SCIENZA E BENI CULTURALI

XXXVI° Convegno Internazionale 2020

GLI EFFETTI DELL'ACQUA SUI BENI CULTURALI
VALUTAZIONI, CRITICHE E MODALITA' DI VERIFICA

Giornate di studi internazionali

Venezia, 17 – 19 novembre 2020

Edizioni Arcadia Ricerche

36° convegno internazionale Scienza e Beni Culturali
Collana Scienza e Beni Culturali
Volume.2020

ISSN 2039-9790
ISBN 978-88-95409-24-5

GLI EFFETTI DELL'ACQUA SUI BENI CULTURALI
VALUTAZIONI, CRITICHE E MODALITA' DI VERIFICA
Venezia, 17-19 novembre 2020

In questo volume vengono pubblicati i contributi estesi che sono stati sottoposti a *double blind peer review* da parte di esperti dello stesso settore.

THE EFFECTS OF WATER ON CULTURAL HERITAGE
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This volume includes extensive contributions (*Full-paper*) that have been subject to double-blind peer review by qualified referees.

EDIZIONE ARCADIA RICERCHE Srl
Parco Scientifico Tecnologico di Venezia
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Tel.:041-5093048 E-mail: arcadia@vegapark.ve.it
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Finito di stampare nel mese di novembre 2020
presso Imoco Industrie Grafiche – Treviso - Italy

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a cura di Guido Biscontin e Guido Driussi

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INDICE

Internal building insulation systems for historic buildings: hygrothermal performance analysis

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Abstract

Promoting the adaptive re-use of heritage buildings is one of three clusters of actions of the European Framework for Action on Cultural Heritage, 2018. To make this operation successful, it is necessary their adaptation to today's indoor comfort requirements and therefore, there is the need to support the energy retrofitting of historic buildings (HB).

Often, when in the presence of HB with high heritage value, the energy retrofit intervention is limited to the internal face of the building envelope (when not in the presence of valuable decoration): no changes are introduced in the façade, at the expense of the loss of recognition of the characteristics of the original building. This strategy can give rise to fundamental risks: using internal insulation layers can alter the original behaviour of historic envelope leading to problems of interstitial condensation or superficial moisture.

The HeLLo project (H2020-MSCA-IF-2017-EF) is based on this assumption, aiming at verifying the performance of some insulation solutions for the interior façade of historic buildings (through hygrothermal simulation software and in situ measuring tests). The research's case study is Palazzo Tassoni Estense, a renaissance Palace in Ferrara.

Within this paper, authors explore and discuss some of the criticalities and hygrothermal risks addressing internal thermal insulation systems for historic buildings, combining the preliminary results of the field activities to the theoretical simulations.

Keywords: *Cultural Heritage, Energy retrofit, Historic building, Hygrothermal performance, In situ monitoring, Simulation*

Introduction

Promoting the adaptive re-use of heritage buildings is one of three clusters of actions of the European Framework for Action on Cultural Heritage, 2018 [1]. Concurrently the field of energy efficiency policy in buildings is central as they account for nearly 40% of final energy consumption [2]. These two premises highlight that one important way of preserving built heritage for the future is to keep it into use, as rethinking an historic building to accommodate new uses enhances preserving it in the memory of the society. Moreover, there is the need to support the action of the energy retrofitting historic buildings since, to make this operation successful, it is necessary their adaptation to today's comfort requirements for indoor human activity.

Under this assumption, then comes the challenge of intervention in historic buildings. Nonetheless, the aesthetic-morphological quality of an historic building is also important, and therefore the effects of one potential intervention on cultural heritage (CH) cannot be disregarded: a compromise must be found between the conservation of the historic building and the energy efficiency strategy in no damaging and possibly, in a compatible, minimally invasive and above all reversible manner [3]. Often, when in the presence of historic buildings with high heritage value, the intervention on the building envelope is limited to internal face of the building envelope: no changes can be introduced in the façade, at the expense of the loss of recognition of the characteristics of the original building. This strategy, commonly leads to the improvement of the building envelope through the insertion of insulation layers on the inner face of historic walls, when not in the presence of valuable decoration. Normally more attention is given to thermal issue and technological aspect but this option can give rise to fundamental risks, first of all hygrothermal ones. Indeed, the use of internal insulation layer can alter the original behaviour of the historic envelope generating problems of interstitial condensation and superficial moisture, i.e. bringing up risks of damage for the historic wall previously not presented. Certainly, when applying a new internal insulation layer to an existing wall, a new 'barrier' is generated between the original wall and the indoor climate. Because of this, *'the structures' dew point (the temperature in which the water vapour condensates) shifts inside'* [4, p. 110]. Ideally, aiming at minimizing hygrothermal risks, in these critical points, the following conditions showing should be respected [4, p.341]:

