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Contribution of an External Wall to the Thermal Load of a Building

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Abstract This work consists of estimating the contribution of a wall facing south on the thermal load of a physical workshop (B13) of the University Alioune Diop of Bambey. After calculating the overall thermal load of the building, the thermo-hygrometric conditions are modified. The study shows that the thermal load can be reduced at least 22% through sobriety actions and those of others actions that do not require significant financial investment.

Keywords Environmental protection, thermal load calculation, energy consumption limitation, global warming, greenhouse effect

Nomenclature

Symbols :

Q	Heat flow in W
U	Overall transfer coefficient in $W.m^{-2}.°C^{-1}$
A	Surface of element in m²
ΔT	Temperature difference in°C
Δx	Dehumidification rate in $g.kg^{-1}$
N	Number of
t	Thickness
h	Thermal convection coefficientin $W.m^{-2}.°C^{-1}$

Greek Letters:

λ	Thermal conductivity, $W.\ m^{-1}.K^{-1}$
τ	Air exchange rate per person, $m^3.h^{-1}$

Indices / Exponents :

glz	Glazing
doo	Door
w	Wall
flr	Floor
p	Person
j	Number of the layer
i	Internal
e	External
ar	Air renewal

Introduction

Since the energy crisis of the 1970s, the limitation of the resource, its high cost and its negative impact on the environment compel us to take better of the issue. For this study centered on the design phase of the building, the choice was therefore made to focus on the dimensioning of HVAC systems through the optimization of thermal balances. The construction industry is increasingly interested in the design and construction of environmentally friendly buildings [1]. It is in support of this energy policy that we have interested in studying the contribution of the wall of a building on its thermal load. This study will certainly help to limit energy consumption, global warming and therefore fight the green effect.

Methodology

Our approach is to estimate the heat load of the room by the conventional method starting from the standard thermal and hygrometric conditions. Actions are gradually being rolled out to reduce the heat load of the room:

a) Raising the set temperature
b) Insulation of the south wall and the iron door
c) Replacement of single glazing in double glazing
d) Establish solar protection
e) Optimize air renewal rates
f) Replace incandescent bulbs with fluorescent or LEDs

From the results obtained, we deduce the respective energy consumption and operating costs.

Specifications

Geographical and climatic conditions in Bambey, Senegal [2]

Table 1: Monthly maximum, average and minimum temperatures in Bambey

Months	January	February	March	April	May	June	July	August	September	October	November	December
Maximum temperature °C	33,3	35,9	37,9	39,3	39,8	38,0	35,3	33,9	34,1	37,1	37,3	34,4
Mean temperature °C	25,6	27,4	28,8	29,9	30,5	30,7	29,7	29,0	29,1	30,3	29,1	26,5
Minimum temperature °C	16,9	18,2	19,2	19,7	21,1	23,1	24,0	23,8	23,6	23,0	19,8	17,6

Thermal comfort

Thermal comfort is defined as the estimated satisfaction with the thermal environment of surrounding environment. Fir a person to feel comfortable, three conditions must be met: the body must maintain a stable internal temperature, the production of sweat must not be too abundant and the average temperature of the skin must be comfortable [3]. According to [4], the thermal comfort models most commonly used are that of [5] and that of [6]. The conditions for an acceptable thermal environment are defined in standard [7] and its addendum 1995 of the ASHRAE entitled thermal environment conditions for human occupancy. It specifies the conditions in which 80% or more of half people find a comfortable atmosphere. In addition, [8] an application standard for workstation ergonomics recommends the following:

- Optimal temperature during summer of 24.5°C with an acceptable range of 23 to 26°C
- Relative humidity of 50%
- Average airspeed less than 0.15 m/s

Mathematical model

The practice room under study (Figure 1) is located in a three-storey building in Bambey. The choice of this place is relevant insofar several data are available at the level of the different research teams in place.

