Energy and Buildings 68 (2014) 732–740

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

External walls design: The role of periodic thermal transmittance and internal areal heat capacity

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ARTICLE INFO

Keywords:
Energy demand
External walls
Thermal parameters
Periodic thermal transmittance
Internal areal heat capacity
Indoor comfort
Italian regulation

ABSTRACT

Recent studies have shown that considering the values of superficial mass (M_s) and periodic thermal transmittance (Y_{mn}) of external walls is not sufficient to achieve energy savings, particularly in summer. For this reason experimental reference values of the internal areal heat capacity (k_1) were introduced.

This study aims to understand the interdependency between some thermal parameters (U, M_s, φ, F_a, Y_{mn}, k_1) of massive and lightweight walls with respect to their energy performance in use in office buildings in Southern Europe. The study has analyzed eight walls with Italian standard U and Y_{mn} values. These walls have been then modified in order to reach k_1 values corresponding to the reference ones. The energy demand to ensure a defined level of indoor thermal comfort has been verified with thermodynamic simulations on a virtual test-room localized in two Italian cities, characterized by different climate conditions.

The research results are: to develop design change strategies for external walls to achieve the k_1 reference values; to quantify the thermal annual energy demand of a virtual test-room equipped with the sample walls and then equipped with the improved walls; to compare the energetic and economic impact for the improved walls against the sample ones.

1. Introduction

In 2002 the European Directive 2002/91/EC [1] introduced the topic of reducing buildings energy demand during summertime: "Recent years have seen a rise in the number of air-conditioning systems in southern European countries. This creates considerable problems at peak load times, increasing the cost of electricity and disrupting the energy balance in those countries. Priority should be given to strategies which enhance the thermal performance of buildings during the summer period. To this end there should be further development of passive cooling techniques, primarily those that improve indoor climatic conditions and the microclimate around buildings."

Therefore in recent years the reduction of the building energy demand for cooling and the achievement of a high level of indoor thermal comfort in summertime are the subjects of many scientific researches carried out in South Europe. Several studies have demonstrated the importance of having a building envelope with a high thermal inertia – particularly for the summertime performance – both for saving energy and indoor comfort [2]. Furthermore, the European regulation UNI EN ISO 13786/2008 [3] has introduced other parameters – in addition to the thermal transmittance (U in W/m^2 K) and the superficial mass (M_s in kg/m^2) – for the evaluation of the thermal inertia and the summer thermal performance of building envelopes. These parameters are:

- thermal time shift, φ (h);
- thermal decrement factor, F_a (dimensionless);
- periodic thermal transmittance, Y_{mn} (W/m^2 K);
- internal areal heat capacity, k_1 (kJ/m^2 K).

The time shift is the period of time between the maximum amplitude of a cause and the maximum amplitude of its effect [3]. The decrement factor is the ratio of the modulus of the periodic thermal transmittance to the steady-state thermal transmittance U [3]. The periodic thermal transmittance (incorporating the concepts of thermal transmittance, time shift and decrement factor) is a complex quantity defined as the complex amplitude of the density of heat flow rate through the surface of the component adjacent to zone m, divided by the complex amplitude of the temperature in zone n when the temperature in zone m is held constant [3]. The internal areal heat capacity is the heat capacity divided by area of element and the heat capacity is the modulus of the net periodic thermal conductance divided by the angular frequency [3].

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http://dx.doi.org/10.1016/j.enbuild.2012.07.049

Table 1
Thermal parameters of external walls according to the Italian regulations: climate zone E.

	Legislation	Reference value
U	D.Lgs. 311/2006	$U < 0.34\,\mathrm{W/m^2\,K}$ – climate zone E (a cold Italian zone)
M_s	D.Lgs. 311/2006	$M_s > 230\,\mathrm{kg/m^2}$ (exception to zone F, the coldest one)
φ	D.M. – 26th June 2009	$8\,\mathrm{h} \geq \varphi > 6\,\mathrm{h}$ average – $\varphi > 12\,\mathrm{h}$ excellent
F_a	D.M. – 26th June 2009	$0.40 \leq F_a < 0.60$ average – $F_a < 0.15$ excellent
Y_{mn}	DPR 59/2009	$Y_{mn} < 0.12\,\mathrm{W/m^2\,K}$

Table 2
Reference value of k_1 defined in the research carried out by Di Perna et al. [7].

Reference value of k_1	
$k_1 \geq 50$	if $Y_{mn} \leq 0{,}04$
$k_1 \geq 70$	if $0.04 \leq Y_{mn} \leq 0.08$
$k_1 \geq 90$	if $0.08 \leq Y_{mn} \leq 0.1$

The Italian legislations [4–6] have defined reference values for some of the mentioned parameters (Table 1) depending on the climate zone. Indeed the Italian law divides Italy into 6 different climate zones, from the coldest (zone F) to the hottest (zone A).[1] In this study the limit of winter and summer performance values of the climate zone E has been considered. The climate zone E is the first zone, among the cold ones, that requires the verification of summer parameters.

