Optimisation of indoor thermal comfort outside the heating season

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ABSTRACT

The most diffuse standards which define a low energy building focus their attention to the reduction of consumptions during the heating period. This approach, which can pay in a heating dominated climate, leads to straightforward guidelines for reaching this purpose and to very few indications to avoid the overheating during the rest of the year.

In a context where both the heating and cooling demand play a comparable role there is a need of clear targets and strategies for all the year as the mentioned standards do for the heating season.

This paper discuss this topic by the presentation of the simulation work done for a low energy building who is going to be build in the region of Milano where both heating and cooling demand represent a severe problem. The research was carried out with the aim to reach the most restrictive target for the heating period and at the same time to understand how could be possible to optimise the structure and the envelope of the building (ventilation, shading, glazing, thermal inertia) in order to control the indoor thermal condition outside the heating season most of the time by the means of natural forces which the context can offer.

1. INTRODUCTION

1.1 The case study

The building object of this study is a residential building for the rehabilitation of young people with social problems. During the daytime they live in common spaces while only nighttime they are allowed to reach the bedroom at first floor. In such a way a clear schedule of utilization of the building is disposable even if it is a residential building.

Some general figures of the building itself are collected in Table 1.

The building was conceived by the architect with a superinsulated envelope made of a lightweight structure having in mind as reference the well-known *Passivhaus* standard (Table 2). The building is mechanically ventilated with a heat recovery system (η = 0,72). Even if the standard is not reached mainly because of large glazed openings, with relative high U-value, and a complicated shape leading to a high number of surfaces that dissipate energy, the building behaves quite well in wintertime with a space heating demand of 23 kWh/(m^2 y) according to EN 832 standard.

1.1 The simulation tools

The evaluation of the building performances was carried out with the help of simulation work. A first geometrical analysis, in order to know exactly the influence of self shading of the building, was done using ECOTECT (Fig. 1).

The simulation risults are summarized in Figure 2 that shows clearly the constantly un-

Table 1: General number of the case study building

N° of occupants	16	-
Gross Volume	1560	m^3
Paved area	450	m^2
Building mass per paved area	482	kg/m^3
Ratio Area / Volume	0.74	-

Table 2: U-values of the building.

	$W/(m^2K)$
Envelope (mean value)	0.27
Walls	0.12 ÷ 0.20
Roof	0.09
Windows (g-value 0,62)	1.40

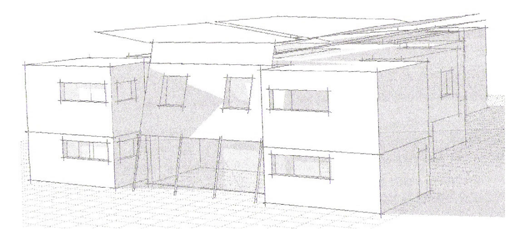

Figure 1: The study of shadows with the software ECOTECT: an image of the building from south-east.

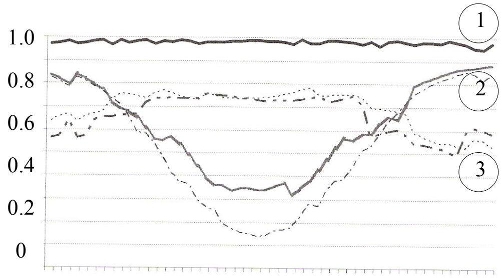

Figure 2: Percentage of irradiated area for different orieta-tion and days of the year (the x axis represents the whole year): 1. Horizontal skylight; 2. Sud facing façade (continuous line) and window (dashed line); 3. West and East oriented windows.

shaded skylight, the effect of self shading in winter for west and east windows and the good performance of the south opening fairly shaded in summer.

Successively these results were integrated within a simulation model in TRNSYS for the comfort (and energy) evaluations presented in the next chapters.

