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CasaClima R: a protocol for energy refurbishment supported by verification tools

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Abstract. This paper presents a reproducible framework for the energy refurbishment of existing buildings. It is constituted by the CasaClima R protocol, a certification procedure described by the "Technical Directive CasaClima R" and aimed at exploiting the energy potential of buildings on a case-by-case basis. Some verification tools support the protocol in order to avoid errors occurring during the planning and construction phase, that could lead to damages of the building´s substance and could cause problems to the health and well-being of the occupants. The implementation and application methods of all framework components and possible future developments will be described, considering the great wealth of historical buildings in Italy and Europe and the great potential for energy savings that can be achieved.

Keywords – design tool, certification scheme, energy requalification, hygrothermal analysis, tools

1. Introduction

It is now clear that the challenge of energy efficiency in construction is played on the existing assets. Giving that in Europe 38% of existing buildings were built before 1960, it is evident that the Italian and European built heritage is strongly characterized by the presence of "historic buildings" [1]. These represent an important cultural resource for our territory but are at the same time extremely energy-intensive goods and they therefore need ad hoc energy requalification interventions.

The fundamental problem of an energetic refurbishment of a historic building is the reproducibility of the methods and processes to other cases. For this reason, the presence of standardized protocols and tools that can support designers in their daily work of energy redesign of existing buildings is scarce.

The objective of this paper is to present a framework suitable to be applied in cases of energy renovation of existing and possibly historical buildings. The core element of this framework is the CasaClima R protocol defined by a series of guidelines and minimum requirements contained in a technical directive. In order to evaluate the actual energy benefit of the measures applied, a supporting energy calculation tool is foreseen as well as some tools for the verification of fundamental aspects such as the reduction/resolution of thermal bridges and the verification of the absence of interstitial condensation.

1.1. Methodological approach

The setup of this framework concerning energy retrofitting of existing and historic buildings is the result of the following steps:

1. the transposition of European directives on building efficiency at regional level
2. identification of the most critical aspects related to energy refurbishment of buildings based on field experience
3. guideline outline based on steps 1 and 2

4 definition and implementation of calculation tools to support designers in accordance with the requirements of the guidelines.

This paper will present the three elements that constituted the framework, namely: CasaClima R protocol, the "FEM-Analysis of existing construction nodes" catalogue and ProCasaClima Hygrothermal tool.

1.2. The concept

The CasaClima R protocol stems from the need to define energy efficiency requirements for existing buildings undergoing renovation. Starting from the assumption that each building has its own history and identity, the aim of the protocol is to maximize the energy improvement potential of each one and to identify the most effective and reasonable measures to exploit it.

It is not a "standard" certification, because the main goal is not to achieve an energy class, but to exploit the available energy potential while improving the indoor comfort for the user and the durability of the intervention. The objectives to be achieved are calculated on a case-by-case basis and take into account the technical, historical-architectural, sanitary, urban planning, compliance with national and social constraints that characterize the condition of the building. What all interventions have in common are the so called "Minimum Requirements" which must be met in full, as reported in the "Technical Directive CasaClima R" [2]. The so-called minimum requirements are referred both to the energy efficiency and the quality of the envelope and systems. Concerning the energy calculations, they are supported by ProCasaClima software, which was mostly developed based on the in-force directives and technical standards.

1.3. Application

The certification process for adherence to the CasaClima R protocol is divided into several steps and involves different actors, to ensure technical competence and third-party monitoring.

First of all, the applicant is any individual or legal entity who or which applies for certification. The energy consultant coordinates the designers, specialist planners and contractors, collects the necessary documents and evidence functional to achieve the certification. A third-party auditor appointed by the CasaClima Agency checks the energy calculation and carries out on-site inspections to verify that the design choices have been applied correctly. Finally, the only body that can issue the certificate and monitor the smooth running of the whole process is the Agency.

The following certification procedure is defined in the CasaClima R protocol:

- Precertification
- Certification
- CasaClima Class

2.2.1 Precertification

The application for certification must be submitted before construction begins. A prerequisite for the acceptance of submitted certification applications is their formal completeness in accordance with the present guidelines. During precertification, compliance with technical requirements (energy calculations, structural certificates, plan drawings, technical documentation, etc.) is verified.

2.2.2 Certification

In this phase checks are carried out at different levels, starting with the verification of the design energy calculation. During the construction site, an Auditor carries out the scheduled inspections and collects technical information required for energy certification through an audit protocol. At the same time, the energy calculation is updated and rechecked if changes are introduced. Finally, there is the measurement of air permeability and the final check of the entire documentation. The Agency then issues the energy certificate.

