INNOVATIVE FAÇADES
Lightweight and Thin Systems with High Inertia for the Thermal Comfort Application in Office Buildings in Southern Europe

Monica Rossi[1]

ABSTRACT

This research demonstrates that lightweight, thin façade systems with innovative materials can combine a higher thermal inertia with a lower energy demand for heating and cooling as compared to massive façades. It is therefore very possible to use innovative light materials (originally developed in and for Central Europe) also in Southern Europe, where the main problem is the energy demand for cooling in summer (in contrast to the energy demand for heating in northern latitudes). Three of those systems were selected and investigated for three different climatic conditions in middle latitudes with respect not only to static energy performance parameters imposed by the Italian legislation (thermal transmittance U and superficial mass M_S*), but also checking two dynamic energy performance parameters defined particularly for non massive structures (phase delay* f_a *and decrement factor* φ*). Additionally a recently introduced by European standard UNI-EN-ISO-13786 parameter (periodic thermal transmittance* Y_{ia}*) was considered. Verification of the energy performance of the façade systems was performed using thermodynamic simulations. The results are:*

- *Development and application of an experimental / simulation procedure for the evaluation of the thermal performance of façade systems in use (annual energy demand: [kWh], costs [€] and .CO2 produced [kg]).*
- *Demonstration that energy performance of new lightweight systems is better than the one of a traditional Italian reference façade system with high* M_S*.*
- *Proposal of possibilities for improving the analyzed façade systems with respect to their application in middle latitudes.*
- *Development of design criteria for the application of the analyzed façades in three climatic zones in Italy.*

KEYWORDS

building envelope, thermal comfort, thermal inertia, dry construction

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[1] PhD, Università degli Studi di Camerino, School of Architecture and Design "Eduardo Vittoria," via Lungo Castellano, 63100 Ascoli Piceno, Italy, monica.rossi@unicam.it.

INTRODUCTION

In the world of architecture and building, sustainable development is about reducing energy demand and CO_2 emission during the entire life cycle of buildings—construction, use, maintenance and demolishing—including the life cycle assessment (LCA) of all materials, products and components used. Since the tested materials are very innovative, it was not possible to obtain information from manufacturers on the energy demand and the CO_2 emission during the manufacturing process. Therefore this research focuses only on the reduction of energy demand and consumption during the building use and, in particular, the energy demand for heating and cooling as a function of the performance of building envelopes.

Considering the building envelope as a dynamic interface between the surrounding and the internal environment, its primary role is to contribute to guarantee internal comfort, whilst limiting the use of non renewable energy sources. As a result, this research has identified a number of building façade systems that can be assembled off-site and combine their lightweight structure with a high energy performance, particularly with respect to reduced thermal transmittance and increased thermal inertia.

Following a detailed analysis of the products that have been developed in Central Europe in recent years, three groups of innovative products—not yet available or applied in Southern Europe (middle latitudes)—have been identified with respect to satisfying those needs / requirements: VIP (Vacuum Insulation Panels), TIM (Transparent Insulation Materials) and PCM (Phase Changing Materials) (Pfundstein 2007).

These products in fact show interesting energetic characteristics, which are difficult to be found in other materials used in the construction of building façades across Southern Europe:

- VIP can combine a high thermal resistance with extremely reduced weight and thickness, due to their evacuated condition (Cremers 2007);
- TIM also feature a high thermal resistance combined with reduced weight and thickness. If attached to an opaque wall, they can greatly increase its thermal storage capacity (Kerschberger, 1996);
- PCM can greatly increase the thermal inertia of a non-massive structure independent of their thickness due to their capacity of changing phase.

CASE STUDIES AND INNOVATIVE FAÇADE SYSTEMS

With the intention to evaluate the applicability of those products in Southern Europe, a number of existing central European buildings, characterised by the use of VIP, TIM or PCM, were selected.

As a result of the analysis of their performance (monitored for at least one year), the buildings identified to be particularly innovative and energy efficient are:

- *a single family house (Fig. 1 and 2) in Neumarkt (Germany) using VIP.* The house with its longitudinal axis in east-west orientation is characterized by a highly insulated northern facade and metal balconies at its southern side. The balconies provide sun protection during summer and are not attached to the structure of the house in order to prevent thermal bridges;
- *an office building (Fig. 3 and 4) in Erfurt (Germany) using cellulose honeycomb TIM*. This project is an energetic retrofit of an already existing six floor building. The load-bearing structure of beams and columns in reinforced concrete was kept, whereas the building façade was completely substituted within only three months;

FIGURE 1. Case study 1—single family house in Neumarkt (Germany), using VIP. Image by: Variotec.

FIGURE 2. Case study 1—section of facade type 1, scale 1:5.

