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Energy performance of buildings: bridging the gap between research and practice

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Abstract

A method to bridge the gap between research and practice, as far as estimation of the building envelope Heat Loss Coefficient is concerned, is to perform measurement of indoor temperature profiles during unoccupied periods when the solar heat gains are sufficient to reach significant indoor-outdoor temperature differences. An observation of indoor temperature profiles was conducted during summer 2014 in a passive house located in Belgium. The observation includes periods with and without occupancy. Occupants were asked to describe their behavior regarding windows opening, closing of external blinds, opening of internal doors. Electric devices were listed and the electricity consumption profile was characterized during occupancy and no occupancy. A calibration process is performed in order to reproduce the global heat balance of the whole building and the zone by zone heat balance. The calibrated model provides an estimation of the Building Heat Loss Coefficient. The influence of the assumptions related to occupants' behavior in summer is confirmed and recommendations are made to better describe that behavior in terms of use of mechanical ventilation, internal doors opening and use of external blinds.

Keywords – Energy performance of buildings, empirical modelling

1. Introduction

Under the Energy Performance of Buildings Directive, EU countries have implemented systems to include energy performance certificates in advertisements for the sale or rental of buildings. The certification process is based on a 4 hours building inspection followed by a calculation process to

estimate the level of the building energy demand and primary energy consumption. Calculations are based on standard occupancy patterns. They do not take into account the real energy consumptions and energy bills, that are difficult to integrate in the assessment because the behavior of occupants and their comfort requirements can deviate strongly from the standard assumptions.

On the other hand, rigorous full test scale experiments and careful modelling studies were conducted by scientists in order to validate their simulation models and explain the discrepancies observed between theoretically predicted and measured building responses [1]. Such a full scale experiment was conducted by the Fraunhofer Institute in Holzkirchen, Germany in 2013 and 2014. It provided well documented data sets regarding building physics and benchmarks for modelers [2,4]. The measurement of building heat loss coefficient through co-heating process is also a field of ongoing research [3].

The rising question is: how could those full scale experiments inspire us in order to improve the EPB evaluation process by integration of data measured on site? What are the most relevant data to collect through a less intrusive collection process?

To answer that question, an observation of indoor temperature profiles was conducted during summer 2014 in a passive house located in Belgium. The observation includes periods with and without occupancy. Occupants were asked to describe their behavior regarding windows opening, closing of external blinds, opening of internal doors. Electric devices were listed and the electricity consumption profile was analyzed in order to produce average electricity consumption profiles. An energy balance of the building is established on basis of measured indoor temperatures and climatic data, focusing on two sunny unoccupied periods. The value of the calculated heat loss coefficient is confirmed. An identification of the zones dynamic parameters is performed on basis of measured indoor temperatures profiles. A dynamic simulation is performed on the identified model in order to reproduce the measured temperatures profiles and results are compared.

2. Case study

The house considered in the present case study is a passive house located in the surrounding of Liege, Belgium. The house is built in a very open environment and south oriented, with large glazing area on that side (Figure 1).



Fig. 1 South-West corner (left) and vertical North-South cross section of the house.

The building fulfills passive standards according to Passive House Planning Package (PHPP), with a reference heated floor area of 232 m², an envelope total area of 583 m² and an average U value of 0.174 W/m²K. The infiltration rate equals 0.32 ac/h at 50 Pa of overpressure.

All the south oriented windows are protected by motorized blinds. The house includes eight zones (fig. 2) and is ventilated by a dual-duct mechanical system with a nominal air flow rate of 300 m³/h, provided with an air/air heat recovery exchanger. The heat recovery exchanger is by-passed in summertime.

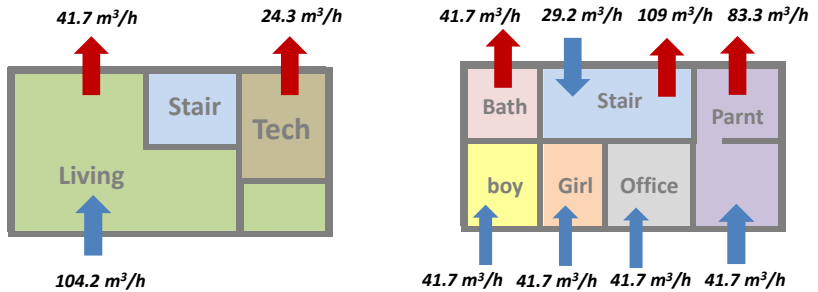


Fig. 2 Ground floor (left) and first floor (right) schematic layout of the house with supply and extracted nominal air flows.

