New Tools for the Hygrothermal Assessment of Building Components: A Comparison of Different Methodologies

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Abstract

This paper presents new tools for the hygrothermal assessment of building components. The first assessment method based on the Glaser approach is implemented on the existing software ProCasaClima, whereas the second method constitutes a new tool for the dynamic simulation of combined transport of heat and moisture in building components: ProCasaClima Hygrothermal. This latter tool is more advanced since it takes into account capillary liquid transport and moisture storage properties of materials. At the same time, ProCasaClima Hygrothermal aims to be user-friendly to maximize its diffusion among technicians. The two assessment methods will be presented and compared in the results through a case study represented by an external wall internally insulated and located in the climate of Bolzano/Bozen. A second analysis is carried out specifically on the Hygrothermal tool to compare the results obtained with two different climate files. The first uses the reference year data provided by the CTI while the second is based on climate data obtained from the software Meteonorm, once again on the city of Bolzano/Bozen, but also including data referring to the rain. Finally, it will be possible to evaluate the influence of this phenomenon on the risk of interstitial condensation for the specific case analysed. The studies presented in this paper are supported by the ERDF European project BuildDOP.

1. Introduction

The main reason behind the necessity of performing an hygrothermal assessment concerns the prevention of building pathologies, degradation of components and comfort issues.

The Italian building stock is rich in buildings requiring energy requalification interventions.

Based on the experience gained by CasaClima Agency on certified buildings, it is clear that some design solutions, which could be critical from the hygrothermal point of view, are often applied in the construction phase without performing the required hygrothermal evaluations in the design stage. This issue is due to the lack of simple and easily accessible evaluation tools as well as to the lack of knowledge of stakeholders involved in the design and construction process of buildings. In particular, the use of vapor barriers or moisture-variable vapor barriers for interior insulation in mixed constructions, common in the Alpine region, can lead to construction damage in the event of improper installation. Moreover, the application of the capillary active insulation system is often limited due to the absence of a user-friendly simulation tool that can predict properly their hygrothermal performances.

Thus, within the BuildDOP project (Agenzia per l'Energia Alto Adige – CasaClima, 2018), the CasaClima Agency with the support of Eurac Research has developed two tools for the hygrothermal analysis of building components: an assessment tool based on the Glaser methodology and a dynamical simulation tool, ProCasaClima Hygrothermal. The aim is to push the application of dynamic hygrothermal simulations, even in smaller renovation projects where interior insulation is frequently used and integrate them in the building certification process. The general objective of the implementation of these two hygrothermal assessment methods is to provide designers and

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building consultants with all the tools needed to perform the verifications required in Appendix D of the CasaClima Technical Directive. This Appendix requires hygrothermal verification in two cases: internally insulated external walls and non-ventilated flat roofing (Agenzia per l'Energia Alto Adige – CasaClima, 2017).

This paper reports the development of the two different calculation approaches designated to the evaluation of interstitial condensation risk on building components i.e. a Glaser based method (EN ISO 13788) and a dynamic simulation tool (EN 15026). The results of the two calculation approaches are compared using a case study. Moreover, the dynamical simulation is performed in two different ways: including and neglecting the effect of driving rain on the building component. The aim is to evaluate the impact of this parameter on the simulation results in a typical Italian climate.

2. Implementation of the Standards

2.1 Glaser Method: UNI EN ISO 13788

The implementation of the above-described methodologies is carried out using the Excel GUI working environment.

Firstly, the Glaser method (EN ISO 13788) has been analysed and implemented step by step following the prescriptions of the standard. The input parameters for the computation are monthly average external conditions (UNI 10349-1) and hygrothermal properties of the materials constituting the building component to be verified.