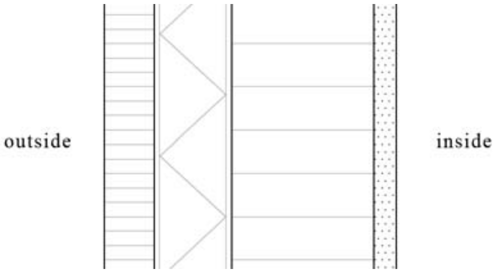


TABLE 1. Case study 1—technical data of façade type 1 (VIP).

	s [m]	λ [W/mK]	ρ [kg/m³]	R [m²k/W]	C [J/kgK]
h_e				0,043	
plywood panel	0,033	0,130	450	0,254	1610
sandwich panel with VIP	0,051	0,010	200	5,100	1050
Gluelam	0,094	0,130	500	0,723	1610
gypsum panel	0,015	0,350	1200	0,043	1010
h_i				0,123	

FIGURE 3. Case study 2—office building in Erfurt (Germany), using TIM made of cellulose. Image by: N. Winter.

FIGURE 4. Case study 2—section of façade type 2, scale 1:5.

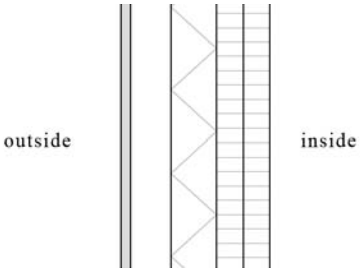


TABLE 2. Case study 2—technical data of façade type 2 (TIM).

	s [m]	λ [W/mK]	ρ [kg/m³]	R [m²k/W]	C J/k gK
h_e				0,043	
low-energy glass	0,006	1,000	250	0,006	2500
air space	0,027	1,730	0	0,156	
TIM in cellulose honeycomb	0,030	0,080	96	0,375	2340
2 wood panels “Pavatex”	0,036	0,016	240	2,250	2100
h_i				0,123	

- *the "Haus der Gegenwart" (Fig. 5 and 6) in Munich (Germany), using gypsum panel with PCM*. The house is a prototype for "current" collective housing, developed during a competition. The private rooms are located at the ground floor with independent access ways. The common rooms are located on the first floor, where the building façade was analyzed.

FIGURE 5. Case study 3—"Haus der Gegenwart" in Munich (Germany), using PCM. Image by: F. Holzherr.

FIGURE 6. Case study 3—section of façade type 3, scale 1:5.

TABLE 3. Case study 3—technical data of façade type 3 (PCM).

	s [m]	λ [W/mK]	ρ [kg/m^3]	R [m^{2}k/W]	C J/k gK
h_e				0,043	
galvanized steel sheet	0,005	50	7800	0,0001	450
air space	0,055	1,730	0	0,156	
multilayer wood panel	0,85	0,150	550	0,566	1660
insulation panel	0,160	0,130	650	3,076	650
moisture barrier	0,005	0,500	980	0,001	980
oriented strand board	0,015	0,130	450	0,1154	770
2 PCM gypsum panels	0,030	0,196	770	0,1531	
h_i				0,123	

PROCEDURE FOR THE EVALUATION OF THE THERMAL PERFORMANCE IN USE OF SELECTED FAÇADE SYSTEMS

In order to verify the potential application of the selected building façade systems in middle latitudes, the systems were evaluated with respect to the current Italian design regulations (Imperadori 2006). This standard defines an upper limit for the thermal transmittance of a façade based on the climatic zone where the building is located and imposes a minimum "superficial mass" [M_S in kg/m^2] for the external vertical surfaces. According to the Italian design regulations (Dlgs. 311/2006, 2007), thermal transmittance [U] has to be lower than 0,33 W/m^{2}K for the coldest climate zone in Italy and the superficial mass [M_S] has to exceed 230 kg/m^2 for the warmest climate zone. In case the value for M_S falls below this limit, an experimental verification is necessary to prove that the thermal inertia is equivalent to that of a façade characterized by the required values. As the selected building façade systems show a very low value of thermal transmittance compared to the design standard—yet their superficial mass is lower than the minimum required (Tables 1, 2 and 3)—it has been necessary to simulate their thermal inertia.

Façade type 1: $U = 0{,}120$ W/m^{2}K, $M_s = 90$ kg/m^2.
Façade type 2: $U = 0{,}330$ W/m^{2}K, $M_s = 16$ kg/m^2.
Façade type 3: $U = 0{,}230$ W/m^{2}K, $M_s = 135{,}34$ kg/m^2.

Given that the design standard does not define a methodology to verify the energetic performance in use, this research has developed an experimental procedure, which simulates the application of the selected building façade systems in three different Italian cities located in diverse climatic zones: Milan (North Italy), Ancona (Central Italy) and Catania (South Italy) (Fig. 7, Table 4).

FIGURE 7. Three test locations and 3D view, section and floor plan of the virtual test-room.