The observation of indoor temperature profiles was conducted during august 2014. It includes two non occupied period characterized by a low level of CO₂ concentration: 11 days in July and 7 days in August (fig. 3). The average external temperature was 21.7 °C during the 11 days of July, with 3 days hot wave at the beginning of the period, and internal temperatures ranging

from 25 to 27.3°C. The average external temperature was only 13.3 °C during the 7 days of August, with sufficient solar heat gains to reach significant indoor-outdoor temperature differences (fig. 3).

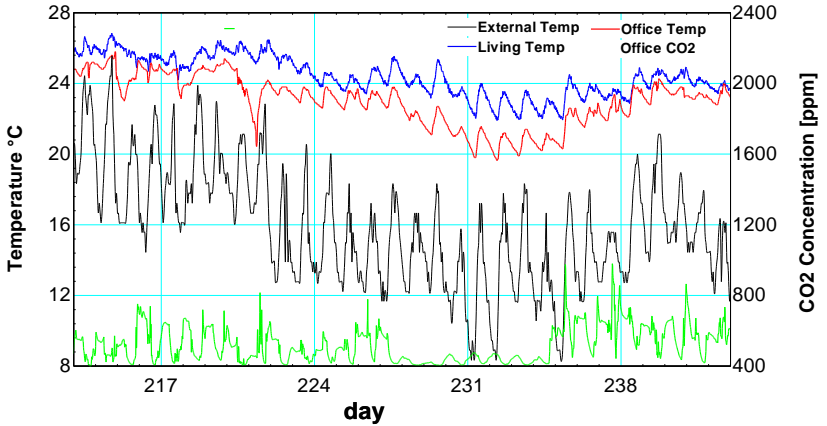


Fig. 3 Measured indoor and outdoor temperatures, and CO2 concentration - August 2014.

Outdoor temperatures, wind orientation and speed, as well as solar irradiations, were measured in a weather station nearby. A heat balance analysis is performed in order to yield a heat balance of the house during both unoccupied periods.

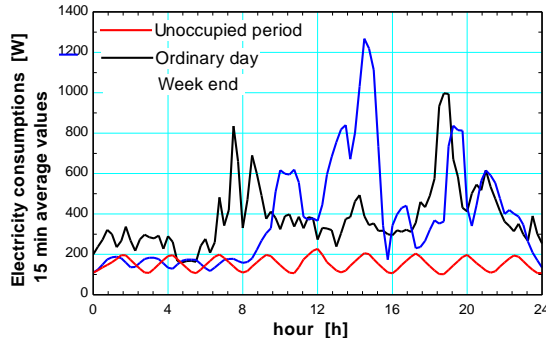


Fig. 4 Electricity consumption 15 min average values – Summer 2015.

Electricity consumption profiles were recorded during summer 2015 (fig. 4). They were considered as sufficiently reliable for 2014 as the same people occupied the house, a fortiori for unoccupied period of time.

3. Heat Balance analysis

Heat inputs and heat losses are computed independently from each other in order to assess the heat balance of each zone and of the whole house (fig. 5).

Heat inputs due to solar heat gains are computed from measured solar irradiations on a horizontal plane. Heat released from electric appliances is input in the living zone at 100% conversion from electric power to heat. Occupants declared that the motorized system operating the blinds was off during the unoccupied periods, and that the blinds were left open. Measurements confirms that blinds were open during the unoccupied period of August. However heat balance analysis of the unoccupied period of July reveals that blinds were closed in the living zone and in two bedrooms.

Transmission heat losses, as well as heat losses due to ventilation and air infiltration, are computed on basis of a dynamic simulation model written with EES Engineering Equation Solver software, *with measured indoor temperatures given as input to the model*. External and internal walls are modeled through 3R2C networks. The capacities modelling the walls are located on their resistances in order to reproduce their admittance for a 24 h time period sinusoidal signal. Occupants declared that the double flow ventilation system was working during the 7 days unoccupied period, and set to 45 % of the nominal air flow. The heat recovery exchanger was by-passed.

Internal and solar heat gains are supposed to be unalterable by the calibration process.

