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# Verification of the energy balance of a passive house by combining measurements and dynamic simulation

Imane REHAB[a]*, Philippe ANDRE[a], Cleide APARECIDIA SILVA[b], Gabrielle MASSY[c], Jules HANNAY[b], Jean LEBRUN[b]

*[a]BEMS, University of Liège, Arlon Campus Environnement, Belgium*
*[b]JCJ Energetics, Liège, Belgium*
*[c]Haute Ecole de la Province de Liège, Liège, Belgium*

## Abstract

Passive houses have, at design stage, to fulfill a number of performance criteria. One of them imposes the normalized theoretical heat demand to be limited to 15 kWh/m², year. In operation, it is very difficult to check, from simple observations or measurements, the real performance of such a house: different energy vectors may be used to meet the space heating as well as the domestic hot water demand, a storage tank may be used and fed by different energy sources (heat pump, direct electricity, solar thermal). The problem is still more complicated if the house is equipped with PV panels which naturally decrease the apparent electrical consumption. In the frame of the IEA Annex 58 project, a passive house was the object of a detailed analysis aiming at estimating the different terms of the energy balance. Some terms were results of direct in situ measurements and unmeasured terms such as solar and internal gains were estimated by dynamic simulation. The combination of measurements and simulation results allowed a reconstruction of a robust energy balance. The paper provides a detailed description of the approach and of each term of the rebuilt energy balance.

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*Keywords:* TRNSYS Simulation, In situ measurments, Passive House, Actual Performance, Energy balance.

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* Corresponding author. Tel.: +3-263-230-937; fax: +3-263-230-800.
*E-mail address:* imane.rehab@ulg.ac.be

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## 1. Introduction

Several studies have, at design stage, shown that the actual performance of a building could deviate significantly from the performance defined. This gap has to be reduced as much as possible, depending on the energy performance level to reach. This is especially true for passive house, were the criteria of performance supposed in design stage, are directly impacted by the quality of execution in site. For such constructions, in situ performances verification is mandatory. In this optic, this paper presents a mean of verification of actual performance of a passive house through a combination of measurements and dynamic simulation.

A detailed description of a case study passive house is developed, based on the specification provided by the owner of the house. This description served as inputs to a dynamic simulation with TRNSYS17. TRNSYS is a transient system simulation program with a modular structure which implements a component-based simulation approach. Components may be simple systems like pumps or fans, or complex systems such as multi-zone buildings [1]. The results of the several simulations are compared to the in situ measurements to estimate and optimized the accuracy of the realized TRNSYS model. As final proposition, the results of the reliable simulation model are combined with the in situ measurements to rebuild the energy.

## 2. Passive House criteria

Passive House buildings are planned, optimized and verified for instance with the Passive House Planning Package (PHPP). According to the Passivhaus Institut, it has to meet the following criteria [2]:

- Theoretical heat demand is not to exceed 15 kWh per square meter of net living space (heated floor area) per year or 10 W per square meter peak demand.
- The total energy consumption must not exceed 120 kWh per square meter per year.
- A maximum of 0.6 air changes per hour at 50 Pascal pressure, as verified with a blower door test.
- Not more than 10 % of the hours in a given year over 25 °C.

To achieve Passive House criteria, building designers must consider as mandatory the following principles: thermal bridge free design, superior windows, ventilation with heat recovery, quality insulation and airtight construction.

## 3. Case study house

The house is located in the area of Liege in Belgium and was built in 2008. It is south oriented, with a large glazing area on that side protected by motorized blinds. Other facades are much less open to sunshine, see Fig.1and Fig.2.

Fig. 1. (a) South facade; (b) West facade; (b) North facade; (b) East facade.

According to the specification, the building has the following characteristics [3]:

- Outdoor volume: 894 $m^3$
- Reference floor area: 232 $m^2$
- Windows: 44 $m^2$ (with 31 $m^2$ South oriented), triple glazing, $U=1\ W/m^2K$

- Opaque walls: 244 m2, U=0.12 W/m²K
- Roof: 174 m2 U=0.1 W/m²K
- The infiltration is of the order of 0.32 Vol/h at 50 Pa of overpressure.
- The house is occupied by a four people family (two parents and two children). All of them are out for work and school during week days.