In particular, in terms of the climate data, the following monthly parameters are necessary for the calculation: outdoor temperature, extreme relative humidity that allows us to obtain the vapour pressure, air temperature and indoor relative humidity. In addition, the properties of materials and products concern conductivity and thermal resistance, the water vapour resistance factor, the equivalent air thickness for the diffusion of water vapour, to which surface resistances are added (R_{se} = 0,04 m^2 x K/W ed R_{si} = 0,25 m^2 x K/W). At each interface between materials, the partial vapor and saturation pressures are computed and, comparing their values, it is possible to identify potential condensation interfaces. In case a condensation layer is identified, the vapour flow rates in that layer are calculated and consequently the amount of condensation or evaporation occurring. The calculation is carried out by means of a graphic monthly method, considering periods of accumulation and evaporation.

This tool has been integrated in the already existing software of the CasaClima Agency "ProCasaClima" in the sheets dedicated to the description of the construction elements. It is possible to select different humidity classes to be applied as indoor climatic conditions, following the prescriptions of the UNI EN ISO 13788 standard.

As output, the user gets an initial feedback on the presence or absence of interstitial condensation in the construction under monthly stationary conditions. In the case of absence, the component can be considered safe under the initial assumptions of absence of driving rain or, more generally, where the phenomena of the hygroscopic capacity of the materials, the transport of humidity to the liquid state and capillary ascent can be considered negligible. By contrast, in the case of presence of interstitial condensation in the component or if it is not possible to apply the stationary method due to the presence of the phenomena described above, the user will have to proceed with a more detailed simulation thorough a dynamic analysis by means of the new simulation tool ProCasaClima Hygrothermal. As the Glaser approach is a simplified method, it presents some limitations: only vapor diffusion is taken into account as a moisture transport mechanism, moisture storage properties of materials are neglected, average monthly climate data are considered and driving rain is completely neglected. It can therefore lead to substantial errors in the evaluation when other transport mechanisms are relevant or when the hygroscopic storage properties as well as the contribution of rain cannot be neglected.

2.2 ProCasaClima Hygrothermal: EN 15026

A more complex and accurate calculation technique is suggested by the EN 15026 standard which includes, unlike the previous procedure, the following aspects: 1. capillary liquid transport 2. hygroscopic storage properties of the material 3. modification of physical properties of materials according to the moisture content 4. hourly weather data 5. effect of radiation and eventually driving rain. The new software ProCasaClima Hygrothermal, developed in cooperation with Eurac Research, responds to these characteristics. The external solver of the tool is the same used in DELPHIN while the graphic interface, the selection of input and output parameters were developed to provide a user-friendly instrument for designers. This tool presents the advantage of combining the ease of use typical of any Excel file and the high level of performance which is featured in the most popular dynamic simulation software such as WUFI or DELPHIN. Above all, this new software is available to the user completely free of charge.

Several aspects have been considered to make the tool user friendly, such as the guided input of data through drop down menus, which helps the designers to select the correct parameters. The tool is currently able to simulate the combined transport of heat and moisture in 1D wall build–ups. Through the application to a case study, the types of data input and output that the new software proposes will be analysed and described in more detail.

3. Simulation

The selected case study construction is reported in the volume "Risanare l'esistente" by Cristina Benedetti and consists of an external wall internally insulated. Referring to Fig. 1, it is possible to recognize the outermost layer of lime cement mortar (3 cm) followed by 45 cm of stone masonry and another layer of mortar. Internally the element is insulated with 12 cm of wood fibre and finally 0.4 cm of internal lime plaster (Benedetti C., 2011).

Firstly, the wall is analysed according to the two calculation methods to compare the results that they generate. Secondly, the focus is applied on the software ProCasaClima Hygrothermal and the same wall is simulated both using climate data that do not include rain and climate date that include rain.

These tests are carried out in the city of Bolzano (Italian climate zone E). The basic hygrothermal properties of the materials constituting the wall are reported in Table 1.