Infiltration air flows are driven by wind orientation and speed, as well as by internal buoyancy effects, which are deduced from indoor temperatures measured in the different zones. Air infiltration flow between zones is handled by a one way model driven by differences of pressure between zones. The initial analysis reveals slight excess of heat gains for the whole house for both periods of analysis (fig. 5 and 6). In July, an excess of heat gains appears in the boy bedroom while an excess of heat losses appears in the parents' bedroom. A calibration is performed by introducing a convective coupling between the parents' room and the stair case. It is handled with a two ways models associated to internal doors. Modelling a convective coupling between the boy bedroom zone and the staircase would increase the unbalance. An indoor temperature gradient is introduced in the staircase zone as function of the solar heat gains, mainly provided by top roof windows.

After that calibration, unbalances are limited except in the boy bedroom.

The resulting heat balance is presented on fig.5 and 6.

The calculated transmission heat loss coefficient equals 101.1 W/K. Adjusting the transmission losses to balance the heat gains of the whole house would increase that heat loss coefficient from 0.7 to 1.4 %. The value of the Heat Loss Coefficient HLC is confirmed. The house reaches the passive standard.

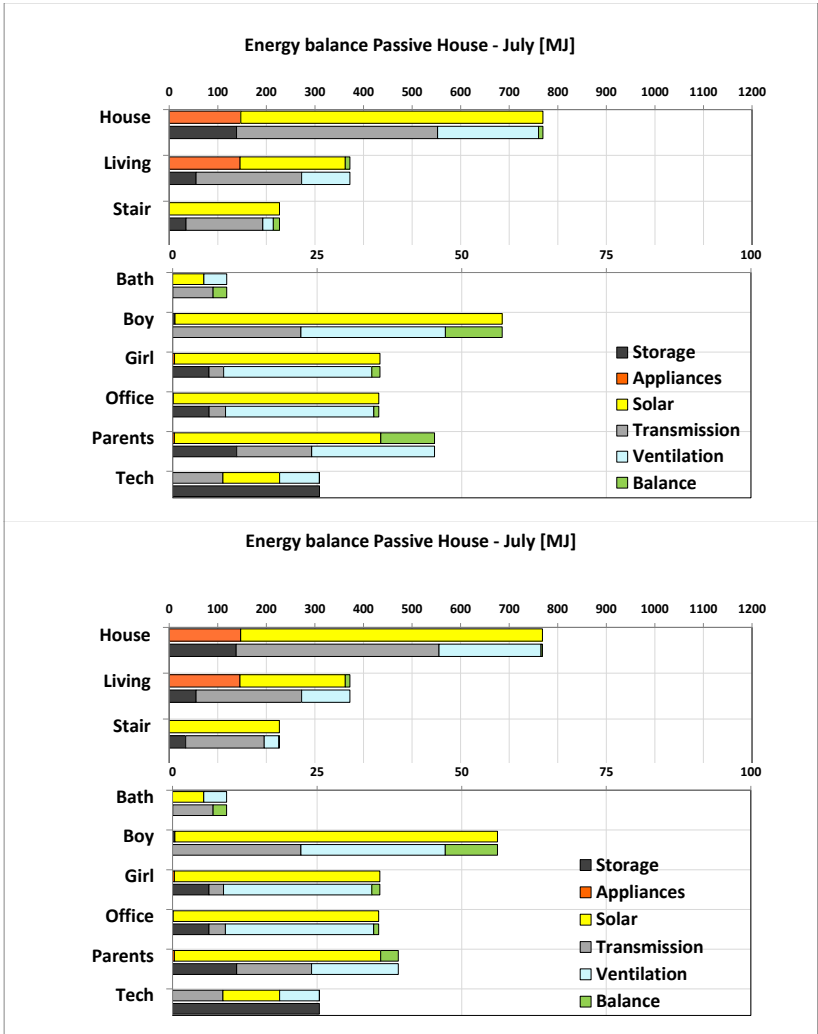


Fig. 5 Heat Balance before (up) and after (down) calibration for 11 days of July.

