Learning from the past: the recovery and the optimization of the original energy behaviour of "Portici" Houses in Bolzano

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SUMMARY

The paper presents the studies realised on the "Portici" Houses, a part of the historic Centre of Bolzano, built at the end of the 12th century. This characteristic architectural typology is composed by a system of houses with narrow facades and a continuous arcade on the front. The serial repetition of this type of building forms a constant structure, interrupted only by a system of atria that provide daylight and fresh air to the dwellings. The surface-to-volume ratio, the dimensions of the courtyards, the presence of internal shadowing, the thermal inertia of walls and cellars, and the colour of the surface finishing have a positive influence on heating and cooling demand of the buildings. Unfortunately, more recently, the users have altered the historic energy system with roofs and canopies to improve comfort and to protect from sun and water. This situation has completely changed the original energy and environmental behaviour. The study aims to restore the original concept and to adapt it to the modern requirements, both optimizing energy efficiency and preserving the heritage values. This means to recognize historical transformations, users' needs, present uses, critical points, and opportunities for the retrofit. The deeper knowledge is the starting point for defining the more appropriate retrofit actions, which include suitable technologies and systems, which are cost-effective, technically and aesthetically compatible with the value of buildings and urban settlement.

Key words: Energy efficiency, energy retrofit, preservation of heritage, low environmental impact, energy behavior, energy concept, survey for users' comfort

1. INTRODUCTION

Energy efficiency and environmental sustainability became a priority of the European Union policies that decided to drastically cut CO_2 emissions and energy consumption and to increase the share of the renewable sources by 2020. In the near future, this process will involve major acceleration of the energy requalification of existing buildings. Interventions on historic buildings require widespread knowledge of history, dimensions, building techniques, structures, materials, and management procedures. Furthermore, a specific study of the built heritage is very important to inspire innovative solutions based on empirical knowledge of the typical pre-industrial world.

These considerations are the basis of the FP7 European Projects 3encult and EFFESUS that aim to reduce the environmental impact of Europe's valuable urban heritage, making significant improvements to its energy efficiency and also conserving and promoting cultural, historic, and architectural values. 3encult project aims to develop the more appropriate passive and active solutions for analysing, conserving and retrofitting the historic buildings, demonstrating that energy efficiency is useful for structural protection as well as for comfort of users and heritage collections. EFFESUS project considers both the energy efficiency of individual buildings, ensembles and districts, as well as energy generation from renewable sources within historic urban districts. It aims to develop and demonstrate methodology and criteria for selecting and prioritising energy efficiency interventions, based on cost-effective technologies compatible with heritage values.

In all cases, the upgrade of the historic centres requires widespread knowledge of history, dimensions, structures, shapes, building techniques, materials, energy concept and management procedures. On the one hand, traditional urban centres and building have developed from a close relationship with the natural environment. On the other hand, the solutions used in the past derived from empirical knowledge of the territorial factors, climatic and cultural belonging.

2. A TYPICAL ALPINE TOWN: BOLZANO-BOZEN

The city of Bolzano-Bozen was founded around 1180. It is a key area of Central Europe, situated in the heart of the Alps, on the main transalpine route between Germany, Austria and Italy. With at present nearly 100.000 inhabitants, it is the main city of the region of South Tyrol. It lies at an altitude of about 250 m a.s.l. and has a mild and dry climate. Due to its location in the basin of a deep valley, high temperatures and heat waves affect the city also during summer. The surrounding mountain ranges with a significant height prevent from balancing currents from the north and moisture from the south. This results in a distinctive continental climate with relatively strong seasonal fluctuations, but also daily fluctuations in temperature. In this area, outweigh the west and southwest winds. In winter there is often no wind or wind from north and northeast. Other winds generally are less frequently. The presence of precipitation, more frequent in summer and less in winter, also characterizes the climate.

