Chapter 18
Building Envelope–Systems Integrated Models: Topic 4

Fabio Conato

Abstract The need to design building envelopes as machines able to offer flexible behaviors due to the variability of the boundary conditions has led to study and develop a methodology for evaluating the correct relationship between casings' energy performances and production systems connected to technical implants. The result was the definition of an application model, able to indicate the most appropriate mix of renewable energies in synergy with the casing. The objective is to maximize the use of renewable energies in compliance with general and functional needs related to the balance of the system.

The study started from the identification and classification of types and families of building envelope, defining materials and operating principles. The simulations used in the assessment models were performed by integrating empirical data with predictive modeling.

The matrix produced was implemented starting from the scenario of the typical needs of each building typology and of every function of it, making possible to evaluate in a forecasting way the variation of primary energy use depending on the performances of each solutions of envelopes.

At the end of this consideration, the model produced was applied to two pilot projects, that constitute the most meaningful product of this research.

Keywords Building envelope • Renewable energies • Technological systems

1 Introduction

The Mediterranean context, and especially that of mainland Italy, is particularly complex from a climate point of view owing to extreme thermal fluctuations and other multiple factors.

All these so-called influential factors determine the constraints and conditions the building envelope needs to respond to in terms of performance.

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The influential factors are classified as fixed and variable, in terms of their degree of variability over time and in the specific context. A further division can be made by distinguishing between internal and external, depending on the spaces they refer to.

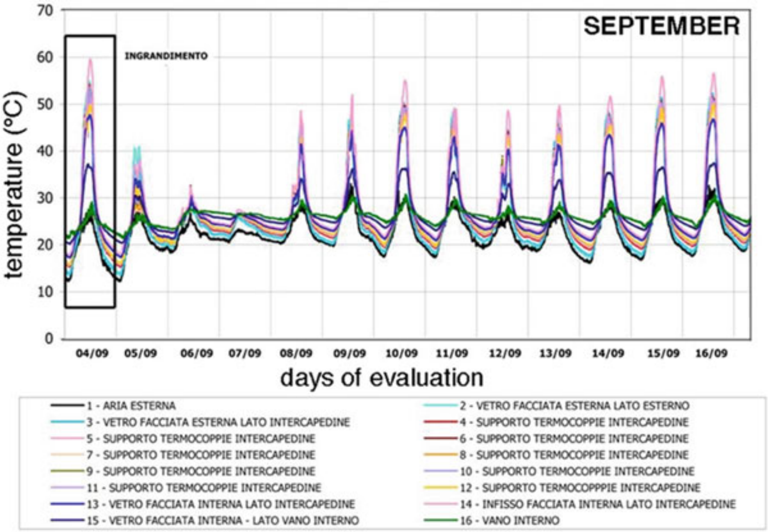
Some examples of *external fixed factors* are the external climatic area of a site, the morphology of the site and the relationship with the surrounding buildings and the orientation of the building in the lot. Some examples of *internal fixed factors* are the intrinsic design factors related to the building project, such as the building type, its intended use and its aspect ratio. The *variable external factors* are defined as the changing seasons and the daily irradiation conditions, the weather variations the general microclimate context the morphology of the site and the relationship with the surrounding buildings, while *internal variable factors* are the internal distribution system and activities inside the compartments.

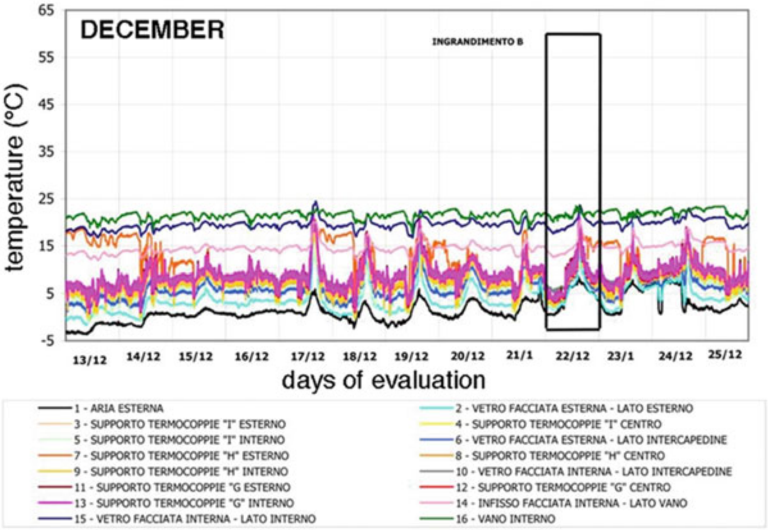
In this context, it is clear that the design of linear behavior building envelope systems presents limits that are sometimes insurmountable; despite the fact that technological research has developed materials and components with increasingly high static performance, the variability of the context in which we work often creates the need to make the same element assume opposing behaviors as a response to the fluctuations of the environmental conditions.

