Optimization of the glazed surface of a building with reference to its consumption for thermal and lighting purposes

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ABSTRACT
The design and the constructive phase of a building, together with air-conditioning equipment management, strongly affect the obtainment of comfort conditions indoors.

Consequently, an accurate analysis of the involved energetic consumption results of primary importance in order to limit energetic cost and pollutant emissions into the atmosphere.

Among building elements particularly its envelope, as a separating element between indoors and out, prove to have a greater importance in determining both comfort conditions and energetic cost, affecting, through its glazed and opaque surfaces, natural ventilation, capture of solar light, noise and heat/cold transfer; consequently, a suitable choice of window surface is pre-eminent in order to minimize energetic and environmental costs.

Thus, the present study is aimed at evaluating the influence of glazed surfaces of buildings on their energetic consumption for thermal and lighting purposes in order to select values able to minimize both energetic and environmental costs.

In addition, a sensitivity analysis of optimum surface values versus degree-days is reported, together with analytical expressions linking the involved parameters.

INDEX TERMS
Optimization; Energy management; Heating; Lighting; Windows

INTRODUCTION
Aim of this study is the optimization of the values of glazed/total surface ratios in buildings with reference to their global energy consumption for thermal and lighting purposes in different climatic regions; as regards particularly thermal consumption, the optimization procedure has been limited to the heating because frequently buildings are not equipped with air-conditioning equipment.

For a building of assigned termo-physical characteristics and established typology of heating and lighting plant, located in several climatic zones of the Italian territory, the seasonal primary energy consumption has been evaluated as a function of the ratio between the glazed and the total surfaces of its facade in order to determine, for each of the selected zones, the value of the optimal ratio that minimize consumption.

An analysis of the distribution of optimum values versus degree-days for different building typologies has subsequently been carried out in order to determine representative analytical expressions.

THERMAL CONSUMPTION
For the evaluation of thermal performances of buildings we have selected a detailed procedure that directly refers to the Italian technical standards concerning the application of the n.

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10/1991 law (GURI, 1991; UNI, 1993), the official Italian government tool in matters of energy consumption in buildings.

The method relies on a global energy balance, taking into account various types of heat losses (transmission and ventilation through the building, losses of the HVAC system due to the phases of production, regulation, distribution and emission of heat) and different heat gains (solar radiation, internal loads, energy transferred by the HVAC plant), all calculated at a monthly base time.

According to the method, the primary energy demand required for the heating of the building is evaluated as the sum of primary energy required for thermal conversion, Q_c, and of primary energy needed by the auxiliary systems, Q_e:

$$Q = Q_c + Q_e . \tag{1}$$

Q_c is given by thermal energy produced by the climatization plant, Q_i, divided by thermal efficiency η for furnace heat plants or by the coefficient of performance *COP* for heat pump plants:

$$Q_c = \frac{Q_p}{\eta} , \tag{2}$$

whereas Q_e consists in the electric energy absorbed by the burner or by the heat pump, Q_a, and by the circulating pump of the thermal fluid, Q_{po}:

$$Q_e = \frac{Q_a + Q_{po}}{\eta_{sen}} , \tag{3}$$

η_{sen} being the mean efficiency of Italian domestic electric sector, equal to 0.36.

Q_p can be evaluated as a function of the useful monthly energy demand Q_{hvs}, and of the efficiencies of the heating elements, η_e, of the distribution system, η_d, and of the regulation system, η_c:

$$Q_p = \frac{Q_{hvs}}{\eta_e \eta_d \eta_c} = \frac{K \cdot \left[F_{il} \cdot (Q_L - Q_{Se}) - \eta_u F_{ig} \cdot (Q_{Si} + Q_I) \right]}{\eta_e \eta_d \eta_c} . \tag{4}$$

As it results from Eqn (4), Q_{hvs} is a function of heat losses, Q_L, of solar gains through external opaque surfaces, Q_{Se}, and through glazed surfaces, Q_{Si}, and of internal gains, Q_I.

It also depends on some reduction factors depending on the intermittent heating regime F_{il} and F_{ig}, on the utilization factor of internal heat gains η_u and on a coefficient K taking into account the working profiles of the building.

The amount of dispersions Q_L can be evaluated by means of the following general expression:

$$Q_x = 86400 \cdot N \cdot H_x \cdot \Delta\theta_x , \tag{5}$$

where N is the number of days in the selected month and H_x and $\Delta\theta_x$, respectively, the heating exchange coefficient and the temperature difference between indoors and the involved external environment.

