Climate optimised building parameters for low energy summer comfort under a discomfort index

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ABSTRACT

An in-dept analysis of a large office building built in the 60s (occupied by the Italian Ministry for the Environment, chosen for its representativity of buildings built in the 50's and 60's) has been performed. A software model of the building has been created and used to simulate its behaviour in the climate zone of Rome, using a dynamic simulation software.

Then a building with the same geometry and same internal gains but with higher storage mass (m > 350 kg/m2, calculated with the method of Heindl – ISO 13786, 1994), selective glazing (U value of windows < 1,8 W/m2K), movable external blinds (solar factor: g < 0,15) and a simple night ventilation strategy has been simulated and optimized to achieve good comfort conditions at low or no energy consumption for mechanical cooling. Blinds have been designed and simulated to obtain required shading without penalizing daylighting.

We calculate the values of the thermo-physical parameters which minimise a discomfort index. elaborated starting from the PMV scale of Fanger.

Comparison of the "original buildings" to the "optimized buildings" shows:

- a 85% reduction of discomfort index supposing the buildings are not air-conditioned;
- a 30% to 80% reduction in energy consumption for cooling supposing the buildings are air-conditioned. A consequent reduction of greenhouse gases emission up to 70÷100 tCO_2-eq/year.

The analysis leads to a proposal for municipal building codes optimized to the climate zone, where the installation of air conditioning is allowed, in new buildings or large retrofits, only if certain target values are achieved by the building envelope and structure.

1. INTRODUCTION

A regulation proposal that answers to the necessity, recently emphasized from the European Community, to reduce energy consumption due to active cooling and to supply instruments able to achieve this objective has been developed in the course of the '90s by the Switzerland Society of Engineers and Architects (SIA, 1992).

Thermo-physical requirements to minimize the consumption of a building are listed in the SIA standard 382/3. According to this approach, the part of building at issue must fulfil the criteria shown in Table 1, where:

- The thermal protection of the building envelope is described by the transmittance (U-value in W/m^2K) of external walls, roof and windows. Its level of impermeability to air infiltrations by the hourly air changes (in h^{-1}).
- The capacity to accumulate internal energy is described by the specific storage mass in kg/m^2 of area (calculated on the base of SIA 382/2 and the Heindl method described in – ISO 13786; we adopt here the SIA terminology: *"masse specifique d'accumulation"*).
- Heat gains through transparent surfaces (or transparent surfaces equipped with solar protections) are represented by the solar factor coefficient.

In this study we acknowledge the rationality of the SIA point of view (first check and improve the quality of the envelope, then install a

Table 1: SIA standard 382/3.

Parameter	Standard
Transmittance of external walls	$\leq$ 0,5 W/m^{2}K
Transmittance of roof	$\leq$ 0,4 W/m^{2}K
Transmittance of windows	$\leq$ 1,8 W/m^{2}K
Air infiltrations	$\leq$ 0,5 h^{-1}
Specific Storage Mass	$\geq$ 350 kg/m^2
Solar factor	$\leq$ 0,15

plant) and we start to explore how the precise values of the parameters should be adapted to other climates (rather than transposed as they are in SIA, which has been done in a small number of municipal building codes in Italy, and probably not applied in practice).

We present here for a climatic area of Italy (Rome), the effectiveness of the SIA approach when adapted to the climate (in this case that of Rome) coupled to a passive cooling technique (night ventilation). Other analysis for a total of 6 climatic areas are underway.

The optimization of the SIA parameters to the climate has been achieved by simulating the building from the point of view of energy balance, thermal comfort and daylighting availability via the software packages Energyplus and Ecotect.

Starting from the audit of the existing office building (Original Building), a first analysis has allowed to estimate the weight of the considered thermo-physical parameters on the thermal comfort of the offices, and to develop the Optimized Building model. Then by comparison with the Original Building we estimate the resulting energy savings and the reduction of greenhouse gas emissions.

We focused our attention on the requirements that influence mainly the building thermal behaviour during the warm season and the Fanger’s PMV scale has been chosen to build an objective function to be used in the optimization.

2. IDENTIFICATION

2.1 Original Building

The building of the Italian Ministry for the Environment is representative of a class of office buildings built in Italy between the '50s and the '70s. This considerable part of the building stock often shows unsatisfactory technical characteristics which would most probably require a retrofit in order to bring it to a satisfactory level in the certification scheme to be introduced according to the Building Directive.

