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Rehafutur – Insitu instrumentation for a comprehensive building analysis

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Abstract

The building industry is called to a generalized use of eco friendly materials for a climate change limitation. In this context, the EU project 'Rehafutur' aims to promote the use of bio-based materials in building. Thus, a traditional north France house was renovated using 8 bio-based materials and was instrumented. The instrumentation allows different parameters monitoring during several months and seasons. In this article, we present an over view of the project and the first recorded data. Then, we focus on the south-east wall data to apply an inverse heat transfer method. The method was developed and applied in our laboratory, it allows thermophysical properties estimation.

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Keywords: Materials characterisation, in situ measurement, physical properties, Rehafutur

1. Introduction

Recently COP21 and Paris agreement were achieved. Building is one of the major axes of reduction in energy consumption and greenhouse gas emissions. In this context, Rehafutur 1 is one of the multiple demonstration sites of the EU project called Cap'Em. The project was achieved thanks to partners (Cd2e -sustainable activities

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organisation- , Maisons et Cités -social housing landlord-, Ekvation -Cluster- and others). All participants aim to promote the use of bio-based materials in building through this project.

Nomenclature

C	Volumetric heat capacity	$\text{J K}^{-1} \text{m}^{-3}$
T	Temperature	$^{\circ}\text{C}$
t	Time	s
x	Space (Thickness)	m
λ	Thermal Conductivity	$\text{W K}^{-1} \text{m}^{-1}$
α	Thermal Diffusivity	$\text{m}^2 \text{s}^{-1}$
p	Parameters array	
F	Objective function	

It is also considered as a reference in hygrothermal buildings' studies in the actual conditions of renovation: north France old mining houses, more than 100 000 units. Rehafutur 1 concerns the rehabilitation of a 20's built mining engineer house using at least 8 bio-based materials. It is now considered as a close to passive establishment open to public [1] (Figure 1).

The original constructions' walls were non-insulated traditional north France bricks based. Now, roof and walls thermal performances are enhanced thanks to an interior insulation by using: hemp concrete bloc (HCB), cellulose wadding, and sheep, linen and wood wools. The actual work aims to share an in situ experience. The first months' data and the first conclusions made on its light are exposed.



Fig. 1. Rehafutur: before and after renovation

2. Instrumentation

To analyse the building behaviour a complete instrumentation was performed. The building was instrumented during renovation using more than 50 sensors. Thus, 70 parameters are monitored to study the building behaviour for a middle term: 2 years.

The building is equipped with an Air Handling Unit (AHU) for an optimum inside air quality and energy exchange between the in and out air. 6 sensors were placed in the basement nearby the AHU for temperatures, relative humidity (RH%) and air velocity monitoring at different locations of the unit. A compact Local Telemetry Unit is used to record the building consumptions. Thus, power consumption at different locations is monitored. In the same time, the four buildings' facades were similarly instrumented. Each wall was equipped with heat flux meters and thermocouples placed at the inside, outside and at the insulation/brick interface. Hygrothermal sensors were also placed at the interfaces (Figure 2). The inside building temperatures and RH% in addition to CO₂ amounts are all monitored at different locations. The outside temperatures and RH% are also recorded.