As regards energy gains, internal gains can in general be assessed by means of tables that provide global monthly values, whereas both contributes of solar gains can be evaluated using the general equation:

$$Q_{Sx} = N \sum_{s=1}^{N_0} q_s \sum_{i=1}^{N_s} A_{e,i} \,, \tag{6}$$

where N is the number of days in the selected month, q the monthly average global solar radiation for a selected orientation and A_e the equivalent area of a generic surface with assigned orientation.

LIGHT CONSUMPTION

In order to determine the monthly amount of primary energy required for lighting purposes, Q_{l}, the artificial lighting period is calculated starting from a predefined occupational profile of the building and assuming that the lighting plant works only when indoor illuminance, E_{ind}, is below a target value (Figure 1).

E_{ind} is calculated by means of the following expression:

$$E_{\mathrm{ind}} = \frac{DF \cdot E_{\mathrm{out}}}{100} \,, \tag{7}$$

where DF is the daylight factor evaluated, for each room of the building, by using the BRS method and E_{out} is outdoor illuminance.

Q_{l} is evaluated using the expression:

$$Q_{\mathrm{l}} = \frac{n_{\mathrm{h}} \cdot N \cdot P_{\mathrm{l}}}{\eta_{\mathrm{sen}}} \,, \tag{8}$$

where n_{h} represents the monthly average of the daily number of hours in which the lighting plant is on, N is the number of days in the selected month and P_{l} the installed electric power.

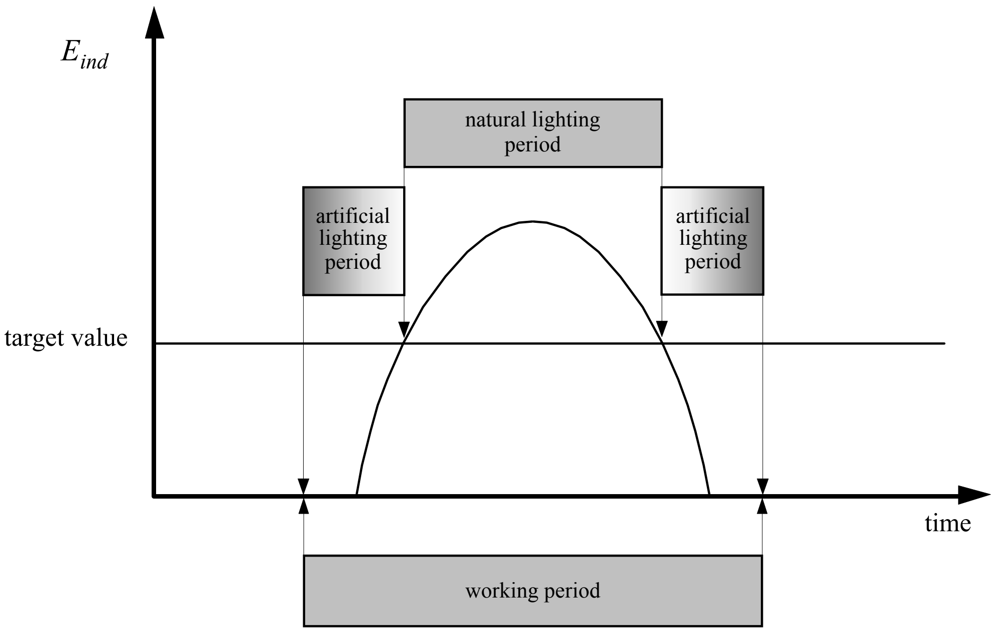

Figure 1 Determination of the time length of the artificial lighting period.

CASE STUDY: APPLICATION TO AN EXAMPLE BUILDING

The methodology has been applied to an office building consisting of three floors, each of them showing a total surface of about 180 m^2 and containing a flat composed of seven rooms.

The building has been equipped with a simple lighting plant, consisting of 100 W lamps per room and has been located in eight Italian towns, whose climatic parameters are reported in Table 1. The indoor air temperature in the heating period has been fixed to 20°C.

Table 1 Climatic parameters of the selected towns

Town	Altitude (m)	Minimum temperature (°C)	Degree-days (°C gg)
Bari	5	0	1185
Bolzano	262	–15	2791
Florence	40	0	1821
Messina	3	5	707
Potenza	819	–3	2472
Rome	20	0	1415
Udine	113	–5	2323

Three different cases have been analysed as regards the opaque element transmittance, U_f, which has been set respectively equal to 1.5, 1.0 and 0.5 W/m^2 K, whereas the transmittance of the glazed surfaces, U_g, has been assumed in all cases equal to 4.0 W/m^2 K.

