Energy retrofitting of non-residential buildings with regards to heritage value and the established cultural landscape

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Abstract. Interior insulation can be a problematic necessity in case of renovating poorly insulated existing buildings of heritage value. The same applies to younger buildings with interior insulation that later might be qualified as worthy of protection due to their role within an established cultural landscape. This article covers a complex of non-residential buildings, which are part of a university campus. These buildings, from the 60's, were built as a mix of poured and prefabricated concrete structures with interior insulation. The buildings' performance, after more than 60 years in use, was analysed based on theoretical knowledge and professional experience, available project documentation, observations, and examinations regarding the current condition of materials and components. Basing on gathered data and primary simulations of hygrothermal performance, the retrofitting potential using internal insulation as a measure of retrofit in consideration of heritage value restrictions was evaluated. Protected buildings of this construction type are, to our knowledge, so far rarely part of retrofit analyses and therefore worthy of being looked at. The building technology used is considered typical for its construction place and time, making the results representative for a larger number of comparable buildings.

1 Introduction

"The building sector is crucial for achieving the EU's (European Union's) energy and environmental goals. Following the introduction of energy performance rules in national building codes, buildings consume only half as much today, compared to typical buildings from the 1980's" [1].

This statement, however, applies to both new and existing buildings while the latter has not been covered as much in past research. New buildings on the other side have to a great extent been built according to currently valid national building codes of the EU member states and cooperating countries, following the recent Energy Performance of Buildings Directive (2010/31/EU) and the Energy Efficiency Directive (2012/27/EU). To achieve the essential and necessary increase of retrofits and motivate existing buildings' owners, the European Commission's focus has for the last years returned to the renovation of the existing building

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stock, where relevant regulations with guidelines are expected to be established soon [2] as the building and construction sector must be prepared in order to meet set goals, see more in the next chapter BACKGROUND.

Existing buildings are complex and difficult to be properly integrated in common regulations, both on the national and international level, as they used to come from multiple periods of time, are built under diverse conditions (including building technologies and materials used), were constructed according to different regulations, and more. Some of them, particularly built before the middle of this century, can have a heritage value and be subordinate restrictions. In Norway, even younger buildings can be protected due to their symbolical meaning or a unique status in established cultural landscape. In such cases, retrofit projects should be developed regarding Cultural Heritage Act of 1979, *Kulturmineloven* [3], currently valid in Norway, possibly including the consultation of heritage authorities.

A case consisting of a protected building complex including two high rise buildings and three low rise buildings from the 60's as part of a university campus was chosen as a subject of analysis in this paper. The buildings are all classified as heritage protection class C (A being the highest). Uniquely, the original construction and building technology utilized *interior insulation as an original solution*. At the same time, the building complex has characteristics very similar to other university buildings built in Europe in the 60-80's and diverse building typologies in Norway, as reported among typical construction methods from this time [4] by SINTEF, one of Europe's largest independent research organizations, from Norway [5]. The case is described more in detail in the following chapter CASE, as well as in a previous paper by the authors, presented and published at the 13th Nordic Symposium on Building Physics (NSB 2023) in Aalborg, Denmark [6]. In that paper, it was concluded that there are two general retrofit scenarios to be investigated further:

Alternative 1) A total retrofit with the use of a new *exterior* insulation and a new (complete) façade solution, which does require a significant intervention in the existing building envelope, where about 80% of the existing materials and components will be necessary to be replaced, which interferes with the existing appearance of buildings and heritage restrictions.

Alternative 2) A total retrofit with the use of a new *interior* insulation completed by a new façade solution, which also is expected to require a significant intervention, where up to 80% of the existing materials and components can be necessary to be replaced, but not interfering with the existing appearance of buildings and avoiding possible collisions with heritage restrictions to a higher degree.

