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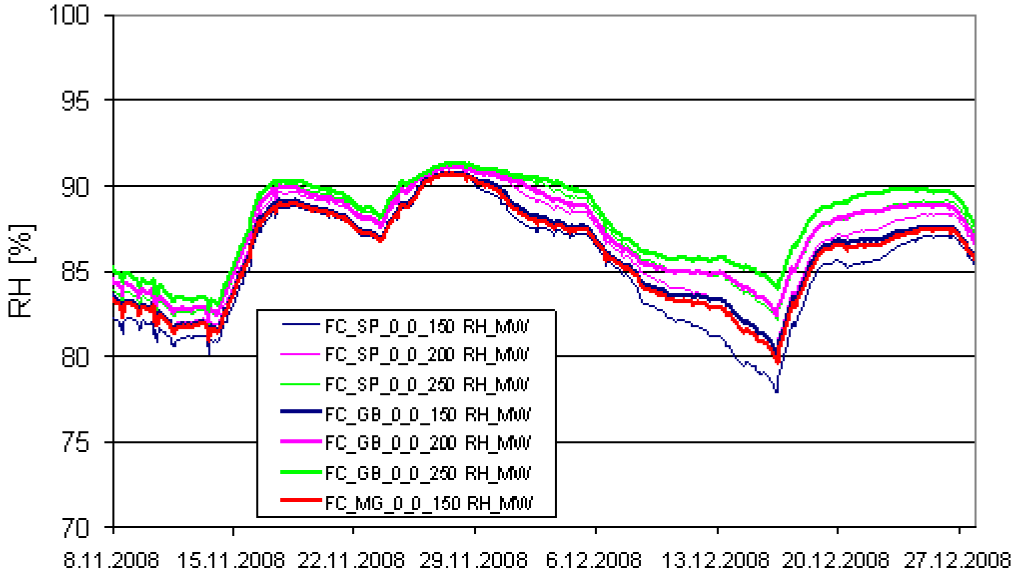

Robust

Hygrothermal performance of over-cladding solutions based on steel

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VTT

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Title

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Abstract

This report summaries the hygrothermal analysis of a steel frame retrofit system. The analysis bases on dynamic heat and moisture calculations with the Wufi Pro 4.1 VTT – program. The analysis is basically in one dimensional, but 2- and 3-dimensional effects, both for heat and moisture transport, are taken into account, when it is assumed important.

Generally, the investigated retrofit system has a good hygrothermal performance in all climates, independent on

- insulation thickness
- slight ventilation or none of the cavity between the old and new structure
- a moderate water intake e.g. from driving rain

An exception is the structure with a thin sheet steel plate on the interior side of the retrofit system. The hygrothermal performance of the structure is not acceptable unless there is a small ventilation of the cavity between the old and new structure.

The critical climates for the hygrothermal performance of the studied structure and its variations of it are cold continental climate and moderate marine climate. This result helps to concentrate further analysis on these climates. If any solution will perform in these climates, it will most probably perform in any of these others.

Preface

ROBUST - Renovation of buildings using steel technologies-project is an RFCS-funded project aiming at improved energy performance of buildings by utilisation of steel technologies. This report focuses on hygrothermal performance of an over-cladding technology suitable for renovation of concrete buildings of 1960 -. 1980.

The technology is analysed using an over-cladding system as an additional insulation system for a typical apartment building of the 1970's. The analysis focuses on the Finnish climate but the simulations were carried out as well in the cold maritime, moderate continental, moderate maritime, and warm continental climates.

Contents

1. Introduction

Buildings account for about 40 % of Europe's primary energy use, and 40 % of CO2 emissions. The total energy use in buildings was 5000 TWh (EU-15, primary energy 7000 TWh) in 2003. Residential sector is responsible of about 77 % of the energy use and related related CO_2 emissions. The emissions by country depend on energy production and industrial structure of a country, e.g., in Finland the building use related emissions are 30 % of the total.

Heating and cooling purposes account for 30 – 40 % of final energy use in buildings. The potential for saving energy by improved insulation level is high, in heating 40 – 60 % and in cooling 70 – 80% in the existing building stock.

The European Commission has recently proposed an Action Plan on Energy Efficiency with concrete measures to reach a target of reducing the EU's energy use on a business-as-usual scenario by 20% by 2020. This level can not be met without substantial investment in renovation of existing building stock, Figure 1.

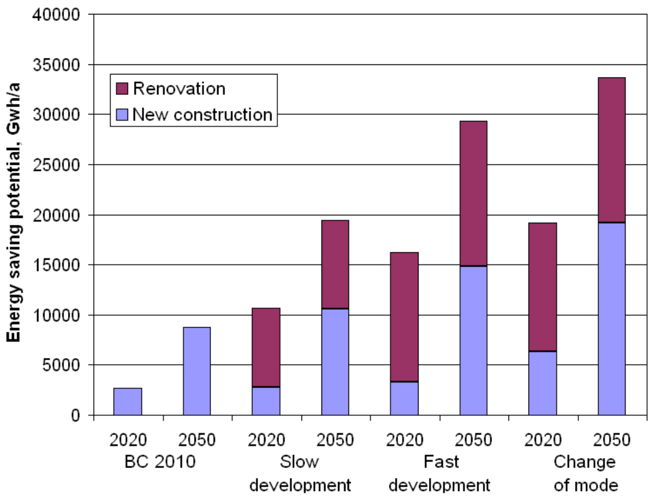


Figure 1. Development scenarios for heating energy demand of the Finnish building stock. The scenarios include the following four assumptions.
(1)Present building code refers to heating energy demand reduction by 30% in 2010 in new construction.
(2) In slow development low-energy buildings are typical in new construction by 2030, and minor energy-efficiency improvements of existing buildings concern 3,5 % of the stock per year.
(3) In fast development low-energy buildings are typical by 2015 and passive houses by 2030, and major improvements in energy-efficiency of existing buildings
(4) Change in modes of operation refers to a situation where all new buildings are passive houses, and major improvements in energy-efficiency of existing
Renovation volume is 3,5 % of the stock a year, new construction 1 – 1,5 % a year, and demolishing rate 1 % a year. The analysis shows that major improvements in existing buildings are required if the aim is to reduce energy use by 20% until year 2020.

Renovation market is growing throughout the Europe, Figure 2. Improvement of energy-efficiency is economically more viable if connected to other improvements of buildings. Typical problems of a Finnish apartment house of 1970's are given in Figure 3. Energy efficiency measures do not always reduce the energy demand. In old buildings indoor air quality is often poor, and the energy savings by implementation of various technologies may cover up the increased energy demand of ventilation. The profitableness of renovation depends also on the relationship between values and costs, and therefore, also improved durability, increased safety and healthiness, appearance and visual impacts of renovation need to be considered.

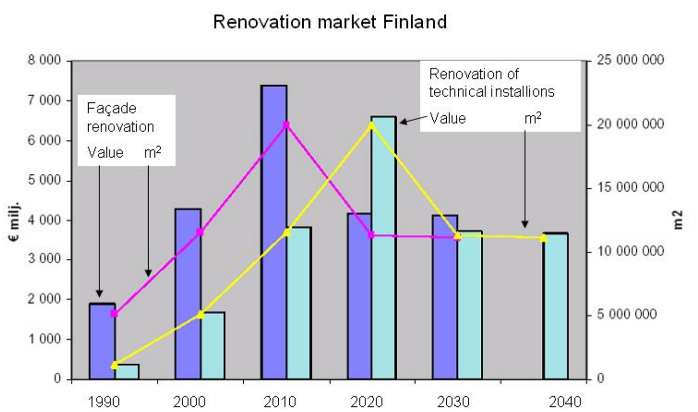


Figure 2. Estimated volume of renovation market in apartment buildings.