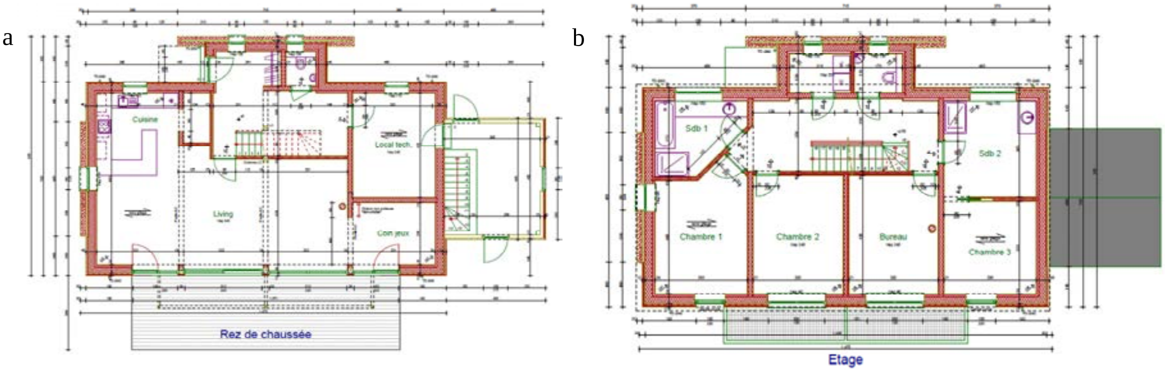


Fig.2. (a) Horizontal cross section at ground level; (b) Horizontal cross section at first floor level.

The house is equipped with [3]:

- A dual-duct mechanical system with fresh air pre-heating through both ground-connected heat exchanger and air/air recovery (effectiveness estimated to 65 %). The system is sized for a nominal air flow rate of 350 m³/h. Electric fan provides three rotation speeds.
- A water floor heating system in the ground floor. The water temperature of the floor heating system is usually maintained in winter time, between 28 and 30°C.
- An electrical floor heating in both bath rooms (installed powers: 250 and 150 W in the large and small bath rooms respectively);
- An electrical convector in the office room of the second floor for occasionally heating.
- Motorized Blinds automatically adjusted every half hour according to indoor temperature. Automatic closing is only allowed when the space heating is already OFF. Any action on artificial lighting is shifting the blind control from automatic to manual mode.
- A common hot water tank, for ground floor space heating and sanitary hot water, heated by an electrical resistance of 4 kW and by 4 m2 of evacuated tubes solar collectors installed on the roof.
- 22.5 m2 of PV collectors are also installed on the roof; their nominal power is of the order of 4500 W. They are expected to produce a total of the order of 4200 to 4800 kWh/year.

## 4. TRNSYS Simulation Model

The detailed radiation multizone building model created within TRNSYS17 required a 3D geometric surface information. We have used for that, a plug-in called Trnsys3d for the Google SketchUp 3D drawing program. This program allowed to create and edit Trnsys3D zones and surfaces, matching interzone surface boundary conditions and set and change default constructions. The Trnsys3d file was imported into the Trnsys17 (Studio & TRNBuild) for adding non-geometric data and running the simulation. Modifications were exported back to the Trnsys3d file.

"Type 56" in TRNSYS represents the geometrical features of the building. Edition of "Type 56" can be done within TRNBuild. It includes descriptions of: zones, walls, windows, infiltration, internal gains and schedule, as described in the specification. Systems of: ventilation, heating, hot water preparation and photovoltaic were described within Trnsys-Studio. Appropriate "Types" were used to represent the real operating mode of each system

[1]. Fig.3 shows the “types” used for modelling the heating system. Weather description was done also in Trnsys-Studio to represent the real outside conditions of the case study house.

