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Renovation of brick buildings constructed 1870-1930

Investigation of the thermal envelope in renovated and re-renovated dwellings

Master's Thesis in the Master´s Programme Structural Engineering and Building Technology

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Cover:
Brick wall from one of the studied buildings.

Name of printer or Department of Civil and Environmetal Engineering.Göteborg, Sweden, 2016

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ABSTRACT

Due to low degree of renovation of brick buildings constructed 1870-1930 and higher demands regarding the energy performance of buildings based on environmental goals, it is of interest to evaluate how to renovate this building type to the aim of this study. Some renovations have been conducted, but there has been insufficient follow-up of the status of these renovations. It is therefore also of importance to evaluate what type of further improvement that should be performed. In this study, literature research and study visits to buildings representative for the selected type of houses have been followed through to evaluate renovation strategies performed on the inspected buildings. The aspects used to evaluate the renovation are energy consumption, U-value, moisture risks and the aesthetics of the building, before and after the renovation. Simulations of energy and moisture performance and calculations of energy savings was done as evaluation.

The study visits confirmed what could be identified in the literature, through the fact that observed building techniques correlated to the ones in the literature. Differences in some details were noted when comparing the buildings, but the details could be identified in descriptions of the specific building type supplied in the literature. Typical for the investigated brick buildings is that they have homogenous load bearing outer walls made of brick and floor slabs made of timber. Both red and yellow bricks are used. The foundation walls are commonly constructed with a combination of bricks and dry stone walls or only bricks. The roof trusses and roof construction offers space which could possibly be converted from storage and unused attic space to apartments.

Efficient renovations conducted to prevent moisture risks, are to cover the outer walls to protect them from rain or to replace the timber in the details of the outer walls with non-organic material. Results show that it is also possible to improve the conditions for details where brick meets timber by filling the air cavities with polyurethane foam, but this requires further investigations. According to energy consumption and U-value, a conversion of the attic into apartments and insulation of at least one of the external wall could in combination provide an efficient result. Considering the aesthetics, efficient strategies can preserve the design and architectural ideas of the building.

Key words: Renovation, re-renovation, brick buildings, construction period 1870-1930, thermal envelope, moisture problems, energy consumption, U-value, aesthetics

Renovering av tegelbyggnader byggda 1870-1930
Undersökning av klimatskalet i renoverade och återrenoverade bostadshus

Examensarbete inom masterprogrammet Structural Engineering and Building Technology

Lukas Lång
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SAMMANFATTNING

På grund av låg renoveringsgrad på tegelbyggnader byggda kring 1870-1930 och högre krav gällande energiprestanda baserade på miljömål, är det relevant att utvärdera hur denna byggnadstyp kan renoveras. Renoveringar har genomförts, men på grund av bristfällig uppföljning av statusen på renoveringarna, är det också viktigt att utvärdera vilken andra, efterkommande renovering som kan göras. I det här arbetet har litteraturstudier och studiebesök vid objekt, som representerar vald hustyp, gjorts för att utvärdera renoveringsstrategier som genomförts på de studerade byggnaderna. Faktorerna som används för att utvärdera renoveringsmetoderna är energiförbrukning, U-värde, fuktrisker, och estetik av byggnaden före och efter renovering. Simulering av värmetekniska och fuktegenskaper samt beräkning av energibesparing utfördes som utvärdering.

Studiebesöken bekräftade vad som kunde hittas i litteraturen. Observerade byggnadstekniker överensstämde med de som hittats i de litterära källorna. Skillnader i detaljer noterades, när objekten jämfördes med varandra, men detaljerna kunde hittas i beskrivningarna som litteraturen förmedlar om byggnadstypen. Utmärkande för tegelbyggnaderna som undersöktes är att alla har homogena, bärande ytterväggar av tegel och bjälklag av trä. Både rött och gult tegel användes. Grundmuren är vanligtvis uppbyggd av en kombination av tegel- och stenväggar eller bara tegelväggar. Takstolarna och takkonstruktionen ger möjlighet till utrymmen som är möjliga att göra om från förråd eller outnyttjad vind till lägenheter.

Effektiva renoveringar med avseende på fuktrisker är att skydda den yttre väggen från regn eller att byta ut träet i detaljerna i ytterväggarna till oorganiskt material. Resultat visar att det är möjligt att förbättra villkoren i detaljer där tegel möter trä genom att fylla luftspalter med polyuretanskum, men det kräver vidare undersökning. I syfte att förbättra energiförbrukning och U-värde är det effektivt att konvertera vinden till lägenheter i kombination med att isolera åtminstone en av fasadsidorna. En effektiv och bra renovering tar hänsyn till estetiken och bevarar byggnadens arkitektoniska drag och uttryck.

Nyckelord: Renovering, återrenovering, tegelhus, byggnadsår 1870-1930, klimatskal, fuktproblem, energiförbrukning, U-värde, estetik

Contents

Preface

This thesis is a part of the project "*Re-renovation: Possibilities for increased energy efficiency and the re-creation of cultural historical values*". The project is financed by Swedish Energy Agency's Programme Save & Preserve.

We would like to thank our supervisors Pär Johansson and Paula Wahlgren, Skanses Fastigheter, Familjebostäder and everyone else that spent time with us and our study visits.

Göteborg, June 2016.

Lång and Sandgren.

Notations

Below some of the terms and expressions are collected from the report and shortly described

Terms and expressions

Boverket	The Swedish National Board of Housing, Building and Planning
Capillary suction	Transport of liquids in the pores of a material
Condensation	When the vapour content reaches the saturated vapour content, the vapour transforms into liquid phase.
Conduction	Heat energy transport through a material
Convection	Transport of gas, either forced or driven by the density or the pressure.
Diffusion	Vapour is transported from higher vapour content to lower vapour content.
Energimyndigheten	The Swedish Energy Angency
Energy class	Classification system based on percentage of energy performance of a building. Energiklass in Swedish.
Energy Performance Certificate (EPC)	A document stating the amount of energy a building consumes. Energideklaration in Swedish.
Länsstyrelsen	The Swedish governmental County Administrative Board.
Mould growth index	Index, 1-6, showing if a risk of mould growth occur.
Radiation	Heat transfer through electromagnetic radiation between surfaces
Rain water absorption factor	The part of the rain water that is available to enter the material through capillary suction. 0 is no absorption and 1 is 100% absorption.
Relative humidity, RH	The ratio of vapour content and saturated vapour content in the air.
Skatteverket	The Swedish governmental tax agency.
Steady state	Constant boundary conditions.
Thermal conductivity	Property of the heat energy transport in a material, λ [W/m*K], sum of convection, radiation and conduction.
Thermal envelope	The materials and the structure

	separating the inner climate from the outer climate in a building.
Transmission loss	Heat loss through the thermal envelope.
U-value	The amount of effect that is transferred through one square meter per difference Kelvin.
Value age	Värdeår in Swedish. If a building is renovated, the value year is counted as the corresponding construction year. The value indicates the degree of renovation

1 Introduction

The Swedish parliament has stated that the energy consumption should be decreased by 20% compared to 2008 (Naturvårdsverket, 2015). Residential buildings and services stands for 40% of the total energy use (Naturvårdsverket, 2015). Directive from EU that energy performance of buildings from 2021 shall be reduced implies that changes need to be made (Regeringskansliet, 2014). Similar methods to affect the energy consumption of the building stock can be detected in history and have been used before (Antell and Paues, 1981). This indicates that the performance of houses regarding energy use, need to be continuously investigated and improved through different kinds of renovations and that the different types of renovations differ throughout the decades. This can also be confirmed to some extent, since follow-up on improvements on buildings have not been defined or conducted to any greater extent (Boverket, 2015). The focus lies more on the renovation of buildings built in the late 20th century than on the ones built before this period. One time era of buildings that has been less observed could be classified as romantic nationalism, with influences of simplified and ordinary brick building in the design and structure. Therefore, results from different renovation methods of old buildings need to be investigated in regard to the final performance. This results can be used to enlighten situations and factors to consider when it comes to improving the energy performance of this type of buildings, for the first renovation as well as for a second.

1.1 Aim

The main aim is to enlighten situations which show efficient and less efficient renovations of the thermal envelope in residential brick buildings constructed between 1870 and 1930, to identify good and bad examples of renovations. Another part of the aim is to conclude what kind of second renovation that is beneficial for the investigated cases and how it should be conducted.

1.2 Specification of research question

The main question is:

- What method of renovation is most efficient for the building type in question?

Following parameters are taken into account when evaluating the research question:

- U-value
- Energy consumption
- Aesthetic
- Moisture risks

1.3 Limitations

The project considers actions of renovation, not actions of maintenance. There are unfortunately no unified definitions of these terms, but according to an interpretation from Boverket and Energimyndigheten, maintenance can be considered as a measure to preserve or restore for example a function of the building while renovation can be considered as an action to change or renew the building to improve the performance to a greater extent (Boverket, 2015).

Furthermore, the report considers renovations that are followed through with the intention to improve the performance of the thermal envelope of the building when it is intended to increase the energy efficiency. The aspects of building physics which are involved when improving the thermal envelope have been focused at.

The buildings that are studied in the project is owned only by real estate companies. The heating source in all the buildings is district heating. The studied buildings are situated in Gothenburg. However, the building type is representative for other cities as well.

1.4 Methodology

One part of the evaluation of the renovation is based on case studies. In the project 5 buildings, of the same building type (brick buildings) with different degrees of renovation, were investigated as case studies. The investigation of these buildings were then together with simulations and expert advice used to validate different kind of renovations of the thermal envelope.

Other brick buildings were considered during the process as well. Buildings with a similar construction type was also observed in order to find similarities and differences between renovations and renovation strategies of brick buildings with different functions.

Simulations of moisture risks and thermal bridges are conducted in WUFI 2D version 3.4 and COMSOL MULTIPHYSICS version 5.2. The mould growth index is controlled in an M-file made by Laukkarinen. Further explanation of the mould growth index model can be found in the paper from Viitanen et al. Manual calculations are made in Smath. The methods and the boundary conditions of the simulations are presented separately in each of the chapters and the appendices about the simulations.

Figure 1.1 below illustrates the methodology and work flow of the project and how the different processes are connected.

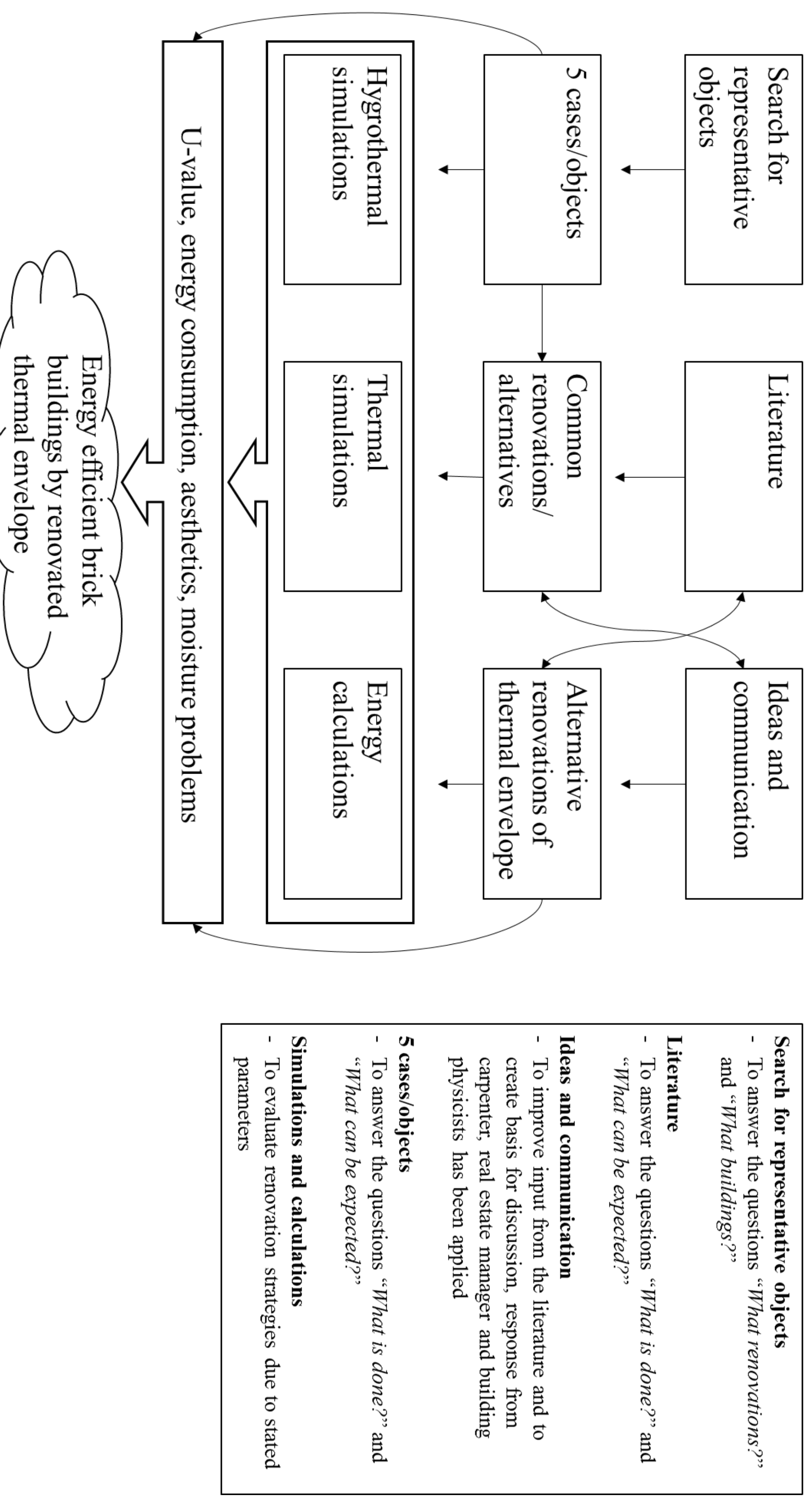


Figure 1.1 Schematic overview of the used methodology.

2 Evaluation Aspects and selection and collection of data

In this chapter will the evaluation aspects used in the project be further presented and explained. The process of selection and collection of data will also be explained.

The renovations are evaluated based on different aspects. Those aspects have been taken into account throughout the whole project, both during the evaluation process and during the site visits. The aspects are chosen according to the aim of the project and according to the literature, which showed the most discussed aspects.

Below is a presentation of the aspects and a description of how they are treated in the project. The following parameters have been stated:

- U-value
- Energy consumption
- Aesthetic
- Moisture risks

U-value is the amount of effect transported through one square meter wall per degree Celsius difference within the unit W/(m^2*K) (Hagentoft, 2001). The U-value depends on the thicknesses of the materials and their thermal conductivity W/(m*K). The U-value is calculated based on equations 2.1 to 2.4.

$$R_i = \frac{d_i}{\lambda} \tag{2.1}$$

$$R_T = R_{si} + \sum R_i + R_{se} \tag{2.2}$$

$$U = \frac{1}{R_T} \tag{2.3}$$

Based on each U-value of the elements a total U-value for the building is calculated, using equation 2.4.

$$U = \frac{\sum U_i * A_i}{\sum A_i} \tag{2.4}$$

Energy consumption is based both on measurements, EPC (Energy Performance Certificate), simulations and on calculations based on the U-values from simulations. The energy loss that is considered in this project is the transmission losses through the thermal envelope.

Equation 2.5 was used to compute the energy saving having the same unit as EPC, kWh/m^2/year.

$$\Delta E = \frac{\Delta U * A *^{\circ} Ch}{A_{temp}} \tag{2.5}$$

The regulation of energy consumption for new built residential building is 75 kWh/m^2/year (Boverket, 2011). The energy consumption of one house can be compared to other buildings by categorization in energy class of the house (Boverket, 2016). Table 2.1 below describes what energy consumption that corresponds to what energy class according to Boverket and Figure 2.1 illustrates the scale itself.

Table 2.1 Energy class for residential buildings (Boverket, 2016).

Energy class	Percentage of regulation, [%]	Allowed energy consumption, [kWh/m^2/year]§
A	≤50	≤37.5
B	>50 – ≤75	>37.5 – ≤56.25
C	>75 – ≤100	>56.25 – ≤75
D	>100 – ≤135	>75 – ≤101.25
E	>135 – ≤180	>101.25 – ≤135
F	>180 – ≤235	>135 – ≤176.25
G	>235	>176.25

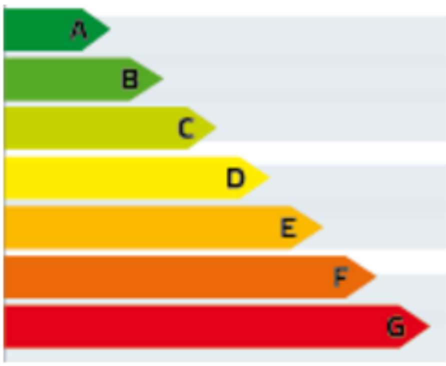


Figure 2.1 Rating scale of energy class based on energy consumption (Boverket, 2016).

The aesthetic is evaluated based on observations of how different renovations affect the appearance of the buildings. No methodology was used to compare or evaluate how the aesthetics was affected in a more complex architectural point of view. The evaluation is rather based on general ideas of aesthetics given from Antell and Paues (1981) and Byggforskningsråden (1990).

Moisture risks are evaluated through identification of risky zones. Simulations of the zones are made both for the original design and for the design after the renovations. The two cases, original and after renovation, are compared in order to evaluate the results of the renovations.

In the project, brick buildings from 1870 to 1930 are studied through literature studies and a case study. Below is a description of how the specific studied building type, brick buildings, was identified and selected together with how the information presented was gathered.

Identification and validation of studied buildings

Björk et al. (2013) presents some statistics concerning the building stock. The authors state that the majority of the multi-family residential buildings built before 1945 are located in the metropolitan areas around Stockholm, Gothenburg and Malmö. Furthermore, approximately 50% of all buildings built before 1945 are three to more than five storey buildings. Concerning the structural system, almost all buildings built before -45 has bearing outer and inner walls. Around 210 000 apartments exist in buildings that are of interest in this project.

Figure 2.2 illustrates the distribution of the building stock in Gothenburg and during what time periods different areas were developed.

Figure 2.2 Distribution of the building stock in Gothenburg during different time periods (Bjerking, 1974).

Brick buildings of relevance was detected by investigating what kind of buildings different property owners located in Gothenburg provides.

To justify the range of the studied building type in the building stock, statistics and history of the building stock was used. The statistics and history was obtained from the agencies Skatteverket and Lantmäteriet. Further explanation will follow below. The statistics and history gave a picture of the spread of brick buildings in cities and confirmed that there is a large number of the selected building type to be found in Gothenburg.

The second step in the process was to list and contact different property owners in Gothenburg. Advice from the supervisors gave an extended list of property owners. By using addresses of where buildings of the study´s type were located, some housing cooperatives could be found. But, since a collaboration with housing cooperatives was considered to be time consuming and the probability to get in contact with them was estimated to be low, they were not considered throughout the rest of the study. The property owners who answered and were interested in a collaboration were further involved in the process of this project.

Other reference buildings were discussed with supervisors in order to obtain knowledge of how similar renovation methods affect buildings with similar constructions.

Collection of data from studied buildings

In order to find information and data regarding the investigated buildings, a number of methods were used. Literature about how the buildings are constructed was studied, energy data from the property owner was collected and drawings and data about renovations were collected both from the property owner and from the Gothenburg city archive.

Field investigations of the houses were conducted. During the field investigation a pre-made checklist was used to collect information from thermography camera, moisture instrument and camera in a systematic way. Inspiration was taken from Bjerking (1971), Humble (1990) and Antell and Paues (1981). The checklist can be found in Appendix VII.