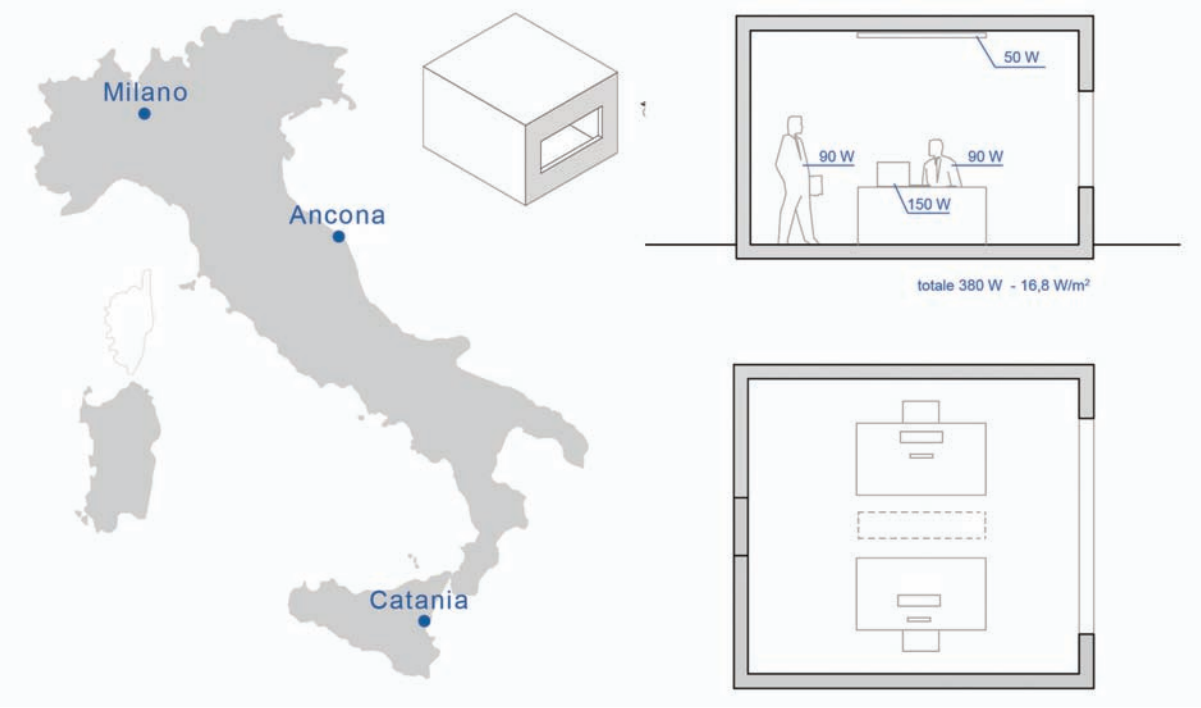


TABLE 4. Climate data for the three Italian test locations. Data obtained from regulation UNI 10349:1994 and measurements of the weather stations at the local airports.

	Milano	Ancona	Catania
Latitude	45°27′ E	43°36′ E	37°30′ E
Longitude	9°11′ N	16°30′N	10°05′ N
Altitude above sea level	122 m	16 m	7 m
Average max temperature in summer	29 °C	30,1 °C	33,6 °C
Average min temperature in winter	–2 °C	1 °C	5 °C
Average annual precipitation	944 mm	776 mm	556 mm
Average wind speed	1,1 m/s	3,2 m/s	4,4 m/s

The energy performance for each of the three selected façade systems has been verified by means of thermodynamic simulations using the software package "Energy Plus" applied to a virtual test room in those three cities. The virtual test room has a floor surface of 22,5 m^2 and a height of 3 m. The room has been simulated as an office space (internal thermal load of 380 W) south-oriented and with a window-to-wall ratio of 30% (Fig. 7).

By means of the simulations not only the static energy performance parameters imposed by the Italian legislation (U and M_S) were checked, but also two dynamic energy performance parameters defined especially for monitoring the thermal inertia of non-massive structures (time shift f_a and decrement factor f) were calculated (Dlgs. 311/2006, 2007). The time shift is the period of time (in hours) between the maximum amplitude of a cause and the maximum amplitude of its effect. In this case, the time shift is the period of time between the maximum value of external surface temperature and the maximum value of internal surface temperature. The decrement factor is the reduction of the amplitude of the heat transmission. Additionally, the annual energy demand necessary to ensure the internal comfort (21°C in winter and 26°C in summer) was calculated assuming a heating system powered by natural gas and an electric cooling system. The annual energy demand is expressed in terms of kWh, € and CO_2 produced (Table 5).

TABLE 5. Method of calculating costs and produced CO_2.

efficiency of the heating system	90%
thermal energy produced per m^3 of natural gas	9 kWh
price of natural gas per m^3	0,65 €
CO_2 emissions per kWh produced	0,20 kg CO_2
1 kWh for heating	0,08 € = 0,20 kg CO_2
EER: Energy Efficiency Ratio	3,3 W/W
price of electric energy mix per kWh	0,19 €
CO_2 emissions per kWh produced	0,58 kg CO_2
1 kWh for cooling	0,05 € = 0,16 kg CO_2

FIGURE 8. Section of reference façade, scale 1:5.

