Calibration of a building simulation model to evaluate the overheating risk in summer period – case study of a passive house in Belgium

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Abstract:

A method based upon a calibrated model of building is proposed here to evaluate the performance in terms of thermal comfort during summer in a passive house. A model of the house was developed and this model was used to determine optimal solutions (cost and efficiency) to reduce or avoid the overheating that could occur in the building. The first step of this work consisted in the calibration of the thermal response of the simulation building model by comparison with the internal temperatures measured in the passive house during summer period. The simulations took into account the occupancy in the house and several other parameters in order to match the temperature sensors data of the house. These parameters were adjusted thanks to sensitivity analysis. An assessment of the accuracy of the simulated model was conducted by computation of sensitivity indicators. When the results of calibration showed a good matching between reference and simulated buildings the simulations were used to assess the best solution to reduce the overheating in passive house rooms which is occurring when the percentage of overheating time is over 5% (Passive House Platform standard in Belgium).

Keywords:

Calibration, Overheating, Dynamic Simulation, Passive house, TRNSYS.

1. Introduction

The purpose of this paper is to submit a calibration methodology by trial-error tests and verification of accuracy by sensitivity indicators computation. This development was thought in order to assess the overheating risk in a passive house located in Belgium by dynamic simulations and determine the best ways to reduce or avoid this risk. The owners of the house provided a lot of information (house plans, blower door test results, behaviour of inhabitants, etc...) which were used to develop the building simulation model. The first step was to calibrate this model using data from the passive house thermal behaviour. The in situ measured temperatures of the house served as reference for the calibration. By a trial-error method some parameters of the building model were adjusted in order to match the thermal response of the model with the thermal sensors measurements in the house. To validate the building simulation model, accuracy indicators were computed based on the work of Bertagnolio [1].

2. Context of the study

This work was conducted in the framework of the EBC Annex 58 [2] of IEA (International Energy Agency – Energy in Buildings and Communities Programme): "*Reliable Building Energy Performance Characterization Based on Full Scale Dynamic Measurements"*. Annex 58 aimed at enhancing the energy performance characterization of buildings with a focus on the residential sector based on *in situ* measurements of building in use. It is frequently observed that real performance of buildings often doesn't match the theoretical performance calculated during the design phase of building.

Therefore some new tools or methods have to be developed to correctly determine the real performance of buildings in use. A secondary objective of the annex was to offer ideal conditions for building simulation model validation. The *in situ* verification implies measurements in building. The main contribution of the work in Annex 58 was to show how collected data during measurement campaigns were used in simulation models [3]. These models could be "detailed" and calibrated upon the available data or "simplified" and identified by parametric identification techniques [3].

A passive house located in Liege area (Belgium) served as a case study. Different measurement campaigns have been conducted in this house to develop several performance verification techniques. The first one is a reconstruction of the energy balance of the house thanks to the collected data. A method with butane combustion was also tested in order to estimate simultaneously the heat loss coefficient and the air exchange rate of the house [3]. Finally, a calibrated simulation model in TRNSYS [4] has been used to evaluate the thermal performance of the house during summer period. This paper will focus on the latter.

3. Method

3.1. Modelling of the reference building: reality to simulation model

Based upon a set of collected information from the owner of the passive house, a 3D model of the building was developed in TRNSYS 3D plugin for Sketchup [5] (Fig. 1). Thanks to 3D modeling the detailed internal and external radiation mode in TRNSYS can be selected. The choice of a detailed radiation mode is justified in this case because of the large glazing area especially at the south frontage where the window ratio is about 39%. In order to represent the reality at best, a correct distribution of direct solar radiation is indeed important [6].

To increase the accuracy of the model some envelope characteristics are also detailed in Sketchup for example the windows recess of 10 centimeters or the presence of shading elements along the house.

a) *b)* *c)*

Fig. 1: 3D model (a) ,2D model (b: house plans), reference building(c), north frontage.

Building envelope and HVAC systems information is essentially extracted from the design calculations of the house ("PHPP" report), plans and interview of the owners to determine their behaviour (occupancy, ventilation control, solar blind control, etc.…).

