1 DEVELOPMENT AND ASSESSMENT OF A LOW COST SENSOR FOR SOLAR
2 HEAT FLUX MEASUREMENTS IN BUILDINGS

3
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11

12 **Abstract**
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14 This paper presents a new type of low cost solar sensor, i.e. a black and white sensor
15 (BWS). The BWS uses the difference in temperature of a white surface (solar energy
16 highly reflected) and a black surface (solar energy highly absorbed) to estimate the solar
17 heat flux through building openings. Results are obtained through a correlation based on
18 a thermal model of the sensor. The correlation contains calibration factors determined
19 from an initial on-site calibration. Results of estimated solar heat flux with two designs of
20 the BWS over two different periods of time were compared with solar measurements of a
21 high precision pyranometer. The two designs of BWS have shown mean weighted
22 relative errors over the sampling periods under 4% for the daily integrated solar energy
23 measured. Finally, a sensitivity analysis of the calibration period was conducted and it
24 was observed that ideal calibration period should consider at least half a day of
25 measurements, including solar peak time, and should be done during clear sky conditions.
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27 *Keywords:* Solar irradiance, solar heat flux, heat transfer, solar sensor, smart window
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30 **Nomenclature**

31	BWS	black and white sensor
32	Ct	surface thermal capacity, $\text{J/m}^2 \cdot \text{K}$
33	G	irradiance, W/m^2
34	k	thermal conductivity, $\text{W/m} \cdot \text{K}$
35	L	sensor cross-section thickness, m
36	Q	heat flux, W/m^2
37	T	temperature, K

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39 Greek symbols

40	α	absorptivity
41	ε	emissivity
42	ρ	density, kg/m^3
43	σ	Stefan-Boltzmann constant ($\sigma = 5.670 \cdot 10^{-8}$), $\text{W/m}^2 \cdot \text{K}^4$

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45 Subscripts / Exponents

46	b	back side of sensor surface
47	B	black surface
48	cond	conductive
49	conv	convective
50	f	front side of sensor surface
51	rad	radiative
52	ref	reference measurements
53	sol	solar
54	st	storage
55	surr	surrounding surfaces
56	W	white surface
57	zone	zone air node

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1. Introduction

With the considerable amount of available technologies in the field of active building envelopes [1][2][3] and the continuously increasing interest of owners to enhance the energy efficiency of their buildings, a lot of opportunities emerge to develop efficient sensors and control algorithms. Among others, windows with efficiently controlled dynamic glazing offer a high potential to control solar heat gain and minimize heating, cooling and lighting loads [4][5]. To control such technologies efficiently, accurate values of solar heat gains entering the building should be measured. Since the need for these solar sensors will increase with the degree of control and intelligence in smart buildings [6], the trade-off between their cost and their accuracy will become even more relevant.

Photovoltaic detectors that have been integrated in various types of irradiance measurement systems [7][8] are typically chosen for solar heat flux measurements because of their relatively accessible prices and ease of use [9]. However, they are sensitive to the spectral distribution and ambient temperature [10][11]. In general, these sensors will experience temperature fluctuation. Also, since a wide variety of spectrally selective coatings are offered for glass [12], the spectral distribution of solar irradiance passing through different windows will be inconsistent between different glazing configurations. For these reasons, errors could be introduced when illumination and temperature conditions are different from those under which the device was calibrated. On the other hand, pyranometers [13] offer more accurate results under various skies (broadband solar heat flux) and ambient air temperatures. There exist different types of thermopile pyranometers [14] such as all black or black and white pyranometers. However these devices are also considerably more expensive.

In order to obtain more accurate results at low costs under any type of sky conditions, this paper covers the development of two different designs of a low-cost broadband BWS constructed of common and inexpensive materials. This sensor is composed of two surfaces with different absorptive properties (a highly reflective white surface and a highly absorptive black surface). Instantaneous solar heat flux measurements are obtained through an on-site calibrated correlation based on the

temperature difference between those two surfaces. The two sensor designs analyzed in this paper were initially developed for smart window control purpose. However, it is worth noticing that the sensor designs and calibration methodology presented in this paper are general enough that they could be used to calibrate sensors for other applications or spectral profiles (for ex.: IR lamps).