Figure 1: Photograph of studied building

A heat balance calculation procedure derived from [9] and similar to that developed in [10-13] and [14] was applied to the room model and is summarized as follows:

Heat flow through walls is given by:

$$Q_1 = U_w A_w \, \Delta T \quad (1)$$

Heat flow through doors is given by:

$$Q_2 = U_d A_d \, \Delta T \quad (2)$$

Heat flow through glazing is given by:

$$Q_3 = U_{glz} A_{glz} \, \Delta T \quad (3)$$

Heat flow through floors is given by:

$$Q_4 = U_{flr} A_{flr} \, \Delta T \quad (4)$$

According to [15], [16] and [17] the overall coefficient of heat transfer, U for a plane multilayer wall is given by the following equation. In case of double glazing, the convection of air trapped between the two glazings is neglected:

$$\frac{1}{U} = \frac{1}{h_i A} + \sum_{j=1}^{n} \frac{t_j}{\lambda_j A} + \frac{1}{h_e A} \quad (5)$$

Sensitive heat flow due to metabolism occupant is given by:

$$Q_5 = 65 \, N_p \quad (6)$$

Latent heat flow due to metabolism occupant is given by:

$$Q_6 = 37 \, N_p \quad (7)$$

Sensitive heat flow due to air renewal is given by:

$$Q_7 = 0.348 \, N_p \, \tau_{ar} \, \Delta T \quad (8)$$

Latent heat flow due to air renewal is given by:

$$Q_8 = 0.824 \, N_p \, \tau_{ar} \, \Delta x \quad (9)$$

Heat flow due to the direct sunlight of glazing is given by:

$$Q_9 = 410 \, A_{glz} \quad (10)$$

Heat flow due to the indirect sunlight of glazing is given by:

$$Q_{10} = 50 \, A_{glz} \quad (11)$$

Heat gains due to lighting is given by:

$$Q_{11} = 15 \, A_{flr} \quad (12)$$

Description of actions

Raising set point temperature (Action 1)

This action consists of raising the set point temperature in order to reduce, on the one hand, the flows by transmission through the walls (Q_1, Q_2, Q_3 and Q_4) and on the other hand the contributions by air renewal (Q_7 and Q_8).

Isolate the south-facing wall and the iron door (Action 2)

This action is to isolate the south-facing wall and the iron door as shown in (*Figure 2 and Figure 3*). Then apply the formulas of relations *(1)* and *(2)* to obtain the exchanged flows Q_1 and Q_2 before and after isolation.

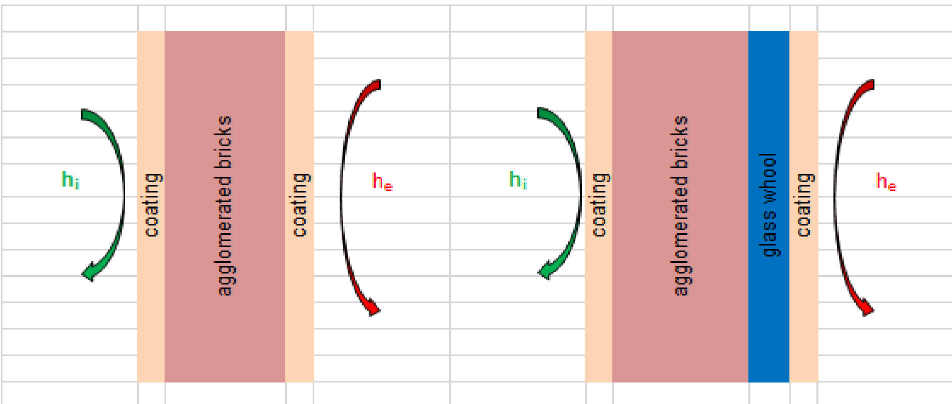

Figure 2: South wall (before and after insulation)