3.2. Weather data

The simulation model of the passive house has been developed in order to reproduce the thermal behaviour of the house during a short measurement campaign in summer 2014 (from July 11th to September 5th 2014). These measurements included internal temperature data in different rooms of the house. Fig.2 shows in which rooms the sensors were installed (red points). There was also a temperature sensor in the attic but the overheating evaluation was not seem relevant for this room.

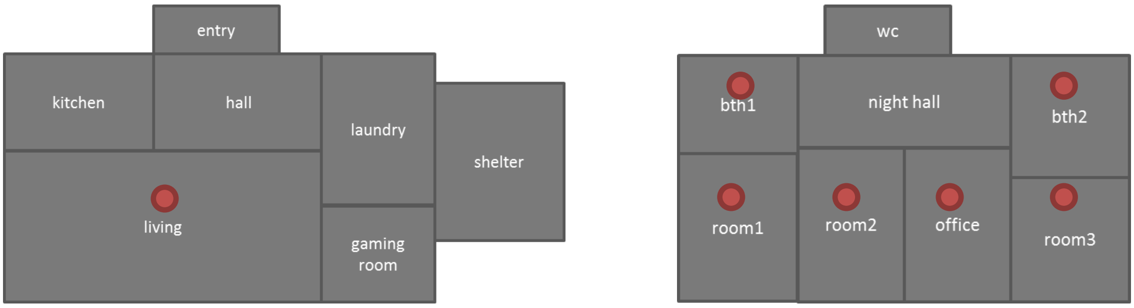

Fig. 2: Thermal zoning of the passive house used in TRNSYS simulations; localization of the thermal sensors is shown with red points.

To calibrate the simulation model the weather data (external air temperature, relative humidity, direct and diffuse solar radiations) are required. The house is located near the city of Liege (about 20km away). The Spatial Center of Liege provided the external air and dew point temperatures, the global, direct and diffuse solar radiations for year 2014 for that city (Figs.A1-A2). Because of gaps present in the files and missing data the climate information were completed with the NOAA website [7] which provides the weather data of Bierset Airport (Liege). Thanks to this information it was possible to rebuild weather conditions in the simulation environment of TRNSYS. Presence of gaps and hybridization of data from different sources are a primary source of errors for the simulations. This error will be reflected in the accuracy of results.

3.3. Calibration parameters, accuracy calculation and model validation

A calibration procedure was carried out with the TRNSYS software by a combination of sensitivity analysis and trial-error method. IEA_EBC Annex 53 work [8] established six families of influence factors on energy consumption in buildings. These six families are divided in two groups; those related to the human behaviour and those not related to human behaviour. Each family includes several parameters. The study [8] compared the influence of each parameter and tried to detect the most important ones.

A set of parameters were selected among these six groups of influence factors in order to be modified in the calibration process of the building simulation model. These parameters are shown in Table 1.

Table 1. Parameters selected to calibrate the building simulation model.

Not Human Behaviour	Human Behaviour
Building envelope	**Occupation factors**
-Infiltration rate	-Unoccupied days per week
	-Internal gains
	Indoor environmental quality
	-Ventilation rate
	-Over-ventilation rate
	-Shading rate
	Building operation
	-Temperature decrease during the day
	-Temperature decrease during the night

The parameters shown in Table 1 have been chosen in relation with the actual characteristics of reference building. In fact all parameters that cannot be modified because of the real configuration of the house were not considered in the calibration process (e.g. it is not possible to change the glazing ratio, thickness of insulation layer, etc.).

For each of the selected parameters trial-error tests were conducted. Measurements of temperature sensors in the house served as reference temperatures. The simulation building model has to match as close as possible these temperature data.

To analyse the difference between the thermal behaviour of the simulated building and that of the real building five mathematical indicators were calculated in order to assess the accuracy of the calibration (MSE – Mean Square Error, RMSE – Root Mean Square Error [1], MAE – Mean Absolute Error [9], MAPE – Mean Absolute Percentage Error [10], R - Correlation Coefficient and R^2 which is the Determination Coefficient calculated between real data and simulated ones [11] (*Fig.B*)). The calculation concerns 5317 observations. When a good set of calibration indicators has been achieved for the model, it can be used in several simulations of measures to fight against overheating in the house. The range of validation for each indicator was based upon the work of Bertagnolio [1].