Recent research carried out by Di Perna et al. [7] has shown "how the limit introduced for the periodic thermal transmittance value leads to the development of envelopes which are totally different from the point of view of comfort. Walls with the same stationary and periodic thermal transmittance, but which differ from each other only in the k_1 value, behave very differently from the point of view of indoor comfort."

In fact, a low Y_{mn} value leads to a reduction of outside thermal load impact, particularly from direct sunlight irradiation on external walls, but it is not able to reduce the contribution of the internal loads. Internal heat loads are however the main cause of excessive indoor temperatures during summertime, particularly in office buildings. Indeed the k_1 value describes the actual capacity to accumulate heat on the inner side of a building element and characterizes the internal thermal mass. An envelope with a high potential for heat accumulation on the inner side has a high k_1 value.

Italian regulations neither mention nor define any limit and/or reference values for k_1. The above mentioned study [7] defined minimum values for k_1 depending on the values of Y_{mn} (Table 2) for the first time.

2. Methodology

This study aims to understand the interdependency between thermal parameters of external walls (Table 1) and to analyze the influence of these thermal parameters on the indoor comfort level in office buildings (characterized by the presence of high internal thermal loads) localized in different climate zones of Southern Europe.

To achieve this goal a research organized by the following three steps has been carried out:

- calculation of the thermal parameters' ($U, M_s, \varphi, F_a, Y_{mn}, k_1$) initial status, for eight selected massive and lightweight external walls;
- design changes on the eight sample walls in order to get k_1 values which are comparable to the new introduced k_1 reference values, still complying with the legislation limits for the other thermal parameters;
- energy demand comparison between a virtual test-room equipped with the sample walls and the same test-rooms equipped with the improved walls. The energy demand has been calculated to achieve a level of indoor hydro-thermal comfort (temperature, relative humidity and air velocity) conforming to Italian regulations.

3. First step: energy performance of the selected external walls

In order to evaluate the relationship between thermal transmittance (U), superficial mass (M_s), time shift (φ), decrement factor (F_a), periodic thermal transmittance (Y_{mn}) and internal areal heat capacity (k_1), 4 massive and 4 lightweight external walls (Table 3 and Fig. 1) have been selected. The selected massive walls have been taken as samples because these are the most commonly used ones in Southern Europe (particularly in Italy). Lightweight external walls, instead, are not really common in Southern European countries. In this study these lightweight walls have been chosen as samples too, because they are often more sustainable than massive walls. Indeed lightweight walls are generally characterized by a reduced weight and material usage, are easy to dismantle and use natural, recycled and/or recyclable materials (for example wood). The 4 selected lightweight walls are not very commonly used in Southern Europe, but they are easily available. Composition and characteristics of walls layers *are taken from literature* [8–11] *or from* product/material technical datasheets.

The sample walls are characterized by different layers, materials and thickness. They have been fully analyzed and the compliance with the Italian Regulation verified (Table 1). Table 4 shows that all selected walls do not have k_1 corresponding to the reported minimum values although they meet the current European and Italian Regulation for summer thermal performance (particularly Y_{mn}). Therefore the walls can be modified to increase k_1 values or to lower the minimum k_1 in accordance to the k_1–Y_{mn} relation as shown in Table 2, where lower Y_{mn} imply lower k_1.

The walls have been investigated to verify their hygrometric performance[2] in two Italian cites characterized by different climate conditions (Milan and Catania). According to the results of water condensation simulations, all walls fall within the limits indicated by the Italian Regulations for office buildings.

4. Second step: improving the external walls

By analyzing every sample wall and changing the layers characteristics and sequence to achieve an adequate k_1 value (in relation

[1] Italian Regulations define different building envelopes U value limits for each climate zone and one universal reference Y_{mn} value for all climate zones. The verification of the Y_{mn} is not necessary for the coldest climate zone (F).

[2] According to UNI EN ISO 13786:2008 and UNI EN ISO 13788:2003, the thermo-hygrometric performance for each external wall has been calculated by means of three analytical software packages: TermoK8® CALC developed by ANIT (Associazione Nazionale per l'Isolamento Termico e acustico) – and free available at http://www.termok8.com/_vti_g1_exe.aspx?rpstry=1_; a software created by A. Ursini Casalena and free available at www.mygreenbuildings.org and a spreadsheet created by Professor V. Corrado and in use for students of the Politecnico di Torino.