pyranometer, pyrgeometer, albedometer.

All the weather metrology and radiations sensors will soon be regrouped on a 12-meter high mast located in the center of INCAS site.

## Special limitations / possibilities

**PASSYS test cells**

PASSYS cells allow to test facades or components up to 3.3m height and 3.6m width. It allows the test of passive solar components like windows or solar blinds as well as small active systems located on facade. Inner components or systems can also be tested.

**Experimental houses**

The low energy houses provide an opportunity to study innovative active energy systems for buildings, such as new ventilation systems, solar thermal heating and DHW systems. Furthermore these houses allow to develop numerous strategies of global energy management and solar inputs control. Within certain limitations, passive solar envelope components can be tested too, like PCMs (phase change materials), innovative coatings, VOC absorbers or even all kinds of innovative sensors. These houses are very performing from an energy consumption point of view with high building construction quality, thus they give a unique possibility to study the latest innovations in energy saving equipments.

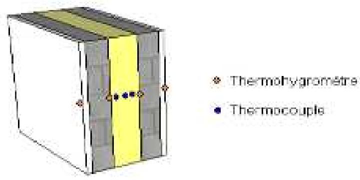
PASSYS cells equipments.

# DATA ANALYSIS

## Typical equipment within test wall

**PASSYS test cells**

The cells are equipped with extensive metrology, enabling to measure surface and air temperatures, humidity, and energy consumption (heating/cooling).




Wall embedded sensors.

**Experimental houses**

The houses are currently fitted with approximately 100 sensors each (wall temperatures, humidity, flow meters, energy consumption, solar irradiation on facade, etc.), with a continuous acquisition system (every minute, 24/7).

Measured temperatures are: external surface, inside the wall structure, internal surface and ambient air (protected from direct solar radiations). This allows to study at the same time the structure of the building (impact of inertia for example) and the indoor climate (comfort analysis). Measurement points are located at the middle of each surface and air temperature gradient is measured according to comfort standard height, at 0.1m, 1.1m and at 1.7m. Simultaneously a black globe temperature measurements and punctually radiant temperature are recorded. Humidity is measured in the wall structure and in one point at each level of the house.

IAQ equipments.

An optical fiber has been set up all around the two high inertia houses, in order to measure inside wall temperatures in many points on every facade.

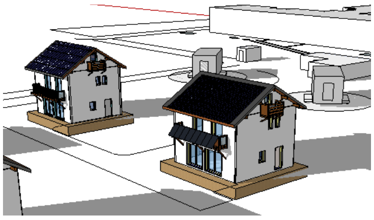
The laboratory is furthermore equipped with portable equipments focused on indoor environmental quality (IAQ, hygrothermal, visual and acoustic comforts). For indoor air quality different parameters can be studied: physical pollution (PM 2.5 and PM 10), chemical pollution (CO, $CO_2$, VOCs and aldehyds and radon).

Optical fiber temperature continuous sensor.

The acquisition of data is performed by Agilent hardware, configured and managed with LabView-based applications. All data are stored in a server which has alarm functions, thus erroneous data are noticed immediately and reported to the user. This gives a very performing reactivity to our data survey system.

## Analysis of the data

A data analysis and data mining tool has been specially developed to study and fit the platform data, with advanced functions in plotting, statistical analysis, etc. Anyway the data analysis approach differs from one project to another. It depends on the characteristics of test components, and also on the focus of the study (energy, comfort).



Models of the experimental houses.

Studies are generally carried out in two steps:

1 – In parallel with numerical studies. The thermal specifications of the PASSYS cells and the passive houses are well known, and the indoor environment can be controlled. Therefore, the tests can be conducted and the results compared with numerical studies (Dynamic Thermal Simulation and/or Computational Fluid Dynamics). In a general way, experimental tests are used to validate and develop numerical simulation tools.

2 – Comparison between cells/houses. There are several identical cells/houses available at INES, with similar specifications. Therefore, tests can be conducted in parallel via two (or more) cells, exposed to the same orientation, equipped with the same systems and metrology, but showcasing various facades or internal materials. In PASSYS cells, the possibility to study the whole wall component exists. For theses studies a special instrumentation is planned with measurements in the structure of the component. Hygrothermal characteristics are determined for the tested component and in parallel for a blind test component in order to quantify the gains and losses of the tested structure by comparison.

# EXAMPLES OF PREVIOUS STUDIES

Model of the multifunctional inner wall – REPLIIC project.

**PASSYS test cells**

- Study of an innovative automation and control system for solar shading.

- REPLIIC: experimental and numerical study of a multifunctional inner wall providing both insulation and heat emission in building energy renovation.

- Effinov'bois (planned): renovation by additional wood frame façade.

- HYGROBAT (planned): methodology for hygrothermal design of wood-based constructions and more generally construction materials based on vegetal fibres.

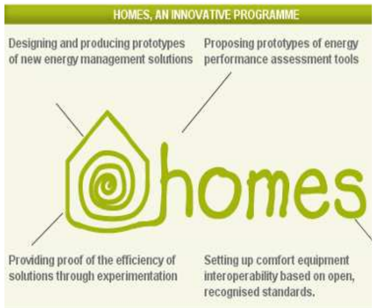
**Experimental houses**

- VAICTEUR AIR²: development of HVAC systems for low energy building.

- Batimetre is a project dedicated to work on the monitoring methodology. The purpose is to understand, through measurements, which parameters have the highest influence on the thermal behaviour of the building. It also aims at defining which are the most important sensors to be placed in a building that has to be monitored.

- DECODE: development of a convergent design tool to simultaneously improve hygrothermal and aero-thermal simulation of buildings.

- HOMES is a 4-year long collaborative innovation program dedicated to Homes and buildings Optimized for Mastery of Energy and Services.




www.homesprogramme.com

# MAINTENANCE / COLLABORATION

## Personnel involved

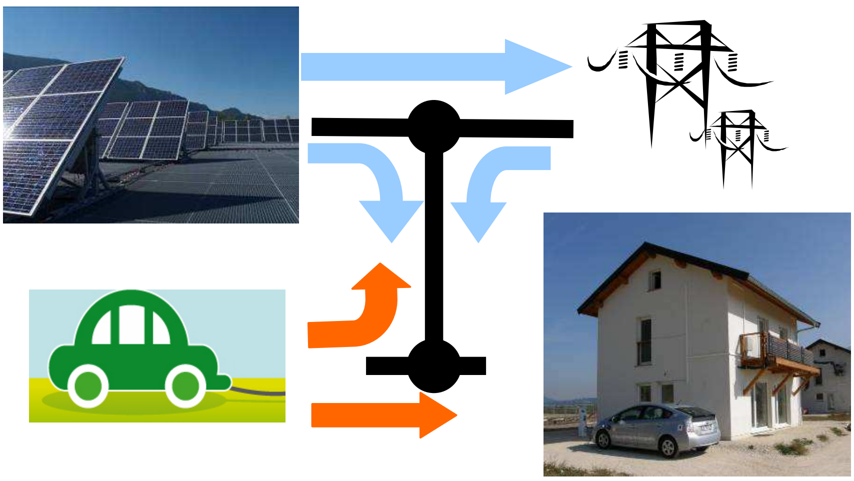
The entire INCAS platform is maintained by the LEB technical staff plus external personnel such as electricians or plumbers. Experiments are carried out by our laboratory team (sensors maintenance, acquisition and analysis). The tested components are generally constructed and installed by the manufacturer.

## International collaboration

Collaboration with international partners in the frame of European research programs and industrial cooperation.

## Link to other devices

The INCAS platform is part of INES facilities and especially research about smart grids and district/city energy management: electrical storage, solar mobility, building - transport energy compliance, thermal storage, district heating, …



Electrical cars and solar station.

# TEST CELL IN FLORENCE


**Institute/organisation:**

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## GENERAL DESCRIPTION

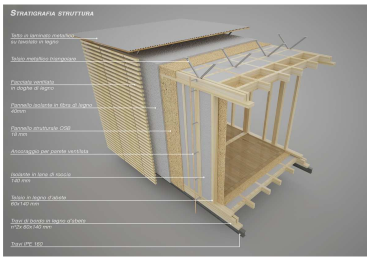
### Main objective of the test facility

Evaluation of thermal-physical properties of new building components is usually carried out in stationary conditions. In South Mediterranean area, thermal variation is significant and the effect of thermal mass should be investigated and taken into account in new and retrofitted projects focusing on thermal comfort in relation of energy saving.

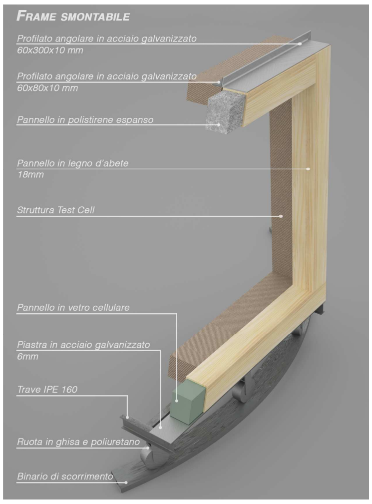
The poster synthetically describes the project of a new test cell proposed by the Florence University, with the aim to became an outdoor laboratory able to test, in the next future, new energy efficiency building components. The project of the test cell is part of a largest project *Abitare Mediterraneo* financed by the Tuscany Region with the scientific contribution of several experts coming from

the Florence University and with the collaboration of several regional building sector's companies

The test-cell will be similar to PASSYS test cell but in wooden structure with low thermal bridges, insulated frame, routable platform, accurate flux sensors, with the aim to measure and compare thermal differences of new opaque and transparent components - on dynamic external conditions - also different day-lit distribution due to orientation.



*The test cell project in wood and with the external solar screening.*




*The insulated frame to test opaque and transparent façade components.*

## Overall lay-out

The test cell is designed in a platform frame in wood, with horizontal and vertical components made with same thickness, same material, same structure, same U-value (0.32 $W/m^2K$). It is able to test façade components into an insulated frame, with dimensions of 2.80 m x 2.80. m.

It is orientable with measurements of interest for the production of new components suitable for Mediterranean climate.

## Inside boundary conditions

The outdoor test cell is an instrument that is required by the Tuscany Region for giving the opportunity principally to local building market to test new products that needs to be used in Mediterranean Climate, products that are able to reduce annual energy consumption in buildings working with a sufficient insulation level and appropriate thermal inertia if necessary.

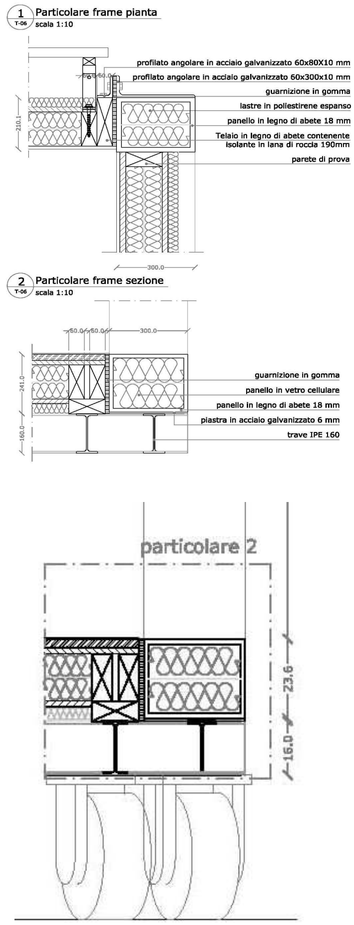
Also, the test cell will be used to evaluate the influence of the orientation when using a transparent components and the correlation with window dimensions and forms in relationship to the daylight factor under clear sky conditions, normally sky during the year in most of the Mediterranean area.

In this way, the test cell has to measure the U and g value of components and also the thermal lag and the DLF. It will have inside a radiator for internal temperature control with a ventilator. They will be used during the winter to evaluate the flux from inside to outside.

*View of the site in which is going to be built the test site*

## Outside boundary conditions

The test facility is located in outdoor under real weather conditions. To reduce the overheating inside the test cell, the envelope is covered by an external shading to reduce to zero the direct solar radiation on test cell components. The screening is realized in wood material at a distance of 20 cm from the test cell envelope to guarantee an adequate ventilation between the test cell and the shading devises.




*Frame’s details*

## Special limitations / possibilities

The test cell is going to be realized to test opaque and transparent vertical building components, ventilated facades, shading devises, and all other vertical building components such as PV systems, PCM materials etc.

It has been designed studying PASSLINK test cells and trying to resolve some limitations emerged in outdoor test cell built in the past, such as overheating, thermal bridge effect, problems due to infiltrations, not insulated frame.

It is not an adiabatic test cell, with a very low thermal bridges do to the wooden structure and due to the fact that all test cell’s components –facades, floor and roof, are made with the same thickness, same materials, same U value. It is positioned on a routable system to evaluate differences in building components performance in different orientation and also to make measurements in terms of DLF. It is the first realized to make measurements dedicated to the Mediterranean Climate. In the next future and with the experience made with the first test cell, the University of Florence will propose a test cell for roof components and another to test systems in an outdoor test cell in two floors.

# DATA ANALYSIS

## Typical equipment within test wall

The test cell will be equipped with indoor and outdoor instrumentation.

In outside a meteorological station will record temperature, RH, wind velocity and direction, solar radiation.

Inside, the test cell will be covered by Flux tiles; internally, the ambient temperature, the surface temperature, RH, air movement, light will be measured. Sensors positions will be the same of PASLINK test cells.

# Examples of previous studies

Up to know no hygrothermal studies have been performed because the test cell is not yet realized: it will be ready in summer 2011.

# Maintenance / collaboration

## Personnel involved

The test cell is going to be realized using a project developed for a PhD thesis at the University of Florence, Technological and Design Department. The project is part of *Abitare Mediterraneo*, project proposed by the University of Florence with the financial support of the Tuscany Region and in collaboration with several Tuscany industries. It is going to be enlarged to other industries interested in developing new products for Mediterranean Habits.

The responsible of the project is Marco Sala; the person responsible for adaptation and construction of the test cell is Giuseppina Alcamo; the responsible of the test facilities is Maurizio De Lucia, Energetic and Mechanical department of the University of Florence. The responsible for instrumentation is Carla Balocco also responsible for data analisys.

## International collaboration

The test site should be active in the Dynastee Network to exchange experience and to collaborate at an international level.

The project of the test cell has been made with the supervision and support of Hans Bloem, JRC Ispra.

## Link to other devices

The test cell is part of a larger strategy of the *Abitare Mediterraneo* Project: new building components need to be certificated not just only from thermo-hygrometric point of view but also they have to be in line with acoustic requirements, fire resistance requirements and structural requirements.

The University of Florence is going to involve internal departments and also external laboratories to give to the companies the most strong and complete support in developing new building components suitable for Mediterranean climate, simulating components with adequate dynamic software, analysing

*Partners involved in Abitare Mediterraneo Project*

LCA and testing under real user conditions and laboratories to certificate new *Abitare Mediterraneo* products.

# RELEVANT LITERATURE

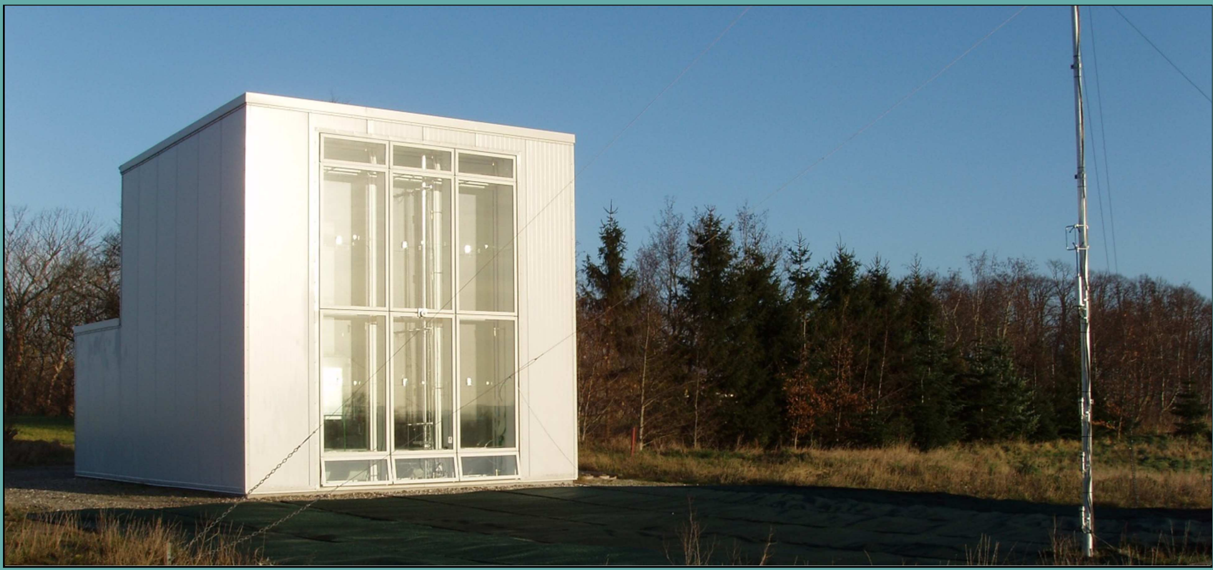
## General literature about the test facility:

G. Alcamo. *Sistemi per valutare e comparare in opera le prestazioni energetiche di componenti edilizi: progetto di una test - cell per il Clima Mediterraneo*. PhD thesis will be discussed next April 2011.

G. Alcamo. *The overheating control in Mediterranean area: thermophysical evaluation of new facade components through a test cell*. Paper for OSDOTTA 2011, under publication.

More information about the *Abitare Mediterraneo* project are available at the following website: *www.abitaremediterraneo.eu*

# THE CUBE



**Institute/organisation:**

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Division of Architectural Engineering
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**Exact location:**

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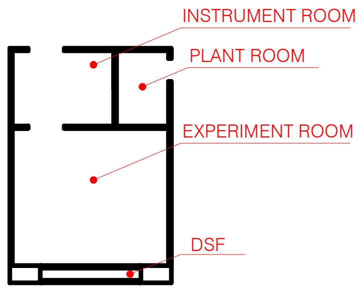
57.02°N, 10.0°E

## GENERAL DESCRIPTION

### Main objective of the test facility

The Cube is an outdoor full-scale test facility located near to the main campus of Aalborg University, Denmark. The Cube was built in the fall of 2005 with the following purposes, in the frame of IEA ECBCS ANNEX 43/SHC Task 34, Subtask E- Double Skin Facade: the detailed investigations of double-skin façade (DSF) performance and the development of empirical test cases for validation of various building simulation software

Though, the major aim of the test facility is the performance investigation of different façade solution.




Plan drawing of the Cube

Southern facade of the Cube

Northern facade of the Cube

KE-low impulse fabric ducts in the experiment room

Ventilation system in the experiment room

## Overall lay-out

The Cube consists of four domains, which are named as: double-skin façade (DSF), experiment room, instrument room and plant room. The experiment room together with the DSF represent the main building of the test facility, which has external dimensions of 6x6x6 metres. External dimensions of the plant and instrument room together is 6(w)x3x3 metres, which are attached to the northern wall of the experiment room.

The key measurements are carried out in the DSF and in the experiment room; meanwhile the instrument room and the plant room are used as a support zone. The instrument room is equipped with dataloggers and computers and the cooling system is installed in the plant room. In the experiment room, a ventilation system is set up for maintaining uniform conditions in the room.

The exact dimensions of the experiment room and double skin façade are summarized in the table below.

| Zone | Width, mm | Depth, mm | Height, mm |
|---|---|---|---|
| DSF | 3555 | 580 | 5450 |
| Experiment room | 5168 | 4959 | 5584 |

*Internal dimensions of the experiment room and double-skin facade*

Building geometry allows replacement of the double-skin façade by any other façade solution for testing. At the moment there is already another façade type has been installed.

The building is very well insulated and airtight.

## Inside boundary conditions

The boundary conditions in the experiment room are normally kept constant; meanwhile façade performance varies according to the outdoor conditions and/or control strategy. If necessary, it is possible to establish different from the described below constant inside boundary conditions.

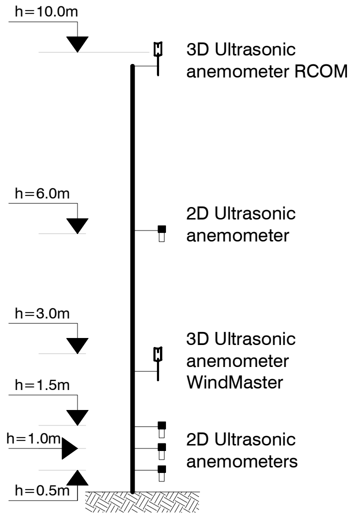
Constant conditions: the temperature in the experiment room can be kept constant, due to ventilation system with the heating and cooling unit installed in the room. In order to avoid temperature gradients in experiment room, a recirculating piston flow with an air speed of approximately 0.2 m/s can be used for supply. The air intake for recirculation is at the top of the room. After the intake the air passes through the preconditioning units of the ventilation system and then it is supplied at the bottom of the room through fabric KE-low impulse ducts. Maximum power on cooling and heating units is 10 kW and 2 kW respectively. Humidity control is not present.

Absorption, reflection and transmission properties of all surfaces in the experiment room were tested and available as a function of the wavelength, in the wavelength interval 250-2500nm.

## Outside boundary conditions

The Cube is a full-scale outdoor test facility, which is exposed to the real climatic conditions. It is located in open flat country, without any shield from wind and sun. The replaceable façade of the Cube is facing south in order to explore the maximum of solar radiation intensity. The outside conditions are measured with equipment placed locally at the test facility. Solar radiation is measured on the roof (global and diffuse) of the building and on the southern façade (total). The wind speed and wind direction are measured at 6 different heights above the ground on a wind mast in front of the building.

