Hygrothermal assessment of historic buildings' external walls: preliminary findings from the RIBuild project for Switzerland

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Abstract. To meet the national regulation on building energy needs while preserving the architectural heritage, the renovation of protected historic buildings implies to insulate internally their facades. However, it is a technically risky solution. This work is part of the European project RIBuild that develops guidelines to ensure moisture-safe solutions. For that purpose, historical buildings were monitored to confront the current state-of-the-art of hygrothermal simulations with in-situ measurements. To enforce these calculations, stones used in Swiss traditional construction were characterised, and materials' modelling were investigated. The results of the study will be integrated into a probabilistic web-tool.

1. Introduction

The useful energy consumption of historical buildings represents 29% of the total useful energy consumption for heating in Switzerland. Renovating the entire historical building stock to meet the SIA380/1:2016 standard total requirements would lead to a 32% reduction of its useful energy consumption [1]. The renovation of historic buildings with a certain degree of protection can lead to the decision to apply interior insulation in order to keep the external facade architecture. However, it is a technically risky solution that can lead to damages on both internal and external parts of the walls and reduce its durability. However, currently the basic hygrothermal method indicated in SIA180(2014), recommending using the Glaser and $F_{R,si}$ steady-state methods is broadly followed due to a lack of guidelines, while these tools are not adapted to hygrothermal complex transient cases [2]. In this research, we investigate the applicability of interior insulation systems in historic buildings in the Swiss renovation context. This work is part of the European project RIBuild (Horizon 2020 programme), a trans-disciplinary project embracing building physics, hygrothermal assessment and statistics. The work plan of RIBuild project for Switzerland is provided hereafter. It follows previous research projects in Switzerland e.g., the SuRHiB project [3] and the MOFEINN project [4].

Figure 1 presents the workflow of the project for the Swiss context. The work's final goal is to develop web-based recommendations for historic buildings – defined as built before 1945 – based on thousands of pre-calculated hygrothermal simulations tailored for the participating countries. For this purpose, a probabilistic approach was developed to run efficiently numerous case studies for each participating country, taking into account the input uncertainties and variabilities. Therefore, Swiss historic construction techniques and materials had to be investigated first. It appeared that 94% of the historic building facades can be classified in three types: facades in brick, in rubble-stone masonry, and in dressed-stone internally doubled with brick [5]. Bricks, mortars and manufactured interior insulation