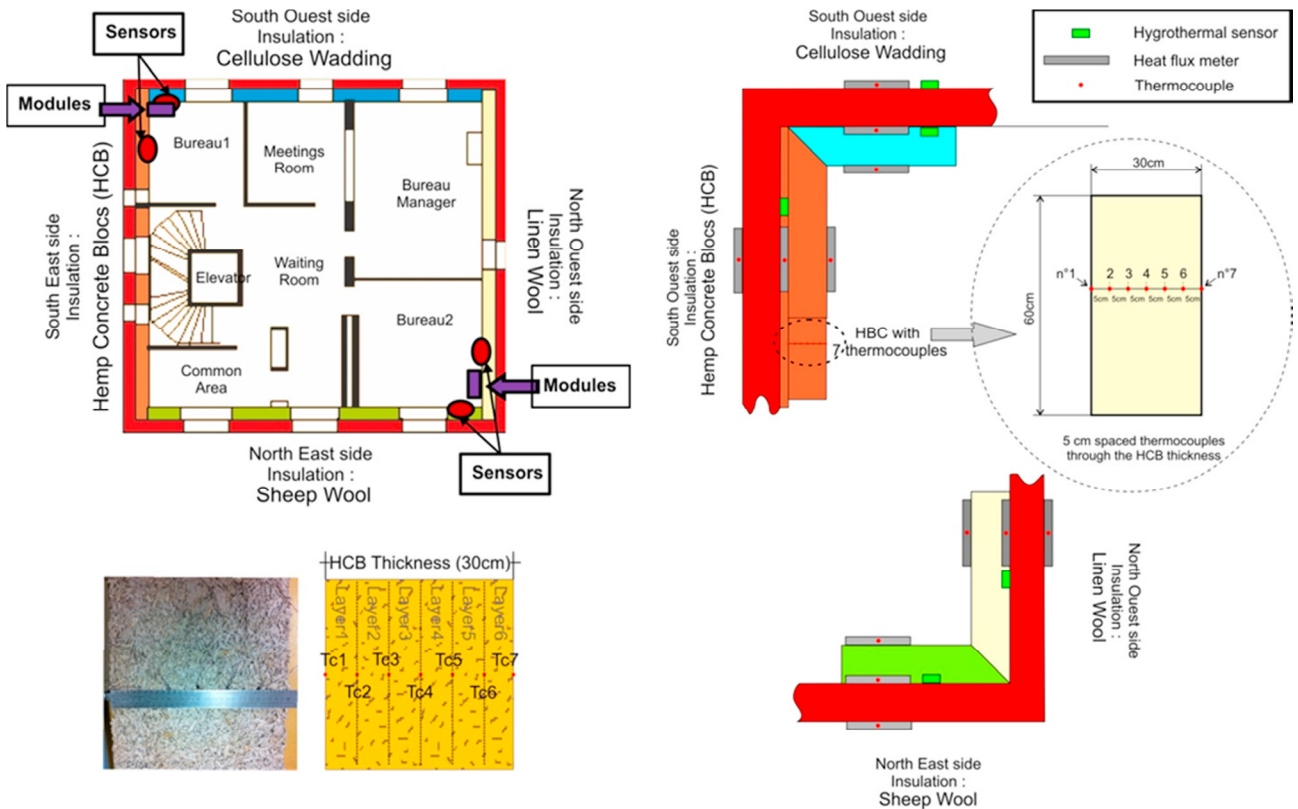


Fig. 2. Instrumentation details

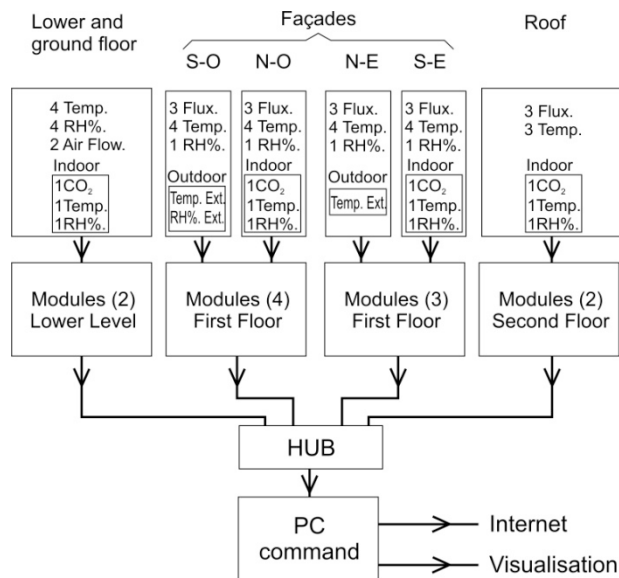


Fig. 3. Instrumentation network

An instrumentation network was imagined to gather the whole data in one accessible monitor. Thus, a programmable display monitor is used to communicate with the measurement network, record different physical variables and display live results (Figure 3).

In addition, 7 thermocouples were placed at different locations through HCB thickness (Figure 2). Thus, an In situ LGCgE developed method application is being possible.

3. Analysis and modelling

The developed method is based on an inverse heat transfer analysis using experimental tests and a numerical model [2]. In fact, the recorded in situ temperatures thanks to the 7 thermocouples ($T_{meas\ i}$, $i=1,\dots,7$) are compared in an optimization algorithm with the model simulated temperatures to predict the HCB behavior. At this stage, the method is applied to estimate the thermophysical properties (ThPs) of the hemp concrete. Next, prior laboratory tests will allow defining the correlation between materials' ThPs and their moisture content. Using future several months' available data will allow us estimating the HCB hydric state. Thus, its hydric and thermal properties will be estimated during the 2 years data exploitation.

Numerical basis of the inverse heat transfer developed method is exposed hereafter.