The intension of this study is to investigate the alternative 2 more in detail, with a focus on investigation of possible retrofit solutions for external walls using interior insulation, as presented more in detail in the following chapters. In case of retrofitting projects, it is less challenging to find a well-working solution for post-insulation of existing roofs or to obtain exemptions from the requirement for post-insulation of basement grounds, while it is more complex and difficult when it comes to finding well-working solutions for post-insulation of the exterior walls above the ground. As reported frequently as the most effective measure to achieve a significant reduction of energy demand for heating in buildings, façade solutions must be paid more attention to.

To our knowledge, there are not many scientific publications addressing buildings, where interior insulation is used originally, located on the inside of external prefabricated concrete slabs, as presented in the chapter CASE. Despite high rise buildings from the 60-80's built in concrete often looking like the chosen case, building technologies and constructions used can vary greatly from country to country. A study by Kaczorek presents a hygrothermal assessment of internally insulated prefabricated concrete external wall above the ground built typically in the 60-80's as a "sandwich" (WK70) in Poland [7] and similarly in other

European countries including Norway [3]. However, these results cannot be considered fully representative for the chosen study due to a different solution chosen for the interior of the external wall construction. Thus, it is important to consider each retrofit-project individually and contribute to the development of a wide set of available and applicable retrofit-solutions (nationally and internationally) which can meet future, more ambitious technical criteria. Found scientific literature studies usually addressed the examination of solutions regarding interior post-insulation of older, often historic, single masonry walls, such as [8] by Vereecken et.al., so again, the results cannot be considered fully representative for this presented case. However, previous probabilistic analyses of energy savings and hygrothermal risks associated with interior post-insulation of an existing wall built in a homogeneous construction, give important indications regarding expected performance of relevant insulation materials. Another study by Zhao et.al. on the evaluation of capillary-active mineral insulation systems for interior retrofit solutions also addressed single masonry walls. The results show a performance of different systems, based on four mineral insulation materials, depending not only on the materials properties but also on specific indoor and outdoor climate conditions. If the possibility of mould growth and interstitial condensation to occur behind the insulation system was found to be probable or high, individual case assessment in the design phase was found *always necessary* to guarantee the damage-free refurbishment [9]. A study on similar materials to be used in similar retrofit-projects was presented by Antolinc et.al., located in continental climate [10]. The results confirm that capillary-active insulation materials proved to be unsuitable for improving the thermal insulation of older buildings built with a similar external wall construction, i.e., single masonry walls and conclude that only a vapour-tight systems can be recommended. However, another deeper and more nuanced study by Vereecken et.al. showed that "caution is required when applying systems composed of a combination of a vapour tight and capillary active material." Finally, the authors noted "that a lower liquid permeability and hence a less capillarity of the insulation material does not necessarily imply an adverse performance, as this could avoid a too high interior surface or room relative humidity for walls exposed to a high wind-driven rain load" and one more time state that "an optimization of the interior insulation systems *strongly demands* a more in depth study" [11].

With respect to the existing buildings architecture, building technology and construction, and possible heritage restrictions, selected solutions for energy efficient retrofitting with the use of interior insulation were evaluated. Basing on gathered and analysed information, technical data, materials, and regarding recommendations found relevant from previous studies, two design alternatives for the energy retrofit of the existing external wall using interior insulation were modelled and simulated:

Retrofit 1) Using a mineral wool as interior insulation and a smart vapour barrier inside.
Retrofit 2) Using a foam glass as interior insulation.

Basing on results from the analysis, none of these proposed retrofit alternatives, basing on interior insulation of the existing external walls, was found worth to be recommended. Thus, alternative retrofit proposals, preferably based on double-skin façade solutions, with respect to the protected status of the campus and following heritage restrictions that can apply in this case, will be paid attention to in future.

Having in mind that the hygrothermal performance of external walls in the analysed case, using *originally* interior insulation, was found not satisfactory due to the risk of mould growth basing on observations, modelling and primarily simulations [6] in WUFI [12] no solutions based on interior insulation (using similar or new, innovative, and better performing materials) should be implemented without a more in-depth going studies regarding:

1) Mycological expertise of the existing building mass.
2) Construction expertise of the existing building mass.