3. PRIMARY ENERGY CONCEPT

The original city stretched around "Via dei Portici", an ancient road of the last decades of the XII Century. The city walls protected the town from external attacks and aggressions. The street has a length of 300 meters and it is oriented from east to west in order to ensure the shelter during winter from the prevailing winds, and in summer from rain and sun. Along this street, on both sides, the "Portici" houses are built, a traditional courthouse with arbours lined up continuously along the road axis. The origins of the building typology can be found much earlier: the predecessors of the arbours (the arcades) were often used in the roman architecture. This model came from Tyrol over southeaster Bavaria to Bohemia, Silesia and finally to Prussia. On a western rail, they were spread from south France, eastern Switzerland and Westphalia. The houses represent a vaulted archway on the ground floor of the building. This archway can be placed in front of the construction or be a part of the houses. They were designed for enhancing thermal protection, comfort, natural ventilation and daylight without increasing of energy consumption.

3.1. Urban planning

In southern Germany and Tyrol, however, there was a special distinctive urban structure, which provided continuous arcades for all the houses, so here a covered road was built. The need to create a permanent settlement "safe" from flooding and with a favourable exposure to the sun led to the street being located on an alluvial cone. The need to avoid major modification in the natural lie of the land and to minimize the effects of the wind imposed an east-west axis on the alignment of the buildings. Along the north side, the houses are bordered with walls that have been destroyed in 1277. To the south stood two towers and a wall, overlooking a moat. An upper and lower imposing gates (Ober e Niedertor) closed the two ends of the street. A mill powered by derivation of the stream Talvera ran along the southern edge (Figures 1-2).

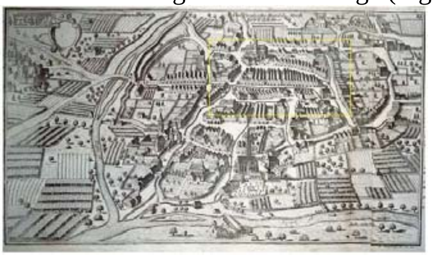


Figure 1. Map of Bolzano, 1700 – 1766 (From Gabriel Bodenehr)
Figure 2. Cadastral map of "Via dei Portici" in Bolzano, 1858 (From Autonomous Province of Bozen)

A characterizing aspect is the continuous arcade along the street. In truth, the line of the buildings has never been continuous because to limit the effects of the high number of fires, the covered walkway and façade was broken into three sections. The arbours, together with the basement, formed an extension of the houses for purchase and sale. In the beginning, the site was not completely covered with buildings: at the end were enclosures for the livestock and a small horticulture area, in direct contact with the city walls. Initially, the buildings had cross sections from 8 to 12 m, appropriate for ensuring the natural air and light and the comfortable temperature.

The first substantial modifications to the original configuration were made in 1277 when the walls and the gates were demolished and the ditches filled in. This process continue until the XVI Century with the saturation of the lots and the consequent construction of new sections of buildings alongside, that in some case are completely independently from the existing structure (Figures 3-4). The more recent buildings were constructed with two or three blocks interspersed with inner courtyards (atrium) to ensure the necessary natural light and air into the interior spaces. The serial repetition of this type of building has been formed a constant structure, interrupted 3-4 times by a passages (Figure 5) that conducted in the parallel streets.


Figures 3 and 4: "Via dei Portici" in the centre of Bolzano (From Authors)
Figure 5. Passages in the "Via dei Portici" in the centre of Bolzano (From Authors)

3.2. Historic buildings

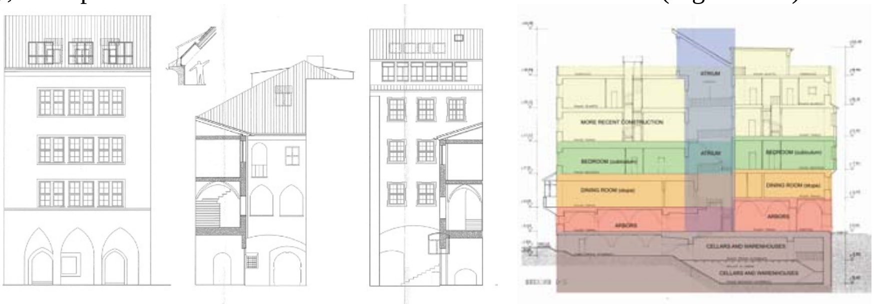
The original typology of the "Portici" Houses acted together dwellings, workshops and warehouses. The three parties were closely connected for functional reasons, as the inhabitants were merchants or artisans. Lying rectangular to the street, which passes from east to west, the buildings are north-south oriented, thus every building has a north and south façade. The eaves side of the saddle roof is oriented towards the street.