Figure 3. Apartment house of the 1970's.

The aim of hygrothermal modelling was to ensure a proper performance of the renovation technology in steel. Impacts of energy-efficiency improvements on hygrothermal performance of exterior all structures were analysed using dynamic thermal and moisture simulations. The analysis focus on the Finnish climate but the simulations were carried out as well in the varying climate conditions in Europe.

2. Simulation applications for moisture simulations

The moisture performance analysis of building structures was carried out using numerical simulation using WUFI Pro 4.1 VTT simulation model. The analysis is basically in one dimension, but 2- and 3-dimensional effects, both for heat and moisture transport, are taken into account, when it is assumed important. This report summaries the hygrothermal analysis of a steel frame retrofit system.

The outdoor climates used in the analysis were

- Cold continental (e.g. Moscow) - CC
- Cold maritime (e.g. Riga) - CM
- Moderate continental (e.g. Berlin) - MC
- Moderate maritime (e.g. London) - MM
- Warm continental (e.g. Bucharest) - WC

Solar and long wave radiation, wind and driving rain were analysed in the simulations.

3. Hygrothermal performance of retrofit steel wall system

3.1 Scope

This report summaries the hygrothermal analysis of a steel frame retrofit system. The analysis is based on dynamic heat and moisture calculations with the Wufi Pro 4.1 VTT – program. The analysis is one dimensional, but 2- and 3-dimensional impacts, both for heat and moisture transport, are taken into account, when it is assumed important.

3.2 The analysed frame system

The analysed system is in Figure 4, mounted on an existing concrete wall. The cross section of the analysed system is also illustrated in Figure 5. A rain screen of sheet steel façade protects the system from outdoor climate. A typical use of the system is in renovation of old concrete sandwich façades. The exterior concrete layer is dismantled. Therefore, the surface for mounting the system is usually not perfectly even.

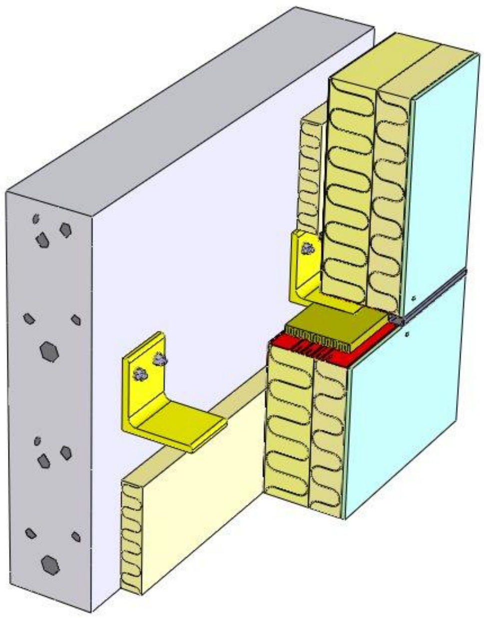
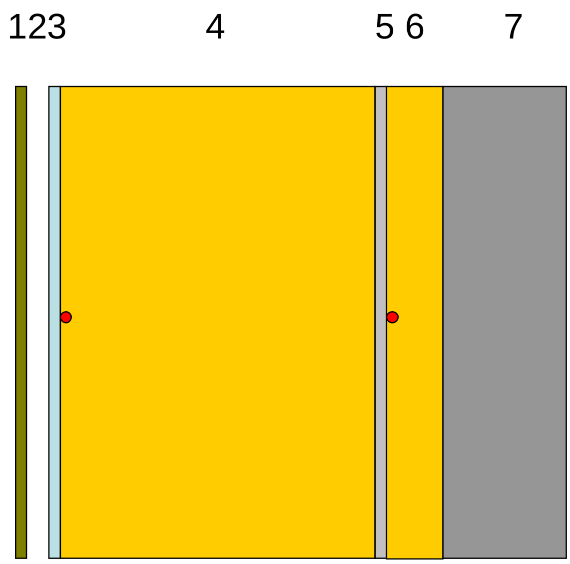


Figure 4. 3D view of the retrofit system

The analysed structure has a ventilated facade with a rain screen. The impacts of different types of rain screens were not analysed. However, a limited parameter analysis on the colour and orientation and risk analysis on the penetration of driving rain in the cavity was carried out.



1. Rain screen facade
2. Ventilated air gap 20 mm
3. Windproof layer, 2 options
    - GB: gypsum board 9 mm
    - FC: fibre cement board 4 mm
4. Mineral wool insulation – 3 options:
    - 150 mm/200 mm/250 mm
5. Inner board – 3 options
    - SP: sheet steel 0,6 mm
    - GB: gypsum board 13 mm
    - MG: metal grid
6. Non-ventilated cavity 50 mm
7. Existing concrete wall 160 mm

● Calculation points

Figure 5. Cross section of the analysed facade system.

Other assumptions include:

- Sufficiently airtight installation of the system on old façade
- No cracks in the old façade (= no air flow from interior)
- Resistance to water vapour transfer on interior side S_d=1
- Good functionality of ventilated facade (> 100 ach)
- Colour of facade (=dark)
- Orientation (=south)

Indoor temperature and humidity level is based on definitions in EN15026 and corresponds to normal activity. This means that temperature is freely floating between 20 and 25 ^{o}C and relative humidity between 30 and 60 %, both depending on the exterior temperature. The outdoor conditions base on reference years in different locations. Following climatic zones – with short names too– were analysed:

- Cold continental (e.g. Moscow) - CC
- Cold maritime (e.g. Riga) - CM
- Moderate continental (e.g. Berlin) - MC
- Moderate maritime (e.g. London) - MM
- Warm continental (e.g. Bucharest) - WC

The most comprehensive study was made for the cold continental climate. On the basis of these results, potential problems for other climates were studied. The model takes into account both long and short wave radiation and driving rain.