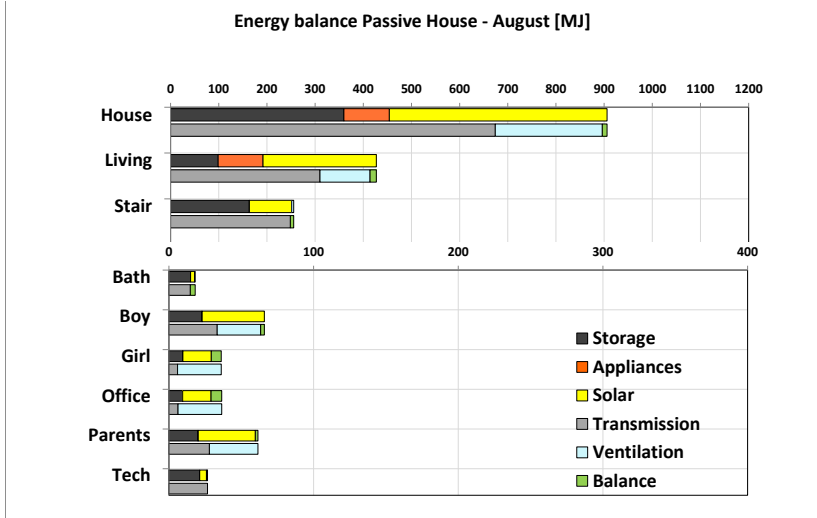


Fig. 6 Heat Balance after calibration for 7 days of August.

4. Dynamic characterization

Identification of building dynamic parameters on basis of measured data is a field of ongoing research [6]. Dynamic building behavior is an important issue to characterize its ability to absorb solar heat gains in order to avoid overheating risks in summer. Building dynamics is also a key issue to characterize its ability to shift the electrical loads from peak hours to off peak hours, when electricity is used for the space heating through heat pumps.

An attempt was made to characterize the building time constant from the observation of the indoor temperature profiles during the 11 days non occupied period in July 2014.

A Fourier analysis is performed in the living zone from (fig. 7):

- An exciting signal E given by:

$$E = \dot{Q}_{solar,gains} + AU_{windows}(t_{out} - t_{in}) + \dot{M}_{a,su} c_{p,a}(t_{a,su} - t_{in}) \quad (1)$$

- A response R given by the measured internal temperature profile:

$$R = t_{in} \quad (2)$$

The transfer function TF and admittance \tilde{A} are complex quantities:

$$TF = R / E \quad \tilde{A} = 1 / TF \quad (3)$$

Where $\dot{Q}_{solar,gains}$ represents the solar heat gains, $AU_{windows}$ area times U value of the windows, t_{out} and t_{in} the external and internal temperatures, $\dot{M}_{a,su}$ the supply air flow, $t_{a,su}$ the supply air temperature and $c_{p,a}=1000$ J/kg-K.

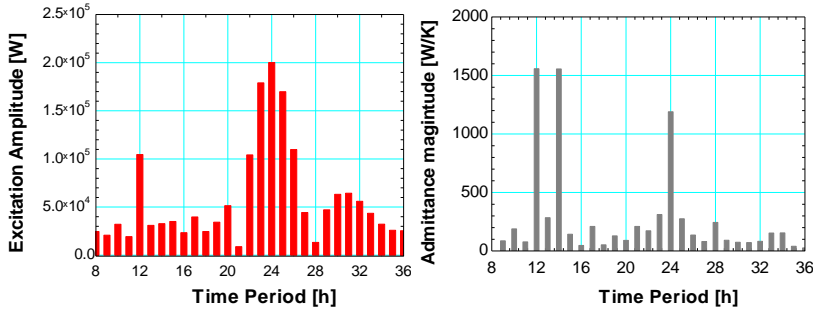


Fig. 7 Fourier analysis of excitation and resulting admittance in the living zone.

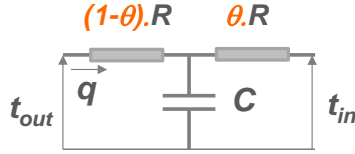


Fig. 8 Model 2R1C of a wall (inside side).

The admittance and time constant of a 2R1C model (fig. 8) are given by:

$$\tilde{A}R = \frac{1+i\omega\tau}{1+i\omega\tau\theta} \quad \tau = RC(1-\theta) \quad (4)$$

The identification of parameters θ and τ can be performed by the following assumption, valid for large values of τ ($\tau > 100$ h):

$$\varphi = \arctan(\omega\tau) - \arctan(\omega\tau\theta) \cong \frac{\pi}{2} - \arctan(\omega\tau\theta) \quad (5)$$

$$\tau = (\omega\theta \tan\varphi)^{-1} \quad \theta = \frac{\tan\varphi^{-2}}{R\Re(\tilde{A})(1+\tan\varphi^{-2})-1}$$

Where R is the resistance of the opaque walls surrounding the zone ($R=1/AU_{\text{opaque walls}}$), C the capacity, \tilde{A} the admittance, ω the pulsation, τ the time constant, θ the location of the capacity on the resistance, φ the phase lag.