a) To avoid interstitial condensation, algae and decay, when the temperature (T) is above 0°C, the relative humidity (RH) should be lower than 95%;

b) To avoid mould development, when T> 0°C, RH < 80%;

c) To avoid frost damage, when T < 0 °C, RH < 95%.

In case any of these scenarios occurs, further situations might take place, putting at risk and lead to the degradation of the historic envelope:

i. frost damage of wall elements can lead to brick break and reduce the wall structural resistance;
ii. mould development and interstitial condensation near to wooden beams ends might lead to their decay, reducing their support / structural capacity;
iii. the accumulation of moisture in various point of the “multi-layered” wall might lead to the modification of the wall summer behaviour (changing their previously exemplary role of thermal inertia).

Unfortunately, despite of the performance of the insulation materials in new buildings, their application in old ones is not enough well known to operate with awareness to ensure the conservation of historic values.

The HeLLo project [5] is based on this assumption, aiming at verifying the performance of some insulation solutions for the interior façade of historic buildings, thanks to a combined strategy of hygrothermal simulation software and in situ measuring tests. Today’s construction market offers varied technologies insulation solutions designed specifically for new buildings. However, it is not always possible to make generalizations due to potential incompatibilities or criticalities that are difficult to foresee during the design phase, in the application in historic buildings. In this context, the HeLLo project aims at spreading the awareness of professionals and the knowledge of the real potential of some retrofit solutions in the case of intervention on historic buildings.

Case study presentation

The research’s case study is Palazzo Tassoni Estense, a renaissance Palace in Ferrara, situated in the southern area of Ferrara’s old town. Built in 1482 for the Estense family it has had many end-uses and since 1991 it holds School of Architecture of Ferrara, **Figure 1**. The Palazzo is a monumental masonry building, of considerable architectural value, listed by the heritage protection authority [6].

For the purpose of this research a specific part of the un-refurbished building was selected: ‘*a room located in the south-west wing of the building, which is currently unoccupied […] so as it has allowed to set up the whole experimentation* [6, p. 10]. On one side, the fact that this part of the building complex is unoccupied permitted more flexibility and quickness on the installation of the insulations systems; on the other side, though the building is rich of historic features no irreversible interventions are foreseen, and these are restricted to the external masonry wall. Aiming at minimizing the impact of the study, one solely wall was chosen to receive the thermal insulation solutions – the one separating this indoor space from the external portico (**Figure 2**). In this specific case, the studied solutions do not reach the ceiling but the intervention stops almost 2 m below.

Figure 1 – Palazzo Tassoni Estense, the main hall at first floor.

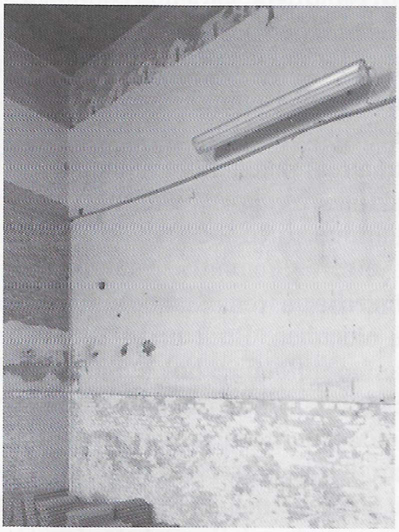


Figure 2 – Palazzo Tassoni Estense, picture of a portion of the not-refurbished room. As shown by the image, the room presents some decoration of the ceiling but also some traces of transformation due to different uses of the last decades.