For reliable estimation of ground-reflected solar radiation, a large carpet is placed on the ground in front of the southern façade of the Cube to achieve uniform reflection from the ground. The fabric of the carpet was chosen so that it does not change its reflectance property when it is wet due to its permeability. Reflectance is approximately 0.1, close to the generally assumed ground reflectance.




Positioning of equipment on the wind mast

3D ultrasonic anemometer

2D ultrasonic anemometer

Photo of pyranometers on the roof of the Cube, Wilhelm Lambrecht pyranometer at the left and BF3 at the right

## Special limitations / possibilities

Specific for the test facility is the possibility to replace the southern façade element. This allows performing experimental studies of any kind of façade solutions. Powerful cooling system allows maintaining necessary inside boundary conditions, but more importantly cooling and heating load to experiment room can be measured accurately. As a result, a complete heat balance can be determined for the experiment room and the façade element can be characterized in terms of solar and heat transmission.

# DATA ANALYSIS

## Typical equipment within test wall

Due to the flexibility of the test facility different façade elements can be tested. As a result the experiments are performed with different objectives and only few devices are used in the test facility as a standard. Standard equipment is used for measurement of outdoor boundary conditions, cooling and heating loads in the experiment room, surface and air temperature in the experiment room. These include thermocouples type K, 2D and 3D ultrasonic anemometers of 3 different types, Wilhelm Lambrecht and BF3 pyranometer on the roof of the Cube and Wilhelm Lambrecht pyranometer in the centre of southern façade. Air humidity is normally measured with COMARK data logger N2003.

Water is used in the cooling unit of the ventilation system. With the purpose to avoid the condensation on the surface of the cooling unit the minimum water temperature was set to 12°C. The difference between the supply and return water temperature from the cooling unit is measured as voltage in mV. The mass flow of the water supplied to the cooling unit is measured with a water flow meter MULTICAL from Kamstrup, which measures in a range from 0 to 1kg/s. Both the temperature difference and the water mass flow are logged by Helios data logger at a frequency 0.1Hz.

The heating unit in the ventilation system is rarely activated, as in the most of cases an additional heating load in the experiment room is generated by a fan from running ventilation system. For keeping a track on all loads to the experiment room, including the heating unit, all equipment in the room is connected to a wattmeter D5255S from producer Norma.

## Accuracy and logging resolution

The wind speed and wind direction measurement is carried out with the frequency of 5 Hz, meanwhile the other data is assembled at a frequency 0.1Hz. Measurement uncertainty of equipment in the test facility is given below.

| *Measurement* | Model/producer | Uncertainty | Range |
|---|---|---|---|
| *Temperature*<br>Datalogger | FLUKE HELIOS | +/- 0.07 °C | |
| *Solar radiation*<br>Diffuse on horizontal surface<br>Total on horizontal surface<br>Total on vertical surface | Delta-T Devices, BF3<br>Wilhelm Lambrecht<br>Wilhelm Lambrecht | +/- 10 %<br>+/- 2%<br>+/- 3% | 1250 W/m$^2$<br>1000 W/m$^2$<br>1000 W/m$^2$ |
| *Wind speed*<br>3D ultrasonic anemometers<br>2D anemometers | Gill, Windmaster research R3<br>Ft. technologies Ltd. | +/- 1%<br>+/- 4% | 30 m/s<br>30 m/s |
| *Wind direction*<br>3D ultrasonic anemometers<br>2D anemometers | Gill, Windmaster research R3<br>Ft. technologies Ltd. | +/- 3°<br>+/- 3° | 0-360 °<br>0-360 ° |
| *Cooling/Heating Load*<br>Supply and return water temperature difference<br>Water mass flow rate<br>Wattmeter | -<br>MULTICAL, Kamstrup<br>Norma, D5255S | +/- 0.1°C<br>+/- 0.1%<br>+/- 0.1% (of readings) | 0.1- 1V<br>0-1 kg/s |

*Measurement uncertainty of equipment used in the experimental set-up.*

## Analysis of the data

The data analysis will only depend on experimental set-up and the goals set for the investigation.

# EXAMPLES OF PREVIOUS STUDIES

In 2006 the test facility was used for investigation of thermal performance of double-skin façade in connection with IEA ECBCS ANNEX 43/SHC Task 34. The measurements were performed for a naturally and mechanically ventilated double façade and resulted in a set of empirical data that can be used for validation of building simulation software.

Present experimental set-up in the Cube. An intelligent façade (left), and unintelligent façade (right).

The above described experiments included measurements of natural air flow rates in the ventilated air gap, velocity profiles in the gap, etc.

In 2008 these experimental results were expanded by measurements with application of shading device in the double façade cavity space.

At the moment the Cube has been modified for an experimental study of intelligent glazed facades. This project concerns the development and validation process of the adaptive façade used in ways to (1) fulfill move closer to the goal of zero energy buildings and (2) fulfill the different needs and demands from the occupants concerning indoor climate. The further goal of the project is to develop algorithms for implementation in thermal building simulation software as well as energy regulation software.

# MAINTENANCE / COLLABORATION

## Personnel involved

Technical staff at the department is responsible for the major changes at the test facility related to adjustments or geometry modification in the measurement campaign. The technical staff is supervised by researchers responsible for the project. The researchers are also responsible for installation, calibration and control of measurement equipment, as well as data acquisition and data analysis.

## International collaboration

There is no specific international collaboration.

## Link to other devices

The Cube is an outdoor full-scale test facility, which is very useful for experiments in a real environment. Though in some cases it is necessary to test and control some particular outdoor conditions. For these purposes a small and a large hot-box available in the laboratory can be used.

A small custom-made hot-box allows testing of smaller façade components (apx. 1.5x1.5m component size). Furthermore a large hot-box that is about to be completed, will allow testing of large façade components with approximate size of components 3.4x3.4 meter.

Besides above mentioned facilities there are a number of indoor full-scale rooms available in the laboratory.

# Relevant literature

## General literature about the test facility:

Kalyanova, O. & Heiselberg, P. 2008. Experimental Set-up and Full-scale measurements in the 'Cube'. Aalborg : Aalborg University. Department of Civil Engineering. 58 s. (DCE Technical Reports; 34).

Kalyanova, O. & Heiselberg, P. 2008 Final Empirical Test Case Specification: Test Case DSF100_e and DSF200_e. Aalborg : Aalborg University. Department of Civil Engineering. 45 s. (DCE Technical Reports; 33).

Kalyanova, O., Jensen, R. L. & Heiselberg, P. 2008. Data Set for Empirical Validation of Double Skin Facade Model. Proceedings of the 8th Symposium on Building Physics in the Nordic Countries: NSB2008, Nordic Symposium on Building Physics 2008. Rode, C. (red.). 1. Technical University of Denmark s. 151-158. 8 s. (DTU Byg Report; R-189).

## Literature on previous measuring campaigns:

Kalyanova, O., Jensen, R. L. & Heiselberg, P. 2007. Measurement of Air Flow Rate in a Naturally Ventilated Double Skin Façade. Proceedings of Roomvent 2007: Helsinki 13-15 June 2007. Seppänen, O. & Säteri, J. (red.). FINVAC ry 10 s.

Larsen, O. K., Heiselberg, P., Felsmann, C., Poirazis, H., Strachan, P. & Wijsman, A. 2009. An Empirical Validation of Building Simulation Software for Modelling of Double-Skin Facade (DSF). Building Simulation 2009 : University of Stractclyde, Glosgow, 27th-30th July: Proceedings of the 11th International Building Performance Simulation Association Conference. Strachan, P. A., Kelly, N. J. & Kummert, M. (red.). Energy Systems Research Unit : University of Strathclyde 8 s.

Marszal, A. J., Thomas, S. J., Larsen, O. K. & Heiselberg, P. 2009. Empirical Validation of Simple Calculation Method for Assessment of Energy Performance in Double-Skin Façade Building. ROOMVENT 2009 : Proceedings of the 11th International ROOMVENT Conference. Kim, K., Yoon, D., Yeo, M. S., Moon, H. & Park, C. (red.). s. 1173-1180. 8 s.

# SEMI-VIRTUAL PLATFORM PEPSY

## GENERAL DESCRIPTION

### Main objective of the test facility

The semi-virtual platform PEPSY (Platform for the Evaluation of Performances of dynamic Systems) has been developed for testing renewable thermal energy systems using a dynamic approach. The platform is based on system emulation (also called hardware in the loop) and allows the performances evaluation of almost any water-flowed energy system such as solar domestic hot water systems, solar combisystems, fossil energy heaters, or ground source heat pump systems.

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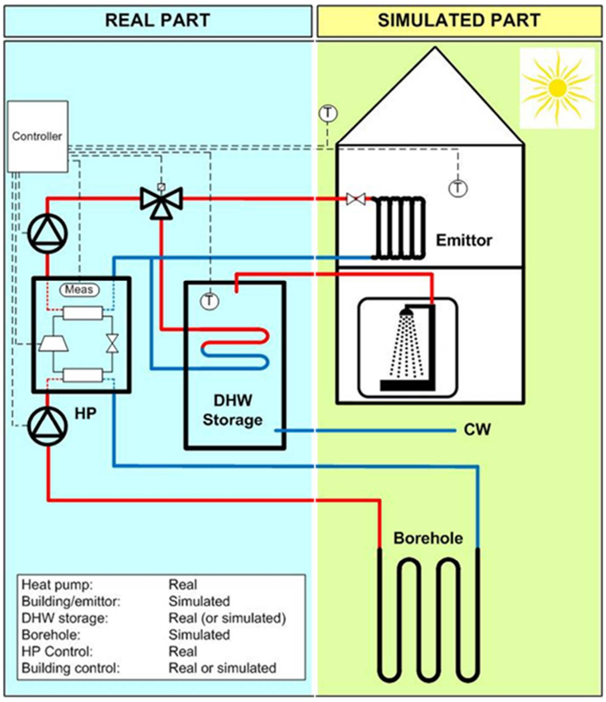
## Overall lay-out

Heat pump module connected to a heat pump

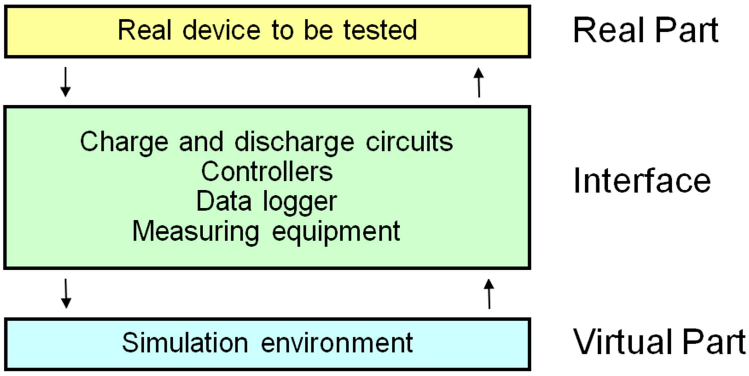
The principle of this emulation test platform is to integrate the product to be tested in a virtual environment. This principle can easily be illustrated using the example of a geothermal heat pump.

The real part (heat pump with all devices to be tested) is connected to the simulated part. In the example below, the virtual part corresponds to the building (exposed to a certain climate) with its emitters, occupants and internal loads as well the geothermal heat exchanger. Conditions at the outlet of the heat pump (condenser side and evaporator side) are measured on the test bench and sent to the virtual part. Each time step of the test, the return conditions (inlet of the heat pump) are controlled using charge/discharge modules. The heat pump does operate as in a real building.

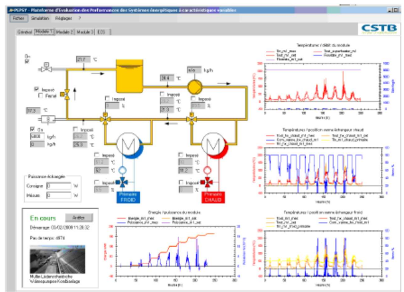



Measurements of the controller that are linked to the simulated conditions (external and room temperature) are simulated using programmable resistances, controlled by the simulation.

The general layout of the test bench is shown in the figure below.




*PEPSY – Emulation technique principle description*



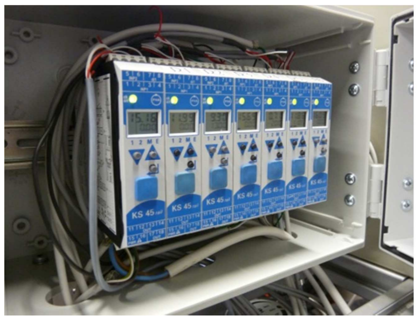
Graphical user interface of the test bench

Simulation is slowed down to real time and the simulation environment (Matlab/Simulink or TRNSYS) enables simultaneously the test bench control, system simulation and online monitoring of the test.

The semi-virtual platform PEPSY is mainly composed of:

- Simulation environment
- Real-to-virtual interface (Data acquisition and test bench control)
- Charge/discharge modules modules able to deliver a fluid to the tested system at desired temperature and flowrate.
- Domestic hot water modules, simulating tap water consumption
- Temperature sensor simulators: Variable resistances for the simulation of temperature sensors

**Simulation environment**: Matlab/Simulink or TRNSYS. The environment allows at the same time to read data from measurement equipment (specific software has been developed for the readings), to run the simulation and to send back set points for the test bench control (also based on specific software). A real time module has also been implemented in order to slow down simulation time to real time, i.e. meaning the the simulation environment is paused until the next time step (typically 10-60 seconds).

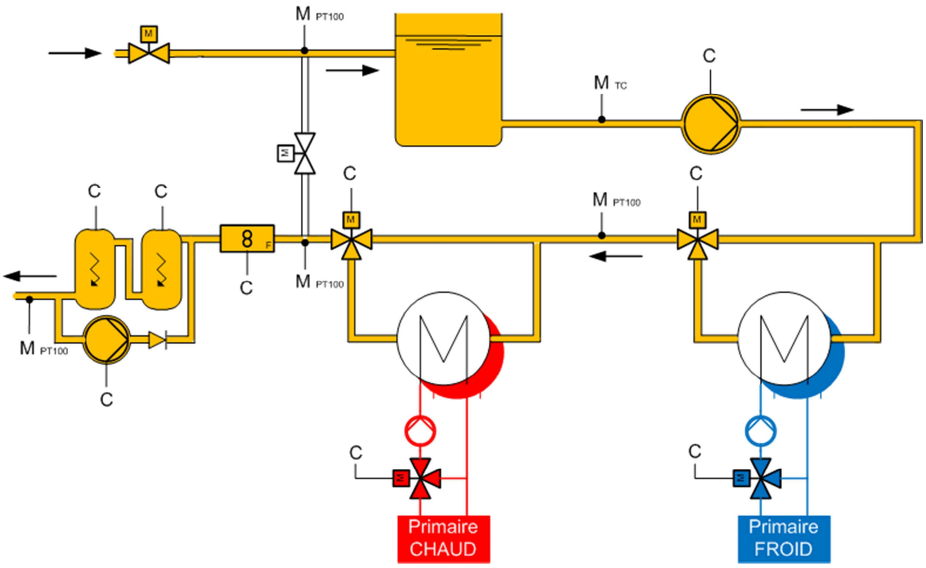


Industrial controllers : real-to-virtual interface

**Real-to-virtual interface:** This interface consists in the data acquisition system (figure) as well as the link to the controllers of the test bench. The test bench uses industrial controllers allowing to control the equipment with a frequency of 100 mseconds.

Test bench facilities (High temperature, Emitter and Water drawing modules

**<u>High temperature module</u>**: typically dedicated to solar collector emulation, this circuit is mainly equipped with a variable speed pump, heat exchangers (one for heating up to 90°C, one for cooling down to 10°C) and additionnal electric resistances in case of temperatures higher than 90°C. The heat exchangers are connected to a primary source (boilers for hot and chillers for cold water production). Manifolds allow to separate primary (test bench) and secondary loop (tested product). A balancing valve allows the adjustment of the pressure drop before each test.




*PEPSY – High temperature module*

Electromagnetic 3-way valves for temperature controlling

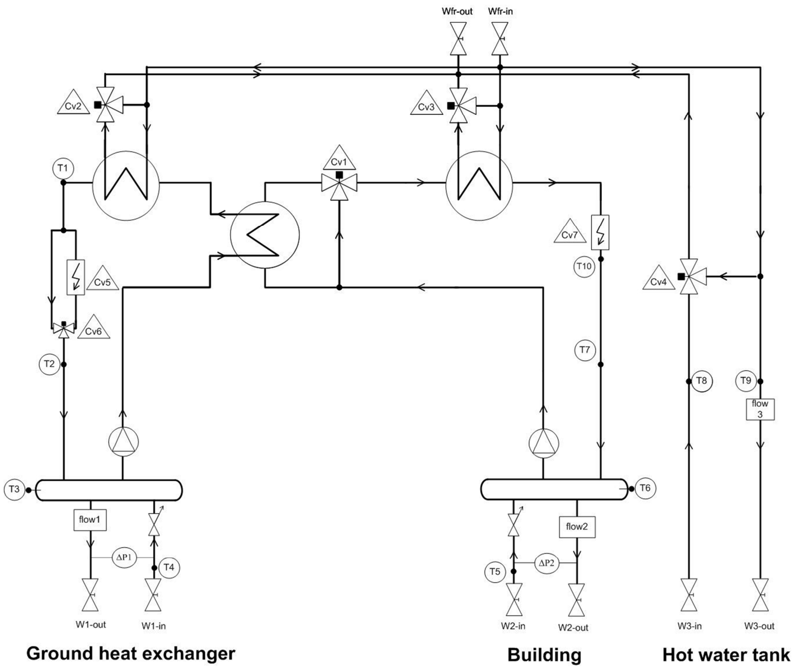
**<u>Emitter module</u>**: These modules allow the emulation of building's emitters such as heating floors or radiators. It is similar to the heat production circuit, equipped with a variable speed pump, heat exchangers (one for heating up to 90°C, one for cooling down to 10°C). They can be used for emulating heating or cooling case. As for the high temperature module, the heat exchangers are connected to a primary source (boilers for hot and chillers for cold water production). Manifolds allow to separate primary (test bench) and secondary loop (tested product). A balancing valve allows the adjustment of the pressure drop before each test.

**<u>Water drawing module</u>**: This module is utilised for simulating domestic tap water drawings. It consists in a set of two way valves in parallel for drawing at different user-defined flowrates that can be adjusted before each test. The minimum cold water temperature is around 10 degrees and can eventually be heated to higher values.

**Temperature sensor simulators**: These simulators are variable resistance boxes. The value of the resistance has to be adjusted at each time step following the temperature/resistance table of the used sensor (e.g. PT500 etc.). The controller of the product to be tested measures thus exactly the temperature calculated by the simulation.


Variable resistance box

**Heat Pump test bench**: This test bench is a variant of the components described previously. It is an independent test bench and includes all necessary modules for testing a ground-source heat pump in heating, cooling and domestic hot water production mode. It consists in three pairs of inlet/outlet, one for the building, one for the ground heat exchangers and one for the domestic hot water. Contrarily to the other modules, the heat pump one is not exclusively supplied by external energy sources since both the condenser's and evaporator's sides of the tested heat pump are sollicitated to provide the necessary energy for the three emulation circuits.




*PEPSY – Heat pump module*

As for the charge/discharge modules, manifolds allow to separate primary (test bench) and secondary loop (tested product). A balancing valve allows the adjustment of the pressure drop before each test.

## Testing methodologies

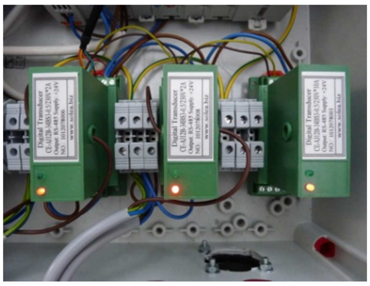
Dynamic testing allows to correctly reproduce results as in in-situ measurements. However, if annual performance figures are required, short testing sequences have to be developed in order to be able to correctly

Gaz counter and pressure transduce

extrapolate to annual figures. 12-day- test sequences have been developed for solar combisystems and for ground source heat pumps. Each of the twelve days corresponds to one months of the year. Both methodologies have been validated in three ways:

- Numerical parametric study in order to demonstrate the validity of performance extrapolation from 12 days to one year. The results for the data extrapolation show an accuracy lower than 5% in terms of performance figures (% of %).
- Comparison with monitoring results (results have been compared to real monitoring projects): the performance figures show good agreement with real monitoring data.
- Interlaboratory comparison (for the case of solar combi-systems): differences between two labs showed differences lower than 10% in the worst case.

## Special limitations / possibilities



Electrical transducers for heat pump (one for compressor, one for groud heat exchanger pump and one for heating floor pump)

The nominal power of the test benches presented is limited to power ranges usually found in single family houses. A third test bench is available for higher power ranges up to 30 kW.

The flexibility of the testing platform allows also the test of combined systems: solar thermal / heat pump combinations, solar PV / heat pump, cogeneration etc.

# DATA ANALYSIS

## Typical equipment

Data loggers

All the PEPSY modules are equipped with thin PT100 sensors (3mm diameter) that are directly immerged in the fluid in the different circuits in order to guarantee short response times. For the fluid flowrates, electromagnetic flowmeters are used. More specifically concerning the tested system, additionnal measurements are performed. For all the electrical energy source systems such as heat pump compressors, pumps, heating resistances, AC/DC parameters (voltage, current, active power, etc) measuring devices are used, mainly to determine the energy consumptions. For gas source systems, three parameters are measured to calculate energy consumptions: temperature, volumic flowrate and pressure of the gas. All measurement devices are either connected to the data acquisition system or directly by a bus (Modbus).