On this building we have executed an audit that has allowed to define the planimetry, the types of building components and the internal gains (occupants, electric lighting system and the other electric equipments and their time schedules). The close similarity in geometry and loads over the different floors has allowed to simplify the problem by simulating in detail only one floor.

This standard floor has been divided in five main thermal zones: south-east zone (20 offices, 710 m^2); north-west zone (21 offices, 514 m^2); north-east zone (3 offices, 66 m^2); south-west zone (3 offices, 33 m^2); internal zone (corridors, WC zones and stair-lift zones, 935 m^2).

The modularity of the two wider office zones (south-east and north-west), has allowed to focus on two types of offices. "Office A" represents the more thermally disadvantaged rooms in summer, with 5 occupants and greater overall gains. "Office B” has 2 occupants and lower overall gains.

In Figure 1 the geometry of the standard floor is shown; in Table 2 the characteristics of two standard office are reported.

The original building has: U value of external walls of 0,98 W/m^{2}K, U value of windows of 5,8 W/m^{2}K, solar factor equal to 0,87 and specific storage mass of 320 kg/m^2.

2.2 Discomfort Index

In order to perform the optimization we chose to build a discomfort index able to weight each hourly time step with its “distance” from comfort conditions, rather than using the simpler method of calculating the number of hours above a certain limit value as it is sometimes

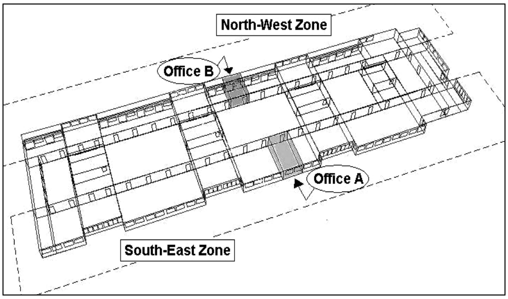

Figure 1: Standard floor model.

Table 2: Standard offices characteristics.

	Orientation	Floor Area	Windows area	Number of Occupants	Installed Electric Power (lighting and equipment)
Office A	South-East	39,6 m^2	5,26 m^2	5	42,7 W/m^2
Office B	North-West	20,9 m^2	7,14 m^2	2	34,1 W/m^2

proposed in the literature.

The discomfort index I_{fanger} is an aggregate index based on the PMV values which in our case have been calculated for each simulation run, each thermal zone and each time step by means of the Energyplus software. It’s a summation, extended to the seasonal time steps, of the absolute values of Fanger’s PMV values if they are larger than 0,5 or lower than – 0,5, which means that we assume as neutral the range between -0,5 and 0,5, in accordance with ISO 7730.

$$I_{fanger} = \sum_{t=1}^{935} (D)_t \cdot \Delta t$$

$$(D)_t = \begin{cases} \left|PMV_{fanger}\right|_t & if \quad \left|PMV_{fanger}\right|_t > 0{,}5 \\ 0 & if \quad \left|PMV_{fanger}\right|_t < 0{,}5 \end{cases}$$

Where Δt is the simulation time step (in this case one hour).

Because we are analysing an office building we have chosen to evaluate its behaviour only during working hours of the summer season for a total of 935 hours.

I_{fanger} is a measure of discomfort over the operation hours of the building and is therefore the objective function we want to minimise.

2.3 Surfaces of Combined Influence (SCI)

In our approach the fundamental parameters, previously listed, have been classified in "summer parameter" and "winter parameter": the first ones mainly influence internal comfort during the warm season, the second ones during the cold season.

The summer parameters on which we focused our attention are:

- specific storage mass;
- solar factor of transparent surfaces;
- hourly air changes for night ventilation.

Starting from the values proposed by SIA (except for air ventilation where SIA does not make prescriptions), each of these parameters has been varied on a scale of 3 values thus developing 27 building models. While varying these three parameters, we kept all the rest unchanged with respect to the original building (geometry, internal gains and windows/doors opening during the day) and we calculated the influence of every parameter on the thermal comfort of rooms as described by our discomfort index.

For the development of the building models and in order to use appropriate values of the considered parameters we have chosen real construction techniques and materials.

In order to vary the solar factor (g) between 0,1 and 0,3, three types of glazed systems have been considered.

In order to achieve the values 220 kg/m^2, 320 kg/m^2 and 650 kg/m^2 for the specific storage mass, we have modified materials and thickness of the building components (Table 3).