Shape and dimensions

The houses are built according to a particular pattern, called "gothic deeper lot", which provided façade with limited and constant amplitude. The length of the houses depended on the needs. The limited space forced to very narrow façade, which are often only two or three windows wide, but extend in depth and include regularly two or three atriums. The typical house is "four steps" wide (4 meters) with a depth more variable. The original surface-to-volume ratio (S/V) ratio of the arcade houses was very low. The compact shape aimed to decrease the heat losses through the building envelope and, simultaneously, to maximize the internal volumes.

Internal distribution

The primary houses with porch, in Romanesque style, consisted of ground floor and usually three upper full stories, up to three-basement floor and an originally non-inhabited top floor. The internal floor exploited well the building physics: orientation and internal functions of the rooms are designed to take advantage from the principles of heat transfer and environmental factors. To create a filter zone with a thermal protection, in the lowest floor are inserted the natural heated rooms. The basements were an extension of the shop on ground floor level and were used as magazine to store goods. On the ground floor, are located the shop and the kitchen, which heated the upper floors with a fireplace (only the wealthiest families also had a fireplace in the first floor). In the upper level are located the rooms with the permanence of people that, where possible, are oriented towards south to capture the solar radiation in winter. A wooden staircase connected to the first and the second floor, which housed respectively the dining room (*stupa* or *stube*) and the bedroom (*cubiculum*). In the bedroom are used the blankets (*coltra*) and the furs to heat up. Originally, the top floor was not used and worked like a thermal buffer (Figures 6-7).



Figures 6 and 7. The "Portici" House in XII Century (From Historic Archive of Bozen)

The room shows are positioned according the occupancy and frequency of use: rooms with less frequency of use or need of daylight (i.e. bathrooms or kitchens) are located in the inner part of the building, around the atria. The more representative and larger rooms (i.e. living space, trading rooms) are located towards "Via dei Portici" while the rooms with less importance (i.e. storage) are in the central and back part of the building.

Atria

As mentioned above the depth of nearly every house is interrupted by two or three atria. The staircases and open passageways are situated here. The courtyards have two functions: they provide the internal rooms with daylight and fresh air. The stairwells are vaulted to protect from direct rain. Usually, the vault is open to the side of the wind incidence, to ensure some cooling at high summer temperatures.

Constructive technologies

The cellar walls are built in masonry of natural stone and lime mortar – not plastered. The foundations are founded directly on the soil and the floor consists of tamped earth. Because of its contact to the surrounding soil and its depth of 6 m and more, the internal climate of cellars is quite independent from the external climate. The basement walls are double-walled: ventilation passages enable the supply of fresh air and keep the cellar free of mold. The constant cool temperatures provided an ideal condition for the storage of food. The ground floor are built of masonry of natural stone and lime mortar. Masonries, ceilings, and roofs are thought for preserving the heat produced internally. Originally, the first floor was made with wooden beams. Because of frequent fires, also this part was been built in natural stones (rough calcareous stone) and lime mortar (XIII Century). Exterior walls have a thickness of 60-80 cm. All walls (except on basement level) are plastered with lime plaster. The openings are small to avoid losses and increase thermal insulation. The original windows didn't have the glazing, as they were too fragile and expensive, but only external shutters in wood and curtains. They were added in the XVII Century. The original window was a wooden box-type from the late baroque era. It consists of two window layers, each with two single-glazed window sashes and a skylight. Ceilings of the upper floors are built in wooden beams with wooden casing and filling material in between. The underside of the ceiling was plastered with lime plaster. The floor construction consists of a wooden substructure and wooden boards. Especially on ground and basement floors, the ceilings are vaulted. The construction of the saddle roof is made in timber rafters with wooden casing and roof tiles on it. The roofs met the needs of climate protection from cold, wind, rain and snow. The specific conformation with two or more layers ensured the same conditions of insolation to each sloping. The inclination of the roof is quite high due to snowfall and rainfall. It is designed also to allow the formation and the maintenance of an additional "snow cover" which ensures thermal insulation of internal spaces.