2. Sensor description and thermal model

The BWS design consists of two thin metal plates with paint coatings of different solar absorptivity values: one highly absorptive coating (i.e.: black painted surface) and one highly reflective coating (i.e.: white painted surface). The painted metal plates are positioned next to each other on the same parallel plane with the painted surfaces (front surfaces) facing the exterior of the building. Temperature sensors are installed at the center of the back side of each metal plate. The high thermal conductivity of the metal plates ensures great accuracy of the surface temperature readings by the temperature sensors by distributing the temperature uniformly over the entire plate area (enabling a 1D heat transfer analysis at the center of the surfaces, where temperature sensors are positioned). The back sides of the metal plates are covered by an insulating material to limit heat transfer through the sensor and could act as the support of the sensor. Figure 1 illustrates a generic design of the sensor. Depending on the purpose of the sensor, many different variations in size and spacing between the painted surfaces could be considered in order to respond to particular needs. In all cases, the design should consider some type of thermal break between the two plates to limit heat transfer between them.

Figure 1 : Generic representation of the sensor.

To calculate solar heat flux from surface temperature readings, the BWS needs a correlation based on a thermal model that could be calibrated on-site to properly adjust the thermal parameters of interest. The present thermal analysis considers a 1D energy balance at the black and white surfaces of the sensor (front surfaces), as shown in Eqs. (1) and (2), respectively. The model considers the absorbed solar energy, radiative and convective heat fluxes at the front surface, conductive heat flux through the back of the sensor and the thermal capacity (heat storage) of the sensor:

$$\alpha_B G_{sol} = Q_{rad,W} + Q_{conv,f} + Q_{cond} + Q_{st,B} \quad (1)$$

$$\alpha_W G_{sol} = Q_{rad,W} + Q_{conv,f} + Q_{cond} + Q_{st,W} \quad (2)$$

Figure 2 illustrates a cross-section of the sensor, representative of both the black and white surfaces, to illustrate the different heat flux contributions of Eqs. (1)-(2).

Figure 2 : Heat balance at the sensor surfaces (cross-section view).

Considering spectrally integrated optical properties, a lumped capacitance model, see chapter 5 of [15], for the sensor thermal capacity and identical values for the black and white surfaces regarding (i) view factors with surrounding surfaces, (ii) convection coefficient (natural convection coefficients on B&W surfaces were estimated, see chapter 9 of [15], and presented sufficiently small differences to be neglected) and (iii) far-infrared emissivities, the energy balances become:

$$\alpha_B G_{sol} = \sigma \epsilon (T_B^4 - T_{Surr}^4) + h_{conv} (T_B - T_{zone}) + \frac{k}{L} (T_B - T_{zone}) + C \frac{\partial T_B}{\partial t} \quad (3)$$

$$\alpha_w G_{sol} = \sigma \epsilon (T_w^4 - T_{surr}^4) + h_{conv} (T_w - T_{zone}) + \frac{k}{L} (T_w - T_{zone}) + C \frac{\partial T_w}{\partial t} \quad (4)$$

Subtracting Eq. (3) from Eq. (4), one achieves an expression for the total solar irradiance on the sensor as a function of the black and white surface temperature measurements:

$$G_{sol} = \frac{\sigma \epsilon (T_B^4 - T_W^4) + h_{conv} (T_B - T_W) + \frac{k}{L} (T_B - T_W) + Ct \frac{(T_B^t - T_B^{t-1}) - (T_W^t - T_W^{t-1})}{\Delta t}}{\alpha_B - \alpha_W} \quad (5)$$

Note that the temporal derivatives of the temperature have been discretized to achieve this equation. Eq. (5) can be rewritten by grouping physical parameters into constants that it will be possible to adjust in order to fit the model with the measurements:

$$G_{sol} = A \sigma (T_B^4 - T_W^4) + B (T_B - T_W) + C \frac{(T_B^t - T_B^{t-1}) - (T_W^t - T_W^{t-1})}{\Delta t} \quad (6)$$

where $A = \frac{\epsilon}{\alpha_B - \alpha_W}$ is the “radiative” term, $B = \frac{h_{conv} + \frac{k}{L}}{\alpha_B - \alpha_W}$ is the “convective” term and

$C = \frac{Ct}{\alpha_B - \alpha_W}$ is the “thermal capacity” term. The calibration factors A, B and C of Eq.

(6) can then be determined using measured values for T_B , T_W in combination with reference measurements for solar heat flux. The following section presents two different sensor designs that were calibrated for solar irradiance measurements using Eq. (6).

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149 3. Experimental setups

The two designs of BWS presented in this paper were tested in the MoWiTT (Mobile Window Thermal Test) facility [16], located at Lawrence Berkeley National Laboratory (LBNL) in Berkeley, CA.

