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Role of Local Building Materials on the Energy Behaviour of Habitats in Ouagadougou

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ABSTRACT

The present work is a contribution to the energy efficiency in the habitats by the valorization of the local building materials in Burkina Faso. A comparative numerical study on the thermal behavior and energy consumption of some habitats in local and modern building materials is carried out. The simulations were carried out using computer code written in FORTRAN language over a period of one year. Analysis of the results shows that habitats in local construction materials (BTC, BLT, adobe) have a better thermal response compared to modern building materials (hollow cinder block). Generally speaking, the temperature and humidity profiles obtained do not make it possible to ensure the summer comfort in these buildings throughout the year. The evaluation of air-conditioning loads to ensure thermal comfort in these habitats shows that they are higher respectively in the blocks, BLT, BTC, adobe constructions. We therefore consider that local building materials represent a good alternative for the search for energy efficiency in buildings.

Key words: Energy efficiency, local building materials, thermal simulation and thermal performance coefficients.

1. Introduction

Burkina Faso, like other countries in sub-Saharan Africa, is a country where the building sector is one of the major energy-consuming sectors. For example, the share of consumption of ventilation and air-conditioning systems in administrative buildings in Burkina Faso is 30000 MWh/year and the equivalent cost of financing is estimated at 3.4 billion CFA Francs / year [1]. This high consumption in the building sector is caused, among other things, by the lack of energy considerations in the design and management of buildings and the lack of energy regulations in the building sector. It is noted that 50% of the energy consumption of the building sector in the world is due to air conditioning, ventilation and heating systems [2]. The energy performance of a building is partly related to its thermal design [3]. In this context, any improvement in the thermal design of the building envelope is a considerable socio-economic interest, especially as building materials come from local sources [4].

For this purpose Toguyeni and al [4] studied the influence of local roofing materials on air conditioning loads in Burkina Faso. The results show that an air-conditioning load reduction of the order of 8% is observable if a clay-straw mixture is used with respect to a clay roof. Also for insulation of 1.5 cm in thickness, savings on cooling loads are achieved in the order of 8.3% for white wood and 12.1% for insulation boards. Coulibaly and al [5], have evaluated the air-conditioning loads of a single-family house built with the "H-brick" whose matrix is filled on the one hand with clay and on the other hand with a clay-straw mixture. Its results have shown that the air-conditioning charges are reduced in the clay-straw mixture due to the low conductivity of this mixture compared to the clay alone. Kabore M. [6], conducted a numerical study on the influence of insulation on the roof of a habitat, he found that the use of insulators with a good reflection coefficient better reduced the thermal gains at the roof. Ouedraogo E. [7] carried out a thermo-mechanical characterization of the local materials used for the building envelope and found that the integration of paper (cellulose) in these materials improved the thermal performance of the latter.

All these studies contribute to the search for energy efficiency in buildings in Burkina Faso. Our study in this context is a contribution to energy efficiency through the use of local building materials in habitats. In this work, we propose a numerical study of the energy consumption in local materials habitats such as compressed earth blocks (BTC), laterite blocks (BLT), raw earth (Adobe) and and those made of modern materials such as cement blocks.

2. Thermal and energy simulation of the building

2.1. Mathematical Modeling

The simulation of the thermal behavior and the evaluation of the energy needs of the building were carried out thanks to a computer code in FORTRAN that we have elaborated. This code is based on the writing of the energy balance of a thermal zone assuming the following hypotheses:

- Conduction heat transfer is unidirectional;
- The air of an area is perfectly transparent to radiation and has a uniform temperature;
- Materials are assimilated to gray bodies;
- The thermo-physical properties of the materials used are constant (Table 1).

Then the balance of energy is obtained by neglecting the transfers due to infiltrations by the expression:

$$C_z \frac{d\theta_z}{d\tau} = \sum_{i=1}^{N} \dot{Q}_{c,i} + \sum_{i=1}^{N_{surface}} h_i A_i \left(\theta_{si} - \theta_z\right) + \dot{m}_v c_p \left(\theta_e - \theta_z\right) + \dot{Q}_{sys} \qquad (1)$$

With N as the number of internal loads $\dot{Q}_{c,i}$, the term $h_i A_i \left(\theta_{si} - \theta_z\right)$ represents the convective exchanges between the i^{th} surface A_i at temperature θ_{si} and the zone of air at temperature θ_z. $\dot{m}_v c_p \left(\theta_e - \theta_z\right)$ represents the heat exchanges due to ventilation and renewal of air with the outside and $\dot{Q}_{sys}$ the exit of the system.