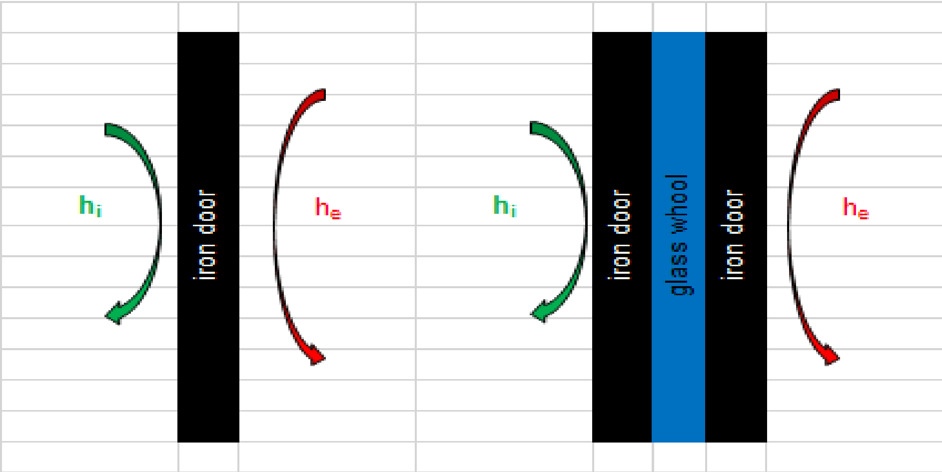

Figure 3: Iron door (before and after insulation)

Replacement the single by double glazing (Action 3)

This action consists in replacing the windows consisting of simple glazing by those of double glazing by inserting a blade of air to reduce the flows by transmission as shown in *Figure 4*.

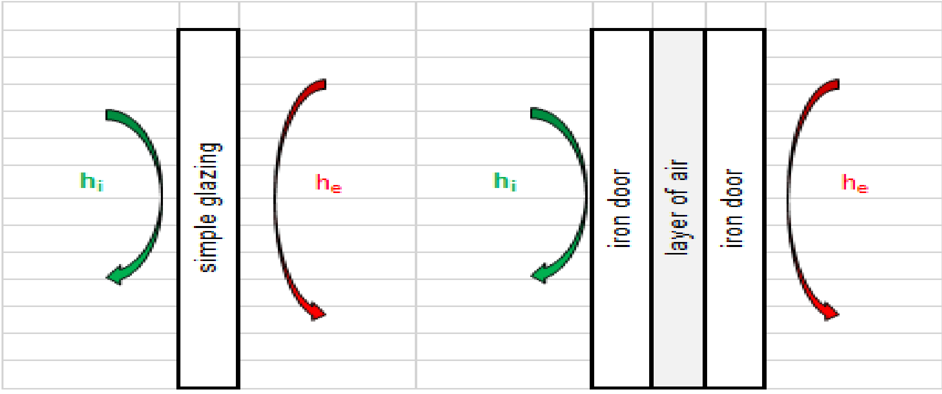

Figure 4: Glass window (before and after change)

Beyond the study concerning the contribution of the slab, other fairly obvious actions such as the establishment of solar protections, the optimization of the rate of renewal of air and the replacement of incandescent bulbs by those of type FLUO or LEDs can reinforce the policy of saving energy in buildings.

Optimizing rate air renewal (Action 4)

When the air conditioning system is of an individual type (split-system), the treated air is completely recycled because the doors and windows remain closed to make the room watertight. In this case, the equipment must be sized on the basis of a power budget where the rate of air exchange is very low. The incidence is very remarkable on the application of relations *(8)* and *(9).*

Solar masks (Action 5)

The creation of solar awnings or masks can significantly reduce the solar flux entering the building modeled by the relations *(10)* and *(11).*

To calculate heat flow due the sunlight, in the case of direct sunlight, the surface of the glazing in multiplied by a coefficient 410 Wm^{-2}. When it is protected from the sun, it is only multiplied by 50 Wm^{-2}.