Sensors, both facing the exterior, were either located in the interior of the MoWiTT facility (Large Sensor) or within the interior air filled cavity of the glazing unit (Small Sensor). Both sensors were positioned parallel to the glazing in order to receive the total hemispheric solar energy that passed through the whole glazing system (and not the frame). The glazing unit was composed, from outside to inside, of 2.2 mm Cardinal loE 180 glass / exterior sealed cavity of 11.7 mm 90% argon filled / 2 mm Cardinal clear glass / interior unsealed cavity of 28.5 mm air filled / 2.2 mm Cardinal i89 glass. The

glazing unit was installed in a Pella Designer Series Fixed Casement window frame. Table 1 presents the window properties under standard NFRC conditions. Center-of-glass (COG) results of Table 1 refer to COG results while *Overall* results consider the overall window with frame. The installed window had dimensions of 0.914 m width by 1.219 m height (3 ft by 4 ft) and was oriented to the south. Measurements were taken during the month of August for the large sensor and during the month of September for the small sensor.

Table 1 : Description of the window optical and thermal properties under standard NFRC conditions

Window	Gap 1 (mm)	Gap 2 (mm)	Gap Fill 1	Gap Fill 2	Emissivity Surface 1	Emissivity Surface 2	Emissivity Surface 3	Emissivity Surface 4	Emissivity Surface 5	COG U factor (Btu/h-ft ² -F)	COG U factor (W/m ² -K)	COG SHGC	COG VT	Overall U factor (Btu/h-ft ² -F)	Overall U factor (W/m ² -K)	Overall SHGC	Overall VT
Pella Designer Fixed Casement	11.7	28.5	ARGON	AIR	0.840	0.068	0.840	0.840	0.149	0.16	0.90	0.60	0.72	0.21	1.19	0.42	0.50

Table 2 presents the considered materials, equipment and design parameters for both sensors. The large sensor was located at approximately 0.1 m from the interior surface of the glazing (Figure 3). Results for the large sensor are presented in Section 4.1. The small sensor, located in the interior glazing cavity (see Figure 4), was positioned at approximately 2 mm from the interior surface of the center glass pane to limit the effect of natural convection of the air cavity at the sensor surfaces. The small sensor also had the advantage to be located in such a way that it could still read solar irradiance when the window shade is down. Results for this sensor are presented in Section 4.2. Both sensors were centered with the window width and located at the sill edge of glass area.

The Hobo temperature logger (large sensor temperature measurements) uses a 2.5 V excitation and the measurement is made between the thermistors and a fixed resistor

(voltage divider). The Ohm to Celsius measurement conversions were managed by the HOBOWare. On the other hand, the Labjack (small sensor temperature measurements) has a built-in 10 μ A fixed current source. Several thermistors were chained in series with this current source including the thermistors of the small black and white sensor. The voltage drop across each thermistor was measured using the A/D (analog to digital) input channels (measured each voltage step in the resistor chain and subtracted to get each sensor). The thermistors resistance of the BWS were calculated with Ohms law from the known current and measured voltage drops. The Ohm to Celsius conversion was then achieved using parameters from the manufacturer's technical datasheet (B parameter equation). However, since the published B parameter equation parameters were found to be less accurate than desired, a second order polynomial fit was applied on top of it based on a sensor calibration (5 to 50°C in a controlled water bath Neslab RTE-221 against reference PRT probes read by an Azonix A1011).

Figure 3 : Large sensor – viewed from the exterior through the glazing.

Table 2 : Description of the sensors

Sensor type	Metal plates	T° sensors	B&W coatings	Insulated backing	Sensor assembly dimensions	Data logger
Small sensor	<u>Material:</u> Copper <u>Thickness:</u> 0.076 mm <u>Width:</u> 22.8 mm <u>Height:</u> 8.6 mm	TTF3A103F34D1BY thermistors sandwiched between two copper foils (conductivity of ~ 400 W/mK) with conductive epoxy Loctite 3873 (conductivity of 1.25 W/mK) <u>Tolerance:</u> $\pm 1\%$ in the range (-40°C to 100°C)	<u>Black Paint:</u> Rustoleum flat black enamel paint (aerosol spray can) <u>White Paint:</u> Rustoleum flat white enamel paint (aerosol spray can)	1.5 mm thick acrylic	<u>Overall thickness:</u> 3.65 mm <u>Overall width:</u> 57.8 mm <u>Overall height:</u> 13 mm <u>Notes:</u> Copper embedded T° sensors were stuck to acrylic with a 1 mm double stick foam	Labjack T7-PRO