systems are generally well documented [6]. However, the hygrothermal properties of Swiss stones could not be found in the available literature. For instance, the SuRHiB project only focused on brick buildings, and the MOFEINN project only characterised the stone on the monitored building for WUFI (see in section 2.2). Six stones were chosen as representative of the Swiss historic construction in the three main topographic zones to be characterised: two sandstones and one shell sandstones for the Midlands, two limestones for the Jura region, and one Gneiss for the Alps. Transient hygrothermal simulations were simultaneously conducted on a refurbished single-family house (SFH) as a demonstration project. On-site measurements were used to evaluate the behaviour of the facades in actual conditions and to calibrate a deterministic 1D simulation, conducted using DELPHIN. This case study was provided by the Berner Fachhochschule (BFH) which completed a similar analysis using the WUFI software. Using the same case study enables the comparison between DELPHIN and WUFI results and as well as between the probabilistic and deterministic hygrothermal assessment with DELPHIN developed in RIBuild. Finally, constructive joists, in particular wooden embedded beams will be further investigated on a multi-familial house (MFH). In this paper, we only present the preliminary results of the comparison between measurements and deterministic simulations on the SFH case study.
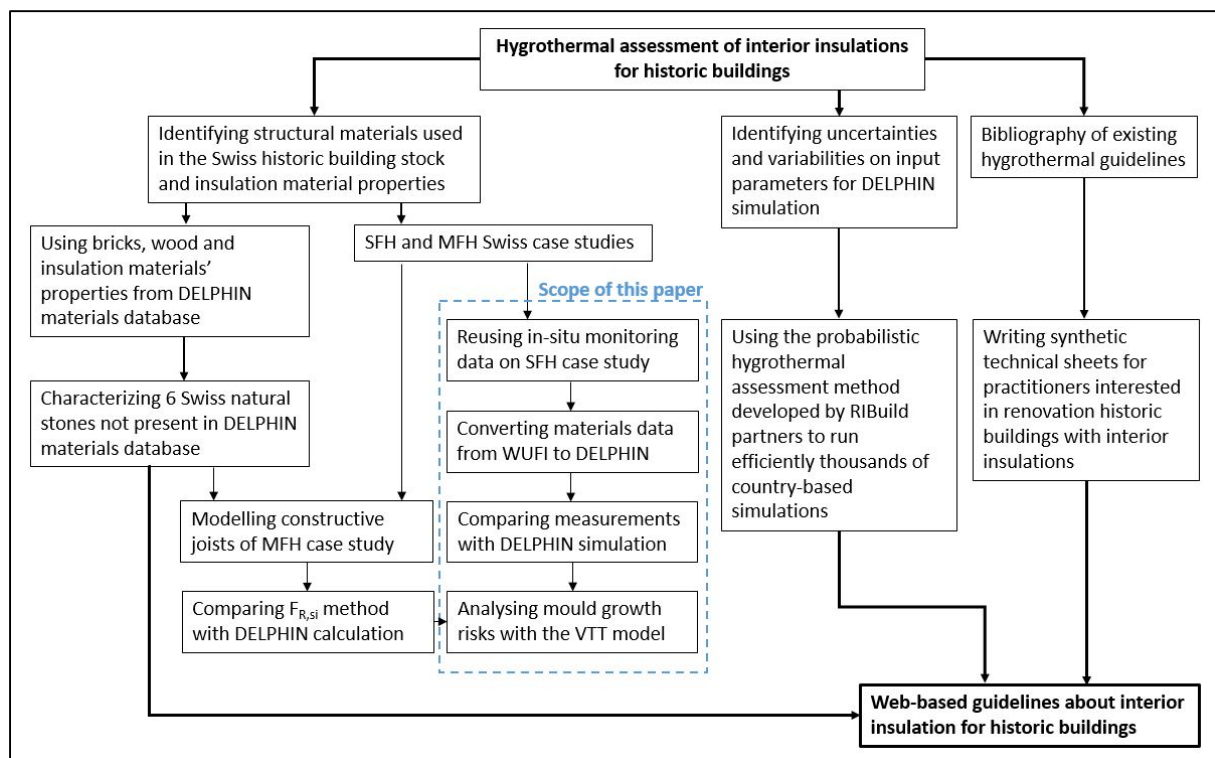

Figure 1: Workflow of the Swiss part of the RIBuild project

2. Materials and methods

2.1. Historic building case study with monitoring data

Using monitored data on a historical building allows evaluating the relevance of numerical simulations by knowing the hygrothermal behaviour of the walls in their real use conditions. This case study [4] is an old traditional farm in the countryside of Bern canton, whose architectural aspect is protected. It is a typical farm from the Swiss midlands, in rubble stone masonry covered with plaster, with visible windows and doors frames in cut shell sandstone. In 2014, the housing part of the farm was refurbished, and the facades were insulated as shown in Table 1

Table 1. Composition of the facades after refurbishment (top: outside, bottom: inside)

Element	Thickness	Material
External rendering	2.0 [cm]	Cement plaster covered by silicone painting
Wall structure	50.0 [cm]	Rubble stone masonry bounded with cement mortar
Insulation	14.0 [cm]	Glass wool Isover PB M 035 (μ=1[-], λ=0.035[W.m^{-1}.K^{-1}])
Vapour barrier	0.3 [cm]	Isover Vario Xtra (0.3[m] $\leq$ sd < 20[m])
Insulation	3.0 [cm]	Glass wool Isover PB M 035
Internal cladding	1.5 [cm]	Fermacell gypsum-plasterboard

Sensors were set up in the different layers of the construction to monitor the temperature and the relative humidity over three years walls oriented northwest and southwest. They were positioned in the plain part of the wall and at 1 [m] from the ground, to limit the influence from constructive joists to focus on the main part of the façade. The hygrothermal risk assessment is conducted at the interface between the insulation and the masonry, as it is the most critical plan towards moisture of the construction.