2 Background

While buildings are responsible for 40% of EU (European Union) energy consumption and 36% of the energy-related greenhouse emissions, heating, cooling, and domestic hot water alone account for 80% of the energy that we, users, consume. Having in mind that "at present, about 35% of the EU's buildings are over 50 years old and almost 75% of the building stock is energy inefficient" and "at the same time, only 1% of the building stock is renovated each year" the need of efforts to increase the renovation rates must not be underestimated to "achieve a highly energy efficient and decarbonised building stock by 2050" [2]. Thus, the European Commission revised its originally established directives on Energy Performance of Buildings (2010/31/EU) and Energy Efficiency (2012/27/EU) in respectively 2018 and 2019, as part of the Clean energy for all Europeans package [13]. In the context of renovation, it is particularly important to mention the new proposed directive (2018/844/EU) amending the previous Energy Performance of Building Directive from 2010. In October 2020, the European Commission introduced its Renovation wave strategy [14], as part of the Green Deal [15], with among others its objective to at least double the annual energy renovation rate of buildings by 2030 and to support deep renovation. As presented in the Climate Target Plan of 2030 and further in the European Green Deal Package, in July 2021, the new proposal aims to target at least 60% reduction of emissions by 2030 in comparison to 2015 to achieve climate neutrality by 2050 [16]. The main measures in the new proposal (being now under consideration by the Council of the European Parliament) are, among others:

- *enhanced* long-term renovation strategies, as national Building Renovation Plans
- *increased* reliability, quality, and digitalisation of Energy Performance Certificates, with energy performance classes to be based on *common* criteria
- *a definition* of deep renovation and the introduction of building renovation passports

Establishing obligatory long-term renovation strategies by EU countries aims at decarbonising the national building stocks by 2050, with milestones for 2030 and 2040. The new proposed directive also requires that member countries set *cost-optimal* minimum energy performance requirements for new and *existing buildings undergoing major renovation*, as well as for the *replacement or retrofit of building elements* like heating and cooling systems, roofs, and walls.

The European Commission has established a set of standards to support the directive called the Energy Performance of Buildings Standards (EPB standards) which are managed by the European Committee for Standardisation (CEN).

At present, all planed building projects, including total renovation, usually have minimum energy requirements according to the national building codes, as is the case in Norway [17]. As practice shows, it can be an effective obstacle to increase the number of retrofits. Thus, the increased focus on establishing legal and common regulations for member countries by the European Commission aims to fill the gap. The ambition is that new buildings will meet at least a zero energy and emissions level (nZEB) by 2030, while all buildings, will meet this level by 2050. Amended directives and guidelines are expected to come soon. Thus, more efforts are needed to prepare the building and construction sector, as well as the society, to meet the ambitious goals. Pilot projects, including various kinds of building functions characteristic for critical periods of time such as 60-80's, are needed to map a status of the critical existing building stock and establish a basis of knowledge, including detailed solutions able to be implemented on a wide scale.

3 Case

The campus Gløshaugen of NTNU (Norges Teknisk Naturvitenskapelige Universitet), presented in Fig. 1, is located close to the centrum of Trondheim and consists of buildings with varying architecture, building technologies and construction methods from different periods of time.