Moreover, in order to point out the consumption associated with different heat production systems, two systems have been selected: a traditional heating furnace and an air–air heat pump.

As regards the lighting of the building, a target value of 400 lux for indoor illuminance, fixed by Italian technical standard UNI 10380 (UNI, 1994) has been assumed; for outdoor illuminance, a set of experimental data processed for some Italian localities has been utilized (CTI, 1997).

The yearly global amount of primary energy has been calculated as a function of the ratio S_g/S_t between the glazed and total facade surface using a simple computer code developed by some of the present authors (Barbieri *et al.*, 1996) and referring to eight different cases, obtained by varying the number of windows and the extension of some of them.

The building has been located in several sites of the Italian territory, different from a climatic point of view, in order to determine, for each of the selected zones, the value of the glazed/opaque ratio that minimize consumption.

An analysis of the distribution of such optimum values with degree-days has subsequently been carried out in order to determine representative analytical expressions.

ANALYSIS OF THE RESULTS

In Figure 2, the yearly energy consumption of the building, for a transmittance value of the opaque elements $U_f = 1.0$ W/m^2 K, is reported.

It is interesting to note that, for each considered town, all the different curves present a value of the ratio S_g/S_t at which energy costs are lower.

In order to sketch the optimum values as a function of the degree-days of the respective towns, the consumption values reported in Figure 2 have been interpolated using a polynomial curve showing the following analytical form:

$$y = a \cdot \exp(b \cdot x) + \sum_{i=0}^{5} c_i x^i \,, \tag{9}$$

which has been derived in order to provide the respective minimum values.

The diagrams obtained are reported in Figure 3.

It is possible to note that optimal ratios are smaller in sites characterized by continental climates with respect to Mediterranean ones: in particular, a decreasing linear trend between optimal values and degree-days is pointed out, showing very high correlation coefficients.

This suggests to limit glazed surface extension (S_g/S_t = 10–15%) in severe climates with respect to warmer ones, where, on the contrary, it is better to design buildings with larger windows (S_g/S_t = 20–25%).

It is also possible to note that as, for each considered town, optimal ratios increase as the transmittance of the opaque elements does and are greater when using heat pump production systems rather than furnaces.

The analytical dependence between optimum ratio S_g/S_t, degree-days of the site GG and transmittance of opaque surfaces U_f can be expressed by means of the following equation:

$$\left(\frac{S_g}{S_t}\right)_{opt} = a + bU_f + (c + dU_f) \times GG \,, \tag{10}$$

where the coefficients referring to different heat production systems are reported in Table 2.

Table 2 Coefficients of Eqn (10) referring to different heat production systems

Heat production system	*a*	*b*	*c*	*d*
Furnace	0.261	–0.016	-3.00×10^{-5}	-1.20×10^{-5}
Heat pump	0.264	–0.007	-2.65×10^{-5}	-1.68×10^{-5}