Fig.3 shows the results for the temperature in the living room. The light grey line represents the sensor temperature and the dark grey line is the simulated one. These results are given for an uncalibrated model. This model has no internal gain, no solar blind protection, infiltration air rate is close to the passive house standard (n50 = 0.6 vol/h) [1] and there is no over-ventilation. It also takes into account the unoccupied period during the campaign.

[1]The infiltration air rate is recalculated in TRNSYS in order to correctly reflect the real pressure difference on site. The value of n50 is divided by an a factor which represents wind influence on the building [12]. For a mean wind protection the a value is 20. In TRNSYS the infiltration air rate is about 0.03 vol/h.

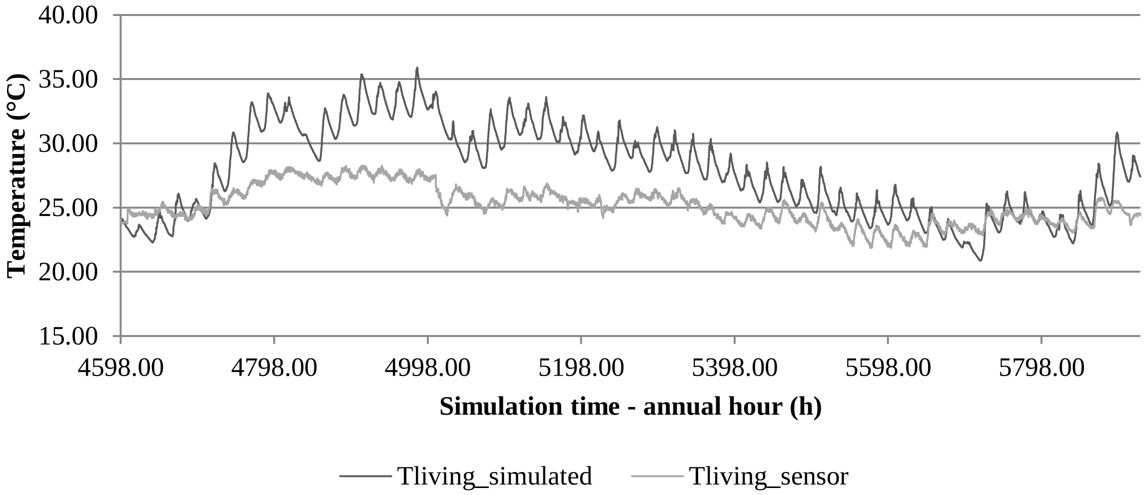

Fig.3. Temperature curves – comparison between the monitored temperatures (light grey line) and simulated temperatures (dark grey line), uncalibrated building simulation model

The statistical indicators were computed for this uncalibrated model. Table 2 shows a high dispersion from the real temperature data.

Table 2. Dispersion index values for an uncalibrated simulation model.

Room	MSE	MAE	MAPE	RMSE	R	R^2
Living room	12.57	2.97	11.5%	3.54	0.75	0.56
Room 1	22.75	4.26	17.8%	4.77	0.58	0.33
Room 2	33.86	5.27	22.3%	5.82	0.43	0.18
Room 3	19.88	3.88	16.4%	4.46	0.52	0.27
Office	30.81	4.98	21.0%	5.55	0.41	0.17
Bathroom 1	15.49	3.32	14.4%	3.94	0.47	0.22
Bathroom 1	17.31	3.48	15.2%	4.16	0.37	0.14

After calibration by trial error tests on the influence parameters shown in Table 1 the results for a calibrated model are shown in Fig.4 and statistical indicators values are given in Table 3.