3.3 Indicators for performance and robustness of the system

The performance of the system was studied by calculating and analysing

- Relative humidity (RH, %) of the critical boundaries: exterior side of insulation and the layer between the old and new construction
- moisture accumulation risk Δ w (kg/m^3) in retrofit insulation

The location of these parameters in the system is illustrated in Figure 6. The relative humidity was recorded as hourly values on the exterior side of the exterior insulation system, and the interior surface of the interior board of the wall system. Also, the robustness of the system on imperfections was studied and the variables are:

- Ventilation rate of the non-ventilated cavity:
    - o $n = 0\ h^{-1}$
    - o $n = 1\ h^{-1}$
- Driving rain 8DR9leakage into the non-ventilated cavity (together with above ventilation options):
    - o DRL = 0% of DR
    - o DRL = 1% of DR

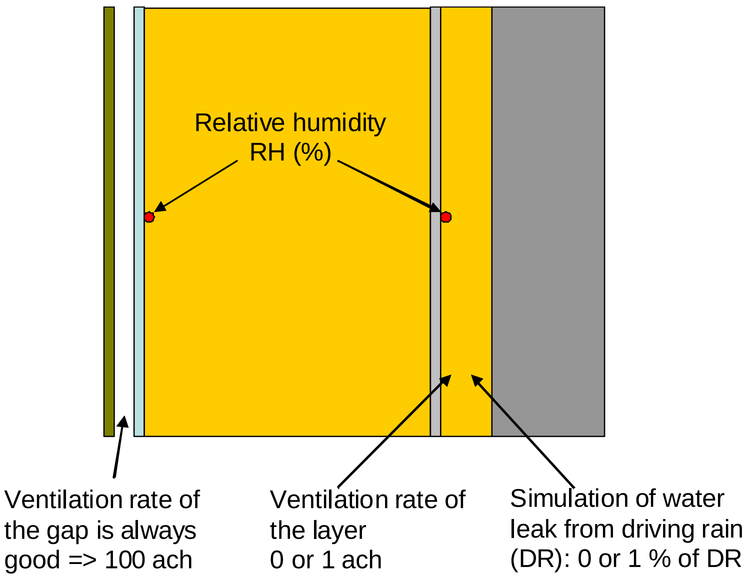


Figure 6. Performance parameters and robustness of the system on imperfections

The ventilation rate and access of the driving rain to the cavity between the old and the new construction are potentially interesting parameters in this study. When mounting the retrofit system, the system is sealed to the old façade and – at least in theory and on the drawing table – this cavity can be assumed as non-ventilated with no access for driving rain. The consequences of possible imperfections in the sealing were studied, and the robustness of the system to imperfections was analysed with the parameters given above. In the cavity, there are strips of mineral wool insulation around the perimeter of a wall element and across it. This reduces also the internal convection in the cavity. On the basis of assumptions on a crack size in the sealing and the existing air pressure potentials, it was estimated that the maximal air exchange rate in the cavity would be 1 ach (air changes per hour).

3.4 Impact of thermal bridges

The focus in this report is on the moisture performance of the retrofitting system. However, There is a minor thermal bridge due to the frame of the system: a C-profile of perforated steel. A detailed cross section of the studied construction is in Figure 7. The thermal conductivities used in the calculations are in the figure.

HEAT2 software was used for the 2-dimensional calculations. The effective thermal conductivity of the perforated C-profile is assumed to be 6 W/mK, based on the results of the RFCS Project MEGA5 carried out in 1995 - 1998.

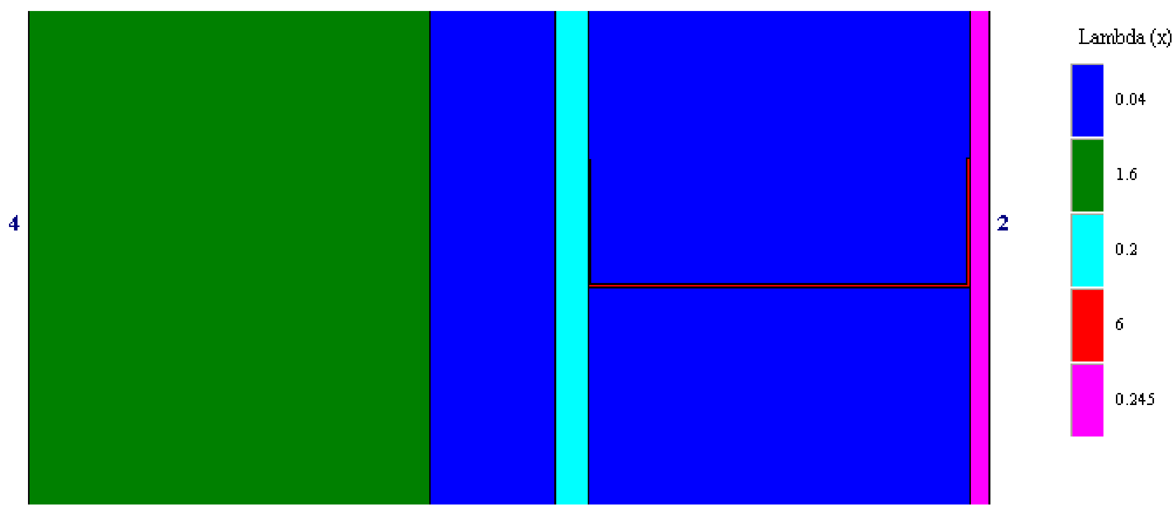


Figure 7. Detailed cross section of the 2D-model of the thermal bridge

3.5 Calculation results

The performance indicators were listed in the previous chapter and were illustrated in Figure 6. One part of the performance deals with the relative humidity and moisture content of the insulation of the wall system. For a good performance, the relative humidity may not be too high, above 80%, for extended periods due to risk for, e.g., biological growth. No accumulation of moisture in the insulation is allowed. Also, the relative humidity between the old structure and the retrofit system may not be above 80 % for extended periods. The worst case scenarios were simulated for relative humidity on the cold side of the layer.

The results are therefore given separated for wall system insulation

- RH according to time (RH(t)) for different solutions
- Maximum RH as a simple indicator for comparing the solutions
- Change in moisture content during the 3rd year gives moisture accumulation risk or drying potential

and the cavity between the old and the new structure

- RH(t) for different solutions
- Max RH as a simple indicator for comparing the solutions
- Role of the ventilation rate and the effect of water intake

The 3rd year of simulation was used for analysis, as it is normally an effective calculation period for this kind of structure to achieve so-called quasi-steady conditions, i.e. conditions that are more or less the same every year.

The names of the cases in the results are given with following nomenclature:

(climate_)exterior side_interior side_ventilation rate_driving rain leakage

E.g., CC_FC_GB_1_0 stands for fibre cement on exterior and gypsum board on inner side of the retrofit system in cold continental climate, and the cavity between the old and the new structure is ventilated at 1 ach, and no rain penetration. Insulation thickness is also given, e.g., 150mm. An overview of possible parameter variations are given in Table 1.

Table 1. Parameter variations. NOTE: This is an original gross list, and all the cases were not simulated, as the results became clear enough even without them.