Materials and methods

Generically, to assess the hygrothermal performance of buildings components and building elements through software simulation, two approaches may be used: one grounded on EN13788 [8], also designated the static method; the second, the dynamic method, based on EN15026 [9]. The first method is also called the 'simplified method' since it assumes that the humidity transport is due solely to the water diffusion vapour, which can, in fact, lead to several error sources, e.g. the use of constant material properties is an approximation, capillary absorption and transport of liquid water can occur in many materials, which can change the distribution of humidity, the real boundary conditions are not constant within a month, or most materials are at least partially hygroscopic and can absorb water vapour, as assumed in [8]. The second method is more complete as it allows predicting '*transient heat and moisture transfer in multi-layer buildings enveloped components subjected to non-steady state climate conditions on either side*' [8, p. 4], which is what actually happens.

In [10], the author recalls an important issue - the error caused by the precautionary calculation, which leads to oversizing the risk of condensation formation. It is therefore of utmost importance to be as precise as possible in ascertaining the real risk.

The addition of a vapour barrier to avoid the possibility of interstitial condensation seems to be the most simply solution but, as reported also in UNI EN ISO 13788 (Appendix NA, p.43), this solution may create more disadvantages in terms of hygrothermal performances and structure's conservation. So, as previously stated, undesired hygrothermal risks should be minimized leading to a conscious choice of the thermal insulation material. Due to the unidentified characteristics of the historic wall and difficulties of survey, this option is often grounded on dynamic hygrothermal simulations [11], [12]. Nonetheless, in [13], authors unveiled some of the criticalities of hygrothermal simulation – which can biased results if data input is not precise (in the case of unknown materials), strengthening the importance of in situ monitoring [14] confirming the simulations.

Site experimentation in heritage buildings has to be carefully studied, considering in particular the characteristics of *compatibility* and *reversibility* required for any acquisition system used in such buildings. Therefore, a new low-cost remote sensing technology serving the conservation constraints was developed with EURAC research and INFN Ferrara teams [7]. For the tests, a real in situ laboratory has been created to monitor, during an entire year, Temperature [T (ºC)] and Relative Humidity [RH (%)] values of different layers of some insulating stratigraphy, heating and humidifying the indoor environment (T ≈ 20ºC, RH ≈ 55%).

The selection of the materials and method of installation of the stratigraphy to be tested has started from general aims to use: i) a biological material, more compatible with historic materials; ii) a material wide spread in the market, to propose useful information for daily job of professionals; iii) a material with a finishing in continuity with the historic ones.

In the light of the above analysis a technical worktable with the national conservation authorities and material's companies was developed [15] to assess the most suitable technological solutions regarding three main criteria:

a) Energy efficiency: to reach a *U*-value which justifies the refurbishment intervention not necessarily to comply with the legislation, but in terms of performance's improvement in balance with conservation aspects;

b) Conservation aspects: final thickness of the insulation solution and laying of the materials / installation method ("dry constructed" systems vs glued installation and discussion of the number of anchoring points on the historic wall), i.e. '*the selected systems feature the possibility of removal at a later state of the application*' [13];

c) Discussion regarding the use of a vapour barrier. It was decided to respect the original "breathability" (i.e. low vapour resistance or vapour open materials), as most historic buildings are "breathable" [16]. In other words, no vapour barrier was added to any of the insulation systems in order not to limit summer drying potential of the historic wall or not to bound the eventually presence of humidity already in the wall (e.g. rising damp). It is noteworthy that in case of typical solid brick walls of historic buildings in Italy, these are highly hygroscopic materials, therefore subject to capillary rise.

Description of the selected solution and in situ monitoring campaign

The result of the worktable with the heritage authorities is evident in the three insulation systems technologies chosen for the in situ monitoring tests, presented in **Table 1**.

Table 1 - Summary of the insulation systems technologies

Insulation material	Bonding system	Total added thickness [mm]
Cork panels	*'dry system'* Natural cork panels (1000x500 mm) interposed with thermal-cut structure, with a gypsum fibre board finishing (12.5 mm)	65
Stone wool panel	*'dry system'* Double stone-wool panel with 'C' metal structure away from the wall, with a plasterboard finishing (12.5 mm)	115
Calcium silicate panel	*'wet system'* Single mineral insulating panel glued with clay mortar, with a mortar layer finishing (10 mm)	115

The monitoring campaign has begun with the present winter season, so within this paper, authors explore and discuss some of the criticalities and hygrothermal risks addressing internal thermal insulation systems for historic buildings, thanks to the preliminary results of the field activities in comparison to the theoretical simulations of one of the three solutions, the cork panels shown in **Figure 3**.