## Accuracy and logging resolution

Global properties of sensors are indicated in the following table:

| Instrument | Calibration range | Accuracy* |
|---|---|---|
| PT100 1/3 DIN 4-wires | 0°C to 60°C | +/- 0.05°C |
| Electromagnetic flowmeter | 150 l/hr to 2500l/hr | 0.5% |
| Electrical counters one-phase (three-phases) | 0 V to 230 V (380V)<br>0 A to 25 A | 0.2% |
| Gas volumetric flow meter | 0.016 $m^3$/hr to 2.5 $m^3$/hr | 0.8% |
| Gas pressure transducer | 0 mbar to 60 mbar (relative) | 0.25% |

** Calibration of temperature sensors has been carried out in the given calibration range using a liquid calibration bath and a coriolis mass flow meters respectively*

# MAINTENANCE / COLLABORATION

## Personnel involved

The PEPSY Platform is maintained by the technical staff of the Renewable Energy Division of CSTB. They are also responsible and in charge for all adaptations, in collaboration with the responsible engineers.

## International collaboration

The KIER (Korean Institute Energy Research) is in collaboration with CSTB concerning this experimental platform.

## Link to other devices

The semi virtual platform PEPSY can be coupled to the ground heat exchangers platform at CSTB – Sophia Antipolis.

# Relevant literature

## General literature about the test facility:

Partenay, V, Développement d'une méthodologie d'évaluation des performances de systèmes de pompes à chaleur géothermiques, Thèse de doctorat, Université de Savoie – LOCIE, 2010

Partenay, V, Riederer, P, Wurtz, E, Salque, T, The Influence of the borehole short-time response on ground source heat pump systems efficiency, Energy and Buildings, accepted, published soon, 2011

Partenay, V, Riederer, P, Wurtz, E, A Global Approach for the Optimisation and Evaluation of Performances of BTES, Stockholm, EFFSTOCK 2009

Riederer, P, Partenay, V, Dynamic Test Method for the Determination of the Global Seasonal Performance Factor of Heat Pumps Used for Heating, Cooling and Domestic Hot Water Preparation, Edinbourg, BS 2009

http://www.cstb.fr/actualites/english-webzine/anglais/march-2010/dearsun-when-thermal-solar-covers-the-building-heat-demand.html

# GEOTHERMAL PLATFORM CSTB

## GENERAL DESCRIPTION

### Main objective of the test facility

The Geothermal Platform has been set up in 2008 at CSTB – Sophia Antipolis with the objective of evaluating experimentally the thermal behaviour of several geothermal heat exchanger configurations. The platform allows on the one hand to improve knowledge of this technology and on the other hand to validate ground heat exchanges modelling.

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CSTB
le futur en construction

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**Exact location:**

Sophia Antipolis, France
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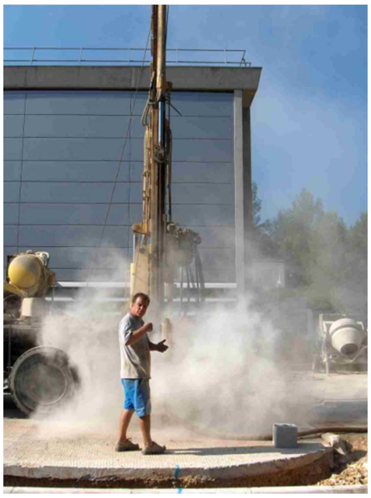
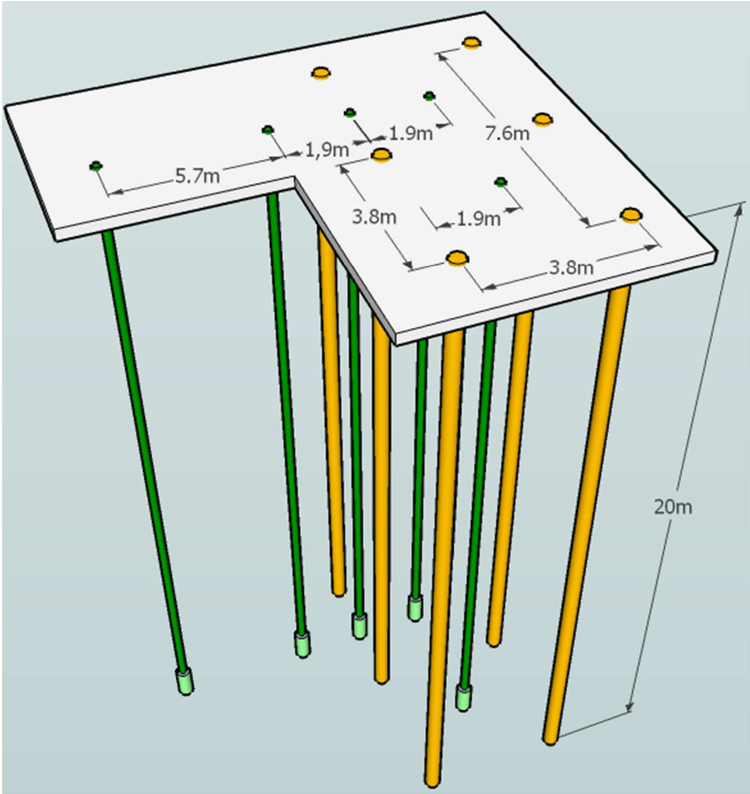
## Overall lay-out



Drilling operation

The geothermal platform consists in rectangular shaped storage of 6 boreholes, 20 meters deep each. The boreholes are equipped with double U-pipe heat exchangers and have been backfilled with a high thermal conductivity blend (2.0 W/m.K). A geological study indicates that the concerned part of the ground is mainly composed by limestone. Furthermore, this study revealed teh presence of groundwater at around 30m depth, information which led to limit borehole drilling down to -20m. The spacing between the boreholes is 3.80m, the estimated activated ground storage volume is about 1700m$^3$, the equivalent of an 800m$^3$ water storage. Temperature sensors are integrated at the centre of each double-U heat exchanger, at three different levels (at 1m, 10m and 20m depth). All borehole heat exchangers are collected in a centralised device consisisting in two manifolds (inlet/outlet).




*Overview of the Geothermal Platform*

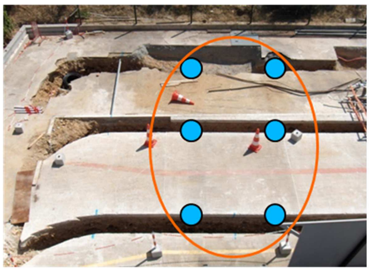
Implementation of a double-U heat exchanger in the ground

In the same area, 5 additional boreholes were drilled to perform soil temperature measurements, at the same depth (-1, -10 & -20m); these boreholes are filled with concrete and are not equipped with any heat exchanger.

Manifolds connected to the ground heat exchangers

## Boundary conditions

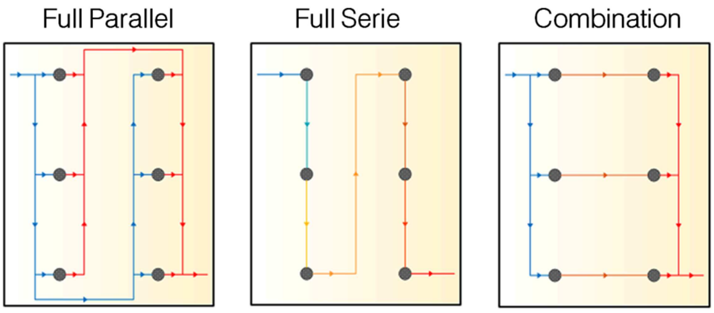
As the main part of the Geothermal Platform is sealed into the ground, inside boundary conditions consist merely in the temperature distribution around and into the heat exchangers. Outside boundary conditions are the fluid temperature and flow rate entering the geothermal platform, controlled following user-defined setpoints.

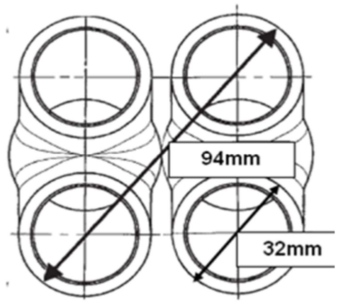


Location of the six boreholes on the CSTB platform

## Special limitations / possibilities

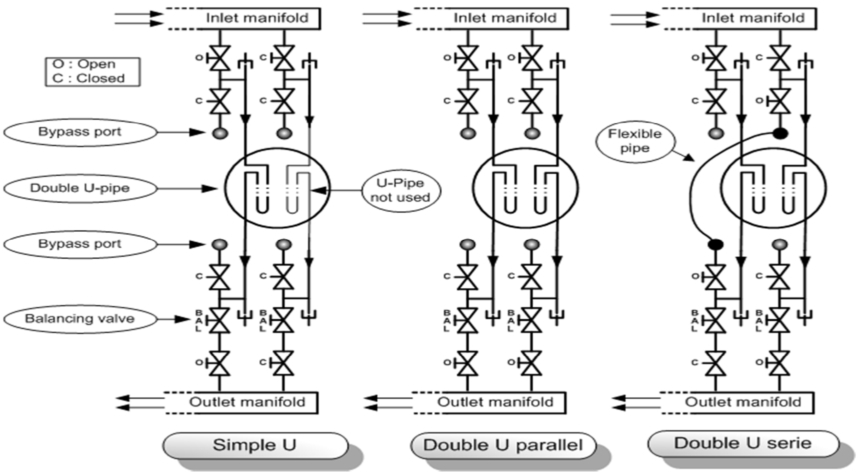
Although the platform configuration is intrinsically limited to one spatial geometry, its main skill is to be able to set a wide variety of borehole thermal energy storage (BTES) configurations. As explained above, all the borehole's pipes are independently collected to a common device that allows any pipe connections. It is then possible to connect boreholes in series, in parallel or combining series and parallel:



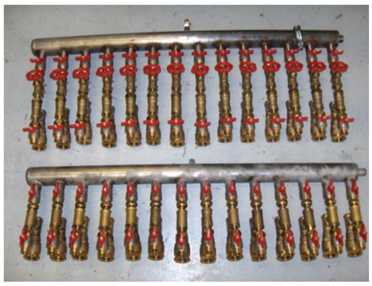




double-U ground heat exchanger

Moreover, all simple U-pipes can be operated independently, therefore each borehole can be utilised as a simple U, double U in series or double U in parallel. The choice of a specific configuration for the borehole field is made by valve opening/closing actions, plugging flexible pipes, and rebalancing the hydraulic network




*Hydronic network of each borehole heat exchanger*



Inlet/outlet manifolds equipped with the set of valves

# DATA ANALYSIS

Integration of thermocouples in the double-U ground heat exchanger

## Typical equipment

The measuring equipment is composed of thermocouples and PT100 sensors. Thermocouples are used for measuring temperatures in the groundand at the center of the ground heat exchangers. PT100 sensors are directly immerged in the fluid circulating in the boreholes, with one sensor per single U-pipe and two additionnal one for the inlet and the outlet of the collector/distributor device. An electromagnetic flow meter allows to measure the fluid flow rate. All measurement devices are then connected to a common data logger.

## Accuracy and logging resolution

Global properties of sensors are indicated in the following table:

| **Instrument** | **Calibration range** | **Accuracy*** |
|---|---|---|
| Thermocouple type T | 5°C to 60 °C | +/- 0.1°C |
| PT100 1/3 DIN 4-wires | 5°C to 60°C | +/- 0.05°C |
| Electromagnetic flowmeter | 150 l/hr to 2500l/hr | 0.5% |

** Calibration of sensors has been carried out in the given calibration range using a liquid calibration bath and a coriolis mass flow meters respectively*

## Analysis of the data

Location of the thermocouple using the pipes spacer

Owing to the multi-configuration possibility of the geothermal Platform, several categories of data analysis can be performed. Basically, a data analysis on the experimental platform focuses either on thermal power injected to (or extracted from) the ground, with regard to the associated temperature levels, or on the temperature distribution in the ground. Furthermore, analysis can be done for different scales, from the evaluation of the performance of one single borehole to the global behavior of a six boreholes BTES. Analysis of different flow rates and injection strategies in the borehole field can also be carried out.

# EXAMPLES OF PREVIOUS STUDIES

Some experiments have already been realised on the Geothermal Platform:

- Thermal Response Tests (TRT) on each ground heat exchanger (for simple-U, double-U in parallel or double-U in serie) of the platform: TRTs are a typical test performed on large-scale BTES for the determination of design data such as the borehole thermal resistance (mK/W) or the ground thermal conductivity (W/mK).
- Closed loop tests for evaluating the influence of the short time response of ground heat exchangers on Ground Coupled Heat Pumps (GSHP) systems efficiency: These tests have been performed by coupling the Geothermal Platform to the semi-virtual laboratory PEPSY of CSTB.
- Long-time heat injection in the ground: It consists in imposing a constant power injection in the Geothermal Platform over several weeks. Temperature distribution measured in the ground during the test has been compared to numerical ground heat exchangers models results.

Possible considered experiments are:

- Evaluation of a variable flow system on the ground heat exchanger performance.
- Influence of different solar energy combinations: from solar-preheated fluid to solar heat injection in the ground, assigning one simple-U pipe of a double-U ground heat exchanger for the solar loop and one for the heat pump.

# MAINTENANCE / COLLABORATION

## Personnel involved

The Geothermal Platform is maintained by the technical staff of the Renewable Energy Division of CSTB. They are also responsible and in charge for all adaptations, in collaboration with the responsible engineers.

## International collaboration

The KIER (Korean Institute Energy Research) is in collaboration with CSTB concerning this experimental platform.

## Link to other devices

Most of the experiments performed on the Geothermal Platform are performed by coupling it to the semi-virtual laboratory (PEPSY), since the latter allows the emulation of almost any water-flowed energy-system in the power range of up to 10kW.

# RELEVANT LITERATURE

## General literature about the test facility:

Partenay, V, Développement d'une méthodologie d'évaluation des performances de systèmes de pompes à chaleur géothermiques, Thèse de doctorat, Université de Savoie – LOCIE, 2010

Partenay, V, Riederer, P, Wurtz, E, Salque, T, The Influence of the borehole short-time response on ground source heat pump systems efficiency, Energy and Buildings, accepted, published soon, 2011

Partenay, V, Riederer, P, Wurtz, E, A Global Approach for the Optimisation and Evaluation of Performances of BTES, Stockholm, EFFSTOCK 2009

Riederer, P, Partenay, V, Dynamic Test Method for the Determination of the Global Seasonal Performance Factor of Heat Pumps Used for Heating, Cooling and Domestic Hot Water Preparation, Edinbourg, BS 2009

# JACQUES GEELEN LABORATORY – ULG ARLON CAMPUS

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## GENERAL DESCRIPTION

### Main objective of the test facility

The aim of this facility is to provide a testing platform for building energy systems combining building demand, heating and cooling emitters, water-based and air-based distribution systems, storage systems and heat and cool production systems. The latter are based upon the use of low exergy systems using renewable sources (solar system and reversible heat pumps).

The facility was built between 2000 and 2002 and includes a climatic chamber in which a well defined climate can be controlled (in terms of temperature and humidity). The facility was first built to host experimentations dealing with the production of fog In an artificial climate and was designed at that time to evolve to the testing of energy systems.

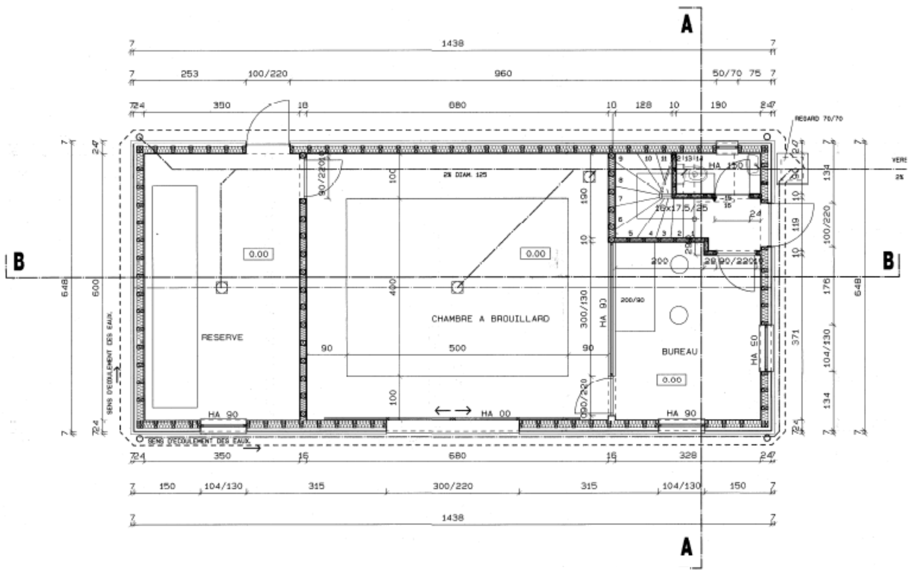
## Overall lay-out

The facility includes 4 zones: the climate chamber which is surrounded by a buffer space (1 m width) where a given temperature profile can be imposed; the offices zone where the measurement interfaces are located and the technical area where all the production, storage and distribution equipment is located.

*Small-scale mock-up of the test facility*

View of the facility during construction

The dimensions of the climatic chamber are 4m x 3m x 2.5m. The buffer space is 1m wide. The climatic chamber can be the object of the testing (by submitting the energy system to controllable and reproducible heating and cooling loads) or can host the tested device (floor heating, air diffusion system, new concept of wall,…). The whole testing facility is made of timber frame wood material with a high level of thermal insulation.




*Floor plan view of the building*

## Inside boundary conditions

The climate chamber can be submitted to a wide range of temperatures (air or resultant): between 10 and 40°C. In the buffer space a similar temperature range can be imposed. The climatic room can be submitted to heating or cooling loads using either electrical resistances or a reversible air conditioner. Latent loads can also be defined using water spraying or vapour production. Inside conditions can also be imposed by the HVAC system of the building using different emitters: floor radiating systems in all rooms, radiating ceiling in the climate chamber, air supply in the climate chamber and in the buffer space.

Inside view of the climate chamber

## Outside boundary conditions

There are two possibilities to define the outside conditions: either the natural climate as it is when the whole building is used as the test object or the buffer space in which an artificial climate can be created when the climate chamber is the object of the testing. This artificial climate can be defined in terms of air temperature in a range between 5°C and 40°C. Hourly or sub-hourly sequences can be imposed. In the future, it is planned to add humidity and solar radiation as variables to control in the buffer space.

View of the heat pump external units (static – above; dynamic – below)

## Special limitations / possibilities

The cross section of the climate chamber is 4 x 2.5m in one direction and 5 x 2.5m in the other direction. This limit the size of the building elements that can be tested in the chamber. Additionally, access to the chamber limit further the dimensions of the tested elements.

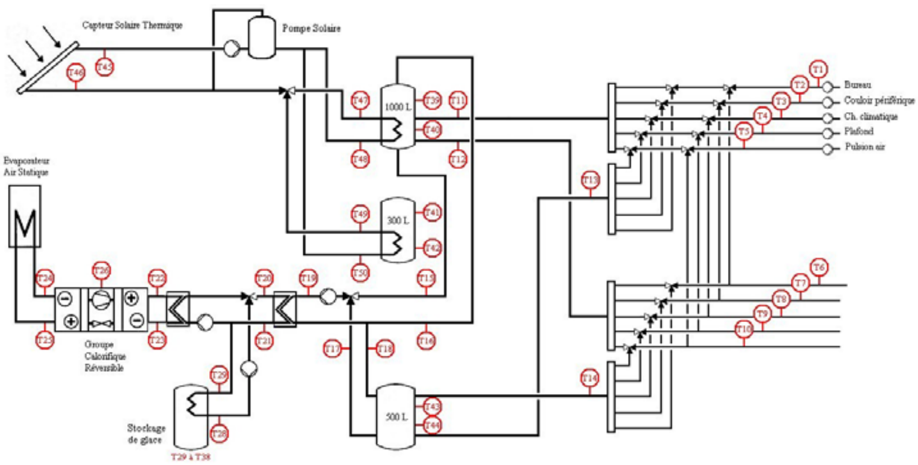
The other important limitation is concerning the temperature range. The lower value is imposed by non-freezing conditions as the both the radiating floor and the radiating ceiling are fed with pure water. Colder temperatures could be afforded by replacing pure water with glycol water in the whole heating circuit.

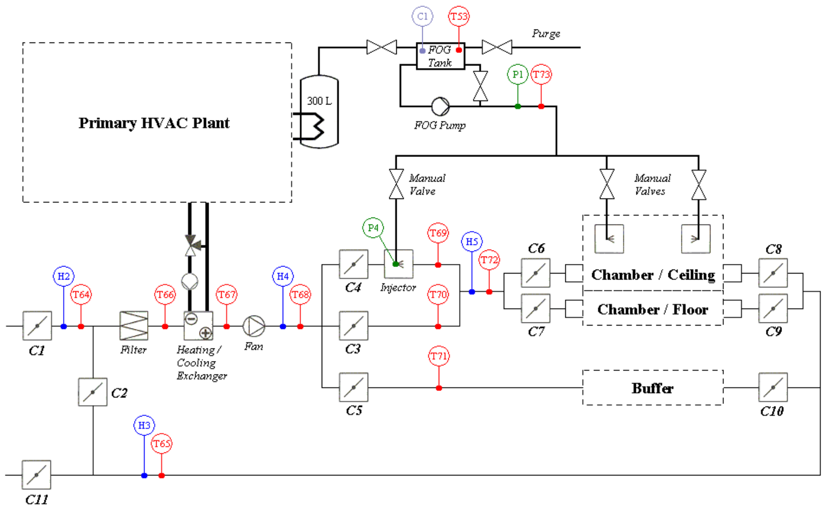
# DATA ANALYSIS

## Typical equipment within test wall

View of the data acquisition system interface

The building is equipped with more than 150 sensors located in both the building spaces and the HVAC systems. In the spaces, the following variables are measured: air temperature, resultant temperature, wet bulb temperature, air velocity. In the HVAC system, the following variables are measured: water temperature, air temperature, air humidity, pressure, flow rates, electricity power and consumption.