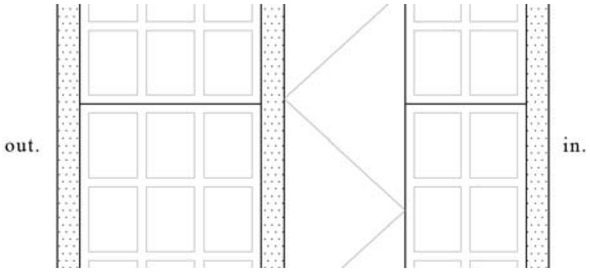


TABLE 6. Technical data of the reference façade.

	s [m]	λ [W/mK]	ρ [kg/m³]	R [m²k/W]	C J/kgK
h_e				0,043	
plaster	0,015	0,900	1800	0,016	910
big honeycomb brick	0,120	0,500	800	0,240	840
plaster	0,015	0,900	1800	0,016	910
insulation panel	0,070	0,30	100	2,300	670
small honeycomb brick	0,080	0,250	700	0,320	840
plaster	0,015	0,350	1200	0,042	1010
h_i				0,123	

The numeric results of the simulation of these three systems were compared with those of a reference façade system (Fig. 8) that is commonly used in buildings in Italy.

Reference façade: $U = 0,33\ W/m^2K$ and $M_s = 31\ kg/m^2$ (Table 6).

Since this research did not only intend to verify the selected façade systems against the design standard, but also to simulate their energy performance, an in-depth analysis was performed, changing the orientation of the test room in the four directions (north, west, south and east) and the window-to-wall ratio of the tested façade (20%, 30% and 50%, corresponding to dimensions of 2,00 × 1,35 m, 3,00 × 1,35 m and 4,10 × 1,56 m). In all the simulations, the energy demand was compared to that of the reference façade in order to establish, moreover, the economic and "environmental" applicability of the considered building façade systems. The applied methodology comprises the following phases:

1. Climatic analysis of three Italian cities in three different climate zones.
2. First set of thermodynamic simulations: Monitoring of the thermal performance of a traditional façade and three innovative façade systems in these cities during one year.
3. Calculation of the annual energy demand [kWh], costs [€] and CO_2 produced [kg] for heating and cooling—first set of simulations.

4. Evaluation of the simulation results and comparison of the energy performance in use of the reference and the tested façade systems.
5. Second set of thermodynamic simulations—sensitivity analysis:
   - variation of orientation towards 4 cardinal points,
   - variation of the window-to-wall ratio for the test system.
6. Calculation of the annual energy demand [kWh], costs [€] and CO_2 produced [kg] for heating and cooling—second set of simulations.
7. Evaluation of the results of the second set of simulations.
8. Elaboration of proposals for improving the analyzed building façade systems.
9. Definition of design guidelines for the application of the analyzed building façade systems in buildings in Southern Europe (middle latitudes).

RESULTS OF THE SIMULATION

The simulations provide the possibility to determine the values of time shift (φ) and decrement factor (f_a) of the building façades as well as the overall annual energy demand during one year (winter and summer) (Fig. 9).

Reference façade : $\varphi = 7$ h, $f_a = 0{,}42$.

Façade type 1: $\varphi = 10{,}62$ h; $f_a = 0{,}20$

Façade type 2: $\varphi = 3{,}46$ h; $f_a = 0{,}85$

Façade type 3: φ and f_a can't be determined due to the nature of PCM

The results of the thermodynamic simulations show not only a good thermal performance and energy saving potential for the new building façades, but also their constraints, particularly when using those systems in buildings in Southern Europe. The tested building façades showed good results during the course of one year, especially in winter. During the summer period, on the other hand, only a minimum energy saving potential was detected (e.g. façade type 2 in Catania was less efficient than the reference façade) (Fig. 9).

These results depend on two main factors: The analyzed building façades were developed for the climatic conditions of central Europe (continental climate), where, in contrast to Italy, energy saving mainly means limiting the energy losses towards the surrounding environment during winter period. The used test room is considered to be an office room, meaning that significant internal thermal loads are present. In this case, also building façade systems with a very good energy performance can't reduce the energy demand for cooling purposes during summer. The use of building façades with a big time shift and decrement factor contributes to limiting the impact of the external thermal load on the internal climate. At the same time, they can't influence the temperature increase due to the internal thermal load and the solar irradiation through the windows.

Based on the above considerations, two different approaches can be derived to solve these two problems:

- Proposals to improve the analyzed building façade systems for their application in southern Europe.
- Criteria for their application in middle latitudes considering not only the building façade but the entire energy concept of the building in which the façade is used.

FIGURE 9. Energy saving potential for the new building façade systems in comparison with the reference building façade.