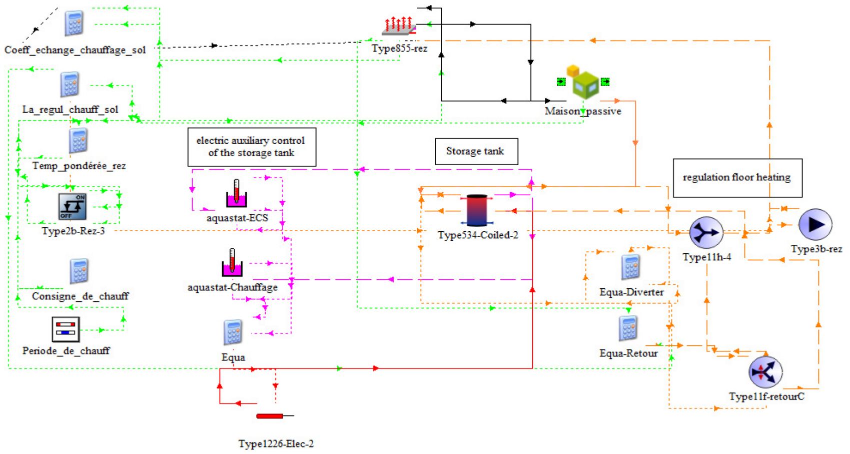
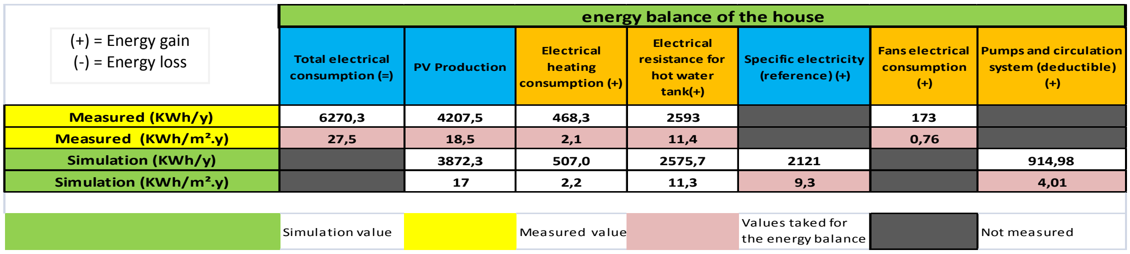


Fig.3. TRNSYS model of the heating system.

## 5. Reconstruction of the energy balance from monitoring and simulation

Necessary data for the energy balance are a combination of measured and simulated or estimated data. Accordingly, the in situ measured data are: the total electricity consumption of the house during 2012; the PV system production, the electricity consumptions of the boiler, electrical radiators and fans, all reported in Fig.4. A monitoring of the indoor temperatures during the winter 2013-2014 was also operated.

Otherwise, estimated used data are: the appliance consumption which is estimated as per the standard of a passive house to 2121 kWh/year [4]; and the consumption of pumps and circulation system which is the remainder value of the deducted sum of consumption items from total measured electrical consumption.



| (+) = Energy gain<br>(-) = Energy loss | energy balance of the house | | | | | | |
|---|---|---|---|---|---|---|---|
| | Total electrical consumption (=) | PV Production | Electrical heating consumption (+) | Electrical resistance for hot water tank(+) | Specific electricity (reference) (+) | Fans electrical consumption (+) | Pumps and circulation system (deductible) (+) |
| **Measured (KWh/y)** | 6270,3 | 4207,5 | 468,3 | 2593 | ■ | 173 | ■ |
| **Measured (KWh/m².y)** | 27,5 | 18,5 | 2,1 | 11,4 | ■ | 0,76 | ■ |
| **Simulation (KWh/y)** | ■ | 3872,3 | 507,0 | 2575,7 | 2121 | ■ | 914,98 |
| **Simulation (KWh/m².y)** | ■ | 17 | 2,2 | 11,3 | 9,3 | ■ | 4,01 |
| 🟩 | Simulation value | 🟨 | Measured value | ▨ | Values taked for the energy balance | ■ | Not measured |

Fig.4. Energy balance of the house.