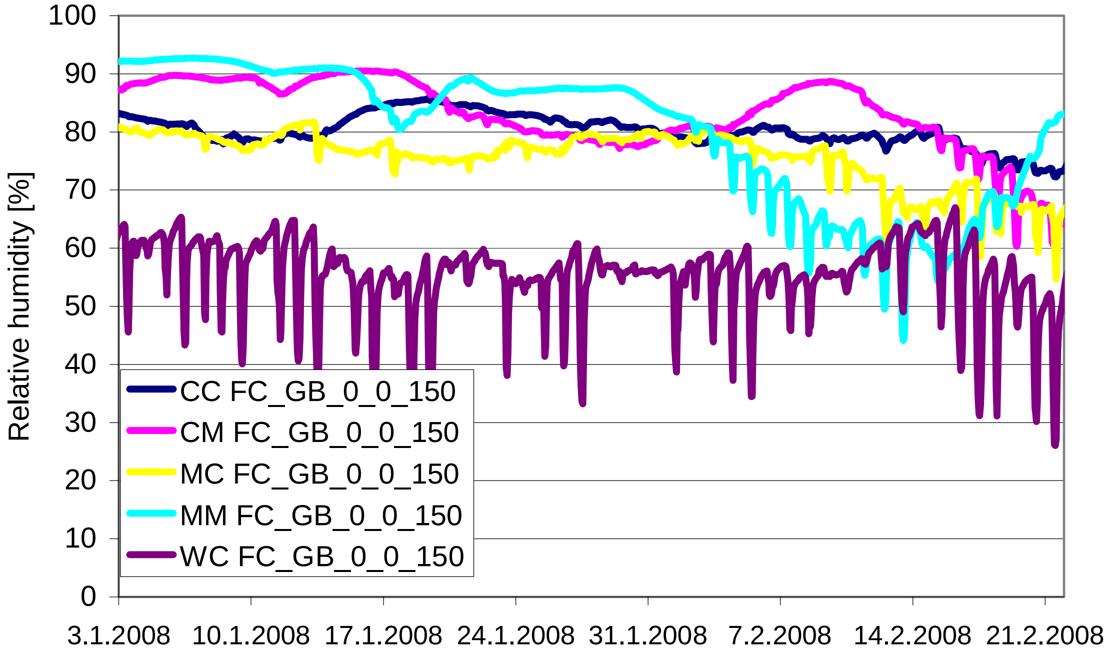
exterior side	interior side	ventilation rate	driving rain leakage
GB_	SP_	0 ach	0 % of DR
GB_	GB_	0 ach	0 % of DR
GB_	MG_	0 ach	0 % of DR
FC_	SP_	0 ach	0 % of DR
FC_	GB_	0 ach	0 % of DR
FC_	MG_	0 ach	0 % of DR

GB_	SP_	1 ach	0 % of DR
GB_	GB_	1 ach	0 % of DR
GB_	MG_	1 ach	0 % of DR
FC_	SP_	1 ach	0 % of DR
FC_	GB_	1 ach	0 % of DR
FC_	MG_	1 ach	0 % of DR
GB_	SP_	0 ach	1% of DR
GB_	GB_	0 ach	1% of DR
GB_	MG_	0 ach	1% of DR
FC_	SP_	0 ach	1% of DR
FC_	GB_	0 ach	1% of DR
FC_	MG_	0 ach	1% of DR
GB_	SP_	1 ach	1% of DR
GB_	GB_	1 ach	1% of DR
GB_	MG_	1 ach	1% of DR
FC_	SP_	1 ach	1% of DR
FC_	GB_	1 ach	1% of DR
FC_	MG_	1 ach	1% of DR

The variation of the cases was largest for calculations in cold continental climate, e.g., for Moscow, and these results were used for parameter analysis. The impact of the climate on the results was one of the parameter variations.

3.5.1 Impact of climate

First the performance of identical structures in different climates were studied. Figures 8 and 9 show hourly values of selected but representative periods of the year. Figure 8 a and b show the relative humidity on the cold side of the insulation layer and Figure 9 a and b show the relative humidity in the non-ventilated cavity.



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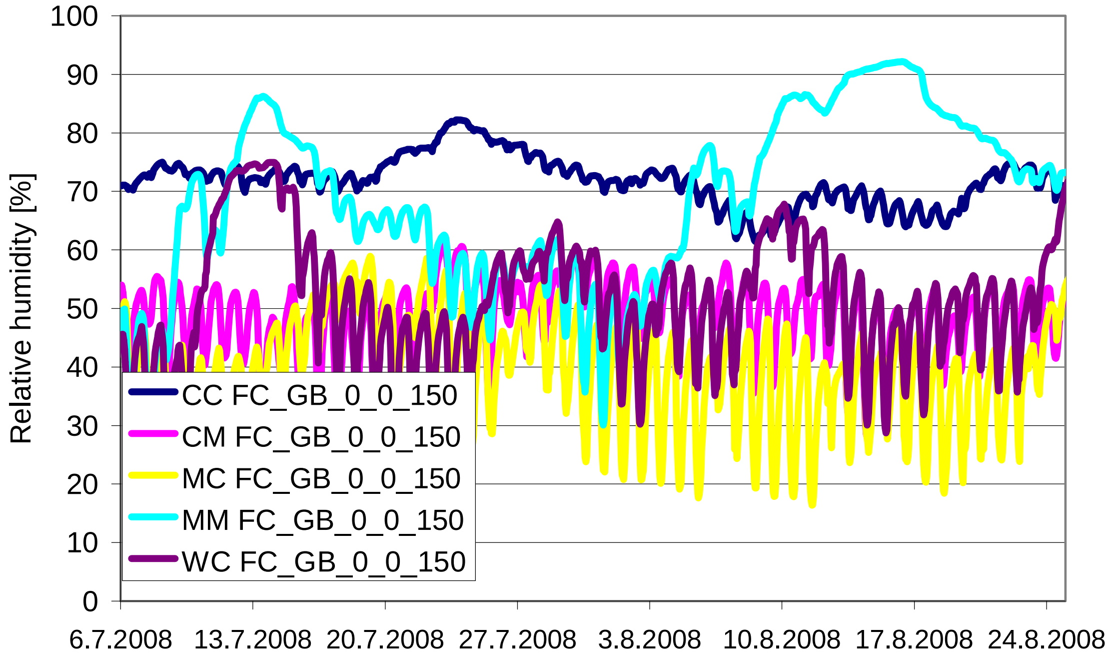
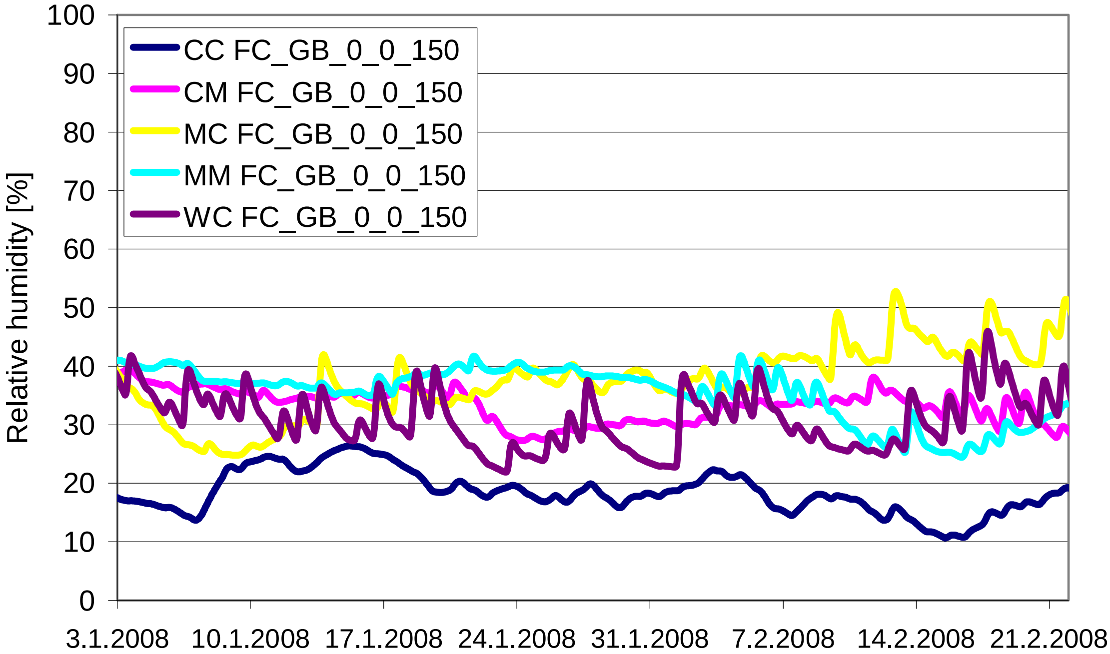


b)

Figure 8. Simulated hourly values of relative humidity RH. Structure with fibre cement and gypsum boards. Insulation thickness 150mm. a) RH on the cold side of mineral wool, winter case, b) RH on the cold side of mineral wool, summer case.