4. CHANGES IN THE ENERGY CONCEPT

4.1. Urban planning

The urban structure has remained almost unchanged over the centuries. The differences are related to the widening of the historical centre around the historical core. The major changes have been made between XVI and XVII Centuries, when the block was completely filled with buildings. Subsequently, there have not been more significant urban changes with a impact on the climate (Figures 8-9).

Figure 8: Map of the city, 2011 (From Autonomous Province of Bozen)
Figure 9. Comparison between map of the city 1858-2011 (From Autonomous Province of Bozen)

4.2. Historic buildings

The buildings, visible today in the forms assumed in the XVII and XVIII Centuries, retain the original medieval structure. The major changes were made in 1950, when the original energy concept was modified with the closure of atria, the use of the top floors and the construction of dormers.

Shape and dimensions

Compared to Romanesque typology, the houses have more raised floors. This causes the change of the surface-to-volume ratio, while the porosity (ratio between full and void volume) remains almost unchanged, maintaining the good cooling conditions of the building. The slenderness (ratio between volume and average surface) increases.

Internal distribution and distribution

Than in the past, the commercial functions on the ground floor have remained unchanged while the layout of the upper floors has been completely changed. The functions are no longer just residential, but also tertiary and commercial. The main entrance still opened out onto the street, while the secondary entrance exploited the alleyway flanking the first block. Access to the third block was directly from the lanes running along the back, constructed after the ditches had been filled in. In short, the changes regard: increasing of the volume (multi-family dwellings), stylistic features, internal layout and construction materials. The modifications merged with the existing, becoming imperceptible precisely they represented continuity with the old. The cellars are used now either for storage, but often also used as showrooms (by covering the stone masonry). This means a massive installation of lighting, cooling and heating, with a negative impact on the energy consumption. During the new paving of the Portici Street the ventilation slots were closed with concrete, so that causes several problems of humidity and mold growth in the cellars. Also, cellar and ground floor are not climatically separated by shops and this cause a higher condensation risk of warm and humid air on the cold surfaces of the cellar walls.

Atrium

In the XIX Centuries, the top openings of the atria have been additionally closed, often repeatedly on the level of different stories. For the closure mostly glass canopies were used especially at the roof level, but often also within the court. In rare cases, there are intermediate canopies from an alternative material (Figures 11-12).

Figures 10-12. Closure of the atrium with canopies, doors and windows (From Authors)

The closure cause a lower air circulation and overheating during summer. In general, are utilized several outdated technologies to improve air changes. These are often no longer functional or too loud to use them. The glass canopies also no longer meet their original purpose: they are not easily accessible and often uncleaning from outside. For this, the insufficient incoming daylight is problematic in many narrow and deep atrium.

Constructive technologies and plant

From the constructive point of view, walls have not undergone major changes. The bearing structure have remained unchanged, while the other walls were demolished to make room for larger rooms. In most cases, now the top floor is habited, losing the original buffer function. There are original windows only in very rare cases: they have been substituted by industrial produced windows with double-glazing. Today, the upper commercial and residential units often have a decentralized boiler in combination with radiators, while the shops usually use no heating system. High internal gains/loads, caused by nonenergy-efficient lighting, and the clothing of customers make a heating system unnecessary. To compensate possibly temperature differences during winter and especially to cool the rooms during summer, electrical air conditioners are used. The units on the upper floors usually don't have any cooling system.

6. METHODOLOGY FOR ENERGY AND ENVIRONMENTAL ASSESSMENT

A survey aimed to analyze the energy efficiency and indoor comfort of Portici Houses. Questionnaires, project plans, data on existing buildings, profile of use and energy consumption were collected for several selected buildings. A residential and commercial building was subjected to a more detailed investigation: all inhabitants of the 11 commercial and residential units participated in a user survey and an on-site inspection. Aim of this inquiry was to quantify the quality of indoor comfort, considering the impact of the outdoor condition. Additionally, a checklist gave answers about the user behavior (i.e. frequency and duration of natural ventilation, measures against overheating), occupancy times, and energy bills. Were also verified structural problems (like humidity or mold) and what users would suggest to improve the quality of living in this house.