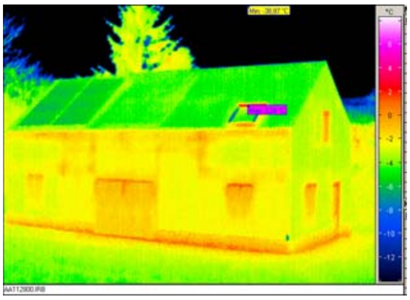



Overview of sensors installed on the Air-Handling Unit

### Accuracy and logging resolution

Temperature measurements are performed using thermistances. Humidity measurements in the climate room use wet-bulb thermometers. Resultant temperatures are measured using globe thermometers. Hot-wore anemometers are also available for air-speed measurements. Data are acquired every second and can be achieved with a time resolution down to 10 seconds.



Infrared analysis of the building

### Analysis of the data

Data are analysed in function of the objective of the research project. In research focusing on the HVAC system, energy balances are calculated from measurements; in studies focusing on the climate chamber, treatment is applied on the temperature, humidity,... measurements. Global measurements carried out on the building included: infrared thermography, blower door test.

## EXAMPLES OF PREVIOUS STUDIES

Blower-door test conducted on the building

Recent projects using the test infrastructure are:

- air diffusion: development of a compact ventilation system with heat recovery
- solar cooling: analysis of the performance of a solar cooling machine in different operating conditions
- floor heating: development of low inertia (low thickness) floor heating concept
- solar chemical storage: development of a concept of solar chemical storage in different operating conditions

Air diffusion visualisation using fumes

## MAINTENANCE / COLLABORATION

### Personnel involved

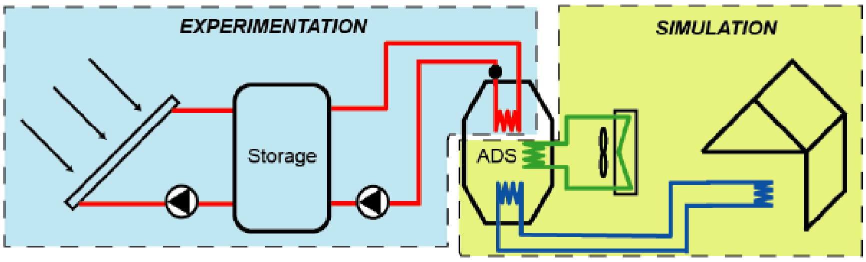
The infrastructure is operated by the research staff with each researcher being involved in the experiment definition, test conduction and data treatment. Most of the technical tasks are performed by the technical staff attached to the research team.

## International collaboration

The large scale test facility was built in the context of a European project and took profit of European funding. However, all researches conducted in the testing facility were at this point funded by regional funds and consequently did not involve international collaboration.

## Link to other devices

The facility is running for the moment as a stand-alone infrastructure. One mid-term objective is presently to establish a connection with the TRNSYS simulation software in order to be able to run "emulation" based tests where a physical component not present or not yet available in the physical facility is replaced by a mathematical model representing the behaviour of this component.




Connection of experimentation and numerical simulation

# RELEVANT LITERATURE

## General literature about the test facility:

Construction of the test facility if described in details in:

ANDRE, Ph. Editor WP7 report: Construction of a prototype environmental chamber. Report of the FOG project (contract G6RD-CT2000-00211), May 2003.

## Literature on previous measuring campaigns:

THOMAS, S. ; ANDRE, Ph. Numerical simulation and performance assessment of an absorption solar air-conditioning system coupled with an office building. Proceeding System Simulation in Buildings, Liège, December 2010

THOMAS, S. ; ANDRE, Ph.; HENNAUT, S. Combination of experimental and simulated small scale solar air-conditioning system. Proceedings EuroSun 2010 Conference, Graz, October 2010

ANDRE, Ph.; KELLY, N.; BOREUX, J-J. ; LACÔTE, P. ; ADAM, Ch. Different approaches for the simulation of an experimental building hosting a climate chamber devoted to artificial fog production. Proceedings Building Simulation 2003 (BS'03), Eindhoven, August 11-14, 2003.

# TEST FACILITY FOR ENERGY SAVING IN BRI AND NILIM

**Institute/organisation:**

N I L I M

National Institute for Land and Infrastructure Management

**Contact person:**

Dr. Hisashi Miura
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miura-h92ta@nilim.go.jp

**Exact location:**

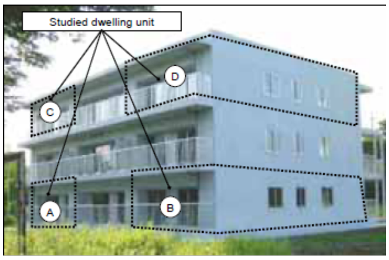
Tsukuba, Ibaraki pref. Japan 36.13°N, 140.08°E

## GENERAL DESCRIPTION

### Major aim of the test facility

Energy performance of residential equipments depends on various factors: outdoor condition, magnitude and frequency of load (for space heating and cooling, DHW etc...), equipment setting by occupants etc... Since these factors are wide range, it's difficult to comprehend what important factors are and how the effects of these factors are.

In order to clarify these influences, detailed field surveys are useful. However, there are some limitations because it's quite difficult to measure detailed data of the equipments and grasp the occupants' behaviours.




The building consists of 9 units and 4 units (A~D in the photo) are used for experimental test.

External passage and entrance door of a test unit.

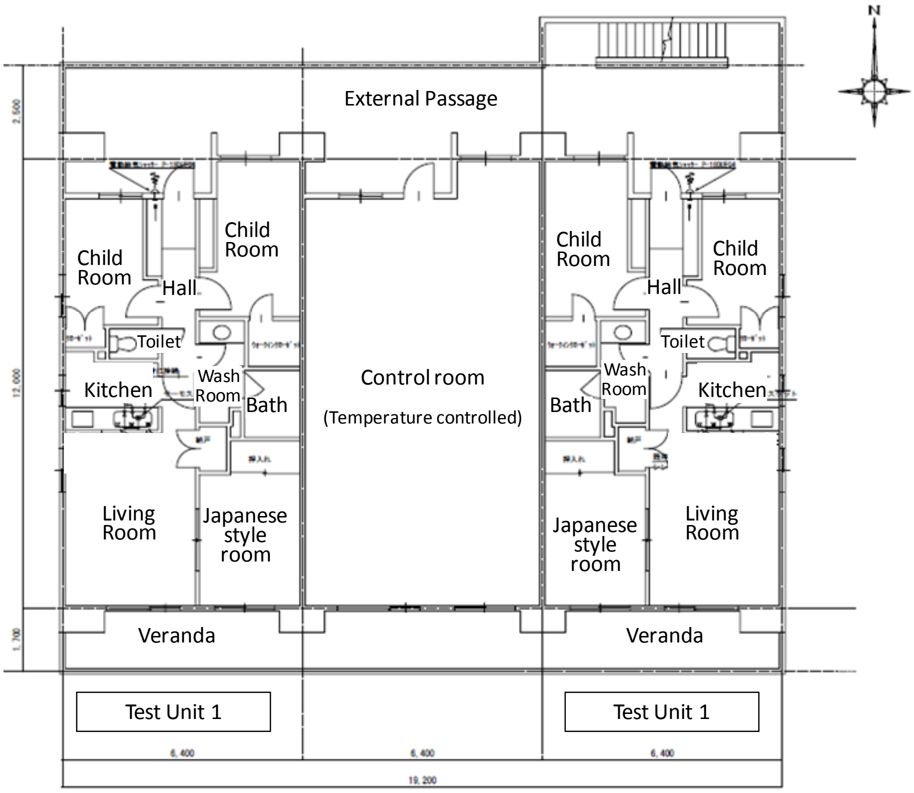
Control Panel

Data server

Therefore, we built apartment building, and installed the measurement system and human occupancy remote control system, by which we could simulate human behaviours automatically based on the pre-set schedule.

## Overall lay-out

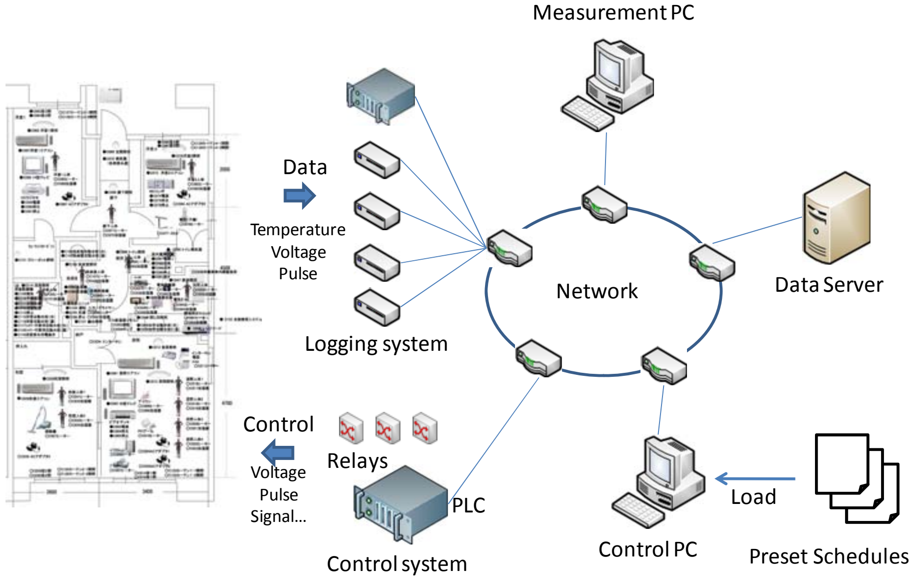
The test facility is in BRI (Building Research Institute) and NILIM (National Institute for Land and Infrastructure Management) in Tsukuba. The facility is 3 story RC constructed apartment building and we used four dwelling units situated in the corners of the building for experimental test and used two units as control room.




*Plan of one floor with two test units and one control room*

Occupants' behaviours shown below can be controlled mechanically by remote-control system based on time schedules preset before the test.

- ➔ Switch on and off all the appliances: TV, lighting, pressing iron, etc...
- ➔ Turn on and off and change settings of the heating / cooling system, DHW system, ventilation system etc...
- ➔ Open and close the windows, curtains and inside doors.
- ➔ Open and close a bathtub cover plate in the bath.
- ➔ Turn on and off the taps in the bath, kitchen and toilet.
- ➔ Simulate the heat and moisture generation from the occupants' bodies and the kitchen when cooking.




*Measurement and control system for simulating occupants' behaviour.*

Heat and moisture generator for simulating occupants: Normally, total heat emission is set at 125W including latent heat of 38W (60g/h) in winter/medium seasons and 44W (70g/h) in summer season.

Heat and moisture generator for simulating cooking: Moisture of 74g/day and heat of 377kJ/day as a total for breakfast, lunch and dinner is normally set, according to the other experiments with subjects.

Controllers for opening and closing window and curtain: we can clarify the effects of utilization of natural ventilation and day lighting.

Energy use by a family is dependent on the number of the family member, its life stage, income, etc. However, quantitative understanding of how multiple aspects of the family lifestyle determine the energy use is not complete at all. This experimental facility can simulate variety of family types and lifestyle of occupants, so that the effect of such human behaviour on the energy use can be clarified.

| TIME | MALE 46 | | FEMALE 44 | | FEMALE 16 | | MALE 14 | |
|---|---|---|---|---|---|---|---|---|
| 0:00 | Sleep 7h | Bed Room | Sleep 7h | Bed Room | Sleep 7h | Room 1 | Sleep 7h45m | Room 2 |
| 0:15 | | | | | | | | |
| 0:30 | | | | | | | | |
| 0:45 | | | | | | | | |
| 5:45 | | | | | | | | |
| 6:00 | | | | | | | | |
| 6:15 | | | | | | | | |
| 6:30 | Make-up | Lavatory | Make-up | Lavatory | | | | |
| 6:45 | newspape | Dining | Cooking | Kitchen | | | | |
| 7:00 | Breakfast | | Breakfast | Dining | Breakfast | Dining | Breakfast | Dining |
| 7:15 | Commuting | Outing | Cooking | Kitchen | Make-up | Lavatory | TV | Living |
| 7:30 | | | TV | Living | TV | Living | Make-up | Lavatory |
| 7:45 | | | Washing/TV | | going to school | Outing | TV | Living |
| 8:00 | | | | | | | | |
| 8:15 | Work | | | | | | going to school | Outing |
| 8:30 | | | | Lavatory | | | | |
| 8:45 | | | TV | Living | high school | | junior high school | |
| 9:00 | | | Cleaning | Living/Bed Room | | | | |
| 9:15 | | | | | | | | |
| 9:30 | | | TV | Living | | | | |
| 18:30 | Commuting | | Cooking | Kitchen | | | Study | Room 2 |
| 18:45 | | | | | | | | |
| 19:00 | | | | | | | | |
| 19:15 | | | | | | | | |
| 19:30 | Supper | Dining | Supper | Dining | Supper | Dining | Supper | Dining |
| 19:45 | | | | | | | | |
| 20:00 | | | | | | | | |
| 20:15 | TV | Living | Cooking | Kitchen | Study | Room 1 | TV | Living |
| 20:30 | | | | | | | | |
| 20:45 | | | TV | Living | | | Bathing | Bathroom |
| 21:00 | | | | | | | cleansing | Lavatory |
| 21:15 | | | | | Bathing | Bathroom | Study | Room 2 |
| 21:30 | | | | | cleansing | Lavatory | | |
| 21:45 | | | | | Study | Room 1 | | |
| 22:00 | Bathing | Bathroom | | | | | | |
| 22:15 | cleansing | Lavatory | | | | | TV Game | |
| 22:30 | Computer | Living | Bathing | Bathroom | | | | |
| 22:45 | | | | | | | | |
| 23:00 | | | TV | Living | | | | |
| 23:15 | | | | | CD+Radio | | Sleep | |
| 23:30 | Sleep | Bed Room | Sleep | Bed Room | | | | |
| 23:45 | | | | | | | | |

*An example of occupants' schedule: this is assumed to be most typical 4-member family schedule on weekday, which is decided according to several investigations.*

Automatically controlled tap: Amount of water is feedback controlled with flow meter by electromagnetic valves.

Controller for opening and closing bathtub cover plate: This simulates the degradation of the water temperature.

Boilers and $CO_2$ heat pump system for DHW: Efficiency of several heat sources is measured with changing connection between the heat source and piping dwelling unit.

By using this test facility, we can test the performance of the appliances, described below.

*Performance of the appliances which can be tested in this facility*

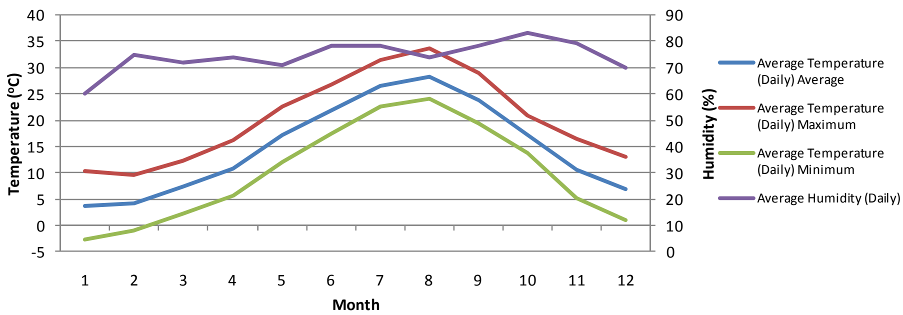
| Category | Test items or appliances |
|---|---|
| Space heating/cooling | Efficiency of room air conditioner |
| | Total efficiency of hot water floor heating system with gas boiler or electric heat pump |
| DHW system | Efficiency of heat sources: gas boiler, kerosene boiler, electric $CO_2$ heat pump |
| | Total efficiency of DHW system including heat loss from the piping |
| | Efficiency of solar collector |
| | Total efficiency of DHW system with solar collector including mix unit control |
| Lighting | Day lighting utilization factor |
| Cross ventilation | Reduction of cooling load by utilizing cross ventilation |
| Mechanical ventilation | Efficiency of main mechanical ventilation |
| | Efficiency of separated controlled exhaust fan of range hood in kitchen |
| Co-generation system | Efficiency of gas co-generation system |
| | Efficiency of fuel cell |

## Inside boundary conditions

Inside boundary conditions depends on the operation of the appliances: Room air conditioner, floor heating system, utilization of cross ventilation, heat and moisture generation from occupants, usage of water, cooking.

## Outside boundary conditions

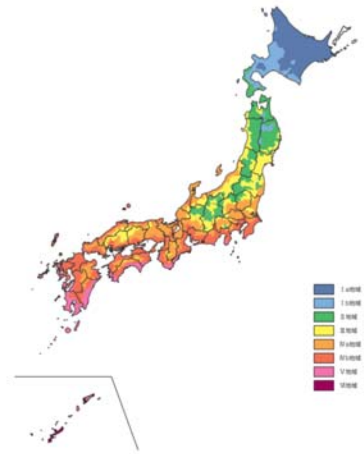
External temperature, humidity, solar radiation, wind speed and direction, and the amount of rainfall are recorded every 10 minutes at the rooftop of the building.




*Outdoor temperature and humidity in Tsukuba*

## Special limitations / possibilities

By using this facility, we can clarify the influence of the factors on the energy performance of the appliances and grasp several complicated phenomena such as defrosting operation, cross ventilation etc… However, as the climate in Tsukuba is mild, we have to carry out separate experiments in order to clarify the performance in the special condition: the performance of the ventilation system with heat exchanger in very cold region, the performance of heat pump system in very cold region, decrease by utilizing cross ventilation in hot humid region etc…



Location of Tsukuba: it is located in mild climate.

# DATA ANALYSIS

## Accuracy and logging resolution

| Item | | Instrument | Number of point | Interval |
|---|---|---|---|---|
| Indoor environment | Air Temperature | Thermocouple | 5 vertically in each room | 5 min. |
| | Relative humidity | Electric hygrometer | 1 in each room | 5 min. |
| | Glove temperature | Thermocouple | 1 in each room | 5 min. |
| | Wall surface temperature | Thermocouple | 6 in each room | 5 min. |
| | Wind velocity | Hot wire anemometer | 1 in each room | 5 min. |
| Outdoor environment | Temperature | Thermocouple | 1 in rooftop | 5 min. |
| | Relative humidity | Resistance hygrometer | 1 in rooftop | 5 min. |
| | Solar radiation | Pyranometer | 1 in rooftop | 5 sec. |
| | Wind direction | Ultrasonic anemometer | 1 in rooftop | 5 sec. |
| | Wind velocity | Ultrasonic anemometer | 1 in rooftop | 5 sec. |
| | Amount of rain fall | Pluviometer | 1 in rooftop | 5 min. |
| Energy consumption | Electric power consumption | Clump sensor | 1 per appliance | 1 min. |
| | Gas consumption | Volumetric flow meter | 1 per appliance | 5 sec. |
| | Kerosene consumption | Volumetric flow meter | 1 per appliance | 5 sec. |
| Water Demand | Water | Volumetric flow meter | 1 per appliance | 5 sec. |
| | Water | Electromagnetic flow sensor | 1 per appliance | 5 sec. |
| Others | Water temperature | Thermocouple | 1 per appliance | 5 sec. |
| | Heat pump medium temperature | Thermocouple | 1 per appliance | 5 sec. |
| | Airflow temperature of RAC | Thermocouple | 2 per appliance | 5 sec. |
| | Airflow humidity of RAC | Electric hygrometer | 2 per appliance | 5 sec. |
| | Rotation meter of RAC | Photomicro sensor | 1 per appliance | 5 sec. |

Example of the measurements. Exchanged air volume through the windows by cross ventilation is being measured by 3-dimmentional ultrasonic anemometers besides windows. And the difference of the external pressure at each surface are also measured.

## Analysis of the data

Data analysis is dependent on the issue described next clause.

# EXAMPLES OF PREVIOUS STUDIES

Examples of previous studies are:

➔ Instantaneous efficiency of room air conditioners in various external conditions, operation mode such as set temperature and heat loads.

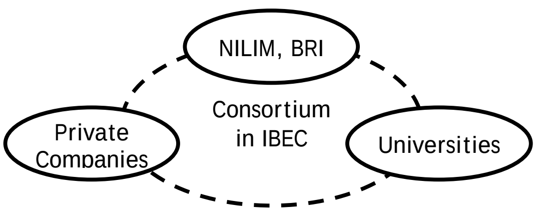
- ➔ Daily average efficiency of DHW system in various external conditions and hot water daily demand. Especially the efficiency of the system which has a hot water storage tank such as CO2 heat pump system and co-generation system.
- ➔ Comparing the effects of the envelope performance on the heating and cooling demand and energy.
- ➔ Effects of the utilization of cross ventilation on cooling load and energy.

# MAINTENANCE / COLLABORATION

## Personal involved

The building is maintained by the technical staffs in BRI (Building Research Institute), who are responsible for building the plan of the experiments, checking and monitoring the measured and logging data and changing the experimental settings according to the type of the experiments. A series of experiment normally is for a week, and on every Tuesdays the staffs change the settings and check the facilities. In addition to that, we make a contract for the maintenance with the company for instrumentation and measurements.

The staffs in Building Research Institute check the data in order to judge which the experiments are carried out successfully and log the results such as data deficit period. The data are analyzed by many researchers in universities, research institutes and private companies, who are the member of the consortium which we built in IBEC (Institute for Building Environment and Energy Conservation) in order to exchange the research topics about residential energy saving. The researchers who analyze the data can download the data through the internet from the data server in BRI.



