28. Heating and cooling demand in buildings: comparison between a parametric model and an audited building

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Abstract Urban population growth together with energy demand increase, among other consequences, provokes the augment of greenhouse gasses emissions (GGE), which contribute to Climate Change. Energy efficiency in buildings becomes essential to reduce demand, keeping acceptable comfort levels for users. Office, housing and commercial buildings consume more than one third of the primary energy produced in Argentina, a similar percentage worldwide. New digital technologies to afford this complex problem combine architectural design and building energy modelling (BEM), like parametric architecture. This tool enables complex tasks as energy efficient building design where materials, energy and information must be considered simultaneously. All these variables can be gathered into one unique transparent process, putting forward energy demand as a key factor for conceptual design decisions. In this paper, we compare the heating demand for one typical winter day with the demand of a house audited by our Laboratory, in order to calibrate our model. The audit shows the results before and after energy efficiency refurbishment. We also calculate the cooling demand for one typical summer day for a future comparison with the audited building.

Keywords Parametric model, Energy efficiency, Energy audit.

1 Introduction

As cities increase their population, the same happens with their energy demand, provoking the augment of GGE which contributes to Climate Change. Energy efficiency is essential as buildings consume more than one third of the primary energy produced in Argentina (BEN, 2013), a similar percentage worldwide (IEA, 2010).

New digital technologies join architectural design together with BEM. We can find many digital tools that integer both areas (Nembrini et al, 2014). Parametric design has become a useful tool to develop complex tasks like energy efficient building design, where materials, energy and information are interchanged with the environment (Hensel et al., 2010). Our tool lets gather all these variables in a unique transparent process, turning energy demand into a key factor during conceptual design stage (Bambardekar, 2009).

We compare the percentage reduction in heating demand between the one obtained by our digital tool and the one obtained by the house audit, before and after efficiency refurbishment. We also calculate cooling demand to compare it with audit results which are still under processing.

2 Methodology

2.1 Description of the audited building

This work bases on the results obtained from an audit of a house situated in the northern area of Great La Plata (Gonnet), which has been refurbished to become more energy efficient, looking for a heating demand reduction (Berardi et al, 2016).

The house´s climate zone is IIIb, temperate hot humid according to Argentina bioclimatic classification ((IRAM Standard 11603, 2011). Average maximum temperature is 28.5ºC in summer and average minimum temperature is 6.7 ºC in winter (IRAM 11603, 2011).

The building has 175sqm in one floor and it is isolated in a plot of land. The neighbourhood has low density and houses are similar to our case study.

Walls are made of 18cm hollow bricks with lime plaster as external and internal finishing. The U value is 1.5 W/m^{2}K, overpassing C level according to IRAM Standard 11605 on maximum values for opaque envelope elements (IRAM Standard 11605, 1996). The refurbishment consisted of the application of an external insulation finishing system known as EIFS to the South curved wall (bedrooms' wall). A 5cm- thick layer of EPS with glass fibre net and cement plaster were added to the outer face of the wall. The new U-value is 0.44 W/m^{2}K and the wall overpasses B level, close to A level (A ≥ 0.38 w/m^{2}K) (Fig. 1)

Flat roofs are made of reinforced concrete (U-value= 1.59W/m^{2}K). Sloped roofs are made of painted metal sheets, air bubble polyethylene membrane and 1”-thick dovetail wood (U=3.64 W/m^{2}K). Roofs do not reach C level, which is equivalent to 1 W/m^{2}K (IRAM Standard 11605), and consequently B level, mandatory for buildings in Buenos Aires Province, according to Energy Efficiency Law (Law 13059, 2003). This law includes IRAM Standard11605 among others on energy efficiency, to determine the required minimum level for envelope elements.

Insulation in sloped roofs was added on the inner side: 100 mm thick glass fibre and dovetail PVC (U-value= 0.37 W/m^{2}K). These roofs nearly reach A level (A ≥ 0.32 W/m^{2}K), according to the referred IRAM Standard.

Fig. 1 Refurbished wall Southern view

Windows have metal BWG n°18 frames with 5+5 mm thick laminated glasses (U-value= 5.86 W/m^{2}K).Clerestories windows are double-glazed (U-value= 3.82W/m^{2}K). The first windows do not achieve minimum U-value= 4W/m^{2}K (IRAM Standard 110507/4, 2010)

Building occupancy consists of a family of 4, who leave the home from 12 to 5 PM during working days. During weekends, we consider that occupancy is 4 inhabitants. To calculate energy demand we consider a working day, as it has more statistical weight (5/7).