Collection of data from Lantmäteriet and Skatteverket has been conducted. Both Lantmäteriet and Skatteverket are government agencies. Services Lantmäteriet provides include geographical data and data about the location of real estates and how they are divided. Skatteverket has data about for example taxation of real estates and necessary parameters of the real estates in the country to justify the taxes. Used from these agencies are data about list of properties, living area, geographical location, building type, and construction year and value age.

3 Building Techniques

In this chapter the building techniques are described. Details, materials, and architectural design are also presented for the brick constructed houses built 1870-1930.

3.1 Foundation wall

Common structures are dry stone walls, double dry stone walls with filling material in between, and brick walls made with frost resistant bricks (Humble, 1990).

Dry stone walls are also commonly used on buildings constructed before 1900 after which concrete walls were introduced (Eriksson and Hansson, 1974).

A common type of foundation walls of brick buildings located in the southern part of Sweden is brick walls. Otherwise, concrete walls or concrete and stone walls are common structures (Björk et al., 2013).

One can suspect for the southern parts and for the western parts of Sweden before 1920 foundation walls of brick, stone or both materials combined was constructed. Around 1910-1940 was the brick replaced by concrete, and from 1930 and forward concrete was mostly used for this element in the structure (Bjerking, 1974).

Two examples of foundation walls are illustrated in Figure 3.1 below.

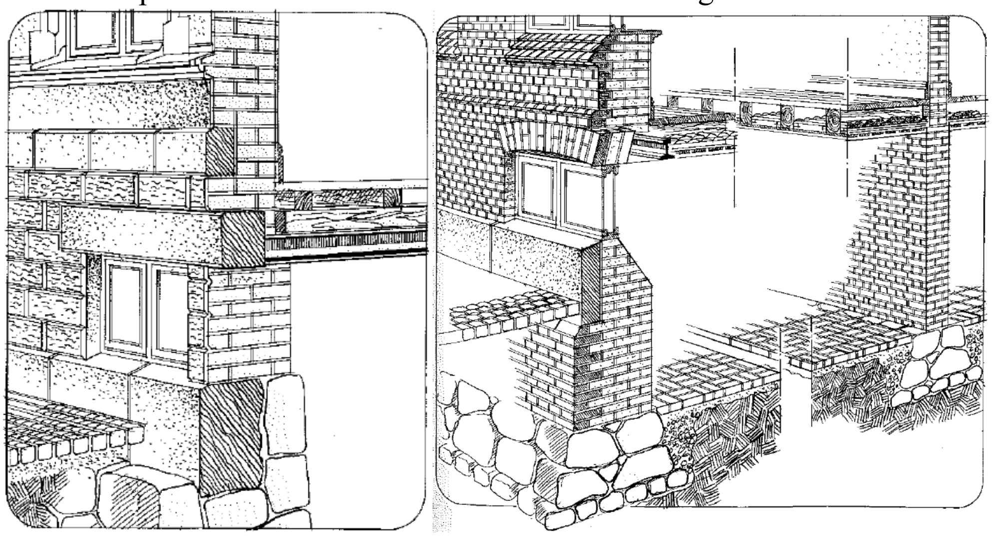


Figure 3.1 Examples of structural composition of two foundation walls (Björk et al., 2013).

3.2 External wall above ground

Before 1945, brick and wood were the most common materials in the outer walls (Björk, et al., 2013).

The outer walls consist of masonry walls with varying thicknesses depending on the load. Normally, the brick walls are covered with stucco (Humble, 1990). The stucco on the interior is often reinforced by reed[1]. The thickness of the brick walls varies between 1 stone wall (32 cm, incl. stucco), 1.5 stone wall (49 cm, incl. stucco) and 2 stone walls (64 cm, incl. stucco). One stone is 30x14.5x7.5 cm. Furthermore, the thicker walls are in the bottom of the building. Depending on the amount of floors, the wall thickness was successively increased from the thinnest to the thickest (Eriksson and Hansson, 1974). The façade facing the court yard was most often covered with stucco (Bjerking, 1974).

Normally the walls are built with yellow and red bricks or mixed of both[1]. The yellow bricks are more sensitive to frost damages due to lower level of sintering[1].

An illustration of an external wall is illustrated in the picture to the right in Figure 3.1 above.

3.3 Roof

The roof is normally constructed of wooden roof trusses covered by tongue and groove wood with asphalt paper. Roof tiles of clay are common on the slope of the roof oriented towards the street, and towards the court yard there are steel covering instead of tiles (Humble, 1990). The roof tiles used are commonly pan tiles (Eriksson and Hansson, 1974). Some buildings even have slate or asbestos tiles on the roof (Björk et al., 2013).

The built inclination and height of the roofs varies over the decades. Houses built around the turn of the century have high, mansard roofs (Eriksson and Hansson, 1974). The authors moreover inform that before this the roofs were lower levelled trusses without mansard. The trusses are resting on the outer brick wall.

Typical roof trusses for attics that are kept cold are illustrated in Figure 3.2.

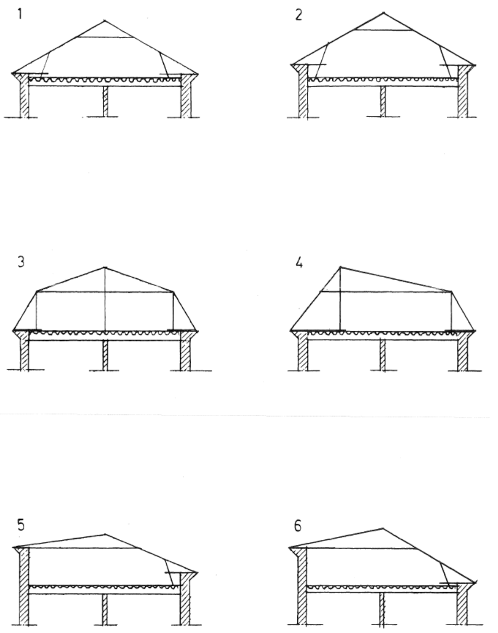


Figure 3.2 Typical designs of roof trusses for cold attics (Bjerking, 1974).

[1] P-O Johansson (Property manager, Skanses fastigheter AB) interviewed 25-02-2016

3.4 Ground and basement slab

The basement slab normally consists of wooden beams covered by tongue and groove wood and on top of that a thin layer of concrete. The concrete on top of the slabs was covered with filling materials left over from the construction and on top of the beams a wooden floor (Humble, 1990). Before 1850 masonry arches were constructed to support the basement slab (Humble, 1990). Thereafter, the steel beams were introduced. They could often consist of rails from the railways (Björk et al., 2013). The arches were then bricked between the steel beams. Humble (1990) writes further that the bricks in the arches were superseded by rectangular concrete slabs around the turn of the century. Also that reinforced concrete slabs can be found in buildings constructed after 1920.

The ground was either covered with sand and bricks or non-reinforced concrete on top of filling materials (Björk et al., 2013).

Figure 3.3 illustrates the basement slab and covering layer of the ground, non-reinforced concrete.

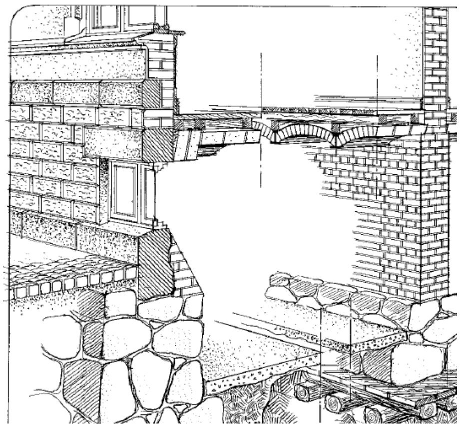


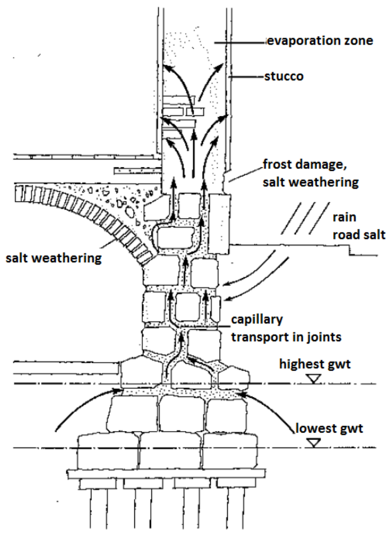
Figure 3.3 Non-reinforced concrete as ground slab (Björk et al., 2013).

3.5 Connections of building elements

In this chapter connections between the building elements are described. As the building techniques have varied over the decades the connections in the buildings have followed.

3.5.1 Foundation wall – external wall above ground

Tared birch bark can be found in the connection of the dry stone wall and the façade wall in order to prevent moisture transport, mainly from capillary suction, from the ground up into the wall structure (Eriksson and Hansson, 1974). This is shown in Figure 3.4.



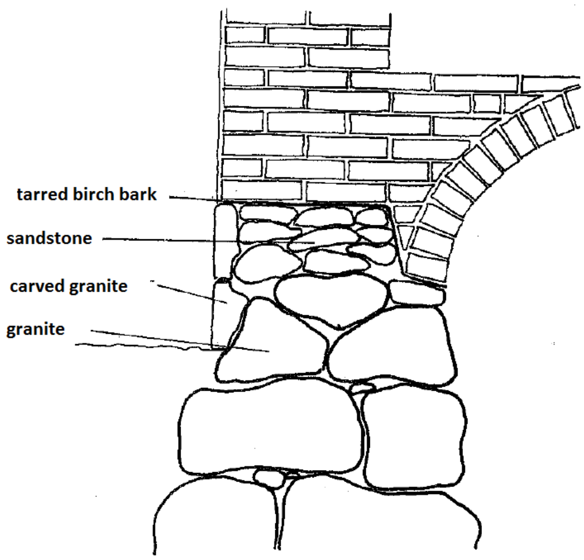


Figure 3.4 *Left: Section through foundation wall transitioning to façade wall, capillary suction transport (Humble, 1990). Right: Section through foundation wall transitioning to façade wall (Eriksson and Hansson, 1974).*

3.5.2 External wall above ground – roof

The design of the connection between the roof trusses and the exterior wall varies depending on the roof design (Björk et al., 2013). According to the authors the roof constructions with mansard roofs have an upper and lower attic floor shown in the left picture of Figure 3.5. Buildings without mansard roofs have a similar connection, but just one floor (Björk et al., 2013). A typical view from inside the attic is shown in the right picture of Figure 3.5.

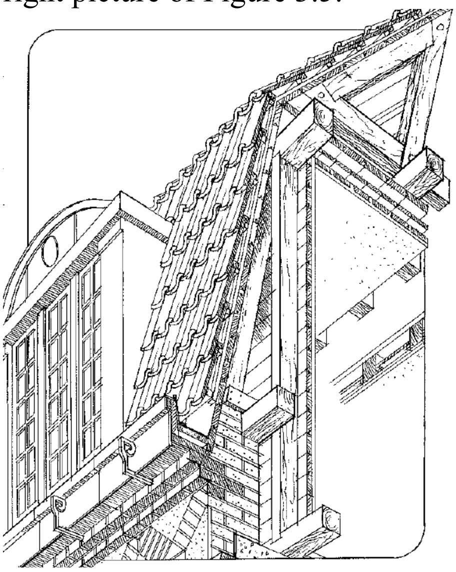



Figure 3.5 *Left: Example of connection to wall, mansard roof (Björk et al., 2013). Right: View from the attic of the connection between the external wall and the roof. Notice the brick wall.*

The connections between the brick wall and the roof trusses are similar to the connections described in Chapter 3, and in Section 3.5.3, *External wall – floor slab* below.

3.5.3 External wall – floor slab

The attic floors are connected to the exterior wall through the beam boxes. The beam boxes are supporting the weight and loads of the slab and the roof (Humble, 1990). To stabilize the construction some of the beams are fastened with anchor steel, in Swedish "*Sträckankare*", though the brick wall, illustrated in the picture to the right in Figure 3.6. The anchor steel is either visible on the façade or hidden in the brick wall (Humble, 1990).

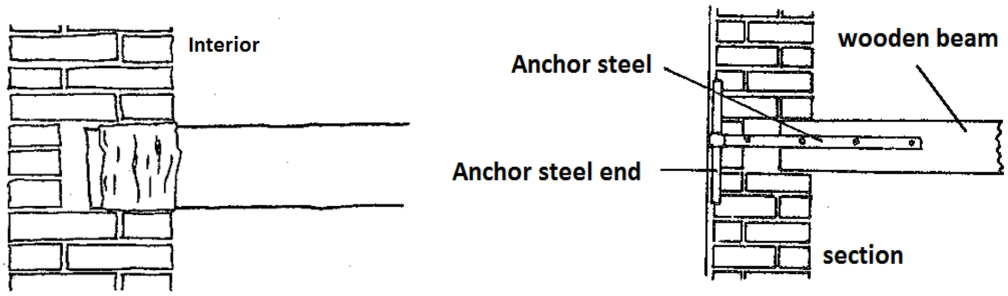


Figure 3.6 Left: Basic example of beam box, covered with birch bark or bituminous paper (Eriksson and Hansson, 1974). Right: Basic example of beam box, with anchor steel (Eriksson and Hansson, 1974).

The beam box is normally 30 cm deep. The support area to the beam varies between 5 and 15 cm, but is normally 15 cm. The ends of the beams were covered with birch bark and emphasized with tar, but the end surface perpendicular to the grain was normally kept un-protected. Around the turn of the century the birch bark was superseded by asphalt paper (Eriksson & Hansson, 1974).

The cavity in the beam boxes was normally partly filled with material remaining from the construction (Eriksson and Hansson, 1974). Also, the dimensions of the beams vary. The height of the beams can be expected to be around 20-22 cm. Common center distances are 55-60 cm.

3.5.4 Windows and other openings in the thermal envelope

The size and the style has varied over the decades (Bjerking, 1974). Bjerking describes two kinds of windows. The first one, se Figure 3.7 is produced until around 1920. The window consists of two separate window sashes. The inner sash is removable and demounted during summers. The second one was introduced around 1910-1930 and has coupled window sashes, se Figure 3.8.

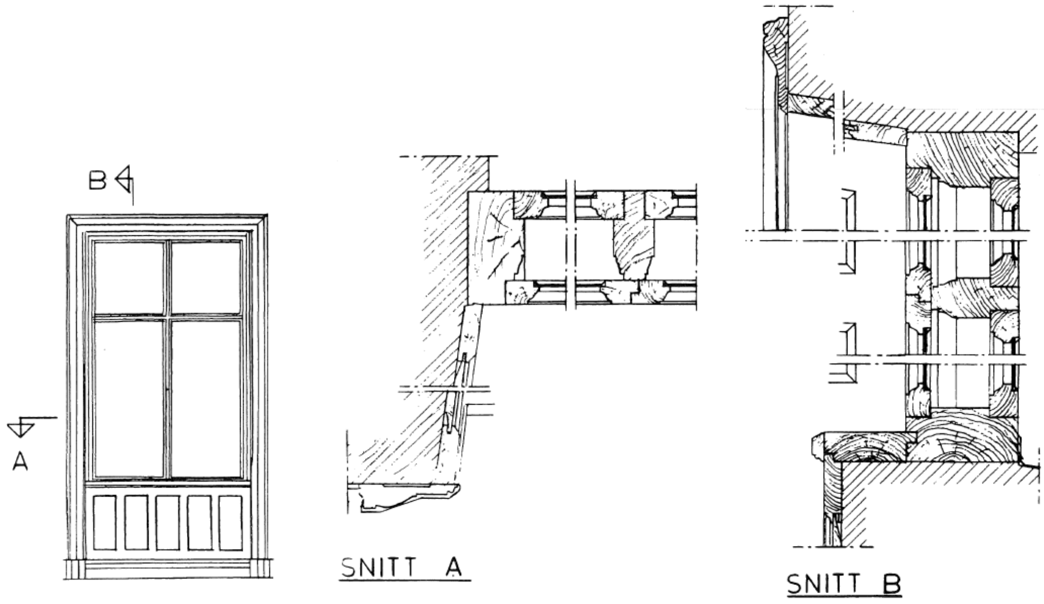


Figure 3.7 Window construction until 1920 (Bjerking, 1974).

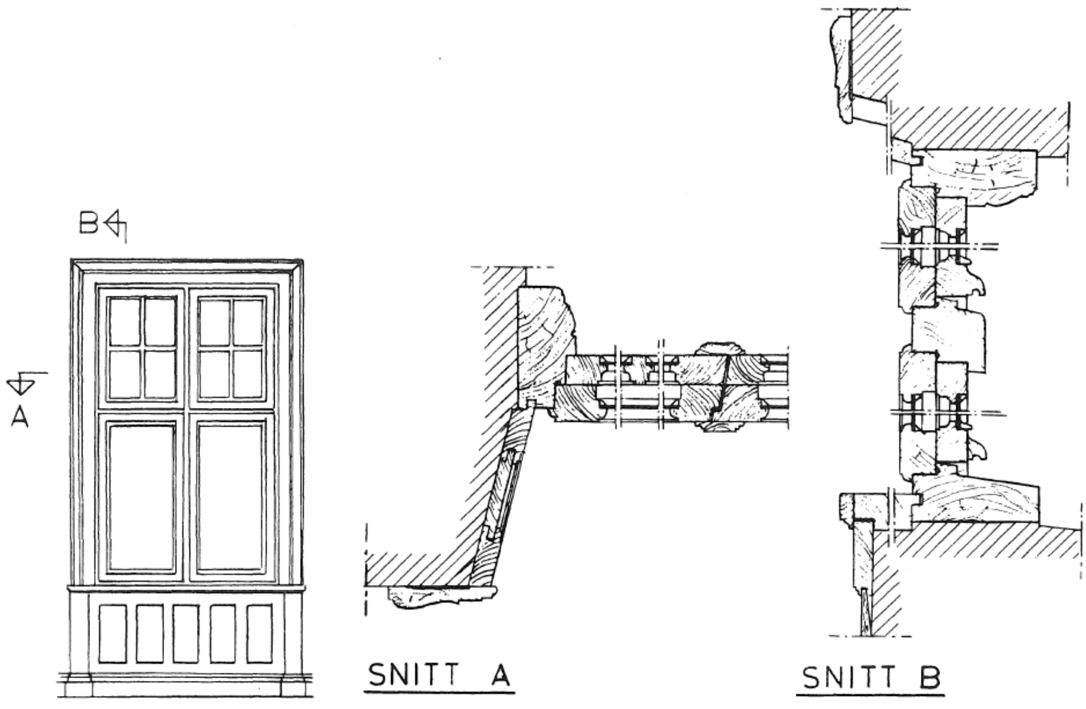


Figure 3.8 Window construction until 1910-1930 (Bjerking, 1974).

A coupled 2-glass window has a U-value around 2.5 W/(m^2*K) [1].According to Gustafsson the windows were delivered unpainted to the construction site. When the windows were mounted all the wooden parts were painted after the window ledge was mounted. Gustafsson states that the windows in that way become more resistant against rain than what modern windows are.

[1] Börje Gustavsson (Building physicist, SP Sveriges Tekniska Forskningsinstitut) interviewed 23-02-2016

3.5.5 Balconies and bay windows

Balconies were around 1890-1940 most often supported by steel edge beams, either U- or I-beams (Bjerking, 1974). The beams were fixed in the brick wall, see Figure 3.9.