2 Research Completed by the Department of Architecture of the University of Ferrara on the Dynamic Behavior of a Double Skin Building – Envelope

Research conducted by us within the Ferrara Department of Architecture, as early as the 2000s, has allowed us to test the application and operation of double layer building envelope systems, glass–glass, in a residential building in the Italian context (Imola, BO).

The study of these systems in operation – already widely used in the Nordic countries but still not widespread in the Italian context, although they are potentially more functional to its complexity – has allowed the understanding of their dynamic behavior. The experimental data obtained confirmed that, thanks to the triggering of physical phenomena – such as the greenhouse effect, the selective reflection and the air pressure control – generated by the combination of the two layers and maximized from the use of glass, it is possible to manage and monitor the effects of temperature peaks arising from daily and seasonal variability and the different climatic conditions between inside and outside spaces. During the winter season, for example, it is possible to accumulate heat inside the interspace, taking advantage of the so-called “tampon effect” arising from this buffer to create an intermediate weather condition between the inside and outside and therefore to obtain a reduction in energy needs; likewise, during the summer season it is possible to exploit the ventilation in the interspace to extract the excess heat, bringing the temperature of the contained air close to the external conditions, thereby reducing the impact of the greenhouse effect. Finally, in the intermediate seasons, the air of the interspace can be managed in a selective manner inside the confined environments in order to obtain from it a positive contribution to the creation of the ideal microclimate.



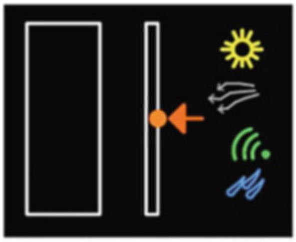


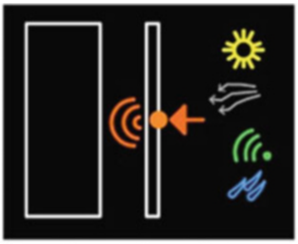
3 Extension and Adaptation of the Concept of Dynamic Behavior Building Envelope

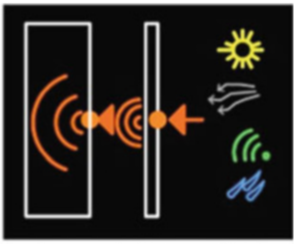
The use of building envelope systems with a double glass–glass layer is a borderline case since this solution is difficult to apply in residential projects within the Mediterranean context. Therefore, in it is not possible to obtain similar performance answers using single building envelope solutions, but it is necessary to define more complex systems that can respond to the dynamic and changing nature of environmental conditions.

Thus, it was determined that in complex climatic environments like the Italian one, it is not feasible to assign the responsibility of managing the fluctuations of the environmental conditions to a single technological resource. It is necessary to refer to a combination of outputs from different solutions. Then the building envelope needs to be designed like a true machine, where the output of each individual element makes a positive contribution to improving the global performance of the system.

The building envelope must therefore be configured as a dynamic behavior system – able to address all the fixed and variable factors that influence the design – on which to the basic skin (made of one or more layers with appropriate static output to the conditions) are added elements of the second skin one by one (e.g., ventilated façades or fixed and mobile shielding systems), which then can interact with the base layer, passively, actively, or interactively, to meet the changing conditions of the environment. These elements can be evolved technological systems (like adjustable shading, nets, or fabrics) or common elements, an integral part of the distribution and technological system of the building (such as projections, balconies, window offsets or boxes).


Dynamic **passive** building envelope


Dynamic **active** building envelope


Dynamic **interactive** building envelope

Further research was completed on the development of empirical evaluation methodologies of the overall effects of different solutions. The outcome is the definition of evaluation grids that allocates a synthetic score to each solution. Then it was possible to obtain quantitative and qualitative estimates of the contribution of each technological solution to the global performance of the building envelope.