The variation of the ventilation rates via night cross-ventilation has been obtained modifying the fraction of external windows and internal doors which is left open at night (Table 4). In other words we don’t impose a certain number of air changes, but we set the amount of windows and doors opening and calculate ventilation rates due to wind pressure, temperature distributions, via the COMIS software model now included in Energyplus.

To determine the optimal combination of summer parameters, that is the combination which minimizes the index of discomfort (I_{Fanger}), the thermal behaviour of the 27 models has been simulated with EnergyPlus.

The attention has been focused on the office zones and, in particular, on the two office types: office A in South-East Zone and office B in North-West Zone. Fixing one of the three parameters at a time at its best value (which minimise the value of I_{Fanger}) and varying the other two, we generated surfaces which describe graphically the influence of those parameters on comfort.

For example, setting the solar factor equal to 0,1 and varying the other two parameters, we obtain the following values of $\mathbf{I_{Fanger}}$:

Table 3: Building components used to vary the specific storage mass.

specific storage mass	**LIGHT: m = 220 kg/m^2**
Elements of external walls (outside-inside)	tile (1 cm) – perforated brick (20 cm) – plaster (1 cm)
Elements of slabs	plaster (1 cm) – cement (15 cm) – concrete (2 cm) – Linoleum (0,5 cm)
Elements of internal walls	plaster (1 cm) – perforated brick (8 cm) – plaster (1 cm)
specific storage mass	**MEDIUM: m = 320 kg/m^2**
Elements of external walls (outside-inside)	tile (1 cm) – perforated brick (12 cm) – air space (10 cm) – perforated brick (12 cm) – plaster (1 cm)
Elements of slabs	plaster (1 cm) – cement (20 cm) – concrete (5 cm) – Linoleum (0,5 cm)
Elements of internal walls	plaster (1 cm) – perforated brick (8 cm) – plaster (1 cm)
specific storage mass	**LARGE: m = 650 kg/m^2**
Elements of external walls (outside-inside)	tile (1 cm) – perforated brick (8 cm) – air space (10 cm) – concrete (20 cm) – plaster (1 cm)
Elements of slabs	plaster (1 cm) – concrete (20 cm) – cement (8 cm) – Linoleum (0,5 cm)
Elements of internal walls	plaster (1 cm) – brick siliceous-calcareous (8 cm) – plaster (1 cm)

I_{Fanger} values at g = 0,1		Night window/door opening fraction		
		null	medium	large
specific storage mass	small	709	250	146
	medium	699	219	123
	large	628	204	118

We assume as a term of reference the less comfortable building model, identified by the highest value of I_{Fanger}: $(I_{Fanger})_{max}$ (in this case, the one with small specific storage mass and windows/doors closed at night). From this we calculate the percentage reduction of the discomfort index (dim%) for the remaining 8 models:

$$(\dim\%)_i = \frac{(I_{Fanger})_{\max} - (I_{Fanger})_i}{(I_{Fanger})_{\max}}$$

I_{Fanger} percentage reduction at g=0,1		Night window/door opening fraction		
		null	medium	large
specific storage mass	small	0,0%	64,8%	79,4%
	medium	1,4%	69,1%	82,6%
	large	11,4%	71,3%	83,3%

The table shows that, having set the solar factor to the value 0,1, the larger improvement to thermal comfort is achieved by the model with large specific storage mass (m = 650 kg/m^2) and with large night window/door opening fraction.

Table 4: Levels of night windows/doors opening fraction.

NIGHT opening.	**Null**	**Medium**	**Large**
% open windows area	0%	12%	25%
% open doors area	0%	50%	100%

Starting from these 9 data it’s possible to develop the surface of combined influence (SCI) (Fig. 2) in the tridimensional space (**I_{Fanger}** percentage reduction, specific storage mass, night window/door opening fraction).

The vertical axis starts from the point of maximum discomfort (**I_{Fanger}** percentage reduction = 0%). The zones with different colours refer to the different ranges of percentage reduction (0%-20%, 20%-40%, ecc.) and they give a graphical indication about the steepness of the surface. The surface shows the individual influence on discomfort of the two parameters free to vary, and visualises the parameter with greater influence.

This method is used to produce, for the considered climatic zone, 6 surfaces of influence: 3 for the office A and 3 for the office B, in each of which, in turn, one of three thermo-physical parameters is held fixed.