					tape. The same foam tape was stuck to the backing of the acrylic too, to increase insulation. B&W metals plates separated by a 11.4 mm gap.	
Large sensor	<u>Material:</u> Aluminum <u>Thickness:</u> 0.77 mm <u>Width:</u> 106 mm <u>Height:</u> 99 mm	Onset TMC6-HD thermistors taped on metal plates with aluminum foil tape (conductivity of ~ 220 W/mK) <u>Tolerance:</u> $\pm 0.25^{\circ}\text{C}$ in the range (0°C to 50°C)	<u>Black Paint:</u> Rustoleum flat black enamel paint (aerosol spray can) <u>White Paint:</u> flat bright white primer	13.5 mm thick EPS foam ($k \approx 0.34 \text{ W/mK}$)	<u>Overall thickness:</u> 14.5 mm <u>Overall width:</u> 217 mm <u>Overall height:</u> 101 mm <u>Notes:</u> B&W metals plates separated by a 5 mm gap.	Onset Hobo U12-013

Figure 4 : Small sensor – viewed from the exterior through the glazing.

The pyranometer (Kipp and Zonen CM11 [17]) used for calibration was positioned inside the room just above the large sensor (vertically mounted). Its accuracy corresponds to maximum errors in the hourly radiation totals of 3%.

3.1 Calibration method

This section presents the methodology used to calibrate the factors A, B and C in Eq. (6) for both types of sensors.

Readings of the temperature sensors for the black and white surfaces were taken on a one minute basis over the entire period of calibration. In the study, both sensors were

calibrated considering daylight hours of a single day (a sensitivity analysis regarding the calibration period is presented in Section 4.3).

Calibration factors are optimized over the entire calibration period (m time steps) in Matlab with the interior-point algorithm of the `fmincon` solver [18]. The error function S to be minimized is defined as:

$$S = \sum_{i=1}^m (G_{\text{sol},i} - G_{\text{ref},i})^2 \quad (7)$$

where G_{sol} is the solar heat flux calculated from Eq. (6) and G_{ref} is the solar heat flux measured with the pyranometer. Bounds of the calibration factors are presented in Table 3.

Table 3 : Bounds for the fitting constants A, B and C in Eq. (6)

Inferior limit		Calibration factors		Superior limit
0	$\leq$	A	$\leq$	5
0	$\leq$	B	$\leq$	100
0	$\leq$	C	$\leq$	2500

In developing the sensor, it was found that the sensor design and its position relative to the exterior could affect the ability of the sensor to estimate the solar flux, and that this should be taken into account in the calibration. For example, Figure 5 illustrates partial shading of the black surface of the large sensor due to the window frame and setback. The black surface in Figure 5 is mostly exposed to diffuse solar irradiance while the white surface is completely exposed to diffuse and direct solar irradiance. Since the same amount of solar irradiance is required on both surfaces for Eq. (6) to give accurate results, data collected when partial shading occurred was not considered in the analysis presented in the following section. Also, since solar transmittance varies significantly between different glazing types, one should keep in mind that the calibration method presented in this section should be performed again whenever the glazing is different.

Figure 5 : Partial shading of the sensor.

4. Results

4.1 Large interior sensor

Since the large sensor was located in the interior of the room, its setback from the exterior wall of the facility created partial shading during some time intervals. In the present case, it was found that partial shading occurred from 9:45AM to 11:00AM and from 14:45 to 16:00. As mentioned earlier, data collected during these time intervals was not considered for the analysis.

The calibration period was during daylight hours of August 20th, 2014. The resulting optimized calibration factors were found to be $A = 3.42 \text{ [W/m}^2\text{K}^4]$, $B = 2.00 \text{ [W/m}^2\text{K}]$, $C = 2500.00 \text{ [J/m}^2\text{K}]$. Results of solar heat flux were then estimated from the correlation up to August 27th, 2014 (range of incident angles varying between approximately 63° and 90°). Figure 6 presents the scatter plot of the solar heat flux obtained with Eq. (6) over the entire period of measurements versus measurements obtained from the pyranometer. From Figure 6, we can see that the correlation offers a good agreement with the reference values (1:1 slope) with 86% of calculated solar irradiance values being within $\pm 10 \text{ W/m}^2$ of the reference values, 11% being between $\pm 10 \text{ W/m}^2$ and $\pm 20 \text{ W/m}^2$, and only 3% of occurrence being over $\pm 20 \text{ W/m}^2$.