	North	South	East	West
Opaque components				
Heavy basic skin	2.5	3	2	3
Light basic skin	3	1	2	1
Correctives				
External layer with low thermal inertia	+0.50	+0.25	–	–
External layer with high thermal inertia	–	–	+0.50	+0.25
Addition of elements of second skin				
Addition of opaque ventilated façade	+0.50	+2	+1	+2
Addition of transparent ventilated façade	+0.50	+2.50	+1	+2.50
Transparent components				
Orientation	1.40	1.90	1.80	1.80
Correctives				
Oversizing of transparent openings (living room) – surface >1/6	−0.80	+0.80	+0.50	−0.50
Addition of elements of second skin				
Summer shading corrective	–	+1	+0.50	+0.80
Winter shading corrective	–	−1	−0.20	−0.50
Presence of solution for energetic recovery (living room)	–	+0.80	+0.30	+0.50
$\text{Synthetic final score} = \frac{\sum_{\text{closure}}(\text{score} + \text{corrective})}{\text{number of closures}}$				

Note that such an approach based on a comparative assessment of the multiple performance effects involved brings together the effects of simple elements with those of complex elements in order to get as close as possible to situations of comfort in indoor spaces characterized by stationary conditions, with significant reduction of thermal peaks conditions.

The presence of a second layer of passive elements, for example, if correctly positioned in relation to openings below, can provide a significant contribution to the control of overheating, effectively shielding the building against incoming solar radiation during the summer season while at the same time allowing radiation through during the winter season in order to obtain a significant heat gain from direct irradiation of glass surfaces.

The experimental data in our possession in fact reveal that the gain obtained by irradiation of each square meter of the glass surface properly exposed represents an average increase in daytime during winter of 1 °C/20 m^3 air. By increasing the portion of the glass surfaces in the living areas by 50 %, an average increase of around 0.7 °C can be obtained instantly, with peaks of up to 3°.

Indirect heat gains can be obtained through complex active systems, (such as ventilated facades, seasonal greenhouses or true double layers) and it is possible to decrease the thermal delta between inside and outside spaces with average temperature increases during the day in winter of around 2 °C/m^3 air, with peaks that reach as high as 5–6°/m^3. This results in a lower dispersion of the building envelope expressed in terms of *equivalent transmittance*, a parameter that expresses the instant variable value of transmittance resulting from the contribution of the average amount of sunshine on the façade throughout the day and from the mass and the heat storage capacity of the materials, placed in the background with respect to the glass surface, that make up the base layer.

If the material constituting the base layer has a good thermal capacity, then the rise in temperature of these layers will in fact result in a significant reduction of the heat flow between the inside and the outside. The increased heaviness of the inner layers results in an increase in the time during which such an effect is prolonged (over 3 h more than in light materials) with a significant increase of the average performance with respect to the latter by 20 %.

This also depends on the type of ventilated façade selected since its dynamic effect will vary depending on the coating material. Obviously this effect is maximized with glass, in which the energy captured from the glass surface for the greenhouse effect is total. In opaque façades, the contribution made by sunshine is exclusively a function of the thermal conductivity of the coating material, of the orientation to which a portion of the façade is exposed and of its ability to radiate heat toward the inside by reducing the thermal delta with the outside.

4 Identification of Building Envelope – Systems Integrated Models

Based on the foregoing premises, research activity was carried out within the Regional Programme for Industrial Research, Innovation and Technology Transfer (PRRIITT) from 2010, in collaboration with “Laboratorio Larco” (*Rete Alta Tecnologia Regione Emilia Romagna*) and several companies. The focus was on the definition of an integration model between the building envelope and the systems of residential buildings. The first phase of this research was aimed at defining costs, reduced consumption and energy-savings goals and determining the balance between building envelope performance and the use of renewable energy sources to meet such requirements.