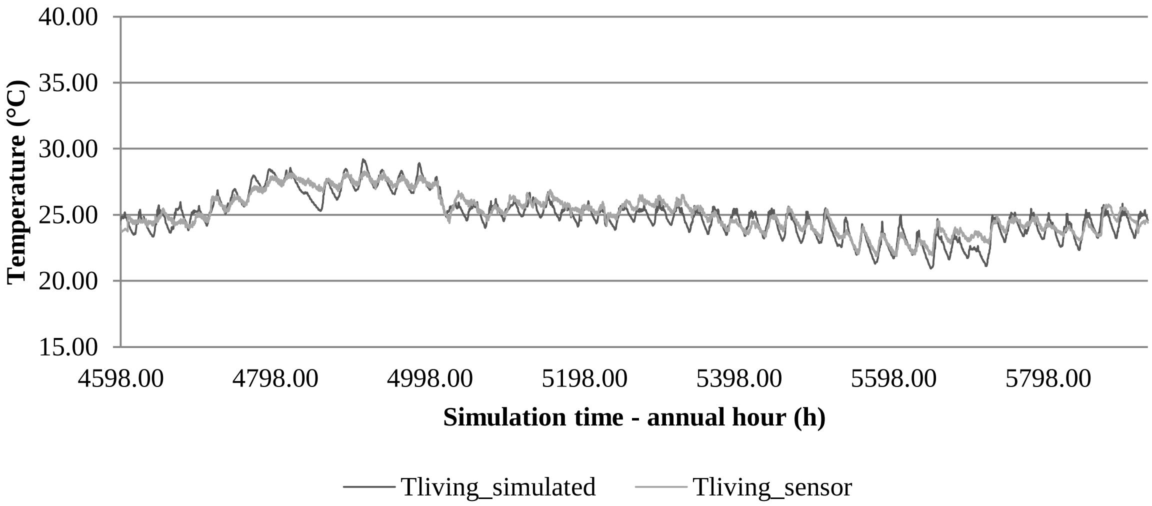

Fig.4. Temperature curves –calibrated building simulation model.

Table 3. Dispersion index values for a calibrated simulation model.

Room	MSE	MAE	MAPE	RMSE	R	R^2
Living room	0.42	0.53	2.1%	0.65	0.79	0.62
Room 1	0.97	0.70	3.0%	0.99	0.78	0.60
Room 2	0.84	0.68	2.9%	0.91	0.73	0.54
Room 3	1.55	0.98	4.1%	1.25	0.82	0.67
Office	1.03	0.82	3.5%	1.02	0.72	0.51
Bathroom 1	2.02	1.01	4.4%	1.42	0.77	0.59
Bathroom 1	2.25	1.12	4.8%	1.50	0.76	0.57

After several tests, the results obtained for this model were considered as sufficient to run the simulations. The statistical indicators values show a better fitting with the real temperatures.

4. Overheating risk evaluation: results

The overheating risk is expressed in percentage to be compared with the annual percentage of overheating allowed by the Passive House Platform (PHP) in Belgium: a maximum value of 5% of time when the internal temperature in building exceeds 25°C is allowed.

In the house monitored in Liege the data show that a risk of overheating exists in different rooms of the building, especially in the living room where the estimated annual overheating is 8% of time. The calibrated simulation model of the house has been used to find the optimal solution to reduce this percentage. Three ways to avoid the overheating risk were tested during the simulations:

- To change the setpoint temperature of solar blind protection activation (initially set at 26°C).
- To change the control of the solar blinds: initially the solar blinds were controlled by the internal temperature. The simulation tested a control based upon the horizontal solar radiation. The solar blinds are opened when the solar radiation on facade is lower than 120 W/m² and they are closed when it upper than 140 W/m². These values correspond to the default values in TRNSYS wizard settings. Two shading factor were also tested in this option. The shading factor values are 0.6 and 1 where 1 corresponds to a total closure of the solar blinds.
- To “manually” open the windows by night when external air temperature is lower than internal air temperature (minimal temperature difference: 2°C). Two renewal air rates were tested, 2 vol/h and 4 vol/h.

The results of each simulation are shown in Table 4. The overheating risk is expressed by an annual estimated percentage when the internal temperature in rooms exceeds 25°C. The first line in Table 4 represents the annual overheating computed in each room based upon the collected temperatures during the summer short campaign. The overheating risk seems to appear in the living room and room 1 with values above the 5% recommended in Belgium. The different options simulated in TRNSYS seem to improve the situation in each room except the solar radiation control of solar blinds with a shading factor of 0.6 that is the least efficient especially in the living room. The most effective ways to reduce overheating in the living room and room 1 is the option with a control of solar blinds from solar radiation on the surface with a shading factor fixed at 1. The other options give also good results in terms of overheating reduction in each room of the house.