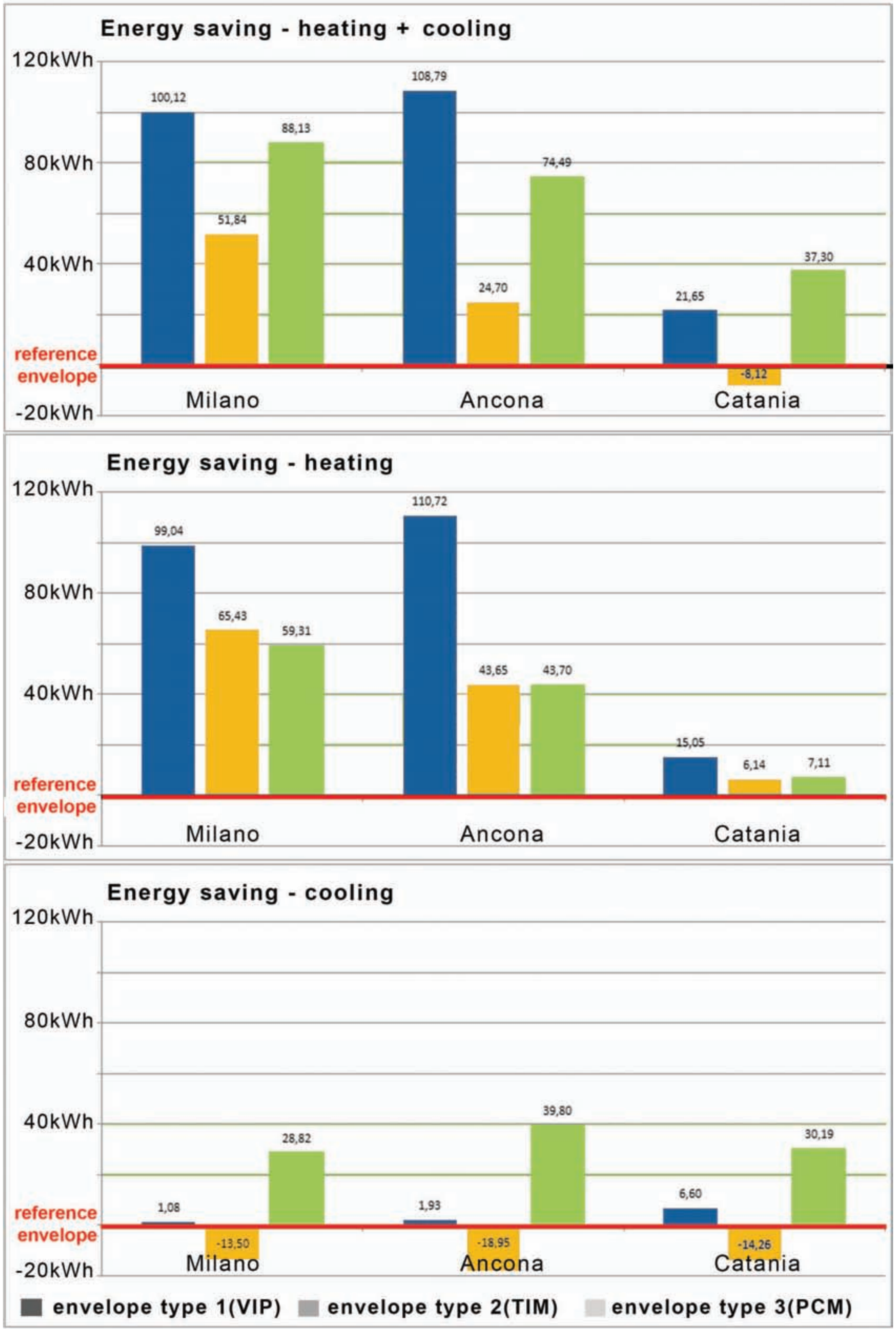
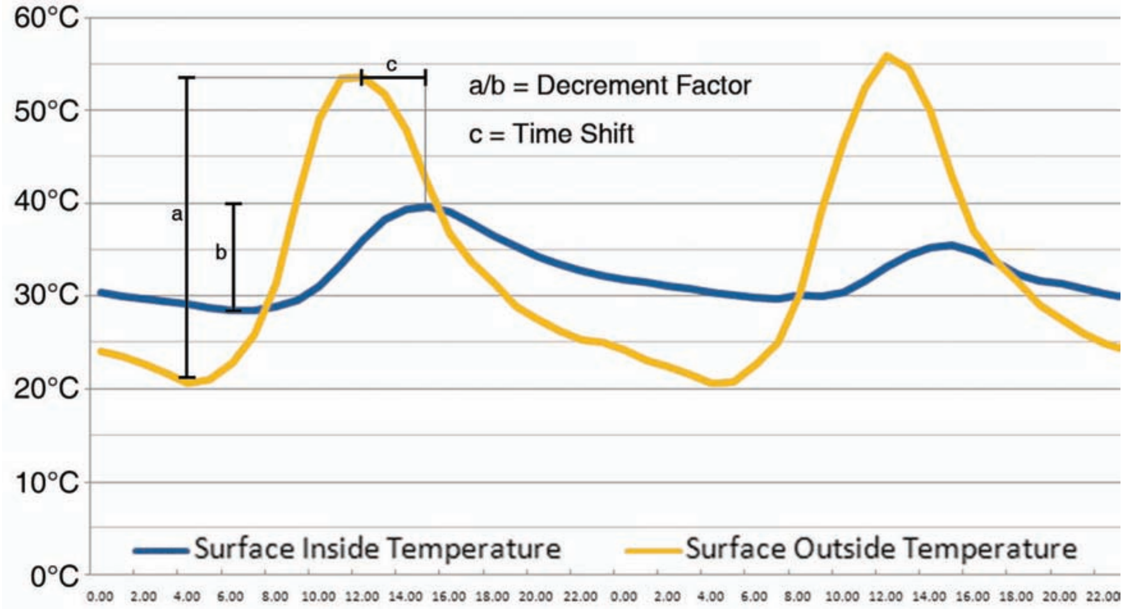