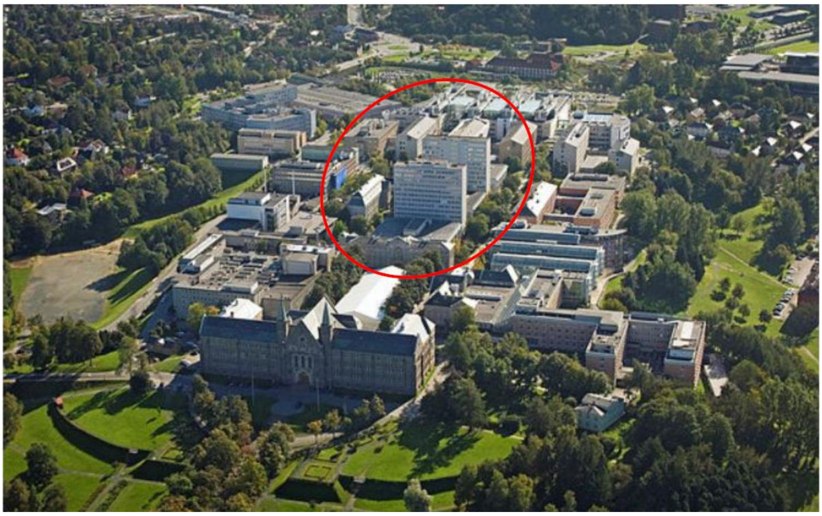

Fig. 1. Gløshaugen campus with central buildings 1 and 2 marked in red, a view from north. Photo: Erik Børseth, Synlig design og foto as/NTNU.

Thus, its established culture landscape is complex, including buildings of varying heritage value, being classified between class A, having the strongest restrictions usually targeting the oldest buildings, and class C with lighter restrictions, as shown in Fig. 2. Regardless of the class, any measures in the exterior on protected buildings placed on the municipality's map for cultural heritage, must be consulted with the Cultural Heritage Office of Trondheim or, if necessary, on a higher, national level.

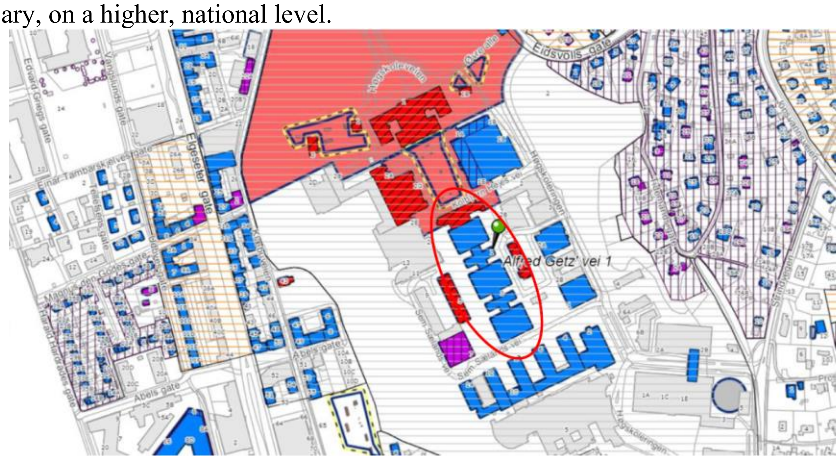

Fig. 2. Campus Gløshaugen, NTNU. Central buildings 1 and 2 (located at Alfred Getz' road 1 & 3) have the class of protection C (blue), which means a *heritage value*, while buildings of a *very high heritage value* have the class of protection A (red) and buildings of a *high heritage value* have the class of protection B (purple). Source: Image by authors from publicly available maps, Municipal Archives of Trondheim.

The chosen complex of university buildings, built in the 60's and placed in protection class C, is centrally located at the NTNU's campus Gløshaugen. It consists of two high-rise buildings, housing mostly offices, and three connecting low-rise buildings, housing mostly educational and public functions, such as auditoria, a bookshop, a canteen, cafeterias, and other public areas, see Fig. 3.

Fig. 3. Campus Gløshaugen, NTNU. Central buildings 1 and 2. Close-ups and details. Photos: Authors.

All buildings of the complex were built with prefabricated concrete elements above ground level, as a main construction, and a poured concrete under ground level, with interior insulation along the external walls. Gable walls, facing east and west, were insulated with porous concrete or mineral wool. Regarding building information found in archives and completed using necessary assumptions, based on available sources as for example presented in Fig. 4 (b), a probable construction of the long existing external walls facing north and south, was modelled, and used for simulation as shown in Fig. 4 (a). Past analyses were concluded by the statement that "the risk for mould must be addressed in present and future considerations as the building documentation indicates the use of organic materials between two vapour-tight layers" [6].