To ensure an adequate TRNSYS model, a large number of simulations were performed to adjust the various parameters. Major modifications concerned the internal gains, control of ventilation/heating systems and domestic hot water consumption. All these parameters were indeed not described in specifications.

Internal gains were estimated according to a schedule of person’s presence and a schedule of user profile of electrical appliance [5]. For ventilation control, the airflow was considered variable in the model according to schedule of presence. In winter period, when the house is occupied, the flow is considered equal to the nominal value of 350m³/h. When the house is unoccupied, the value is reduced to 175m³/h. During overheating periods in summer, a free cooling is considered when external temperature is below the indoor temperature. For the inverse case, an over-ventilation is considered equal to 420m³/h. For heating control, simulations took into account the measured indoor temperature as “set points” for water and electrical floor heating systems. Finally, domestic hot water consumption was estimated to 200 L per day at a temperature of 55°C.

### *5.1. Results and analysis*

Results of simulation show that the TRNSYS model is able to reproduce measured consumptions accurately. Accuracy of results is given by percentages in Fig.5. This result demonstrates that it is possible, with a good knowledge of the house physical proprieties, to realise a reliable TRNSYS model.

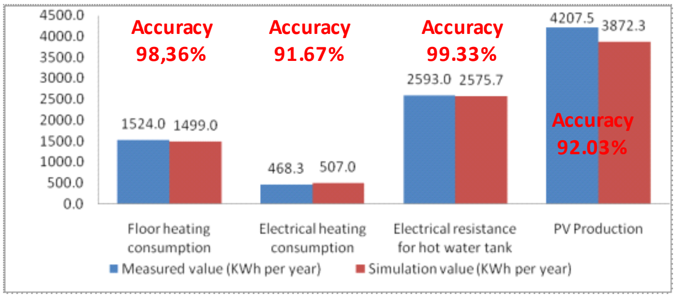
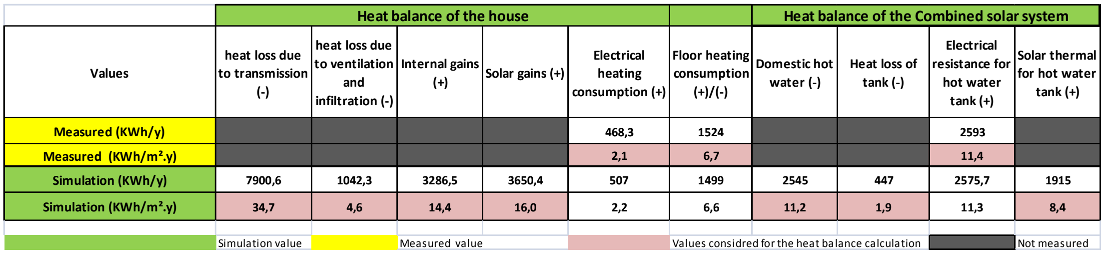


Fig.5. Comparison of measured and simulation values (kWh/y).

The reliability of the TRNSYS model is also verified by a combination of measured and simulated values to rebuild the heat balance of the house and the heat balance of the combined solar system as shown in Fig.6.



| | Heat balance of the house | | | | | | Heat balance of the Combined solar system | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Values | heat loss due to transmission (-) | heat loss due to ventilation and infiltration (-) | Internal gains (+) | Solar gains (+) | Electrical heating consumption (+) | Floor heating consumption (+)/(-) | Domestic hot water (-) | Heat loss of tank (-) | Electrical resistance for hot water tank (+) | Solar thermal for hot water tank (+) |
| Measured (KWh/y) | ⬛ | ⬛ | ⬛ | ⬛ | 468,3 | 1524 | ⬛ | ⬛ | 2593 | ⬛ |
| Measured (KWh/m².y) | ⬛ | ⬛ | ⬛ | ⬛ | 2,1 | 6,7 | ⬛ | ⬛ | 11,4 | ⬛ |
| Simulation (KWh/y) | 7900,6 | 1042,3 | 3286,5 | 3650,4 | 507 | 1499 | 2545 | 447 | 2575,7 | 1915 |
| Simulation (KWh/m².y) | 34,7 | 4,6 | 14,4 | 16,0 | 2,2 | 6,6 | 11,2 | 1,9 | 11,3 | 8,4 |
| | | | | | | | | | | |
| 🟩 | Simulation value | 🟨 | Measured value | | 🟥 | Values considred for the heat balance calculation | | | ⬛ | Not measured |

Fig.6. Heat balance results.