The house has a natural gas heater: Goodman which provides 24000 Kcal/h and an electric cooler Goodman. Distribution ducts are made of round metal sheet with inner insulation.

2.2 Parametric modelling

We employ a previous digital tool (Camporeale, 2012) of our own to parameterize the building geometry and to calculate energy demand for typical winter and summer days. It is been already fully described in a paper (Camporeale et al, 2016)

Weather data was obtained from the meteorological station Vantage Pro2 which our Laboratory has installed in Gonnet, and integrates the University of La Plata network. Temperature values were analysed from 2008 to 2015. With these data, we calculated mean minimum and maximum temperatures for typical winter and summer days. Then, we calculated hourly temperatures, employing MODTEM programme (Gonzalo, 2003).Comfort indoor temperature was fixed in 20ºC for winter, the same as in the energy audit. Air change rate was estimated in 1.2/h. Building air volume is 458 m^3. We employed the U-values provided in the cited paper (Berardi, 2016). Comfort temperature is 25ºC for summer.

2.3 Heating demand calculation

We analysed the building conditions before and after the efficiency refurbishment. Heating demand is the algebraic sum of thermal gains and losses for each hour. The process is the same that employs IRAM Standard 11659/1 (IRAM 11659/1, 2004) and 2 (IRAM 11659/2, 2007) to calculate cooling demand for solar peak hour, making it extensive to each hour. In contrast with the cited standards, we considered Sol-air temperature for opaque envelope elements during hours with solar radiation. We consider gains and losses during a typical winter day (Eq. 1):

$$Q_{HEAT}=.\sum_{i=1}^{n}(Q_c + Q_r + Q_a - Q_o - Q_s)(1)$$

Q_{HEAT}: hourly gains and losses for a typical winter day in W
Q_c= thermal losses through envelope in W
Q_r= thermal losses through air changes in W
Q_a= thermal losses through heating system
Qo= internal gains in W
Qs= solar gains in W
n= 1 to 24
We analyse each term separately “Eq. 2”:

$$Q_c=\sum_{i=0}^{n}\Delta t_{iSA}\,.\,(U_m S_m+U_c S_c)+\sum_{i=0}^{n}\Delta t_i\, U_v S_v+P_p.\,24 \qquad (2)$$

Q_c= envelope heat losses in W
Δt_{iSA}= difference between sol-air and indoor temperatures per hour in ºC

n= 1 to 24
U_m= wall thermal transmittance in W/m^{2}K
S_m= walls area in m^2
U_c= roof thermal transmittance in W/m^{2}K
S_c= roof areas in m^2
Uv= window thermal transmittance in W/m^{2}K
P_p= floor losses in W

The next term corresponds to air infiltration losses through windows “Eq. 3”:

$$Q_r = 0{,}35.n_{ren}.V.\ 24h \qquad (3)$$

Q_r= air infiltration losses in W
0.35= air specific capacity in Wh/m^{3}K
n_{ren}= number of air changes per hour in 1/h
V= building air volume in m^3

We analyse the next term “Eq. 4”:

$$Q_a = \sum_{i=1}^{n} C_{AR}.(0{,}25.\Delta t_i + 0{,}61\Delta w) \qquad (4)$$

Q_a= indoor air sensible heat in W
C_{AR}= air flow to renew in m^3/h
0,25= constant between the ratio of air specific heat at 21°C and 50% relative humidity and its volume in W/m^{3}C.
Δt_i= difference between indoor and outdoor temperatures for each hour
0.61= constant between the mean value of the heat released due to 1g water vapour condensation and the corresponding air volume in g/kg
Aw= difference between outdoor and indoor air specific humidity in g/kg

We consider solar gains “Ec.5”:

$$Q_s = F_s . K_V . \sum_{o \in O} Av_o . \sum_{i=1}^{n} Is_{oi} \qquad (5)$$

Q_S= solar gains through windows in W
F_s: solar factor
K_V: thermal transmittance in W/m^{2}K
A_{Vo}: window area in m^2
O= {North, South, East, West}
Is_{oi}: solar radiation according to position and orientation
n=1 to 24

$$Q_{oSL} = \sum_{i=1}^{n} (Q_{i\ perS} + Q_{i\ perL} + Q_{i\ ilumS} + Q_{i\ equipS} + Q_{i\ condS}) \qquad (6)$$

donde:

Q_{oSL}=latent and sensible heat by internal sources: people, equipment, lighting and air-conditioning ducts in W.