6.1. Results of the assessment

Comfort

Inhabitants evaluated the indoor temperature particularly on a scale of -4 to +4 as "hot" (+3) or even "very hot" (+4). Was used a scale more detailed than the standard UNI EN ISO 7730 (2006) to have a better understanding of the summer comfort, when the temperatures are extremely hot. During winter, the assessment is not uniform, depending on settings of heating system, physical activity and use of the unit as well as the personal perception, the interviewed people felt from "cold" (-3) to "warm" (+2) (Figure 13).

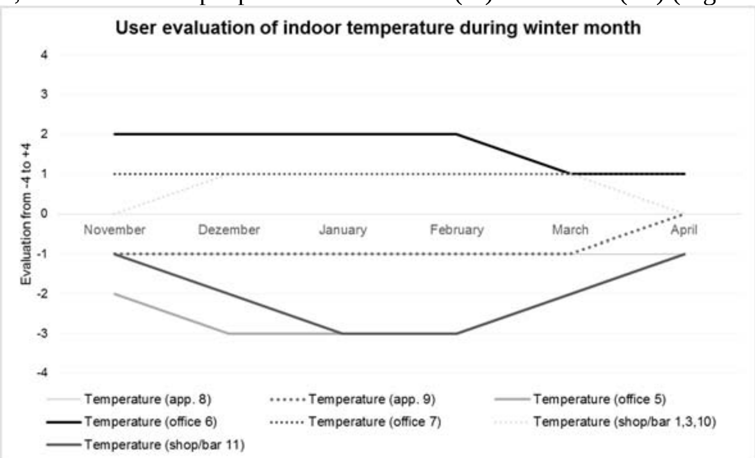


Figure 13. User evaluation of indoor temperature during winter

The user survey showed a tendency towards overheating about 3-4 weeks during summer (Figure 14).

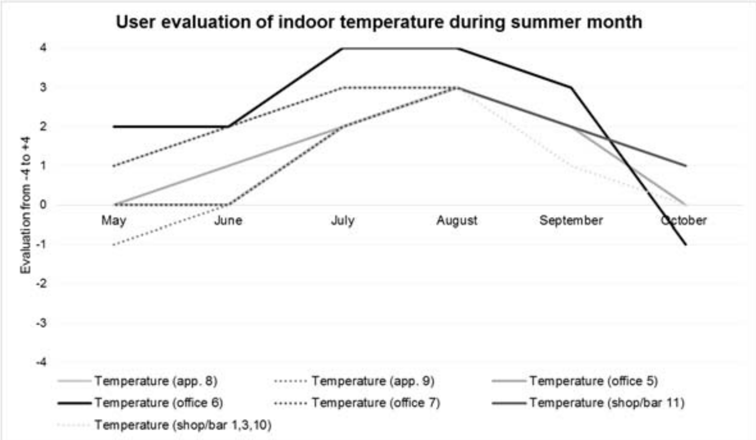


Figure 14. User evaluation of indoor temperature during summer

For the other evaluation, the scale was the traditional proposed by the standard UNI EN ISO 7730 (2006). The interviews showed that users are quite satisfied with the internal comfort in general. The supply of fresh air is evaluated as sufficient while the supply of daylight is sufficient depending on position and orientation of the rooms. There is a lack of daylight inside the building and in the spaces towards the atria. This is due to the change of use: now there are also office rooms with a higher demand for lighting (Figure 15).