An “energy flow diagram” given in Fig.7 summarizes the combination of considered measured and simulated values to rebuild the heat balance and energy balance. Analysis of the rebuilt energy balance given in Fig.8 (a) shows that the case study house fits clearly passive house requirements with: 8.8 kWh/m²y of consumption for the total heating demand. If not taking the lighting and appliances consumptions, this house can be considered as a “nearly zero energy building”: the thermal and PV collectors are roughly covering the whole (space and sanitary water) yearly heating demand, see Fig.8 (b).

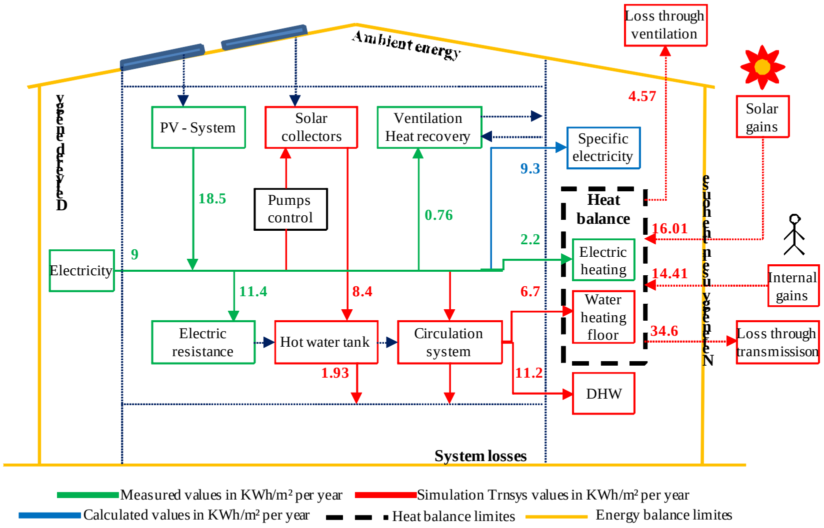


Fig.7. Energy flow diagram.

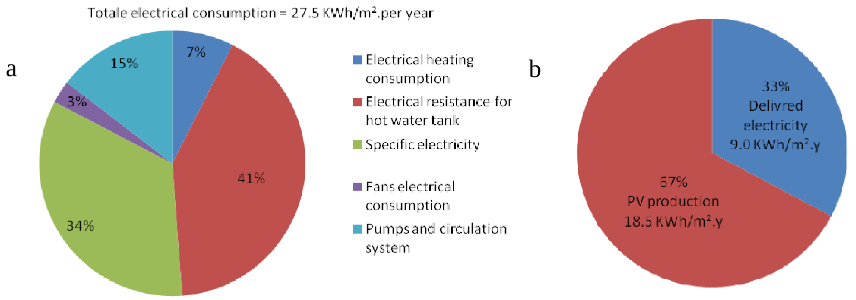


Fig.8. (a) Energy balance based on measurements and simulation values. (b) PV use rate in electrical consumption.

## 6. Conclusion

Normally, energy balance is calculated at design stage exclusively based on dynamic simulation results. The added value of this work was to rebuild a “robust” energy balance with data from full scale in situ measurements and reliable dynamic simulation results. The approach was to measure the electrical consumption and internal/external temperatures. Electrical consumption was directly used as input to the energy balance. Measured indoor temperatures were used as input to the TRNSYS dynamic simulation model which provided as results, the remaining data of the energy balance: internal and solar gains, heat losses. As final conclusion, the provided methodology and TRNSYS model can perform simulations for other similar passive houses, after a calibration phase, especially when the available information is incomplete.

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