2.2.3 CasaClima Class

At the end of this process, an energy certificate is issued stating the energy class achieved by the refurbishment. The definitive CasaClima class corresponds to the worst case between the energy efficiency of the envelope and the overall energy efficiency class. The classification, as reported in Figure 1, refers to the energy KPIs (energy efficiency of the building envelope, equivalent primary energy demand for heating and cooling, total energy efficiency heating and cooling). The energy efficiency of the building envelope EGH, i.e. its performance during the heating season, is a parameter referring to the climatic data of the provincial capital. The overall energy efficiency GEE (envelope and installations) is a parameter referring to the municipality. Both these KPIs are calculated using the official CasaClima calculation tool.

Klima Haus class	Energy efficiency of the building envelope **EGH_{WGB}** [kWh/m²a]	Equivalent primary energy demand only heating **PEH_{WBG}** [kg $CO_{2\ eqv}$/m²a]	Equivalent primary energy demand (only cooling) **PEK_{WBG}**** [kg $CO_{2\ eqv}$/m²a]	Overall energy efficiency (heating and cooling) **GEE_{WBG}** (= PEH_{WBG}+ PEK_{WBG}) [kg $CO_{2\ eqv}$/m²a]
Gold*	≤ 10	≤ 10	≤ 5	≤ 15
A*	≤ 30	≤ 20	≤ 10	≤ 30
B	≤ 50	≤ 35	≤ 15	≤ 50
C	≤ 70	≤ 50	≤ 20	≤ 70
D	≤ 90	≤ 65	≤ 25	≤ 90
E	≤ 120	≤ 90	≤ 30	≤ 120
F	≤ 160	≤ 120	≤ 40	≤ 160
G	≤ 160	>120	>40	>160

Figure 1. CasaClima Class

1.4. Comparison with other protocols

The CasaClima R protocol is mostly focused on the energy performance of the building and the avoidance of those errors occurring during the planning and construction phase, that could lead to damages of the building´s substance and could cause problems to the health and well-being of the occupants. CasaClima R follows a target approach, that means that it is based on a set of KPIs with defined minimum quality requirements that must be all mandatory fulfilled. The minimum requirements take into account the initial state of the building in the achievement of an energy saving target. Other existing protocols in this field, as for example the EnerPHit certification, require the achievement of prescribed thermal transmittance values of building components, or alternatively a certain value of energy needs for heating [3]. The CasaClima R protocol applies to existing buildings but not necessarily to buildings of particular historical value. The GBC Historic Building protocol is more focused on this issue. GBC Historic Building' treats and respects the historical subject and combines it with energy improvement. The building subject to certification must have been built before 1945 for at least 50% of the existing technical elements. The certification concerns the restoration, recovery and redevelopment of historic buildings integrated with new uses, safeguarding the parts of the building to be protected due to their historicity. The GBC HB protocol measures the sustainability of the building according to thematic areas such as: historical value, site sustainability, water management, energy and atmosphere, materials and resources, indoor environmental quality, design innovation and regional priority.
So, while CasaClima R works on the basis of qualitative requirements, GBC HB is a score-based certification method [4].

3. Verification tool: "FEM-Analysis existing construction nodes" catalogue

3.1 The concept

The catalogue "FEM-Analysis of existing construction nodes" [5] collects a set of common thermal bridges that can occur because of an energy retrofit of the building, for which the critical internal surface temperatures are calculated. The objective of this document is to provide ready-made and validated solutions that allow for a quick interpretation by designers to solve thermal bridges according to the requirements of the Technical Directive. The catalogue only takes into account thermal aspects and does not describe solutions referred to other construction requirements such as acoustic, moisture and weather protection, air tightness.

3.2 Method

The temperatures of the different construction nodes have been calculated with the two-dimensional finite element method (FEM according to UNI EN ISO 10211 [6]), and in particular by means of the tool THERM[7]. The internal temperature of the conditioned space has been set to 20°C and the internal surface resistance (Rsi) to 0,25 m^2KW^{-1}. Starting from the scheme of identification of the nodes, for each of the identified typologies have been assumed different constructive variants, that are then modelled by varying the following parameters:

- the thermal resistance value of the first insulating material R1
- the thermal resistance value of the first insulating material R2
- the thermal resistance value of the masonry RM
- the outdoor temperature chosen as the average monthly temperature of the coldest month in relation to the location of the building θ_e

Considering all the values or ranges of values that these parameters can assume (Table 1), the result is that 384 simulations were carried out for each construction node. The final result of interest is the surface temperature of the critical point of the node, as required by the technical directive.