Q_{iperS}= people sensible heat in W
Q_{iperL}= people latent heat in W
Q_{iilum}= lighting internal gains in W
Q_{iequip}= equipment internal gains W
Q_{icondS}= duct internal gains in W
n= 1 to 24

Equipment gains will not be considered in our case study.

We discriminate heating demand into envelope components in order to compare the audit results with our results, before and after the efficiency refurbishment.

Audit measurement period comprehends from July, 17th to August, 4th, 2014. Natural gas consumption input let us calculate thermal losses in AuditCAD in the two mentioned states.

2.4 Cooling demand calculation

We calculate cooling demand in the same way as heating demand (Camporeale et al., 2016) “Eq. 7”:

$$Q_{COOL}= Q_c+Q_a+Q_o+Q_s \qquad (7)$$

Q_{COOL}= thermal gains for a typical summer day in W
Q_c= envelope gains in W
Q_a= ventilation gains
Q_o= internal gains in W
Q_s= solar gains in W

Analysing each term separately “Eq. 8”:

$$Q_c=\sum_{i=0}^{n} \Delta t_{iSA} \cdot (K_m S_m+K_c S_c)+ \sum_{i=0}^{n} \Delta t_i \, K_v S_v \qquad (8)$$

References are the same as in “Eq. 2”.

Next term corresponds to ventilation gains “Eq. 9”:

$$Q_a=\sum_{i=1}^{n} C_{AR} . (0{,}25 . \Delta t_i \; + 0{,}61 \Delta w) \quad (9)$$

References are the same as in "Eq. 4".

We consider solar gains “Eq. 10”:

$$Q_s = F_s . K_v . \sum_{o \in O} Av_o \, . \sum_{i=1}^{n} Is_{oi} \qquad (10)$$

References are the same as in “Eq. 5”.

The last term corresponds to internal gains “Eq. 11”:

$$Q_{oSL} = \sum_{i=1}^{n} Q_{i\ perS} + Q_{i\ perL} + Q_{i\ ilumS} + Q_{i\ equipS} + Q_{i\ condS} \qquad (11)$$

References are the same as in “Eq. 6”.
Equipment gains will not be consider as it happens with heating demand.

3 Results analysis

Heating demand results calculated with the parametric programme show the envelope elements losses separately: walls, glazing and roofs for each orientation before and after the refurbishment (Fig. 2) (Table 1):

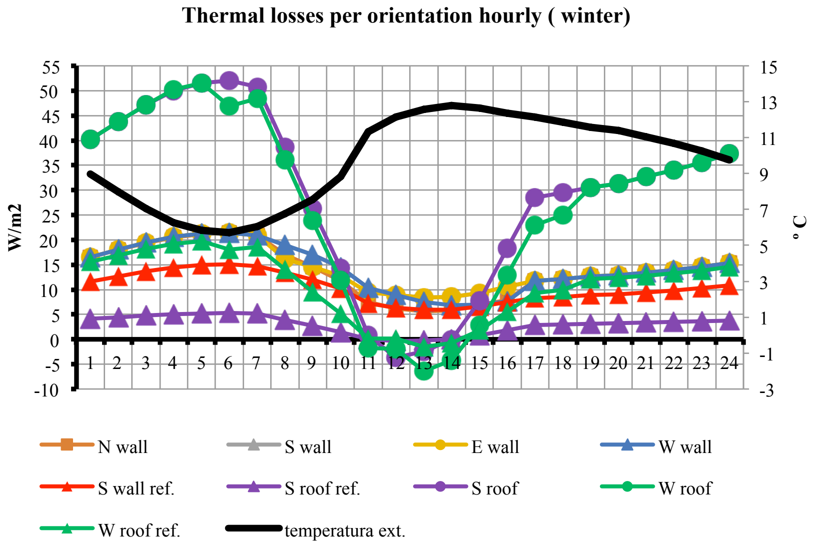


Fig. 2 Thermal losses by sources and hourly external temperatures (winter)

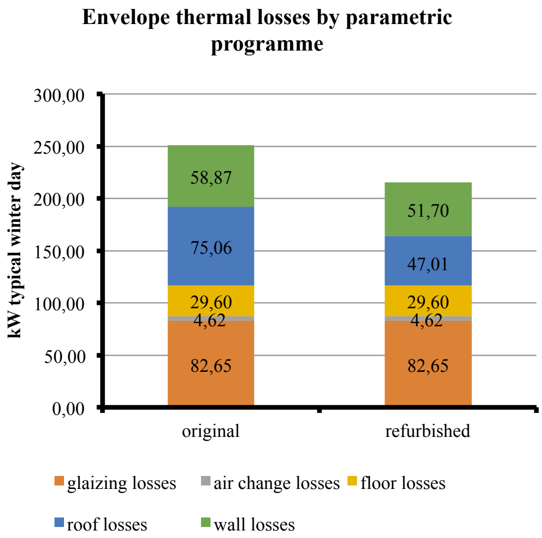
Table 1 Losses and gains before and after efficiency refurbishment

