EXPERIMENTAL METHOD TO DETERMINE THE ENERGY ENVELOPE PERFORMANCE OF BUILDINGS

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ABSTRACT

In France, buildings represent 40% of the annual energy consumption. This sector represents an important stack to achieve the objective of reducing by 4 the greenhouse gas emissions by 2050. Knowledge of construction techniques and the use of equipments are the main keys to realize low energy buildings.

To achieve this aim, we monitored 24 experimental buildings. In order to evaluate these experimental buildings we compare the monitored energy performance to the predicted energy performance and explain the differences between both performances.

Therefore, we developed an in-situ method to determine the thermal envelope performance of buildings \( U_{\text{building}} \). The buildings are monitored in order to know the followings inputs:

- Occupancy rate;
- Heat supply;
- Solar supply;
- Ventilation and airflow losses
- Distributions losses

The method is based on the following equation which translates the energy balance of a building's envelope:

\[
U_{\text{building}} \times (T_{\text{inside}} - T_{\text{outside}}) = \sum Q_{\text{supply}} - \sum Q_{\text{losses}}
\]

With

- \( U_{\text{building}} \): thermal performance envelope
- \( Q_{\text{supply}} \): energy supply of the building
- \( Q_{\text{losses}} \): energy losses of the building
- \( T_{\text{inside}} \): inside building’s temperature
- \( T_{\text{outside}} \): outside building’s temperature

The aim of this paper is to present the developed method and monitoring protocol. In order to validate the proposed experimental approach, we will present applications on different monitoring buildings in context of the project PREBAT (Research Program on Building’s Evaluation): the restaurant of the primary school of Langueux.

THE EBBE METHOD

The energy balance of the building envelope

The method is based on the equation 1 which translates the energy balance of a building:

\[
Q_{\text{heat supply}} = Q_{\text{envelope transmissions}} + Q_{\text{internal supply}} + Q_{\text{solar supply}} + Q_{\text{airflow losses}} \quad [\text{kWh}]
\]

With

- \( Q_{\text{heat supply}} \): energy supply for heating the building
- \( Q_{\text{internal supply}} \): energy supply due to the internal gain : occupancy, electric appliance and lighting
- \( Q_{\text{solar supply}} \): energy supply due to solar gain
- \( Q_{\text{airflow losses}} \): energy losses due to airflow : ventilation and building air tightness

INTRODUCTION

In France, buildings represent 40% of the annual energy consumption. This sector represents an important stack to achieve the objective of reducing by 4 the greenhouse gas emissions by 2050. Knowledge of construction techniques and the use of equipments are the main keys to realize low energy buildings.

To achieve this aim, we monitored 24 experimental buildings. In order to assess these experimental buildings we compare the monitored energy performance to the predicted energy performance, through the EBBE Method (energy balance of building’s envelope) that helps us to explain the differences between both performances.

Therefore, we developed an in-situ method to determine the thermal losses of building’s envelope \( U_{\text{building}} \). It is based on the energy balance equation of the building’s envelope and on a monitoring protocol defined in order to be able to calculate each terms of the equation.

The aim of this paper is to present the EBBE (energy balance of building’s envelope) method and the monitoring protocol. In order to test the proposed approach, we will present an application on a monitored building in context of the project CEBO (Research Program on Existing Building’s Evaluation): the restaurant of the primary school of Langueux.
We developed a method to determine each terms of the equation based on 3 tools that enable to resolve the energy balance of building. As it is shown on the following schedule, we have (cf. Figure 1):

- Tool n°1: Solar supply. This tool allows calculating the solar supply to the building during the considered period.
- Tool n°2: air flow losses. It permits to calculate the losses due to ventilation, opening windows and air tightness of the building.
- Tool n°3: Internal supply, for calculating the internal gain due to occupancy, lighting and equipment.
- Tool n°4: Energy balance of building’s envelope with the results of tools n°1, 2, 3 and the inputs known by the monitoring of the building, we are able to make the energy balance of building envelope and estimate the energy supply for energy balance of building’s envelope.