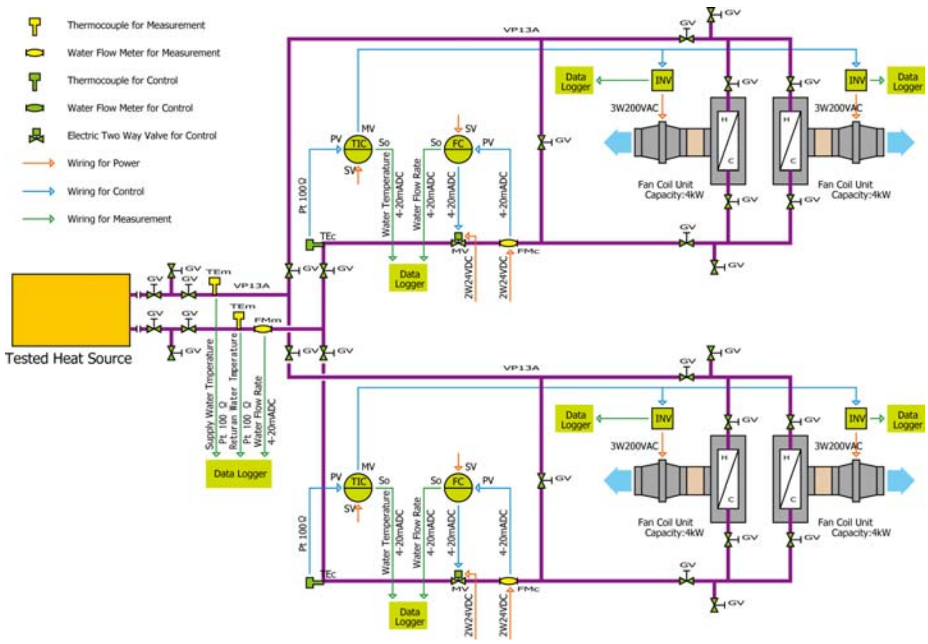

*Consortium in IBEC: The analyzed results are shared among the member in the consortium in IBEC. More than 20 private companies such as electric and gas service, house builder, equipment manufacture are joining and more than 20 universities are joining in research phase from 2008 to 2012.*

## International collaboration

No international collaboration.

## Link with other devices

From the data analysis measured in this facility, the various factors and effects on energy saving can be clarified. After grasping and understanding these factors, we carried out the experiments under the situation that we can control the condition such as the external air temperature in order to understand the effects clearer and/or sometimes in order to develop the mathematical model of the appliances. One of the appliances is the simulated heating and cooling load generators in the climate artificial chamber in order to measure the efficiency of the heat sources for heating and cooling under various conditions.



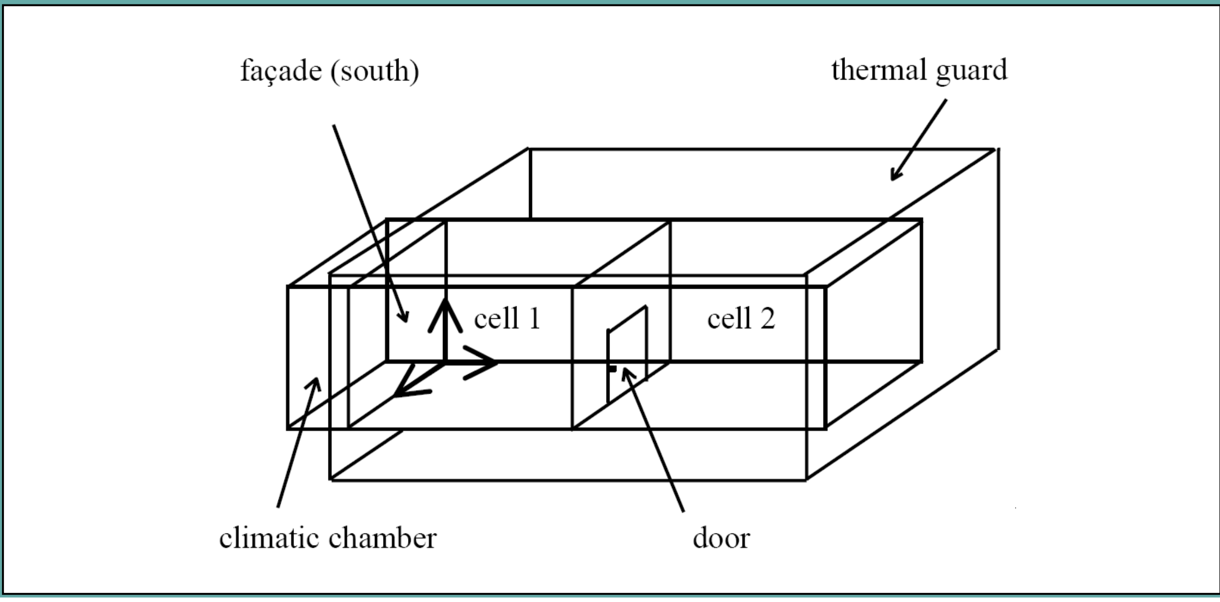

*Simulated heating and cooling load generators: Load is controlled by changing the number of fan coil units used and frequency of the fans.*

# RELEVANT LITERATURE

## Literature on previous measuring campaigns:

T.Sawachi, S.Nishizawa, H.Hiromi, H.Miura, Estimation on the Effectiveness of Cross Ventilation as a Passive Cooling Method for Houses, Journal of Ventilation pp.179-186,vol 7, No.2, 2008.9

# MINIBAT TEST FACILITY




## GENERAL DESCRIPTION

### Main objective of the test facility

MINIBAT test facility consists of two cells (rooms). One face of cell 1 is adjacent to a climatic chamber; remaining five sides are thermally guarded. Walls and indoor volumes are equipped with numerous sensors, and both cells can be ventilated, heated, cooled, etc.

The aim of this test facility is to gain understanding on heat and air transfers within one building room, between two rooms, and through an external wall coupled with a room. The facility enables to gather detailed data for validation of numerical models. As the outdoor climate is simulated by a weather generator, boundary conditions can be easily duplicated.

**Institute/organisation:**

CETHIL, UMR CNRS 5008, INSA de Lyon, Université Lyon 1

**Contact person:**

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INSA de Lyon
Bât. Sadi Carnot, cethil UMR 5008
69621 Villeurbanne cedex,
FRANCE
tel: (+33)472.438.777
e-mail: joseph.virgone@insa-lyon.fr

**Exact location:**

FRANCE, Lyon
(indoor test facility)

Typical studies include air distribution, heating, cooling systems as well as façade systems.

## Overall lay-out

The Minibat experimental facility is formed by two identical test cells, each one with the dimensions of L × W × H = 3.1 m x 3.1 m x 2.5 m (Figure 1).

| Wall | Material | Thickness |
|---|---|---|
| [-] | [-] | [mm] |
| Floor | Cellular concrete | 200 |
| Vertical wall | Plasterboard | 10 |
| | Polystyrene | 50 |
| | Plasterboard | 10 |
| | Agglomerated wood | 50 |
| Ceiling | Plasterboard | 10 |
| | Plywood | 8 |
| | Mineral wool | 55 |
| | Wood | 25 |

*Table 1. Wall composition (from the interior of the test cell to the thermal buffer zone)*

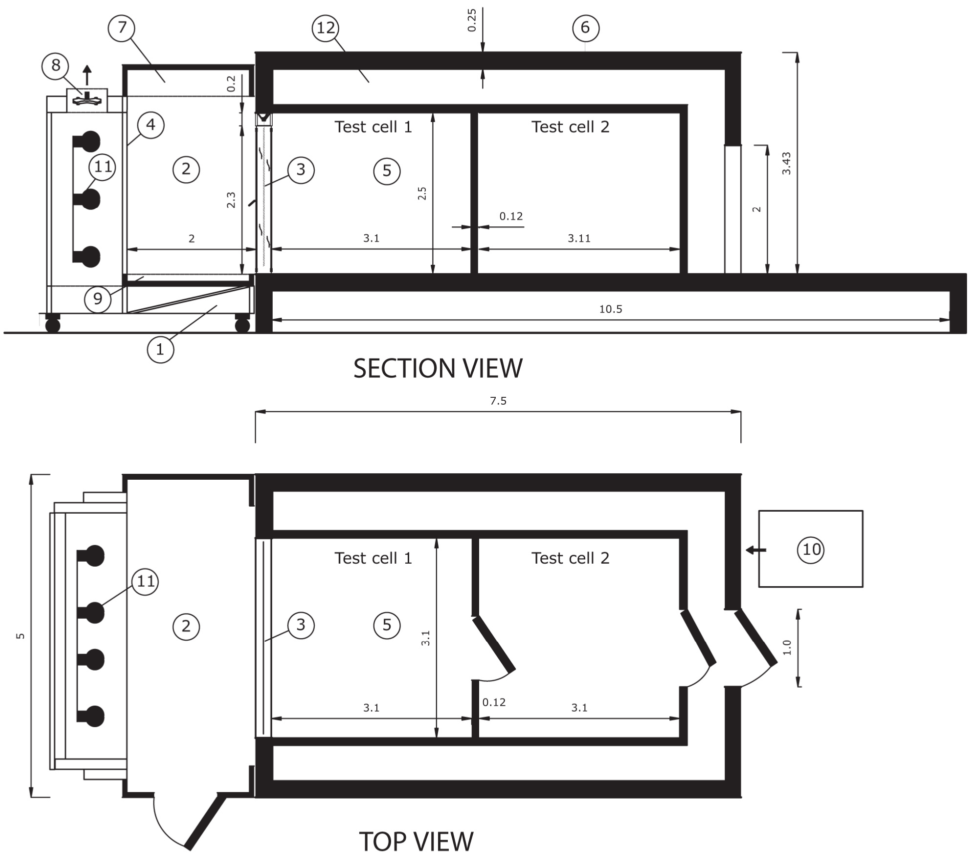



*Figure 1. Test cell facility scheme: 1, cooling unit; 2, weather generator; 3, movable facade; 4, protection glass of the solar simulator; 5, test cell; 6, concrete; 7, air blowing plenum; 8, solar simulator's heat removal ventilators; 9, air extraction plenum; 10, HVAC unit of the buffer zone; 11, solar simulator; 12, controlled buffer zone.*

Five walls of each cell are in contact with a thermal buffer zone with controlled temperature. Table 1 gives the overview of materials used.

The south façade of the test cell 1 (3.1m x 2.5 m) is movable and can be replaced by the tested component. It is in contact with the weather generator capable of simulating the outdoor conditions (temperature and solar radiation).

## Inside boundary conditions

To create a homogeneous and regular volume of air inside the thermal buffer zone, an air distribution network is installed. The air diffusers are located in the upper part of the buffer zone and air outlets in the lower part. The air temperature inside of the buffer zone is controlled by an ON/OFF charge controller with a differential of ±0.5°C.

Each cell is equipped with an HVAC system, in order to control inlet air conditions. The position of air inlets and outlets is movable; moreover, in each cell, different heating, cooling or ventilation systems can be installed and tested.

## Outside boundary conditions

Outdoor conditions are simulated by the weather generator. An air treatment unit controls the air temperatures in the weather generator between -5 and +40°C, with a stability of ±0.2°C. A set of 12 projectors containing specially designed lamps simulates solar radiation. These 1000 W, gas-discharge lamps have a radiation spectrum close to the solar spectrum (Figure 2 and 3)

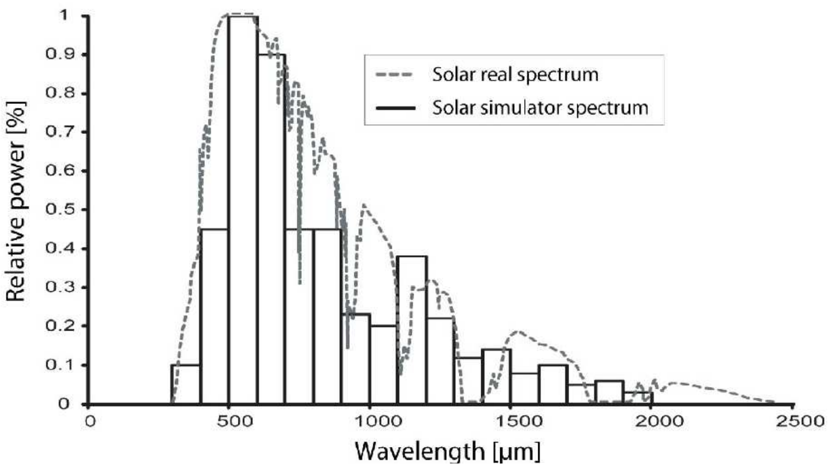



*Figure 2. Radiative spectrum of the solar simulator*

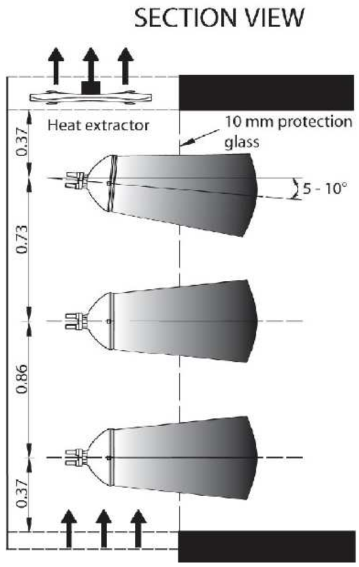



*Figure 3. Solar Simulator.*

## Special limitations / possibilities

As all the boundary conditions are artificial, this facility allows testing different elements under identical conditions.

Moreover, as both the façade system and the room can be instrumented, the facility allows simultaneous testing of the transfers within the tested wall and of its impact on the room.

Recently the facility was refurbished: the wall separating cells 1 and 2 was removed, and some sensors replaced.

# DATA ANALYSIS

## Typical equipment

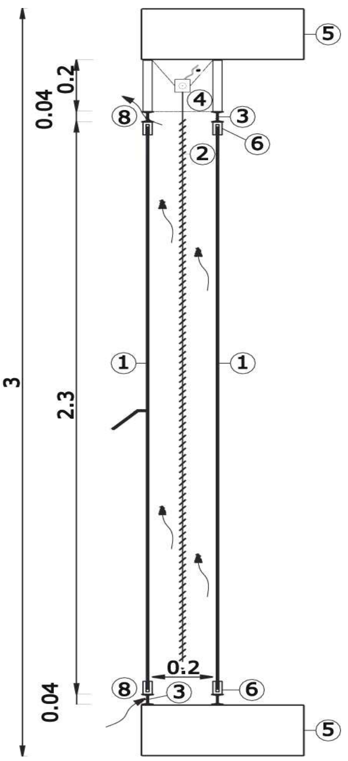



*Figure 4. Example of a tested wall: double-skin façade: 1, 6 mm glass layer; 2, motorized solar protection (W=0.025 m); 3, metallic support; 4, solar protection action box; 5, structural concrete beam; 6, aluminum frame; 7, pane opening articulation; 8, ventilation openings.*

The metrology installed in the experimental facility is organized in two categories, one for the test cell with all the auxiliary equipment and the other one for the tested elements. Both measurement systems are composed of a substantial number of thermocouples and Pt100 sensors, some relative humidity sensors, air velocity probes, one inline flowmeter and one stand alone pyranometer for the solar radiation. In total more than 200 measurements are recorded at each time-step for the test-cell and auxiliary equipment.

The entire test cell is equipped with nine evenly spaced temperature sensors on each interior and exterior surfaces (facing the inside of the cell and facing the thermal buffer zone).

Air temperature, relative humidity and air velocity are measured in several points in the test cell. In some investigations, the sensors were placed on an automatically moving device, and temperature and air velocity fields were measured inside the cell on a defined grid (typically 10cm x 10cm).

## Accuracy and logging resolution

Sensors (see Table 2) are connected to a Keithley 7200 central multiplexing station. Measurements are then carried out using a multimeter Keithley 2700. Acquisition and recording of data are done by a computer station using Labview software, connected to the multimeter through a GPIB bridge.

| Sensor | Type | Precision |
|---|---|---|
| Thermocouple | K | ±0.3°C |
| Thermocouple | T | ±0.6°C |
| Platinum RTD | Pt100 | ±0.2°C |
| Flow rate | - | ±0.5 % |
| Air velocity transducer | TSI omnidirectional | ±3 % |

*Table 2. Main sensors installed in the test cell*

## Analysis of the data

Data analysis, as well as numerical models used for data analysis, are strongly depending on the investigated issue. Steady state detailed temperature and air velocity fields in the indoor air in can be compared with CFD simulations. Wall performance models can be tested (using values measured on different points inside the wall), and their impact on indoor conditions can be validated against experimental data.

# EXAMPLES OF PREVIOUS STUDIES

Many past and ongoing research projects, PhD thesis and industrial collaborations used Minibat facility. Main applications concerns studies on:

- indoor air quality : pollutant distribution in a room air and the efficiency of ventilation systems,
- hygro-thermal comfort and energy efficiency for different ventilation systems and heating/cooling elements (chilling ceilings, radiators, cross ventilation, etc.),
- detailed analysis of air jets from air inlets, and their mixing with the indoor air,
- novel façade elements: double-skin façades, phase change materials, etc.
- air flow between two rooms through an closed or open door.

*Double-Skin Façade tested on Minibat*

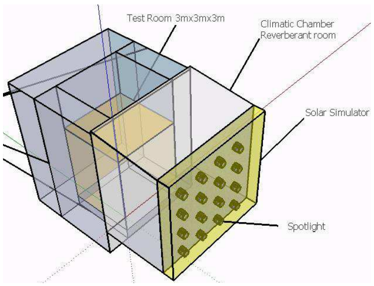
# MAINTENANCE / COLLABORATION

## Personnel involved

The building is maintained by the technical and research staff of the CETHIL. They are also responsible and in charge for all adaptations, new measuring campaigns, etc. in collaboration with the responsible engineering or researcher. The latter also performs the data analysis.

## International collaboration

Some specific international collaboration were done in the past. All of them were temporary and related to a particular project.




*Scheme of 3CUBE*

## Link to other devices

Our institute, CETHIL, is building a new climatic chamber, 3CUBE, a research platform opened to academic and industrial research.

Its aim is to obtain controlled indoor and outdoor environment of 3m x 3m x 3m cube in order to obtain benchmark data for heat and mass transfer through the envelopes and in the indoor environment. The test cell will be equipped with the most advanced measurement systems for heat and mass transfer in materials and for 3D flow and temperature distribution.

# RELEVANT LITERATURE

## General literature about the test facility:

F. Allard, J. Brau, C. Inard, J.M. Pallier. 1987. Thermal experiments of full-scale dwelling cells in artificial climatic conditions. *Energy and Buildings*, Vol. 10:1, p. 49-58

## Literature on previous measuring campaigns:

V. Gavan, M. Woloszyn, F. Kuznik, J.-J. Roux. 2010. Experimental study of a mechanically ventilated double-skin façade with venetian sun-shading device: A full-scale investigation in controlled environment. *Solar Energy*, vol 84/2, p. 183-195.

T. Catalina, J. Virgone, F. Kuznik. 2009. Evaluation of thermal comfort using combined CFD and experimentation study in a test room equipped with a cooling ceiling. *Building and Environment*, Vol. 44/8, p. 1740-1750.

F. Kuznik, J. Virgone. 2009. Experimental assessment of a phase change material for wall building use. *Applied Energy*, Vol 86/10, p. 2038-2046

F. Kuznik, J. Virgone, J.-J. Roux. 2008. Energetic efficiency of room wall containing PCM wallboard: A full-scale experimental investigation. *Energy and Buildings*, 40/2, p. 148-156

F. Kuznik, G. Rusaouën, J. Brau. 2007. Experimental and numerical study of a full scale ventilated enclosure: Comparison of four two equations closure turbulence models. *Building and Environment*, 42/3, p. 1043-1053.

F. Kuznik, G. Rusaouën, R. Hohota. 2006. Experimental and numerical study of a mechanically ventilated enclosure with thermal effects. *Energy and Buildings*, 38/8, p 931-938

M. Woloszyn, J. Virgone, S. Mélen. 2005. Experimental study of an air-distribution system for operating room applications. *International Journal of Ventilation* vol. 4 n°1. 1-11.

M. Woloszyn, J. Virgone, S. Mélen. 2004. Diagonal air-distribution system for operating rooms: experiment and modeling. *Buildings and Environment*, vol. 39/10, 1171-1178.

C. Teodosiu, R. Hohota, G. Rusaouën, M. Woloszyn. 2003. Numerical predictions of indoor air humidity and its effect on indoor environment. *Buildings and Environment* 38/5, 655-664.

S. Laporthe, J. Virgone, S. Castanet. 2001. A comparative study of two tracer gases: $SF_6$ and $N_2O$. *Building and Environment*, 36/3, p. 313-320

# VERU - IBP HOLZKIRCHEN

## GENERAL DESCRIPTION

### Main objective of the test facility

- Fundamental studies regarding the overall energy efficiency of buildings
- Investigations aimed at establishing minimum requirements for proof procedures
- Research and development work concerning building units and building services components, aimed at reducing the primary energy demand or at optimising the integration into both façade concepts and technical equipment concepts under aspects of building physics

**Institute/organisation:**

Fraunhofer IBP

Fraunhofer-Institut für Bauphysik
Standort Holzkirchen
Abteilung Energiesysteme,
Deutschland

**Contact person:**

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Fraunhoferstr. 10
D-83626 Valley
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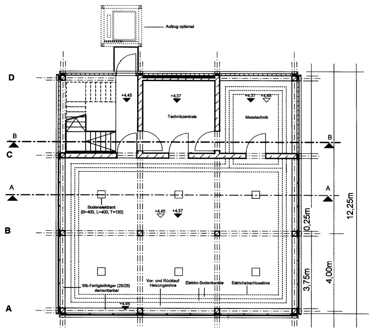
**Exact location:**

Holzkirchen, Deutschland
47.88°N, 11.73°E

South-west view of the VERU test building.




Floor plan showing the test rooms and the utility rooms.