Thermal losses and gains	**Original** **kWx typical winter day**	**Refurbished** **kWx typical winter day**	**Demand reduction** **%**
solar	-188.22	-188.22	0
internal	6	6	0
glazing	82.65	82.65	0
Air change	4.62	4.62	0
floor	29.60	29.60	0
roof	75.06	47.01	37.38
wall	58.87	51.70	12.17
total	293.59	255.40	14.04
Gains and losses sum	111.38	73.18	

Table 3 Percentage comparison of thermal losses between parametric and AuditCAD programmes after efficiency refurbishment

Envelope elements	**Parametric programme**	**AuditCAD**	**Difference %**
Roofs	37,38%	43,08%	-5,70%
Walls	12,17%	10,68%	1,49%
Weighted total	14,04%	17,69%	-3,65%

Then, we compare the results obtained by the two programmes (Fig. 3). AuditCAD does not take into account solar gains but the parametric programme does.


Envelope thermal losses by parametric programme

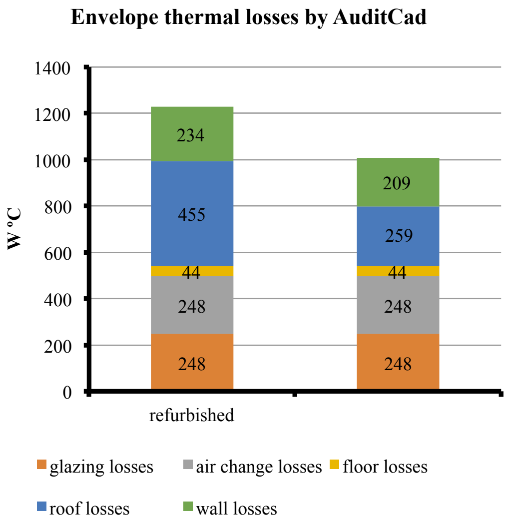

Envelope thermal losses by AuditCad

Fig. 3 Thermal losses by parametric programme and AuditCAD (Winter)

We calculated AuditCAD loss percentages considering the data provided in the cited paper (Berardi, et al., 2016). Differences between both programmes do not overpass 5.7%.; which belongs to roof losses while wall losses difference is only 1.49%. If we compare the two weighted percentages, the difference is 3.65%.

Air change losses are not considered because the rate was not audited but estimated from consumption data. Difference between both programmes is notable even considering the same rate: 1.2/h. Parametric programme shows a 2.14% percentage of the total losses while AuditCAD shows 24.12 %. Figure 4 shows cooling demand according to parametric programme. Refurbished roof losses reflect an important reduction for cooling demand: 96.15%. Wall losses reduction is not so significant because the refurbished area is very small: 16.72m2 over 172.49 m2 (16.72%).

These results could not be compared yet as audit data is still under processing.

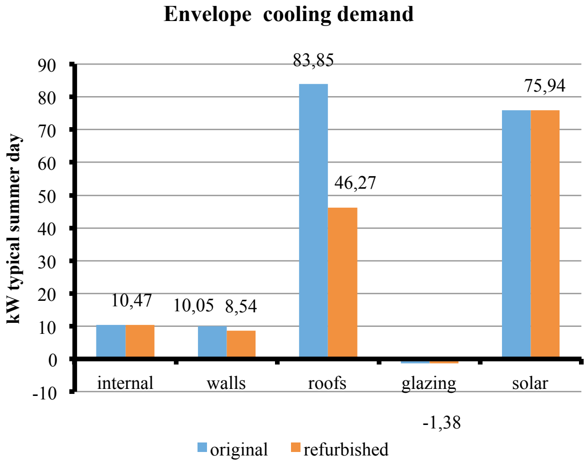


Fig. 4 Cooling demand for a typical summer day

4 Conclusions

These results let us infer that the parametric programme is well calibrated referring to audit results. However, air changes should be measured in situ, as we found significant differences between the two programmes.

The validation of this energy evaluation tool allows applying it to building conceptual design, to obtain an estimation of heating and cooling demands. This is a steady state process which does not require long time and large computational resources, in contrast with simulations which require better material definition and consume more time and resources.

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