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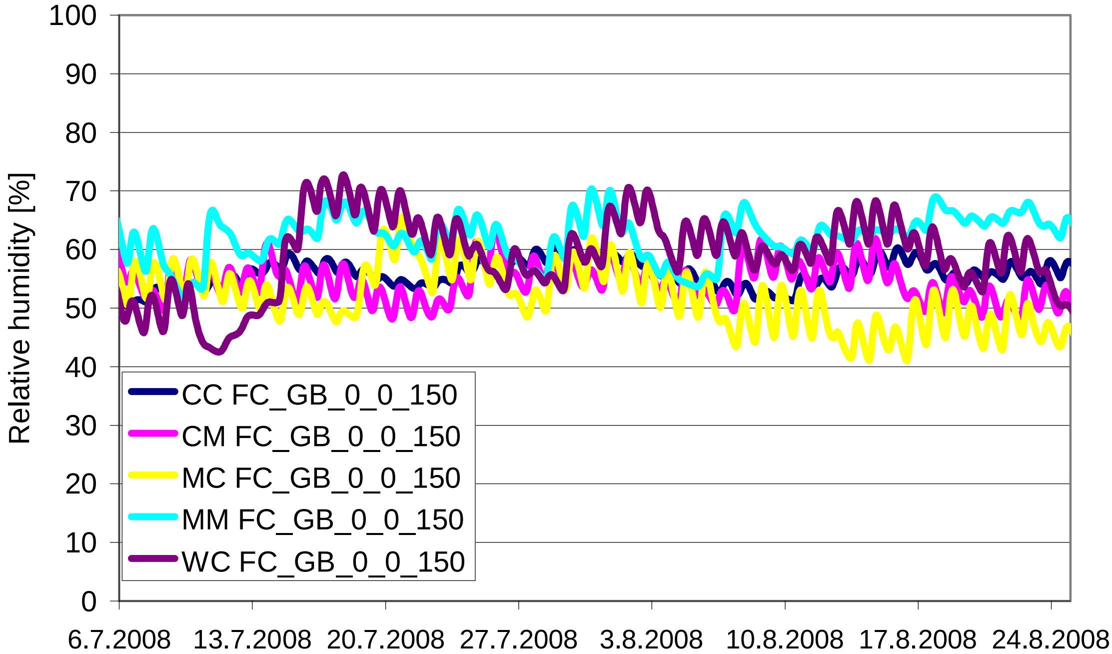

b)

Figure 9. Simulated hourly values of relative humidity RH. Structure with fibre cement and gypsum boards. Insulation thickness 150mm. a) RH in the cavity, winter case, b) RH in the cavity, summer case

The simulation results show that for a relatively diffusion open structure, the air humidity in the non-ventilated cavity is not too high in any of the studied climates. The relative humidity of the cold side insulation, on the contrary, can become rather high for all climates but warm continental. The high humidity and low temperature in winter is not as critical as high relative humidity in summer. Figure 9b gives an indication that the solution should be carefully designed in cold continental as well as moderate marine climates.

3.5.2 Impact of insulation thickness and diffusion resistance

The results of structure comparisons with different insulation thicknesses and a diffusion open inside board of the retrofit system (gypsum board GB) or diffusion tight plate board (sheet steel SP) are in Figure 10. Both yearly average values and maximum values are given.

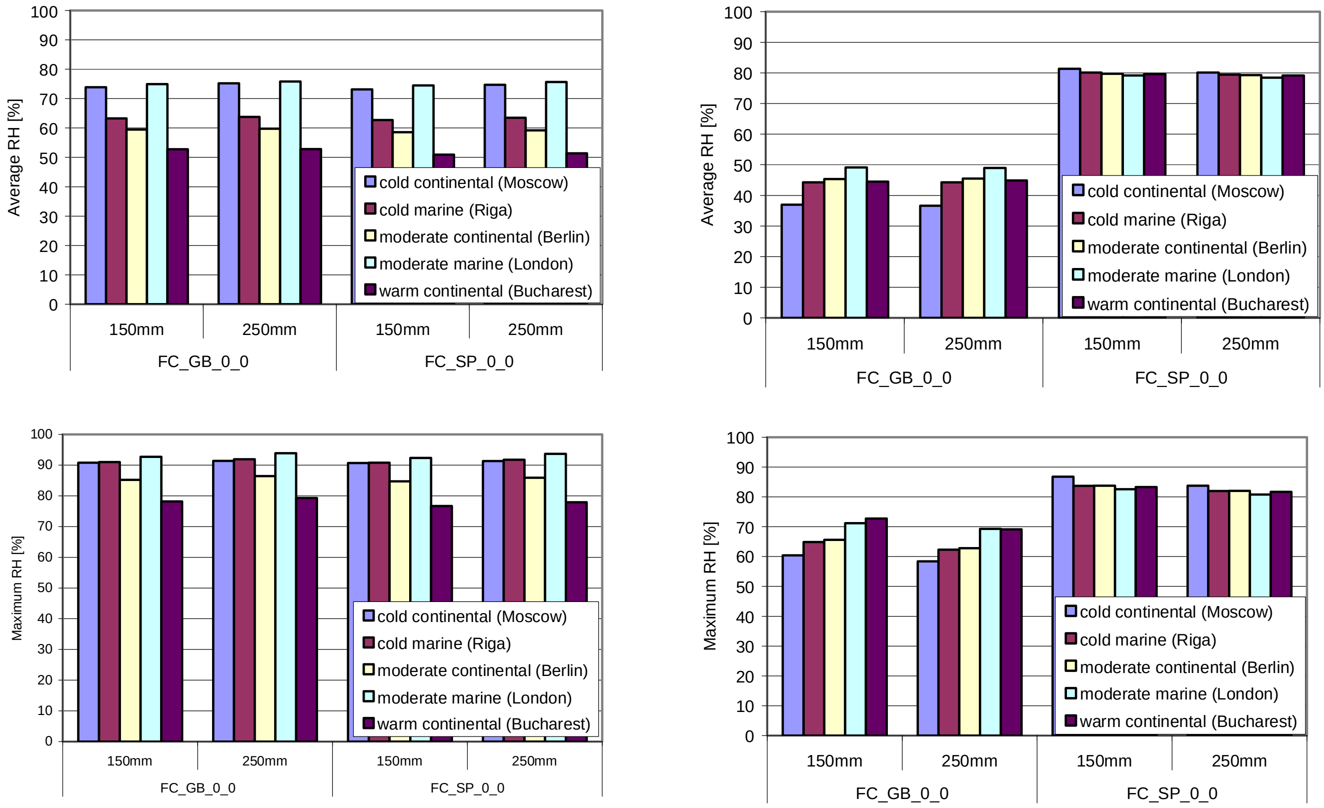

Figure 10. Yearly average and maximum values of relative humidity (RH). Comparison of different climates, role of insulation thickness together with choice of inner board of the retrofit system. a) Average RH in the retrofit insulation , b) Average RH in the cavity, c) Maximum RH in the retrofit insulation and d) Maximum RH in the cavity.

