Influence of Air Leakage in Building’s Walls on Heat Transmission Loss through its Envelope

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ABSTRACT

The energy consumption of a building is evaluated by neglecting the heat loss which can occur when the air passes through the envelope. However, recent studies showed that air leakage plays a significant role by affecting the thermal performances of walls and the energy consumption. Most studies have focused on the quantification of air leakage flows through the building shell, without addressing the problem of the heat exchange between this airflow and the construction materials as the air passes through the envelope. The standard way of calculating a building load considers conduction (or assimilated) losses independently of airflow energy losses.

In this paper we present results from a parametric study conducted on two buildings: a single family dwelling and a school building in order to have a global view on air leakage impact on the overall heating load of a building. According to our calculations a significant part of energy load can be attributed to air leakage: till 8% for the single family dwelling and 12% for the school building.

KEYWORDS

Air leakage, air exchange, effective heat loss, thermal coupling.

INTRODUCTION

Current calculation methods for building energy consumption assume that heat loss associated with air leakage can be evaluated by multiplying the amount of air leakage by the sensible enthalpy gradient between inside and outside air.

Furthermore the transmission heat loss through the building shell is evaluated independently from air leakage passing through the envelope. In other word the interaction between the air leakage and the building structure in neglected. Many researchers have indicated that these assumptions may lead to an overestimation of building heat loss, especially when ventilation could results of unintentional air leakage through the envelope (Kohonen & Virtanen 1987 and Claridge & Bhattacharyya 1995). This interaction modifies the actual building heat loss compared to the conventional method that deals with heat transmission and air leakage effect independently. In a former paper we developed a simple model to predict the interaction between air leakage flow and the building structure (Barhoun & Guarracino, 2004). We have introduced a correction factor which is equal to the effective conduction heat loss divided by the area of the wall and the temperature gradient though the wall:

\[ U_L = \frac{\Phi_{\text{conduction}}}{A\cdot(T_w - T_c)} \]  
(Eqn. 1)
Where, $U_L \left( W \cdot m^{-1} \cdot k^{-1} \right)$, the effective U-value of the wall, $\Phi_{\text{conduction}} \left( W \cdot m^{-2} \right)$ the effective conduction heat loss through the wall, $A \left( m^2 \right)$ the area of the wall and $T_i \left( k \right)$ the temperature of the inside, $T_o \left( k \right)$ the temperature of the outside.

The aim of this paper is to present an application on two buildings in order to have a global view on air leakage impact on building heat loss. These two buildings are: a single family dwelling and a school building. First of all we have conducted air flow simulations using CONTAMW in order to predict air leakage flow rate inside building's walls. CONTAMW is a multizone air flow program that permit to predict air transfer between outside and inside as a function of various parameters such as wind speed and direction, temperature gradient and other parameters related to the nature of ground and the orientation of the building. Then we have applied our model to evaluate the effective U-value of each wall affected by air leakage and finally we have integrated that on the whole building.

**CASE STUDIES**

The single family dwelling was built in 1974 just before the first French Thermal Regulation. It's located in the south of France.

The school building called “Internat” was built in 1969 and rehabilitated recently. This building have a rectangular shape (146 m length by 14.5 m wide) aligned on the axe NE-SW. It has 4 levels of total surface of 10500 m² and a volume of 30700 m³. It also disposes of largely glazed façades oriented SE and NW. 18 m³/hour/person ventilation is assured by a central mechanical extraction system.

**AIR LEAKAGE IN BUILDING COMPONENTS MODELING**

The aim of this part is to predict air exchange between the different zones that constitute the building and outside by voluntary openings (reglementary ventilation) and unintentional cracks in the building’s envelope (air leakage). There are two main kind of air leakage: direct air flow leakage that flows through cracks directly to the heated space and diffuse air leakage that occurs in junctions between walls and other components of the envelope (wall/wall, wall/window – door junctions). The second kind of air leakage that flows through its structure may modify the thermal performance of the last one. In this approach we are interested by evaluating the
second kind of air leakage in order to evaluate its impact on heat transmission through the building shell.