Table 4. Estimated annual overheating percentage in the passive house for different scenario – results for a calibrated simulation model in TRNSYS; [1]shading factor for solar blinds; [2]air flow rate through windows when a manual opening is applied.

	Living room	Office	Room 1	Room 2	Room 3	Bathroom 1	Bathroom 2
Reference Overheating percentage	8%	4%	6%	4%	3%	4%	3%
Setpoint solar blind : 24°C	3.7%	1.4%	3.7%	2.0%	0.4%	1.8%	0.4%
Solar radiation regulation / Shading factor[1] : 0.6	7.5%	2.5%	5.2%	3.9%	0.7%	2.5%	1.0%
Solar radiation regulation / Shading factor : 1.0	1.6%	0%	0.8%	0%	0%	0%	0%
Manual windows opening / night freecooling Air rate[2] : 2 vol/hr	5.4%	1.0%	0.6%	0.3%	0.3%	0.3%	0.2%
Manual windows opening / night freecooling Air rate : 4 vol/hr	4.7%	0.8%	0.3%	0.1%	0.1%	0%	0%

5. Discussions

It was possible to calibrate a simple simulation model using short sets of temperature data. However the difficulties are to get on one hand reliable and complete weather data and on the other hand to obtain information about the house (architectural, structural, operational, etc.) in order to build a simulation model as accurate as possible. Sorting and organization of weather data represented the most time-consuming part besides the calibration test and validation.

Another remark is the difficulty to get an accuracy of the model in dynamic conditions. Indeed the calibration of a given influence parameter may result in a good fitting in a room but at the same time causes dispersion of values in another room. The problem is that in thermal dynamic simulation the variation of a parameter causes different responses in the thermal zones of the model due to occupancy factor for example or other phenomenons like sun exposure, inertia, etc. Another explanation of this difference is the sensors resolution of 0.5°C.

Among the various scenario considered the most efficient is the control of solar blinds based upon the solar radiation intensity with a shading factor of 1. However this solution isn’t cost efficient because it means changing the entire solar protection system and investing in a new type of sensors more expensive than the thermal sensor currently installed in the house. Moreover, with a shading factor of 1, the total closure of the solar blinds during the day could be uncomfortable for the occupants who may have to switch on the lights. For these reasons the scenario of night freecooling when the external air temperature is lower than the internal room temperature is recommended. The disadvantage is that this solution will depend on human interaction and sometimes the temperature seems to drop below 20°C (Fig.5) which could be inconvenient for the occupants. But this remains a very good way of fighting against overheating and moreover without any cost. Thanks to freecooling, the annual estimated percentage of overheating falls below 5% in the living room. There is a residual overheating percentage occurring during the holidays period where the occupants are not present (Fig.5). It is nevertheless considered that if nobody is present to feel the overheating then there is not overheating problem at all.