2. CLIMATE

The case study is located in Lodi, close to Milano in Northern part of Italy. The climate is cold in winter and warm and humid in summer (Table 3). Even if the building regulation in Italy imposes limits only for the space heating demand, the cooling demand could represent a great amount in energy utilization in building even in mild seasons.

The value showed in Table 4 represents average values: instantaneous figures could be much lower or higher due to the possible great temperature range characteristic of such a climate (see Figure 5 for hourly temperature values during the overheated period).

For these reasons we focused our attention on the period of the year outside the heating season in order to evaluate the behaviour of such a building mainly designed following rules developed in a heating dominated climate.

Table 3: Monthly average values for external air temperature (ϑ_e), horizontal irradiation (I_{hor}) and relative humidity (UR). Analysis from the test reference year of Milano-Linate.

	ϑ_e in °C	I_{hor} in W/m^2	UR in %
Jan	0.3	106	89
Feb	4.1	185	84
Mar	8.5	295	84
Apr	13.8	418	78
May	16.9	488	71
Jun	20.2	535	78
Jul	20.4	563	62
Aug	21.7	472	77
Sep	18.8	361	87
Oct	12.9	211	90
Nov	7.5	101	90
Dec	2.4	77	89

Table 4: Space heating demand.

	kWh/(m^{2}y)
Transmission losses	33
Ventilation losses	15
Useful solar gains	9
Useful internal gains	14
Space heating demand	25

2.1 Short comments on the heating season

As mentioned above the heating demand is low: about ¼ of the limit of the Italian regulation.

Another consequence of the strategies adopted to save energy in wintertime (i.e. a conservative strategy coupled with a generous supply of solar gains) is the shortening of the heating season (from 3.nov to 17.mar for an amount of 134 days instead of 175). Also the peak power requested is reduced by the high insulation level of the envelope (10.2 kW that occours for about 20 hours per year).

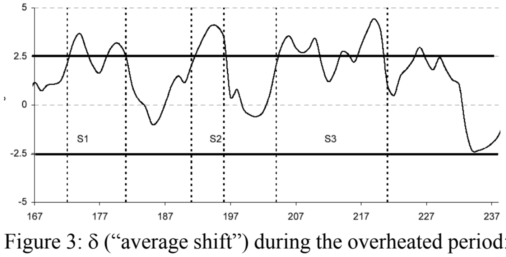

Figure 3: δ (“average shift”) during the overheated period: the peaks indicated the need of cooling system.

With the support of a climatic analysis it was found that the heating period can be subdivided into two parts: $\vartheta_e < 5°C$ and $\vartheta_e < 9°C$, where ϑ_e is the monthly mean external air temperature.

2.2 The definition of the non-heating period

Once found the heating season according to the characteristics of the building and the need to heat it, all the rest of the year is stated as *non-heating period*.

For such a period we defined a division on subperiods on the basis of a climatic data analysis and the response of the building to these forces in terms of thermal comfort. For every subperiod differents strategies leading to thermal confort of the occupants were tested.

3. EVALUATION OF THERMAL COMFORT

Since one of our aims was to reach the thermal comfort of the occupant by the means of the exploitement of the context resources, the building must work as a naturally ventilated building (NV) for most of the time outside the heating season. As asymptote one can think to avoid entirely the use of a cooling system but this target should not conflict whit the thermal comfort of occupants.

For these reasons we found very useful the adaptive approach in describing the thermal comfort (De Dear and Brager, 2002):

$$\vartheta_{com} = 17.8 + 0.31\ \vartheta_e \qquad (1)$$

where:

ϑ_{com} comfort temperature in °C;

ϑ_e monthly mean external air temperature in °C.