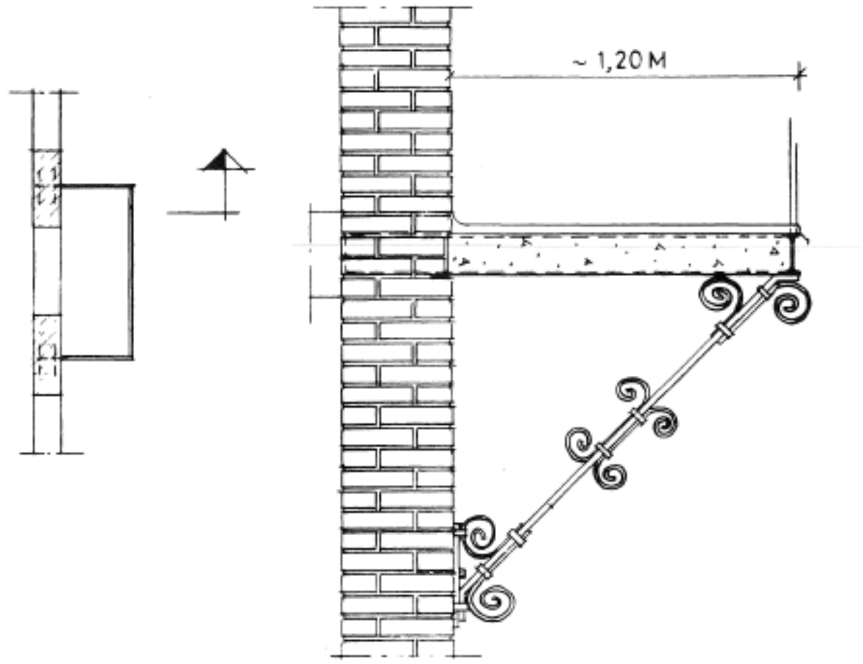


Figure 3.9 Balcony construction (Bjerking, 1974).

The bay windows could be quite extended which resulted in heavy steel beams (Bjerking, 1974). The steel beams had to be fixed deep into the slab, see figure 3.10.

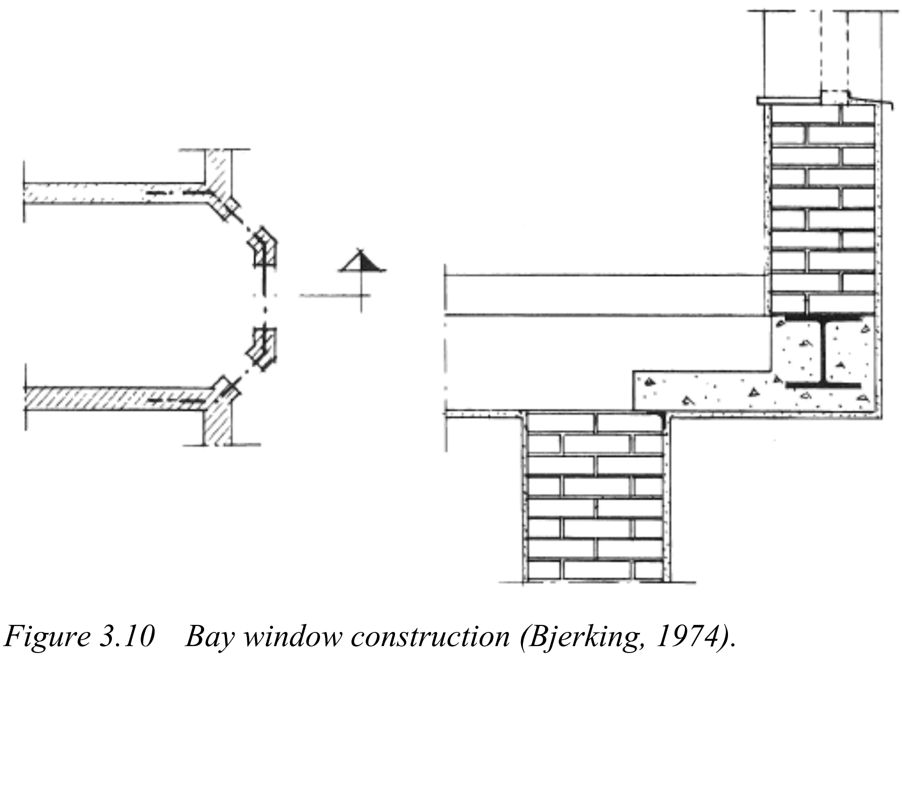


Figure 3.10 Bay window construction (Bjerking, 1974).

4 Renovations 1930-2016

Buildings from around 1900 have due to their age went through a lot of modernisations and renovations to fulfil the modern standard (Humble, 1990). According to Bjerking (1974) the brick buildings in the city of Gothenburg are not highly affected by the changes that have been made to the building stock in the centre of the city. In other words, the degree of renovation should be lower in the brick buildings than in the other building types. The renovation methods have been varying over the years (Antell and Paues, 1981).

4.1 Tradition and history of renovations

In this chapter traditional and historical renovation over the decades are described. Renovations have both an architectural and a functional aspect (Antell and Paues, 1981). Further described is that renovations made the last 50 years have caused conflict between these two aspects.

4.1.1 Extra insulation

During the seventies it was popular to add insulation to the buildings. Antell and Paues (1981) believe that a lot of the extra insulation was a result from the energy saving contribution by the government during the seventies. The renovations during that time were made with very cheap and time efficient methods, which did not always follow the architectural design of the buildings (Antell and Paues, 1981). Figure 4.1 below illustrates an example.

Figure 4.1 Façade facing court yard covered with metal sheets (Antell and Paues, 1981).

The studied buildings in the case studies indicate that the houses were normally renovated with insulatoin on the façade facing the inner yard. The façade facing the street is normally intact. The material used for insulation of the visited buildings was mineral wool, which was covered with metal sheets or stucco without air gap.

Energimyndigheten (2009) describes different methods when it comes to adding extra insulation. It can be added to the attic, walls, floor and basement. Furthermore, descriptions of different side effects that could occur due to these changes. Adding extra insulation to the attic can give two opportunities; to insulate the attic floor and obtain a cold attic, or to insulate the roof and obtain a warmer attic. When insulating the attic floor, it is of importance to make sure that the slab construction becomes air tight to prevent diffusion and forced convection of humid air.

When insulating the walls, two options are possible, to insulate either the interior or exterior side of the wall. Though, attention should be paid when the interior side of the structure is insulated since the existing wall structure becomes colder (Energimyndigheten, 2009). Internal insulation has been conducted in some buildings, but when used needs to be properly investigated (Humble, 1990).

When it comes to the floor, recommendations are given to only use this method for buildings with crawl space and spaces similar to this. This has to be done with care, since the thermal properties in the crawl space are changed and problems with moisture and mould could occur. One way to retain the applied heat to the crawl space is to use heated air in the ventilation of the crawl space. The heat can for example be extracted from the sun. To insulate buildings with basement, similar alternatives are given as for the walls. External insulation keeps the wall structure warmer and hence dryer. Interior insulation should be designed with an air gap (Energimyndigheten, 2009).

4.1.2 Windows

Most of the studied buildings have newer or renovated windows. When changing the whole window including the frame, it is very complicated to solve the fastening into the brick in a proper way[1]. One solution to get around the problem is to fasten the new window frame in the old one. In that way the strong original fastening is kept, but the glass pane gets smaller due to the new frame[1].

Another method to improve the U-value of the window, without changing the window is to add an extra glass pane. The extra glass is added on the inside of the window with a spacer in between. In that way an improved U-value of the glass area is achieved. This solution is often used if the exterior of the window needs to be intact (Grundels, 2016). The extra pane is mounted on the old window in the apartments. In other words, the window does not need to be transported to the factory (Grundels, 2016). The U_g-value resulted in 1.0 W/(m^2*K) after a renovation of coupled 2-glass windows[1]. Observe that the U_g-value only accounts for the glass area. The thermal bridges from the sashes and the frame are not included.

In some buildings inadequate maintenance or low quality of the windows force the property owners to change the whole window[1].

4.1.3 Apartments in the attic

Instead of insulating the attic slab, another alternative is to renovate the attic into apartments. Then the outer roof is insulated and the living area in the house is increased by almost one through the number of floors.

Depending on how the renovation is made, the space can be used in different ways. One alternative is to use the whole attic space and insulate the roof from inside.

[1] P-O Johansson (Property manager, Skanses fastigheter AB) interviewed 25-02-2016

Another alternative could be not to use all the space in the attic. Some part of the space is then saved as a cold, lower attic, see Figure 4.2 (Bjerking, 1974).

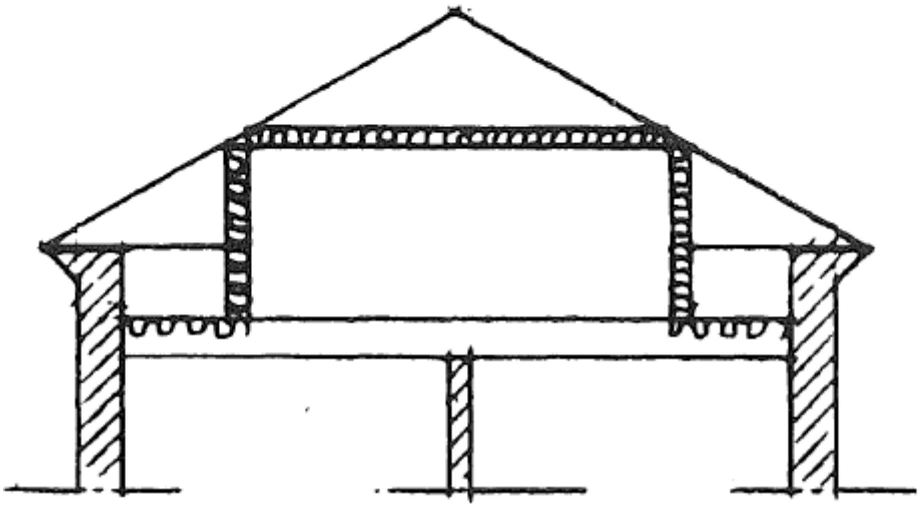


Figure 4.2 Section of an alternative to attic apartments (Bjerking, 1974).

In order to ventilate between the roof layer and the insulation layer, ventilation hoods are mounted in the roof eaves as well as ventilation funnels in the roof ridge[1]. According to Johansson it is common to have storage for the residents in the attics. If that is the case, he says that the renovation of the apartments in the attic also includes solving storage area somewhere else.

4.2 Alternative renovations

Other, less common, renovations are also possible. If the façade is in poor condition or a lot of the wooden load bearing parts are rotten, the simple renovations mentioned above are not enough.

4.2.1 New load bearing wall

If the wall is damaged by frost or other attacks and the original architecture needs to be kept, an alternative is to demount the brick façade, sort and clean the bricks and rebuild it with the original brick[2]. With this method it is possible to achieve a modern exterior wall with original appearance. The loadbearing part in this wall does not need to be the bricks. Therefore, the amount of bricks needed could be reduced and the damaged bricks can be sorted out.

4.2.2 Concrete sandwich elements

If the house is in such a bad shape that it needs to be rebuilt and the original architecture for some reason is important to keep in the area, modern techniques can be used to rebuild the same design, but still result in a modern thermal envelope (Strängbetong, 2016).

[1] P-O Johansson (Property manager, Skanses fastigheter AB) interviewed 25-02-2016
[2] Elin Andersson (Responsible for information, Peab Fastighetsutveckling Sverige AB) interviewed 09-03-2016

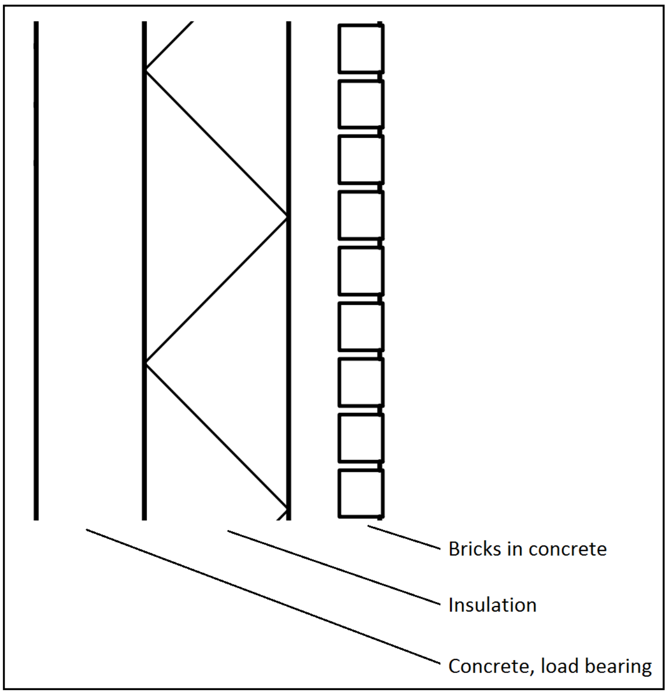


Figure 4.3 Section of a new sandwich element with remounted bricks (Strängbetong, 2016).

Strängbetong has rebuilt some warehouses in the area Eriksberg in Gothenburg. It was important to keep the old appearance of the area and the buildings were supposed to be converted into residential buildings (Strängbetong, 2016). The warehouses were demounted and the brick remounted in concrete sandwich elements, see Figure 4.3 and 4.4. The old appearance of the bricks was re-made in walls constructed in the factory of Strängbetong.

Figure 4.4 Example of a new sandwich element with remounted bricks. Photos: Strängbetong (2016).

4.2.3 New beam ends

Rotten beam ends that are connecting to the brick wall are a known problem in brick buildings. According to Humble (1990) a moderately rotten beam end can be cured through boring holes in this, which are then filled with boron salt. The salt will dissolve when the beam end is humidified and in that way impregnate the wood.

If the rotting is more serious, the exposed part needs to be exchanged and the new part needs to be connected to the old beam. The new part should also be secured from capillary suction. Recommendation of using asphalt paper are given (Humble, 1990). If there is room in the beam box, further recommendations are presented, and suggest insulation of the outer parts of the box with cellular plastic to lower the risk of condensation if the interior air through convection enters the beam box (Humble, 1990).

The new part of the beam can be produced from preservation wood with pressure treatment (Humble, 1990). Newer sources as Broomé (2000) argue that this kind of wood will emit malodourous gases when humidified and should therefore not be used.

Sometimes the rotting process has gone so far that fungi has grown and caused serious dry rot[1]. Jonsson mentioins a renovation where fungi were found in a lot of the load bearing floor joists. In that renovation all the beam ends were exchanged and the area was treated with boron chemicals against the fungi. Jonsson also mentions that the ends of the beams were covered with “rubber socks” to reduce the risk of capillary suction, which could have started new dry rot processes. The joints in the brick walls had to be remade due to the weathering caused by the fungi. The walls were kept non-insulated to avoid frost damages in the brick façade.

4.2.4 New steel frame

If all the wooden load bearing parts are not enough when a building is changing the function for example, it is possible to keep the brick walls and replace the wooden columns and the beams with steel. This method was used in a project in Vienna in Austria, se Figure 4.5. In this case the steel frame was mounted to resist earthquakes[2].

Figure 4.5 New steel frame in an old brick building in Vienna. Photo: Pär Johansson.

[1] Andreas Jonsson (Carpenter and M.Sc. in civil engineering, Chalmers) interviewed 10-03-2016

[2] Pär Johansson (Assistant Professor, Civil and Environmental Engineering, Building Technology, Chalmers) interviewed 12-05-2016

5 Description of Studied Buildings

In total 5 houses are studied in this project. The houses are all situated in different districts in Gothenburg. They are owned by real estate companies of different size and the residents are renting the apartments. Some of the buildings have restaurants and shops on the first level. All the buildings are heated from district heating. All information presented in this chapter originates from the property owners.

5.1 Building 1

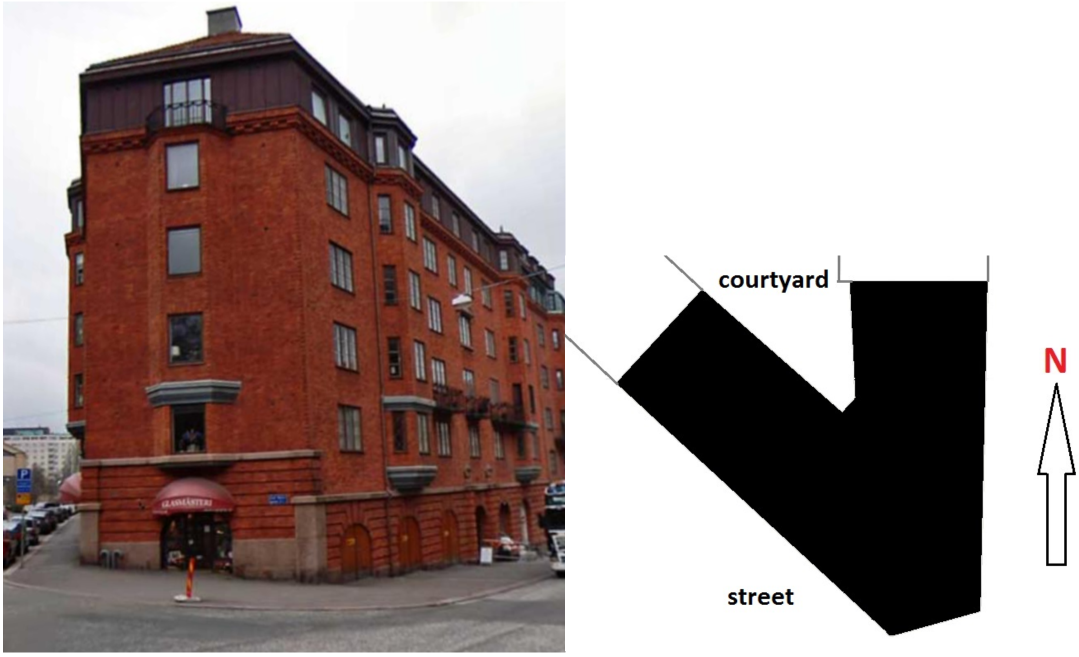


Figure 5.1 Left: Street view of building 1. Photo: Hitta.se. Right: Orientation of building 1.

The building showed in Figure 5.1 is located in the corner of its block and is V-shaped. One of the façades facing the street is oriented south-west and the other south-east. The very corner of the building is oriented to the south, slightly south-east. It was constructed 1917 and is a seven storey building.

Thermal envelope

The façade facing the street has not been renovated to any extent. This part of the climate envelope consists of brick wall, with different thickness depending on floor level, windows and gates. The colour of the bricks is red. The gates are not changed, which is also the case for most of the windows. Change of windows has happened on irregular basis. A 50 mm layer of stone wool has been added to the façade facing the inner courtyard, see Figure 5.2 below. Stucco has been applied as the external layer, illustrated in the middle picture in Figure 652. An air gap does not exist in this added construction.

Figure 5.2 Left: Added insulation layer behind covering steel plate in a corner. Middle: External stucco and fastening of the insulation visible through a damage. Right: Window ledge connection to the façade.

Otherwise, also the wall facing the inner court yard consists of brick. The windows in this wall are original wooden windows consisting of two panes. New window ledges are integrated into the stucco, see the picture to the right in Figure 5.2.

The foundation walls are in original shape. They are made of brick and dry stone. Just like the foundation walls, the roof is also intact and unchanged. Figure 3.5 in Section 3.5 illustrates the design of the roof. Tiles are covering both slopes of the roof.

Energy consumption

According to the Energy Performance Certificate (EPC), the energy consumption of the building is 109 [kWh/m^2/year], which gives grade E in Figure 2.1 and Table 2.1.

Aesthetics

There are differences in the windows of the building. Original windows kept on one side of the house, and on the other side they have been changed due to different circumstances. The lower part of the bay window facing the street has been renovated. The original gates have been kept. On the inner courtyard insulation covers some of the original edge between roof and wall.

Moisture risks

Algae growth is visible below windows on the insulated wall where little sun light reaches, also along some corners. It was noted that the foundation wall was moist and the paint of the wall was flaking heavily. One beam of the attic floor slab had once collapsed due to rot.