Insulation thickness play almost no role for the hygrothermal performance of structures. The diffusion resistance of the inner board of the retrofit system plays a big role for all the climates. The problems for the sheet steel solutions occur typically in the non-ventilated cavity: The old structure of concrete (assumed with no cracks) is still more diffusion open than a sheet steel layer, and therefore the relative humidity of the cavity will raise.

The properties of the inner board of the system plays also a role for the moisture accumulation vs. drying potential of the retrofit insulation: Figure 11 shows the drying potential of the structure in all climates when the inner board is diffusion open. The sheet steel plate board structure causes accumulation of moisture in most climates. Insulation thickness of the diffusion open structure increases the drying potential in all climates.

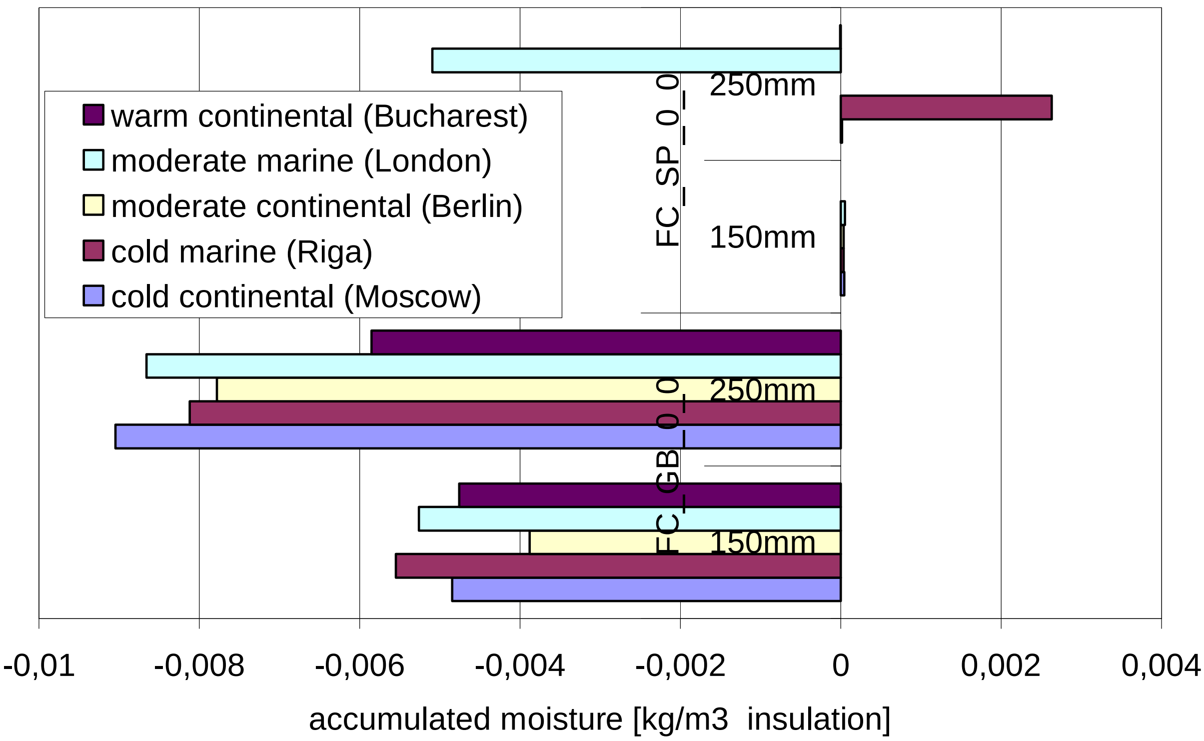

Figure 11. Accumulated moisture in the retrofit insulation. Negative moisture accumulation = Drying potential.

More detailed analysis of the role of insulation thickness and the different choices of inner boards of the retrofit system was carried out for cold continental climate. Figure 12 shows relative humidity on the cold side of the retrofit insulation. Relative humidity increases for increasing thickness, and it is higher for gypsum board solution than for sheet steel solution. Solution with only metal grid on the warm side of the retrofit gives practically same hygrothermal results as with gypsum board. In all cases, there is a fibre cement board on exterior side.

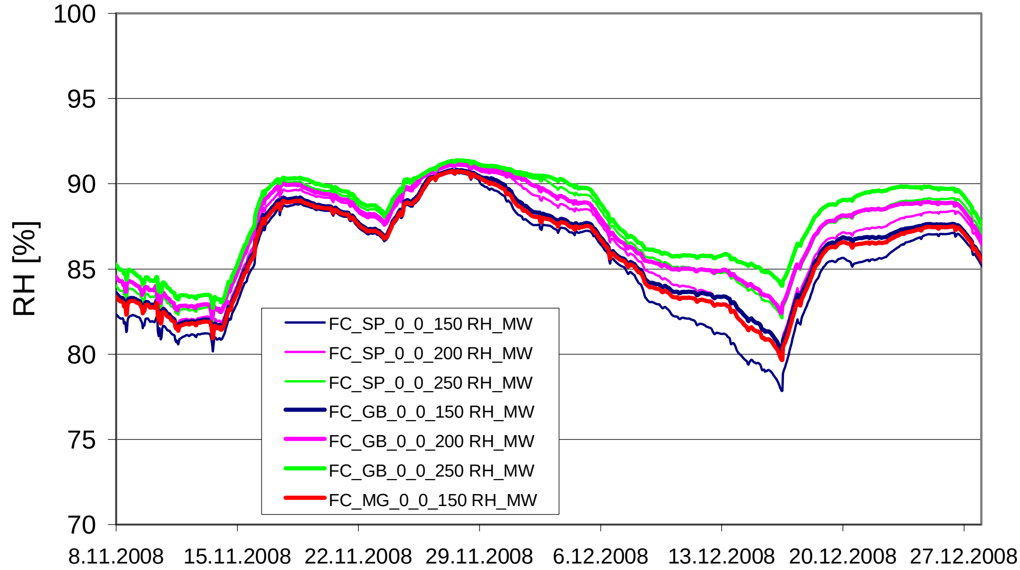

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Figure 12. Relative humidity on the cold side of the rterofit insulation. Effect of thickness and inner board in cold continental climate.

3.5.3 Impact of ventilation of the non-ventilated cavity

The analysis so far has given indications for potential problems with the solution with sheet steel on the inside of the retrofit insulation in cases the structure is extremely airtight with no ventilation in the cavity between the retrofit and existing wall. Ventilated (1 ach) cavity helps to dry out the structure, Figure 13. For the slightly ventilated cavity, the structure dries due to increasing insulation level.