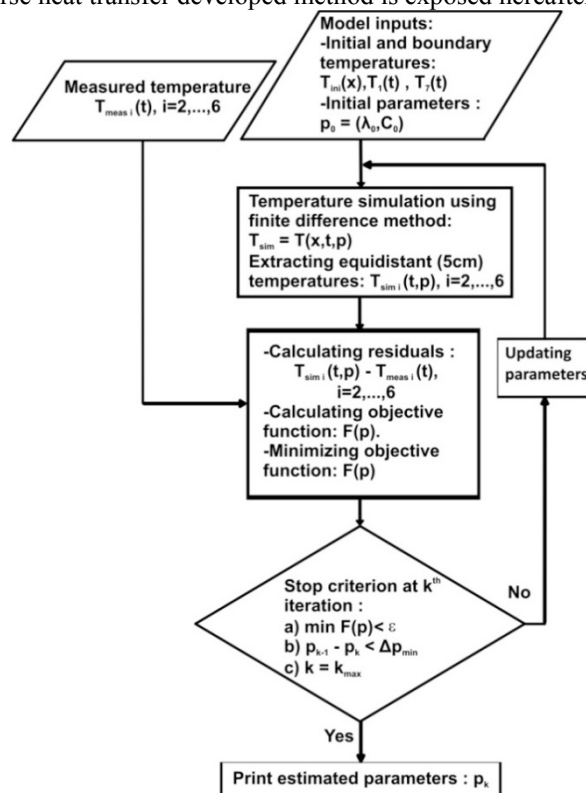


Fig. 4. Inverse analysis diagram: ThPs estimation

First, a direct heat transfer model is implemented on Matlab[®] to solve the heat equation (equation 1). The direct model inputs are: initial ($T_{ini}(x)$) and boundary conditions ($T_1(t)$ and $T_7(t)$) and the user initial ThPs (λ_0 : thermal conductivity and C_0 : volumetric heat capacity). The initial HCB temperature is determined thanks to the first recorded temperatures through the material's thickness (Figure 2). Boundary conditions are determined thanks to the HCB boundary recorded temperatures. The materials' ThPs are determined in laboratory thanks to a Guarded Hot Plate setup (please refer to EN 12667, EN 13939 and previous work [3]). The model outputs are: simulated temperatures (T_{sim}) through the HCB thickness (1D). For more information about the experimental setup or the model validation and sensitivity study, please refer to our previous work [4].

$$C \frac{\partial T}{\partial t} = \lambda \frac{\partial^2 T}{\partial x^2} \text{ or } : \frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2} \quad (1)$$

The simulated temperatures are compared to recorded temperatures in an iterative optimisation algorithm implemented on Matlab[®]. Thus, an objective function (equations 2 and 3) is minimised and new thermal properties are estimated over the 6 supposed layers (Figure 2). When at least one stop criterion is satisfied, the iterations stop and the optimum ThPs are reached (Figure 4). Next, the inverse heat analysis results and first recorded data are exposed.

$$f_j(p) = \frac{T_{meas j} - T_{sim j}(p)}{\max(T_{meas j}) - \min(T_{meas j})} \quad (2)$$

$$F(p) = \sum_j f_j(p)^2 \quad (3)$$

4. Results and discussion

In this section, the building envelope recorded parameters are exposed. Then, the inverse developed method results are exposed and discussed. The rest of recorded parameters are still being analysed. The results of the most instrumented side (S-E wall) are presented.

During the summer afternoons the S-E wall is exposed to radiation and heat flux reach high values up to 566W/m². High temperatures up to 43°C are recorded. The attenuation of the most part of incident radiation takes place through the 34cm bricks thickness where the estimated thermal lag reach values up to 12 hours. Thus, bricks large thickness plays an important role in building indoor comfort during hot periods. This comfort is being analysed thanks to the hygrothermal sensors and recorded ambient temperature and RH%. The recorded data will allow in a future analysis to estimate the S-E wall heat loss per year.

Hygrothermal probe placed at the interface (Figure 2) provides important information about the condensation risk at this location. Thanks to the recorded temperature and RH% the dew point evolution is estimated and also the condensation's risk. The chosen period present a supposed high risk, when passing from hot to cold periods. During recording data, no real condensation risk has been observed. The future analysis of cold period data will allow us to define if the condensation occurs at the interface and also to fine the most risky points. The recorded data through the HCB thickness thanks to the 7 thermocouples corresponds to the measured temperatures “ T_{meas} ” on the diagram (Figure 4)

The results of the inverse method are shown on Figure 5. One can see the curve fitting between simulated and measured temperatures at the Tc6 position (Figure 2) during the first week recorded data (Sep 15th to Sep 22nd). The first week recorded data is used to estimate the ThPs of the instrumented HBC. The estimation is repeated for all the analyzed data: from Sep 15th to Nov 4th. The rest of data is being analyzed. The estimated ThPs evolution is presented on the same Figures 5. One can see the variation of the thermal conductivity, the volumetric heat capacity and the deduced thermal diffusivity. The thermal diffusivity through the HCB is not constant; it is time and space dependent. Its minimum values are estimated for the layer 6: location of the highest temperatures. The maximum thermal diffusivity values are estimated for the layer 1 location of low temperatures and thus high relative humidity. 20.41% is the mean relative deviation between the minimum and the maximum thermal diffusivity values. This is due to the high water and water vapor diffusivities compared to the HCB dry bulk.