Tool 1 Solar energy supply
To determine the solar gain, we used the tool developed by J.A. Bouchet, CETE Méditerranée, for the project PREBAT (Research Program on Building’s Evaluation). This tool calculates the solar energy supply for energy balance of building’s envelope with the daily global irradiance of the place considered.

For each face of the building, the tool defined for each day of the year, the equivalent horizontal surface of the building for the direct and the diffuse radiation.

We usually do not have the measured global radiation. Therefore, the tools consider that the value of the global radiation is near to the average of the 10 last years. With the weather data of 40 cities in France, we are able to determine the solar gain for the place considered.

Tool 2 Airflows loss
The airflow loss is due to heat losses through ventilation \(Q_{\text{airflow losses ventilation}}\) and through the building’s air tightness \(Q_{\text{airflow losses tightness}}\).

\[
Q_{\text{airflow losses}} = Q_{\text{airflow losses ventilation}} + Q_{\text{airflow losses tightness}} \quad [\text{kWh}]
\]  

To determine the airflow losses due to ventilation, we have to monitoring the inside and outside temperature and the electricity consumption of the ventilation extractors. We assume that the maximal electricity consumption is associated to maximal airflows according to the technical manual of the equipments. With these data, we are able to calculate the heat losses due to ventilation for each week according to the equation 7.

\[
Q_{\text{airflow losses ventilation}} = 0.34 \times V_{\text{ventilation}} \times (T_{\text{inside}} - T_{\text{outside}}) \quad [\text{kWh}]
\]  

With 
\(V_{\text{ventilation}}\) the airflow due to the ventilation extractors  
\(T_{\text{inside}}\) the inside temperature inside  
\(T_{\text{outside}}\) the outside temperature

The calculation of heat loss due to building’s air tightness is based on measured air tightness according to the protocol defined by the norm NF EN 13829. The airflows through the building envelope.
due to tightness, $V_{t_{ightness}}$ is then calculated with equation 8.

$$V_{t_{ightness}} = I_4 + 1 + 2 \cdot V_{heat} \cdot e \cdot f \quad [m^3/h]$$

With

- $I_4 [m^3/h.m^2]$ the air tightness of the building measured
- $V_{heat} [m^3]$ the heated volume of the building
- $S [m^2]$ the inside surface of the building’s envelope
- $e$ height corrective coefficient, taking into account the augmentation of the wind speed with the height (cf. figure 4)
- $f$ the exposition coefficient, depends on the exposition of the building to the wind (cf. figure 5)

The studied period is during winter and we consider that the occupants do not open the windows. We do not have any energy loss due to opening windows.

### Tool 3: internal energy supply

The internal energy supply is due to occupancy $Q_{occupancy}$, lighting $Q_{lighting}$, and electric appliance gain $Q_{equipment}$ and electric appliance gain $Q_{internal}$ and electric appliance gain $Q_{equipment}$.

$$Q_{internal} = Q_{occupancy} + Q_{lighting} + Q_{equipment}$$

The internal energy due to occupancy is calculated from the occupancy rate per hour with the metabolism energy production according to the activity Met $[W/m^2]$ (cf. Table 1) and with a correction for children. We consider that the corporal area is 1.8 m$^2$ for adults and 1 m$^2$ for children.

The internal energy supply due to occupancy $Q_{occupancy}$ is given by the following equation:

$$Q_{occupancy} = Met \cdot S \cdot t \quad [kWh]$$

With

- $S [m^2]$ the corporal area of the occupant
- $t [h]$ the time of occupancy
- Met $[W/m^2]$ the metabolism energy production

### Activity Metabolism energy production

<table>
<thead>
<tr>
<th>Activity</th>
<th>Metabolism energy production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest, be lying</td>
<td>46 [W/m²] [Met]</td>
</tr>
<tr>
<td>Rest, be sit</td>
<td>58 [W/m²] [Met]</td>
</tr>
<tr>
<td>Sedentary activity (work desk, at home, school, laboratory)</td>
<td>70 [W/m²] [Met]</td>
</tr>
<tr>
<td>Slight activity, standing up (Purchasing, laboratory, slight industry)</td>
<td>93 [W/m²] [Met]</td>
</tr>
<tr>
<td>Moderate activity, standing up (sale, housework, work on machines)</td>
<td>116 [W/m²] [Met]</td>
</tr>
<tr>
<td>Walking with 2km/h speed</td>
<td>110 [W/m²] [Met]</td>
</tr>
</tbody>
</table>

The unit of the metabolism energy production is the met. One met corresponds to the metabolism of one person at rest and valued 58.2 W/m² per corporal unit surface, knowing that the rate of corporal surface is 1.8 m² for an person.