2.2. Inputs for simulation with DELPHIN

Users must define materials in the DELPHIN input format. All of the materials used in the construction are already in the database, except the rubble-stone masonry. A stone from the nearby quarry was previously characterised for the WUFI software, that uses different materials models. Figure 2 shows the moisture storage input data for WUFI, measured by the Institute for Building Physics (IBP) [7]. In the frame of the RIBuild project, these data were converted into the DELPHIN format, as shown in Figure 3, thanks to an analytical method developed with the Institut für Bauklimatik Dresden [8].
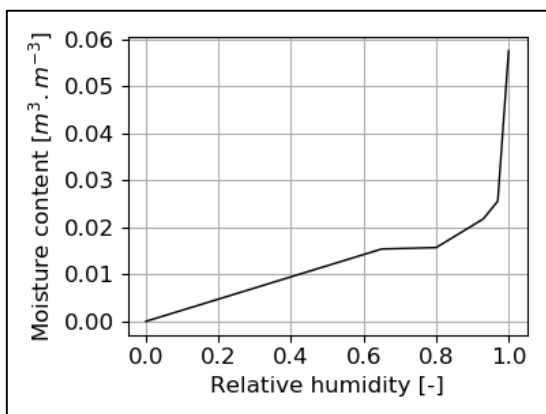

Figure 2: Sorption isotherm of Brüttelen stone as material's input for WUFI
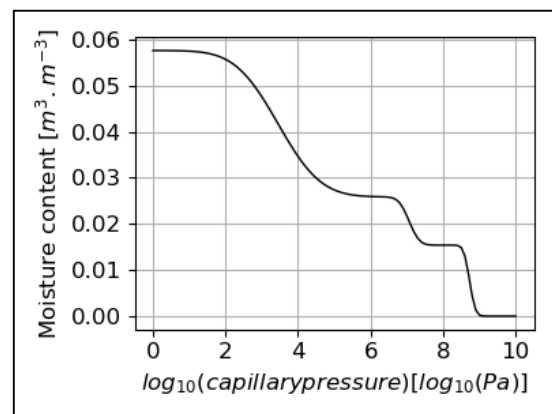
Figure 3: Moisture sorption curve of Brüttelen stone as material's input for DELPHIN

The DELPHIN material's files must contain the following parameters: porosity p [%], thermal capacity cp [J.kg^{-1}.K^{-1}] and conductivity λ [W.m^{-1}.K^{-1}], water absorption coefficient a$_w$ [kg.m^{-2}.s$^{-0.5}$], water content as reference θ_{80} [m^3.m^{-3}] and at saturation θ_{eff} [m^3.m^{-3}], moisture storage function (water content θ depending on log$_{10}$ of capillary pressure pC [log$_{10}$(Pa)]), moisture transport function (liquid conductivity K$_L$ [s] as a function of θ) and resistance coefficient to vapour diffusion μ [-]. The boundary conditions and simulation settings were set-up for the case study according to Table 2

Table 2. Boundary conditions and calculation process of the deterministic simulation

Input parameter	Input distribution or value
Location and wall orientation	Brüttelen (BE), 315° (0°=North)
Meteorological climate data	Weather station of Cressier. Radiation inputs from Payerne
Simulation period	From 08/05/2015 to 31/01/2018
Interior climate EN15026	Adaptive indoor climate model according to WTA 6.2 "normal climate plus 5% moisture load indoor"
Outdoor boundary condition	No rain, no direct or diffuse sun, no long wave radiation from the sky, protected from the wind
Initial conditions	$T_0=15[°C]$; $HR_0=86[\%]$

2.3. Outputs and mould growth assessment

For the simulation of the SFH case study, the considered failure mode is the mould growth assessment. According to the VTT model, the mould index is calculated as a function of temperature, relative humidity, time and substrate (the nature and state of the element that could receive mould growth) [9]. The mould index has no dimension and is comprised between 0 and 6. Each unit indicate a level of mould development, from 0: no mould growth to 6: 100% of surface covered. The threshold value indicating safe moisture levels is 1: beginning of mould growth. The mould index is calculated at the most critical point of the construction, in this case, the interface between the masonry and the insulation. Hence, temperature and relative humidity at this position are requested as outputs of the simulation.

