Short report on the research project:

Quantification and reduction of moisture-related heat losses in the listed building stock

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The responsibility for the content of the research report lies with the authors.

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1. Initial situation

The upgrading of building envelopes is an important aspect to reduce the required energy for interior heating. In the listed building stock however, the installation of insulating materials is problematic in physical terms as well as the conservation of historical buildings (see Fig. 2 and Fig. 3). The reduction of moisture-related heat losses caused by exterior walls out of masonry represents a new solution in this field and was therefore scientifically investigated as part of this research project.

2. Goal of the research project

The relevance of this research topic is getting more clearly looking at the thermal conductivity of water, which is 23 to 90 times higher than air, depending on the state of aggregation (see Fig. 1). For example, the expulsion of air contained in the pores of external wall bricks by the action of driving rain leads to a significant change in the effective thermal conductivity of this wall. Laboratory tests on dry and damp bricks confirm this effect. For example, a thermal conductivity of 0,463 W/(mK) was determined for a brick with a bulk density of 1.556 kg/m^3 at an average temperature of 10 °C and a volume-related moisture content of 0 %. If the moisture content rises to 20 % and then to 40 %, a change of the thermal conductivity to approximately 0,82 W/(mK) or 1,22 W/(mK) is associated. This corresponds to a reduction of insulation properties of approximately 44 % at 20 % volume-related moisture content and approximately 62 % at 40 % volume-related moisture content. Another important factor influencing the thermal conductivity of damp bricks are temperatures below 0 °C. This could be observed in tests in which bricks with a bulk density of 1.880 kg/m^3 and 30 % volume-related moisture content were cooled from 10 °C to -10 °C. The thermal conductivity increased from 1,37 W/(mK) to 1,79 W/(mK). This corresponds to a reduction of insulation properties of approximately 24 %.[1]

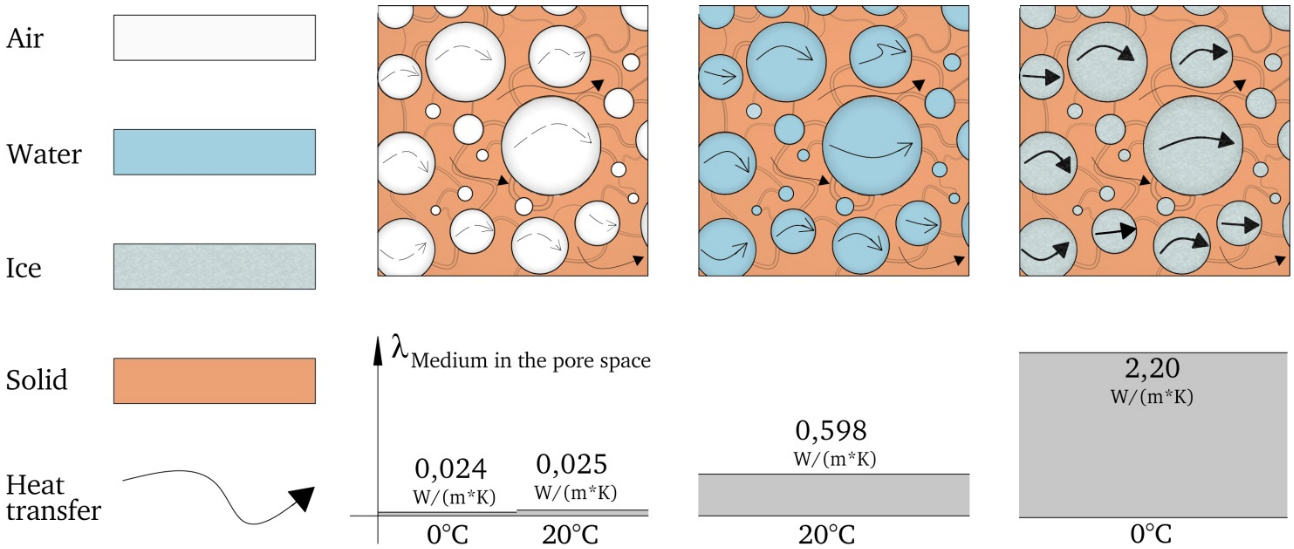

Fig. 1 - Heat transfer incremention as a function of the medium in the pore space, A1