The internal gain due to electric appliance is calculated from the number in use per hour with their
electric power (cf. table 2). We assume the electric appliance is only in use when building is occupied.

\[ Q_{\text{internal supply equipment}} = \sum_{i=1}^{n} t_i \cdot P_i \quad \text{[kWh]} \quad \text{equation 5} \]

With

- \( N \) the number of appliance
- \( t_i \) [h] the time of use of appliance \( n^i \)
- \( P_i \) [Wh] the heat energy due to the use of appliance \( n^i \)

The heat energy due to the use during one hour is given in the table for several types of equipments and function of the state of use.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>State of use</th>
<th>Heat energy [Wh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central processing unit</td>
<td>ON</td>
<td>47</td>
</tr>
<tr>
<td>Sleep mode</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OFF</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>Screen</td>
<td>ON</td>
<td>21</td>
</tr>
<tr>
<td>Sleep mode</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>OFF</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>Printer</td>
<td>ON</td>
<td>52</td>
</tr>
<tr>
<td>Sleep mode</td>
<td>17.5</td>
<td></td>
</tr>
<tr>
<td>OFF</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Photocopier</td>
<td>ON</td>
<td>133</td>
</tr>
<tr>
<td>Sleep mode</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>OFF</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>fax</td>
<td>ON</td>
<td>25</td>
</tr>
<tr>
<td>Sleep mode</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>OFF</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Electric range</td>
<td>ON</td>
<td>1150</td>
</tr>
<tr>
<td>Induction range</td>
<td>ON</td>
<td>588</td>
</tr>
<tr>
<td>Vitroceramic range</td>
<td>ON</td>
<td>999</td>
</tr>
<tr>
<td>Oven</td>
<td>ON</td>
<td>1331</td>
</tr>
<tr>
<td>Small Oven</td>
<td>ON</td>
<td>898</td>
</tr>
<tr>
<td>Microwave</td>
<td>ON</td>
<td>913</td>
</tr>
<tr>
<td>Kettle</td>
<td>ON</td>
<td>1200</td>
</tr>
<tr>
<td>Collepot</td>
<td>ON</td>
<td>800</td>
</tr>
</tbody>
</table>

**Figure 5.** Heat energy due to the use of equipment during one hour

To assess the internal gain due to lighting \( Q_{\text{internal supply}} \), we assume that 100% of the electricity consumption of a light is dissipated in internal gain. Therefore, we can deduce the energy supply due to lighting for each week of the concerned period by monitoring the electricity consumption per hour of lighting.

**Tool 4: EBBE: Resolving the energy balance of the envelop**

With tools n°1, 2 and 3 we can calculate:

- \( Q_{\text{internal supply}} \): energy supply due to the occupancy, the equipments and the use of lighting
- \( Q_{\text{solar supply}} \): energy supply due to solar gain
- \( Q_{\text{airflow losses}} \): energy losses due to ventilation and building’s air tightness airflow

Monitoring the inside and outside temperature, we can choose an experimental value of the thermal envelope performance \( U_{\text{building}} \) to make the energy balance of building’s envelope.

\[ Q_{\text{calculated}} = U_{\text{building}} \cdot (T_{\text{inside}} - T_{\text{outside}}) + Q_{\text{internal supply}} + Q_{\text{solar supply}} + Q_{\text{airflow losses}} \quad \text{[kWh]} \quad \text{equation 10} \]

With the inputs known by the monitoring of the building, we can calculate the rate of energy supply for heating the building \( Q_{\text{measured}} \).