3. Results

3.1. Deterministic simulations compared to in-situ monitoring

The deterministic simulation was calibrated with the measurements to get reliable results. Figure 4 and Figure 5 show respectively the evolution of measured and simulated temperature and relative humidity at the interface between the masonry and the insulation. The calibration of the temperature is quite accurate, with an average deviation of 0.9°C over almost 3 years, and a maximum of 3.5°C in extreme weather conditions. In terms of relative humidity, however, the deviation between simulation and measurements is higher. The same value of the maximum is reached, which is the most important to evaluate moisture and condensation risk, but it is not reached at the same period of the year. Similarly, the decrease of relative humidity in simulation happens much later than in measurements (falls instead of spring). This shows that the model has much more inertia in terms of moisture buffering that the existing wall. This deviation is very similar to the WUFI results as found in the MOFEINN project [10] and is a current general issue in long-term hygrothermal assessment [11].
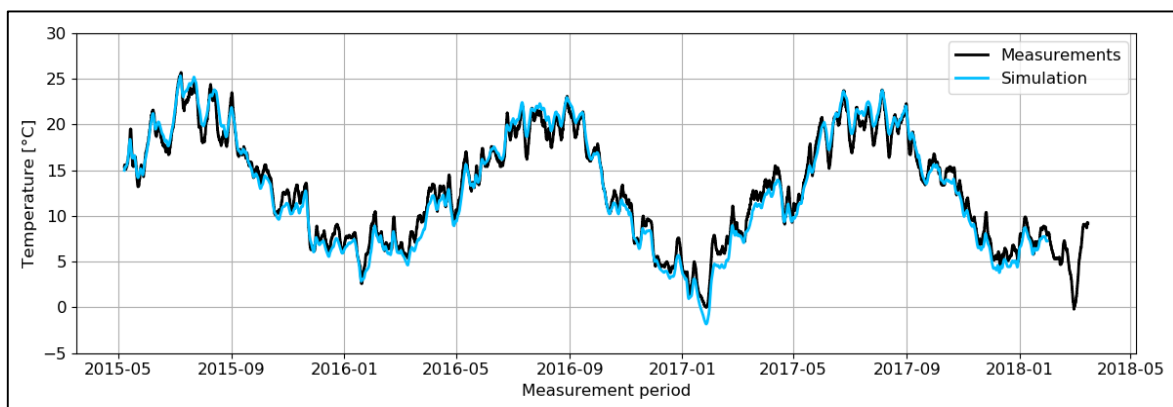

Figure 4: Comparison between measurements and deterministic simulation of temperature at the interface masonry-insulation.
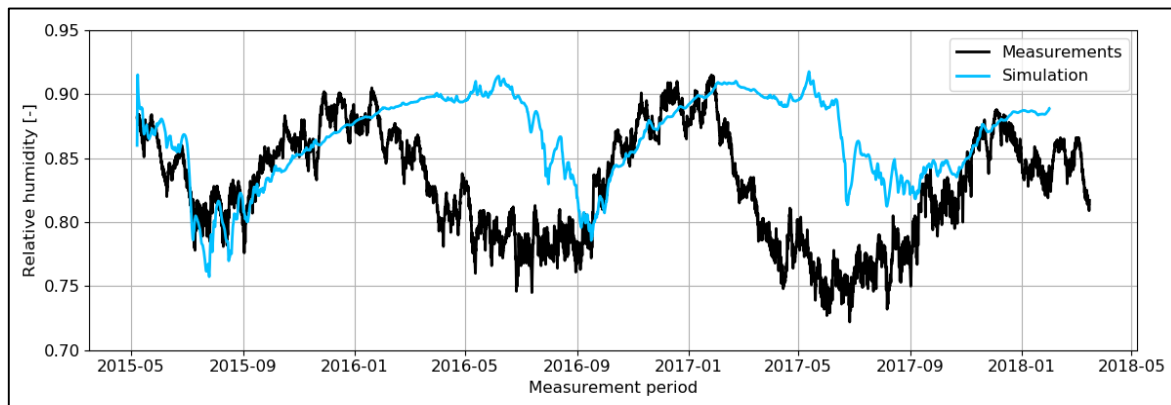
Figure 5: Comparison between measurements and deterministic simulation of relative humidity at the interface masonry-insulation