Figure 6 : Large sensor solar irradiance obtained from the correlation, Eq. (6), as a function of the pyranometer measurements.

Since for several applications one will be interested in the integrated values of solar energy entering the building over a certain period of time [19] rather than in instantaneous solar intensities, it is relevant to make sure that the correlation can give accurate time integrated results. Figure 7 illustrates the daily integrated solar energy values calculated with the calibrated correlation and measured by the pyranometer.

Figure 7 : Large sensor integrated solar energy measurements on a daily basis.

From Figure 7 we can see that the BWS gives extremely accurate values for solar energy passing through the window with a mean weighted relative error of 1.5%. The mean weighted relative error is defined by:

$$\text{Error} = \frac{\sum_{i=1}^n \frac{|E_{\text{sol},i} - E_{\text{ref},i}|}{\bar{E}_{\text{ref}}}}{n} \cdot 100 \quad (8)$$

On an hourly basis, the mean weighted relative error is 3.7%. As previously said, the presented results do not consider hours of partial shading. In some applications (e.g. real time control with solar heat flux input), the large sensor design would not be appropriate because of the lack of reliable data during extended periods of time. Furthermore, since the large sensor design is quite bulky, material costs are not minimized and it cannot be easily integrated in between window glass panes for more permanent measurement applications. For these reasons, a smaller sensor was design and tested, as presented in the next sub-section.

4.2 Small sensor integrated into the glazing unit

Since small sensor setback from the exterior wall plane was significantly lower than the one for the large sensor, partial shading hours were different. The setback was actually small enough to consider all data collected between 8:00 and 17:00.

The calibration period was during daylight hours of September 18th, 2014. The resulting optimized calibration factors were found to be $A = 1.99 \text{ [W/m}^2\text{K}^4]$, $B = 47.35 \text{ [W/m}^2\text{K}]$, $C = 1963.30 \text{ [J/m}^2\text{K}]$. Results of solar heat flux were then estimated from the correlation up to September 23rd, 2014 (range of incident angles varying between approximately 53° and 90°). Figure 8 presents the scatter plot of the solar heat flux obtained with Eq. (6) over the entire period of measurements versus measurements obtained from the pyranometer. From Figure 8, we can see that, as for the large sensor, the correlation offers a good agreement with the reference values with 74% of calculated solar irradiance values being within $\pm 10 \text{ W/m}^2$ of the reference values, 18% being between $\pm 10 \text{ W/m}^2$ and $\pm 20 \text{ W/m}^2$, and only 8% of occurrence being over $\pm 20 \text{ W/m}^2$.

Figure 8 : Small sensor solar irradiance obtained from the correlation, Eq. (6), as a function of the pyranometer measurements.

Figure 9 illustrates the daily integrated solar energy values calculated with the calibrated correlation and measured by the pyranometer. From Figure 9 we can see that the BWS gives extremely accurate values for solar energy passing through the window glazing with a mean weighted relative error of 2.9%. The same analysis, but on an hourly basis, gave a mean weighted relative error of 3.9%.

Figure 9 : Small sensor integrated solar energy measurements on a daily basis.

Based on these results, instantaneous solar heat flux measurements obtained with the small sensor are less accurate than the ones obtained with the large sensor (solar irradiance values being 86% within $\pm 10 \text{ W/m}^2$ for the large sensor compared to 74% for the small sensor). Integrated energy results present the same behavior between the two sensor designs with smaller differences in results (daily and hourly mean weighted relative errors being, respectively, 1.5% and 3.7% for the large sensor compared to 2.9%

and 3.9% for the small sensor). The loss of accuracy of the small sensor could be explained by two major reasons. First, the small sensor is located in the window IGU that experiences higher variations in convection coefficient (fluctuating ambient temperature). Also, because of its size and shape, the small sensor is more sensitive to the thermal edge effects (temperature gradients parallel to the plane of the black and white surfaces) that have not been considered in the model (Eq. (6)). This reduction in accuracy for the small sensor is however compensated by its larger flexibility in terms of periods where collected solar heat flux data is reliable (periods without partial shading). The small sensor thus presents a very good tradeoff between accuracy and real-time control purpose since results are accurate enough for many applications and give reliable inputs for real-time control applications.