Using economic bulbs (Action 6)

The replacement of the incandescent bulbs by fluorescent or electroluminescent types helps to reduce the thermal load considerably:

The first economic ones have an artificial appearance with a color rendering between 65 and 88% compared to incandescent or halogen lamps where the CRI is 98 to 100%. However, they require a certain ignition time and contain mercury which is a dangerous product [18] and [19].

For the second category, performance doubles every two years and prices fall by at least 20% each year (70 lumens / W vs. 16 lumens / W).

However:

- They cannot work with a dimmer
- They are relatively expensive
- The manufacturing process is very energy intensive (negative life cycle)
- Materials for manufacturing (Indium and Gallium) are limited resources

Results

The thermal balance is established from specifications including the indoor and outdoor thermo-hygrometric conditions, the dimensional characteristics of the room to be treated as well as the thermal properties of the walls constituting the envelope. The maintenance cost was estimated on the basis of equipment operation at an average of 1,200 hours per year.

Table 2: Thermal balance according to basic gelling conditions

T_i (°C)	24	ΔT_{pe}:	14	ΔT :	10		Lat:	14°C	
RH_i -%	50	Δx (g/kg_{as}):	18,33	Length	15,0		Long:	17°C couvert	
T_e (°C)	38	x_i (g/kg_{as}):	9,30	Width	8,0		Alt:	39 m	
RH_e -%	65	x_e (g/kg_{as}):	27,63	Height	3,5		N_p	17	
									(Calculation support de calcul : PSYDIAG)
ITEM	DESCRIPTION						PARAMETERS		Total thermal power
1	TRANSMISSION HEAT FLOW					Aire m²	ΔT °C	W/m².°C	WATTS
1.a	Glazing					18,0	14	5,71	1 439
1.b	Door					3,9	14	5,88	319
1.c	South wall					40,5	14	2,52	1 429
1.d	East wall					28,0	10	2,26	633
1.e	North wall					42,6	14	2,52	1 503
1.f	West wall					28,0	10	2,26	633
1.g	Sunny high floor					-00	14	1,95	-00
1.h	Hight floor not sunny					120,0	10	1,95	2 340
1.i	Low floor					120,0	10	1,95	2 340
2	INTERNAL GAINS						Np	W/p	
2.a	Sensible heat						17	65	1 105
2.b	Latent heat						17	37	629
3	AIR RENEWAL						Np	m³/h/p	
3a	Sensible heat						17	15	1 242
3b	Latent heat						17	15	3 852
4	SUNSHINE OF GLAZING						Aire m²	W/m²	
3.a	Direct						12,0	410	4 920
3.b	Diffuse						6,0	49,2	295
5	OTHERS CONTRIBUTIONS						Aire m²	W/m²	
5.a	Lighting						120	15	1 800
5.b	Electical appliances in operation (17 computers including teacher's)								20
TOTAL THERMAL BALANCE (W):									24 499
3 x Sp-024	Cooling capacity (W)		21 300		Operating time (hours)				1 200
1 x Sp-012	Cooling capacity (W)		3 500		Annual consumption (kWh):				11 904
	Total installed cooling capacity (W)		24 800		Annual cost of operation (USD):				2 857
	Performance coefficent, COP		2,5						
	Absorbed electrical power (W)		9 920						

Once the refrigerating power of the devices is identified, the respective performance coefficients are used to deduce the electrical power absorbed and calculate the energy consumption and then the operating costs over the year.
The application of the relationships of *(1)* to *(12)* on the chosen building model makes it possible to estimate its heat balance presented according to *Table* 2.

Thermal balance according raising set temperature
The same calculation as the previous one is carried out by raising the set temperature from 24 to 26°C and the results are shown in *Table 3*.