In a future analysis, the hydric material state will be estimated, and thus, its moisture content evolution.

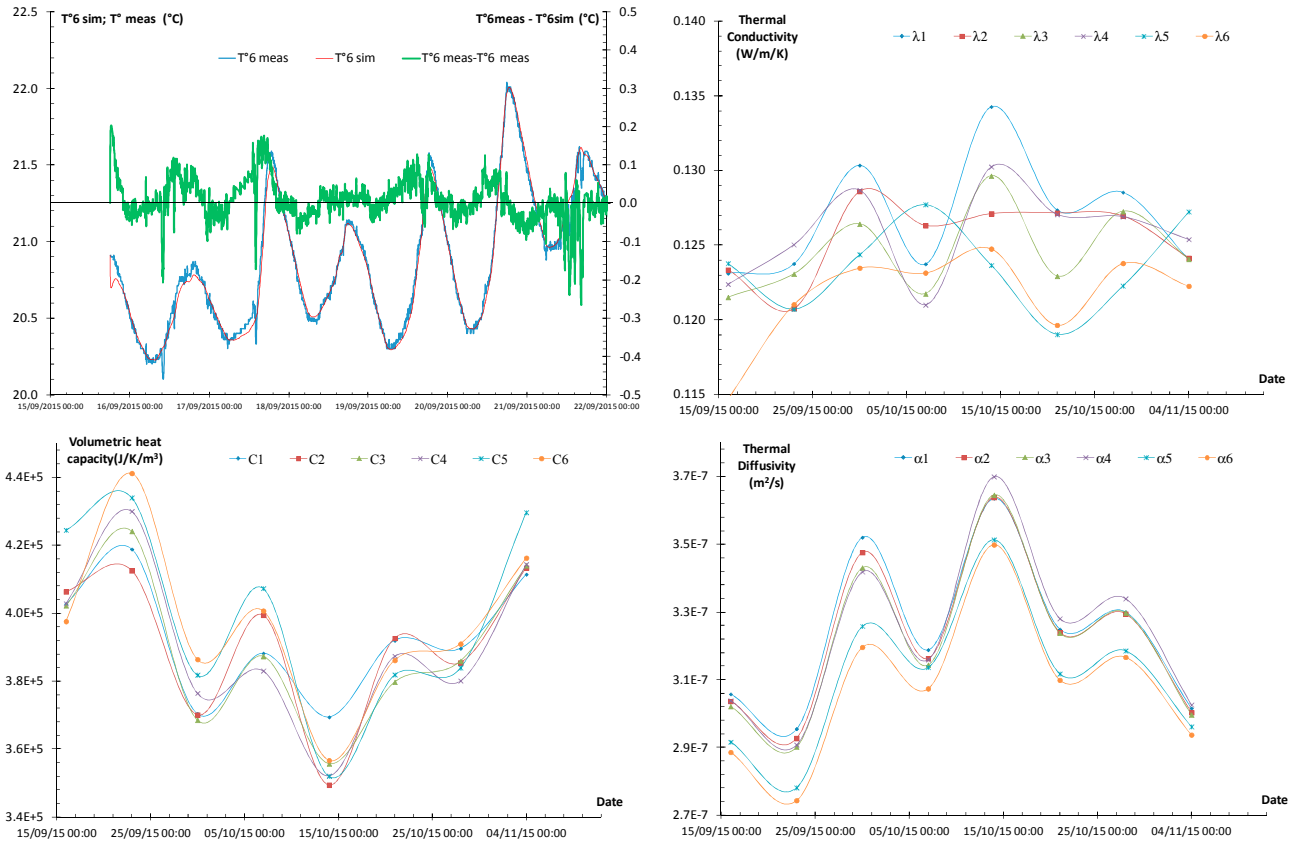


Fig. 5. Estimation results.

5. Conclusion

The EU project: Rehafutur is presented in this paper. A North France traditional mining engineer house was renovated and instrumented. The instrumentation and the first months' recorded data are presented. A laboratory developed inverse method is described and its results presented. The applied method allows monitoring the thermophysical properties of an instrumented Hemp Concrete Bloc "HCB" during several weeks. Next analysis will allow estimating the moisture content of studied HCB.

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