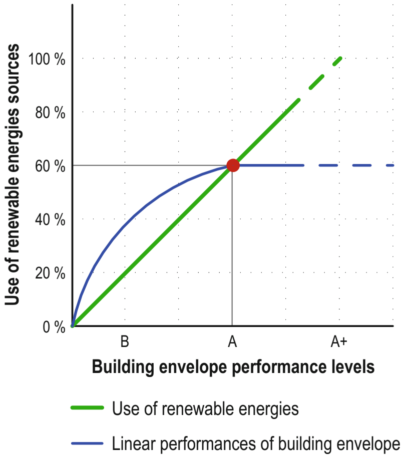
There are some borderline context cases in which the trend is to maximize the use of renewable energy sources, neglecting the level of performance of the building envelope. This is the case of the Canadian urban residential sector, consisting largely of high-rise buildings in which mostly renewable energy (hydropower) is used since it is available at very low cost in the Canadian territory. Attention is paid to the application of water and air control technology through the building envelope, while aspects related to the reduction of energy requirements are neglected. Another extreme is the design of the building envelope focusing on minimizing the primary energy consumption and then obtain the minimum residual usage from fossil energy sources. This is the case of the so-called Passive House, in which the detailed and careful planning and design of the casing systems focus on maximizing the positive contributions of the environmental conditions and minimizing thermal dispersion, thereby making it possible to resort to almost negligible external energy sourcing for air conditioning and heating, making less relevant the adoption of nonrenewable energy sources for the containment of management and deployment costs.

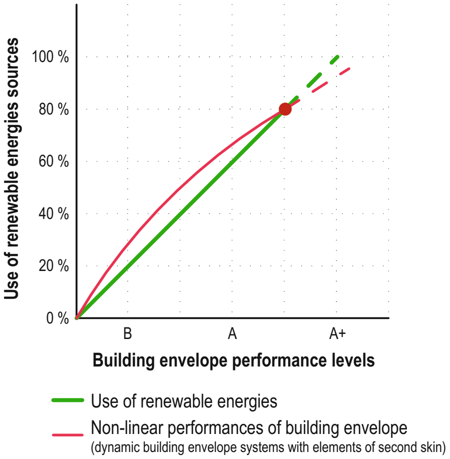
However, in a climatic environment like that in Italy – with complex and articulated residential complexes - that have intrinsic challenges that don't allow the implementation of the approaches described earlier – it is critical to find the balance between the technological aspects of the building envelope envelope and energy systems. This balance seeks to reduce the primary energy requirements and then make it compatible with the use of renewable energy sources through the correct design of building envelope systems while maintaining a positive economic outlook.

Once the usage of renewable energy was defined in relation to the effects on the energy systems that use a variety of renewable energy sources, the second phase of the research started. This was related to three scenarios of building envelope systems. The goal was to understand the threshold of convenience for the integration of technological and performance components linked to the casing with the internal systems.

Three types of building envelope were defined (*A – Energy Class B building, annual consumption under 40 kWh; B – Energy Class A building, annual consumption under 20 kWh, and C – Energy Class A+ building, annual consumption under 15 kWh*) and cross-referenced with the different facility scenarios available.

First, it was determined that in this specific context, the percentage of renewable energy supply should be between 60 and 70 % of the total energy needs. Second, in those cases where the facility systems obtain more than 60 % of their energy from renewable energy sources, the reduction in fossil fuels is not proportional to the level of linear response of the building envelope. The contribution of the latter, over the identified performance threshold, is significant only if it is designed correctly to interact with external environmental conditions, managing the effects of thermal peaks with the application of a second layer according to the scope. The application of a significant component of renewable energy installations, in fact, requires the most stable operating conditions to avoid inefficiencies or having to cope with peak conditions with the renewable component alone.





5 Planning Stage: Application of Models to Case Studies

The third phase was to support the technological and architectonical design of two pilot projects, located in the Bologna province – mainly residential – of comparable size but with very different structural and functional characteristics. It is a mainly residential block within the new Bertalia-Lazzaretto implementation plan, and a complex situated in the municipality of Castel Maggiore (Bologna) consists of a 22-floor residential tower, a square, a shopping center and offices. After analyzing these interventions, the ideal percentages of renewable energy installations were determined and then applied to the corresponding building envelope performance characteristics, following the balance described earlier.

The selection of energy systems was made based on their compatibility – from both functional and architectural points of view – with the typological and climatic aspects of the context in which we operate. Therefore, a mix was selected combining geothermal energy, as the renewable energy source, and cogeneration, as a nonrenewable energy source, which provides functional and economic benefits.

Solar energy was excluded because it does not meet the functional requirements owing to the variability on the climatic context in which we operate. With regard to nonrenewable energy, a cogeneration plant system was selected because it is ideal for integration with geothermal systems since it generates electricity for power, allows both summer and winter regimes, and enjoys tax reduction benefits in the Italian legal framework, related to the tax reduction of methane gas.