- Determining the interaction of building units and technical equipment components in overall energy concepts or in building systems
- Validation and further development of computing models for simulating energetic and physical interrelations in buildings
- Preparing standard sets of data for the validation of software products in the fields of building simulation / building services equipment simulation, daylighting, flow simulation, comfortable indoor environment

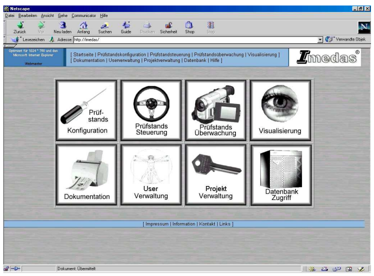
## Overall lay-out

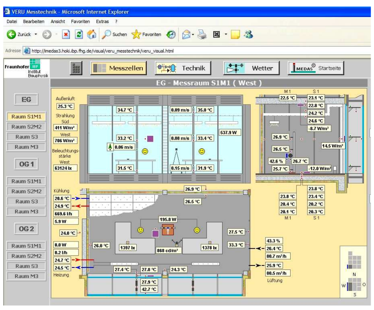
The reinforced-concrete construction of the three-storey test building was raised in the unshaded part of the Holzkirchen outdoor test site on a surface area of 12 m x 12 m. On each floor there are six square test cells, which can be investigated both individually and in combination (for instance, if concepts for open-plan offices or conference halls are to be examined). The false ceilings being partially demountable, it is possible to investigate multi-storeyed spaces or halls. Moreover, removable roof slabs allow integrating transparent roof components, instead. Three test cells located in the northern area of each level serve as a stair well, host supply installations and the measurement instrumentation. Parts of the solid false ceilings contain systems for activating the concrete core.

## Inside boundary conditions

The VERU test facility has been provided with an extensive basic equipment for monitoring the relevant system parameters, like e.g. medium temperatures and mass flows inside the heating circuits and the cooling cycles, air flows, relative humidity und temperatures in the supply and extract air cycles, indoor air temperatures, indoor air humidity, surface temperatures and heat flows inside the test rooms and at the façade. The demand for electrical auxiliary energy for pumps and heating grids is documented by no stationary recordings, just like the time profile of the internal heat sources.

The central control of the test facility is managed by a modular storage-programmable control system (SPS). Measurement data are collected by IMEDAS™ (a specialised data acquisition system that was also developed by IBP scientists) which also communicates with the central control unit, storing relevant process data and system states in the central data base. Furthermore, Imedas™ enables engineers to visualize processes that are currently occurring at measurement sites via the intranet and the internet. Settings and boundary parameters can be modified and controlled from any workplace, protected by passwords, thus allowing to display latest test-facility data at trade-show presentations, for potential clients and in one's own company.



Exemplary presentation of the internet-based IMEDAS™ process visualisation system

## Outside boundary conditions

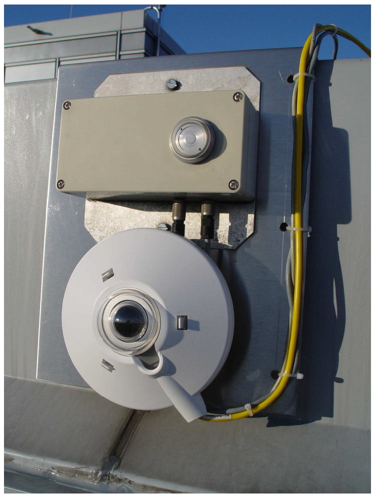
Climatic data recording is carried out by the central weather station at IBP Holzkirchen. This records the most important meteorological boundary conditions such as directional and diffuse global radiation, external air temperature, relative humidity, wind speed and direction in addition to their pressure. In addition, further external air temperatures in addition to the directional radiation in the east, south and west directions are technically measured directly at the VERU building. In addition to the measured radiation data, the directional lighting levels are measured in the facade orientation in addition to horizontally on the roof of the VERU test building.

New weather station (since 2010) at the IBP Holzkirchen

## Special limitations / possibilities

Up to 2010 the VERU test facility was especially used for investigations concerning the energetic behaviour of certains components or technical equipment. In the year 2010 there could be started a considerable retrofitting in order to realise two comparable test cells facing south. The energetic equality will be achieved by adiabatic layers in the boundary room elements: they can be heated or cooled by water registers. Thus comparative measurements of lighting systems, HVAC-systems, façade components etc. will be possible.

# DATA ANALYSIS



Measurement of the illuminance at the south facade of VERU

## Typical equipment within test wall

To record all the energy flows relevant to the investigations, in addition to assessing the thermal and visual subjective comfort in the room, numerous measuring sensors are usually installed in each individual test room. The feed and return temperatures in the hydraulic circuits in addition to those in mass flows can be measured to record the heating and cooling performances. In each test room, air flow volume sensors can be built into the feed air and exhaust air circuits, and the temperatures at the air intake and air exhaust from the test rooms can be measured in order to balance the energy transport via the mechanical ventilation systems.

In addition to these energy balance ratios for heating, cooling and ventilation of individual test rooms, the electrical power consumption for artificial lighting in addition to the power consumption for internal heat sources can be measured additionally. The internal heat sources include heat given out by people in the rooms in addition to equipment such as computers, monitors, printers etc. This thermal quantity is added to the test rooms using so-called cooling load simulators. These are electrically heated tubes which have

Cooling load simulator

Temperature sensor for determining the operative temperature and air temperature

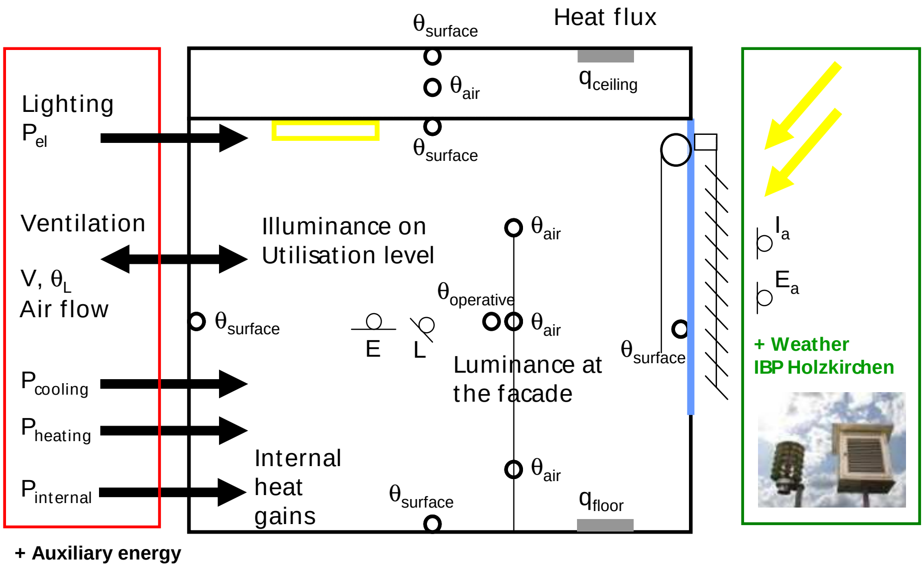
similar behaviour with regard to convective and radiation heat output to human beings.

Numerous measured variables for assessing the thermal comfort of the room can be recorded in addition to the energetic parameters. These are initially the air temperatures measured at various heights. In order to avoid possible heating up of the air temperature sensors by the incident solar radiation, a radiation protector consisting of a highly-mirrored plastic tube is fitted around the temperature sensor. In addition to the air temperature sensors, the operative temperature can be measured using a so-called globe thermometer. Furthermore, surface temperature sensors are often installed on the envelope surfaces on the floor, on the ceiling, at the partition walls and on the facade.

In addition to the surface temperature sensors, heat flow meters can be installed above the floor or above the ceilings in the neighbouring test rooms to assist in balancing the heat flows with whose help a more precise energetic balance is possible for individual test rooms.

In order to assess visual comfort or to check for sufficient brightness at workplaces, illumination level sensors can be installed at each workplace height.

A glare-free facade is essential for visual comfort in addition to sufficient lighting levels at the workplace. In order to assess the glare situation at the facade, additional luminance sensors can be installed in the rooms which record the major part of the transparent facade surface and whose measured mean luminance can be referred to as an assessment criterion for facade glare levels. Furthermore, this sensor signal can also be used for controlling the shade provider and less protection.




Measurement point overview in test rooms

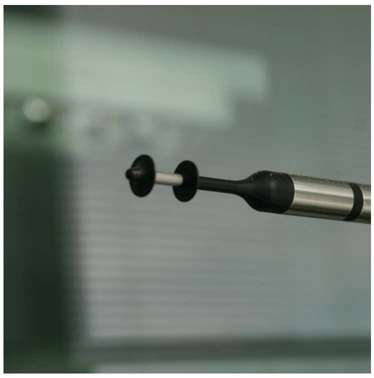
$\theta_{RL}$ room air temperature (e.g. 0.1 m / 1.1 m / 1.7 m height)
$\theta_{O}$ operative room temperature (Globe thermometer at 1.1 m height)
$\theta_{OFT}$ surface temperatures of envelope surfaces
$P_{cooling}$ cooling output
$P_{heating}$ heating output
$P_{internal}$ internal heat source output
$V$, $\theta_{L}$ ventilation (feed/exhaust air)
$P_{el}$ electric lighting output
$E$ lighting levels at workplace
$L$ luminance at facade
$q$ heat flow density
$I_{a}$ direct radiation
$E_{a}$ vertical lighting levels

Depending on the building services fittings in individual test rooms, further sensory apparatus can sometimes be necessary in addition to the sensor components installed as standard. These are necessary, for example, for closer analysis of the decentralised air-conditioning technology in addition to the glass double facade. Numerous measurement sensors are also installed during heat and cold supply or distribution in addition to the thermal air treatment. These are used firstly for determining the are used for monitoring, checking and optimising of each individual component.
In addition to these permanently recorded measured variables, further measurement processes can be used during the investigations or during initial start-up and during regular control tests. These are, in brief, the procedure for determining the sealtightness of individual test rooms, the so-called blower door measuring process, and a measuring process for determining the actual air change rate in rooms with the help of a tracer gas - the so-called tracer gas measuring process. Determination of large-surface temperature distribution both inside the test rooms and outside on the VERU building can be carried out with the help of an infrared thermal imaging camera. Further analyses can be carried out with the help of a surface resolution luminance camera in addition to recording the mean luminance distribution via the fixed luminance sensors at the facade.

Photometer head for determining luminance (upper image) and lighting levels (lower image)

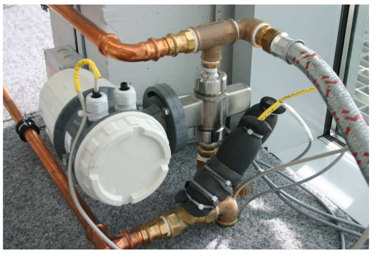
## Accuracy and logging resolution

The globe thermometer for determining the operative temperature in the room consists of a black-painted hollow copper sphere and a PT100 resistance thermometer in a stainless steel jacket with its sensor tip in the centre of the sphere. The accuracy of the temperature sensor is ±0.3 K (DIN EN 60751 Class B). The temperature sensor for measuring the air temperature in the room works with a PT100 ceramic resistor covered in a radiation protector which prevents warming up of the sensor by direct sun radiation. The radiation protector consists of a self-adhesive mirrored film with a reflection ratio of 92 %. It is fitted on two centrically located tubes with diameters of 45 and 65 mm. the radiation detector is 100 mm high, the sensor is located at around 30 mm above the bottom of the tube. The accuracy of the temperature sensor is ±0.1 K (DIN EN 60751 Class 1/3 B).



Airflow probe

The $V(\lambda)$ matching quality of the photometer head for light level measurement for assessment of lighting at the workplace in accordance with DIN 5032 T6 is f1<3% (Class A) with a cosine-corrected spatial assessment



Magneto-inductive flow meter for determining mass flows in heating and cooling circuits.

f2<1.5%. The V(λ) matching quality of the photometer head with luminance attachment in accordance with DIN 5032 T6 is also f1<3% (Class A) with a cosine-corrected spatial assessment f2<1.5%.

Flow measurement takes place calorimetrically in accordance with the heat transmission principle. A heatable thermo resistance element is regulated to a constant overtemperature relative to the medium temperature. The heat emitted by the medium increases with increasing mass flow. The heating voltage is a direct measurement of the flow speed. Measurement accuracy is ±0.15 m/s in addition to ±6 % of the measured value.

The mass flow of both the heating and cooling circuits are determined with the help of magneto-inductive flow meters in combination with high-precision PT100 immersion sensor thermometers. The immersion sensors for determining the feed and return temperatures have an accuracy of ±0.03 K. The basic accuracy of the magneto-inductive flow meter is approximately ±0.5 % of the relevant measured value.

## Analysis of the data

The first step of data analysis is done by a software system developed at IBP and optimised for the requirements of structural physics research, called Imedas™. It is a server-supported system which bundles all project information and makes it available to those participating in the measurement project via corresponding function modules. Editing takes place using a normal web browser. Imedas™ consists of the following individual modules:

- planning tools (test bench configuration)
- measurement and communication program
- visualisation with and without integrated HMI functions
- central database for measurement and condition values
- documentation and information system
- user and project management

With Imedas™ can be created graphs automatically which is useful for the first interpretations and the data control. The real analysis of the data is then done by other software tools (e. g. MS-Excel, Origin etc.). The kind of analysis depends strongly on the investigations and cannot be described blanket.

# EXAMPLES OF PREVIOUS STUDIES

The VERU test facility was built in 2002 and inaugurated in 2004. Since that time there were treated the following studies (extract):

- Metrological evaluation of the german regulation DIN V 18599 “Energy efficiency in buildings – Calculation of the energy needs, delivered energy and primary energy for heating, cooling, ventilation, domestic hot water and lighting”
- Development of a simple calculation method for the energetic behaviour of double skin facades
- Energetic evaluation of internal sun protection systems
- Investigations concerning the transmission of radiation through photovoltaic glass elements and their temperature behaviour
- Investigations on solar heat elements
- Probant test concerning the human performance under different indoor climate situations
- Investigations concerning the increase of efficiency of photovoltaic elements by cooling through PCM-elements

# MAINTENANCE / COLLABORATION

## Personnel involved

The VERU test facility is run by the group façade concepts (Group leader: Herbert Sinnesbichler) in the department energy systems of the IBP.

## International collaboration

There exists collaboration with the institute Tecnalia in Derio, Bilbao (Spain) and their test facility “KUBIK” which aims at similar investigations as VERU. IBP gave advice in the conception and design of “KUBIK”.

## Link to other devices

VERU is a stand-alone facility.

# Relevant literature

## General literature about the test facility:

There exist a general flyer about VERU in German and English which can be ordered at the IBP Holzkirchen.

## Literature on previous measuring campaigns:

Sinnesbichler, H. et al.: Weiterentwicklung und Evaluierung von Technologien und von Bewertungsmethoden zur Steigerung der Gesamtenergieeffizienz von Gebäuden (EnEff06), IBP-Bericht WTB-02-2007.

Heusler, I.; Sinnesbichler, H.; Erhorn, H.; Nimtsch, A.: Erarbeitung einer vereinfachten Berechnungsmethode für Doppelfassaden für die Integration in die deutsche EPBD-Energieeffizienzbewertungsmethode DIN V 18599 (Bewertungsmethode GDF), IBP-Bericht Nr. ESB-002/2009 HOKI.

Sinnesbichler, H.; Eberl, M.: Temporärer Wärmeschutz durch Rollläden mit Infrarot reflektierender Oberflächenbeschichtung, IBP-Mitteilung 496, 36 (2009).

Heusler, I.; Kersken, M.; Sinnesbichler, H.: Untersuchung der Potenziale von innen liegenden Sicht- und Sonnenschutzsystemen zur Verringerung des Heizwärmebedarfs von Gebäuden, IBP-Bericht ESB-007/2009 HOKI.

Hauser, G.; Sinnesbichler, H.; Eberl, M.: Nächtliche Kühlung mittels eines modifizierten Solarkollektors, IBP-Mitteilung 498, 37 (2010).

# KUBIK BY TECNALIA


**Institute/organisation:**

FUNDACIÓN TECNALIA RESEARCH & INOVATION
Construction Business Unit

**Contact person:**

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Inés Apraiz

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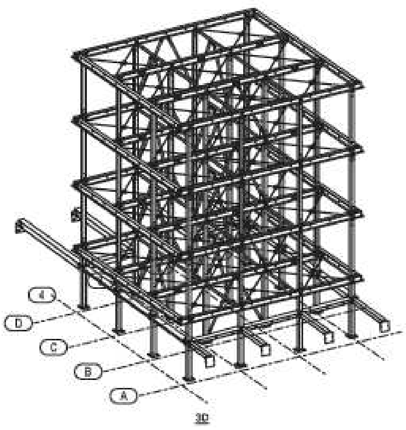
**Exact location:**

Derio (Bizkaia), Spain

43.29°N, -2.87°E

## General description



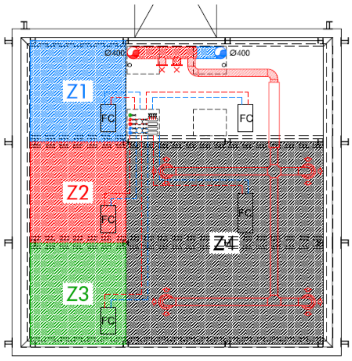

### Main objective of the test facility

KUBIK is aimed to the development of new concepts, products and services to improve the energy efficiency of buildings.

### Overall lay-out

The R&D infrastructure consists of a building able to provide up to 500 m2 distributed in an underground floor, a ground floor and up to two storeys;


Picture of the building with no elements in the façade (with no configuration)




Measurement areas in each one of the storeys for evaluation the energy performance of the elements under realistic conditions

Thermal generation for its distribution in the measurement areas

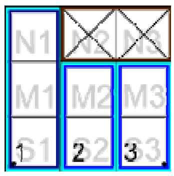
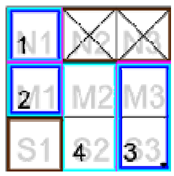
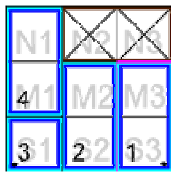
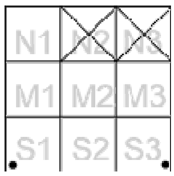
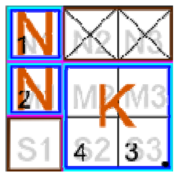
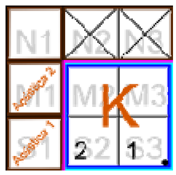
the main dimensions are 10,00 m. width x 10,00 m. length x 10,00 meter high (plus and underground floor 3,00 m. depth).

The supply of energy is based on the combination of conventional and renewable energy (geothermic, solar and wind). In addition, the building is equipped with a monitoring and control system which provides the necessary information for the R&D activities.

## Inside boundary conditions

KUBIK enables the evaluation of energy performance, acoustic performance and air tightness evaluation of the scenarios built, see Fig. 2, taking into account the holistic interaction of the constructive solution for the envelope, the intelligent management of the climatisation and lighting systems and the supply from non-renewable and renewable energy sources.

The main aim of KUBIK is to provide a better understanding of the performance at room or at building level, acknowledging the traditional laboratories as the better for the characterisation at component level according international agreed standards.

| Scenarios | Ground Floor | First Floor | Second Floor |
|---|---|---|---|
| Available simultaneously, independent climatisation zones |  |  |  |
| Current layout off scenarios |  |  |  |

Captions:
N1, 2, 3: Northern roms M1, 2, 3: Middle rooms S1, 2, 3: Souther rooms Acústica 1, 2: Rooms equipped for acoustic research.

R insulated
VIP insulated
Ventilated thermal zone
Unventilated Thermal zone

*Figure 1: Plan views showing the available layouts with independent HVAC systems*

KUBIK has an advanced monitoring system, equipped with over 800 sensors that records conditions inside and outside the experimental facility, climatic conditions. Researchers and customers have access via the Internet to measurements being taken in the scenarios where the performance of the products and systems under development are evaluated. In addition, the monitoring system is integrated into an Intelligent Energy Management System which optimises the energy consumption of the building. The experimentally-obtained results enable diagnoses and proposals for potential product improvements to be made.

## Outside boundary conditions

The surrounding area of the facility is fully open to all meteorological conditions, not being affected by any surrounding element. A detailed analysis of solar shadings produced by all surrounding elements like trees and streetlights was performed, and lead to the conclusion of some trees being transplanted to avoid any effects to the building.

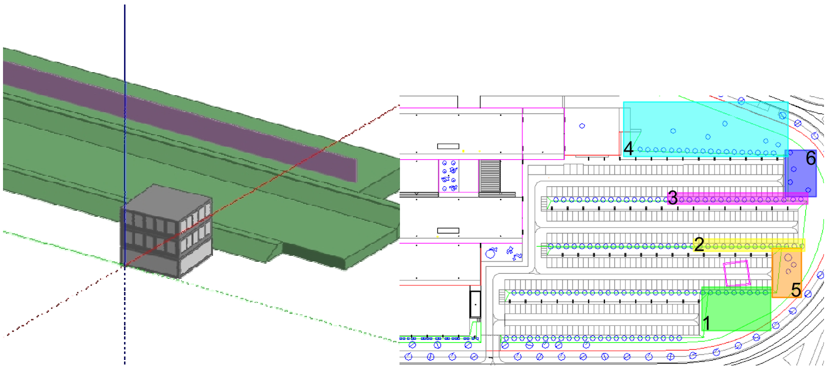



*Figure 2: Left, model of the building and surrounding elements. Right, identification of each element with potential shading effect on the building.*

## Special limitations / possibilities

Thanks to its flexibility, KUBIK can integrate all type of elements that are commonly used in construction. By elements are considered not only architectural solutions (curtain wall, prefabricated façade elements,…) but also thermal generation and storage equipments (thermal energy storage solutions, solar cooling equipment,…), electricity generation and storage solutions (BIPV elements,…) as well as any BIMS and/or building automation concept. All these solutions can be analyzed and improved under the realistic testing conditions of KUBIK, thanks to the monitoring and data system.