In detail we made a statistical analysis, weekly based, on the parameter δ ("*average shift*", see equation 2) and as criterion we defined four classes of thermal comfort (or discomfort):

- *D-* negative discomfort: when $\delta < -2.5$ K;
- *C-* negative comfort: when $-2.5 < \delta < 0$ K identify a comfort period sightly cold;
- *C+* positive comfort: when $0 < \delta < 2.5$ K identify a comfort period sightly warm;
- *D+* positive discomfort: when $\delta > 2.5$ K identify the overheated period

$$\delta = \vartheta_{op} - \vartheta_{com} \qquad (2)$$

where:

ϑ_{op} operative temperature in °C as result of simulations;

ϑ_{com} comfort temperature in °C as defined in equation (1).

More detailed analysis were also carried out considering the overheating degree hours (expressed in K hours) calculated as the integral of the ϑ_{op} considering ϑ_{com} as lower limit. Finaly, but not presented here, an hourly analysis based on the ATG standard, briefly represented by the equation (3) (Rauc, 2004), was also done.

$$\vartheta_{com} = [1\cdot\vartheta_0 + 0.8\cdot\vartheta_1 + 0.4\cdot\vartheta_2 + 0.2\cdot\vartheta_3] / 2.4 \qquad (3)$$

where:

ϑ_{com} comfort temperature in °C;

ϑ_0 today temperature in °C;

ϑ_1 yesterday temperature in °C;

ϑ_2 2 days ago temperature in °C;

ϑ_3 3 days ago temperature in °C;

3. RESULTS

In this chapter the main results are presented.

3.1 Outside the heating period

Outside the heating season the external climate, represented by the test reference year of Milano-Linate, acts on the building (as it is defined in the chapter 1) and make possible the definition of a wide range of periods (Table 5), which describe a typical behavior of the whole system in a detailed way.

In the following lines we summarize this periodization and the effect on building design and optimization.

I this period is usually (for common building) included in the heating season. Due to the superinsulation of the envelope the recourse to the heating plant is occasional[1]. Ventilation is still the major cause of losses, but solar gains on south facade during sunny days are sufficient to balance the wastes.

II this short period is representive of "cold holes" in the season due to occasional lacking of irradiation sufficient to make impossi-

[1] Nevertheless a small amount of heating demand is needed: c. 2 kWh/(m^2 y) data for periods I+II+X (i.e the dual of *legal* heating period with respect to the *real* heating period).

Table 5: Identification of the periods of the non-heating season.

Periods	Start	End	Lenght
I	17.mar	5.apr	13
II	6.apr	14.apr	8
III	15.apr	17.may	32
IV	18.may	15.jun	28
V	16.jun	25.aug	70
VI	26.aug	7.sep	11
VII	7.sep	15.sep	8
VIII	16.sep	12.oct	26
IX	13.oct	22.oct	9
X	23.oct	5.nov	13

Table 6: Climatic parameters related to the periods of the non-heated season.

Periods	$\vartheta_{e,\ monthly}$ °C	$\vartheta_{e,\ weekly}$ °C	$I_{hor,\ weekly}$ W/(m^{2}K)
I II	10 ÷ 14	< 12	250 ÷ 350
III IV	14 ÷ 17	15 ÷ 18	350 ÷ 400 250 ÷ 350
V	> 21	> 22	350 ÷ 450
VI	19 ÷ 21	19 ÷ 21	350 ÷ 400
VII	> 21	21 ÷ 22	250 ÷ 300
VIII	17 ÷ 19	15 ÷ 18	200 ÷ 300
IX X	10 ÷ 14	< 13	< 250

ble to avoid the switching on of heating system even if not continuosly.

III during this period the outside temperatures are mild and the irradiations not extreme. A good balance and/or alternance between daytime ventilation and solar shading according to external conditions and occupants desires (sigltly warm C+ or sightly cold C-) permits to reach ideal condition are of thermal comfort. The shading of the horizontal skylight became to be important.

IV in accordance with the previous perdiod with less irradiation and higher temperature: this leads to a reduction of the daytime ventilation.

V this is the first overheated period. The role of night ventilation is important to lower the internal temperatures, the daytime ventilation is difficult most of the time due to extreme temperatures. The shading coefficient of all glazed surfaces (skylight) has to be close 1 as much as possible in coherence of daylight needs. In this period there is a non negligeable number of hours outside the comfort band (Figure 4).