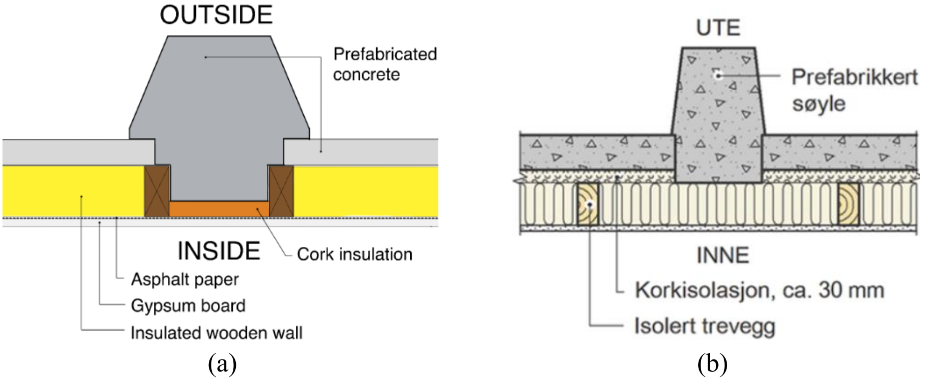

Fig. 4. Horizontal section. Construction principle of the existing external walls used for simulation (a) compared to one of the typical building constructions used in the past in Norway (b), as reported by SINTEF [4]. Illustrations: Authors (a) and SINTEF (b).

4 Method

A literature review was carried out using the Scopus and the Web of Science databases, but only few papers were found relevant for this presented study, focusing on retrofit solutions using interior insulation in case of non-residential buildings built using a combination of poured and prefabricated concrete as a construction method.

To map a status of the chosen building complex, archived documents and technical data were gathered and analysed. Site visits, interviews with users, as well as complimentary measurements (limited due to the buildings are in use), were used as tools, as recommended in the start of any case that involves existing buildings to be renovated [18]. The *observations* allowed to work out a progress plan and chose relevant solutions to be evaluated more in-depth to decide if retrofit solutions based on interior insulation of external walls can be recommended in this case.

As the central buildings of NTNU are classified as protection class C of heritage value, the analysis was carried out with a view to restrictions imposed by the authorities, with a respect to the procedure for planning and implementing major measures in existing buildings recommended in Norway by SINTEF [19], and following a statement regarding registered cultural heritage value given by the Cultural Heritage Office, and the City Architect of Trondheim that aesthetic considerations must nevertheless be given high priority in case of protected buildings.

However, existing buildings planned to be totally renovated have the same technical requirements as new buildings in Norway today, as shortly presented in Table 1. Assuming that it will be challenging to meet the Norwegian requirements for passive house in this case, with U-values for external walls between 0,10-0,12 W/(m²·K) to be found in NS3701 standard as recommended, the goal to meet the minimum energy requirements, TEK17, was found satisfactory for the analysis.

Table 1. Energy requirements according to the Norwegian standards for a university building.

Energy standard	Components Floor ǀ External wall ǀ Roof ǀ Window [W/(m²·K)]	Air leakage [1/h]	Energy demand Heating ǀ Cooling ǀ Total [kWh/(m²·a)]
TEK17	≤ 0.18 ǀ ≤ **0.22** ǀ ≤ 0.18 ǀ ≤ 1.2	≤ 1.5	(-) [a] ǀ (-) [a] ǀ 125
NS3701: 2012	(-) [a] ǀ (-) [a] ǀ (-) [a] ǀ ≤ 0.8	≤ 0.6	(-) [b] ǀ (-) [b] ǀ (-) [a]

[a] Not specified in the Norwegian building code, minimum energy requirements in TEK17 [17], or in the Norwegian standard for non-residential buildings (passive house) NS3701:2012 [20].
[b] Not specified / must be calculated depending on a specific building function, treated area and climate zone, according to NS3701: 2012.