Table 3: Thermal balance according to raise set temperature

ITEM	DESCRIPTION	PARAMETERS			Total thermal power
1	TRANSMISSION HEAT FLOW	Aire m²	ΔT °C	W/m².°C	WATTS
1.a	Glazing	18,0	14	5,71	1 439
1.b	Door	3,9	14	5,88	319
1.c	South wall	40,5	14	2,52	1 429
1.d	East wall	28,0	10	2,26	633
1.e	North wall	42,6	14	2,52	1 503
1.f	West wall	28,0	10	2,26	633
1.g	Sunny high floor	-00	14	1,95	-00
1.h	Hight floor not sunny	120,0	10	1,95	2 340
1.i	Low floor	120,0	10	1,95	2 340
3	AIR RENEWAL		Np	m³/h/p	
3a	Sensible heat		17	15	1 242
3b	Latent heat		17	15	3 852
TOTAL THERMAL BALANCE (W):					15 729

ITEM	DESCRIPTION	PARAMETERS			Total thermal power
1	TRANSMISSION HEAT FLOW	Aire m²	ΔT °C	W/m².°C	WATTS
1.a	Glazing	18,0	12	5,71	1 233
1.b	Door	3,9	12	5,88	273
1.c	South wall	40,5	12	2,52	1 225
1.d	East wall	28,0	8	2,26	506
1.e	North wall	42,6	12	2,52	1 288
1.f	West wall	28,0	8	2,26	506
1.g	Sunny high floor	-00	12	1,95	-00
1.h	Hight floor not sunny	120,0	8	1,95	1 872
1.i	Low floor	120,0	8	1,95	1 872
3	AIR RENEWAL		Np	m³/h/p	
3a	Sensible heat		17	15	1 065
3b	Latent heat		17	15	3 601
TOTAL THERMAL BALANCE (W):					13 442

When the set temperature is raised from 24 to 26°C, the heat flows affected are the transmissions through the walls and the air renewal. The respective contributions go from 15,729 W to 13,442 W, i.e. a gain of 2,287 W corresponding to 9.33%

Thermal balance according isolating south-facing wall and the iron door
The same calculation as the previous one is carried out by isolating south-facing wall and maintain the set temperature of 26 °C.
The results of *Table 4* show that the contribution goes from 8776 to 7465 W. Reported in the general balance sheet of *Table 2*, this corresponds to a reduction of 4.62%.

Table 4: Thermal balance according isolating south-facing wall and iron door

ITEM	DESCRIPTION	PARAMETERS			Total thermal power
1	TRANSMISSION HEAT FLOW	Aire m²	ΔT °C	W/m².°C	WATTS
1.a	Glazing	18,0	12	5,71	1 233
1.b	Door	3,9	12	5,88	273
1.c	South wall	40,5	12	2,52	1 225
1.d	East wall	28,0	8	2,26	506
1.e	North wall	42,6	12	2,52	1 288
1.f	West wall	28,0	8	2,26	506
1.g	Sunny high floor	-00	12	1,95	-00
1.h	Hight floor not sunny	120,0	8	1,95	1 872
1.i	Low floor	120,0	8	1,95	1 872
TOTAL THERMAL BALANCE (W):					8 776

ITEM	DESCRIPTION	PARAMETERS			Total thermal power
1	TRANSMISSION HEAT FLOW	Aire m²	ΔT °C	W/m².°C	WATTS
1.a	Glazing	18,0	12	5,71	1 233
1.b	Door	3,9	12	0,37	17
1.c	South wall	40,5	12	0,35	170
1.d	East wall	28,0	8	2,26	506
1.e	North wall	42,6	12	2,52	1 288
1.f	West wall	28,0	8	2,26	506
1.g	Sunny high floor	-00	12	1,95	-00
1.h	Hight floor not sunny	120,0	8	1,95	1 872
1.i	Low floor	120,0	8	1,95	1 872
TOTAL THERMAL BALANCE (W):					7 465

Thermal balance according replacing single by double glazing

The same calculation as the previous one (*Table 2*) is made by replacing single glazing with double glazing.