5.2 Building 2

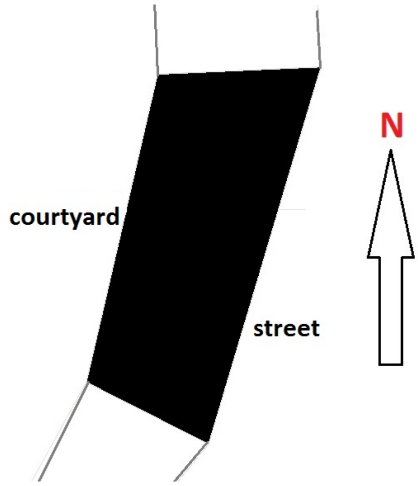


Figure 5.3 Left: Street view of building 2. Photo: Hitta.se. Right: Orientation of building 2.

The second studied house, see Figure 5.3, is oriented south-east, north-west. It is not located at the very corner of the block like the first building, but is instead built in the middle of its block. The façade facing the street is the side oriented towards south-east. The house was built 1929 and has five floors used as apartments, a bottom floor consisting of shops and a restaurant and an attic partly converted to apartments. The building is located along a slope.

Thermal envelope

To the side of the street the façade has not been changed since the year of construction, which means that the original brick wall remains. The brick which has been used is red brick. The windows were changed around 1980, but the original windows were kept in the stairwell. To the side facing the yard 100 mm of mineral wool has been added to the façade with a coat of stucco, see picture to the left in Figure 5.4. The windows were kept in the same depth in the wall construction after the insulation was added, illustrated in the middle picture in the same figure. The picture to the right shows that window ledges of the windows facing the street have also been replaced. The corners of the ledges have not been folded, but cut.

Figure 5.4 Left: Added insulation on the wall facing the yard. Middle: Window and wall connection facing the yard. Right: Window and wall connection facing the street.

There is no insulation added in the interior. The only thing changed is the interior layer in form of paint and panels.

The attic has partly been renovated into apartments. The apartments do not fill the whole volume of the attic. There is still a cold volume above the roof to the apartments. In other words, there is still a small attic area above the apartments in the attic. The areas that have not been converted into apartments are used for storage. The roof has tiles on the slope facing the street and sheet metal on the slope facing the yard.

The foundation walls are made with brick and dry stone wall combined, see figure 5.5 below. The figure also shows discolorations. It is possible that they origin due to moisture problems.

Figure 5.5 Design and construction of the foundation wall with discolorations.

Energy consumption
According to the EPC, the energy consumption is 135 [kWh/m^2/year], which gives grade E in Figure 2.1 and Table 2.1.

Aesthetics
The façade facing to the street is original. The newer windows have been chosen to match the original windows, which keeps the impression of the house. The doors to the stairwell is also original.

To the side facing the yard the façade has been changed with an extra layer of insulation and a stucco coat. Many houses of this kind had stucco on the façades facing the yard as a part of the original design. Therefore, it is hard to say how far from original the added insulation really is. The extra insulation hides the details on the top of the façade connecting to the roof trusses.

When the apartments in the attic were built dormer windows were added. It can be discussed if these really match the rest of the architecture of the house.

Moisture risks
Extra insulation gives a deeper window setting, which make the performance of the window ledge very important. In this case, the ledge has acceptable inclination, but the folding on the edges could have been bigger to avoid rain water from entering the wall construction.

In some areas of the foundation wall discolorations could be observed, see figure 5.5 above. This was not the case everywhere, see Figure 5.6 below.

Figure 5.6 Areas of the foundation wall free from discolorations.

A certain smell could be noted in the attic, which can be considered as typical for attics.

5.3 Building 3

Figure 5.7 Street view and orientation of building 3.

The third building, showed in Figure 5.7, which was visited is oriented in a bend of its block with the façade facing the street pointing at south and south-east. The inner courtyard is facing north, north-west. This building is constructed with yellow bricks and was built 1932. It has five storeys with apartments, an attic in original design and shops on the bottom floor.

Thermal envelope

The walls towards the street are unchanged, they are brick walls with different thickness depending on floor level. The walls towards the yard are similar, no insulation has been added in this case. The original gates have been kept. The windows are built-on, and an extra window pane was added on the inside, as described in Chapter 4 and Section 4.1.2 – *Windows*. The original frame was kept and additional cover by steel to the exterior parts was added, see Figure 5.8.

Figure 5.8 Left: Added cover to a window in the basement wall. The wooden frame is visible beneath the cover plates. Middle: Added cover to a window of an apartment. The wooden frame was less visible than in the previous figure. Right: New and old window ledge.

The roof was renewed. The original structure was kept and was slightly improved with a double layer of roofing felt. The tiles are made of slate. Figure 5.9 below illustrates the design of the roof trusses.

Figure 5.9 Design of roof trusses and connection of roof and exterior wall. Notice the brick wall.

The basement has been painted and extended. There is a crawl space underneath the bottom slab due to ground level that shifts in elevation. The foundation walls in the basement are constructed of brick and concrete.

Energy consumption
According to the EPC, the energy consumption is 145 [kWh/m^2/year], which gives grade F in Figure 2.1 and Table 2.1.

Aesthetics
The façades are mainly untouched. The wooden frames of the windows are no longer visible, but the colour of the windows and their original shape remains.

Moisture risks
Inspection of the façade towards the street indicates large exposure to weather and wind, since exterior damages can be seen. These damages consist mostly of frost damages. The condition of the bricks on the façade facing the yard was better.

Since an extra window pane was added and the frame was kept unchanged there are no new moisture risks in the connection wall-frame. Extra weather protection was added on the exterior of the frame, which at least should not worsen the situation, if this cover could work as a rain coat. Although, to guarantee quality or function, could be difficult[1]. Figure 6.10 below illustrates that the inclination of the mounted ledge was not necessarily follow the original and can even be less than the original inclination in some places. This resulted in standing water on the new window ledge.

[1] Börje Gustavsson (Building physicist, SP Sveriges Tekniska Forskningsinstitut) interviewed 23-02-2016

Figure 5.10 Difference in inclination of window ledges resulting in standing water.

5.4 Building 4

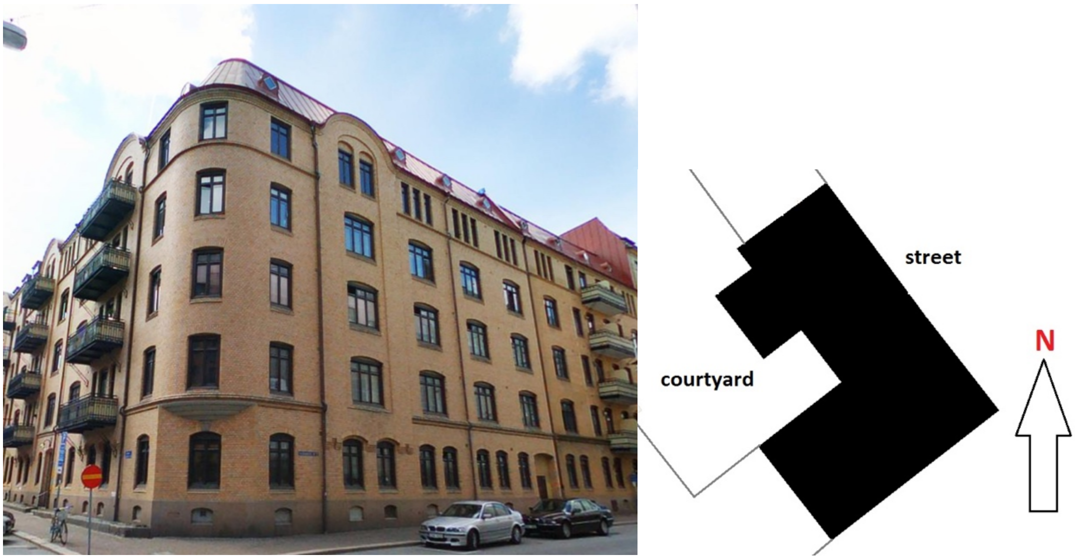


Figure 5.11 Street view of building 4.

This building, see Figure 5.11, is situated in a corner of its block, just like Building 1. Although, this block has a rectangular shape. One of the façades facing the street is oriented south-east and the other north-east. The yard faces northwest. This building has apartments on all of its six floors, including a renovated attic. The basement contains storage areas and similar. Subsidence is visible, and yellow bricks has been used for the construction. The house was built 1907.

Thermal envelope
The façades towards the streets are entirely original. The thickness of the brick walls differs with the height of the building. The windows have probably been changed around 1970. The new windows are 2-glassed windows, see figure 5.12 below. They probably have energy performance comparable to the original windows. The openings in the walls that are reserved for the windows do not always have the same shape as the installed windows. The extra volume is covered by a wooden plate, see Figure 5.12.

Figure 5.12 Left: Corner of installed windows. Right: Difference in shape of window and opening in façade.

All the façades facing the yard is clad with 50 mm mineral wool with wooden frame. The insulation is covered by painted, corrugated steel, see Figure 5.13. Figure 5.13 also illustrates how the addition of the layers has been performed.

Figure 5.13 Left: Façade facing to the yard. Right: Added corrugated steel and mineral wool.

The majority of the area in the attic has been renovated and converted into apartments. Some areas are left to function as storage. The roof trusses were saved and insulation was added below the existing roof structure with a distance for an air gap in between. Metal sheet covers the roof.

Energy consumption
According to the EPC, the energy consumption is 126 [kWh/m^2/year], which gives grade E in Figure 2.1 and Table 2.1.

Aesthetics
To the side facing the street the façade is close to original. When the windows were changed, the rounded top of the window probably became straight, see Figure 5.12 above. The changes to the façade of the yard are illustrated in Figure 5.14 below.

Figure 5.14 Changed window and its connection to the corrugated steel.

Moisture risks
No signs of frost damages, such as those which could be observed on Building 3, could be detected on the yellow brick façade. No moisture problems were noticed when the attic was converted into apartments, but when the same renovation was performed on the adjacent building a severe fungal infestation was found in the original parts of the structure, which then was removed and replaced.

Figure 5.15 below illustrates that indications of moist foundation walls can be identified since the paint is flaking.

Figure 5.15 Flaking paint on foundation wall.

5.5 Building 5

Figure 5.16 Left: Street view of building 5. Photo: Hitta.se. Right: Orientation of building 5.

The final building, seen in Figure 6.16, is making the very corner of its block. The inner courtyard is facing north and west, the façade facing the street is oriented in south and east direction. The colour of the bricks is red and the building has five levels of apartments and a bottom floor with shops. It is a sloping house with a basement below the bottom floor, which are located on street level. The construction year is 1929.

Thermal envelope

All exterior walls consist of brick and are in original shape. The thickness differs with the height of the building. The majority of the windows have been changed, but some original windows are still in use, see Figure 5.17. The windows of the shops on street level are original as well as the gates and doors.

Figure 5.17 Left: Original wooden window. Right: Frame-in-frame window.

When changing the windows, the original frame was kept and a new window frame was probably installed into it, see figure 5.17.

The attic has kept its original design and is illustrated in Figure 5.18 below.

Figure 5.18 View of attic and structure of the roof.

The foundation walls are built mainly of bricks and partially of dry stone walls.

Energy consumption

According to the EPC, the energy consumption is 172 [kWh/m^2/year], which gives grade F in Figure 2.1 and Table 2.1.

Aesthetics

The major changes to this building concerns the windows. The windows changed are the windows of the apartments, otherwise the original design has been preserved to a great extent. The installation of windows in the existing frames makes the windows smaller than before.

Moisture risks

The basement was noticeably hot and dry, probably due to excess heat from the heating system of the building, which might neutralize a possible moisture damage. No signs of damages due to weather exposure could be noticed on the façades. The design of the window ledges is presented below in figure 5.19. No moisture damages could be observed around the changed windows.

Figure 5.19 Original window ledge.

6 Simulations and calculations

Follow does an overview of the simulations and calculations performed. More about them in detail can be found in the attached appendices:

- Appendix II, thermal simulations, COMSOL
- Appendix III, hygrothermal simulations, wall, WUFI
- Appendix IV, hygrothermal simulations, support of slab in wall, WUFI
- Appendix V, hygrothermal simulations, roof-wall, WUFI
- Appendix VIII, climate conditions from WUFI

6.1 Hygrothermal simulations

Three risky zones are chosen to be simulated. The zones are the basic wall, point 1 in figure 6.1, the connection between the brick wall and the slab beam, point 3, and the connection between the wall and the attic slab beam, point 1. The zones are illustrated in Figure 6.1 below.

A change of the thermal envelope will affect the conditions in the building materials. During a renovation it is important to know what impact a certain solution will have on the construction. Therefore, the impact of a certain renovation is simulated in the three zones.

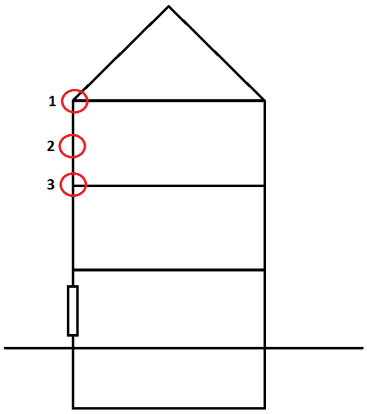


Figure 6.1 Marking of investigated areas, point 1-3.

The types of renovations that are simulated have been chosen based on what was observed during visits of the studied buildings and also on what was found in the literature. Some alternative solutions for renovation were also simulated. Simulations of the wall considers original design and internal and external insulation with expanded polystyrene and mineral wool with different weather protection for the cases with external insulation. Simulations of the support of the slab in the wall consider original design, internal and external insulation with different weather protection for the external insulation cases and a situation where the cavity is filled with polyurethane foam with closed cell instead of air. Simulations of the connection roof-wall consider different lengths of the overhang of the roof and insulated or non-insulated attic.

It is during normal conditions possible to neglect condensation on the surfaces inside a beam box which is illustrated in picture 3.6 in Chapter 3 Section 3.5.3, *External wall – floor slab* (Humble, 1990). The case is based on an external layer with an infinite vapour resistance, which gives the highest possible accumulation of moisture from the inside air in the structure. Humble continues with claiming that even if it is possible to neglect the condensation, a high vapour resistant layer on the exterior side of the wall would make the situation worse. No air change was assumed to take place in the cavity of the beam box.

Built-in weather data for Gothenburg and pre-defined indoor climate was used for all hygrothermal simulations performed, and initial conditions of the structure were assumed to be similar to the outdoor conditions at the beginning of the simulation period. The details were set to face south, which is the direction most exposed to rain. The simulation period was set to 3 or 6 years and started and ended in October.

The geometry of the wall and the support of the slab in the wall is chosen based on the three different thicknesses in a normal house constructed of brick. Lowest in the house is the wall which has the highest load and therefore also the thickest construction, 2 bricks, 600 mm. In the higher floors in the house the walls are normally thinner. In this case the thinner wall is 1 brick, 300 mm. The simulations are made based on the middle wall, which consists of 1.5 bricks, 450 mm (Eriksson and Hansson, 1974). More about the dimensions of the connection slab-wall can be found in Chapter 3 and in Section 3.5.3 *External wall – floor slab*.

A built-in function adjusts the amount of rain that the simulated detail will be exposed to. It is named rain water absorption factor in the program. The factor can be set to values from 0-1. WUFI support recommends setting this value to 0.7. In the simulations of the walls and supports of the slab, the recommended value was used. When simulating the attic, this factor was varied due to the length of the overhang of the roof. A larger overhang was assumed to decrease the degree of exposure to rain and the value was prescribed to be 0, while a non-existing overhang does the contrary and the value was set to 0.7 instead of 0.

6.1.1 Wall

In order to investigate how different extra layers of materials can affect the conditions in the wall, some renovation alternatives are simulated. The simulations of the simple wall were conducted mainly to control the risk of frost damage in the brick, but also to see the relative humidity distribution in the wall over time. Detailed information about the simulation of the wall can be found in Appendix III. Table 6.1 describes the different cases that were simulated.

Table 6.1 Description of simulated situations of the wall.

Simulation number	Description of simulation
1	Brick wall with thickness of 1.5 brick with internal stucco layer
2	Brick wall with thickness of 1.5 brick with internal and external stucco layer
3	Brick wall with thickness of 1.5 brick with 50 mm external layer of expanded polystyrene and internal and external stucco layer
4	Brick wall with thickness of 1.5 brick with 50 mm external layer of mineral wool and internal and external stucco layer
5	Brick wall with thickness of 1.5 brick with internal stucco and 50 mm external layer of mineral wool with steel sheets as weather protection (non-ventilated air gap)
6	Brick wall with thickness of 1.5 brick with 50 mm internal layer of mineral wool covered by gypsum boards

Figure 6.2 illustrates simulation number 1 from the table above with the positions of the measuring points and material.

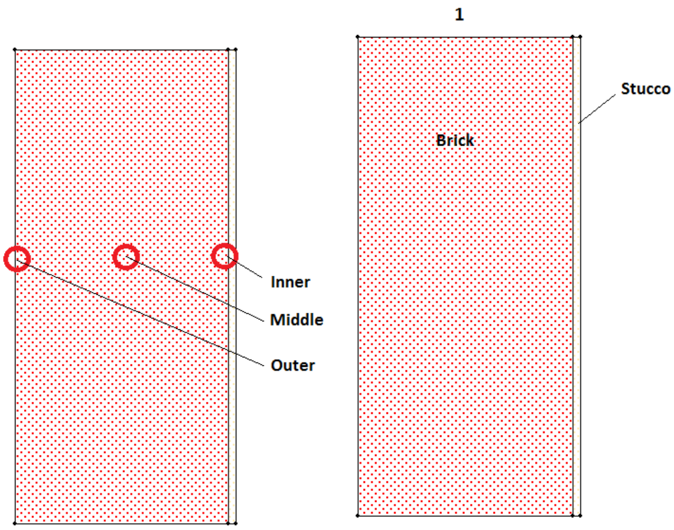


Figure 6.2 Left: Original wall and unmodified model used for simulations of the wall, including measuring points. Right: Material assigned in the model.

6.1.2 Support of slab in wall

One big problem is rotting ends on the beams in the beam boxes on the brick construction (Eriksson and Hansson, 1974). A study from Eriksson and Hansson (1974) shows that about 12% of the beams in an investigated block were rotten. If no signs of rot show or if the signs are detected too late the result can be a collapsing slab, as mentioned in Chapter 5, Section 5.1 *Building1*. Detailed information about the simulation of the beam box can be found in Appendix IV. Table 6.2 describes the different cases that were simulated.

Table 6.2 Description of simulated situations of the support of the slab in the wall.

Simulation number	Description of simulation
1	Non-insulated brick walls with thickness of 1.5 brick, with an internal layer of stucco
2	Non-insulated brick wall with internal and external stucco layer
3	Brick wall with thickness of 1.5 brick insulated with 50 mm exterior layer of expanded polystyrene (EPS) with 15 mm stucco
4	Brick wall with thickness of 1.5 brick insulated with 50 mm exterior layer of mineral wool with 15 mm stucco
5	Brick wall with thickness of 1.5 brick insulated with 50 mm exterior layer of mineral wool with non-ventilated air layered steel façade
6	Non-insulated brick wall with cavity filled with polyurethane foam (closed cells)
7	Brick wall with thickness of 1.5 brick insulated with 50 mm internal mineral wool and gypsum board

Figure 6.3 illustrates simulation number 1 from the table above with the positions of the measuring points and material.