Our study concerns the city of Ouagadougou, which brings us to use the climate file of this city as input for our various simulations. This is the standard year developed by E. Ouedraogo and al. [8] from 15-year meteorological data (Table 1). This typical meteorological year represents the average climate of the city of Ouagadougou.

Table 1: Year Model considered [8]

Year	Month	N° of month	Average day	Day of the year
1994	*January*	*1*	*17*	*17*
1992	*February*	*2*	*16*	*47*
2006	*March*	*3*	*16*	*75*
2002	*April*	*4*	*15*	*105*
2001	*May*	*5*	*15*	*135*
1996	*June*	*6*	*11*	*162*
1994	*July*	*7*	*17*	*198*
2006	*August*	*8*	*16*	*228*
2006	*September*	*9*	*15*	*258*
1999	*October*	*10*	*15*	*288*
2001	*November*	*11*	*14*	*318*
1998	*December*	*12*	*10*	*344*

Figure 1 shows the evolution of the global horizontal solar flux density and the evolution of the mean ambient temperature of the air for the twelve (12) typical days of the year. This figure shows that April is the warmest period of the year with a maximum flow density of 974 W/m^2 at 12:00 and a maximum mean air temperature of 40.6 ° C at 15:00.

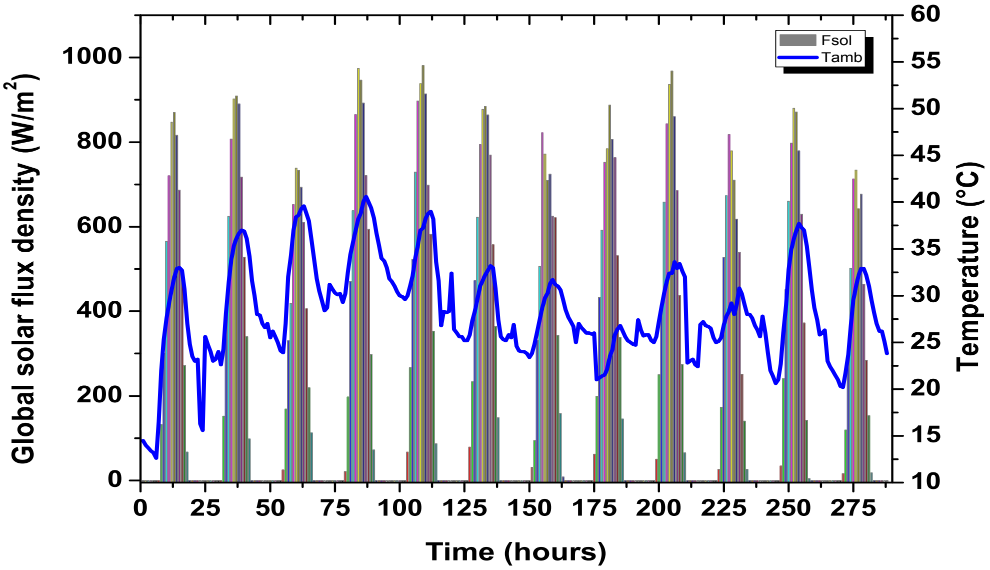

Figure 1: Global flow density and ambient air temperature for the typical year of the city of Ouagadougou

The habitat models chosen for the simulation are of the single-zone type. For the purposes of the study, we will consider habitats whose walls are built successively in agglomerates of cement, blocks of compressed earth (BTC), block of laterite slice (BLT) or raw earth (adobe) with 18cm of thickness. The inside of the wall is covered with a white paint. The roof of the housing is made of galvanized steel sheet 1mm thick. The thermo-physical properties of the building envelope are given in Table 2.