The existing wall structure was simulated in a first step as basis for following retrofit alternatives for several possible constructions to account both for uncertainties and the inhomogeneous character of the structure. These baseline simulations of the existing structure suggested a high risk of mould growth inside the exterior walls, as presented in mentioned study published in the NSB 2023 conference paper by the authors [6]. The simulation conditions in WUFI, the chosen software for hygrothermal analyses, are summarized in Table 2.

Table 2. Simulation conditions, WUFI.

Identifier	Condition
Exterior surfaces	File: Trondheim; NBI / NTNU for temperature and relative humidity
Interior surfaces	File: Trondheim; NBI / NTNU
Orientation	Azimuth 155° (central building orientation of northern wall), Inclination 90°
Building type	Tall building, upper part, more than 20 m
Numerical grid	50 x 50
Mode	Heat transport calculation and moisture transport calculation
Simulation timeframe	5 years

Two *theoretical* proposals of the external wall design-solutions for energy retrofit with interior insulation were modelled and simulated in WUFI:

Retrofit 1) Using a mineral wool as interior insulation and a smart vapour barrier inside. It means that all organic materials inside the existing external wall construction used originally were removed and replaced, wooden beams by metal profiles and asphalt paper by a smart vapour barrier. The originally used interior insulation of mineral wool (10 cm) was replaced by 25 cm of new insulation of mineral wool divided in three layers, and gypsum cladding, as shown in Fig. 5 (a). The wooden profile on the inside of the smart vapour barrier can be replaced by a profile of aluminium alternatively. Existing façade panels of prefabricated concrete were completed by a layer of alkali-activated concrete render (ACC) of 2.5 cm.

Retrofit 2) Using foam glass as interior insulation.
It means that all originally used materials inside the existing external wall construction of prefabricated concrete were removed and replaced by an interior insulation of 25 cm of foam glass and gypsum cladding, as shown in Fig. 5 (b). Existing façade panels of prefabricated concrete were completed by a layer of alkali-activated concrete render (ACC) of 2.5 cm.

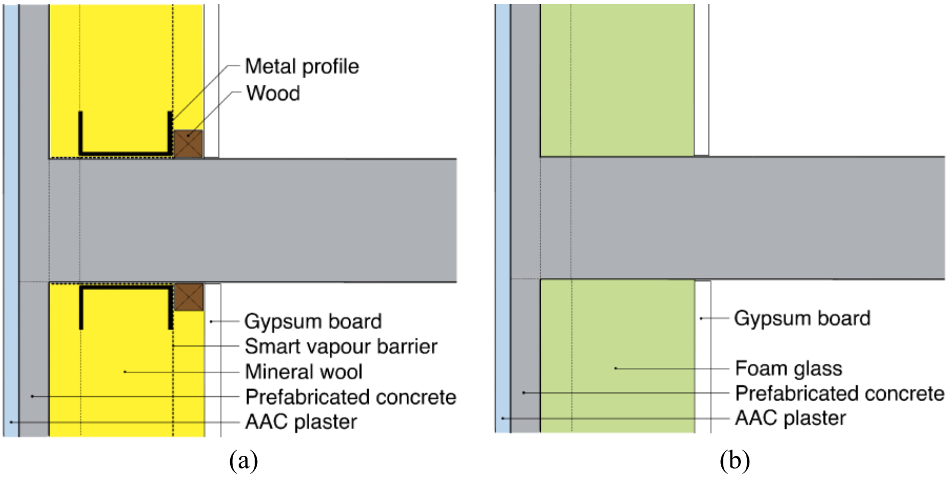

Fig. 5. Vertical sections. Proposals of the external wall design-solutions for energy retrofit with interior insulation: Retrofit 1 (a) and Retrofit 2 (b). Illustrations: Authors.

5 Results

With respect to the existing buildings architecture, building technology and construction, as well as possible heritage restrictions, two selected solutions for energy efficient retrofitting of external walls with the use of interior insulation were evaluated to determine if interior insulation can be recommended.