Table 1. Values or ranges of values assumed by the parameters involved in the FEM simulation.

	Values
R1 [m^2KW^{-1}]	No insulation; $1.5 \leq R1 < 3.0$; $3.0 \leq R1 < 4.5$; $R1 \geq 4.5$
R2 [m^2KW^{-1}]	No insulation; $0.5 \leq R2 < 1.5$; $1.5 \leq R2 < 2.5$; $R2 \geq 2.5$
RM [m^2KW^{-1}]	$0.1 \leq RM < 0.5$; $0.5 \leq RM < 0.8$; $0.8 \leq RM < 1.5$; $R1 \geq 1.5$
θ_e [°C]	-8.0; -6.5; -5.0; -3.5; -2.0; -0.5; 1.0; 2.5

3.3 Application

The catalogue can be used in two ways by technicians. In fact, it is possible to use it to validate one's own design choices or alternatively to understand how to solve the thermal bridges. The steps for proper use of the document are as follows:

1. Choose the type of thermal bridge of interest following the identification code and the graphical description.
2. Choose, in the identified sheet, the thermal resistance values of the two insulators (if present) and of the masonry. In this activity it is possible to refer to a specific table that relates the thermal conductivity of materials with their thickness to determine the thermal resistance.
3. Identify the average monthly outdoor temperature of the coldest month in relation to the location of the building.

Crossing this information on the corresponding sheet the internal surface temperature of the construction detail is given [6]. An example is provided in Figure 2.