Table 5: Thermal balance according replacing single by double glazing

ITEM	DESCRIPTION	PARAMETERS			Total thermal power
1	TRANSMISSION HEAT FLOW	Aire m²	ΔT °C	W/m².°C	WATTS
1.a	Glazing	18,0	12	5,71	1 233
1.b	Door	3,9	12	0,37	17
1.c	South wall	40,5	12	0,35	170
1.d	East wall	28,0	8	2,26	506
1.e	North wall	42,6	12	2,52	1 288
1.f	West wall	28,0	8	2,26	506
1.g	Sunny high floor	-00	12	1,95	-00
1.h	Hight floor not sunny	120,0	8	1,95	1 872
1.i	Low floor	120,0	8	1,95	1 872
TOTAL THERMAL BALANCE (W):					7 465

ITEM	DESCRIPTION	PARAMETERS			Total thermal power
1	TRANSMISSION HEAT FLOW	Aire m²	ΔT °C	W/m².°C	WATTS
1.a	Glazing	18,0	12	1,77	382
1.b	Door	3,9	12	0,37	17
1.c	South wall	40,5	12	0,35	170
1.d	East wall	28,0	8	2,26	506
1.e	North wall	42,6	12	2,52	1 288
1.f	West wall	28,0	8	2,26	506
1.g	Sunny high floor	-00	12	1,95	-00
1.h	Hight floor not sunny	120,0	8	1,95	1 872
1.i	Low floor	120,0	8	1,95	1 872
TOTAL THERMAL BALANCE (W):					6 614

The results of *Table 5* show that the contribution goes from 7465 to 6614W. This difference reported in the general balance sheet of *Table 2*, this corresponds to a reduction of 3.47%.

Thermal balance according optimizing rate air renewal

The rate air renewal calculation is estimated according to the regulations using an air renewal rate of 15 m^3 per hour and per person. There are configurations where renewal is done only by occasional opening of doors and windows, which would correspond to a maximum of 5 m^3 per hour and per person.

Table 6: Thermal balance according optimizing rate air renewal

ITEM	DESCRIPTION	PARAMETERS		Total thermal power
3	AIR RENEWAL	Np	m³/h/p	
3a	Sensible heat	17	15	1 065
3b	Latent heat	17	15	3 601
TOTAL THERMAL BALANCE (W):				4 666
3	AIR RENEWAL	Np	m³/h/p	
3a	Sensible heat	17	5	355
3b	Latent heat	17	5	1 200
TOTAL THERMAL BALANCE (W):				1 555

The results of *Table 6* show that the contribution goes from 4666 to 1555W. This difference reported in the general balance sheet of *Table 2*, this corresponds to a reduction of 12.7%.

Thermal balance according putting solar masks

The same calculation as the previous one (*Table 2*) is performed by putting on sun masks.

Table 7: Thermal balance according putting solar masks

ITEM	DESCRIPTION	PARAMETERS		Total thermal power
4	SUNSHINE OF GLAZING	Aire m²	W/m²	
4.a	Direct	12,0	410	4 920
4.b	Diffuse	6,0	49,2	295
TOTAL THERMAL BALANCE (W):				5 215
4	SUNSHINE OF GLAZING	Aire m²	W/m²	
4.a	Direct	-00	410	-00
4.b	Diffuse	18,0	49,2	886
TOTAL THERMAL BALANCE (W):				886

The results of *Table 7* show that the contribution goes from 5215 to 886W. This difference reported in the general balance sheet of *Table 2*, this corresponds to a reduction of 17,7%.