Due to the brevity of the developed monitoring campaign, a 9-week period was analysed (November 16th – January 18th). Data were recorded every minute. The investigation was focused on the most critical point of eventual interstitial condensation formation: the layer between insulation and historic wall. Having this into consideration and aiming at avoiding biased results due to water capillarity absorption, two measuring points were monitored on the "retrofitted" wall, at 1.90 m and 3.40 m from the floor, respectively. The full description of the monitoring system can be found in [7].

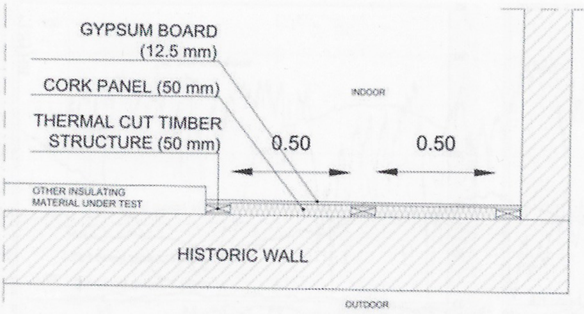


Figure 3 – Horizontal section of the historic wall internal insulated with the cork panels system.

Simulation

The dynamic hygrothermal analysis is developed through a 2D transient heat and moisture transfer model, as suggested by UNI EN 15026 [9]. Delphin software (v.6.0.20) [17]) was used to perform the simulation. *'Outdoor climate data used in the simulations are 2017's hourly data of T (°C) and RH (%) collected from a local weather station [monthly averages of hourly climate data: 1.7 ≤T (°C) ≤ 26.5 and 65 ≤RH (%) ≤ 89], used as 'reference year''* [13].

Results of the 10th year are analyzed. The materials used in the simulations, chosen from the software database, are listed in **Table 2**. The indoor climate was defined according to the adaptive indoor climate model present in Delphin database, 20 ≤ T (°C)≤ 25 and 35 ≤ RH (%) ≤65, according to UNI EN 15026 [9].

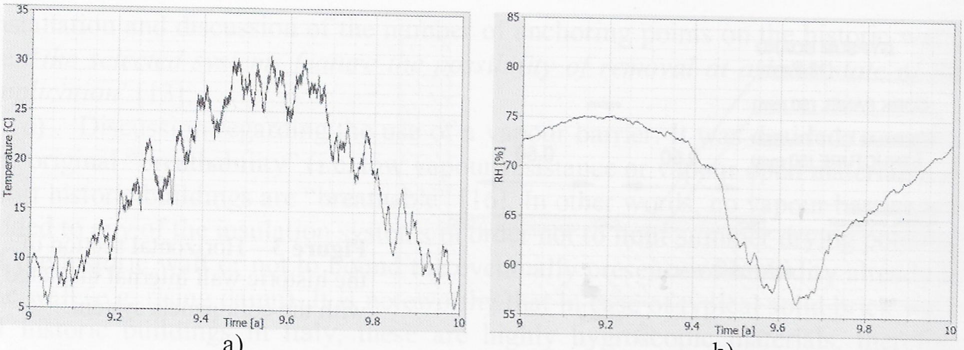
Table 2 - Hygrothermal properties of the selected materials

	r [kg/m^3]	λ [w/mK]	C_p [J/KgK]	μ [-]	A_w [kg/m^{2}s^{05}]
Historic brick	1759	0.624	1092	24.5	0.185
Historic lime plaster	1603	0.690	869	19.0	0.179
Lime mortar	1739	1.050	1057	28.3	0.494
Cork (Co)	114	0.047	2253	28.9	0.009
Gypsum fibre board	1133	0.320	1220	16.8	0.057

Dry density (r), Thermal conductivity (λ), Specific Heat capacity (C_p), Water vapor diffusion resistance factor (μ), and Water absorption coefficient (A_w).