[1] ACHTZIGER 1984, S. 161 - 163
Vgl. KRISCHER 1978, S. 279 - 280

In existing buildings in particular, wall structures are often characterised by inadequate or missing moisture protection and strong temperature fluctuations through the building components (see Fig. 2 and Fig. 3). The reduction of humidity and temperature stresses may invoke an energetic improvement even without insulating materials. Hence the objectives of this research project were the investigations of the interrelations between moisture-loaded brick masonry and the resulting heat losses, to quantify insulation properties changes and the related heating energy. The development and analysis of suitable retrofitting measures that lead to a measurable reduction in moisture-related heat losses was also part of the research project.

Fig. 2 - Decorated gabled houses in Mönchstraße in Stralsund (some with façade damages), A1

Fig. 3 - Historical storehouse building (residential use) in Gützkower Landstraße in Greifswald, A1

Two research concepts were used to achieve the research goals. In the context of the *1st research concept* "*Measuring and Evaluation*" 5 test buildings with the same cubature were erected and monitored by means of a heat and moisture monitoring over 4 heating periods in 2016 and 2017. Different single-shell wall structures (with externally exposed, water-repelling impregnated, plastered and internally insulated masonry) have been implemented (see Fig. 4 to Fig. 6). In addition, one of the 5 test buildings was artificially irrigated. The test building with external plaster was also finished with a water-repellent façade paint.

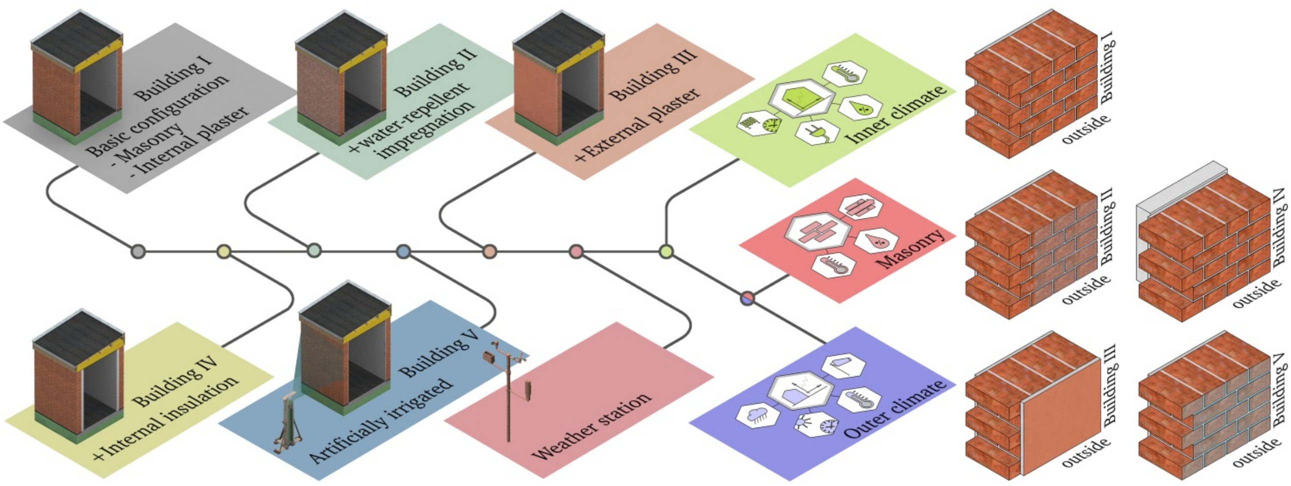

Fig. 4 - Scheme of the test setup as part of the 1st research concept, A1

Fig. 5 - Test site 1 with the test buildings 1, 5 and 2 (from left to right), A1

Fig. 6 - Test site 2 with the test buildings 4 and 3 (from left to right), A1

With the 2^{nd} *research concept* "*Calculation and Evaluation*", hygrothermal simulations of components were carried out for all wall structures of the test buildings. These were used to investigate the heat flux density, the non-steady U-values, the moisture load and distribution as well as the component temperatures. Hygrothermal building simulations were used to determine the influence of masonry moisture to the heat demand of the test buildings.