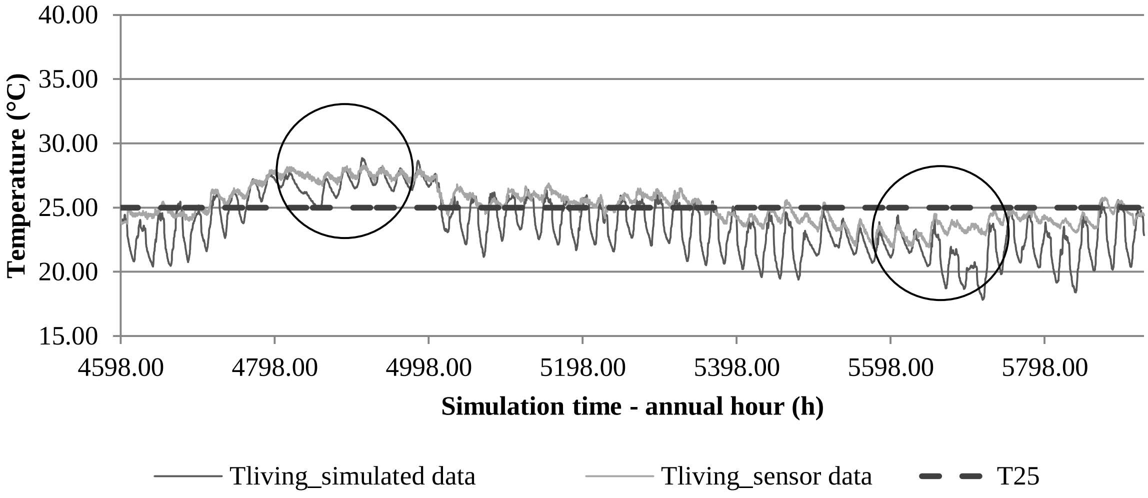

Fig.5. Temperatures in the living room: in dark line the simulated temperatures obtained with TRNSYS with a night freecooling; in grey line the reference temperatures data (sensors), dot line represents the limit of 25°C.Circles show the two holiday periods.

6. Conclusion

The method presented in this paper is a quick approach to evaluate the optimal solutions that could be used in a building to reduce or avoid the overheating risk. The procedure shows that it is possible to calibrate a simple model of building from a short period of data acquisition of in situ temperatures. The model could also be used in an audit process to evaluate the comfort during summer under different climates.

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We also want to thank the Spatial Center of Liege who provided meteorological data of Liege for the dynamic simulations.

Appendix A

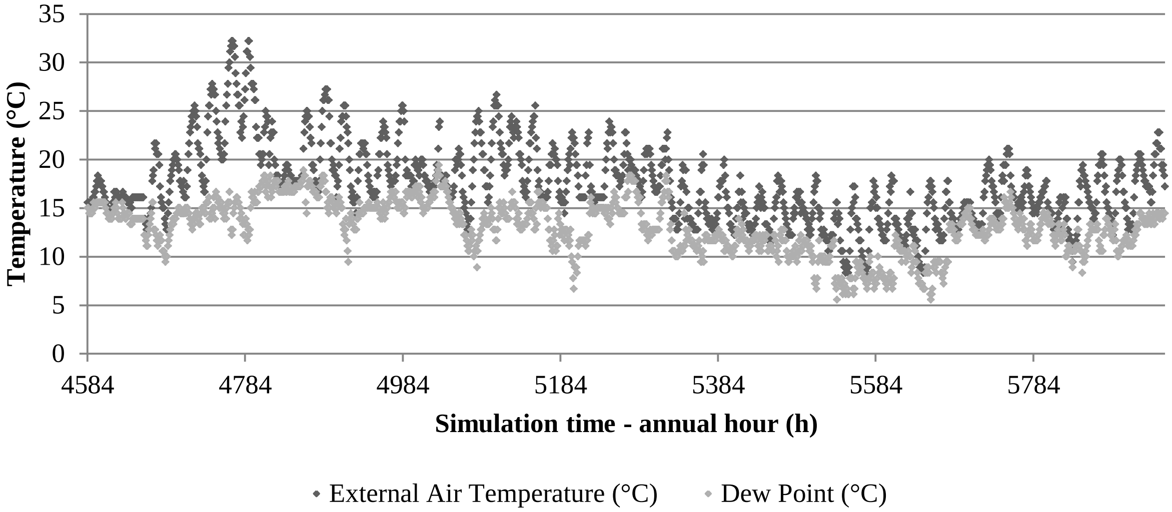

Fig. A.1. Weather data of SCL, external air temperature and dew point. The data were sorted to match the correct period of measurement in the study (summer period in 2014).