Results and discussion

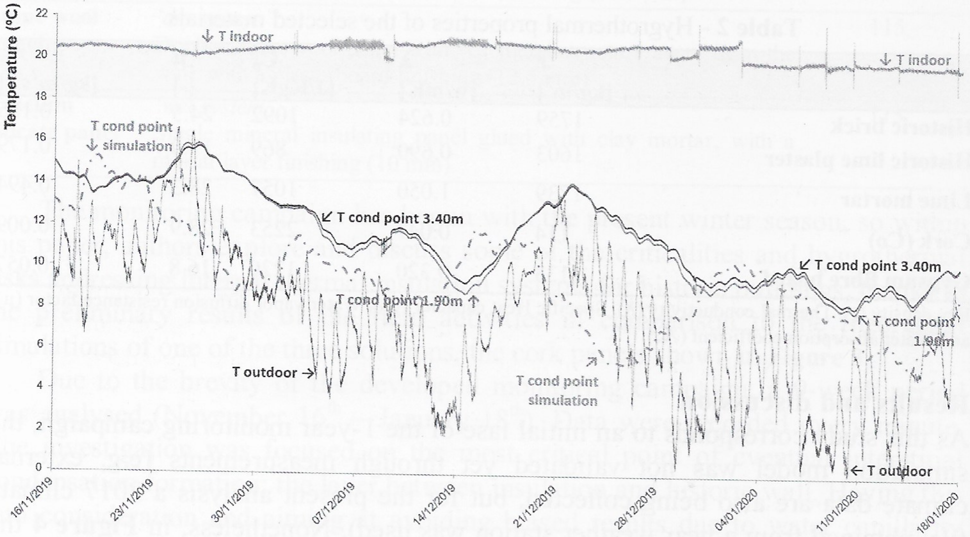
As this study corresponds to an initial fase of the 1-year monitoring campaign, the simulation model was not validated yet through measurements (e.g. external climate data are also being collected, but for the present analysis a 2017 climate file, obtained from a near weather station was used). Nonetheless, in **Figure 4** the simulation results (temperature and relative humidity) of the point of the stratigraphy behing the insulation during the last year of simulation, the most critical point, are depicted.



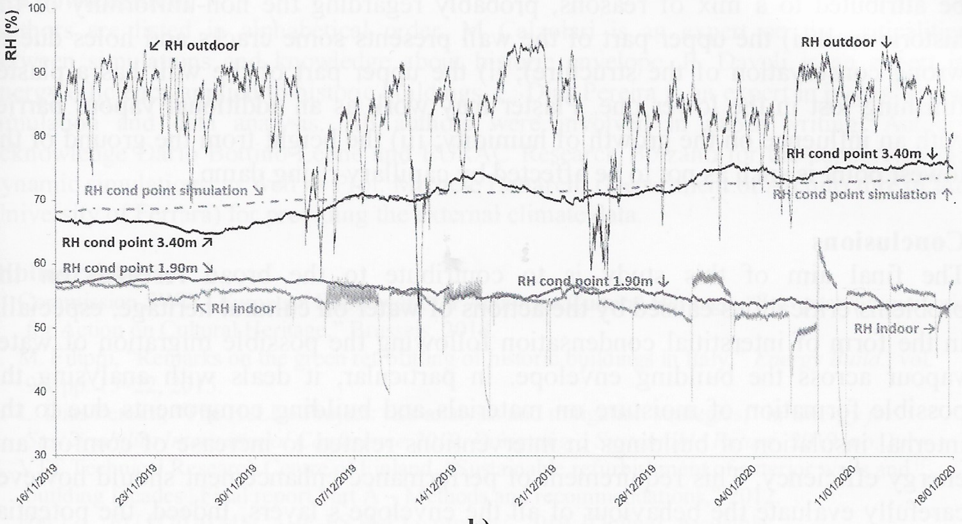
a) b)

Figure 4 – Inner surface behaviour of point of the wall behind insulation during the last year of simulation: a) Temperature [°C]; b) RH [%].

As observed, both from the T and RH simulated results: i) frost damage in this point is out of question since T_{min}>5.1 °C; ii) interstitial condensation is not expected either since RH_{max} < 76 %. Though the model has not been 'calibrated' yet (e.g. using data of monitored outdoor climate), some preliminary analysis between the simulation and the in situ measurements are possible, as observed in **Figure 5**. Here, monitored values onsite of RH and T measured values between 16/11/2019 and 18/01/2020 are placed side by side with the simulated values for the same period of the last year of simulation.



a)



b)

Figure 5 – Inner surface behaviour of point of the wall behind insulation during the last year of simulation and in situ data: a) Temperature (°C); b) RH [%].