We can compare the difference between measured and calculated energy supply for heating for a thermal performance envelope \( U_{\text{building}} \).

\[ \delta = \frac{Q_{\text{measured}} - Q_{\text{calculated}}}{Q_{\text{measured}}} \times 100 \quad \% \quad \text{equation 11} \]

The difference is calculated for each week of the considered period. We can choose a thermal performance envelope \( U_{\text{building}} \) when the difference is minimized between the values calculated and measured.

**The monitoring protocol**

The monitoring protocol has to be defined in order to retrieve the necessary inputs to resolve the equations of the EBBE method.

- the internal gain : number of electric power, occupation rate and hours, lighting consumption
- heat supply of heating system : heat supply monitoring
- solar gain : global horizontal radiance
- airflow losses : building’s air tightness according norm NF EN 13829
- ventilation : electric consumption of the extractors
- In-and outdoor air temperature for the heat losses calculation due to airflow and for resolving the heat balance equation

Frequency of measuring has to be hourly.
APPLICATION

Monitored building

The case studied is on the restaurant of a primary school based in the city of Languex, France. The building was built in 1987 and its area is 713 m². It is composed with 2 rooms for receiving the children and a part for prepare the cooking. The heat system is a gas boiler with fin-type radiator. Three single extractors maintain the ventilation of the locals.

Thanks to the monitored protocol, a calorimeter was installed to follow the energy supply for heating the building by the boiler. Electric counters were put in to follow the electric consumption of lighting and the three ventilation extractors. Several thermometer in different rooms enable to follow the inside temperature. The time step of each measure is one hour.

The monitoring was made for 14 weeks, from the 4th of January 2010 to the 11th of April 2010.

Tool 1 Solar energy supply

With the solar inputs measured, we calculated the solar energy supply for energy balance of building’s envelope with the daily global irradiance of the place considered.

Tool 2 Airflow Losses

We measured the tightness of the building, based on the protocol defined by the norm NF EN 13829. The result was a tightness of $I_1 = 2.5 \text{ m}^3/\text{h.m}^2$ for a building envelope of 1232 m² and a volume of 2053 m³. The airflow through the building envelope calculated with tool n° 2 is about 350 m³/h.

Tool 3 Internal energy supply

The restaurant is occupied by 350 children and 15 adults on Monday, Tuesday, Thursday and Friday. They eat from 12:00 to 14:00. 7 people work for prepare the cooking and wash the room from 10:00 to 12:00 and from 14:00 to 16:00.

On Wednesday, we just have 73 people in the restaurant for eating. During holidays, we don’t have any occupation of the building.

30 percent of the adult population have a sedentary activity and 70% gave a slight activity. The entire population of children has a slight activity. The following rate gives the internal energy supply due to occupancy during a week.

During one worked week, the internal energy supply due to occupancy is about 193 kWh.

The equipments in the building are:

- 1 central processing
- 1 screen
- 1 fax
- 1 oven
- 1 microwave
- 1 kettle
- 1 coffeepot

The following table gives the state of use during occupation and inoccupation of the building.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Occupation</th>
<th>Inoccupation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ON</td>
<td>Sleep mode</td>
</tr>
<tr>
<td>Central processing</td>
<td>80%</td>
<td>20%</td>
</tr>
<tr>
<td>Screen</td>
<td>80%</td>
<td>20%</td>
</tr>
<tr>
<td>Fax</td>
<td>10%</td>
<td>90%</td>
</tr>
<tr>
<td>Oven</td>
<td>60%</td>
<td>-</td>
</tr>
<tr>
<td>Microwave</td>
<td>60%</td>
<td>-</td>
</tr>
<tr>
<td>Kettle</td>
<td>40%</td>
<td>-</td>
</tr>
<tr>
<td>coffeepot</td>
<td>2%</td>
<td>-</td>
</tr>
</tbody>
</table>

According to the occupancy rate, established previously, this is the rate of energy supply due to equipment during one week.
During one worked week, the total internal energy supply due to equipment is about 53 kWh.

**Tool 4 Energy Balance of the envelope**

In order to make the energy balance of the envelope, we measured the energy supply for heat the building during 14 weeks.