4.3 Effect of the calibration period

While calibrating the BWS, it is necessary to make sure that the calibration period is sufficient to ensure a good accuracy for the correlation when solar conditions change (variations in solar intensity and/or spectral distribution). For example, we can observe important changes of solar irradiance measured by the pyranometer from one day to another (see Figure 10). The first two days of measurements in Figure 10b (Sept. 18th and 19th) present high solar irradiance values with some lower values scattered throughout the day (more importantly during the morning of Sept. 18th). These two days could be defined as partially cloudy days. The following two days (Sept. 20th and 21st) present very low solar irradiance values and are defined as overcast days. Finally, the last two days (Sept. 22nd and 23rd) present a very smooth variation of solar irradiance measurements with high solar intensity at noon and could be defined as clear sky days. Furthermore, solar irradiance changes from hour to hour in part because of sun's position. It is thus relevant to analyze the influence of the moment of the day when the calibration period is defined as well as the day itself (type of sky conditions). For this reason, this section presents different calibration periods considered to fit the constant of Eq. (6). In other words, for each calibration day, one set of A, B and C is thus determined. Then, the resulting models were used to verify whether they were able to predict solar irradiance for all days for which measurements with the pyranometer were available (including the

calibration day, i.e. between August 20th and August 27th 2014 for the large sensor and between Sept. 18th and Sept. 23rd 2014 for the small sensor).

Figure 10 : Solar heat flux measured by the pyranometer between 8:00 AM to 5:00 PM from a) August 20th, 2014 to August 27th, 2014 and b) September 18th, 2014 to September 23rd, 2014.

Figure 11 presents the influence of the calibration period on the BWS precision by considering different days and calibration period. The term “BWS precision” represents the percentage of calculated irradiance values obtained with the calibrated correlation that are within 10 W/m² compared to the measurements of the pyranometer. Each point in Figure 11 represents the BWS precision for a calibration period starting at 9:00AM and stopping at the calibration period stop time (x-axis). Figure 11a and Figure 11b present results for the large and small sensors, respectively. From Figure 11, we observe, for both sensor designs, that the precision increases as the calibration period increases and stabilizes when calibration period reaches 1:00PM (calibration period of 5 hours), i.e.

after half a day of solar measurements, including the solar peak. Also, we observe that partially cloudy days (i.e. August 22nd and 25th for the large sensor and Sept. 18th and 19th for the small sensor) and overcast days (August 20th for the large sensor and Sept. 20th and 21st for the small sensor) present a BWS precision that is more sensitive to the calibration period. On the other hand, clear sky days (August 21st, 23rd, 24th, 26th and 27th for the large sensor and Sept. 22nd and 23rd for the small sensor) present more stable results and higher precision. It is thus recommended, based on this sensitivity analysis, to choose a day with clear sky conditions for the “on-site” calibration. Also, as mentioned in the previous section, it is clear from Figure 11 that the sensor design influences its accuracy (large sensor precision of 93% compared to 76% for the small sensor).

Figure 11 : BWS precision (i.e. a) large sensor and b) small sensor) as a function of the calibration period stopping time (considering a calibration starting time of 8:00 AM) and of the calibration day.

5. Conclusions

This paper presents a new type of low cost solar sensor, i.e. a black and white sensor that calculates instantaneous solar heat flux based on a 1D heat transfer model. The heat transfer model contains calibration factors defining the radiative, convective/conductive and capacitive parameters of the sensor.

In the present study the sensor was calibrated on-site with a reference pyranometer prior to measurements. However, to increase the ease of use, it would be relevant in the future to develop a procedure allowing off-site or lab calibration of the sensor.

Two different designs of sensor were presented, i.e. a large sensor located in the interior of building and a small sensor located into the interior glazing cavity of a triple pane glazing. Both sensors have shown satisfactory accuracy for solar heat flux measurements. Among the two designs tested, the large sensor was more accurate, mainly due to the fact that it was exposed to more stable conditions and edge effects were limited. However, it is shown that the large sensor measurements are limited to more restricted periods of time since partial shading is occurring during extended periods of time (which is not the case for the small sensor). Moreover, if window shading is down, the large sensor could not continue to measure solar irradiance while the small sensor could. Different sizes and locations could thus be used in order to suit different applications, but further studies must be conducted in order to assess edge effects for very small sizes of the sensor black and white surfaces.

Since this study presents results gathered over a particular period of the year, further studies should determine the long term performance of the sensors calibration.

Finally, since photosensors are largely used for solar irradiance measurements, future research should compare this kind of sensor to conventional silicon sensors in order to define more precisely the pros and cons of both types (e.g., spectral sensitivity, cost, lifetime, etc.).

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