# DATA ANALYSIS

## Typical equipment within test wall

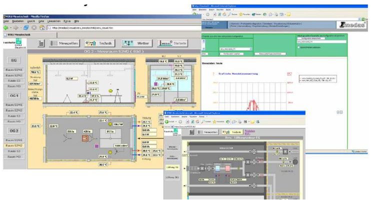
The infrastructure has up to seven individual measurement rooms; one control room and one service room per each of the three floors, see Fig. 9. It provides the possibility to combine some individual rooms into a unique measurement

Prefabricated concrete façade element, developed with Norten-pH

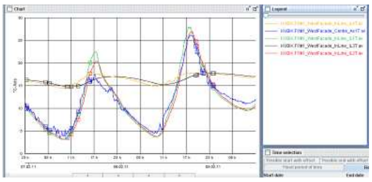
Green roof in Kubik, developed with Intemper, S.A.

Wooden façade element, developed together with Biohaus Goierri, S.L.

PV-Curtain wall developed by TECNALIA



Measurement software, developed with Fraunhofer-IBP

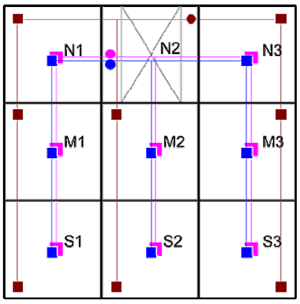


Data management system of KUBIK

Sensors in the roof of KUBIK

room if it is required by the experiment it and also allows to have all the three floors as a unique building, for example an specific office, school, etc….. This flexibility is possible thanks to the structural design and to the services design: each individual measurement room has the HVAC, power and data network that needs to build a scenario.

The Figure 9 shows the nine rooms of each floor with the electrical and data network: the individual measurement rooms are: N1, M1, M2, M3, S1, S2 and S3; the control room is N3 and the service room is N2. Figure 6 shows too an example of a possible layout of one floor: three individual measurement rooms (N1, M1 y S1) and one combined measurement room (a combination of M2, M3, S2, and S3) and their respective HVAC system.




Captions:
Blue boxes: sensor at floor level
Pink boxes: sensor at ceiling level
Brown boxes: power electricity

*Figure 3: Equipment by each individual measurement rooms.*

The monitoring system is in charge of data gathering and management tasks and to provide comprehensive information necessary for the analysis along. It collects data from the: measurement system; building automation system, HVAC control system and external meteorological conditions.

The monitoring system is equipped with over 800 sensors that records conditions inside and outside, weather conditions, the experimental facility. Researchers have access via the Internet to measurements being taken. The test measurement system includes the following sensors: indoor air temperature, surface temperature, radiant temperature, humidity, air velocity, heat flux, solar irradiance, luminance, CO2 concentration,…

## Accuracy and logging resolution

Some of the sensors installed in KUBIK are described:

| Sensors | | | | Measurement devices | | |
|---|---|---|---|---|---|---|
| Sensor | Manufacturer | Type | Accuracy | Manufacturer | Type | Accuracy |
| Surface Temperature | Thermo Sensor GmbH | PT100 2113-1-072 2113-1-073 2153-1-891 | ± 0,1 °C | Beckhoff | EL3202-0010 | ≤ ± 0.1 °C |
| Air Temperature | Thermo Sensor GmbH | PT100 2113-1-074 | ± 0,1 °C | Beckhoff | EL3202-0010 | ≤ ± 0.1 °C |
| Solar radiation | Kipp & Zonen | CMP-6 | ±5% | Beckhoff | EL3602-0010 | ≤ ± 0.1 of FSV |
| Heatflux sensor | Phymeas GbR | Type 7 | ±5% | Beckhoff | EL3602-0010 | ≤ ± 0.1 of FSV |
| Relative humidity sensor | Galltec Mess-und Regeltechnik GmbH | FPC 1/5 | ±2% rh (5…95 % rh at 10..40°C) | Beckhoff | EL3064 | ≤ ± 0.1 of FSV |
| Lux meter sensor | Czibula & Grundmann GmbH | 091206 | cosine error f2 < 1,5 % | Beckhoff | EL3064 | ≤ ± 0.1 of FSV |

## Analysis of the data

The chosen measuring and management system is based on a PLC platform with Windows Embedded technology allows simultaneous scenarios analysis as well as with different requirements, boundary conditions.... The PLC layer of the control system is in charge of gathering data from the sensors and writing commands into the remote actuators, not only this but the PLC layer processes update the central database with the sensor and actuator values.

Air tightness test being performed in a measurement room in KUBIK

# EXAMPLES OF PREVIOUS STUDIES

The facility was inaugurated in June 2010. Therefore still no publications on studies have been generated.

Radiation and temperature sensors on a measurement room in KUBIK

# MAINTENANCE / COLLABORATION

## Personnel involved

There are 4 persons dedicated to the facility, one mechanical engineer for the HVAC system, one telecommunication engineer for the monitoring, one physics as scientific coordinator and one professional for providing support.

## International collaboration

TECNALIA and IBP-Fraunhofer have collaborated in the development of Kubik, taking the VERU facility located in Holzkirchen (Bayern-Germany) as previous experience.

TECNALIA has initiated the European-funded project RIEEB (Research Infrastructure on Energy Efficiency in Buildings) to asses the impact of creating a European Network of Experimental Buildings / Research Infrastructures on Energy Efficiency.

Water tightness analysis of the prefabricated concrete façade element

## Link to other devices

KUBIK is connected to the MicroGrid facility located in the main building of the Sustainable Development Division. The Microgrid is connected to several sources of energy like a wind mile, solar PV panels, Hydrogen cell, electricity storage solutions, etc.

*Figure 4: Micro Grid (part of DerLab) installed in TECNALIA-Sustainable Division*

# Relevant literature

## General literature about the test facility:

**Kubik, una infraestructura singular para la eficiencia energética en edificación,** EnergíaBerria, energía del cluster de energía del País Vasco. Agosto 2009. Ed. Cluster de Energía. BI-2650-99

**KUBIK: Open Building approach for the construction of an unique experimental facility aimed to improve energy efficiency in buildings,** Proceedings of the O&SB2010 "Open and Sustainable Building", ISBN: 978-84-88734-06-8

**KUBIK by TECNALIA, I+D+I sobre eficiencia energética en edificación** Revista DYNA Ingeniería e Industria, 2011 ISSN: 0012-7361

## Literature on previous measuring campaigns:

The facility was inaugurated in June 2010. Therefore still no publications on studies have been generated.


Southern façade of KUBIK

Northern façade of KUBIK

Eastern façade of KUBIK

KUBIK

# SALFORD ENERGY HOUSE


## GENERAL DESCRIPTION

### Main objective of the test facility

The test facility (Energy House) has been designed and developed to allow leading academics and researchers to conduct test and experiments, to improve the energy efficiency of "hard to treat" properties. This includes the development and testing of new materials, systems and products as well as looking at behaviour change associated with the adoption of energy efficiency measures in the home.

**Institute/organisation:**

University of Salford
A Greater Manchester University

University of Salford

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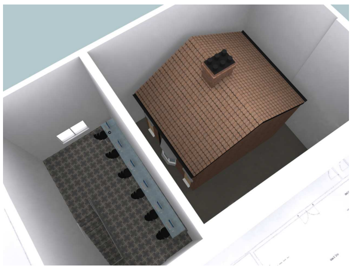
**Exact location:**

Salford
Greater Manchester
England



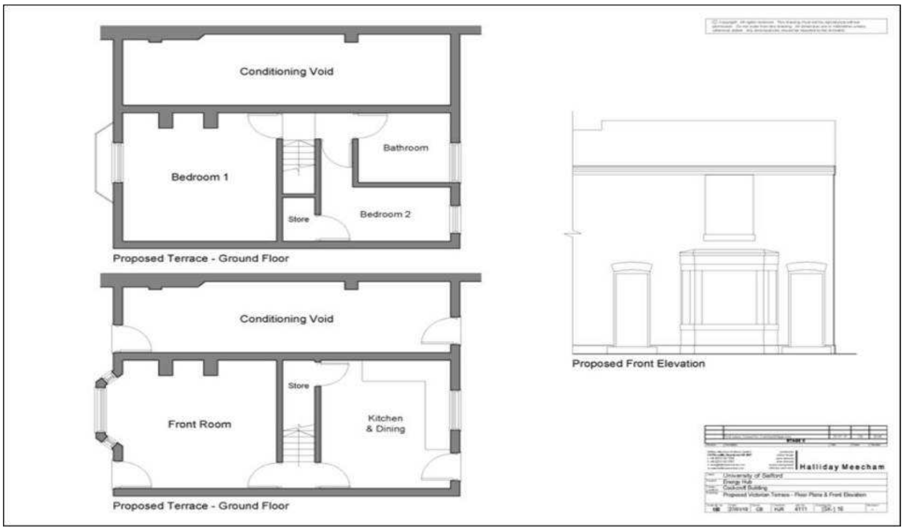
Salford Energy House in a fully environmentally controllable chamber.

The Energy House and its adjacent conditioning void, used to control and monitor energy loss and heat transfer through party walls.

## Overall lay-out

The unique, test facility, which is believed to be Europe's 1st fully sized, fully functional house with in a laboratory, where climatic conditions can be simulated and recreated.

The Energy House a traditional two up two down (two rooms down stairs and three rooms upstairs) represents approximately 22% ok the current housing stock of the UK.




*The Energy House, a traditional style terrace house, with two rooms on the ground floor (living room and kitchen diner), the upstairs consist of two bedrooms and a bathroom.*

## Inside boundary conditions

The house, is a fully functional / liveable house, and includes fully fitted kitchen (with all appliances) fully fitted and functional bathroom. To start with the Energy House has been fitted with a condensing boiler for heating and hot water, which can and will be changed to allow different heating systems etc to be developed and tested. The Energy House can accommodate voltage optimisation systems as well as a variable voltage main that allows for the development and testing of a low energy house.

An adjacent property (1/3rd) of a house has also bee created to allow test to be conducted on the party / adjoining wall between the two properties.

## Outside boundary conditions

The Energy House has been constructed in a climatic chamber in which the following elements / whether conditions can be recreated: -

The fully functioning kitchen.

- *Temperature (-6$^0$C - +30$^0$C) with an accuracy of 0.25$^0$C*
- *Humidity (10% - 80%) with an accuracy of 1%*
- *Rain equivalent to 200mm per hour*
- *Snow*
- *Light Wind*

Fully functioning living room.

## Special limitations / possibilities

The Energy House will allow for collaborative research and testing of varying products and systems, including: -

- Insulation and cladding both internal (walls, floor and roof) and external g systems.
- Appliances from heating and water systems through to white and consumer goods

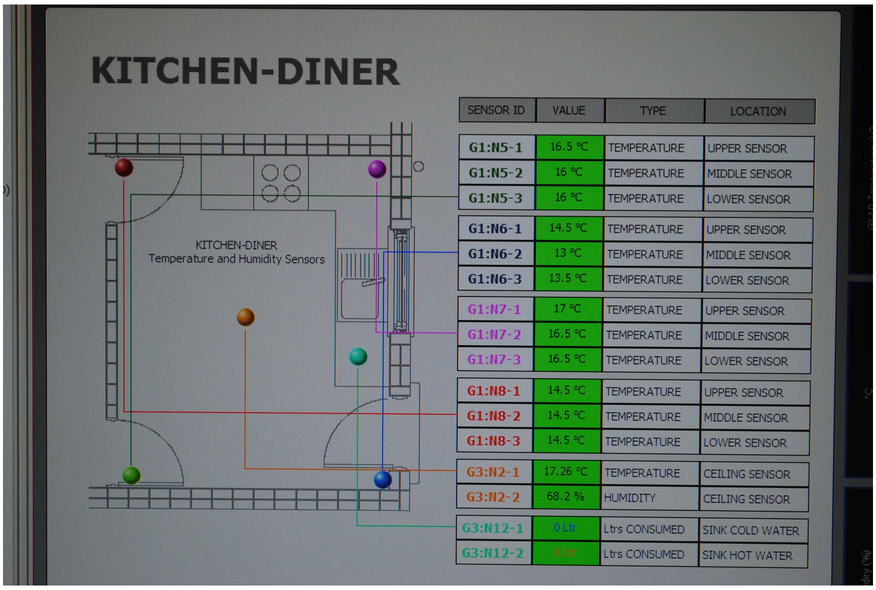
One of the fully functioning bedrooms.

# DATA ANALYSIS

## Typical equipment within test wall

Monitoring of the Energy House is facilitated through the use of wireless mesh networks of sensor nodes with protocols and signalling based on the internationally ratified IEEE 802.15.4 standard which operates on the 2.4GHz band. The sensors system comprises three SenzaGate wireless gateways and an array of Senzablock wireless nodes. Wireless nodes are distributed around the Energy House for measuring and continually monitoring the different parameters.

Each of the rooms within the Energy House comprise of 4 temperature sensors each with three probes, to measure temperature at three heights within the room, and are located in each corner of the room. A humidity sensor is also located in the centre of each of the rooms.




*Screen shot showing sensor locations and readings for the Kitchen-Diner within the Energy House.*

Consumption of electricity gas and water is also monitored throughout the Energy House. Appliance monitoring is undertaken using industry standard ZigbeePro wireless smart meter plug devices, which have continually measure  of kWh, kVARh, Watts, Amps and Volts to three decimal places with an accuracy better than +/- 0.5%

Inside the Energy House, industry standard water flow meters have been fitted to the toilet feed, shower and bath feed, washing machine and kitchen sink. Separate flow metering can be applied at any stage to measure waster water flow.

The chamber itself has thermal and CCTV cameras which are continually monitoring the building. The thermal image cameras are on pan and tilt mountings and are programmed to continually monitor heat loss from the Energy House.

## Accuracy and logging resolution

**Temperature Sensors**

| | |
|---|---|
| Sample rate (max) | 1 kHz |
| Scan cycle (typical) | 10 s – 1 day |
| Scan cycle (min) | 100 ms |
| Range | -40 to +125 °C |

| | |
|---|---|
| Resolution | 0.01 °C |
| Accuracy | +/- 0.5 °C @ 25 °C |

**Humidity Sensors**

| | |
|---|---|
| Sample rate (max) | 1 kHz |
| Scan cycle (typical) | 10 s – 1 day |
| Scan cycle (min) | 100 ms |
| Range | 10% - 90% rH |
| Resolution | 0.05 %rH |
| Accuracy | 3% @ rH < 20% and > 80% |

**Differential Pressure Sensors**

| | |
|---|---|
| Sample rate (max) | 1 kHz |
| Scan cycle (typical) | 10 s - 1 day |
| Scan cycle (min) | 100 ms |
| Range | ± 500 Pa (±5 mbar) |
| Resolution | 0.5 Pa |
| Accuracy | 0.2 Pa ± 3% of measured value |

## Analysis of the data

Currently priority software is used from ANEC to record data and monitor the Energy House; ONCALL which uses its polling mechanism to extract data from the E-Senza nodes and sensors. ONCALL can poll Modbus and TCP devices at frequencies of up to every 5 seconds which is adequate for most environmental monitoring requirements such as this one.

The ONCALL system has been built around the industry standard MS SQL client/server model. The ONCALL server is located in a server farm at Salford and is available via the campus network. ONCALL Viewer client software provides the GUI and operator interface to the Energy Hub ONCALL system. It uses SQL Connect enabling distributed and multiple users to concurrently access and view predefined topology views, collected data in graphical, tabulated and report form via a local GUI on XP Pro or Windows Vista workstations.

Unlike many other vendor specific BMS (Building Management System) applications, the specified here's independence from proprietary solutions and protocols makes it an ideal solution for the consolidation and production of visualised data often delivering previously "invisible" correlations between data sets and events.

# EXAMPLES OF PREVIOUS STUDIES

The Energy House is the centre piece to the University's cross discipline energy theme. In order to address the energy crisis, and building on the University's internationally recognised strengths in Teaching and Learning, Research and Innovation and Engagement the University has developed an interdisciplinary Energy Theme, consisting of four sub themes

- Energy Generation
- Energy Conversion and Demand Reduction
- Socio-economic Issues and Aspects of a Low-Carbon Lifestyle
- Resources

# MAINTENANCE / COLLABORATION

## Personnel involved

As with all the testing and development facilities at the University, the Energy House is manned by fully trained and experience technicians, who conduct the tests. This is supported by leading academic and researchers, from the But Environment, Physics, Materials Science, Mechanical and Electrical Engineering

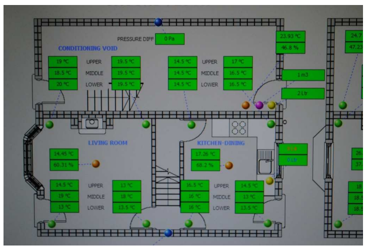
## International collaboration

The University is internationally recognised for its industrial collaborations, through a range of projects and programmes, including Knowledge Transfer Partnerships (KTPs), European Funded initiatives (for example Framework programmes), Traditional Consultancy and Collaborative Research and Development projects.

Sample sensor used for measuring temperature and humidity levels throughout the house.

Sample temperature probe used within the Energy House.

All there utilities (gas, electricity and water) are monitored throughout the Energy House to individual appliance level.



Sample screen showing temperatures and humidity levels throughout the Energy House.

## Link to other devices

The house will be complemented by the University's existing state-of-the-art world leading facilities, including: -

- UKAS Accredited Thermal Test laboratory which will allows leading researchers and academics to work with organisations to develop and test new thermal and insulation products for the building / housing market, incusing solid wall insulation products

- UKAS Acoustics Laboratories that provide a unique facility that enables our researchers and academics to develop and test new should insulation products for the building sector.

- Full analytical and material testing facilities, with core techniques that include Microscopy, NMR and X-Ray Diffraction.

- External Properties, which are used to monitor consumer behaviour within properties that have undergone retrofit schemes and those that haven't this date is used to simulate everyday activity within the Energy House.

# ENERGYFLEXHOUSE®

## GENERAL DESCRIPTION

### Main objective of the test facility

EnergyFlexHouse® consists of two, two-storied, single-family houses with a total heated gross area of 216 m² each. The two buildings are in principle identical, but while the one building acts as a technical laboratory (EnergyFlexLab), the other is occupied by typical families who test the energy services (EnergyFlexFamily). Each family lives in EnergyFlexFamily for 3-5 months at a time. In principle, everything can be changed in the two buildings: the thermal envelope, heating system, ventilation system, renewable energy, etc. The buildings were put into operation during the autumn of 2009.

In EnergyFlexLab focus is on short-term tests where the interaction between installations, buildings and real weather conditions gives a unique possibility of testing components and systems under realistic conditions. In addition EnergyFlexFamily makes it possible to test user behaviour, influence and acceptance of and interaction with the components and systems – i.e. EnergyFlexFamily is a living lab.

**Institute/organisation:**

DANISH TECHNOLOGICAL INSTITUTE

Energy and Climate
Danish Technological Institute
Taastrup, Denmark

**Contact person:**

Mikael Grimmig
Gregersensvej
DK-2730 Taastrup
DENMARK
tel: +45 72 20 24 15
mg@teknologisk.dk

**Exact location:**

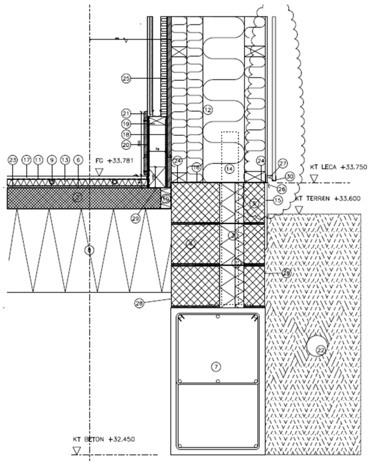
Taastrup, Denmark
55°39'N, 12°16'E

## Overall lay-out

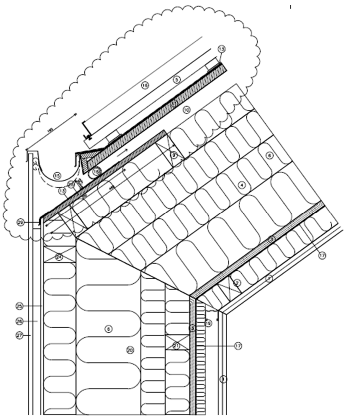
EnergyFlexHouse was built to resemble an attractive, Danish, detached, single-family house, designed so most people would get the feeling: “I could live in this building”.

The houses are built so they are better than the Low E class 1 defined in the former Danish Building Code from 2008, which is more or less identical to Low E class 2015 in the new Danish Building Code from 2010. The annual energy demand for space heating, ventilation, DHW and building-related electricity (not including energy for the household) amounts to less than 30 kWh/m². With the pv production, EnergyFlexFamily is energy neutral over the year including the demand for electricity of the household and an electric vehicle. The EnergyFlexFamily is a prosumer: a traditional consumer, an energy producer and energy storage when it is needed from the grid.

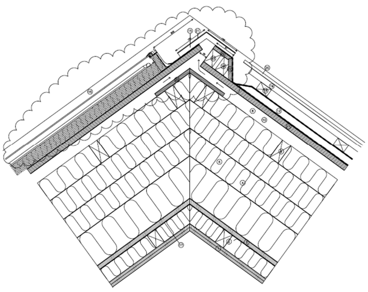
The houses are constructed with a core insulated wooden frame structure as shown in figure 1 and 2.



The foundation of EnergyFlexHouse.



The eaves of EnergyFlexHouse.



The ridge of EnergFlexHouse.