**RESULTS**

The following table shows the energy balance of building’s envelope for the restaurant of the primary school in Langueux for a thermal performance envelope of $U_{building} = 0.8 \text{ W/m}^2\text{K}$. Just 3 weeks are shown instead of the 14 weeks of study.

<table>
<thead>
<tr>
<th>Week</th>
<th>Solar energy supply</th>
<th>Energy supply due to lighting</th>
<th>Energy supply due to occupants and equipment</th>
<th>Airflow loss due to ventilation</th>
<th>Airflow loss due to infiltration of the envelope</th>
<th>Heat loss through envelope transfers [kW]</th>
<th>Heat supply calculated for $U_{building} = 0.8 \text{ W/m}^2\text{K}$</th>
<th>Heat supply measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>147</td>
<td>51.1</td>
<td>252</td>
<td>-759</td>
<td>-693</td>
<td>-4590</td>
<td>-5592</td>
<td>-7450</td>
</tr>
<tr>
<td>2</td>
<td>157</td>
<td>47.5</td>
<td>252</td>
<td>-737</td>
<td>-658.7</td>
<td>-4360</td>
<td>-5300</td>
<td>-5190</td>
</tr>
<tr>
<td>3</td>
<td>184</td>
<td>51.8</td>
<td>252</td>
<td>-585</td>
<td>-557</td>
<td>-3692</td>
<td>-4348</td>
<td>-3900</td>
</tr>
</tbody>
</table>

**Figure 9.** Energy balance of building’s envelope for the restaurant of the primary school for $U_{building} = 0.8 \text{ W/m}^2\text{K}$

We varied the thermal performance envelope $U_{building}$ from 0.75 W/m$^2$K to 1.1 W/m$^2$K and the following table give the difference $\delta$ between the energy supply for heat calculated and measured.

<table>
<thead>
<tr>
<th>$U_{building}$</th>
<th>0.75 W/m$^2$K</th>
<th>0.85 W/m$^2$K</th>
<th>0.9 W/m$^2$K</th>
<th>0.95 W/m$^2$K</th>
<th>1.0 W/m$^2$K</th>
<th>1.05 W/m$^2$K</th>
<th>1.1 W/m$^2$K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week</td>
<td>Difference $\delta$ between the energy supply for heat calculated and measured [%]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>35</td>
<td>32</td>
<td>28</td>
<td>25</td>
<td>22</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>11</td>
<td>6</td>
<td>11</td>
<td>17</td>
<td>22</td>
<td>27</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>16</td>
<td>8</td>
<td>3</td>
<td>5</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>13</td>
<td>8</td>
<td>6</td>
<td>11</td>
<td>16</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>19</td>
<td>14</td>
<td>10</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>12</td>
<td>17</td>
<td>23</td>
<td>28</td>
<td>34</td>
<td>39</td>
</tr>
<tr>
<td>7</td>
<td>19</td>
<td>14</td>
<td>10</td>
<td>5</td>
<td>4</td>
<td>8</td>
<td>13</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td>16</td>
<td>22</td>
<td>28</td>
<td>34</td>
<td>40</td>
<td>46</td>
</tr>
<tr>
<td>9</td>
<td>18</td>
<td>25</td>
<td>32</td>
<td>39</td>
<td>46</td>
<td>53</td>
<td>59</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
<td>0</td>
<td>6</td>
<td>12</td>
<td>19</td>
<td>25</td>
<td>31</td>
</tr>
<tr>
<td>11</td>
<td>20</td>
<td>15</td>
<td>10</td>
<td>4</td>
<td>1</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>12</td>
<td>6</td>
<td>0</td>
<td>6</td>
<td>12</td>
<td>18</td>
<td>24</td>
<td>30</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>8</td>
<td>14</td>
<td>21</td>
<td>28</td>
<td>35</td>
<td>42</td>
</tr>
</tbody>
</table>

**Figure 10.** Energy supply for heat measured and calculated for different values of thermal performance envelope $U_{building}$

The following table gives the minimum, maximum, average and the relative scatter for the difference $\delta$ between the energy supply for heat calculated and measured for a thermal performance envelope $U_{building}$ from 0.75 to 1.1 W/m$^2$K.