The first retrofit alternative tested consists of the removal of all existing material exempt the concrete structure and the use of mineral wool and steel support on the interior, as displayed in Fig. 5 (a). For the hygrothermal analysis, two positions within the proposed solution were tested, the fist in the insulation layer right at the prefabricated concrete and the second one within the wood studs. For the first spot, the construction showed a high moisture content, while the second spot had less moisture, assumably due to hygrothermal exchange with the indoor environment. Used material characteristics can be found in Table 3 and associated isopleths in Fig. 6.

Table 3. Material properties, Retrofit 1.

Nr.	Material	Bulk density [kg/m³]	Porosity [m³/m³]	Specific heat capacity [J/(kg·K)]	Thermal conductivity [W/(m·K)]	Vapor diffusion resistance [-]
1	AAC plaster	500	0.77	850	0.12	8
2	Concrete 35/45	2220	0.18	850	1.6	248
3	Aerated concrete	500	0.77	850	0.12	8
4	Mineral wool	60	0.95	850	0.04	1.3
5	Metal unperforated	7800	0.001	450	46	6400
6	Vapour barrier Klimastar vario 5-Star	80	0.001	2300	2.3	4900
7	Hardwood	650	0.47	1400	0.13	200
8	Gypsum board	850	0.65	850	0.2	8.3

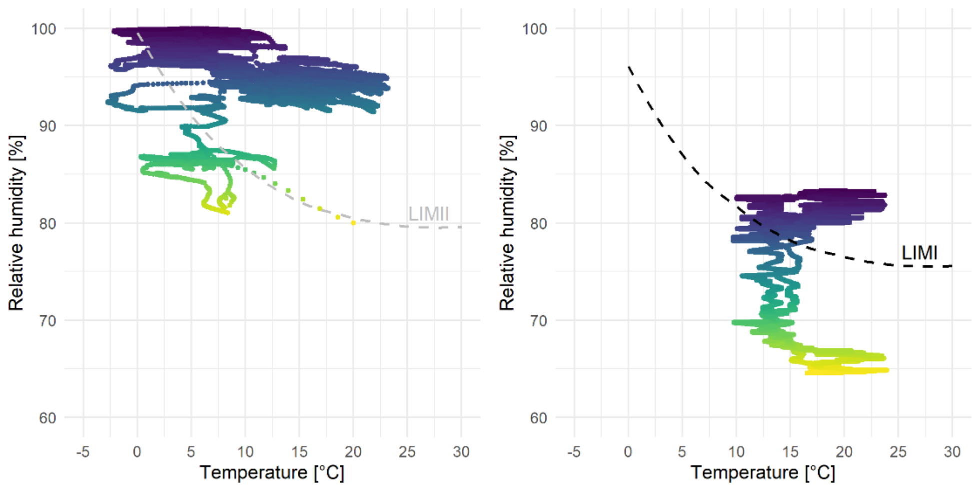

Fig. 6. Simulation results, Retrofit 1, based on WUFI (12).

A simulation period of five years was considered suitable (for both alternatives) as moisture levels converged quickly within the first year and then stayed stable.

The second retrofit alternative depends on the use of foam glass as replacement for the existing materials exempt of the concrete structure. The corresponding hygrothermal analysis was performed to assess the performance of the second alternative, used material parameters are displayed in Table 4. Isopleths, represented in Fig. 7, show high moisture content for both the insulation layer close to the concrete structure on the exterior and the insulation layer close to the gypsum layer on the interior.

Table 4. Material properties, Retrofit 2.