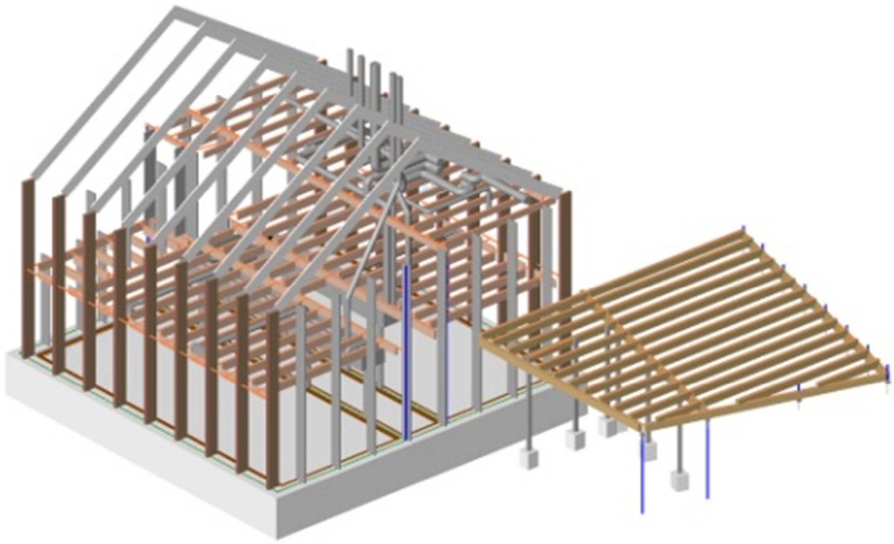


*Figure1. The load-bearing wooden skeleton of EnergyFlexHouse.*

The insulation of the walls and roof is divided into several layers which can be stripped off to resemble the insulation level at different periods. The labels in figure 2 are:

- red arrow: the demand of the Danish Building code from 1977
- green arrow: the demand of the Danish Building code from 1995
- blue arrow: thickness in order to reach the Low E class 1 in the Danish Building code from 2008

By adjusting the thickness of the insulation and replacing the Low E windows, it is also possible to test energy saving solutions for renovation purposes.

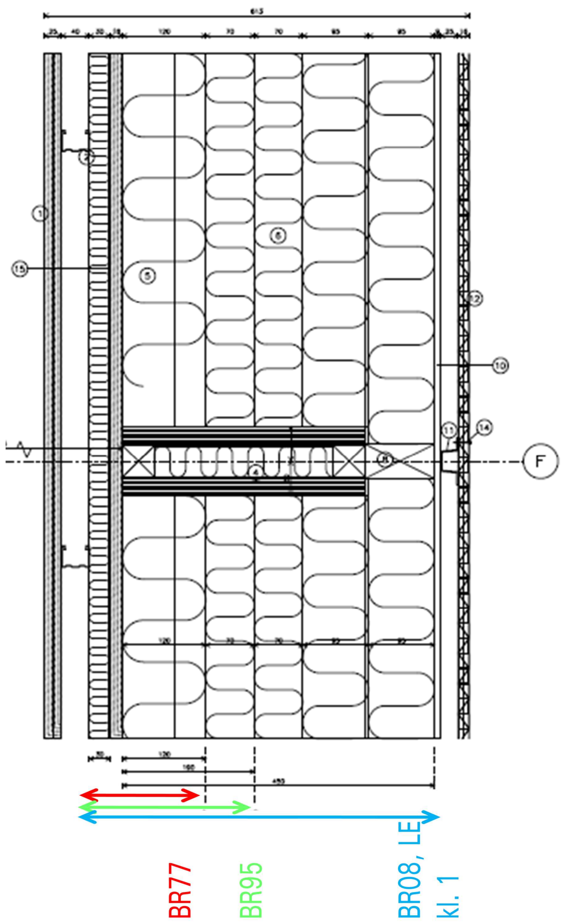



*Figure 2. Horizontal cross section of an EnergyFlexHouse wall.*

The U-values of the original design of EnergyFlexHouse are:

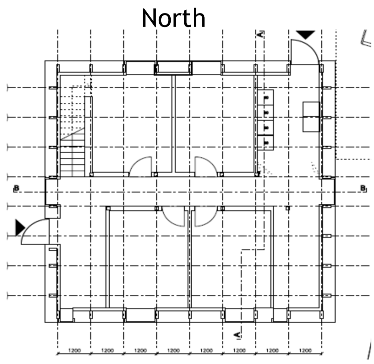
| | |
|---|---|
| External walls: | 0.08 W/m²K |
| Roof: | 0.09 W/m²K |
| Ground floor slap: | 0.105 W/m²K |
| Windows in external walls: | 0.73-0.9 W/m²K |
| Skylights: | 1.4 W/m²K |

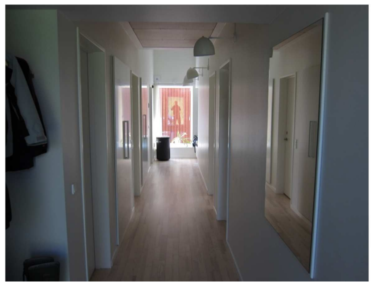
The layout of the two houses is similar to the layout of many Danish single-family houses (although reversed concerning the use of the two floors):

- Ground floor: 4 rooms and 2 bathrooms
- 1st floor: combined kitchen and living room

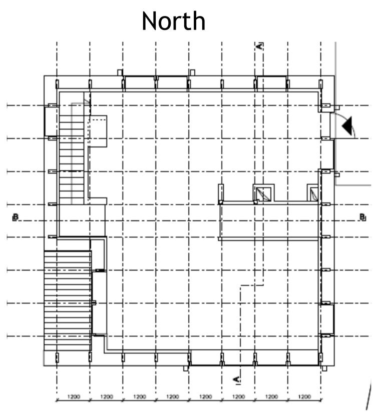
At the ground floor of EnergyFlexLab the floor plan allows for side-by-side testing: two rooms facing south are identical and two rooms facing north are identical.

Both buildings are equipped with pv and solar collectors as seen in figure 3.

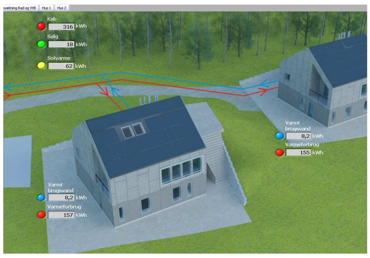


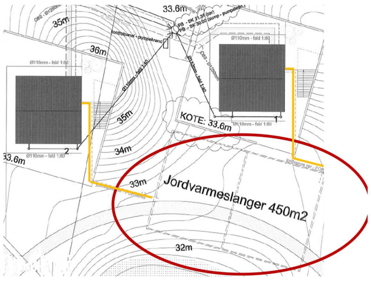
The floor plan and picture of the ground floor of EnergyFlexHouse.




The floor plan and picture of the 1st floor of EnergyFlexHouse.



District heating for EnergyFlexHouse.




Area with ground source heat exchangers for the ground coupled heat pumps in EnergyFlexHouse.

Sun screening of the windows facing south on EnergyFlexHouse.

Floor heating in the ground floor during construction of EnergyFlexHouse.

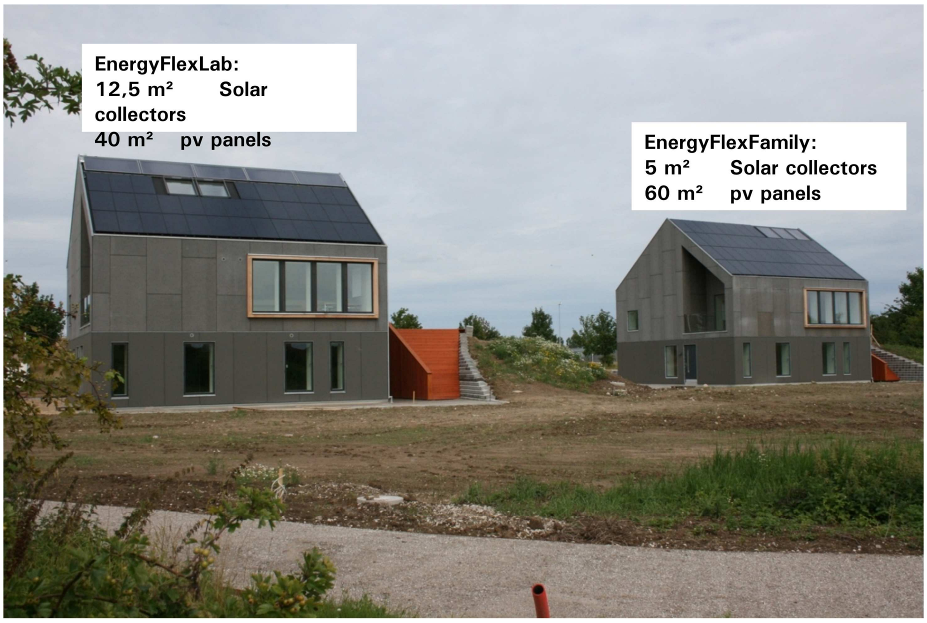



*Figure 3: The solar collectors and pv panels of the two EnergyFlexHouses. Approximately 20 $m^2$pv is needed for the electric vehicle.*

## Inside boundary conditions

Different possibilities are available for creating the desired indoor climate in EnergyFlexHouse:

- Heating: boilers – gas, oil, pellets, ..
  heat pumps: ground couples, air to water, air to air
  district heating
  solar heating
- Ventilation: mechanical: with passive heat exchanger and/or air to air heat recovery heat pump
  natural ventilation
  hybrid ventilation
- Solar radiation: sun screening
- Cooling: so far no cooling system has been installed but it may be later if required by tests
- Heat distribution system: floor heating, radiators (either by the window or at the back wall) or via the ventilation systems

The internal conditions in EnergyFlexLab may be adjusted in order to reach the conditions required by a test. In EnergyFlexHouse the conditions are the normal comfort conditions in a house, expected by the families who live there.

*Figure 4. The first family in EnergyFlexFamily.*

## Outside boundary conditions

The outside conditions are the actual weather conditions on Zealand, Denmark where EnergyFlexHouse is situated.

In order to monitor the microclimate around the two houses, several sensors are applied:

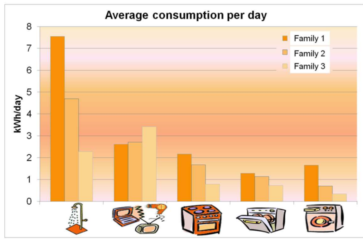
- Weather station at 10 m: ambient temperature, wind speed, wind direction, rain, humidity, barometric pressure
- Solar radiation: global and diffuse horizontal
  total on south, west and east of the houses
  on the south facing roof of the houses
- Ambient temperature: at the south, west, east and north of the houses
- Long wave radiation: horizontal

## Special limitations / possibilities

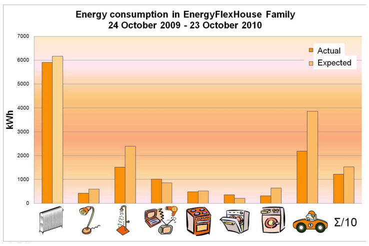
The houses are designed to limit constraints as much as possible: meaning that everything in principle can be changed.

The limitations are the size and orientation of the houses and the specific conditions created by the Danish weather.

For envelope components, the size limit is determined by the distance between the wooden, load-bearing skeleton. That distance is 1.2 m.




Mean daily energy demand of three different families distributed on different services.




Energy demand disributed on services during the first year with three families in EnergyFlexFamily.

Combined global and diffuse radiation pyrgeometer

Pyranometers and pyrgeometer at the roof of EnergyFlexLab.

Pyranometer and temperature sensor at the south wall of EnergyFlexLab.

# Data analysis

## Data acquisition system

The basic layout of the data acquisition system is shown in figure 5 and 6. Figure 5 shows the data acquisition system in EnergyFlexLab, while figure 6 shows the data administration. The data acquisition system in EnergyFlexFamily is similar to figure 5, but in order not to disturb the families the room sensors are wireless. In addition the electricity demand on all plugs, ceiling points and of the white goods in EnergyFlexHouse is measured individually and the opening of doors and windows is logged.

Heat meters at EnergyFlexLab.

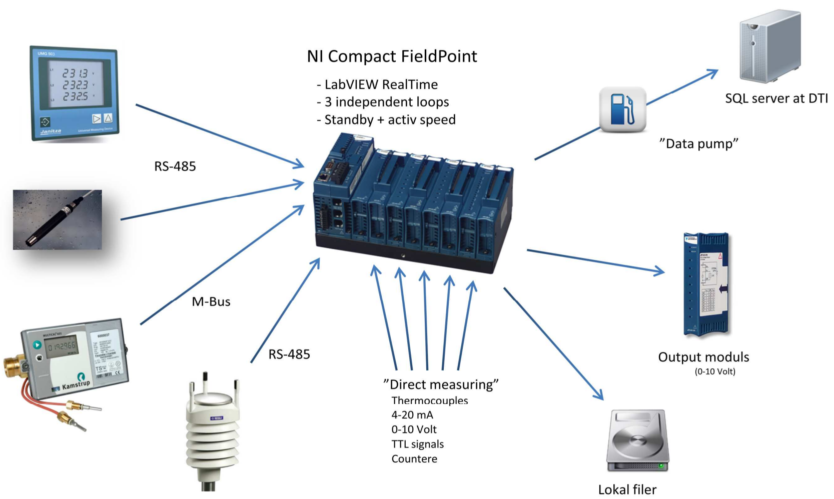
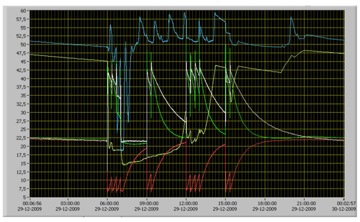



*Figure 5. The data acquisition system in EnergyFlexLab.*



Cold and hot water temperature and temperatures in the DHW tank.

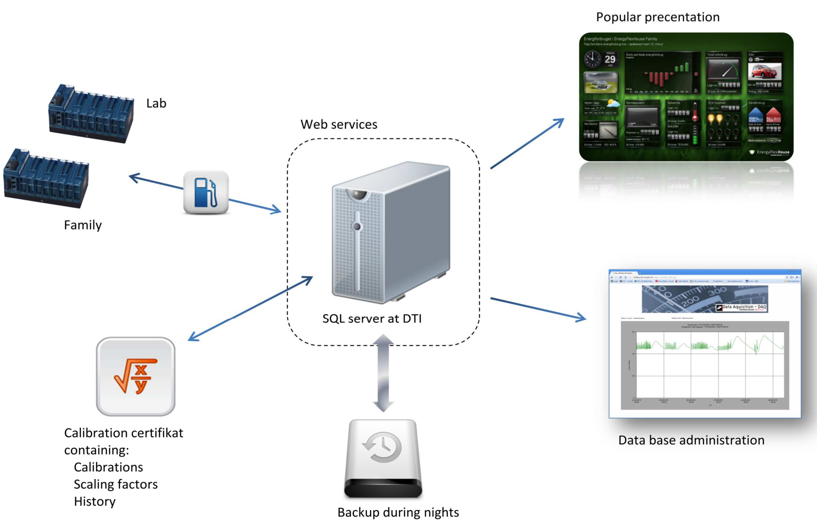



*Figure 6. Data administration.*

At the beginning of 2011, up to 700 measuring points were included in the EnergyFlexHouse data acquisition system. The data acquisition system is scalable so new sensors may be added.

In addition to the the weather sensors, the basic sensor set consists of:

- air temperature sensors
- surface temperature sensors
- temperature sensors embedded in the constructions
- temperature sensors in the installations
- air humidity sensors – both in rooms and ventilation systems
- $CO_2$ sensors - both in rooms and ventilation systems
- heat flux sensors
- air speed sensors - both in rooms and in ventilations systems
- lux sensors
- contacts on windows and doors
- heat flow meters
- electricity meters
- multi amperimeters

Air, globe and surface temperature sensors, humidity sensors, lux sensor and heat flux sensor in one side-by-side room in EnergyFlexLab.

## Accuracy and logging resolution

All sensors and meters have been calibrated and the documentation is available on file - as shown in the left bottom corner of figure 6.

Embedded temperature sensors in the floor of one of the side-by-side test rooms in EnergyFlexLab before concrete was poured in.

## Analysis of the data

There is no standard procedure for analysis of the measured data from EnergyFlexHouse as many very different tests and experiments may be carried out. However, one standard analysis is carried out on data from EnergyFlexFamily: a rolling annual energy balance including a popular presentation as seen in figure 6 and 7.


*Figure 8. Popular presentation of the energy balance in EnergyFlexFamily.*

Link to the popular presentation: http://datalog.energyflexhouse.dk/pview/index_en.html

# Examples of previous studies

Several studies have been, are being conducted or are scheduled to be carried out in EnergyFlexHouse – e.g.:

Optimized control of e.g. solar screening in order to decrease overheating.


Electric vehicle used by the families in EnergyFlexFamily.

**EnergyFlexFamily:**

- The possibility of obtaining energy neutrality on an annual basis is being investigated with real families living in the building
- The user acceptance of different energy efficient lighting systems
- Optimized control of the installations (heating, ventilation and solar screening) in order to optimize the indoor climate while minimizing the energy demand
- Utilization of the electricity demand of households as regulation power for the grid
- Development of a micro ground coupled heat pump for single family low energy houses
- Electric vehicles in combination with energy neutral homes

**EnergyFlexLab:**

- Heating (both space heating and DHW) via low temperature district heating
- PCM (phase change materials) in the floor slap for increasing the thermal storage capacity of the constructions
- Low energy windows with less dew on the outside
- Energy efficient DHW installations
- Demand controlled ventilation. Natural ventilation during the summer
- Optimization of the forward temperature to floor heating in order to increase the COP of a heat pump
- Optimization of the combination of savings and renewable energy sources on site in order to reach energy neutrality

# Maintenance / collaboration

## Personnel involved

The buildings are operated and maintained by the employees of the Energy and Climate Division at Danish Technological Institute.

## International collaboration

No formal international collabortion has yet been established, but promising contact with e.g. UC Berkeley, Lawrence Berkeley National Lab, Standford, ITRI (Taiwan) and Research Centre for Zero Emmission Buildings, Norway, is ongoing.

Danish Tecnological Institute is looking for international collaboration and project opportunities utilizing EnergyFlexHouse as part of the Danish contribution.

## Link to other devices

The two EnergyFlexHouses are part of the overall test possibilities at Danish Technological Institute as illustrated in figure 8.

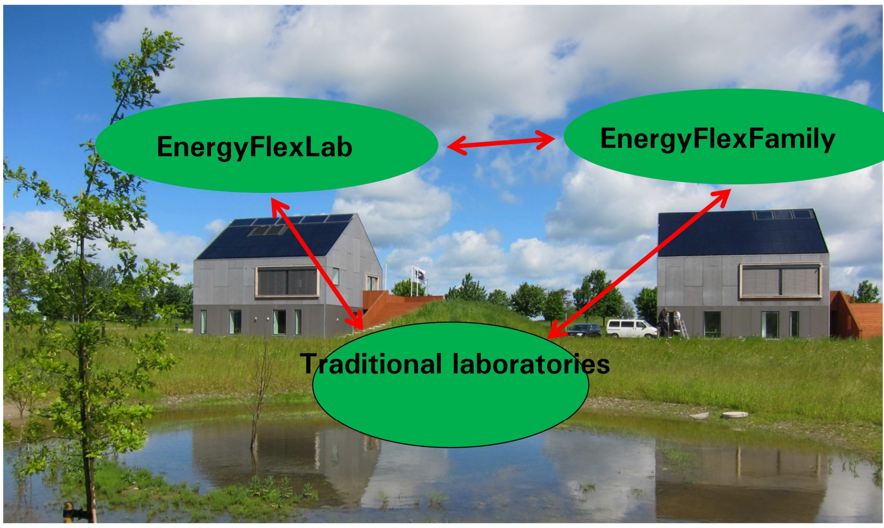


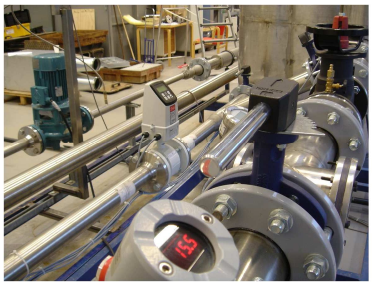

*Figure 8. The interaction between the two EnergyFlexHouses and the traditional laboratories at Danish Technological Institute.*

The traditional laboratories at Danish Technological Institute offer detailed component tests of: insulation materials, windows, ventilation systems, heat pumps, district heating units, circulation pumps, radiators, cooling systems, white goods, pv systems, consumer electronics, etc.

A logical test setup is:

- test and optimization of individual components in laboratory
- test of the interaction between components and building under real weather conditions: EnergyFlexLab
- test of the interaction between components, building and users under every-day conditions including user acceptance: EnergyFlexFamily (living lab)

Test of building components in hot box.

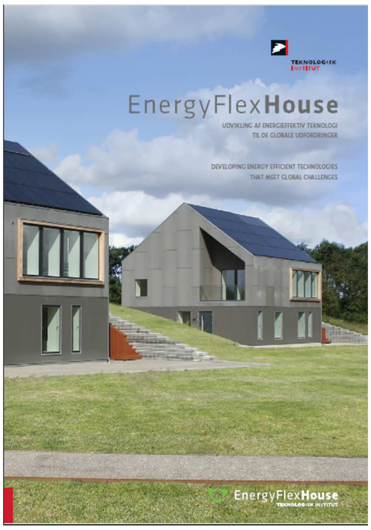


Test of circulation pumps.

Test of heat pumps.

Test of pv systems.

# Relevant literature




http://www.dti.dk/inspiration/25348

## General literature about the test facility:

EnergyFlexHouse – Developing energy efficient technologies that meet global challenges. http://www.dti.dk/inspiration/25348

Homepage of EnergyFlexHouse: http://www.dti.dk/inspiration/25348

## Literature on previous measuring campaigns:

Not yet published