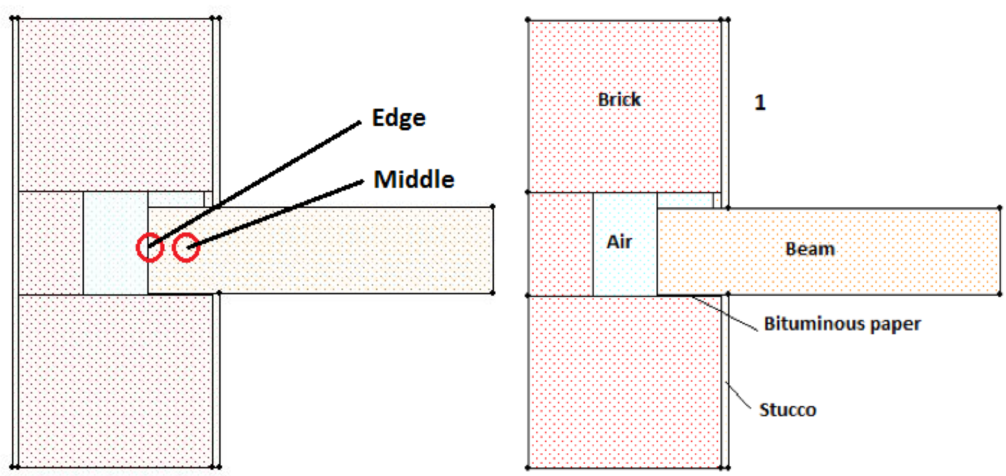


Figure 6.3 Left: Original beam box and unmodified model used for simulations of the support of the slab in the wall, including measuring points. Right: Material assigned in the model.

6.1.3 Connection roof – wall

When it comes to renovations of the attic, from a cold attic to warm apartments, the insulation layer will change the conditions in the roof trusses and the slab beams. In order to minimize the risk of mould growth and rotting processes, a certain solution for insulation needs to be investigated. More about this can be read in Chapter 4, and in section 4.1.1 *Extra insulation*.

In the houses of the block that was investigated by Eriksson and Hansson (1974) about 20% of the beams connecting the roof and the wall were rotten.

When insulation was added to the roof construction, indoor climate was assigned to the internal surfaces. The thickness of the insulation was set to 300 mm. For the situation where no insulation was added outdoor temperature was assigned to the surfaces of the attic, according to Petersson (2013). Detailed information about the simulation of the roof-wall connection can be found in Appendix V. Table 6.3 describes the different cases that were simulated.

Table 6.3 Description of simulated situations of the connection roof – wall.

Simulation number	Description of simulation
1	Insulation and large overhang
2	Insulation and intermediate overhang
3	Insulation and no overhang
4	No insulation and no overhang

Figure 6.4 illustrates simulation number 1-4 from the table above and materials. The positions of the measuring points are the same as presented in Figure 6.4 above.

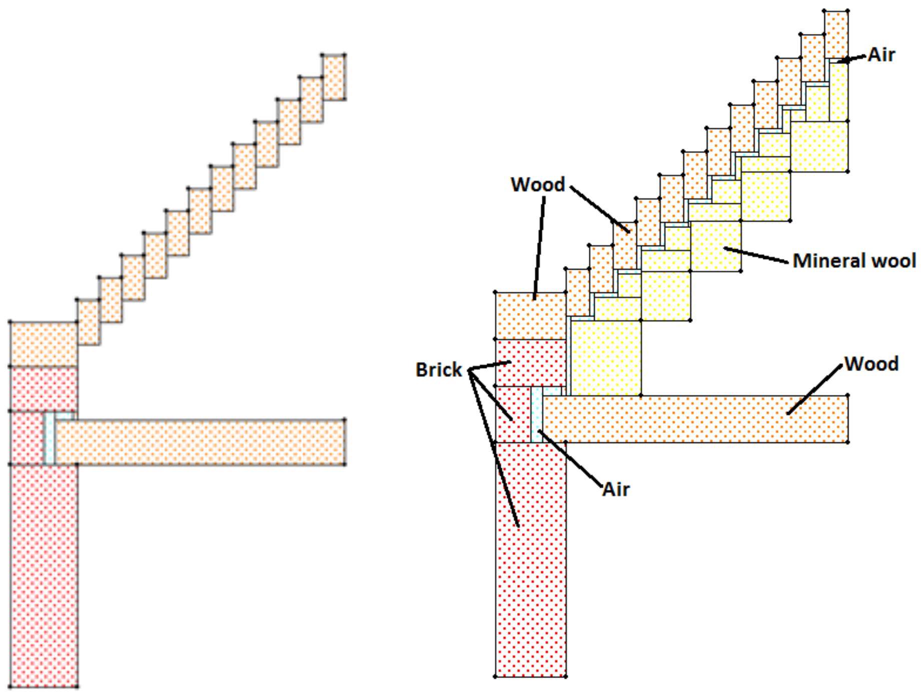


Figure 6.4 Left: Original roof-wall connection and unmodified model used for simulations of the connection wall – roof. Right: Insulated connection and material assigned in the model.

6.2 Simulations of thermal performance

The aim of conduction simulations in COMSOL was to compute U-values $W/(m^2*K)$ of the structural components that are of interest in this project. This enabled the calculation of potential energy savings a certain renovation strategy can result in.

The structural elements that were simulated were the wall and the connection of the wall and the slab beam. The geometry used was the same as described in Chapter 6, Section 6.1 *Hygrothermal simulations*. The two components, wall and connection, was merged and provided a U-value for the total wall structure. The simulated situations are based on what has been observed in the studied buildings and what was found in the literature. Different thicknesses of the brick walls were considered based on what is mentioned in Chapter 3, Section 3.2 *External wall above ground*. The thicknesses are 450 mm and 300 mm. The thickness of the insulation layers was 50 mm and 100 mm when added on the external side of the wall and 50 mm when added internally.

In order to compute the U-value of the other elements in the thermal envelope, such as roof, basement and windows, other methods have been used. To compute the performance of the roof, one-dimensional calculations were performed. U-values for the windows were obtained from the literature and the interviews. To consider the basement, a method presented by Petersson (2013) was used.

6.3 Calculation of energy performance

To see how a certain type of renovation affects the transmission losses, the energy data before and after the renovation is investigated. For the renovations where no energy data is available, simplified calculations are made.

The energy consumption through the district heating system is measured for some years before and after the renovation year. The consumption is adjusted based on degree days for the average year. Energy for the warm water is neglected. Out of this an average yearly energy consumption before and after the renovation is calculated. The method is further described in BFS 2013:16 BED 6, Boverket (2013). This gives percentage change in the yearly energy consumption before and after the renovation.

For the renovations made earlier than available energy data, the average U-value of the house is calculated instead. The U-values are based on the simulations of the thermal performance. The energy savings are then calculated as the percentage change in the total U-value. To get a reference, the average geometry of the windows, roofs, walls, and ground are calculated from the 5 houses.

The different situations regarded were in addition to the original case; change of window, added insulation with 50 mm or 100 mm insulation at one or two façades and converting the attic to apartments. The cases were computed separately. When changing the windows, the U-value of the windows was assumed to be reduced from 2.8 W/(m^2*K) to 1.2 W/(m^2*K).

7 Results and analysis of simulations and calculations

Below follows an analysis and some of the results of the simulations and calculations presented in the previous section. More about them in detail can be found in the attached appendices mentioned before.

7.1 Hygrothermal simulations

The simulations for the simple wall, seen in Appendix III, showed no risk of frost damages for any of the alternatives, based on the fact that the critical water content was set as 90% of the saturated free water content together with a temperature below zero ˚C. The relative humidity after 3 years simulation is showed in Table 7.1 for the three points (outer, middle, inner).

None of the 6 types of walls with different layers of insulation and façade materials show risk of frost damages with the simplified control of frost damages. If a more advanced control would have been used, where the brick material was further investigated and the number of freeze- and thaw cycles were taken into account the result could show higher risks.

The simulations are made with the façade facing south. The south façade is exposed to the most driving rain, but also the most amount of sun light. If the simulations were made for all the directions, even the simple frost damage control would maybe indicate risk.

Table 7.1 RH after 3 years, in the end of the simulation of the simple wall.

Simulation number	RH [%] outer	RH [%] middle	RH [%] inner
1 (wall)	81.3	96.2	82.5
2 (wall)	67.9	61.1	59.6
3 (wall)	54.8	53.8	57.6
4 (wall)	57.4	51.9	57.1
5 (wall)	54.5	54.8	57.8
6 (wall)	82.4	96.8	91.0

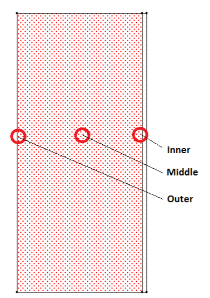


Table 7.2 shows the RH in the edge and middle point of the beam ends in the end of the simulations for the slab connection in the wall. It also shows the mould growth index.

The basic wall (type 1) which has no covering layer on the exterior side, shows a non-stabilized increasing relative humidity in both the edge points and the middle points. After the 3 years simulation the RH has reached close to 93% on the edge and close to 83% in the middle. Since it is not stabilized yet and has an increasing trend, the values will not be lower. In other words, the whole part of the beam that is on the support has a very high risk of rot. This is also proved in the hygrothermal diagram, which shows that the temperature and relative humidity during most of the time is above the safe level when it comes to mould growth in organic materials. This is also seen in the control of risk for mould growth in Appendix IV.

The best version of wall according to the simulations in Appendix IV is type 4 with 50 mm mineral wool and stucco layer. The one with corrugated steel, type 5, gives 3 percentages higher relative humidity in both points.

One type of solution that is possible to do if the owner to the house does not want to cover the brick wall is to fill the air in the beam box with polyurethane foam. The results from the simulations in Appendix IV give a non-stabilized RH curve which is close to 70% at the edge of the beam. The hygrothermal conditions are on the safe side. To be shore if the solution really is safe, a second simulation with doubled time steps were made. It shows that the RH after six years reaches about 70%. According to the hygrothermal diagram the conditions in the beam are within the area when it comes to mould growth. The control of the mould growth index does not show any risk either.

Table 7.2 Mould growth index and RH in edge point for simulations of slab in wall after 3 years.

Simulation number	RH [%] Outer	RH [%] Middle	Mould growth, index 0-6
1 (slab in wall)	92.4	82.6	4-5
2 (slab in wall)	59.1	57.2	0
3 (slab in wall)	54.5	53.5	0
4 (slab in wall)	52.5	51.4	0
5 (slab in wall)	55.9	54.5	0
6 (slab in wall)	68.2	65.8	0
7 (slab in wall)	93.8	86.3	4-5

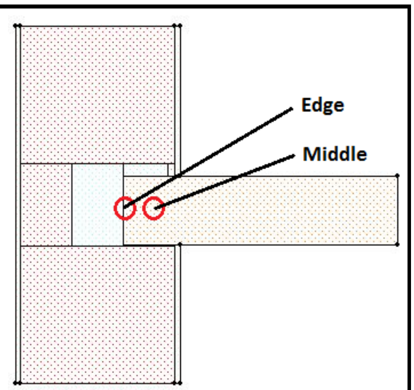


Table 7.3 shows the RH in the measured points of the beam ends in the end of the simulations for the attic slab and the mould growth index.

The influence of an overhang by decreasing the rain water absorption factor was performed in these simulations. It also provides insight as to how the rain water absorption factor affects the structure and how great of an influence the factor has on the results. No air exchanges in the cavity behind the insulation were simulated.

The only situation that can be considered not to be a case with an overhanging risk of mould growth in the support was the first case where the overhang was large and the rain water absorption factor was set to zero. This can also be concluded from the isopleth. The relative humidity in the edge is of similar magnitude as the relative humidity in the middle but varies to greater extent. The simulation period for this case seems to be sufficient, the curve for both edge and middle appears to be stabilized after three years.

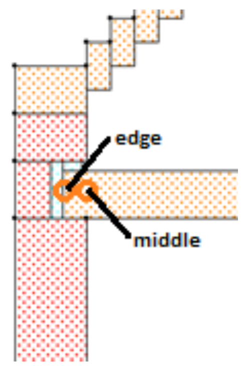
The simulation period could perhaps be extended when it comes to the other three cases concerning the evaluation of the middle point, but it is possible to predict the mean value of the relative humidity and its amplitude. This is not unexpected, since this evaluation point is located deeper into the structure and hence requires more time to stabilize and reach steady-state conditions.

The second case, where the overhang is a bit shorter than in the first case and the rain water absorption factor was set to 0.3, generated high values of relative humidity both at the edge and in the middle, up to 80% and almost always above 70%. According to the mould growth index there was basically no risk of mould growth after all. When considering the isopleth, a similar conclusion can be drawn. The isopleth presents that there are situations when the relative humidity matched with a critical temperature, but not sufficiently common to generate mould growth.

Both cases where the overhang was simulated not to exist and the rain water absorption factor was set to the recommended value of 0.7, relative humidities well above 80% was the result for both the edge and for the middle points. Mould growth index and isopleths indicate that these are critical cases and that the risk for mould growth is great. Concerning the mould growth index for these situations, there appears to be no decline which means that the mould does not disappear.

Table 7.3 Mould growth index and RH in edge point for simulations of attic slab after 3 years.

Simulation number	RH [%] Outer	RH [%] Middle	Mould growth, index 0-6
1 (connection roof – wall)	64.7	63.7	0
2 (connection roof – wall)	75.0	73.3	0
3 (connection roof – wall)	89.6	84.8	3-4
4 (connection roof – wall)	86.5	83.3	3-4



7.2 Thermal simulations

Table 7.4 below gives reduction of U-value of a wall section.

Table 7.4 Reduction of U-value due to different thicknesses of added insulation.

Wall thickness [mm]	U-value, original structure [W/(m^2*K)]	U-value, structure with added insulation [W/(m^2*K)]	Reduction of U-value [%]	Width of added insulation [mm]
300	1.45	0.52	64	50
		0.31	79	100
450	1.07	0.46	57	50
		0.29	73	100

Due to the thickness of the walls and the thermal conductivity of the brick and masonry the U-value of the uninsulated walls was not remarkably high. This gives that thinner walls located higher up in building has colder surface temperature on interior side than the thicker ones.

Not very much insulation is needed to reduce the U-value of the details significantly. The magnitude of the difference in reductions due to the different thicknesses of added insulation is also of interest. In one way, the reduction obtained with 50 mm added insulation can be considered sufficient. On the other hand, if this particular type of renovation is about to be executed, one can argue that it is better to add 100 mm since the renovation process is about to take place nevertheless.

Table 7.5 below gives reduction of U-value of a wall section including a support.

Table 7.5 Reduction of U-value due to different thicknesses of added insulation.

Wall thickness [mm]	U-value, original structure [W/(m^2*K)]	U-value, structure with added insulation [W/(m^2*K)]	Reduction of U-value [%]	Width of added insulation [mm]
300	1.43	0.52	64	50
		0.32	78	100
450	1.06	0.46	57	50
		0.29	72	100

The support does not work as a thermal bridge since the thermal conductivity of wood is lower than for brick. This gave a very small difference in the U-value when considering a section of an ordinary original wall structure. The difference of the two sections also indicates similarities when it comes to the reduction of the U-value.

Table 7.6 below gives reduction of U-value of a wall section including a support where the cavity is filled with insulation material instead of air

Table 7.6 Reduction of U-value due to added insulation in cavity.

Wall thickness [mm]	U-value, original structure [W/(m^2*K)]	U-value, structure with added insulation [W/(m^2*K)]	Reduction of U-value [%]
300	1.43	1.40	2
450	1.06	1.02	4

Insulating the cavity decreases the U-value by 2% for a wall with thickness 300 mm and 4% for a wall with thickness 450 mm. The impact on the thermal performance is very small. There was larger impact on thicker wall, probably because the cavity is larger.

7.3 Energy calculations

Total U-values after some renovations are presented in Table 7.7. The calculations for all the reductions can be found in Appendix VI. The reductions of the U-values and percentage reduction are based on the average geometry of the five studied buildings. For a certain building the numbers can differ, due to deviant proportions in geometry. The renovation of the attic apartments is increasing the A_{temp}. To give an indication on how much the extra heated area influences the results of the energy consumption per square meter heated are, also the reduction of U/A_{temp} is presented for the renovation of the attic apartments.

Table 7.7 U-value reduction due to different renovations.

Renovation	U [W/(m²*K)]	Reduction U [%]	Reduction U/A_{temp} [%]
Original	1.52	-	
Windows, 2.8->1.2	1.34	12	
100 mm court yard	1.27	16	
50 mm court yard	1.32	13	
100 mm all walls	1.03	32	
50 mm all walls	1.12	26	
Attic apartments	1.06	30	40

In Table 7.8 energy savings are presented for the different renovations. The savings are based on equation 2.5. The savings are also presented in diagrams in Figure 7.1 and 7.2.

Table 7.8 Energy savings due to U-value reduction from renovations.

Renovation	Original U-value [W/m²*K]	New U-value [W/m²*K]	ΔU [W/m²*K]	A, thermal envelope [m²]	degree hours [°Ch]	Atemp [m²]	ΔE [kWh/m²/year]
Windows	1.52	1.34	0.18	2444	80000	3108	11
100 mm court yard	1.52	1.27	0.25	2444	80000	3108	16
50 mm court yard	1.52	1.32	0.20	2444	80000	3108	13
100 mm all walls	1.52	1.03	0.49	2444	80000	3108	31
50 mm all walls	1.52	1.12	0.40	2444	80000	3108	25
Attic apartments	1.52	1.06	0.46	2444	80000	3108	29

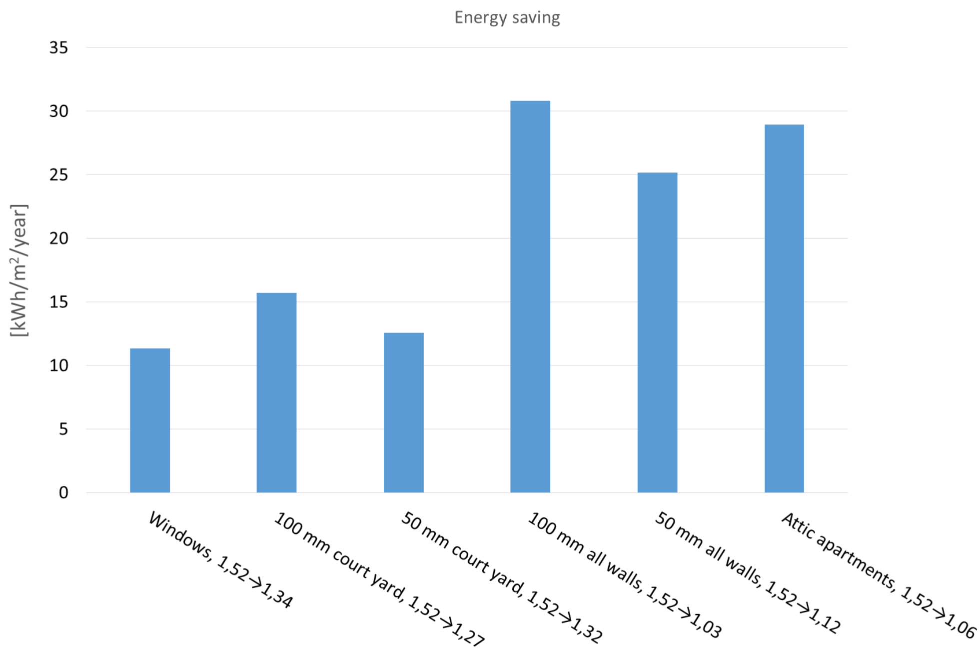


Figure 7.1 Diagram with energy savings due to U-value reduction from renovations.