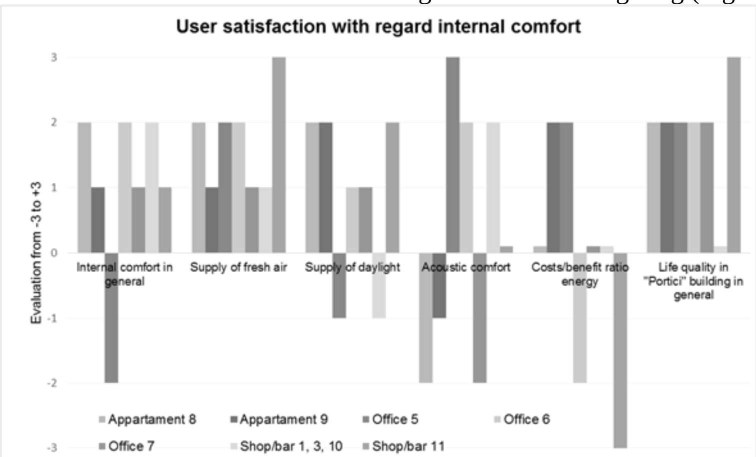


Figure 15. User satisfaction with regard internal comfort

Daylight Factor is a ratio that represents the amount of illumination available indoors relative to the illumination present outdoors at the same time under overcast skies. It determines the quantitative characteristics of daylight in a particular workspace, in order to verify if a room has sufficient daylight. On-site lux measurements, obtained in a static way (at a single point in time), confirmed a punctual daylight factor in the different room lower than 2.0%, which would be the minimum value to guarantee an acceptable supply of daylight. Furthermore people feel disturbed by noise particularly from the street (people, musicians, delivery of goods), when they keep the windows open. The energy costs/benefit ratio is evaluated very differently – some users perceive it as low other as much too high. In general, people are quite satisfied with the life quality in a Portici House.

Structural problems

Almost all the houses of the Portici Street and the parallel roads are in an acceptable condition. Most of them were refurbished and adapted to new functions and housing demands during the centuries and therefore interventions do not meet the latest requirements. One of the few structural defects, which were mentioned in the survey, are moisture problems in the basement rooms. The fact that heated rooms on ground floor are no longer climatically separated from the cellar rooms, allows the humid warm air to pass into the cool basement rooms and to condensate on the cold wall surfaces. In addition, inadequate ventilation of the basement rooms exacerbates the problem.

Energy consumption

During the general study a very often repeated statement concerned the high cost of energy for heating and cooling. To illuminate, heat or cool the vast spaces especially of the shop areas is very costly. In our particular case, the annual calculation for heating from energy bills showed a comparatively low energy consumption (Figure 16).

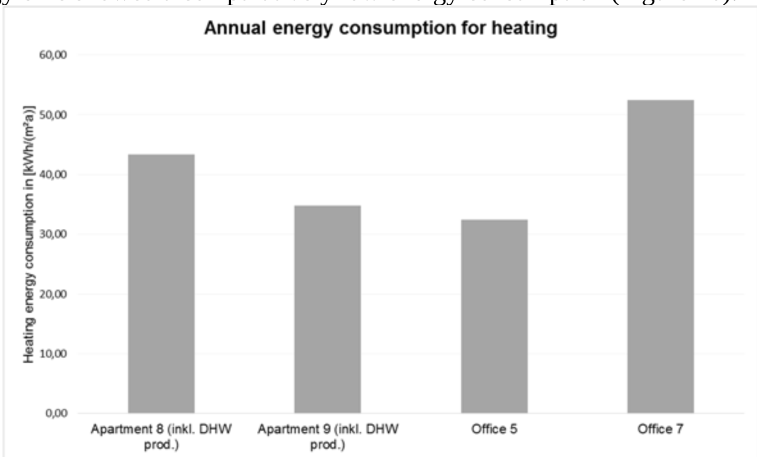


Figure 16. Annual energy consumption for heating in different units

The annual energy consumption for heating varies from around only 32 kWh/m²a to around 52 kWh/m²a. This is due to the fact, that in the year 2000 the thermal transmittance of the envelope has been improved by insulating the roof construction and substituting the composite windows from the 60th with new double glazed windows. Furthermore, the storage of heat in the thick wall construction allows switching on the heating system comparatively late in autumn. The users heat up during the day only the main rooms of the offices or apartments and switch off the heating system during the night. Anyhow, energy consumption for cooling and lighting the shops remains high.

7. ENERGY RETROFIT

The energy efficiency retrofitting of the Portici Houses may include the internal insulation of walls, floors and roofs, the upgrading of the performances of windows and the selection of high efficiency boilers. Many of the Portici houses have historically and artistically very valuable paintings or decorative elements on the inside surfaces and on the facades. This excludes in almost all cases interventions on the walls: exterior insulation is therefore on most surfaces not possible, as well as the installation of solar panels on the walls. The internal insulation of walls may include the use of capillary active materials that transport moisture in the opposite direction of the diffusion flow back towards the warm interior surface. This gives a certain tolerance to minor production faults or damages. In advance, it is necessary to consolidate the walls to guarantee the mechanical resistance and also to consider the prevention of condensation at beam end of the wooden ceiling. The isolation of the slab over the arcades can be achieved by filling the space between the wooden layers with bulk material, such as vermiculite, expanded clay or similar. The internal insulation of roofs is also possible. The replacement of windows can be reached by different interventions according to their historical value. First, it is necessary to preserve, maintain and upgrade the historic windows. When they have to be replaced, hand-crafted wooden windows possibly also with handmade glass are preferred, in order to come closer to the original appearance of the house. In the building analysed, all these interventions have already been made, except the isolation of the slab over the arcades. Therefore, are proposed other innovative solutions, departing from the discovery of the original energy concept.