FIGURE 10. Example of the calculation of time shift and decrement factor of the reference façade system.



PROPOSALS FOR IMPROVING THE TESTED FAÇADES

In order to improve the energy performance of the tested façade systems for their application in the climate zones of Southern Europe, suggestions for improvement were developed for manufactures as well as for potential users.

Façade Type 1 (VIP)

The VIP façade system shows good energy performance and no further modifications are considered to be necessary. In order to further improve the energy performance of a building with this façade system, strategic-functional choices have to be approached during the design process of the building rather than changing the stratification, thickness and materials of this system. At Catania the use of the VIP façade system makes it possible to avoid the heating installation thus saving investment and maintenance costs.

Façade Type 2 (TIM)

A good energy performance was observed for this façade type during winter. Nevertheless, excessive energy demand for cooling in summer was detected. This is mainly due to a reduced value of the time shift of 2,5 hours, meaning that changes in external temperature arrive inside the room only 2,5 hours later. As a result, four suggestions for improvement were developed (Table 7), all of which include a new panel of various materials inserted between TIM and a pavatex panel.

The optimized façade systems have the following characteristics:

Proposal 1: $U = 0{,}329\ W/m^2K$, $M_s = 93\ kg/m^2$.

Proposal 2: $U = 0{,}327\ W/m^2K$, $M_s = 301\ kg/m^2$.

Proposal 3: $U = 0{,}158\ W/m^2K$, $M_s = 23{,}8\ kg/m^2$.

Proposal 4: $U= 0{,}124\ W/m^2K$, $M_s= 23{,}2\ kg/m^2$.

TABLE 7. Proposal to improve the façade type 2 (TIM).

		s [m]	λ [W/mK]	ρ [kg/m^3]
Proposal 1	concrete panel middle density	0,08	1,35	1000
Proposal 2	concrete panel high density	0,12	1,50	2400
Proposal 3	insulation panel	0,12	0,036	90
Proposal 4	sandwich panel QASA (VIP)	0,051	0,010	200

TABLE 8. Energy saving potential for the optimized building façade in comparison with the reference system.

	Milano	Ancona	Catania
Façade type 2	51,85 kWh	24,70 kWh	-8,12 kWh
Proposal 1	50,90 kWh	25,48 kWh	-5,76 kWh
Proposal 2	50,49 kWh	26,38 kWh	-3,56 kWh
Proposal 3	80,88 kWh	46,20 kWh	1,19 kWh
Proposal 4	91,76 kWh	55,15 kWh	6,57 kWh

The performance of the optimized building façade systems were analyzed and verified in terms of thermodynamic simulations. The results of thermodynamic simulations did not reveal positive results for the first two proposals, but significant outcomes for the second two proposals (Table 8).

These results highlight that a reduction of the thermal transmittance of the façade corresponds directly to a reduction of the energy demand. An increased superficial mass, on the other hand, does not necessarily mean an improved energy performance, as proposed by the Italian design regulations. The façade type 2 optimized according to proposal 4 does not only show good values for thermal transmittance (U) and superficial mass (M_S) but also better values for the dynamic performance as compared to those of the non-optimized façade 2.

Façade type 2: φ = 3,46 h; f_a = 0,85

Façade type 2 optimized (proposal 4): φ = 8,49 h; f_a = 0,39

Façade Type 3 (PCM)

The façade system containing PCM has a good energy performance during summer. In order to further improve its energy performance during the summer period in hotter climate zones two proposals for improvement were developed. Both of them utilize a PCM with a higher melting temperature (28°C and 30°C) in contrast to the original façade type 3 (PCM melting point 26°C). The simulation results (Table 9) of the optimized façade system type 3 proved that an increasing melting temperature of the PCM has an energy saving effect only in the hottest of the three considered Italian cities.

TABLE 9. Energy saving potential for the optimized building façade in comparison with the reference system.

	Milano	Ancona	Catania
Façade type 3 (26°C)	88,13 kWh	74,49 kWh	37,30 kWh
Proposal 1 (28°C)	80,89 kWh	74,33 kWh	40,98 kWh
Proposal 2 (30°C)	79,90 kWh	66,54 kWh	43,01 kWh

The results further demonstrate that using materials that have the ability of changing their thermal performance with changing temperature (PCM) requires a priori accurate climatic analysis of the desired construction site in order to optimize their energy performance. Using PCM without knowing the average daily and monthly temperature—and especially the range of temperature fluctuation during one day—cannot be energetically and economically efficient.