All the results show that, in this specific situation (stratigraphy related to geographical zone), in terms of moisture performance, no risks were verified. Both in situ monitoring and simulation showed RH (%) always below the reference values: 95% in case of interstitial condensation and frost damage, and 80% in the case of mould growth. Simultaneously, the temperature value was always above 0°C. Although, some important observations can be made:

1. an absolutely precise and calibrated comparison of the results was not possible yet, due to the short surveyed period. Only within the future monitoring months it will be possible to generate the in situ external climate file ahead imported into the simulation software;
2. in general, however, it can be noticed that, in case of T, both probes revealed most favoured results than those eventually induced by the simulation;
3. in the case of RH, instead, the values obtained from the probe at 3.40 m practically fit those obtained from the simulation (abstractly measured at any height of the wall). On the other hand, if the 1.90 m probe is taken into consideration, there is a difference of 15% between the measured and simulated values, as the theoretical values are higher. This discrepancy underlines the complexity of mapping an historic wall.

Some other comments are due concerning the RH monitored data. Between point at 1.90 m and 3.40 m a difference of 15 % ± 5 is surveyed. Compared to expectations a greater percentage of humidity is monitored at the higher test point rather than at the lower. The difference – to be ascertained in the long time - may be attributed to a mix of reasons, probably regarding the non-uniformity of the historic wall: i) the upper part of the wall presents some cracks and holes due to wrong conservation of the structure); ii) the upper part of the wall has a plaster finishing lost in the lower one. Plaster may work as an additional vapour barrier with an influence on the growth of humidity; iii) the height from the ground of the lowest point is such as not to be affected by capillary rising damp.

Conclusions

The final aim of this study is to contribute to the broad research on the problems/criticalities caused by the actions of water on cultural heritage, especially in the form of interstitial condensation following the possible migration of water vapour across the building envelope. In particular, it deals with analysing the possible formation of moisture on materials and building components due to the internal insulation of buildings in interventions related to increase of comfort and energy efficiency. This requirement of performance enhancement should however carefully evaluate the behaviour of all the envelope’s layers. Indeed, the potential formation of humidity is both a cause of degradation for the historical envelope, and of a reduction in the insulating performance and duration of the materials used for its improvement. The investigation and critical analysis are supported by specifically conducted instrumental tests.

Moreover, it is of great importance to develop this kind of deep analysis to increase the awareness of designers when called to intervene on historic heritage. The possibility to know all the related risks contributes to reach better results in term of conservation, without renounce to the opportunity to enhance the energy performance also of historic buildings.

As these preliminary results show, the design answer in term of insulation of historic walls is neither simple nor univocal. Often in case of heritage the most suitable solution depends on the specific case: i) level of historic value of the structure, from which varies the retrofit solution; ii) envelope’s thickness and original materials; iii) insulating material under use. In the monitored case, the use of a very “breathable” material with low thickness and dry installation gives good result from the point of view of hygrothermal issue, even if different observations may be done, as presented, in relation of the presence of original external plaster or not.

When a retrofit action with insulation system placed on the inner face of walls is planned – due to adaptive re-use or ‘simply’ energy improvement, designers should put great attention to the risk related with water (mould growth, moisture and interstitial condensation development) aiming at simulating, before the final decision, the several solution matrix to minimize this problem without losing the opportunity to enhance the energy performance of the buildings in respect to conservative issues.

Acknowledgment

Authors are listed in alphabetical order. M. Calzolari is an expert on the criticalities between simulations and knowledge about historic envelope. P. Davoli is an expert in energy efficiency applied to historic buildings. L. Dias Pereira is an expert in hygrothermal simulation and data analysis. All authors were involved in paper writing. Authors acknowledge Dario Bottino-Leone and EURAC Research Bolzano for the support on the dynamic simulations, as well as Prof. Michele Bottarelli (Department of Architecture of the University of Ferrara) for providing the external climate data.

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ISSN 2039-9790
ISBN 978-88-95409-24-5