Both the component and building simulations were carried out over a period of 5 years (2016 to 2020) for the Loitz test site (driving rain exposure group 1) and for the Holzkirchen site (driving rain exposure group 3). The simulation results of the 2^{nd} *research concept* were used to validate the measurement results of the 1^{st} *research concept* in order to provide recommendations for the energetic improvement of external walls by means of moisture-reducing measures.

3. Summary

In the context of the 1^{st} *research concept*, the scientific approach of the research project under the weather conditions at the test site was validated. Both the short-time measurements with a microwave moisture meter and a thermographic camera as well as the long-term measurements with the monitoring system proofed that moisture loading of external walls can impact relevantly their surface temperatures (see Fig. 7 and Fig. 8) and hence their insulation properties (see Fig. 9).

Fig. 7 - Moisture distribution on south and east façades of the artificial irrigated test building 5, A2

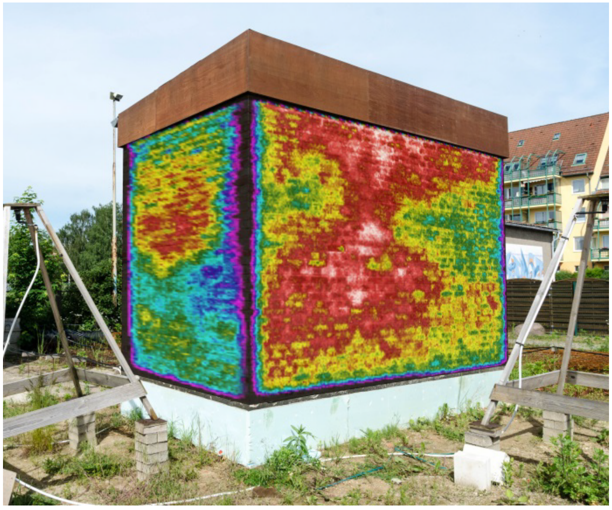

Fig. 8 - Thermogram on south and east façades of the artificial irrigated test building 5, A2