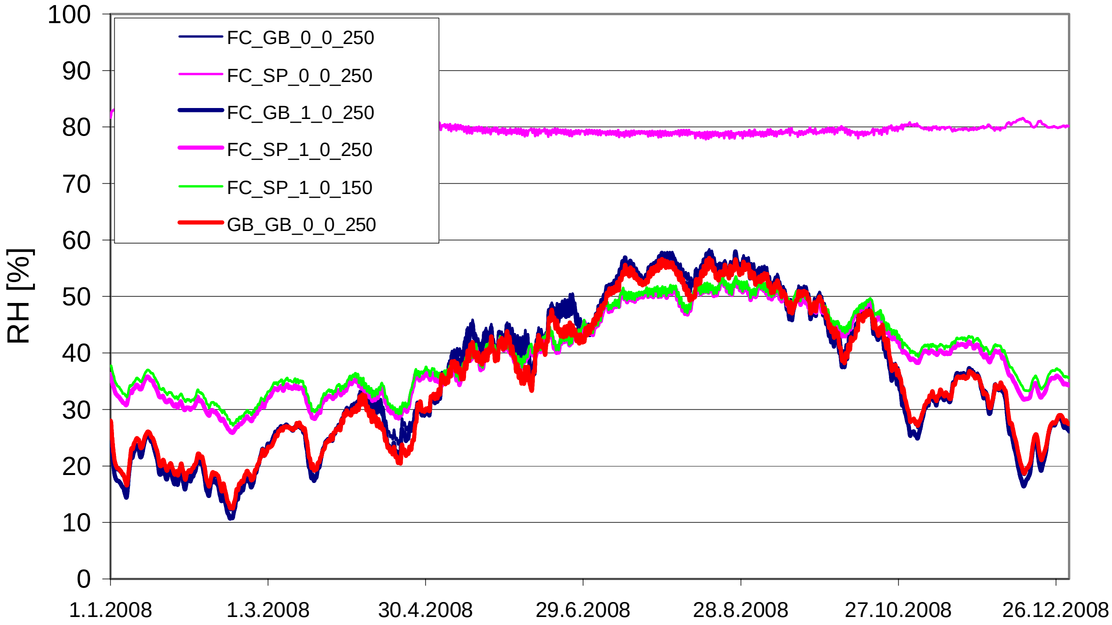
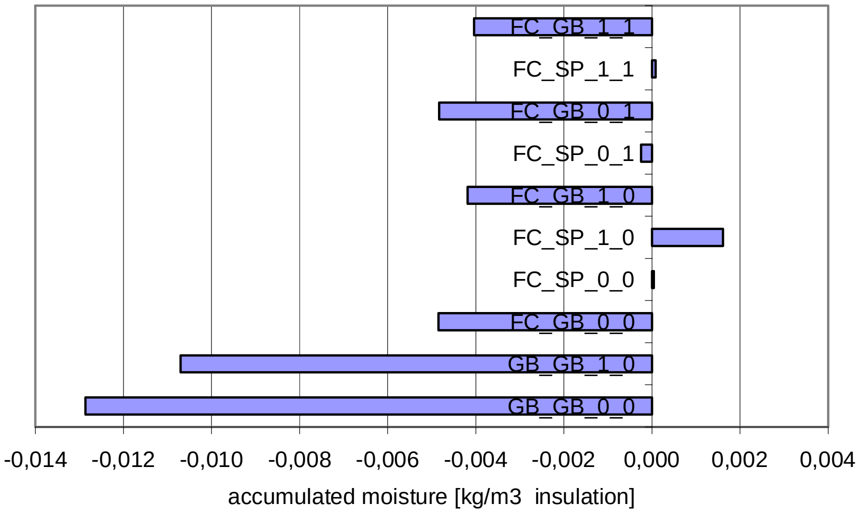


Figure 13. RH in the cavity between old and new construction. Cold continental climate.

If the retrofit structure has gypsum board on both sides, there is hardly no effect of insulation thickness or ventilation rate of cavity. The diffusion open structure with a well ventilated cavity on the exterior side will perform satisfactorily. Increasing insulation thickness improves the conditions marginally.

The results of a parametric analysis of impact of a small ventilation of the cavity and at the same time the potential risk of rain penetration and drying potential, results from parameter analysis are in Figure 14 a and b.

The results show that gypsum board on exterior is better for drying capacity than fibre cement board. The small ventilation of the cavity reduces the drying capacity of the retrofit insulation due to reduced temperature. Structures with sheet steel have minimum of drying capacity and in the case with ventilation of the cavity, moisture will accumulate in the insulation. In general, drying capacity increases for increasing insulation thickness. Figure17b shows how the maximum relative humidity of the insulation increases slightly for increasing insulation thickness. On the other hand, there is no difference in relative humidity in the insulation if the interior side of the retrofit system is gypsum board or sheet steel, or whether there is ventilation in the cavity or not. The maximum relative humidity is higher if exterior side is gypsum board compared to fibre cement board. Ventilation of the cavity has a minor positive effect for the solutions with gypsum board on both sides.



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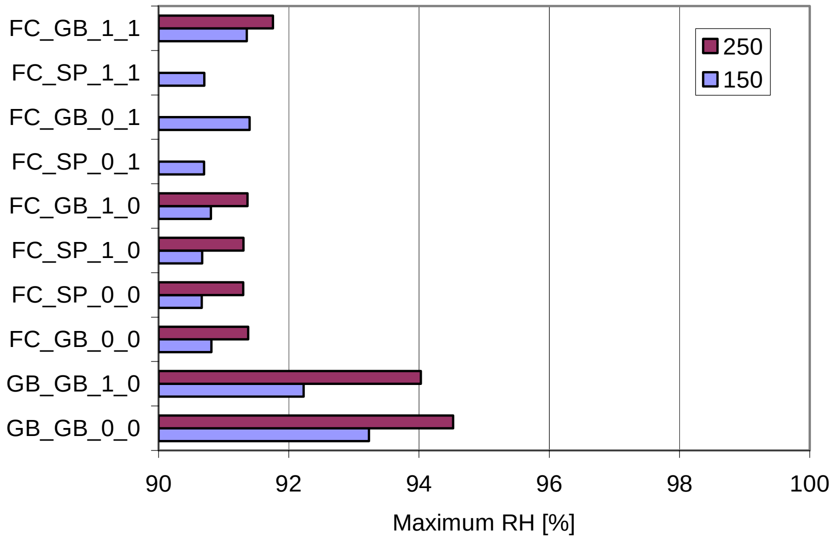

b)

Figure 14. Retrofit insulation. Cold continental climate. a) Accumulated moisture. Insulation thickness 150 mm. Impact of inner board, ventilation and rain penetration. Negative moisture accumulation = Drying potential. b) Maximum relative humidity.

A small ventilation of the cavity reduces the relative humidity of the cavity dramatically for the structure with sheet steel for all cases Figure 15. For other structures, ventilation gives almost no effect or a slight increase in already low relative humidity. If there is e driving rain penetration in the structure, the peaks in relative humidity increases for all structures – and the ventilation of the cavity has only a very little impact, except for the structure with the sheet steel on the inside of the retrofit system.