Table 2: Thermo-physical properties of materials [6,7]

Materials	Thermal conductivity *(W/m.K)*	Specific Heat *(J/kg.K)*	Density (kg / m^3)
Agglomerated cement	0.833	1000	1000
Mortar-coated	1.15	1000	1700
Concrete	1.4	840	2240
BTC	0.671	1492	1960
BLT	0.625	1510	1850
Adobe (Raw Earth)	0.556	1417	1835
Galvanized steel sheet	50	480	7800

2.2. Evaluation of energy performances

The energy demand of a building for its cooling can be obtained through several expressions proposed by the literature [9], [10], [11]. We consider here the relation of Kreith [10] giving the expression of the energy needed for the cooling of a habitat because of the difference of temperature between the outside and the inside [12] by:

$$E_{ref} = 86,4 \times G.V.DJR \tag{2}$$

With:

$$DJR = m_k \sum_{k=1}^{n} \left(T_{e,k} - T_{bre} \right) \tag{3}$$

$$m_k = \begin{cases} 1 \ si \ T_{e,k} \geq T_{bre} \\ 0 \ si \ T_{e,k} \prec T_{bre} \end{cases} \tag{4}$$

The degrees-days of cooling (DJR) represent the positive variation between the outdoor temperature and the cooling base temperature.

Coefficient G is the global heat loss coefficient. It makes it possible to characterize the thermal performance of a building by taking into account the exchanges of heat by conduction, by convection and by renewal of air. Its expression is:

$$G=\frac{1}{V}\left[\sum_{i=1}^{m}\left(\sum_{j}K_jS_j+\sum_{n}K_nl_n+C_vN_iV_i\right)\right] \quad (5)$$

In addition to the heat loss coefficient G, we will use the overall heat transfer coefficient Ubât which characterizes the overall thermal insulation level of the building envelope. Its expression is:

$$U_{bât}=\frac{\left(\sum_{j}K_jS_j+\sum_{n}K_nl_n+\sum_{l}\chi_l\right)}{\sum_{j}S_j} \quad (6)$$

The terms:

$\sum_{j}K_jS_j$: Represents gains through the walls

$\sum_{n}K_nl_n$: Represents gains through the linear thermal bridges

$\sum_{l}\chi_l$: Represents gains through point thermal bridges

C_vN_iV : Represents gains per air renewal

3. Results and Analysis

3.1. Indoor air temperature profiles

Figure 2 shows the evolution of indoor air temperature profiles over the 12 typical days of the year for the three types of building materials considered. It is observed that the temperature curves of the indoor air in the different rooms have the same behavior except that in the cement block where the temperature variations are greater. Indeed, indoor air temperatures within cement blocks are higher during the first six months (January to June) and relatively low during the rest of the year compared to temperatures in the adobe, BLT and BTC. This is due to the thermal properties of the cement block, because the thermal diffusivity of cement blocks is higher than that of the local materials (adobe, BLT and BTC), so its temperature varies much faster with the external conditions. It will be remembered from this figure that habitats of local building materials are less sensitive to external climatic conditions (damping of peak temperatures) compared to buildings made of cement blocks.

This first analysis of the evolution of internal temperatures in the different habitats will allow us to evaluate the cooling energy requirements for a given set of temperature of the air inside the habitat.

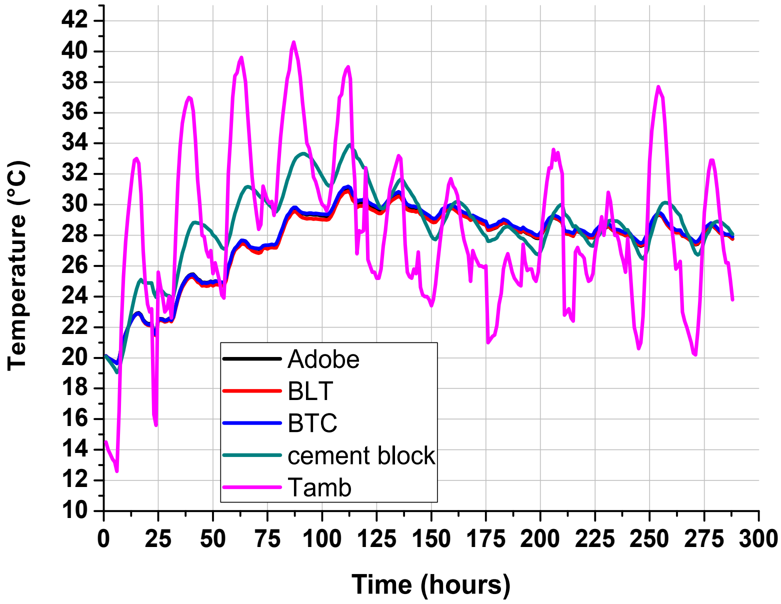

Figure 2: Evolution of temperature profiles in the room with different building materials