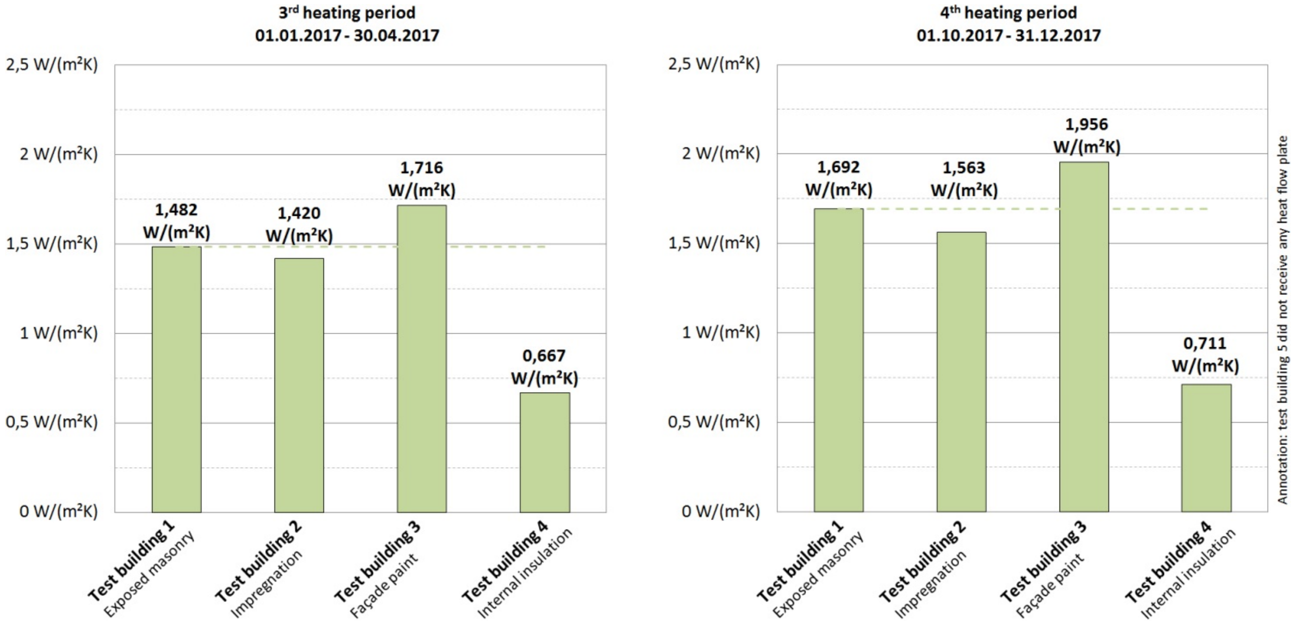

Fig. 9 - Non-steady U-values of the west wall for the 3rd and 4th heating period 2017, A1

The effects of water-repelling impregnation and of the exterior plaster with water-repellent façade paint on the insulating properties of the exterior walls and on heat consumption were also recorded (see Fig. 9 and Fig. 10). Positive effects were observed for water-repelling impregnation. However, the exterior plaster with water-repellent façade paint had an opposite effect due to formation of fissures and the associated moisture penetration. This was particularly evident in the insulating properties of the most exposed west wall.

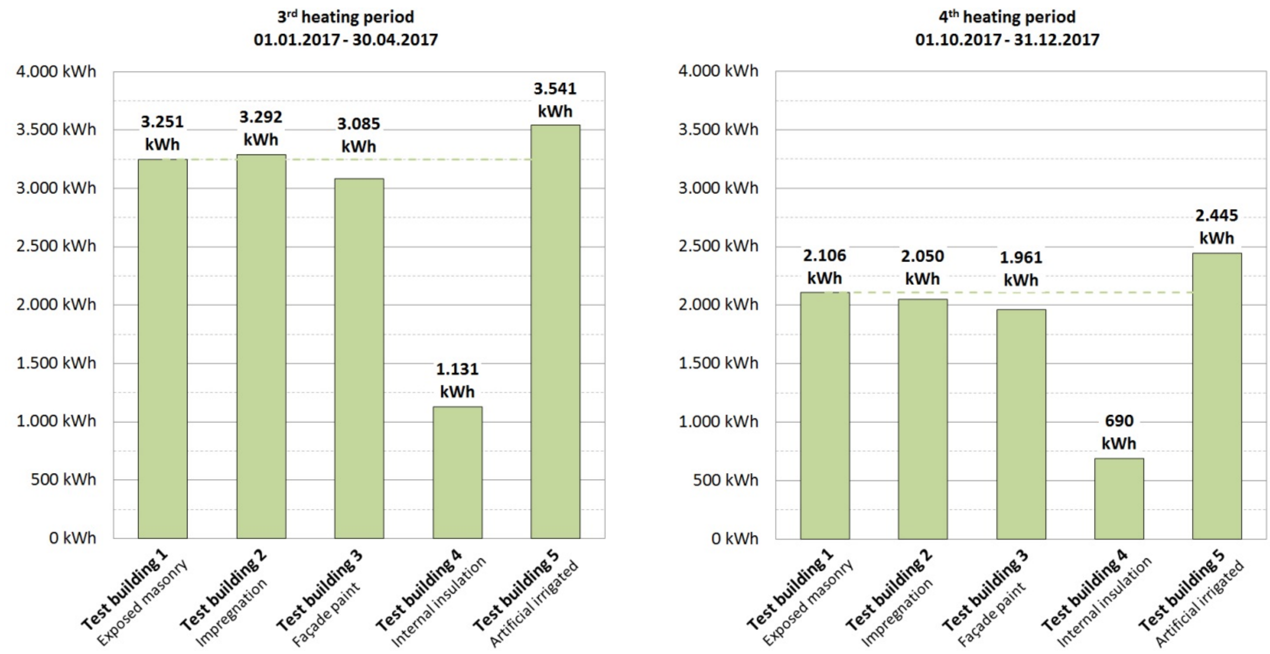

Fig. 10 - Heat consumption of the test buildings 1 to 5 for the 3rd and 4th heating period 2017, A1