We used CONTAM to model air exchange between outside and inside through the envelope. CONTAM is a multizone air exchange model developed by the National Institute of Science and Technology that has been validated by different experimental measurements (Haghighat, 2003 and Fang & Persily 1994). It contains also a large bibliography in term of experimental Effective Leakage Area for a wide variety of envelope components. A parametric study is done in order to evaluate air leakage flow rate through all the components of the envelope. The main common hypotheses for the two building are: Temperature gradient of 20 degrees between outside and inside, a wind velocity that varies between 0 and 10 m/s.

For the single family dwelling we have analyzed two scenarios: in the first one the ventilation is assured by a central mechanical extraction system. In the second scenario the ventilation is only assured by natural way through the different openings in the envelope. A pressure gradient of 10 pascals is supposed. These two scenarios allow us to study the combined effect of wind, buoyancy and ventilation system on air leakage flow rates through the envelope.

The school building was divided to 4 zones, each one represents a level. The wind blows in the NE-SW direction (perpendicular to the building’s façades).

![Diagram of the first floor of the single family dwelling with CONTAM](image)

**Figure 3**: Modeling of the first floor of the single family dwelling with CONTAM

**Summary of essential results**

We present here some of the principle results for air leakage flow rates through opaque walls. Figure 4 and Figure 5 represent the air leakage flow rate in opaque walls of the single family house for the first (with mechanical ventilation) and the second scenario (with natural ventilation). As these figures show, we can note the principle results: when ventilation is assured by a mechanical system almost all leakage flows are positives. It means that the use of an extraction system induce air infiltration through cracks and openings. The only case of exfiltration appears in the
south wall of the first floor starting from a wind velocity of 7 m/s. For the second scenario both infiltration and exfiltration cases are present. When air speed is high (> 5 m/s) exfiltration occurs in almost all the opposite walls to wind direction. We note here that for the north wall only infiltration occurs.

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Figure 4: First scenario: Air leakage flow rates in house’s opaque walls.

Figure 5: Second scenario: Air leakage flow rates in house’s opaque walls.

For school building the number of curves to present is very high. That’s why we have chosen not to show them in this paper.

HEAT LOSS THROUGH THE BUILDING ENVELOPE

In this part we conduct the computation of heat loss by transmission through the envelope for the two case studies. Our objective is to integrate the thermal impact of air leakage to heat loss computation. First of all a conventional computation of heat loss is made. In this case the interaction between air leakage and the envelope structure is neglected. Then by adding the impact of air leakage on heat transmission loss through opaque walls, an additional computation is done and that for the single family dwelling and the "Internat" school building envelope is characterized in the new French thermal regulation by coefficient $U_{\text{bât}}$:

$$U_{\text{bât}} = \frac{H_f}{A_f}$$ (Eqn. 2)
Where $A_T$ is the total interior wall surface ($m^2$) and $H_T$ is the heat loss by transmission ($W/k$) given by:

$$H_T = H_D + H_S + H_U \quad (Eqn. \ 3)$$

Where $H_D$ heat loss transmission through vertical walls in contact with outside,
$H_S$ heat loss transmission through floors,
$H_U$ heat loss transmission through surfaces in contact with non-heated zones.

Therefore only $H_D$ transmission coefficient can be affected by air leakage.

**Conventional method**

For the single family dwelling the distribution of heat loss through the different components of the envelope is given by figure 6. As shown in this figure, heat loss through vertical walls represents about 41% of the total transmission loss through the envelope. What is left is divided between: floor (27%), Glazing (14%), roof (8%) and thermal bridges (10%).

![Figure 6: Distribution of heat loss through the envelope](image)

“Internat” school building was partitioned to four zones each one representing a floor. The conventional computation is made using Climawin which is a computational tool allowing the computation of heat loss in respect to French thermal regulation. Results for the entire building and for each zone are shown in table 1.