Thermal balance according using economic bulbs

The same calculation as the previous one (*Table 2*) is performed by putting on economic bulbs

Table 8: Thermal balance according using economic bulbs

ITEM	DESCRIPTION	PARAMETERS		Total thermal power
5	OTHERS CONTRIBUTIONS	Aire m²	W/m²	
5.a	Lighting	120	15	1 800
TOTAL THERMAL BALANCE (W):				1 800
5	OTHERS CONTRIBUTIONS	Aire m²	W/m²	
5.a	Lighting	120	3,5	420
TOTAL THERMAL BALANCE (W):				420

The results of *Table 8* show that the contribution goes from 1800 to 420W. This difference reported in the general balance sheet of *Table 2*, this corresponds to a reduction of 5.63%.

Summary of Results

The results from the above actions can be grouped together in the table of *Table 9*.

Table 9: Summary of results

Actions	A0	A1	A2	A3	A4	A5	A6
Thermal load - kW	24,5	22,2	20,9	20,1	16,9	12,6	11,2
Electrical power - kW	9,8	8,9	8,4	8,0	6,8	5,0	4,5
Annual consumption - kWh	11 760	10 661	10 032	9 624	8 131	6 053	5 390
Maintenance cost - USD	2 822	2 559	2 408	2 310	1 951	1 451	1 294
Contribution of each action (%)	0%	9,3%	4,6%	3,5%	12,7%	17,7%	5,6%
Cumulative contribution (%)	0%	9,3%	14,7%	18,2%	30,9%	48,5%	54,2%

The exploitation of the data makes it possible to show the profile of the loads according to the actions listed above:

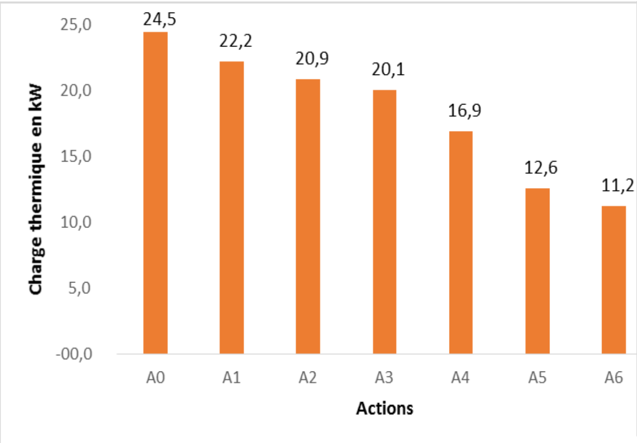

Figure 5: Thermal load profile according to actions

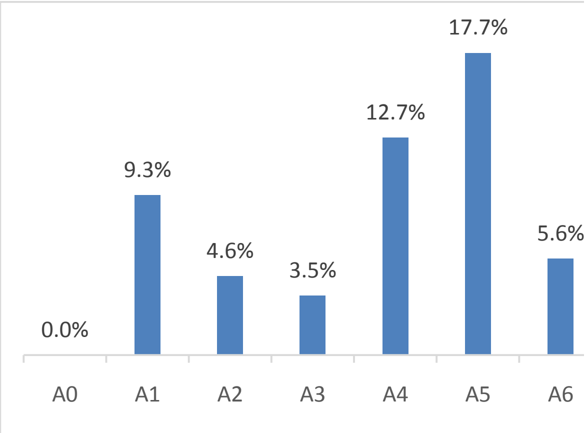

Figure 6: Contribution of each action in%

The first lesson that can be drawn is that the combination of the above actions reduces the thermal load and maintenance cost by almost 54%.

Conclusion

This study clearly shows that substantial energy savings can be achieved through simple and inexpensive actions. The results show that we can reduce by at least 22% of the load from only actions that can be described as sobriety.

We can reach the 54% mark but with actions of financial investments for which it is necessary to make an economic study to assess the relevance (A2, A3, A5 and A6).

However, to better refine the operating time, a study under dynamic conditions is necessary given the large variations in the outside temperature. Also a study on the replacement of cement walls with those of earth typha whose very interesting insulating qualities already established are in progress.

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