The simulation results obtained with the *2nd research concept* for the Loitz test site tend to confirm the measurements (see Fig. 11 and Fig. 12). For the Holzkirchen site, on the other hand, there are greater moisture loads and thus greater heat losses through the unprotected exterior walls. Measures to reduce the moisture load are even more beneficial from an energy point of view (see Fig. 13 and Fig. 14).

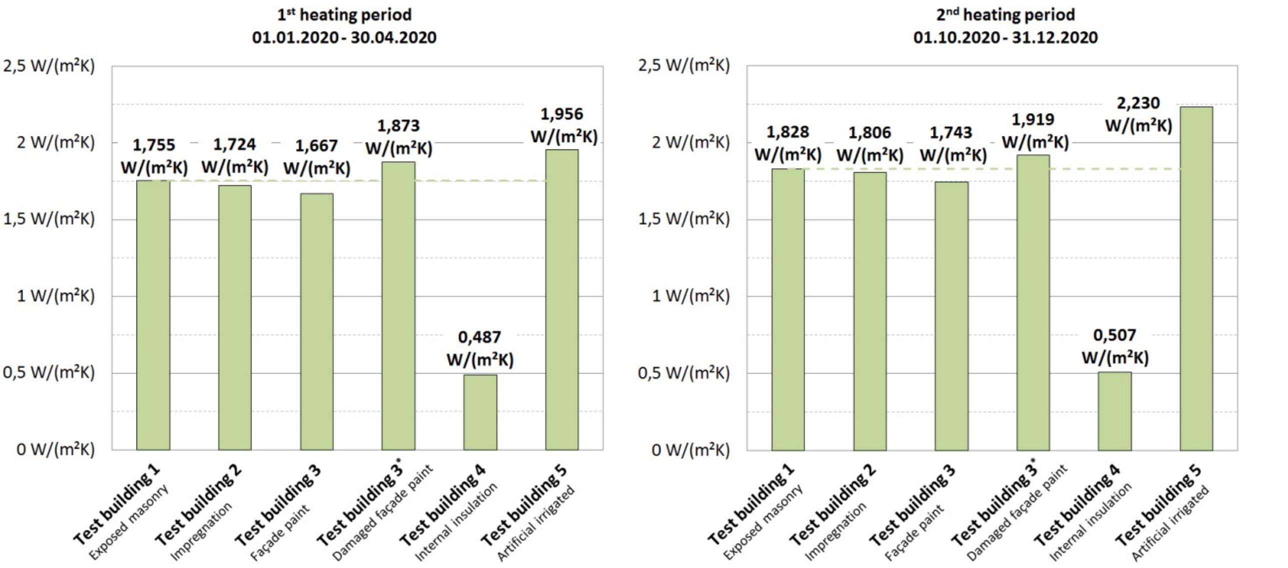

Fig. 11 - Non-steady U-values of the west wall for the last simulation year (Loitz test site), A1