Nr.	Material	Bulk density [kg/m³]	Porosity [m³/m³]	Specific heat capacity [J/(kg·K)]	Thermal conductivity [W/(m·K)]	Vapor diffusion resistance [-]
1	AAC plaster	500	0.77	850	0.12	8
2	Concrete 35/45	2220	0.18	850	1.6	248
3	Aerated concrete	500	0.77	850	0.12	8
4	Foam glass	166	0.25	1000	0.05	1500000
5	Gypsum board	850	0.65	850	0.2	8.3

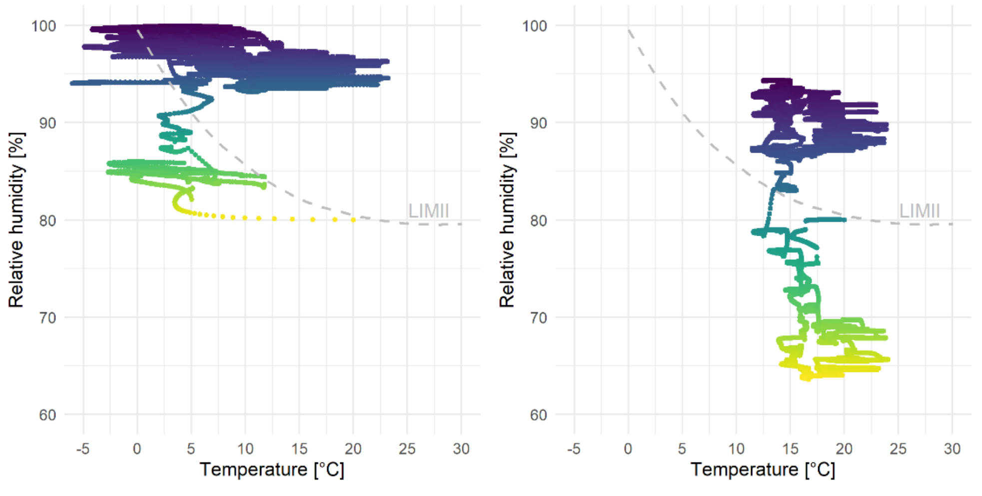

Fig. 7. Simulation results, Retrofit 2, based on WUFI (12).

6 Conclusion

Both chosen retrofit alternatives showed high moisture contents and therefore a risk for moisture-related issues such as mould growth. Thus, interior insulation was found not worth to be recommended as a preferred retrofit measure in the analysed case due to:

1) Identified moisture related problems inside the *existing* exterior walls.
2) Identified moisture related problems using proposed *theoretical* retrofit solutions based on newer and expected better performing materials, as well.

The first alternative contains wooden and therefore biodegradable elements. That means that special attention must be paid to LIM I (see Fig. 6) that represents the relative humidity limit for biodegradable materials. According to the analysis of alternative 1 in WUFI, the wood studs are above the limit line for most of the year. The mould index at 1.01 [-] states “additional criteria or investigations are needed for assessing acceptability” (WUFI software). That means that the solution is not acceptable as it is but demands further evaluation of alternative materials etc., especially as relative humidity levels at the concrete structure go up to 100 % (mould index = 5.25 [-], "usually not acceptable”).

The second alternative does not utilize any biodegradable materials and mostly relies on foam glass. Again, relative humidity levels are very high at almost 100% (mould index = 5.24 [-], “usually not acceptable”) at the concrete structure and still at around 90% (mould index = 3.95 [-], “usually not acceptable”) in the insulation layer close to the gypsum boards, which can, additionally to reducing insulation capability, compromise the gypsum boards.

Comparing both retrofit alternatives, the one utilizing the variable vapor barrier (alternative 1) shows better results with a lower risk of moisture within most of the construction. Mold growth rate and mould growth index are low and acceptable for the largest share of the insulation layer apart from a thin layer of insulation next to the concrete elements on the outside and within the wooden structure.

Future work will focus on finding alternative retrofit measures probably based on exterior insulation of the existing external walls, using preferably double-skin façade solutions, and regarding the protected status of the buildings.

Having in mind the hygrothermal performance of the existing external walls, that use *original* interior insulation, simulated alternatives were found not satisfactory due to the found risk of high moisture content inside its construction. No retrofit solutions should be implemented without a more in-depth going study regarding mycological and construction expertise of the existing building mass.

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