3.2. Evaluation of mould growth with the VTT model

The VTT model applied to the measurements and the simulation gives very similar results, with an average of mould growth index of 0.0 [-] and 0.1 [-] respectively, with a standard deviation of 0.1 [-] in both cases. It means that there are no mould growth happens. This result was expected, as the Glaser-method can be used in such a construction and gives a moisture-safe result in the construction detail.

4. Discussion

4.1. Simulation confronted with measurements

Figure 4 shows that the hygrothermal models are quite good to evaluate the evolution of temperature. However, concerning the relative humidity, a great gap can be observed between measurements and simulation, that could not be filled by changing materials properties in a reasonable and realistic way. It is then unlikely that it comes from the materials models themselves, especially as there are different in WUFI and DELPHIN but get similar results [10]. This fitting between the two tools highlighted in this case study is reassuring, as it shows that the two models give similar results when the same inputs are given. Similar deviations in measured and simulated relative humidity have been observed in the other case studies analysed involved in the RIBuild project. This deviation is thus more likely to come from the moisture storage and transport models, which will be documented in the coming RIBuild report about on-site measurements vs. simulations [11].

Mould growth results of both measurements and simulation are consistent with the results of the Glaser method, as in this type of construction in this type of use conditions, moisture transport is only driven by vapour diffusion. However, at the position of the beam ends (constructive joists between the facades and the wooden intermediate floor), there are high chances that the mould growth index would be more important. If the use of a tool like DELPHIN makes more sense in practice for simulating the plain part of the wall (1D) for capillary active systems with water storage (e.g., aerated concrete, calcium silicate) the obtained results can now be used to calibrate the 2D or 3D simulation of such a construction detail. As a further part of this study, this thermal bridge will be simulated in the coming steps to evaluate the moisture risk at this level of the construction.

4.2. Uncertainties in input parameters

As a deterministic hygrothermal assessment tool, DELPHIN allows until 3D transient simulations using average values or functions as input parameters as shown in the previous case study. While some input parameters can be fully known, as the wall orientation, others are inherently uncertain, as the exterior heat coefficient. These input uncertainties cannot be reduced and lead to a deviation between the reality and the simulation. This deviation is compensated by a multi-factorial calibration, where the user changes one-by-one each input parameter. To better represent the real hygrothermal behaviour of a historic wall, a probabilistic assessment method using multi-layered Monte-Carlo simulation as developed as part of the RIBuild project will be used in a future step of this work [12]. Instead of considering input parameters as single values, mathematical distributions that represent for each

parameter the probability of each possible value will be used. Some preliminary works developed by the project partners (KU Leuven) show the feasibility of the approach and will be further applied on the Swiss SFH case study. It will not solve the deviation found for the relative humidity between simulations and measurements but will contribute to better reflect the measurements by giving a range of results in a defined confidence interval instead of considering an average output value. The probabilistic framework developed will also be used further in the RIBuild web-tool guidance allowing interested practitioners to simulate the hygrothermal assessment of typical external walls for different countries including Switzerland using a varying level of details.

5. Conclusion

This case study allowed comparing measurements with simulation made with DELPHIN. As other long-term monitoring studies, it highlighted the good correspondence for temperature and the great inertia of the moisture modelling compared to reality. The present case study also allowed investigating the similarities and differences between DELPHIN and WUFI. As a perspective, a deeper investigation could be led on this models' comparison. Further investigations with 2D and 3D simulations will also be led to focus on the weakest points of the buildings of the SFH and MFH case studies. In parallel, the other hygrothermal simulations on the MFH case study and for other configurations will be investigated. Last but not least, the probabilistic assessment will be conducted to prepare the pre-calculated web-based guidelines for interior insulations. Based on this work, operational guidelines for internal insulation of historical facades will be tailor-made for Switzerland.

6. References

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