<table>
<thead>
<tr>
<th>Zones (floors)</th>
<th>$U_{bat}$ (W/m².k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entire building</td>
<td>1,292</td>
</tr>
<tr>
<td>1st floor</td>
<td>1,358</td>
</tr>
<tr>
<td>2nd floor</td>
<td>2,201</td>
</tr>
<tr>
<td>3rd floor</td>
<td>2,219</td>
</tr>
<tr>
<td>4th floor</td>
<td>0,715</td>
</tr>
</tbody>
</table>
Effective heat loss due to air leakage

As we saw on the previous part (Air leakage modeling) air leakage flow rate was predicted for each vertical wall and for a wind speed varying from 0 to 10 m/s and that for both the single family dwelling and the school building. By applying the model that we developed (Barhoun & Guarracino, 2004) we have evaluated the effective $U$-value of each wall affected by air leakage as described Eqn. 1. Then we have conducted the computation of heat loss by transmission through the envelope for the two case studies in integrating the leakage effect on heat transmission.

Single family dwelling

For single family dwelling the relative variation of $U_{\text{bât}}$-value compared to the conventional method is shown on Figure 7 (a) and Figure 8 (a) for the two scenarios studied. On these figures we have shown also the relative variation of coefficient $H_0$ on Figure 7 (b) and Figure 8 (b).

![Figure 7](image1.png)
![Figure 8](image2.png)

Figure 7: First scenario: Relative variation of $U_{\text{bât}}$-value (a) and $H_0$ (b).

![Figure 8](image3.png)

Figure 8: Second scenario: Relative variation of $U_{\text{bât}}$-value (a) and $H_0$ (b).
For the first scenario studied it appears that the relative variation of $U_{bât}$-value is always positive. It ranges between 3% and 4.5%. This result is relied directly to the role played by the mechanical extraction system that induces air infiltration in almost all the cavities in the envelope. When we look at the variation of $H_D$ in function of wind speed, we can realize that the variation in more significant. In fact $H_D$ varies between 5 and 9.3%.

For the second scenario case in the absence of a mechanical ventilation system both infiltration and exfiltration were found. But in term of heat loss effect the role of exfiltration was preponderant. That’s why the relative variations of $U_{bât}$ and are $H_D$ negative.

*Internat school building*

As in the single family dwelling case an assessment of effective U-value for all walls affected by air leakage was done. After that we have evaluated the effective $U_{bât}$-value for each zone and for the entire building. The three graphs below show the relative variation of $U_{bât}$-value (Figure 9(a)), $H_D$-value (Figure 9(b)) for the entire building and finally the variation of $U_{bât}$-value for each zone (Figure 10) by means of wind speed. By dividing the “Internat” building on four zones, each one representing a floor, we wanted to study the effect of building’s high in addition to the role of wind, buoyancy and the mechanical ventilation system.

The first graph shows that $U_{bât}$-value for the entire building varies between 1% and 4.1%. But in term of $H_D$ relative variation values are near 30%.

When we look at the variation of $U_{bât}$ per zone (Figure 10) the role of building’s high is obvious. In fact this variation is more significant on higher floor than lower floors. This variation attains a value between 8% and 12% on the fourth floor for a wind speed between 2 and 10 m/s.

![Figure 9: Relative variation of $U_{bât}$ in function of wind velocity for the entire “Internat” building (a) and heat transmission through opaque walls only (b)](image)
CONCLUSION

In this paper we have treated the role of air leakage in heat transfer by transmission through the building’s envelope for two case studies. This work complete the previous work that we have done by developing a model in order to predict the interaction between air leakage and the wall structure (H. Barhoun, 2004).

This work was divided on three main parts: first of all, air exchange simulations were conducted in order to evaluate air leakage flow rates through vertical opaque walls. These values were then implemented on our model in order to estimate the $U_L$-value of each wall (as described in Eqn. 1.). Finally by integrating the air leakage effect on the entire building’s envelope we have found that conventional method for heat loss assessment, by neglecting the interaction between air leakage and the building’s structure, misestimate the real effective heat loss.

Therefore, as a perspective of this work, we can recommend first of all extending this study on a biggest panel of buildings in order to carry out recommendations and to approach a correction factor that takes into account the real contribution of air leakage in heat loss.

References