Table 1 – Fundamental hygrothermal properties of materials used for the hygrothermal assessment. The reported parameters are: bulk density (ρ), specific heat capacity (c_p), thermal conductivity (λ), vapor diffusion resistance factor (μ)

ID	Material	ρ [kg/m³]	c_P [J/kg K]	λ [W/m K]	μ [-]
1	Lime Plaster (fine)	1600	850	0,70	7
2	Wood Fibre Insulation Board	168	1700	0,045	39
3	Lime cement mortar	1900	850	0,80	19
4	Sandstone Krenzheimer	2400	1000	2,00	248
5	Lime cement mortar	1900	850	0,80	19

3.1 UNI EN ISO 13788 Evaluation

The interstitial condensation assessment carried out in accordance with the standard UNI EN ISO 13788 is applied to the city of Bolzano using the monthly external climate data taken from the standard UNI 10349. As regards the indoor boundary conditions, these are deduced in accordance with the UNI EN ISO 13788 standard, considering the third humidity class ("Buildings with unknown occupation") for maritime climates. However, the tool implemented in ProCasaClima gives the user the possibility to choose any of the 5 humidity classes for the verification.

3.2 ProCasaClima Hygrothermal Simulation

In this section the relevant input parameters for the simulation with the new software and the relative outputs are described through the application to the case study construction.

In ProCasaClima Hygrothermal materials can be chosen by the user from a rich database, which is the same of the DELPHIN software. There is also the possibility for the user to customize his/her own materials starting from a material in the database and then changing its name and its main hygrothermal characteristics and then saving it in a user defined database. The component is graphically displayed with its own layers and the position of monitors, as reported in Fig. 1.

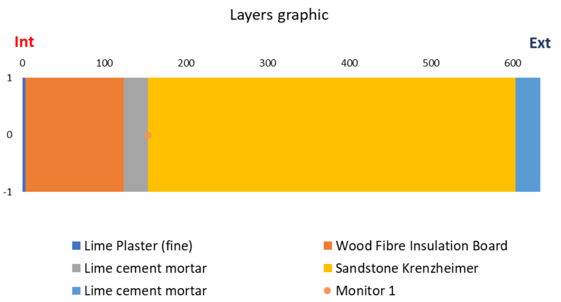

Fig. 1 – Graphical visualization of the layers constituting the building element and of the monitor position within the GUI of ProCasaClima Hygrothermal

Monitors provide detailed outputs for a specific position of the construction, considered to be particularly dangerous from the hygrothermal point of view by the user.

In terms of the climate data, ProCasaClima Hygrothermal has an internal database containing the data for all Italian provinces developed by the CTI (Murano et al., 2016). A temperature correction is subsequently applied to the climate data if the analysed construction has a different altitude with respect to the location included in the database. These data, processed in the form of TRYs according to the standard EN ISO 15927-4, include outdoor temperatures, relative humidity, global and diffuse radiation and wind speed all on an hourly basis. Alternatively, the user can import his own climate data in a .csv format, which can also be generated with the support of the software Meteonorm. In this case, not only can the user select the province but also the exact GPS coordinates of his case study to best simulate local aspects such as the influence of the horizon on the climate. Unlike the previous case, in the latter it will be possible to obtain the precipitation data in the chosen site and see them graphically represented as illustrated in Fig. 2.

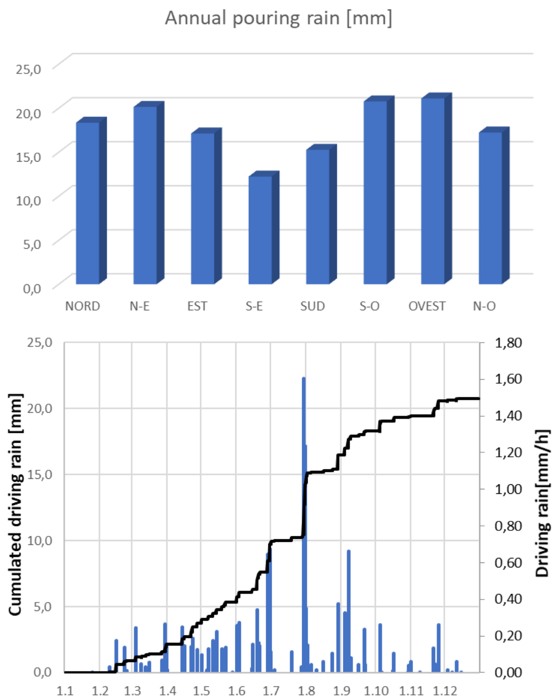

Fig. 2 – Graphs of the annual driving rain subdivided on the 8 orientations for the climate of Bolzano taken from Meteonorm. Below: hourly and cumulated driving rain data for the west façade

The construction is simulated selecting the west orientation, since it represents the direction in which there is the greatest amount of driving rain during the year. This will maximize the influence of this parameter, for the evaluation of the impact of driving rain on the simulation.