Dämmstoff Coibentazione (R_1) [m²K/W]		ohne senza				≥ 1.5 < 3.0				≥ 3.0 < 4.5				≥ 4.5				
Mauerwerk Muratura (R_M) [m²K/W]		≥ 0.1 < 0.5	≥ 0.5 < 0.8	≥ 0.8 < 1.5	≥ 1.5	≥ 0.1 < 0.5	≥ 0.5 < 0.8	≥ 0.8 < 1.5	≥ 1.5	≥ 0.1 < 0.5	≥ 0.5 < 0.8	≥ 0.8 < 1.5	≥ 1.5	≥ 0.1 < 0.5	≥ 0.5 < 0.8	≥ 0.8 < 1.5	≥ 1.5	θ_e [°C]
Dämmstoff Coibentazione [m²K/W] (R_2): ohne senza	1	7,5	8,3	8,3	8,3	11,0	9,9	9,8	9,6	11,4	10,1	9,9	9,6	11,5	10,1	9,9	9,8	-8.0
	2	8,2	8,9	8,9	8,9	11,5	10,5	10,3	10,2	11,8	10,6	10,5	10,2	12,0	10,6	10,5	10,3	-6.5
	3	8,9	9,6	9,6	9,6	12,0	11,0	10,9	10,7	12,3	11,1	11,0	10,7	12,4	11,1	11,0	10,9	-5.0
	4	9,5	10,2	10,2	10,2	12,5	11,5	11,4	11,3	12,7	11,7	11,5	11,3	12,9	11,7	11,5	11,4	-3.5
	5	10,2	10,8	10,8	10,8	13,0	12,1	12,0	11,8	13,2	12,2	12,1	11,8	13,3	12,2	12,1	12,0	-2.0
	6	10,9	11,4	11,4	11,4	13,4	12,6	12,5	12,4	13,7	12,7	12,6	12,4	13,8	12,7	12,6	12,5	-0.5
	7	11,5	12,1	12,1	12,1	13,9	13,2	13,1	12,9	14,1	13,3	13,2	12,9	14,2	13,3	13,2	13,1	+1.0
	8	12,2	12,7	12,7	12,7	14,4	13,7	13,6	13,5	14,6	13,8	13,7	13,5	14,7	13,8	13,7	13,6	+2.5
≥ 0.5 < 1.5	9	7,7	8,8	8,8	8,8	12,0	10,7	10,6	10,4	12,3	10,9	10,7	10,6	12,3	11,0	10,9	10,6	-8.0
	10	8,3	9,4	9,4	9,4	12,4	11,2	11,1	10,9	12,7	11,4	11,2	11,1	12,7	11,5	11,4	11,1	-6.5
	11	9,0	10,0	10,0	10,0	12,9	11,7	11,6	11,4	13,1	11,9	11,7	11,6	13,1	12,0	11,9	11,6	-5.0
	12	9,7	10,6	10,6	10,6	13,3	12,2	12,1	11,9	13,6	12,3	12,2	12,1	13,6	12,5	12,3	12,1	-3.5
	13	10,3	11,2	11,2	11,2	13,7	12,7	12,6	12,5	14,0	12,8	12,7	12,6	14,0	13,0	12,8	12,6	-2.0
	14	11,0	11,8	11,8	11,8	14,1	13,2	13,1	13,0	14,4	13,3	13,2	13,1	14,4	13,4	13,3	13,1	-0.5
	15	11,6	12,4	12,4	12,4	14,6	13,7	13,6	13,5	14,8	13,8	13,7	13,6	14,8	13,9	13,8	13,6	+1.0
	16	12,3	13,0	13,0	13,0	15,0	14,2	14,1	14,0	15,2	14,3	14,2	14,1	15,2	14,4	14,3	14,1	+2.5
≥ 1.5 < 2.5	17	7,8	9,0	9,0	9,0	12,2	11,0	10,9	10,6	12,5	11,2	11,0	10,7	12,5	11,2	11,0	10,7	-8.0
	18	8,5	9,6	9,6	9,6	12,6	11,5	11,4	11,1	12,9	11,7	11,5	11,2	12,9	11,7	11,5	11,2	-6.5
	19	9,1	10,1	10,1	10,1	13,0	12,0	11,9	11,6	13,3	12,1	12,0	11,7	13,3	12,1	12,0	11,7	-5.0
	20	9,8	10,7	10,7	10,7	13,4	12,5	12,3	12,1	13,7	12,6	12,5	12,2	13,7	12,6	12,5	12,2	-3.5
	21	10,4	11,3	11,3	11,3	13,8	13,0	12,8	12,6	14,1	13,1	13,0	12,7	14,1	13,1	13,0	12,7	-2.0
	22	11,1	11,9	11,9	11,9	14,3	13,4	13,3	13,1	14,5	13,6	13,4	13,2	14,5	13,6	13,4	13,2	-0.5
	23	11,7	12,5	12,5	12,5	14,7	13,9	13,8	13,6	14,9	14,0	13,9	13,7	14,9	14,0	13,9	13,7	+1.0
	24	12,4	13,1	13,1	13,1	15,1	14,4	14,3	14,1	15,3	14,5	14,4	14,2	15,3	14,5	14,4	14,2	+2.5
≥ 2.5	25	7,8	9,1	9,1	9,0	12,2	11,0	10,9	10,7	12,5	11,2	11,0	10,9	12,6	11,4	11,2	10,9	-8.0
	26	8,5	9,7	9,7	9,6	12,6	11,5	11,4	11,2	12,9	11,7	11,5	11,4	13,0	11,8	11,7	11,4	-6.5
	27	9,1	10,3	10,3	10,1	13,0	12,0	11,9	11,7	13,3	12,1	12,0	11,9	13,4	12,3	12,1	11,9	-5.0
	28	9,8	10,9	10,9	10,7	13,4	12,5	12,3	12,2	13,7	12,6	12,5	12,3	13,8	12,7	12,6	12,3	-3.5
	29	10,4	11,5	11,5	11,3	13,8	13,0	12,8	12,7	14,1	13,1	13,0	12,8	14,2	13,2	13,1	12,8	-2.0
	30	11,1	12,0	12,0	11,9	14,3	13,4	13,3	13,2	14,5	13,6	13,4	13,3	14,6	13,7	13,6	13,3	-0.5
	31	11,7	12,6	12,6	12,5	14,7	13,9	13,8	13,7	14,9	14,0	13,9	13,8	15,0	14,1	14,0	13,8	+1.0
	32	12,4	13,2	13,2	13,1	15,1	14,4	14,3	14,2	15,3	14,5	14,4	14,3	15,4	14,6	14,5	14,3	+2.5