VERIFICATION OF THE OPTIMIZED FACADE SYSTEMS BASED ON NEW NATIONAL AND EUROPEAN STANDARDS

During the preparation of this research, the issue of energy saving in summer cooling has gained growing international attention. Several new national and European laws were launched to regulate the performance of minimum thermal inertia of building shells and particularly façades.

The Italian regulation D.M.- 26th June 2009 determines that in case the superficial mass for the façades falls below $230 kg/m^2$, a verification of the parameters time shift (φ) and decrement factor (f_a) is necessary—the same parameters this research had previously decided to evaluate. The new design regulation defines values for low time shift and high decrement factor in five categories (bad, sufficient, middle, good and excellent).

Despite the fact that the research phase on decrement factor and time shift was made before the new regulations were published, the optimized façade systems result in having a good valuation based on the above table, whilst the reference façade—although having a large superficial mass—doesn't show good performance.

Reference façade: $\varphi = 7$ h sufficient, $f_a = 0{,}42$ sufficient.

Façade type 1: $\varphi = 10{,}62$ h good; $f_a = 0{,}20$ good.

Façade type 2 optimized (proposal 4): $\varphi = 8{,}49$ h middle; $f_a = 0{,}39$ middle.

For façade type 3 it is not possible to assess time shift and decrement factor due to the presence of PCM, but the thermal annual savings are substantial.

Moreover, during the preparation of this research the European standard UNI-EN-ISO-13786 was published. This standard introduces, in addition to reaffirming the importance of time shift and decrement factor, a new parameter for evaluating the thermal inertia of building shells: the periodic thermal transmittance (Y_{ia}). The periodic thermal transmittance

TABLE 10. Evaluation of the values of time shift and decrement factor on the basis of the new Italian regulation (Ministero dello Sviluppo Economico, 2009).

Time shift	Decrement factor	Evaluation
$\varphi > 12$	$f_a < 0{,}15$	excellent
$12 \geq \varphi > 10$	$0{,}15 \leq f_a < 0{,}30$	good
$10 \geq \varphi > 8$	$0{,}30 \leq f_a < 0{,}40$	middle
$8 \geq \varphi > 6$	$0{,}40 \leq f_a < 0{,}60$	sufficient
$\varphi \geq 6$	$f_a \leq 0{,}60$	bad

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"* (European Committee for Standardization 2008). The European standard UNI-EN-ISO-13786 defines how to calculate the periodic thermal transmittance whereas Italian Law DPR 59 2th April 2009 defines that for façades a periodic thermal transmittance value must be ≤ 0,12 W/m^{2}K (DPR 59/2009, 2009). Based on this new standard the value of the periodic thermal transmittance has been calculated for the reference façade and the optimized façades.

Reference façade: Y_{ia} = 0,1353, not sufficient

Façade type 1: Y_{ia} = 0,0498, excellent

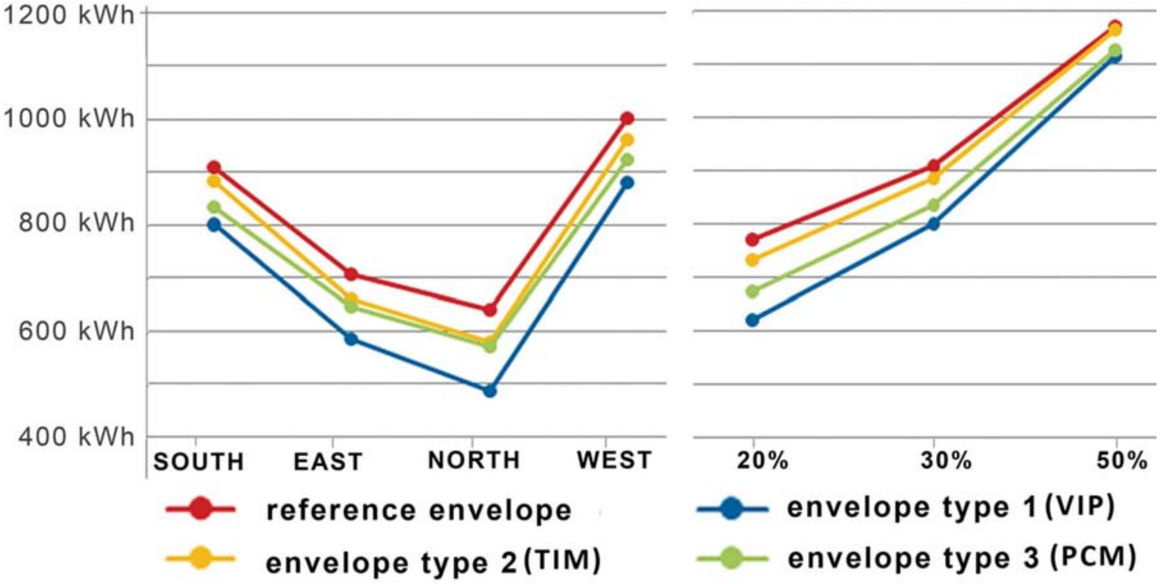
Façade type 2 optimized (proposal 4): Y_{ia} = 0,0580 excellent

In façade type 3 it is not possible to assess time shift and decrement factor for the presence of PCM, but the thermal annual savings is substantial.