The interior climate in ProCasaClima Hygrothermal is calculated on the basis of external temperature and relative humidity by means of two simplified adaptive interior climate models that are described in the standard EN 15026 and EN ISO 13788. The user has the possibility to select the classes provided by both standards, but for the simulation object of this paper the third class in maritime climate provided by EN ISO 13788 is chosen to have the same boundary conditions with respect to the simplified calculation method. This approach for calculating internal climate data leads to a variation of the internal temperature during the year in the range between 20 °C and 23.7 °C and relative humidity ranging from 43% to 71%.

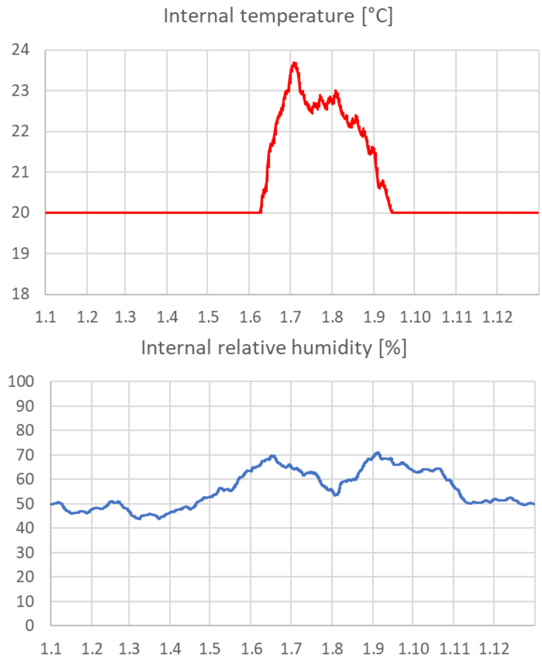

Fig. 3 – Trend of the internal temperature and relative humidity during the year calculated following the prescriptions of the standard EN ISO 13788

The heat and vapour transmission coefficients are set according to the EN ISO 6946 and EN 15026 standards according to the type of construction element analysed (external wall, roof). In particular, for the study conducted in this paper the heat conduction exchange coefficient is equal to 25 W/m²K (R_{se} = 0.04 m²K/W) while the vapour diffusion coefficient is 8.034 x 10^{-8} s/m. For internal surfaces these parameters assume respectively the following values: 4 W/m²K (R_{si} = 0.25 m²K/W (to take into account the presence of furniture) and 2.420 x 10^{-8} s/m.

The starting month for the dynamic simulation is conventionally fixed at October, being the first month of heating for the climate zones most at risk of interstitial condensation, i.e. Italian climate zones E and F. 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 (Larcher et al., 2019). The driving rain coefficients consistent with the EN ISO 15927-3 standard are: roughness coefficient (1.01), topographic coefficient (1.00), obstruction coefficient (0.80), coefficient relative to the wall (0.40), splashing coefficient (0.70), total reduction coefficient (0.23).

4. Discussion and Result Analysis

The evaluation carried out in accordance with UNI EN ISO 13788 standard (Glaser method) presents a risk of interstitial condensation, even if limited. Two interfaces are involved: the one between the masonry and the internal plaster layer and the one between the plaster and the internal insulation. Globally, the period of condensation extends from November to March and then dries completely in spring. The maximum value of accumulated condensation occurs in the month of February and is equal to 64.7 g/m². Even if it is not a particularly high value, it should be taken into account that the Glaser method states the simplifications mentioned in section 2.2, so it is appropriate to evaluate the same component with a more detailed calculation method that considers phenomena such as capillary liquid transport and hygroscopic storage properties.