For office A, the building model which guarantees best conditions of thermal comfort is the one with specific storage mass equal to 650 kg/m^2 (heavy), large night opening fraction and solar factor equal to 0,1. As for office B, the best building model is the one with medium specific storage mass (320 kg/m^2). In all situations discomfort is directly proportional to the solar factor and inversely proportional to the level of night ventilation as shown in Figure 2.

Therefore we have found that the level of specific storage mass associated with best comfort levels can vary in different parts of the same

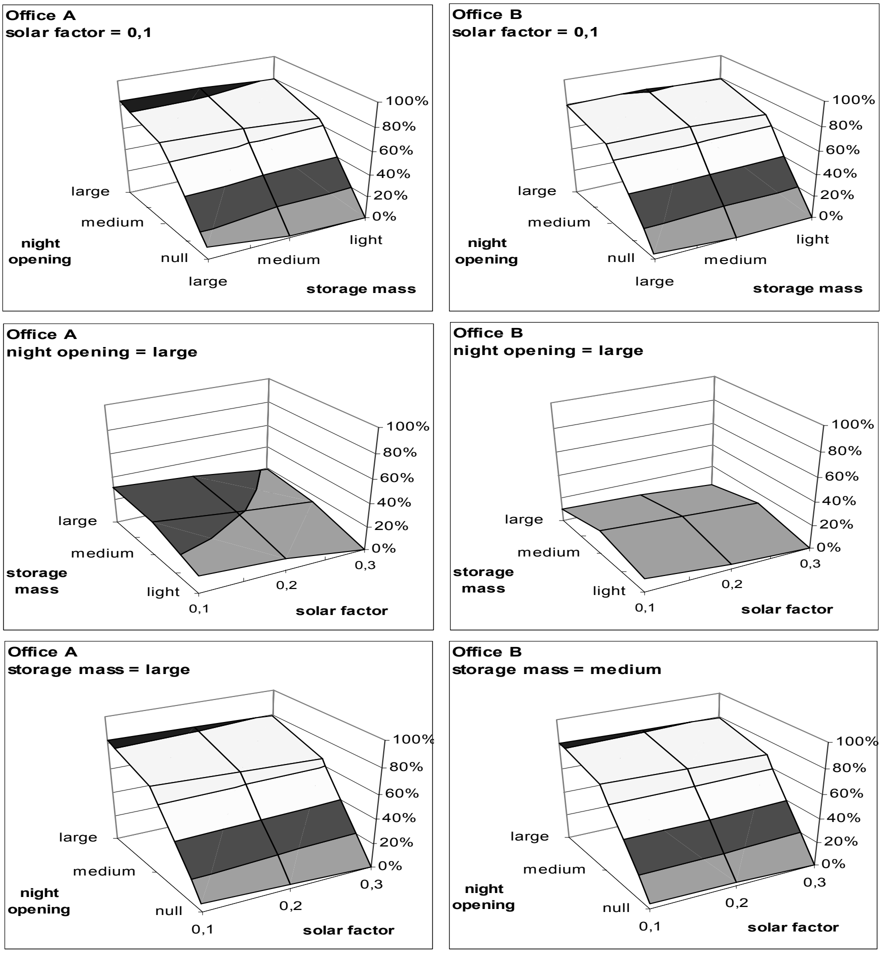

Figure 2: Percentage reduction of the discomfort index I_{Fanger} due to variations in solar factor, specific storage mass, and night opening fraction for office A and office B for Rome climate.

building. This result depends on the definition of the index and on the level of internal gains. The increase of the building thermal inertia typically involves a reduction in the daily fluctuation of hourly PMV values: both maximum and minimum peaks are reduced in massive constructions (Fig. 3).

In Rome, the heavy construction diminishes the frequency of PMV values between 0,8 and 1,4 and increases the frequency of PMV values between 0 and 0,7. Because in rooms with smaller internal gains (office B) hourly PMV not particularly elevated are found, the increases of medium-low PMV have more effect on the discomfort index than the reduction of the maximum values.

However the difference in comfort in office B going from medium to large effective storage mass is small compared to the changes linked to changing opening fraction value, so it is largely acceptable to use the same value specific thermal mass for the entire building as an optimal value.