Table 1. Dynamic parameters of external opaque walls for different zones.

Zone	τ h	$AU_{\text{opaque walls}}$ W/K	θ	C J/K
Living	279.9	15.93	0.006311	1.615E+07
Boy room	320.0	2.894	0.008719	3.363E+06
Girl room	561.1	1.255	0.003134	2.543E+06

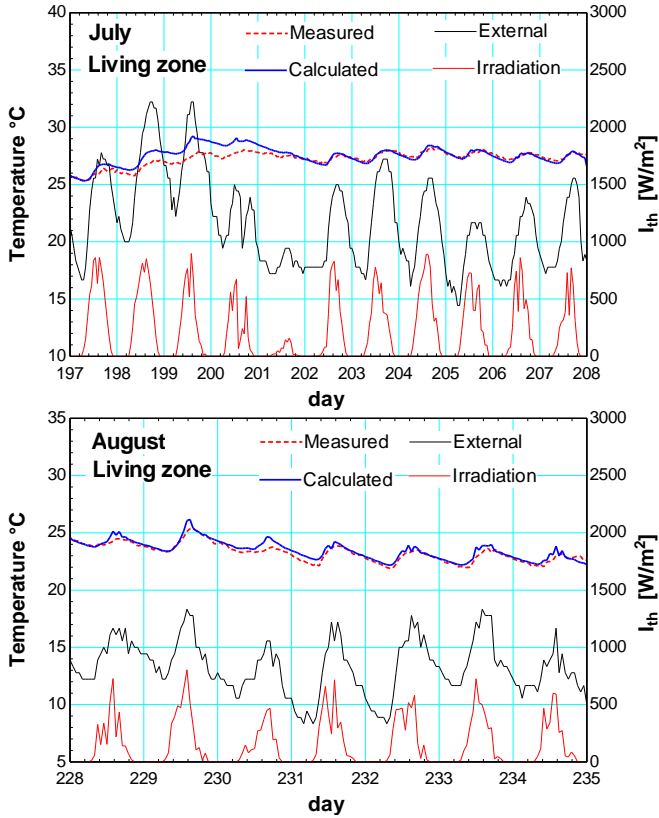


Fig. 9 Simulation results in the living zone for 11 days of July and 7 days of August (internal and external temperatures, solar irradiation).

The thermal mass reproducing the time constant is shared on external opaque walls as function of their AU values. A simulation is performed over both non occupied periods in order to reproduce the measured indoor temperature profile (fig. 9).

Simulation results reproduce well the daily variation of the indoor temperature but discrepancies are observed for the 3 hot wave days at the beginning of July period.

5. Conclusion

One way to bridge the gap between research and practice, as far as estimation of the building envelope Heat Loss Coefficient is concerned, is to

perform measurement of indoor temperature profiles during unoccupied periods when the solar heat gains are sufficient to reach significant indoor-outdoor temperature differences. The estimation of HLC can be improved by collecting relevant data related to the occupants' behavior such as opening of external blinds, opening of internal doors, operating mode of the ventilation system in terms of selected fan speed, by-pass of heat recovery exchanger and related control law, if any. By-pass of the heat recovery exchanger should be preferred because it avoids assumptions related to the efficiency of the heat exchanger. The electricity consumptions should be monitored in order to quantify the internal heat gains due to appliances. Weather data should be collected as well, ideally on site: external temperature, wind speed and orientation, diffuse and global solar irradiation, low wave heat losses. The data collection process should be completed with a blower door test.

Collected data can be used either to identify the building static heat loss coefficient or to identify its time constant and dynamic parameters. A step by step calibration process starting from an initial model and aiming to establish the heat balance of the building is an opportunity to better identify its static heat loss coefficient. A Fourier analysis of the temperature response is an opportunity to assess the time constant of the building zones. Both strategies are ways to improve the EPB evaluation process by integrating site measurements data. The assessment of the HLC is a way to confirm that the house reaches the passive standard requirements.

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