VI it's an anomalia in the overheated season (mild temperatures). Strategies are the same as period V but with good results for all the time.

VII this period represents the coda of the overheated season with a less intense irradiation that allows a better comfort than period V; nevertheless a night ventilation and a careful control of solar gains are still necessary.

VIII the lowering of temperature does not require anymore the use of night cooling by ventilation. For such a high insulated building and with a good solar gain that needs a faible control this period presents an optimal opportunity to reach thermal comfort.

IX and X with these periods starts, for common buildings, the heating season. For the case study a good comfort is possible without switching on the heating system due to high useful solar gains. Daytime ventilation must

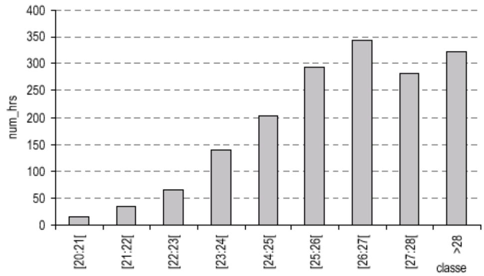

Figure 4: Frequency distribution of temperature during period V.

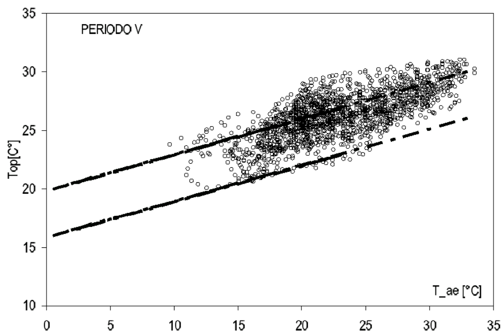

Figure 5: Hourly value of internal operative temperature represented in function of the hourly values of external temperature for the period V. It must be notice that even high figures of external temperature are possible (above 30°C) even if the average value of the temperature appears low (see Table 3).

be kept to the minimum values suggested for indoor air quality.

3.2 The cooling needs: proposal

During period V 38.4% of hours resulted outside the comfort band defined by the adaptive approach. Therefore, in order to guarantee good condition for the occupants, a cooling system is neeeded. A floor radiant system with a mechanical ventilation with UR control to avoid surface condensation was proposed. Simulations (set point fixed to 26°C) demonstrate the faisability of such a system with a cooling load q = 25 W/m^2.

3.3 The role of thermal mass

The building object of this study was a lighweight structure. Some results are surely affected by this hypotesis and some test simulations done with "heavier" internal partitions seeems to confirm that. Moving towards a massive building the values of degree hours are less extreme even if the class of comfort for different periods remains the same.

A good effect of the mass, not yet tested, could be the possibility to increase nighttime ventilation (for the previuos results kept at a maximum of 2 ACH to be realistic): we expect a better behaviour of the building in the overrheated period (from V to VII).

Negative effects of thermal mass we found for some cofiguration of the building with poor solar gains: transition period (I-II, IX-X) without skylight. This suggest a carefull balance between openings (effective to receive solar gains) and irradiated massive components.

During the heating season a massive building is comparable with a lighweight structure; where in the transition periods a massive building behaves better in the dual period (average of 0.5 kWh/(m^2 y)).

4. CONCLUSIONS

In this paper a detailed simulation study of a higly insulated residential building was presented.

Major outcomes of our research are:

- a revision of strategies mainly focused for the heating season in order to be efficient during the all year for a region where both heating and cooling play a significant role;
- a methodology strictly related to the interaction between the weather conditions and the strategies applied for the building design on the basis of the adaptive approach for the thermal comfort evaluation.

Improvements of this research are still possible mainly concerning the role of thermal mass of internal partitions in conjunction with ventilation and solar gains, and facing with the effects of UR on the occupants thermal comfort.

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