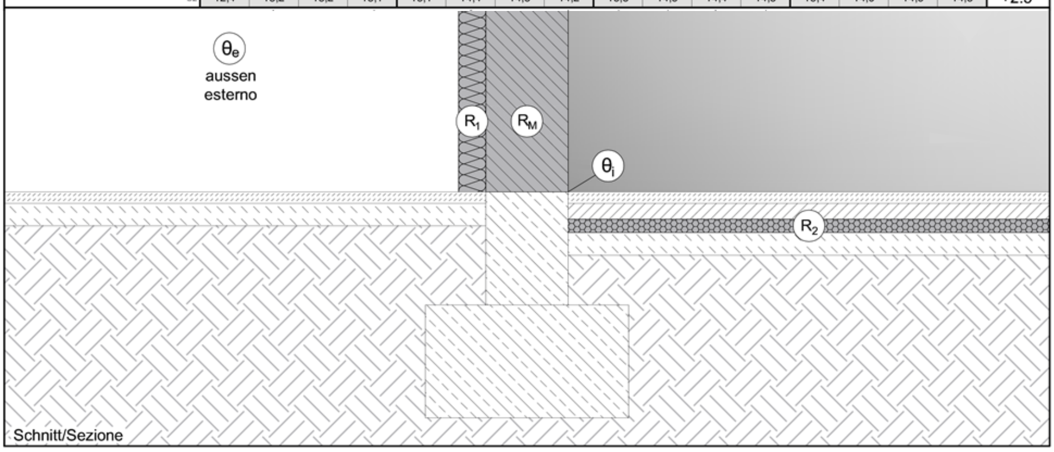

Figure 2. Example of a construction detail sheet with corresponding graphical description and internal surface temperatures

4. Comparison with the threshold temperature values of the Technical Directive which is deduced from the f_{Rsi} calculation method reported in the standard EN ISO 13788 [8].

4. Verification tool: ProCasaClima Hygrothermal

4.1 The concept

The energy requalification interventions of existing and in particular of historical buildings often require design solutions that modify the hygrometric behaviour of the building element. For instance, applying insulation from the inside, in order to maintain the external façade, by using capillary active materials or integrating moisture-variable membranes, can lead to construction damage in the event of improper installation. For this reason, it is often necessary to carry out a thermo-hygrometric assessment to verify the absence of surface or interstitial condensation. As the complexity of the construction layers increases, the stationary Glaser approach (EN ISO 13788), which introduces several simplifications in the calculation, may no longer be sufficient. A more complex and accurate calculation technique is suggested by the standard EN 15026 [9] which includes, unlike the previous procedure, the following aspects: 1. hourly weather data 2. capillary liquid transport 3. hygroscopic storage properties materials 4. variation of physical properties of materials according to the moisture content 5. effect of radiation and eventually driving rain. The new software ProCasaClima Hygrothermal, developed in cooperation with Eurac Research within the European project BuildDOP FESR1022 [10], responds to these characteristics [11].

The main objective for which the software ProCasaClima Hygrothermal was developed is to provide practitioners with an accurate and easy-to-use tool, that goes beyond the traditional hygrothermal assessment method based on the Glaser approach and is coherent with the Technical Directive CasaClima R [12].

4.2 Method

To promote wide dissemination of the calculation tool, a lot of work has been made to make it user friendly and affordable to a large number of practitioners. Firstly, it is formed by an Excel GUI which is a working environment that most of the designers are familiar with. Secondly, the input of the necessary data for the simulation is guided, for instance through the use of drop-down menus. Then, the relevant outputs needed for the evaluation of the hygrothermal performances of the building component are predefined. Moreover, the diffusion of ProCasaClima Hygrothermal will be facilitated by the fact that it will be distributed free of charge.

The solver is an external one, and specifically the same that is used within the software DELPHIN [13], validated according to the standard EN 15026. It is launched through the GUI and that provides the actual solution of the physical equations. Also the materials database the user can choose from is the same of the software DELPHIN. For the definition of the boundary conditions (internal and external), the relevant regulations were followed.

4.3 Application

To better organise the input data and the output consistency, the tool ProCasaClima Hygrothermal is divided into several sheets. At the beginning the general data of the building element and its location can be entered, then it is time to define the layers of materials. These can be chosen by the user from a rich database, which is the same of the DELPHIN software as mentioned before, but it is also possible to customize materials starting from one in the database. The component is graphically displayed with its own layers and the position of monitors, as reported in Figure 3. Monitors provide detailed outputs for a specific position of the construction, considered to be particularly critical from the hygrothermal point of view by the user.