The output types provided by ProCasaClima Hygrothermal are of a spatial and temporal nature, consisting of temperatures, relative humidity and moisture content for the different layers or monitor positions. In this section outputs provided by the software are analyzed, comparing the case in which the contribution of rain is taken into account (climate data generated with Meteonorm) to that in which precipitations are neglected (CTI typical meteorological years climate data).

The first result analyzed is the total moisture content accumulated in the all construction over the years. The simulation is carried out over a period of 3 years and the third-year trend is the one to be considered significant in order to assess the risk of interstitial condensation. Indeed, simulating a longer period of time, the curve of the third year would be repeated periodically in the following years.

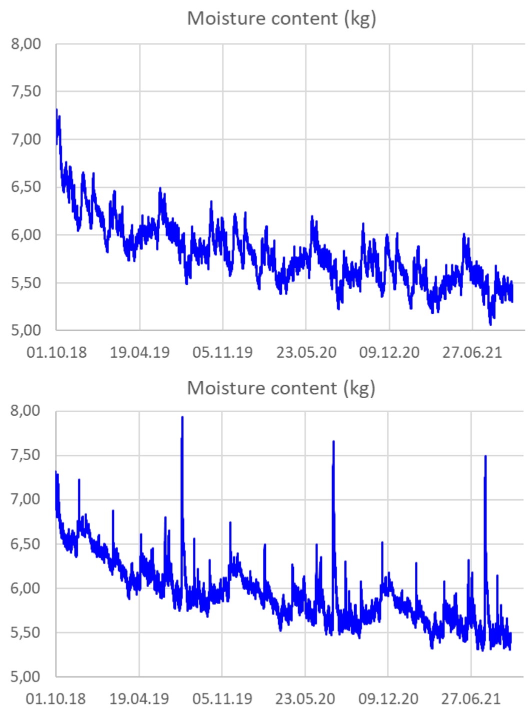

Fig. 4 – Trend of the moisture content in the constructive element during the 3 years of simulation taking into consideration in the upper graph the climate data of Bolzano provided by the CTI (no rain) and in the lower part the Meteonorm data

The results for the third year of simulation show a higher moisture content in the second case compared to the first with peaks during the rainy seasons up to 7.5 kg/m² of moisture in the structure while in the first case this parameter never exceeds the value of 6.2 kg/m². However, the presence of driving rain introduces significant modifications of the total moisture content only for limited time frames during the most severe rain events. Far from these rain events the moisture accumulated in the construction is comparable in the two simulations. In addition, it can be observed that the overall decreasing trend of the total moisture content is the same in both simulations.

The next outputs are the spatial profiles of relative humidity in which the minimum, average and maximum values of this parameter are shown in the component for the third and last year of simulation. The interface with the highest value of relative humidity is the one between the internal plaster adjacent to the insulation and the masonry. For this reason, in this position a monitor is inserted, which makes it possible to analyze this specific part of the construction in more detail.