<table>
<thead>
<tr>
<th>$U_{building}$</th>
<th>0.75 W/m$^2$K</th>
<th>0.85 W/m$^2$K</th>
<th>0.9 W/m$^2$K</th>
<th>0.95 W/m$^2$K</th>
<th>1.0 W/m$^2$K</th>
<th>1.05 W/m$^2$K</th>
<th>1.1 W/m$^2$K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference $\delta$ between the energy supply for heat calculated and measured [%]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-500,0</td>
<td>0,0</td>
<td>500,0</td>
<td>1000,0</td>
<td>1500,0</td>
<td>2000,0</td>
<td>2500,0</td>
</tr>
</tbody>
</table>

**Figure 8.** Internal energy supply due to equipment [Wh] during a week (168hours)
According to this table, we can see that the difference $\delta$ between the energy supply for heat calculated and measured, has the smaller average for a thermal performance envelope $U_{\text{building}}$ between 0.8 and 0.85 W/m².K.

**DISCUSSION**

The figure 12 shows the comparison between the energy supply for heat measured with the monitoring protocol $Q_{\text{measured}}$ and the energy supply for heat calculated with the EBBE method $Q_{\text{calculated}}$, for different thermal performance envelope $U_{\text{building}}$.

Before the week n°1, the building was not heated during 2 weeks because of the Christmas holidays. This period was very cold, and the building has a high thermal inertia. The energy supply for heat supply was important during the week n°1. The EBBE method doesn’t take into account these phenomena of thermal inertia. Therefore we should to not take into account the week n°1 to choose the thermal performance envelope $U_{\text{building}}$.

In addition, during weeks n°7, 8, 11, 12, 13 and 14, as we can see and the figure 10, the average outside temperature is higher than 7°C. During these periods, the occupants use the windows and the EBBE method does not take into account the inherent airflows. Therefore, we should not consider these weeks for choosing the thermal performance envelope $U_{\text{building}}$.

Eliminating weeks n°1, 7, 8, 11, 12, 13, 14, we calculated the new difference $\delta$ between the energy supply for heat calculated and measured for different thermal performance envelope $U_{\text{building}}$ from 0.75 to 1.1 W/m².K. The following table gives the minimum, maximum, average and the relative scatter for the difference $\delta$ between the energy supply for heat calculated and measured for a thermal performance envelope $U_{\text{building}}$ from 0.75 to 1.1 W/m².K.
According to this table, we can suggest a new value of thermal performance envelope $U_{\text{building}}$ between 0.8 and 0.85 W/m².K.

Moreover, Thanks to the works of [David E.Claridge], it has been shown that infiltrations due to tightness $Q_{\text{airflow losses}}^\text{tightness}$ lead to a smaller change in the energy load than is customarily calculated. Changes as small as 20 percent of the calculated value were observed. Taking into account this possibility, we calculated the thermal performance envelope with airflows calculated reduced by 20 percent.

With this new consideration, we calculated the difference $\delta$ between the energy supply for heat calculated and measured lead to a thermal performance envelope of 0.85 and 0.9 W/m².K.

By the standard method of adding the theoretical thermal performance of each wall of the building, we calculated a thermal performance envelope $U_{\text{building}}$ of 1.0 W/m².K. We can consider that the EBBE method on this building, gives a good approximation of the theoretical results.

**CONCLUSION**

With the EBBE method, we defined a protocol of monitoring building and achieve to determine an experimental thermal performance envelope on the case of a building. A significant discrepancy is observed between the calculated and measured results.

The modelling of the opening of windows by the occupant has to be developed. Our protocol of monitoring building does not integrate devices to record the opening of windows by the occupants. This measure could be added for several locals of the buildings. Another possibility is to submit to the occupants to a questionnaire and elaborate a pattern of opening windows by the occupants.

A study on the uncertainty on the measure of the monitoring has to be done, in order to appreciate the results of the EBBE method. This method has also to be tested on larger amount of buildings. We planned to do it on 24 experimental building with high energy performance.

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