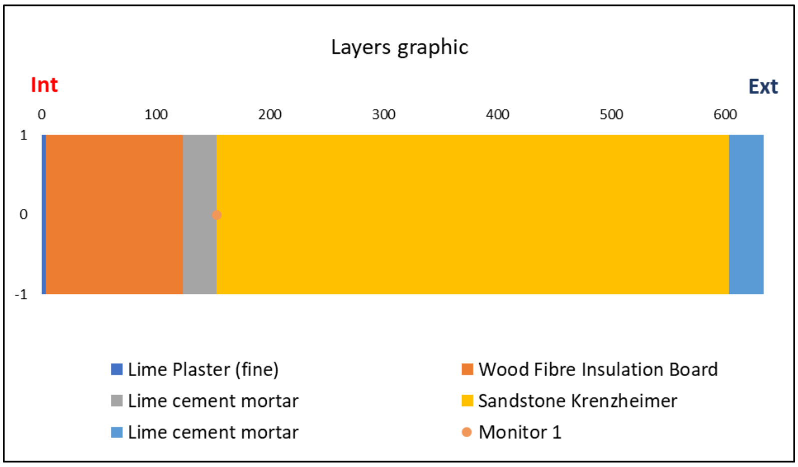

Figure 3. Example of a graphical visualization of the layers constituting the building element and of the monitor position within the GUI of ProCasaClima Hygrothermal

Concerning the external boundary conditions, a database containing the data for all Italian provinces developed by the CTI is available in the software [14]. These data, processed in the form of TRYs according to the standard EN ISO 15927-4 [15], include hourly outdoor temperatures, relative humidity, global and diffuse radiation and wind speed. Alternatively, the user can import his own climate data in .wac format so that it will be possible to obtain the precipitation data in the chosen site and to apply the driving rain coefficients consistent with the EN ISO 15927-3 standard [16]. The interior climate in ProCasaClima Hygrothermal is calculated according to the two simplified adaptive models described in the standard EN 15026 and UNI EN ISO 13788.

The starting month for the dynamic simulation is conventionally fixed in October and a timeframe of at least 3 years of simulation is recommended in order to reduce the influence of the starting conditions set by default i.e. relative humidity equal to 80% and internal temperature of 20 °C.

The outputs are all graphical and are divided into 3 types:

- total moisture content inside the component,
- spatial profiles of temperature, relative humidity and moisture content
- trend of temperature, relative humidity and moisture content for each layer and monitor position

Interpretation criteria suggested to connect these outputs with an evaluation of the hygrothermal risk are reported in the Appendix D of the Technical Directive and referred to maximum level of moisture content and relative humidity in the most critical points.

4.4 Future exploitation

At present, the software represents a valid alternative to the most famous and widely used software for thermo-hygrometric simulation in dynamic regime such as WUFI [] or DELPHIN. It is easier to use and more user-friendly, not only because of the extremely intuitive Excel GUI environment, but also because the types of results to be displayed are already preset.

The tool is currently capable of simulating the combined transport of heat and moisture in 1D wall build-ups, but it is not yet possible to simulate the hygrometric behavior of a 2D detail. Furthermore, there is still no possibility to simulate the transport of humidity by convection, a phenomenon that could occur if the building element is not perfectly airtight. This means that it must be assumed that all the simulated components are perfectly airtight.

Some limitations are also found in the climate data database provided within the software, which contains measured data only for Italian provincial capitals, but in any case, not including precipitations. This is precisely one of the aspects that is intended to be strengthened in the future, through an in-depth study of climate data, initially limited to the Alto Adige, in order to be able to propose much more accurate data.

5. Conclusion

This paper has presented the CasaClima R certification, a protocol for energy requalification of existing and possibly historic buildings. It is the main part of a broader framework for retrofitting of building which involves also guidelines, experts, calculation and verification tools. These tools have been developed to not only harmonise and improve the planning of retrofits, but also to align the control mechanisms in order to better verify the implementation of the planning decisions in terms of energy performance. This also makes it possible to react better to changes during the construction phase, as can often be the case with refurbishments.

The tools to support and validate design choices are the catalogue "FEM-Analysis of existing construction nodes" and the software ProCasaClima Hygrothermal. They respectively support the resolution of thermal bridges and the verification of the absence of interstitial condensation of the building elements, especially in the case of insulation intervention from the inside. The framework as a whole and its various elements will always be reviewed and updated to keep pace with scientific and technological advances.

To date, 230 buildings in Italy have been certified according to the CasaClima R protocol and ProCasaClima Hygrothermal tool has been downloaded by more than 2000 users.

Preliminary studies have already been carried out to develop a protocol suitable for historic buildings under fine arts protection, for which the intervention limits are even more restrictive.

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