3.2. Temperature profiles on the external and internal walls of habitats

Figures 3, 4, 5 and 6 show the evolution of temperature profiles on the external and internal walls of the different habitats for the typical day of January. All the figures show that the walls decrease the peaks of temperature inside the habitats. In general, temperature profiles in earthen constructions (Adobe, BTC, and BLT) have similar behaviors because of their similar thermal properties. Indeed, during the period between 1:00 and 9:00, the temperatures of the internal walls of the earthen constructions are higher than the temperatures of the external walls. After 9:00, the process is reversed and the temperatures of the external walls are higher and higher due to the solar flux received by these external walls.

The evolution of temperature profiles on the external and internal walls of the cement block wall (FIG. 6) exhibits a behavior similar to that of earthen walls, with the difference that the temperatures on the inner wall of the block wall vary much more Rapidly with the temperatures of the outer wall. In the case of earthen constructions, the temperatures of the internal walls vary very little with the temperatures of the external walls.

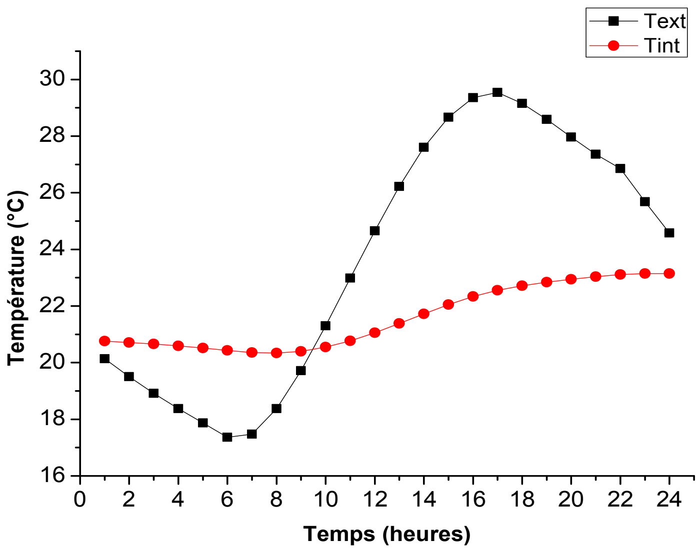

Figure 3: Evolution of temperature profiles on the external and internal walls of the south wall (Adobe)

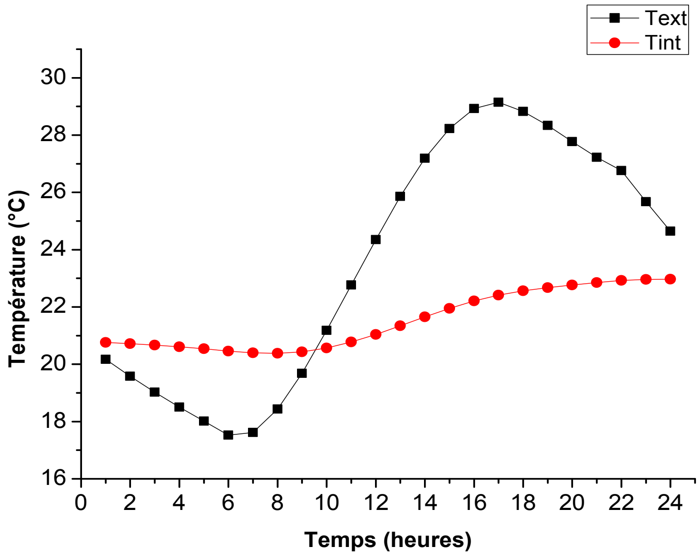

Figure 4: Evolution of the temperature profiles on the external and internal walls of the south wall (BLT)