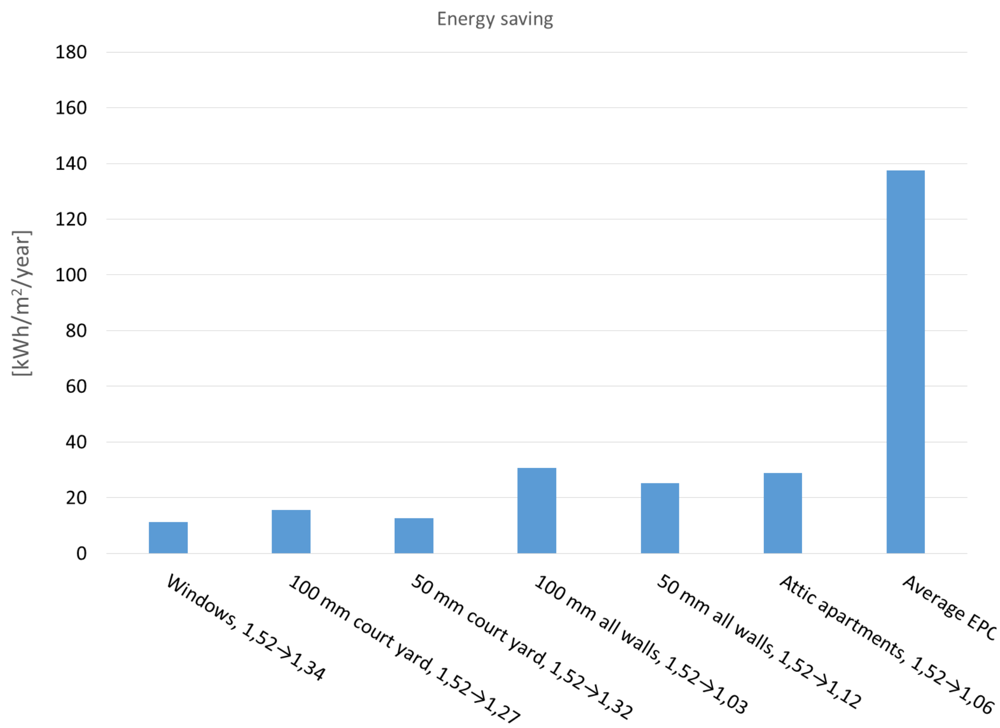


Figure 7.2 Diagram with energy savings due to U-value reduction from renovations and average EPC.

If all possible combined renovations would be made (windows, 100 mm on all walls and attic apartments) showed in Figure 7.2, the average EPC would decrease from 138 to 67 kWh/m^2/year. According to the rating scale from Boverket in Figure 2.1 and Table 2.1 this means that the grade would go from F to C for the average EPC.

8 Discussion

Below follows a discussion of the methods, results, parameters and alternatives that have been presented in the report.

Construction of buildings in the literature and in practice

According to the literature concrete slabs were introduced around the turn of the century. None of the studied buildings had pure concrete slabs. Whether the concrete slabs are common or not for brick buildings in Gothenburg during this time is hard to determine from the selection of studied buildings. To get more adequate information a larger selection of buildings should have been investigated through studies of drawings from City Archive of Gothenburg.

If the concrete slabs are more common than what the selection tells, the simulations made in this project are less representative for the studied buildings, brick buildings constructed between 1870 and 1930. Regardless of the amount of concrete slab constructed houses, the project represents a significant part of the buildings, due to the late introduction of concrete slabs.

As for the rest, the buildings matched well with the building type and what could be expected based on the literature, but were different enough in comparison to show altered details. For example, the roof trusses diverged among the studied buildings, but were all to be found in the literature.

Method of selection and collection of data

There are different ways to conclude which building type is of most interest to evaluate. Free choice is one way. The downside of this type of choice is that the motivation to why the chosen building type was of interest might be entirely subjective and not scientifically established enough.

Another way of selection is through registers and databases. The use of databases requires validated and similar information about all buildings in the building stock. In this state, these factors might give a misleading picture. The reliability of the data of the registered buildings can also give a misleading picture, some buildings might not be included in the database. Although, a database is a good tool to prove that there are a number of houses with similar properties and can then provide support when arguing that the existence of the buildings is of relevance.

A third alternative could be to study buildings that are the most common building type to be renovated. This approach is more governed by the market and by those who are in position of making renovations, and might by this not cover the spectrum of interest from a scientific approach.

One can also consider this from a point of view where the very building is not of major interest, but rather the renovation itself. If one for example studies the changing of windows in the thermal envelope and does not consider the wall type where the window is located to be of major interest, another perspective can be used in the project.

The available literature, through which background information about the buildings could be obtained, provided a sufficient amount of data for this cause. To find examples of different renovations and renovation strategies was also possible in large extent. One might think that the range of the literature was quite narrow and old, but a lot has been written about the field already. If one considers a specific renovation, it might be possible to find even more examples in the literature. One thing that can be claimed to be problematic is how connections and details are designed. The literature provides typical examples, but when comparing them to reality it can be difficult to validate these designs.

The energy data which was given from the property owners, consisted of both measuring of the total energy provided to the buildings from district heating and from EPCs. One flaw with EPCs is that they might be produced with different levels of ambition and resemblance when validating the properties of the building. The measured value of the total energy provided to the building are in this sense a more reliable source of information. On the other hand, if the data from EPCs can be considered as reliable, comparisons can easily be made.

Data from the drawings did not provide much information about renovations on the buildings. In some cases, the documentation was well performed, and in some cases it was not. Drawings were not available for situations when external insulation was mounted on the façades or when windows were changed. For one case where the attic recently was converted into apartments, detailed drawings were available.

The field investigations provided the opportunity of asking the property owner questions about the building. A separate meeting for this cause is an alternative method that would probably result in a more beneficial outcome, since the property owners´ time does not need to be claimed during collection of data through different methods. To talk with the property owner can provide good information about the history of the building and renovations performed, if the owner is familiar with this information.
Data collected from the field investigations could provide information that would justify calculations made. It is then of importance to be able to collect these measurements from cases that are simulated.

Collection of valuable data could be performed through being a part of a renovation while the thermal envelope t was to be changed. A better insight in the status of the building could then be reached.

Aesthetic aspects
When renovations are conducted, it is possible that the building gives new impressions. This should be considered if the impressions of the building are of interest. Adding extra insulation and a new external layer to the façade might affect the energy performance positively, but it might affect the inhabitants negatively since the new façade can be seen as ugly or inappropriate. Windows which are not adapted to the opening in the wall is another example.

When it comes to preserving an old façade, adding external layers can be considered as a good option, as long as one does not take into account that the original façade cannot be seen. The external layers will be exposed to the outdoor climate instead of the original façade. If it in the future, then for example is possible to insulate the buildings from the inside without exposing the façade to moisture risks, the layers can be removed some parts of the architectural basic idea still remains.

Another problem with exterior insulation, except the hidden architecture, is the room. When the extra layer is added, the room for sidewalks decreases. This can also be a reason to why the façades facing the street are not insulated.

8.1 Hygrothermal simulations

Common results for all simulation made are presented and discussed before the results for the individual details simulated are discussed separately.

The façade was set to facing south in all of the performed simulations. This is the most exposed direction of driving rain for the used geographical location in WUFI. This has to be considered during comparison between different buildings. Changing direction could decrease the moisture load and provide more beneficial results, especially if none of the façades of the building are facing south and if the building is situated between two houses.

The material properties that were assigned were based on built-in material data in WUFI. Changed properties will give different results. The properties of the materials that are built-in and used in the simulations do not necessarily need to be consistent with the materials that are used in reality. If, for example, the historical timber that is used in the slab is denser than the timber assigned in the program, it is possible that the relative humidity over the simulated time period in the material would have a lower magnitude than the given results, due to the fact that it is more compact and less permeable. Whether this relationship really holds or not, needs to be further investigated.

To verify the rain water absorption factor, a test wall could be built and examined considering relative humidity and water content while the test wall is exposed to rain in different degrees. This would also provide guidance when it comes to deciding the magnitude of the rain water absorption factor.

During the simulations, no air exchanges in the cavity where the slab is supported was assigned. Different options are possible for this particular part in the simulations. One could reason, that indoor air, due to natural convection, meets the cold surfaces of the end of the slab where it can condensate. Although one problem with this is, that in order to estimate the number of air exchanges in this cavity requires research itself. Also, it is reasonable to assume that it is more or less air tight between the interior room and the cavity where the slab is supported. Presented literature also claims that during normal conditions condensation due to vapour diffusion could be neglected. Since the rain absorption factor has such a large influence on the results even when air exchanges are not considered, it is sufficient to not let the air exchanges occur. Although, if an external layer of insulation was to be added as well as polyurethane foam, the conditions of relative humidity becomes more beneficial than when nothing is done or when insulation is added interiorly. This might have to do with the temperature in the structure. Externally added insulation makes the surfaces warmer.

An external layer of stucco also provides better conditions. It is possible that the stucco acts like a rain barrier and slows the capillary suction down.

It is very difficult to predict how a ventilated air gap would affect the results. In one way, the air could ventilate moisture away. On the other hand, ventilation could work as a moisture source depending on the conditions of the air and the temperature of the surfaces. It is also not easy to estimate the number of air exchanges in the cavity. If one wants to consider this, more specialized and deeper investigation should be executed.

Wall

The frost damage control conducted in this project indicates which wall that has higher risks of frost damages rather than showing if there really is a risk of frost damages. In other words, the control cannot tell if the risk does not exist, only compare which wall has the highest risk of frost damage.

In order to conclude that a certain brick wall will not be frost damaged due to a renovation, it is necessary to conduct an analysis on the brick material before doing the simulations and before determining the critical conditions.

Support of slab in wall

The results from the simulations made for the beam box do not show that all beam ends need be rotten. The boundary conditions are set to give the climate on the most critical part of the façade facing south. What the results show is rather that many of the beam ends are having a high risk of mould growth in some critical parts in the house.

To avoid a collapsing floor, it is convenient to inspect the beams and improve them in conjunction with a renovation of the climate envelope.

The safer types of renovations are the ones where the bricks are covered externally. The simulations are made based on the outer layer having no damage. In case of damage in the outer layer, the alternative with corrugated steel is probably better than the other externally covered alternatives. When driving rain enters the construction the air layer increase the drying compared to the stucco façade.

The method with polyurethane foam filling in the beam box is dependent on the dimension of the beam box. The air gap between the brick and the beam needs to be big enough to give a vapour resistance that can stop the moisture from the driving rain. Many of the brick constructed houses probably have geometries that differ from the geometry in the simulations.

Connection roof – wall

Since case one to three had identical conditions and only different rain water absorption factors one could claim that this arbitrary factor should be chosen with great care since the results differ with great magnitude.

The geometry of the model could be simplified if one can argue in favour of not including the pitched part of the roof. One difficulty needs to be handled in this case, namely the boundary condition on the top of the structure. The surface cannot be considered to be adiabatic since heat and moisture transport has the possibility to take place in two directions.

The only situation that can be considered not to be a case with an overhanging risk of mould growth in the support was the first case where the overhang was large and the rain water absorption factor was set to zero.

The temperature inside the attic for the reference case could also be discussed. It was set to be equal to the outside temperature in the simulations conducted. To be more accurate, a designed temperature curve for a specific case could be implemented, along with air exchanges inside the attic.

8.2 Thermal simulations

Insulation of these wall types makes them more alike than before and the thickness of the wall becomes less relevant due to the influence of the insulation. This also leads to more similar surface temperatures of the interior side of the wall. When insulating exteriorly, the construction on the inside of the insulation will obtain an increased temperature. This would probably affect an aspect that was not considered in this thesis, namely the thermal comfort, which would probably be improved since the surface temperatures will be higher than before insulation was added to the construction.

To verify the calculations, following factors could be controlled.

- Measure with thermographic camera to verify surface temperatures and hence the U-value
- Verify material data
- Verify that no air exchanges take place in the cavity

For specific cases, a verification of the dimensions in the geometry is needed. Since the thermal performance of a wall section including a support of the slab was very similar to a section of the wall with nothing but wall, it might be of less interest to put effort into this detail from this point of view.

Neglecting the possible ventilation in the cavity of the beam box probably has small impact on the thermal performance. Although, other aspects are connected to this as well, such as the performance due to moisture problems. Insulation of the cavity probably reduces the ventilation rate, and will increase the surface temperatures of the supported slab. These factors will for certain affect the moisture conditions in the detail.

8.3 Energy calculations

The energy calculations were based on mean values of the properties of the visited buildings. In other words the properties regarding areas of structural components and geometry and U-values of the components. When using this type of information, the result will only indicate what can be predicted of the model. It is not equal to stating that the result is exact, but will still give a relation between savings of the different types of renovation strategies. To obtain more accurate savings of a certain building, the properties of that particular house have to be used when computing the saving.

To make all changes simultaneously might not be possible from an economical point of view, but indicates that a large saving can be achieved and the performance of the building in regard to energy consumption can be improved. This also provides incitement to retain and preserve the buildings rather than demolishing them to make room for new ones. When considering buildings of the studied type in the building stock where it is possible to make only some of these renovations, the savings will have less magnitude.

8.4 Alternative and innovative renovation methods

Renovations that involve demounting the brick wall are a big and probably very costly method. On the other hand, the result is a modern thermal envelope with the old impression of the building. One positive thing that could compensate the big cost is that the newer wall will be thinner and provide the building with a bigger floor area.

In case the attic is not used for storage a converging into apartments is a good idea. The total floor area in the house is increased by almost one through the amount of floors and the insulation of the roof is increased. Important to consider during this kind of renovation is that the conditions around the beam ends are changed and need to be analysed.

During the project, ideas about renovations were written down. Renovations that were discussed during the project, but that are not considered and investigated in this report are the following:

- Heat the air in the basement with energy from the sun
- Beam end made out of non-organic material
- New steel frame that is insulated with an air gap to the existing outer wall

One of the buildings, Building 5, had excessive heat from the heating system in the basement as mentioned in in Chapter 5, Section 5.5 *Building 5*. This resulted in a high tempered basement which felt very dry. After the site visit, ideas about how to achieve this climate without using costly energy were discussed. One idea could be to use the energy from the sun to heat the area in the basement. This means that the heat can be extracted from the sun efficiently, during the summer. During this period the air that enters the basement will be hot and humid while the surfaces inside the basement are cold which can lead to moisture problems. If heat from the sun can be used to increase the temperature of the basement, it might prevent moisture problems in situations where it is not possible to insulate the foundation wall or install drainage.

Rotting beam ends are a problem both in the original construction and in some renovation methods. To avoid this problem, beam ends out of non-organic material could be produced.

The renovation described in Chapter 4, Section 4.2.4 *New steel frame,* inspired an idea about making a new thermal envelope inside the old one with an air gap in between the new thermal envelope and the existing brick wall. This method could be used on the façade facing the street, while the façade facing the inner yard is treated from the outside instead. Then the original impression of the house is kept, but some floor area is sacrificed.

9 Conclusion

The safer types of renovations regarding moisture risks are the ones where the bricks are covered externally, or in any other way prevent the moisture load from the rain. If no changes are to be made to the façade, there are solutions to decrease the risk of mould growth of the slab ends. These solutions need to be individually controlled and analysed, and will only improve the hygrothermal properties of the thermal envelope. The improvement of the thermal performance, the U-value, is neglect able.

The most beneficial renovation regarding energy use is insulation of all exterior walls or conversion of attic space apartments. Both ways save more than 30% transmission losses. If the windows are changed, all the façades are insulated with 100 mm and the attic space is converted into apartments, it is possible to decrease the transmission losses by about 70%.

The control of frost damages in this report cannot tell if the risk does not exist, only compare which wall has the highest risk of frost damage. For the simulated cases, the wall type with internal insulation and original design are the most risky.

Common for the brick buildings are problems with driving rain. The rain water absorption factor in the simulation should therefore be chosen with great care since the results differ with great magnitude due to this number. In other words, the rain water absorption factor cannot be estimated. It has to be proved through a practical test.

In order to get an improved investigation during the case study it is better to study cases where renovations are taking place, to be able to measure and control certain details.

If the aesthetic point of view is important to follow, the complexity of the renovation is increased. Solutions that keep the appearance of the building intact need thorough simulations and analysis

9.1 Future work

Future studies that could be conducted in order to develop the knowledge about renovation of old brick buildings are presented below:

- Investigate which types of bricks that are the most common in brick buildings constructed during the period considered in the project, which is 1870-1930. The investigation should give useful information that can be used when determining if any renovation method causes frost damages in the brick wall.

- Investigate how a non-organic beam end can be produced and how it can be installed in the buildings.

- Do further investigation on how an internal thermal envelope can be constructed and designed for brick buildings constructed 1870-1930.

- Investigate how the quality and properties of old timber differs from new timber.

- Do a case study like this project, but the cases should include ongoing renovations.

- Do practical tests to estimate the rain water absorption factor.

- Do an inventory of the beam ends in some brick buildings constructed 1870-1930 in Gothenburg.

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11 Appendices

11.1 Appendix I, data about the buildings

11.2 Appendix II, thermal simulations, COMSOL

11.3 Appendix III, hygrothermal simulations, wall, WUFI

11.4 Appendix IV, hygrothermal simulations, support of slab in wall, WUFI

11.5 Appendix V, hygrothermal simulations, roof–wall, WUFI

11.6 Appendix VI, energy readings and energy saving calculations

11.7 Appendix VII, protocol for inspection of buildings

11.8 Appendix VIII, climate conditions from WUFI

Appendix I

Data about the studied objects

Contents

Data about the studied objects

Follow does an overview of data of the studied objects concerning properties of the buildings and energy consumption.

Table 1 Data about the studied objects.

Building	1	Comment	2	Comment	3	Comment	4	Comment	5	Comment
Construction year	1917		1887		1932		1907		1929	
Value age	1930		1970		1932		1982		1970	
Floors	7	Bottom floors + apartment floors + attic floor	7	Bottom floor + apartment floors + attic floor with apartments	7	Bottom floor + apartment floors + cold attic	6	Bottom floor + aprtment floors + attic with apartments	7	Sloping house with basement floors on different levels
Foundation	Deep foundation and and shallow	Partly of both							Basement + foundation on the rock	
Slab construction	Wooden beams + concrete layer		Wooden beams + concrete layer		Wooden beams + conrete		Wooden beams + concrete		Wooden beams + concrete	
Ownership	Real estate company		Real estate company		Real estate company		Real estate company owned by the community		Real estate company	
Sort of brick	Red		Red		Yellow		Yellow		Red	
Roof			Brick and steel	Brick facing the street and steel to the yard	Schiffer		Steel		Tiles and steel roof	
Windows	Wooden coupled 2-glass	Some windows were changed, with the original wooden frame kept	2+1-glass	Installed around 1980	Renovated original windows	Extra spacer and glass pane	2-glass	Probably changed around 1970-1980 according to the design	2+1-glass	New windows mounted in the old frame
Walls	Solid brick + 50mm mineral wool + stucco	Insulated walls facing the yard	Solid brick + 100mm mineral wool + stucco	Insulated walls facing the yard	Solid brick	Non-insulated	Solid brick + 50mm mineral wool + steel façade		Solid brick	Interior surface probably covered with stucco on reed
Energy performance [kWh/m^2 year]	109		135		145		126		172	
BOA (living area) [m^2]	1469		2085		1108		3260		1456	
LOA (local area) [m^2]	1550		285		193		0		211	
A_{temp} [m^2]	5091		2634		1566		4075		2084	

The table and diagram below presents the energy consumption of the objects.

Table 2 Energy consumption of the studied objects.