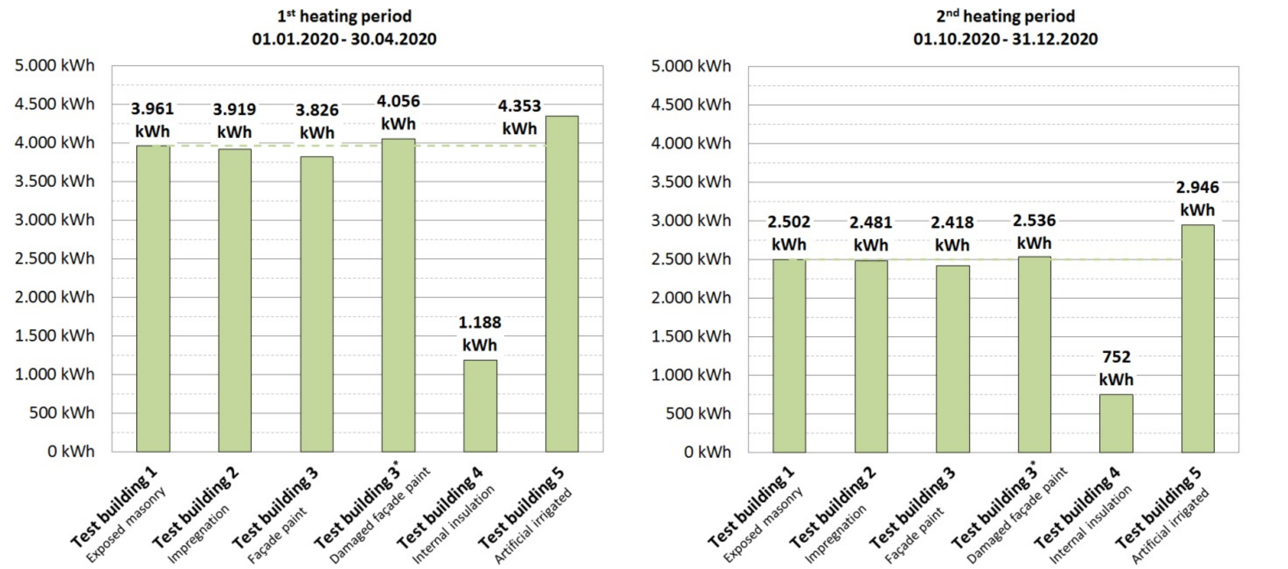

Fig. 12 - Heat demand of the test buildings 1 to 5 for the last simulation year (Loitz test site), A1

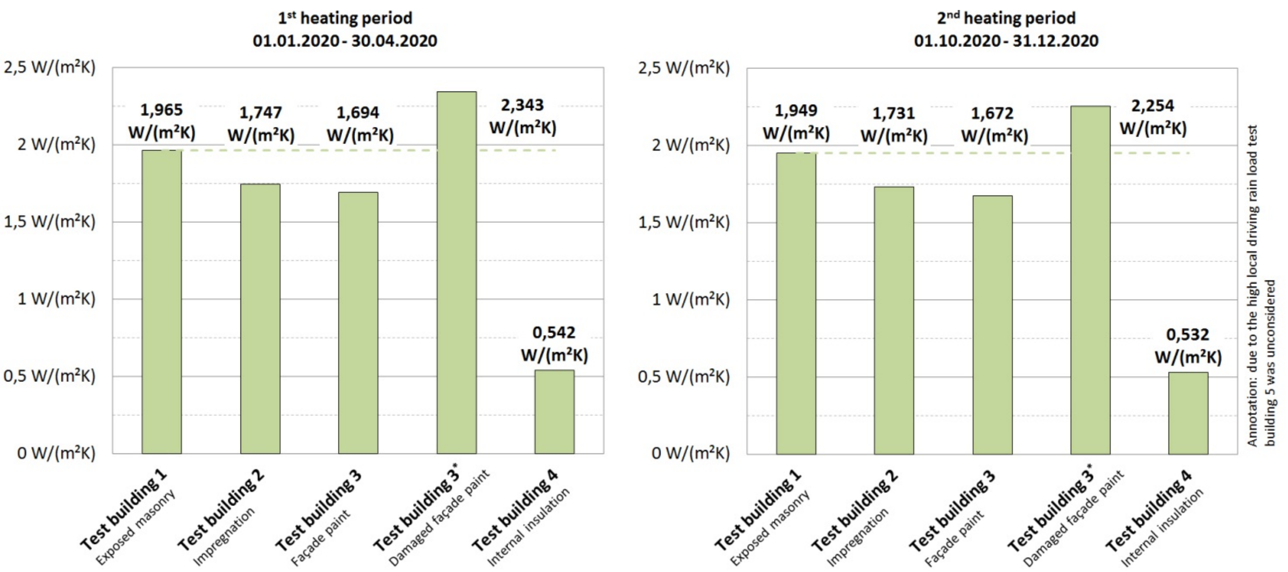

Fig. 13 - Non-steady U-values of the west wall for the last simulation year (Holzkirchen site), A1