In the two case studies, the facilities consist of geothermal probes connected to heat pumps and cogenerators. The percentages of use of renewable and nonrenewable energy are the same for both projects – 60 and 40 %, respectively.

In the Castel Maggiore tower, the system provides for a continuous operation owing to the expected high-volume consumption intended for commercial use. The cogeneration system, which has an absorption system and is powered by two 100 kW turbines, provides an on-call heating or cooling operation mainly associated with the use of hot water for the residential units and the summer and winter cooling of the commercial areas. In the Lazzaretto project, the cogeneration system, powered by two 100 kW turbines, operates intermittently. The heat is directed toward accumulators.

Therefore, the technological characteristics of both buildings were defined in order to achieve the expected performance effects through the design of the base layers and the elements of the second layer. The effects of the building envelope solutions were predicted using synthetic points. This made it possible to further refine the building envelope models in order to obtain the most effective stationary conditions inside the spaces.

In the tower of Castel Maggiore (Bologna), the defined building envelope model is made of two layers (opaque basecoat and second transparent layer) separated by a variable interspace. At the Lazzaretto project, it was not possible to adopt a single type of building envelope, but the sum of different contributions from elements of the second layer was resorted to. These were evaluated in relation to the specific needs. The building envelope model defined here therefore presents a second opaque layer with a summation of point and widespread features on the second layer.

Once the building envelope models were defined, the consumption of renewable energy was estimated in relation to each project as well as to the environmental impact of such integrated solutions, putting the integrated models thus obtained compared to traditional scenarios in compliance with local regulations.

6 Implementation Phase: The Yard

The implementation phase of the two projects included several verification and refining activities of the developed model, aimed on the one hand at verifying the effective behavior of the facility systems – through the selection of the most suitable and reliable components and equipment and soil testing to assess the exact efficiency of geothermal systems. On the other hand, it included the design of the building envelope system to achieve the performance expectations. In both case studies, the technological solutions adopted to maximize the positive effect of their implementation were studied in detail.

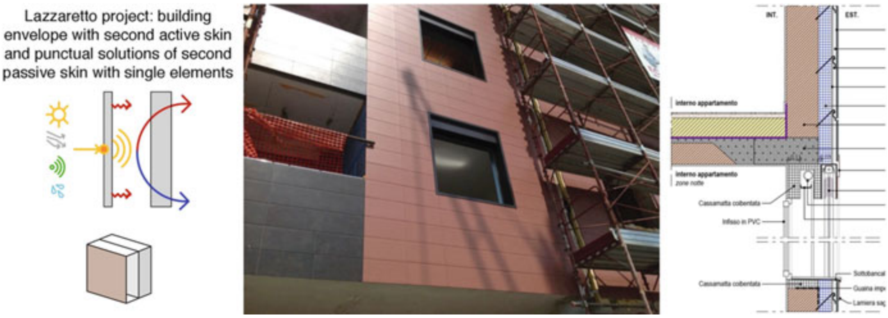
At the Castel Maggiore tower, the closure consists of a building envelope with a second active layer (transparent on opaque) and punctual solutions of interactive individual elements of the building envelope. The base layer (made of aerated concrete and masonry sealer coat) is applied along all the façades of the tower, meeting thermal and environmental standards required by law. The second layer – in active operation – is made of glass, with typology to individual elements (consisting of a curtain wall with structural fastening, with different surface finishings according to the orientation and the functional requirements of the individual rooms that overlook it).

The particular type of façade with ducted operation was chosen to inhibit the excessive chimney effect that would have occurred owing to the height of the building and that would have cancelled the positive contribution owing to radiation and the overheating of the air in the interspace. By using glass as a finishing material, this effect was increased, maximizing heat gain in winter and translating the incident solar energy into a significant reduction of the transmittance equivalent.

To control the incident solar radiation, at the openings that face outward, punctual interactive solutions were adopted (glass blades) that offer a different behavior in different seasons. During the winter season, the blades enable the management of sunshine directly on the base layer, with a consequent thermal gain for the greenhouse effect; in summer, these elements can control the entering luminous flow, keeping the blades upright, the frequency of incident infrared radiation on the glass surface is damped, becoming ultraviolet light, and the incoming heat then dissipates within the interspace between the two layers, allowing only light within the confined environment. Finally, the living areas are equipped with significant openings, using passive elements, generated by a correct dimensioning of the terrace–parapet system against the transparent base layer.