Year	Building 1 [kWh/m²]	Building 2 [kWh/m²]	Building 3 [kWh/m²]	Building 4 [kWh/m²]	Building 5 [kWh/m²]
2005	104	123	121	128	154
2006	116	133	139	141	150
2007	99	126	134	141	147
2008	98	128	134	137	152
2009	99	121	126	136	147
2010	94	105	102	119	135
2011	101	123	81	128	153
2012	100	117	101	121	134
2013	100	135	117	144	161
2014	107	129	99	137	152
2015	112	117	91	127	147
Energideklaration	107	130	142	117	159

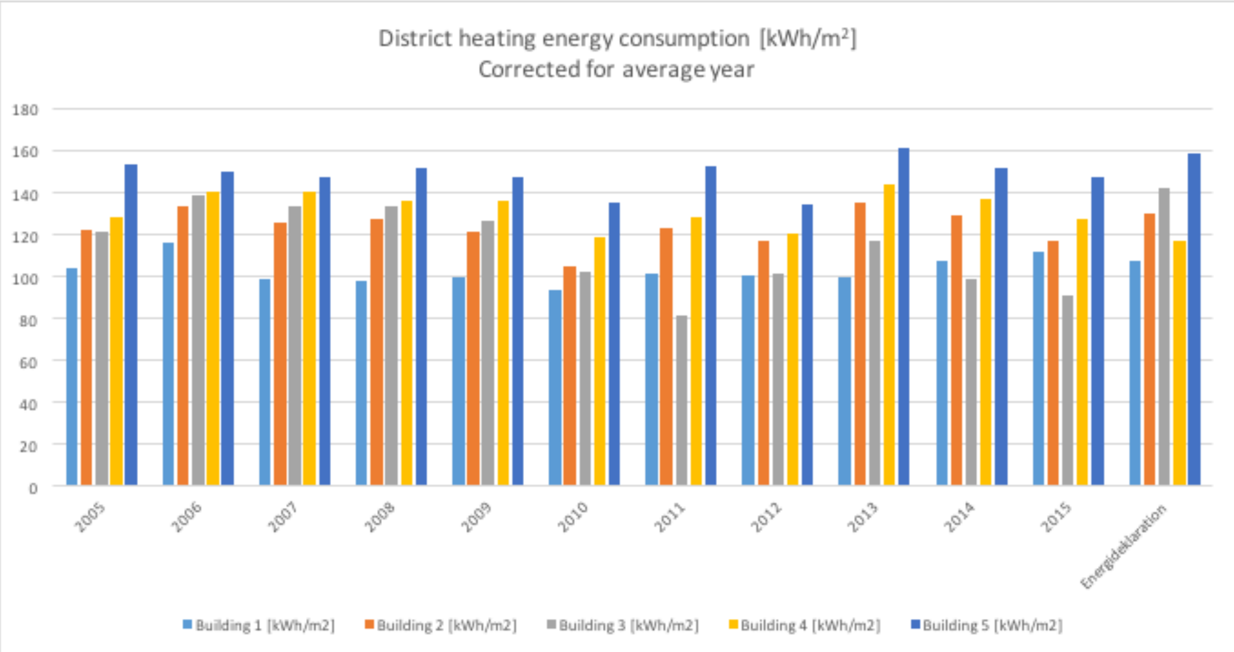


Figure 1 Energy consumption of the studied objects.

Appendix II

Thermal simulations
Comsol

Contents

Wooden beam, support in brick wall and ordinary brick wall

Two modelled details will be presented in this appendix. The first detail is a cut through an ordinary brick wall and the second detail is the support of the slab in the wall. The results that was expected from the simulations was the U-value of the detail, and therefore steady-state calculations were executed. Surface temperatures for some surfaces has also been computed.

All cases have been modelled with a wall width of 300mm and 450mm, which corresponds to a brick walls constructed by 1½ - stone and 2-stone.

The ordinary wall has been modelled with following variations:

1. Ordinary wall
2. Added insulation, thickness 50mm and 100mm

The detail of the support of the slab in the wall has been modelled with following variations:

1. Air in cavity between slab and wall.
2. Added insulation to the exterior side of the wall, thickness 50mm and 100mm.
3. Insulation in cavity between slab and wall.
4. Added insulation to the interior side of the wall, thickness 50mm.

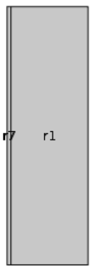
Program information

COMSOL 5.2, version number 5.2.0.220 has been used to perform the calculations.

Geometry

The geometry is based on data supported from the literature and on information collected from the study visits.

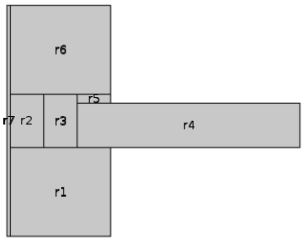
Ordinary brick wall



Any thermal resistance from possible surface layers, such as stucco, on the interior side of the wall has been neglected. This, since it is not known what material there is to be found on this part of the wall structure.

The height of the wall was set to 1m in all cases. The thickness of the exterior stucco was set to 15mm.

Support of slab in wall



With the same reasoning as above, thermal resistance from any interior surface layer has been neglected. The cavity between the slab and the wall, denoted as “*r3*” and “*r5*” in the figure above has different dimensions depending on the width of the wall, see table below.

Wall width [mm]	300		450	
Rectangle	Height [mm]	Width [mm]	Height [mm]	Width [mm]
r3	240	50	240	150
r5	40	100	40	150

The height of the rectangles “*r1*” and “*r6*” was adjusted until the isothermal contours stabilized above and below the connection. Based on the same reasoning, the width of “*r4*” was determined.

The height of the slab was set to 200mm. The thickness of the exterior stucco was set to 15mm.

Materials

Material assigned to the wall was brick, the slab was assigned as wood and the cavity as air or insulation.

Air cavity – (source: Hagentoft, 2001)

- Modelled as non-ventilated air gap, very difficult to estimate any ventilation rate in the gap and from where the air will be supplied. Thus, heat will be transferred by conduction and convection
- Air gaps has different thermal properties based on orientation and thickness
    - Orientation
        - Horizontal and vertical air gaps in model, has different thermal properties which has been considered
        - Heat transfer coefficient depends on which side of top and bottom that is warm
        - Simulation gives, with boundary conditions described below, that bottom side is warmer than top side. This results in horizontal heat transfer coefficient is 1.3-1.5 times larger than vertical heat transfer coefficient.
        - In this case, considered to be 1.5 times larger. High value of alpaha_c+cd gives low value of resistance R in thermal network, which means that the capacity of insulation of air is not accounted for as much as it could be, which gives makes the wall less efficient from the current point of view (thermal resistance), to not over-estimate the capacity of the connection
    - Thickness

        - Thermal conductivity is mostly consisted by conduction for narrow air gaps. Increased thickness of gap gives less influence by conduction and more by convection
        - Thickness of horizontal air gap is now set to 40mm and vertical to 50 or 150mm. Range of vertical thickness is considered
        - For air gaps larger than approximately 20mm, difference in surface temperature affects the heat transfer coefficient
        - Mean value of heat transfer coefficient was considered. Based on different thicknesses and temperature differences of the gap
- Radiation between surfaces in the cavity is considered.
    - Emissivity of wood: 0.9 and brick: 0.93
    - View factor: 1
    - Mean temperature of surfaces
        - Surface 1 was given indoor temperature T1: 21°C
        - Surface 2 was given temperature T2: -20, -19, …, +19, +20°C
        - Mean of T1 and T2 was computed: T12.1, T12.2, … , T12.39, T12.40
        - Mean of T12.1, T12.2, … , T12.39, T12.40 was computed and used
        - Iteration can improve alpha_r when surface temperatures was computed based on boundary conditions below. Difference was 6%, considered to not be that significant to affect the results in any larger extent

For the air, radiation, conduction and convection are merged into one heat capacity coefficient. COMSOL treat this coefficient as thermal conductivity.

Brick was considered to be an isotropic material, no difference in thermal conductivity due to direction inside the material. Wood was considered to be an anisotropic material with different thermal conductivity depending on direction.

Table below presents used data.

Material	Thermal conductivity λ [W/m*K]
Stucco	0.80
Brick	0.60
Thermal insulation, wall	0.04
Thermal insulation, cavity	0.025
Wood, long. dir.	0.23
Wood, rad. dir.	0.09
Air, 50mm	0.31
Air, 40mm	0.28
Air, 150mm	0.92

Boundary conditions and initial conditions

Since steady-state situation was considered was the initial conditions of minor interest.

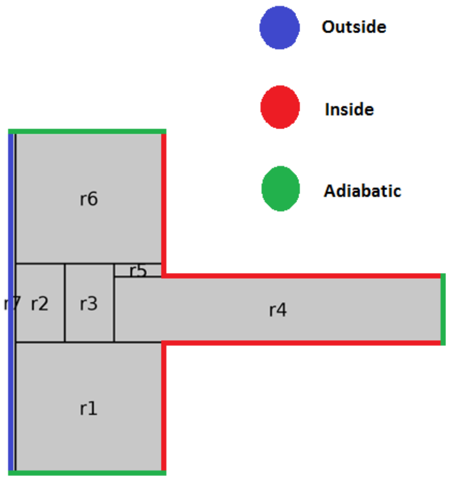
Temperature and heat transfer coefficients of the surfaces was assigned. Adiabatic surfaces were assigned to the cuts/edges.

    - Temperature
        - To get U-value:

- Tin 1°C
- Tout 0°C

o Heat transfer coefficients, Hagentoft (2001)
  - Indoor: 7.7 W/m^2 *K or 0.13 m^2 *K/W
  - Outdoor: 25 W/m^2 *K or 0.04 0.13 m^2 *K/W

Surfaces:



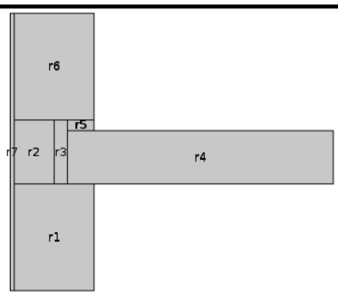
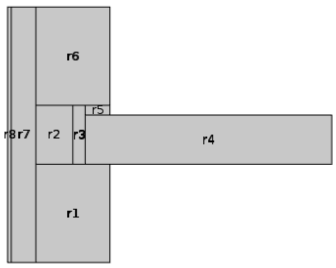
Results

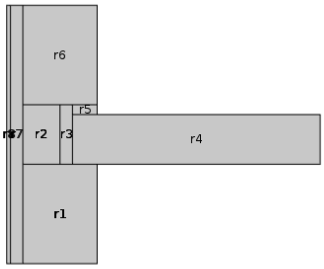
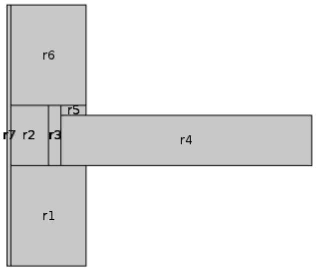
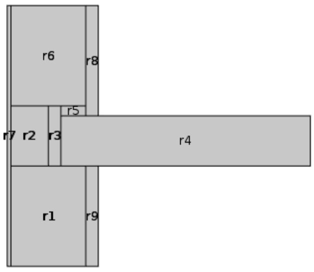
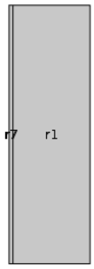
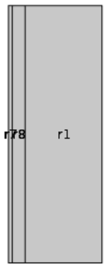
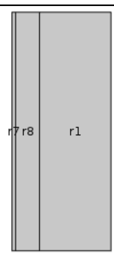
U-value are computed by considering a part of the wall with following dimensions:

- Width equal to distance between floor beams horizontally
- Height equal to distance between floor beams vertically

The dimensions of the horizontal and vertical distances are based on the objects of the study visits.

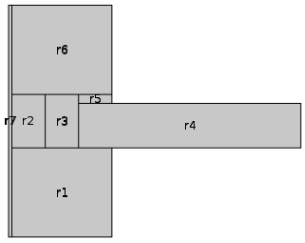
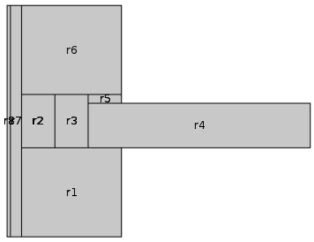
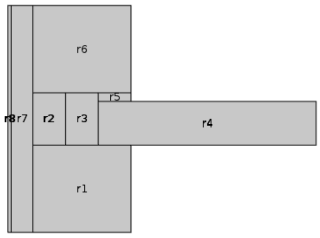
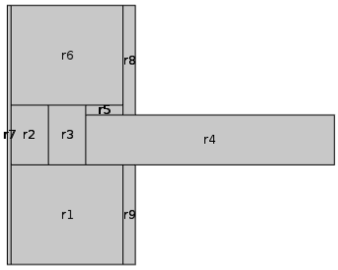
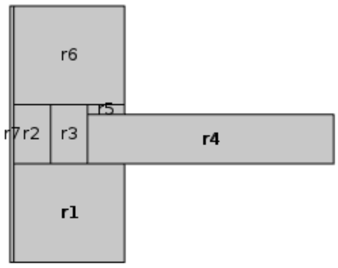
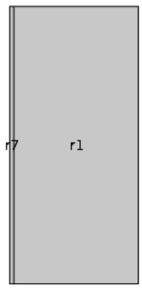
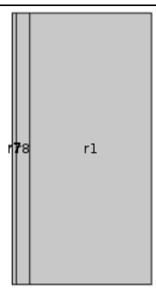
Walls with thickness 300mm

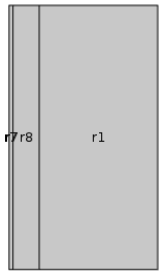
Model	U-value [W/K]	Comment
	1.43	Model 7 Air in cavity
	0.32	Model 10 100mm insulation on exterior side

	0.52	Model 11 50mm insulation on exterior side
	1.40	Model 12 Insulation in cavity
	0.54	Model 13 50mm insulation on interior side
	1.45	Model 16 Ordinary wall
	0.52	Model 17 100mm insulation on exterior side
	0.31	Model 20 100mm insulation on exterior side

Walls with thickness 450mm

Model [PICTURES]	U-value [W/K]	Comment

	1.06	Model 6 Air in cavity
	0.46	Model 8 50mm insulation on exterior side
	0.29	Model 9 100mm insulation on exterior side
	0.47	Model 14 50mm insulation on interior side
	1.02	Model 21 Insulation in cavity
	1.07	Model 15 Ordinary wall
	0.46	Model 18 50mm insulation on exterior side

	0.29	Model 19 100mm insulation on exterior side

Appendix III

Hygrothermal simulations

Wall

Contents

Brick wall

This appendix presents the data and the results for simulations in WUFI of different types of brick walls. The simulations show the temperature and the water content in the brick over a period of three years. The results are supposed to indicate if there is a risk of frost damage in the bricks. The results are indicating which kind of renovation solution that is beneficial for the brick in the wall. Totally 6 different types are studied:

1. 1.5 brick wall with internal stucco layer
2. 1.5 brick wall with internal and external stucco layer
3. 1.5 brick wall with 50 mm EPS insulation and internal and external stucco layer
4. 1.5 brick wall with 50 mm mineral wool insulation and internal and external stucco layer
5. 1.5 brick wall with internal stucco and 50 mm mineral wool with non-ventilated air layer
6. 1.5 brick wall with 50 mm internal insulation and internal stucco layer

Observe that the aim of the simulations is to give an indication of the effect of the different types of walls. For a certain case, precise geometry and material parameters need to be deeper investigated.

Software

The software used for the simulations is WUFI 2D version 3.3. WUFI is a software based on finite volumes and handles transient heat and moisture transports of 2-dimensional geometries. WUFI allows you to add driving rain and heat and moisture sources, which is relevant in this case.

Geometry

Figure 1 shows the basic geometry of the brick wall. The brick wall is 450 mm thick and the section in the Wufi simulation is 1000 mm high. The geometry is based on an average geometry. In other words, the geometry can differ from house to house. The marked areas in figure 1 show the points (outer, middle and edge) where the temperature and the water content are measured.

Figure 2 shows the six different geometries with each materials marked.

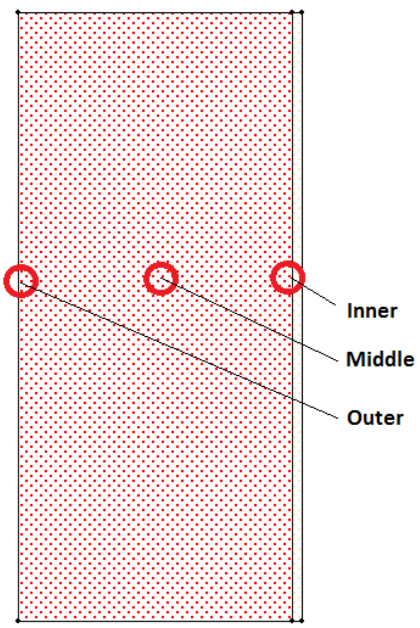


Figure 1, basic geometry with measurement points

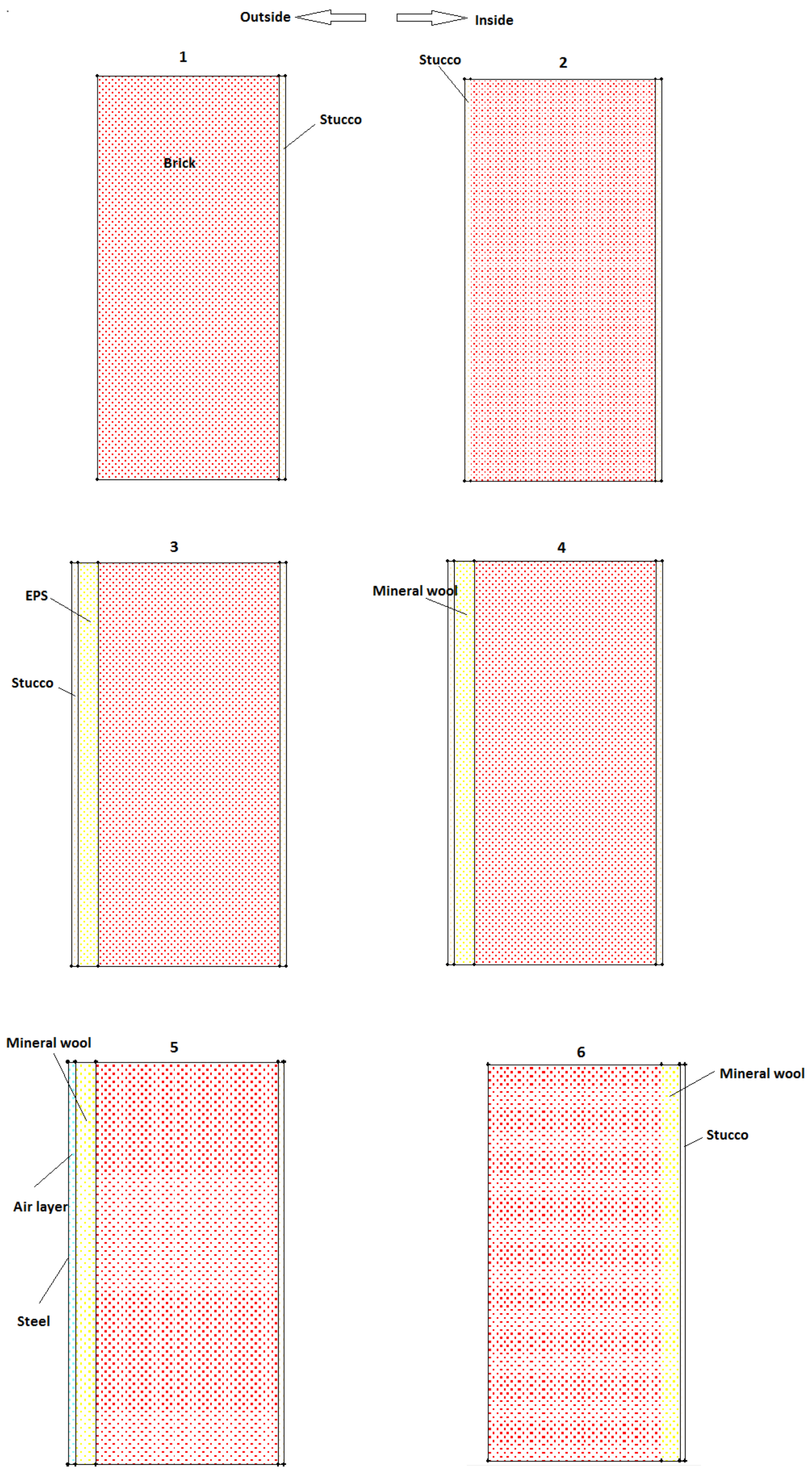


Figure 2, geometries and materials

Boundary conditions and initial conditions

Three boundary conditions are used and are described below. Figure 3 shows the boundary conditions in the geometry.