2.4 Optimised Building

Based on the previous analysis it was possible to define an optimised building, choosing in detail the materials and components necessary to achieve the specified values of the physical parameters. The optimised building has a large

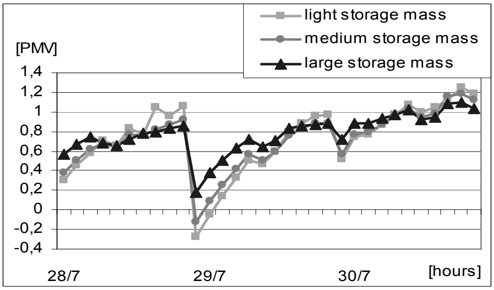

Figure 3: Influence of specific storage mass on hourly PMV values.

specific storage mass, large nigh opening fraction and a combination of low-emissive glass and movable sun blinds to reduce the solar factor to 0,1. Blinds have been designed and simulated via Ecotect to obtain the required shading without penalizing daylighting.

3. COMPARISON

The Original and Optimised Building can be compared with respect to thermal comfort, energy consumption and the environmental impact.

As for thermal comfort in a free float situation (Fig. 4), moving from the Original building to the Optimised building very hot hours (PMV>2) are avoided and warm hours (1<PMV<2) remarkably reduced: in office A, from 67% to 2%. In office A the neutral hours (-0,5<PMV<0,5) increase from 9% to 82%; in office B from 30% to 85%.

Supposing both buildings are mechanically air-conditioned, we have calculated a energy saving ranging from 33% to 78%, depending on the temperature set point (Fig. 5). Considering the national coefficients of conversion the reductions of CO_2 emissions has been estimated. These are reported in Table 5.

4. CONCLUSIONS

Our analysis and simulation of a building representative of a large fraction of the Italian office building stock shows that in the Rome climate large energy savings and summer comfort improvements are achievable via simple measures on window frames, glazing and solar protections coupled with a simple night ventilation strategy (opening 25% of window area and 100% of internal doors at night).

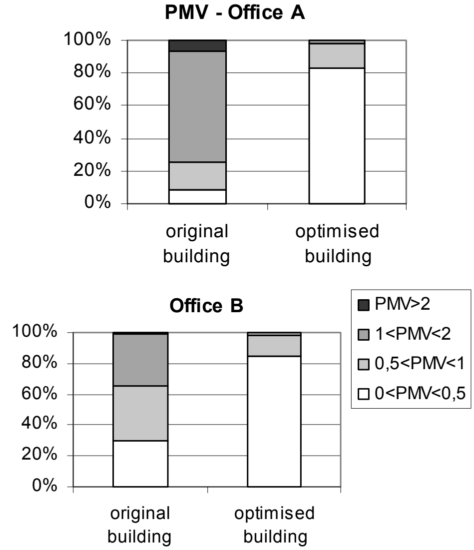

Figure 4: Comparison of number of hours at different PMV levels during warm season, in Rome.

Obviously there might be practical difficulties in realizing such a strategy in offices not designed with this in mind (security problems, etc.) but these can be overcome during a retrofit or avoided in new buildings.

The optimization procedure presented here is currently being used to simulate buildings located in the 6 different climatic zones of Italy and to determine the optimal values of storage specific mass, shading coefficient, night opening fraction in order minimize the values of discomfort index in a free float situation or energy consumption in case of mechanical air conditioning. Those optimum values – different for the 6 climatic zones - could be set in municipal

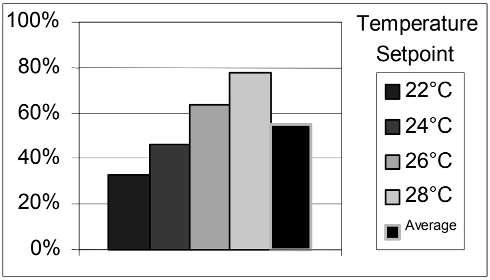

Figure 5: Difference in energy consumption between Original and Optimised building.

Table 5: CO_2-eq emissions for active cooling of two building models with different setpoints of temperature.

CO_2-eq annual emissions [tCO_2/year]		Set-point of internal temperature			
		22°C	24°C	26°C	28°C
Rome	Original building	285,1	221,6	157,6	90,2
	Optimised building	192,2	120,1	56,9	20,3
	Reduction	92,9	101,5	100,8	69,9

building codes as targets to be achieved before installing an air conditioning system, in a similar way to the Swiss SIA V 382/3.

The graphical representations (surfaces of combined influence, different for each climatic zone) could be a useful visual tool to help the intuition of architects and designers about the influence of the physical parameters on comfort and energy consumption in the early phases of design.

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