In the Lazzaretto project, instead, the closures have a second layer (opaque on opaque) with punctual solutions with passive second-layer individual discrete elements (opaque on transparent). The ventilated façade here is made with ceramic material (porcelain gres) chosen by virtue of its thinness associated with excellent thermal conductivity and therefore able to contribute fairly quickly to warming the interspace. The underlying masonry, built with blocks of very thick porous brick, is capable of prolonging this effect up to a maximum of 6 h from its onset. In this case, a difference in pressure is created inside the interspace, which is lower than inside the tower – the difference is due to the height of the building. To make the heat gain significant, it was necessary to adopt systems for mechanical ventilation at variable flow to make the most use of the positive effect created within the interspace.

The problems arising from direct sunlight during the summer season and the consequent overheating of the interior –corresponding to building envelope solutions where the base layer is made from simple transparent fixtures – are resolved by punctual elements on the second layer belonging to the distribution and technology systems of the building (such as jetties and terraces) and designed according to the orientation of the building, in order to impose an effective glare control and the resulting light flux entering the compartments.



7 Monitoring Phase

The implementation of the integrated models thus obtained presented some problems, as expected, mostly linked to the need to adjust such articulated and complex systems. To determine the most suitable regulation criteria for managing the computerized control of these systems, an analysis was completed on the first completed project (Isolato 2A – Bertalia-Lazzaretto). It was a manual compilation of changes linked to the adopted system typologies, based on 45 regulation points.

Next, thanks to the compilation of the operative regulations, it was possible to understand their relationship with the functionality of the building envelope system. This helped to refine the defined model further by incorporating corrections on the functionality and the refining of the second-layer elements (for example, modifying the façade ventilation modalities or inserting adjustable sunshades).

Thanks to this activity, it was possible to determine 12 common scenarios that summarize the operation model of the facility systems (linked to the stationary and peak conditions of summer and winter, day and night, and the stationary condition of the intermediate seasons) that allow the balance in relation to the performance of the casing, the instant contribution of the different energy sources (both renewable and non) keeping the annual sourcing from renewable sources close to the forecasted estimate (60–70 %) and making the system able to adapt to the fluctuations of the detected conditions.

Finally, by analyzing data on the consumption of gas and electricity – in order to calculate the management costs of the buildings and ensure that they correspond to the initial objectives – it was confirmed that, on the one hand, the actual consumption data are in line with those of maximum forecasted projections and, on the other, the other system parts are basically oversized; the forecasted models were conservative, defining performances of the systems obtained between building envelope and systems higher than foreseen in the initial phase. This has therefore allowed a further refinement of the model thus defined, increasing the storage capacity of the heat produced by the systems while limiting their period of operation compared to the expected threshold, thereby reducing the stress on the ground caused by geothermal probes and limiting the operation of the components that exploit nonrenewable energies to daylight hours only. The redefined model has therefore allowed the development of an electronic and information system based on the scenarios described.

Types of scenarios (operation of systems)	Percentage of use of renewable energies in defined building envelope–systems integrated model	Appraised percentage of use of renewable energy in linear building envelope model (without elements of second skin)
1. Summer, stationary conditions – day	80	50
2. Summer, stationary conditions – night	55	30
3. Summer, peak conditions – day	50	30
4. Summer, peak conditions – night	30	5
5. Winter, stationary conditions – day	60	40
6. Winter, stationary conditions – night	50	30
7. Winter, peak conditions – day	30	5
8. Winter, peak conditions – night	20	0
9. Spring, stationary conditions – day	100	60
10. Spring, stationary conditions – night	70	40
11. Autumn, stationary conditions – day	100	60

Annual consumption: Bertalia-Lazzaretto block 2A – Bologna (Jan 2014–Jan 2015)		
HSW	Heating	Cooling
2756,96 mc	238 365,30 kWh	35 820,80 kWh

(continued)

Annual consumption: Bertalia-Lazzaretto block 2A – Bologna (Jan 2014–Jan 2015)		
HSW	Heating	Cooling
€30 050,86	€18 706,91	€12 895,49
Approx. 2.40 €/sm	Approx. 1.50 €/sm	Approx. 1.10 €/sm
Total 5 € /sm as predicted		