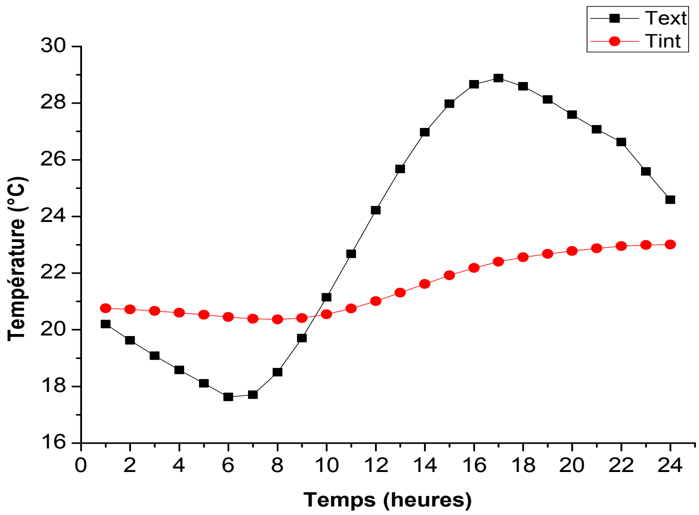

Figure 5: Evolution of the temperature profiles on the external and internal wall of the south wall (BTC)

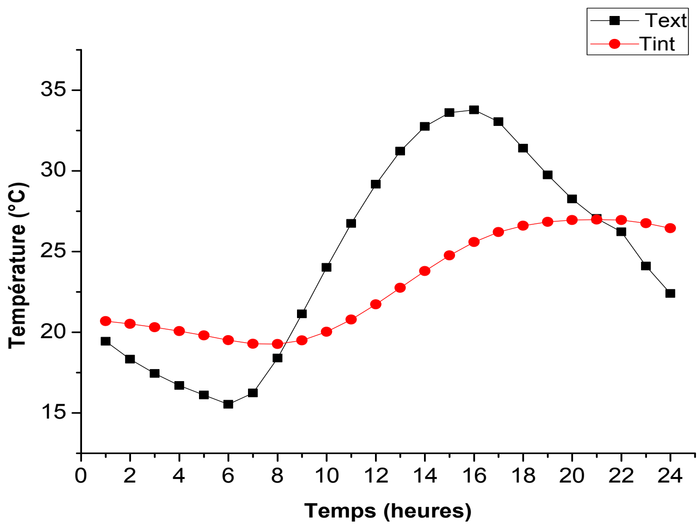

Figure 6: Evolution of the temperature profiles on the external and internal walls of the south wall (Cement block)

3.3. Evaluation of air conditioning needs in habitats

In figure 7, cooling needs are presented in the four habitat types considered. These requirements represent the sensitive loads to be controlled to ensure an internal comfort temperature of 27 ° C in the premises.
The analysis of this graph globally shows that the significant cooling loads during the year are significantly higher in cement block constructions compared to local materials constructions (Adobe, BTC, BLT). Note that for the period between July and October, air conditioning loads in cinder block construction are lower compared to loads in other constructions. This is due to the fact that this period corresponds to the wettest period of the year for the city of Ouagadougou. Thus, with humidity, the thermal properties of the materials are modified. Since the thermal properties of the cement blocks are more sensitive to external climatic conditions, temperatures inside these constructions are relatively lower than in earthen constructions during cold periods, resulting in a low need for air conditioning.
If we look at the construction of local materials, we can see that the BTC construction has the highest sensitive loads, followed by the adobe construction. Indeed, since BTCs are mechanically stabilized with cement (6%), these thermal properties, such as conductivity, increase slightly, and that is the reason why there are slightly higher air conditioning loads in BTC habitats than in other habitats. Land (adobe, BLT).

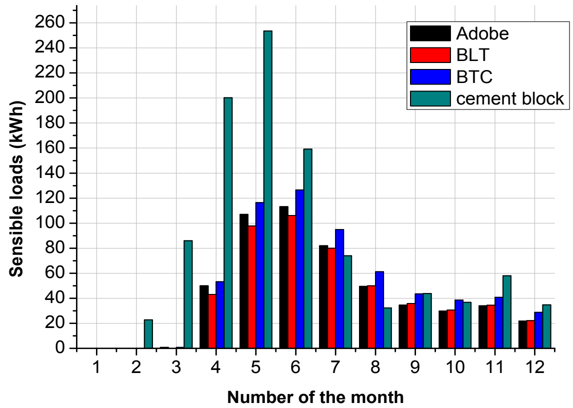

Figure 7: Significant air-conditioning loads in the different rooms according to building materials

Figure 8 shows the energy savings achievable in habitats on sensitive air conditioning loads by using local building materials compared to cement blocks. It should be noted that outside the months of July and August the air conditioning costs are reduced in the earthen rooms compared to those in cement blocks.