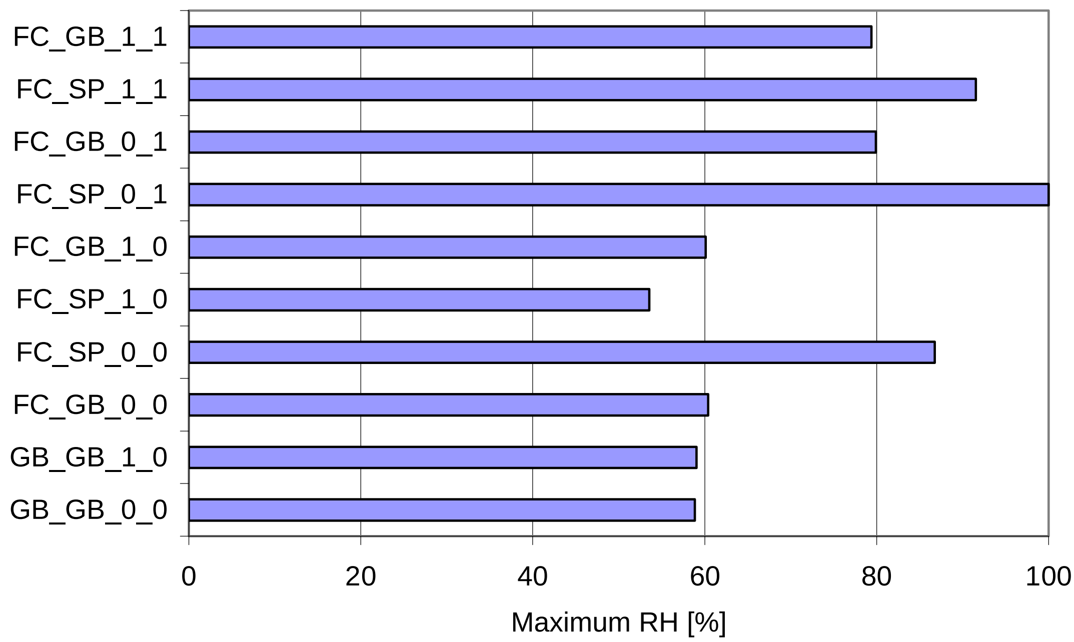

Figure 15. Maximum RH in the cavity. Insulation thickness 150 mm. Cold continental climate.

3.5.4 Impact of thermal bridges

The thermal bridge effect as a result of the 2D calculation is in Figure 16. The temperature on the inner side of the gypsum board of the retrofit system is about 14,5 ^{o}C when there is no thermal bridge, and about 12,1 ^{o}C on top the C-profile for a case with indoor temperature is 20 ^{o}C and outdoor temperature 0 ^{o}C.

The impact of a thermal bridge on the hygrothermal performance in a dynamic case is calculated with Wufi, in cold continental climate. The results are in Figure 17. The relative humidity will be higher behind the thermal bridges but it will not be an explanation for any performance problem, as the difference is very little when the RH is highest. Also, the temperature behind the thermal bridge is lower, which again reduces the risk for any biological growth.

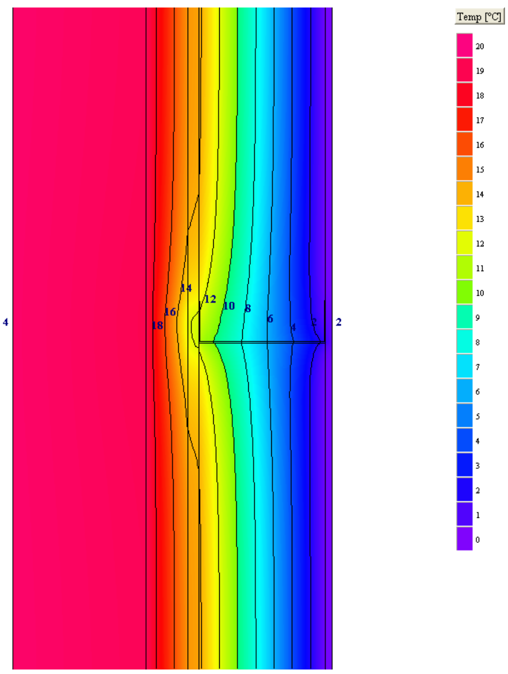

Figure 16. Isotherms showing the thermal bridge effect of the C-profile

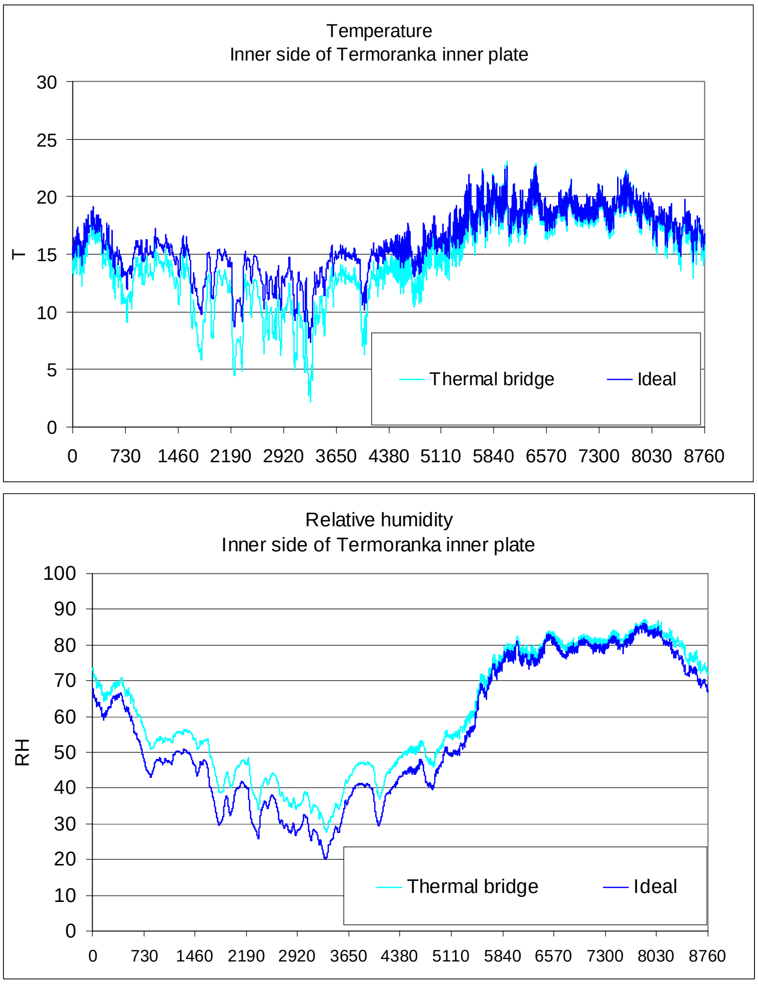

Figure 17. Effect of thermal bridge on temperature and relative humidity.

3.6 Conclusion

Generally, the investigated retrofit system has a good hygrothermal performance in all climates, independent on

- insulation thickness
- slight ventilation or none of the cavity between the old and new structure
- a moderate water intake e.g. from driving rain

An exception is the structure with a thin sheet steel plate on the interior side of the retro-fit system. The hygrothermal performance of the structure is not acceptable unless there is a small ventilation of the cavity between the old and new structure.

The critical climates for the hygrothermal performance of the studied structure and its variations of it are cold continental climate and moderate marine climate. This result helps to concentrate further analysis on these climates. If any solution will perform in these climates, it will most probably perform in any of these others.