DESIGN CRITERIA FOR THE APPLICATION AT MIDDLE LATITUDES

The orientation and the variation of the window-to-wall ratio of the test facade influence considerably the calculated annual energy demand (Fig. 11). Based on the sensitivity analysis, it can be stated that—for an office building in middle latitudes—the most energy efficient orientation is northwards and the window-to-wall ratio should not exceed 20%. Nevertheless, window size can be increased, if sufficient shading is provided (Herzog, 2004). The potential users of these criteria are architects and engineers.

FIGURE 11. Diagram summarizing the results of the sensitivity analysis in the case of Ancona.



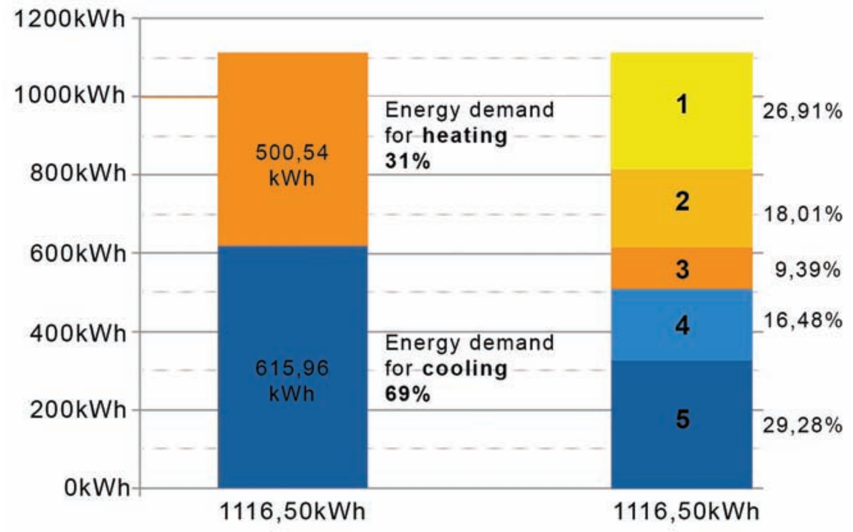
CONCLUSION

This research has demonstrated that thin non-massive building façades with a reduced superficial mass and realized with VIP, TIM or PCM can have a lower annual energy demand compared to massive building façades, also if used in middle latitudes, where the main problem is the energy demand for cooling in summer. Furthermore it is possible to reduce the summer energy demand for cooling with simple modifications to the tested façades systems (addition of a layer in the façade type 2 with TIM and increasing melting temperature in the façade type 3 with PCM).

However, in order to meet this goal a high energy performance building façade (little thermal transmittance U, decrement factor φ and periodic thermal transmittance Y_{ia}; big time shift f_a) alone is not sufficient but it is necessary that the design of a building is based on a consistent energy concept that addresses all aspects of decisions during the design process at different scales. The main design choices that affect the building's energy demand are: building orientation towards 4 cardinal points and towards prevailing winds, building form (surface/volume), internal organization of the space, size and orientation of windows, shading system and natural ventilation strategy (Tucci 2006). Based on the results of the simulation it was further possible to identify the influences that determine the overall energy demand of an office building e.g. in Milan (Fig. 12).

To reduce the energy demand for heating (loss through window and wall) and the energy demand for cooling (due to heat transfer through the wall and due to solar irradiation through the window) it is not sufficient to use only a high energy performance façade system and a high energy performance glass for the windows. Therefore, an efficient shading system must be developed that protects against the sun in summer (in Milan 16,48% of the annual energy demand, fig.12) and not in winter.

FIGURE 12. Causes determining a building's energy demand in the case of Milan. 1-Heating loss through window, 2-Heating loss through wall, 3-Cooling demand due to heat transport through the wall, 4-Cooling demand due to solar irradiation through the window, 5-Cooling demand due to internal thermal load.



However, to reduce the cooling demand due to internal thermal loads (in Milan 29,28% of the annual energy demand, fig.12) it is necessary to develop an appropriate strategy for natural ventilation, that uses prevailing winds and natural air movements caused by pressure differences between inside and outside.

This research has demonstrated that thin non-massive building façades realized with VIP, TIM or PCM have a high potential in reducing the annual energy demand in an office building located in different Italian climatic zones. But the use of such systems must at the same time necessarily be supported by appropriate design choices. These appropriate design choices can't be defined by scientific research, since the design of each building is a particular case. For this reason, the designer can successfully implement these tested façade systems, but has also to consider in each case the specific micro-climatic condition of the location and habits of the users (Hegger 2008).

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