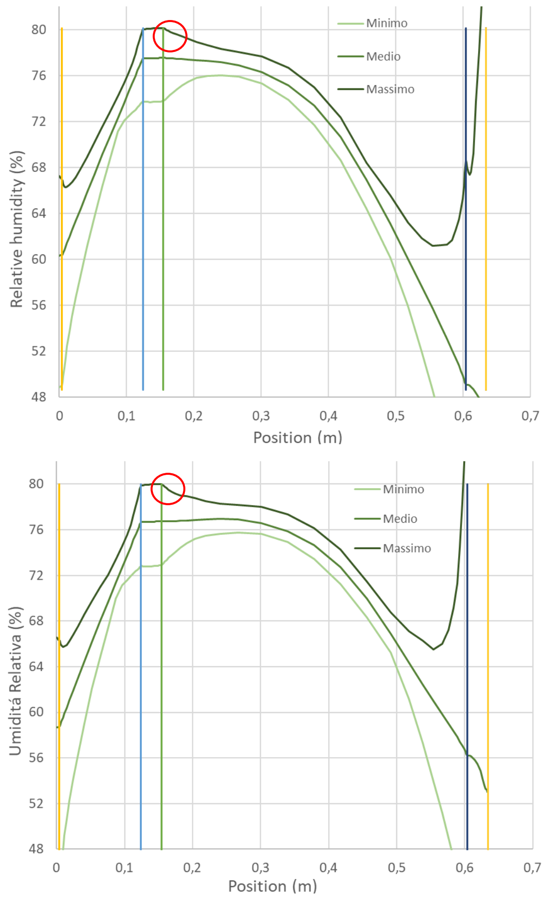

Fig. 5 – Spatial profiles representing the maximum, average and minimum value of relative humidity obtained in the last year of simulation in the element, once again comparing the situation starting with the climate data of Bolzano provided by the CTI (no rain) and in the lower part the Meteonorm data. The red circle contains the critical point of the element

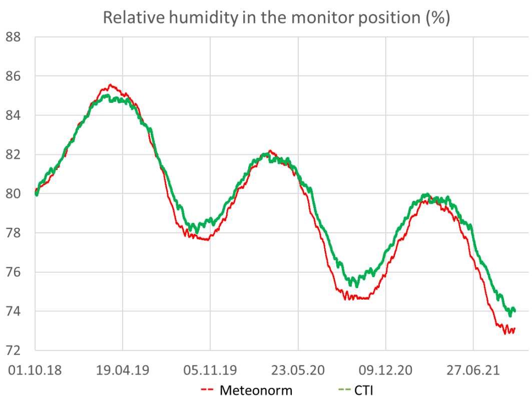

Fig. 6 – Trend of the relative humidity in the monitor position during the simulation period. The red line refers to the simulation performed with data containing rain contributes (Meteonorm). The green line refers to the simulation performed using CTI climate data

In the interface that divides the masonry from the existing interior plaster, the simulation results in a temperature range varying from 3 °C to 30 °C and a relative humidity value from 74% to 85% in the case of external climatic data provided by the CTI and present in the climate data base of Pro-CasaClima Hygrothermal. A similar behavior is also found for the climatic data obtained from Meteonorm (that include rain) with a variation of temperatures from 2 to 31 °C and relative humidity ranging from 73% to 85%. No condensation occurs in the construction since the relative humidity is way below 95% which is considered the threshold where free water starts to be present in building materials (W.T.A. Merkblatt 6-5).

The output presented in Fig. 5 and Fig. 6 confirms that the impact of driving rain is very limited in this climate and for this construction. The effect of the driving rain is visible only for short time frames and only in the outer layers of the construction and therefore it does not lead to any modification when analyzing the formation of interstitial condensation.

5. Conclusion

This paper has presented the approach for the interstitial condensation verification implemented in the new generation of the CasaClima software in order to provide the user with simple and clear tools to meet the requirements of the CasaClima Technical Directive.

The main focus is on the new software Pro-CasaClima Hygrothermal, a tool for the hygrothermal modelling of one-dimensional construction elements in dynamic regime. To highlight all the characteristics of the new tool, a case study has been applied, represented by an external wall in stone masonry insulated internally with 12 cm of wood fibre. Two different climatic datasets referring to the city of Bolzano are applied, one includes the effect of the driving rain and the other does not.

The risk of condensation in stationary conditions was also assessed, using the Glaser method, which was also implemented in the CasaClima software package. It can therefore be considered that three verifications were carried out globally on the same stratigraphy, comparing calculation methods and different climatic conditions including or excluding rain. In all cases, the same interface was highlighted as the most critical, i.e. the one between the stone masonry and the existing interior plaster. The verification in stationary conditions shows a risk of formation of interstitial condensation with a maximum value of condensation accumulated in the month of February equal to 64,7 g/m^2. The other two simulations do not highlight this risk and do not differ with regard to the relative humidity value in the critical interface. It can be concluded that, in the specific case of the analysed wall and for the climate of Bolzano, the rain has a negligible impact on the results.

Future developments of the study will focus on the simulation of different constructions in different and more extreme climatic zones to verify the reliability of the trend recorded for the case study illustrated in this paper and located in Bolzano.

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