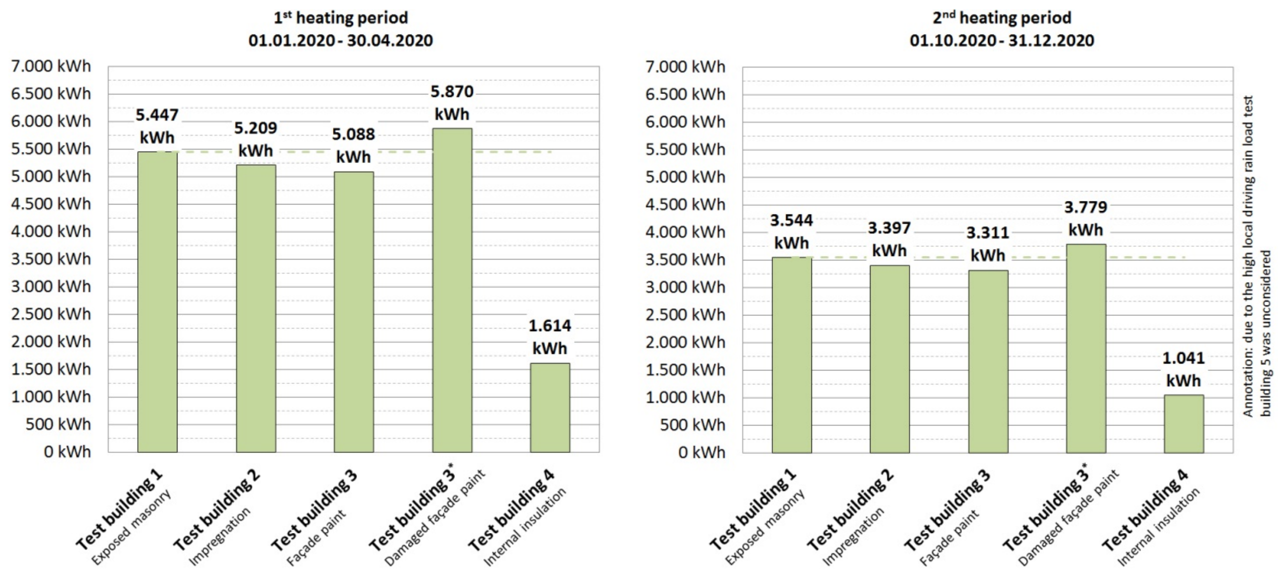

Fig. 14 - Heat demand of the test buildings 1 to 4 for the last simulation year (Holzkirchen site), A1

4. Key data

Short title:	Moisture-related heat losses
Total costs:	244.120,33 €
State subsidy:	162.220,33 €
Share of the institute KGBauko:	4.100,00 €
Share of Burgaß Bau GmbH:	77.800,00 €
Project duration:	31 months, 01.10.2015 to 30.04.2018

5. Literature

[1] ACHTZIGER, Joachim / CAMMERER, Joseph: Einfluß des Feuchtegehaltes auf die Wärmeleitfähigkeit von Bau- und Dämmstoffen. Bericht zum Forschungsvorhaben Nr. BI 5 - 80 01 83 - 4. Gräfelfing 1984.

[2] KRISCHER, Otto / KAST, Werner: Die wissenschaftlichen Grundlagen der Trocknungstechnik (3. Aufl.). Berlin / Heidelberg / New York 1978.

6. Figures

A1 - Author

A2 - RÜHL, Maximilian: Hygrothermische Analyse von feuchtem Mauerwerk (Masterthesis). Darmstadt 2017.