7.1. Hybrid natural ventilation

Stack ventilation is one of the most effective and reliable methods of driving natural ventilation for atria and adjacent spaces. It is proposed a hybrid natural ventilation strategy: a system where natural ventilation is promoted whenever the outdoor air temperature is lower than the atrium air temperature and kept air-tight, whenever the outdoor air temperature is higher than the atrium air temperature. This strategy may be implemented using a set of temperature controlled motorized louvers install at the ground floor of the atrium that open and close the doors at fixed time. Another cooling strategy will be studied in detail: to exploit the low internal temperatures of the basement stores during summer. In this case, the base will not be ventilated and must be climatically separated from the above floors. A ventilation system with a recovery unit exchanges and cools down the supply air of the upper floors with the cool air from the “cooling reservoir” of the cellar.

7.2. Shading

Some of the Portici houses have traditional shading elements. The traditional design of these shading elements are wooden shutters with adjustable slats. Many of the houses anyhow do not have a shading system. Often the high-decorated façade and the small distance between the windows in the façade makes the use of wooden shutters impossible for technical and for conservation aspects. In these cases, the integration of a modern shading device into the window system, that would also meet the aesthetic demand from conservation point of view, would help to avoid high indoor temperatures during summertime.

7.3. Optimization of daylight

To improve the supply of daylight especially in the inner rooms of the building, old chimneys or chambers that have no function anymore, could be used for a heliostat system. To bring down the daylight from the roof into the depth of the building a main mirror has to be installed on the roof. The existing chimneys serve as a vertical channel to transport the sunlight: over mirrors in these chimneys an over openings toward the rooms the light is reflected and distributes into the rooms. In addition a enhanced daylight autonomy would be desirable. This could be achieved by the integration of daylight redirection into the window and shading system. Wall surfaces should be coated with bright wall paint to reflect the incoming light in a better way.

7.4. Lighting

The substitution of the lighting systems in the shops and restaurants with high efficient illumination like LED systems would be a very effective measure to reduce energy consumption significantly and to reduce the risk of overheating during the summer season.

7.5. Integrated PV

The heating of the outdoor spaces of the bar is obtained with infrared lamps. The systems, used also by the historic Marketplace of Piazza delle Erbe, have a high energy consumption. The intervention may design an integrated photovoltaic shelters thought for the centre of the town, in order to preserve the heritage value and to reduce the energy consumption for heating. Similarly, on existing roofs is possible to predict reversible and integrated PV tiles because the Heritage Office don't exclude this. To affect less the appearance the use of solar films is a viable alternative.

CONCLUSIONS

The updating of old centres to adapt to contemporary societies requires the attention to sustainability criteria and environmental issue, both at urban and building scale. In historic houses, the recovery of the original energy concept permits to reach together comfort standards without compromising the heritage value. In the "Portici" houses, the major change has been made since the Fifties. These modifies apparently are made by imperceptible measures that don't altered the aesthetic aspect of the building but, in practice, are completely indifferent to the original physical structure and responsible of numerous negative alterations of the fabric. Related to energy bills and comfort analysis, a correct project should be reduce the heating losses and increase the solar gains. This requires the improvement of thermal resistance and airtightness of the envelope and the guarantee of daylight and natural ventilation. For this, atria are key elements for a deep refurbishment of the buildings, in order to develop hybrid and natural ventilation, daylight redirection, control of solar gain and discomfort glare. Also, the lighting project of stores, shops and bar requires the replacement of existing energy sources with more efficient systems that allow space heating. Finally, the PV integration may be studied at urban level, obviating to the problems of compatibility and reversibility with the historic building.

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