For example, the use of BLT habitat generates the most energy saving of around 155kWh for the months of April and May compared to a cement blocked habitat. The use of BLT and adobe constructions results in an energy saving of about 150kWh for these same periods.

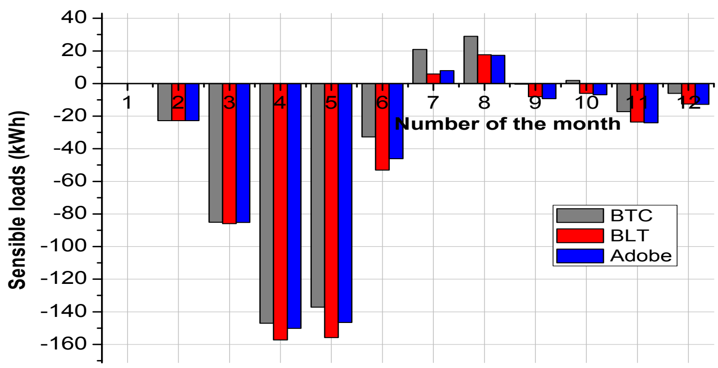

Figure 8: Potential for energy savings through the use of local building materials

In Table 3, we present the energy performance coefficients for the different types of habitats considered. As described above, we calculate the annual mean values of the heat loss coefficient and of the overall coefficient of thermal transmission using the numerical code. It should be noted, however, that, taking into account heat transfers by air exchange for the calculation of the heat loss coefficient, we have set the value of the hourly rate of air exchange at 0.5 vol / h.

The higher the values of these coefficients, the less efficient they are. From this point of view, it is observed that the habitats in earth materials are thermally better than the habitat in cement blocks. The habitat in BLT is the most efficient, followed by that in adobe, confirming once again the good thermal properties of the material 'earth'.

Table 3: Energy performance coefficients of habitats as a function of material

	Adobe	***BLT***	***BTC***	***Cement block***
G ($W.m^{-3}.K^{-1}$)	**1.23**	**1.22**	**1.27**	**1.35**
Ubât ($W.m^{-2}.K^{-1}$)	**0.69**	**0.68**	**0.72**	**0.77**

4. Conclusion

In this work, a comparative thermal energy study was carried out between several habitats built of local building materials (BTC, BLT, adobe) and of modern building materials (cement blocks).

Analysis of indoor air temperature distribution in habitats revealed that temperatures were relatively lower in earthen constructions than in cement blocks. The assessment of energy requirements in these habitats also shows high energy consumption in cement block buildings compared to those in earth. This was confirmed by the coefficients of thermal performance of these habitats. Indeed, the thermal performance coefficients Ubat and G are lower in earthen constructions (adobe, BTC, BLT) than in modern constructions (cement block).

This study could be supplemented by the inclusion of latent loads in order to evaluate the air conditioning needs. A passive air conditioning system should also be considered to combat these loads. Note that this study is also part of the valorization of local building materials because it highlights the advantages of using local building materials in the search for energy efficiency in buildings.

Nomenclature

θ_z	Air temperature at the thermal zone, K
θ_e	Ambient air temperature outside, K
C_z	Thermal capacity of the air at the thermal zone $J.kg^{-1}.K^{-1}$
h_i	Coefficient of exchange by convection of the air with surface i, $W.m^{-2}.K$
A_i	Area of surface i, m^2
E_{ref}	Cooling energy, kWh
DJR	Degrees / days of cooling, K
T_{bre}	Cooling base temperature K
G	Coefficient of heat loss, $W.m^{-3}.K^{-1}$
$U_{bât}$	Overall heat transfer coefficient, $W.m^{-2}.K^{-1}$
K_j	Coefficient of surface transmission of the building component j of the building envelope $W.m^{-2}.K^{-1}$
K_n	Linear thermal transmission coefficient n, $W.m^{-1}.K^{-1}$

χ_l	Point thermal transfer coefficient, $W.K^{-1}$
l_n	Length of linear thermal bridge n, m
N	Hourly air renewal rate, h^{-1}
C_v, c_p	Volumetric heat and volumetric air, $W.m^{-3}.K^{-1}$, $W.kg^{-1}.K^{-1}$
$\dot{m}_v$	Mass flow of air, $kg.s^{-1}$

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