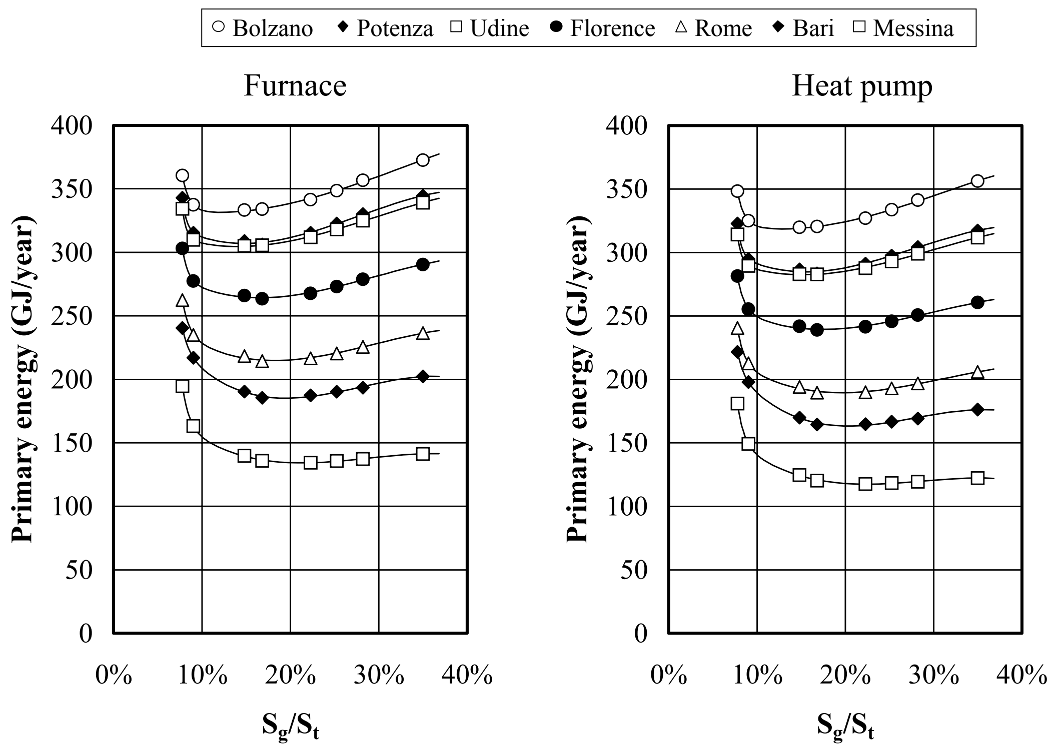

Figure 2 Primary energy consumption for thermal and lighting purposes in the selected towns ($U_f = 1.0$ W/m^2 K, $U_g = 4.0$ W/m^2 K).

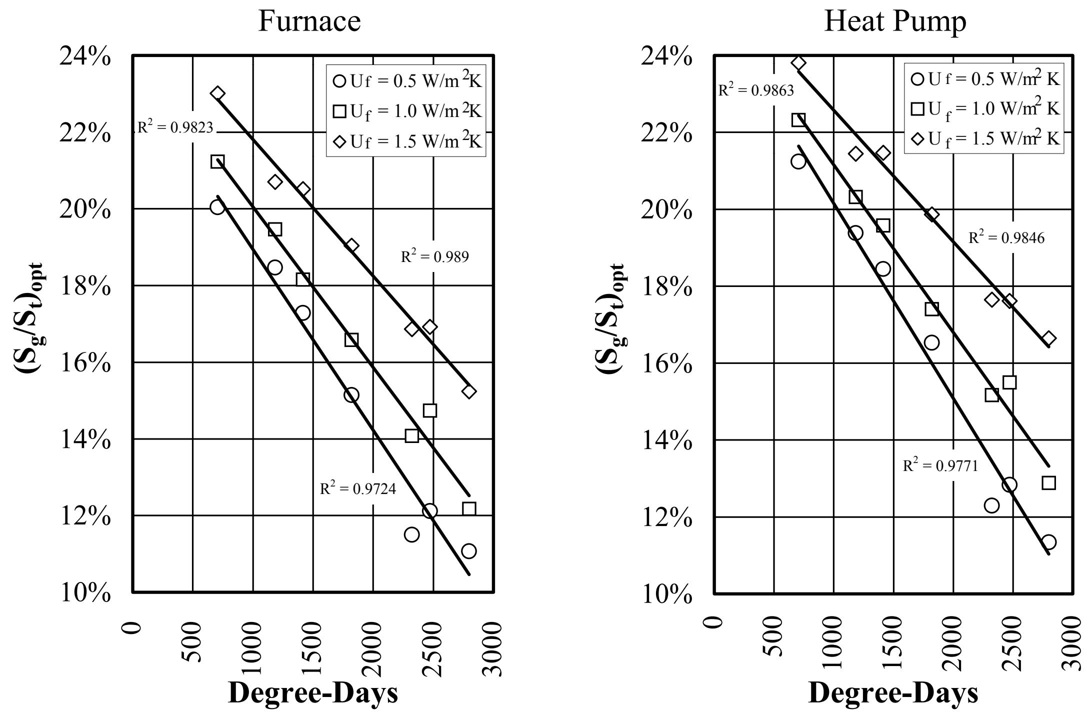

Figure 3 Optimum values of the ratio between glazed and total facade surface as a function of the degree-days.

CONCLUSIONS

Through the paper an assessment of the yearly energy demand of a building for heating and lighting purposes has been carried out as a function of the glazed/total surface ratio, in order to point out eventual existence of values which minimize energy consumption and determine the distribution of such minimum values in different climatic zones.

The analysis has been effected varying the typologies of the heating plant, the thermo-physical characteristics of the building and its location on the Italian territory.

For all the analysed cases the results confirm the existence of a minimum in yearly energy demand; moreover, the study shows that optimum ratios are smaller for severe climates with respect to Mediterranean ones, pointing out a decreasing linear trend versus degree-days. Optimum values decrease as facade transmittance does and are smaller for furnace systems in respect to heat pump ones.

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