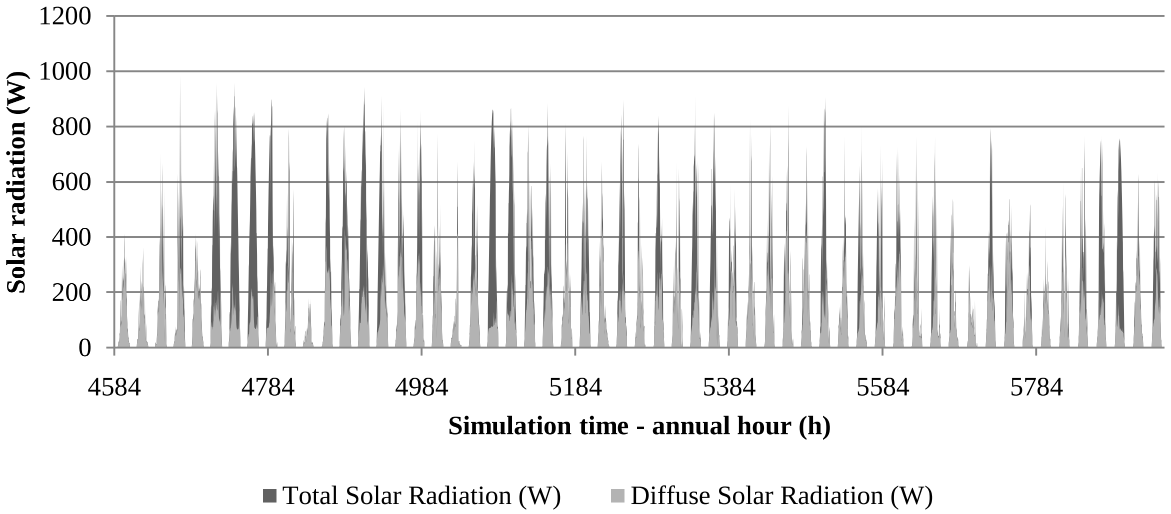

Fig. A.2. Weather data of SCL, total and diffuse solar radiations. The data were sorted to match the correct period of measurement in the study (summer period in 2014).

Appendix B

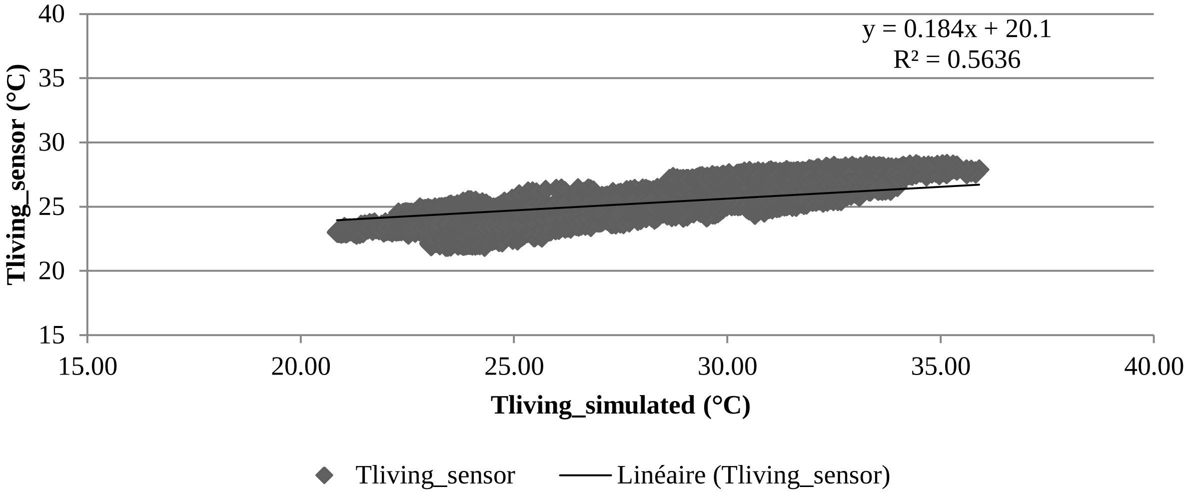

Fig. B. Calculation of determination coefficient between monitored and simulated temperatures in the living room.

Nomenclature

DHW: Domestic Hot Water

EBC (formerly ECBCS): Energy in Buildings and Communities Programme

HVAC: Heating Ventilation and Air-Conditioning

IDF: Input Data File

IEA: International Energy Agency

MAE: Mean Absolute Error

MAPE: Mean Absolute Percentage Error

MSE: Mean Square Error

n50 : Air infiltration rate at pressure difference of 50 Pascal, vol/h

NOAA: National Oceanic and Atmospheric Administration

PHP : Passive House Platform (in Belgium : "PmP")

PHPP: Passive House Planning Package

R: Correlation coefficient

R^2: Determination coefficient

RMSE: Root Mean Square Error

SCL: Spatial Center of Liege

TRNSYS: Transient System Simulation Tool

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