Out:

- Climate, Gothenburg

	Temperature [°C]	Relative humidity [%]
Mean	8.8	74
Maximum	27.8	94
Minimum	-12.2	19

- Façade facing south
- Heat transfer coefficient, 25 W/(m^{2}*K)
- Short- and long-wave radiation absorptivity and emissivity depending on material
- Rain water absorption factor, 0.7

In:

- Climate, medium moisture load, indoor (21±1 °C, 50±10 RH)
- Heat transfer coefficient, 7.7 W/(m^{2}*K)

Adiabatic:

- Adiabatic system border.

Initial conditions:

- 15 °C and 60% relative humidity in all materials. Start value is set based on the month where the calculation is started.

Figure 3, basic geometry with boundary conditions

Materials

The materials used in the simulations are chosen from the material database in WUFI. The materials, with relevant data are showed in table 2.

Table 1, material data

Material	Bulk density [kg/m^3]	Porosity [m^3/m^3]	Spec. heat capacity [J/KgK]	Thermal conductivity [W/m*K]	Water vapour diffusion resistance factor [-]
Solid brick masonry	1900	0.24	850	0.6	10
Mineral plaster (stucco)	1900	0.24	850	0.8	25
EPS	30	0.95	1500	0.04	50
Mineral wool	60	0.95	850	0.04	1.3
Air gap 20 mm (including convection and radiation)	1.3	0.999	1000	0.13	0.56

Results

Relative humidity, temperature and water content are presented in this chapter. The data are, where it is possible, plotted in the same graph to simplify the comparison. In some cases the data differed too much to be presented in the same diagram. Observe the scale on the y-axis where the types of wall are presented in separate diagrams.

To see if there is any obvious risk of frost damage, the temperature is plotted against the water content. The critical water content is set as 90% of the saturated free water content. With 90% of the saturated free water content, any frozen water will fill the pours cause of expansion during the freezing.

Relative humidity

Figure 4-10 show the relative humidity over the three calculated years in the points marked in figure 1 for each of the six types of beam supports.

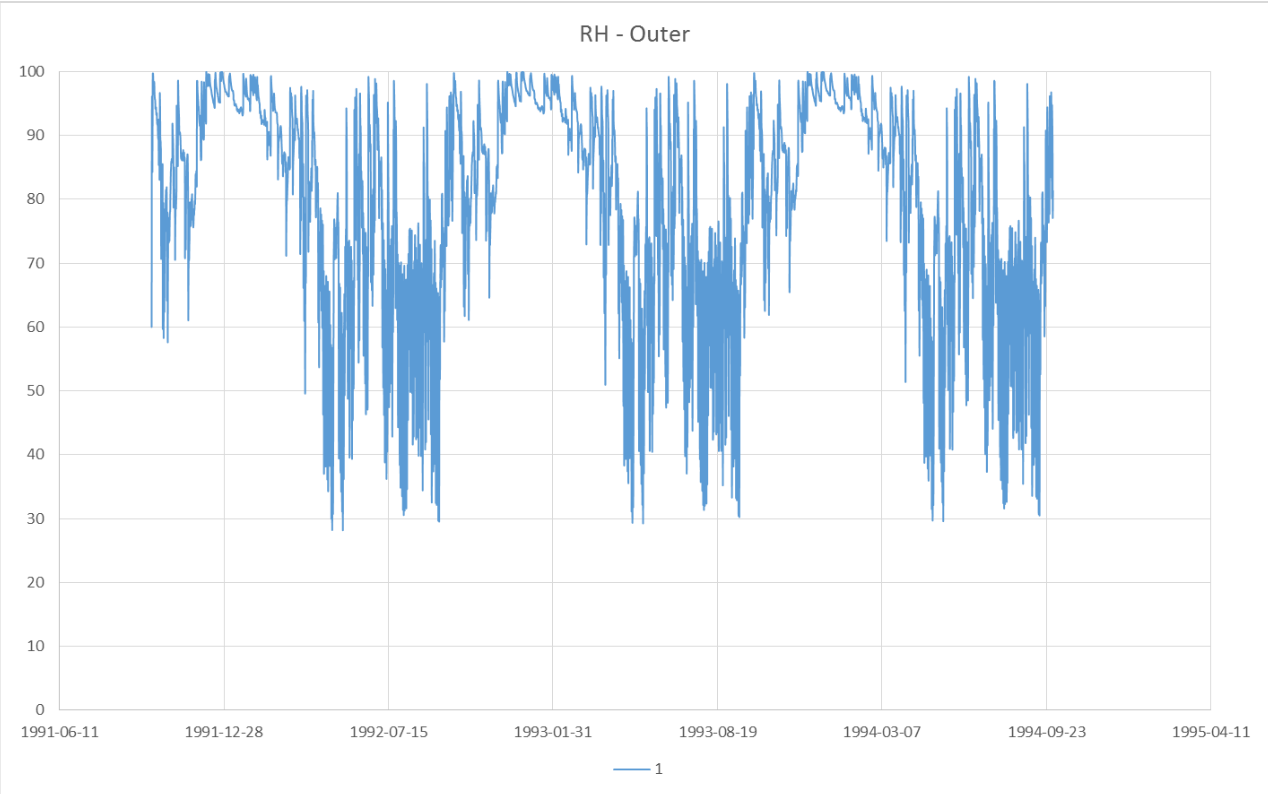


Figure 4, relative humidity, outer point, type 1

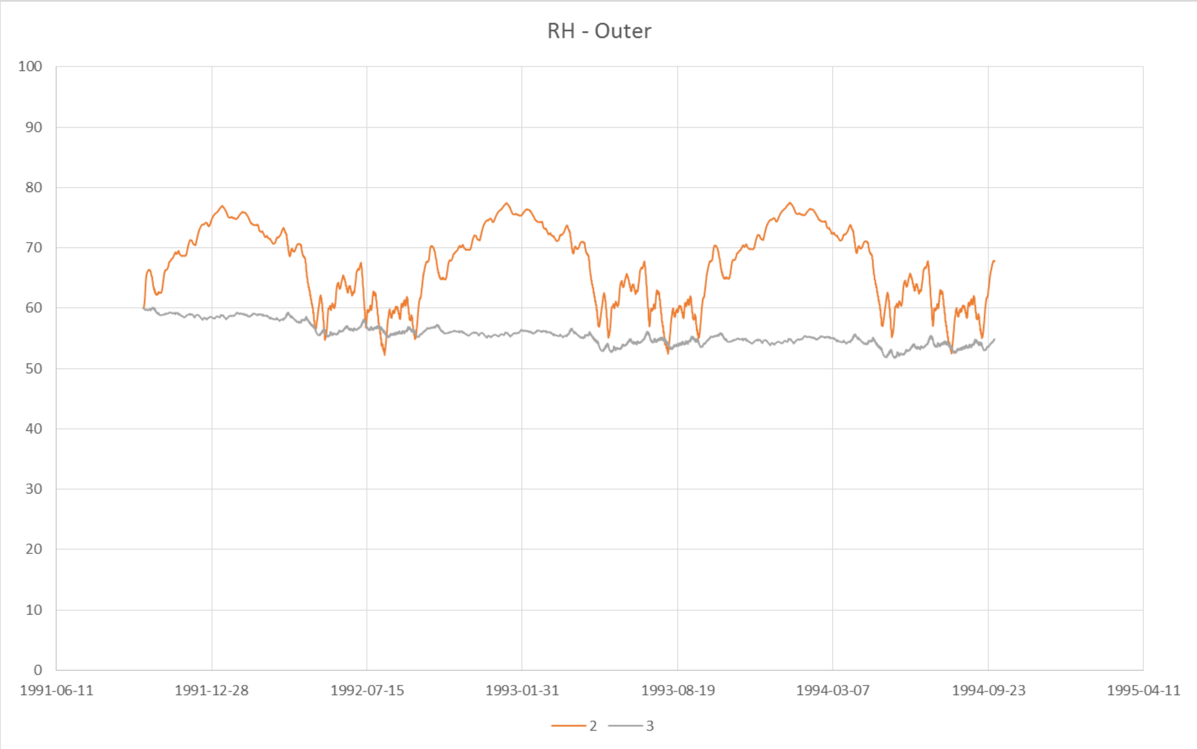


Figure 5, relative humidity, outer point, type 2-3

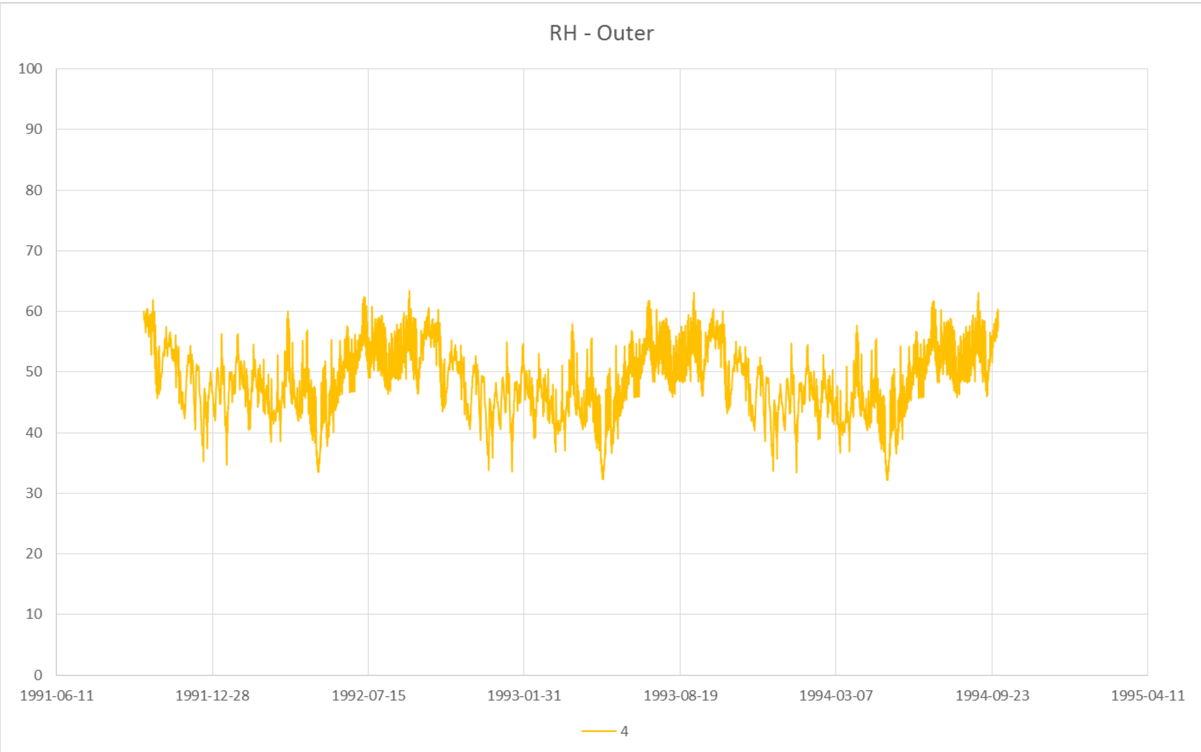


Figure 6, relative humidity, outer point, type 4

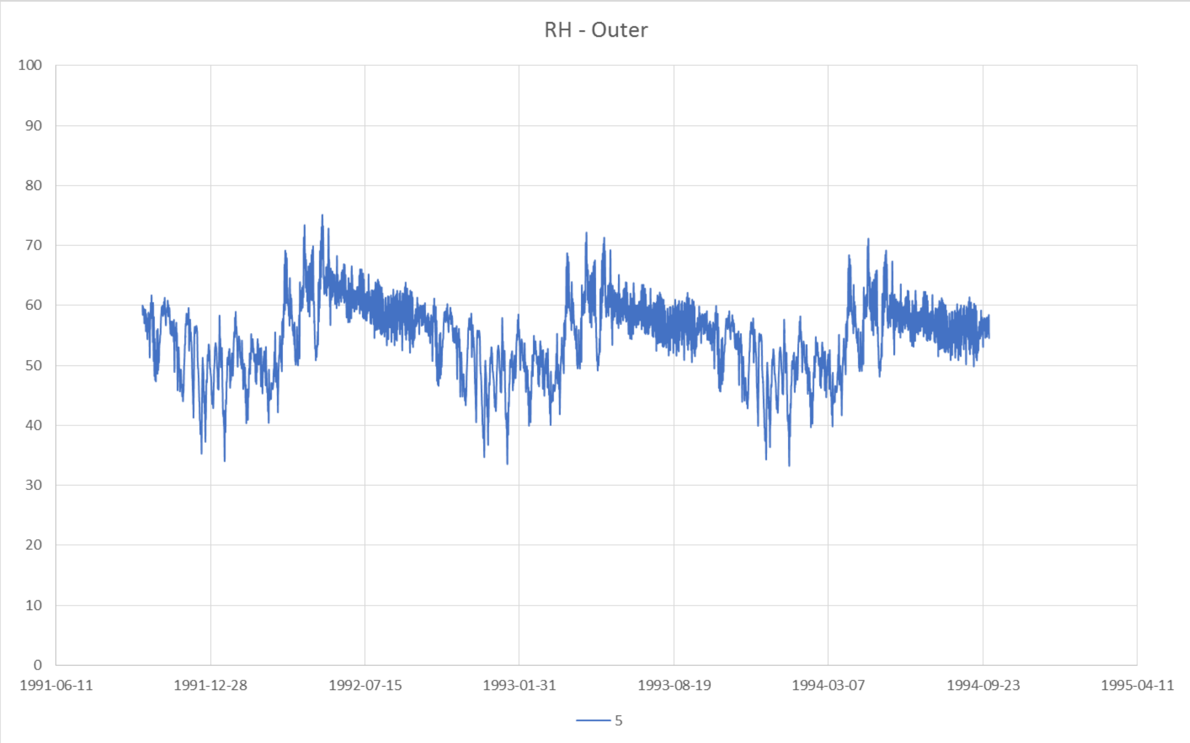


Figure 7, relative humidity, outer point, type 5

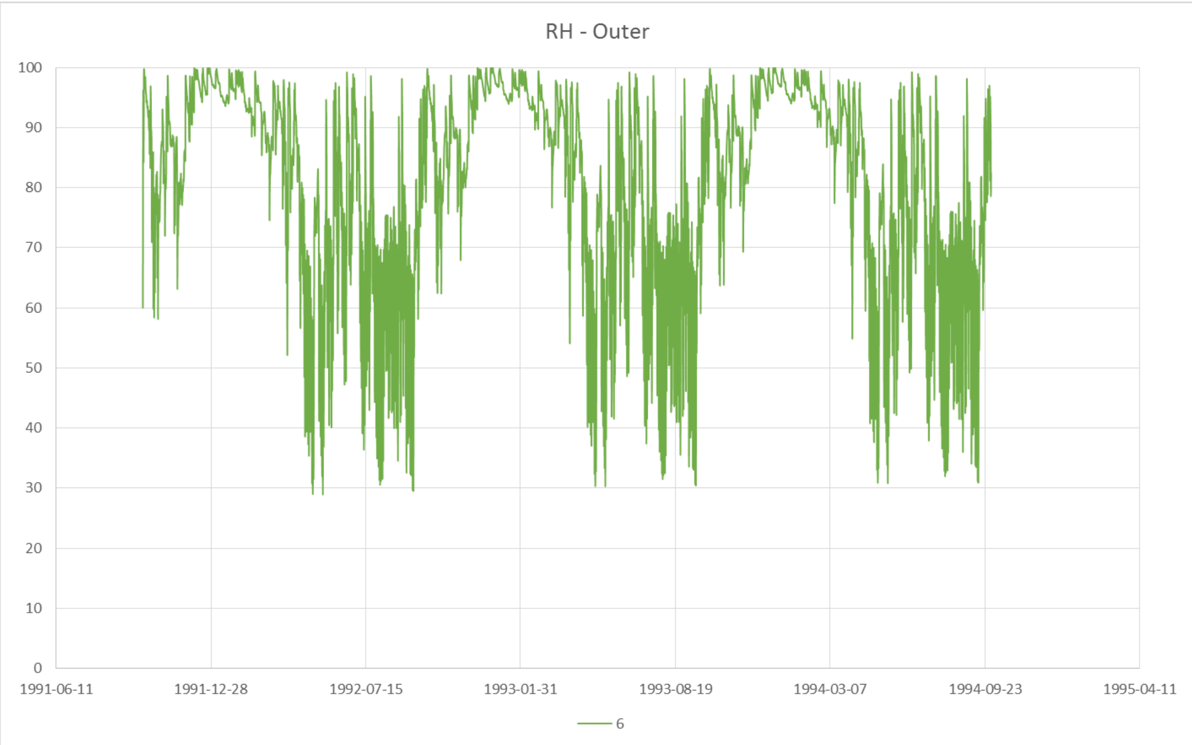


Figure 8, relative humidity, outer point, type 6

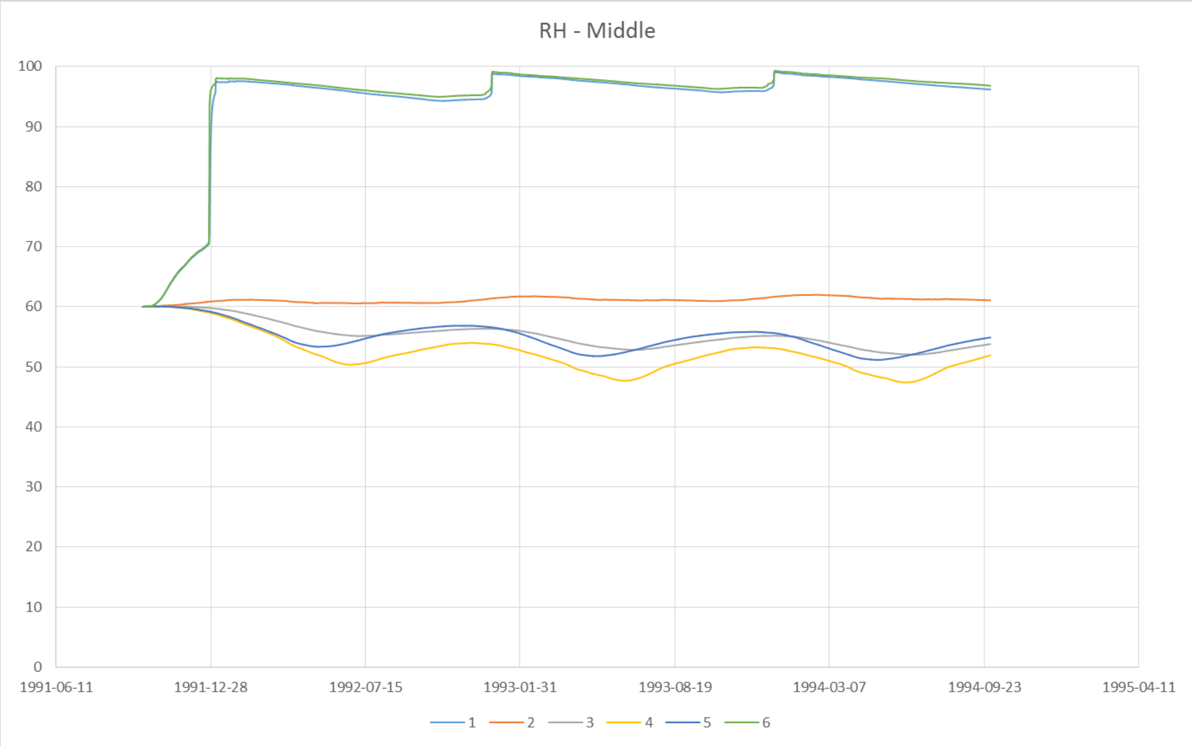


Figure 9, relative humidity, middle point, type 1-6

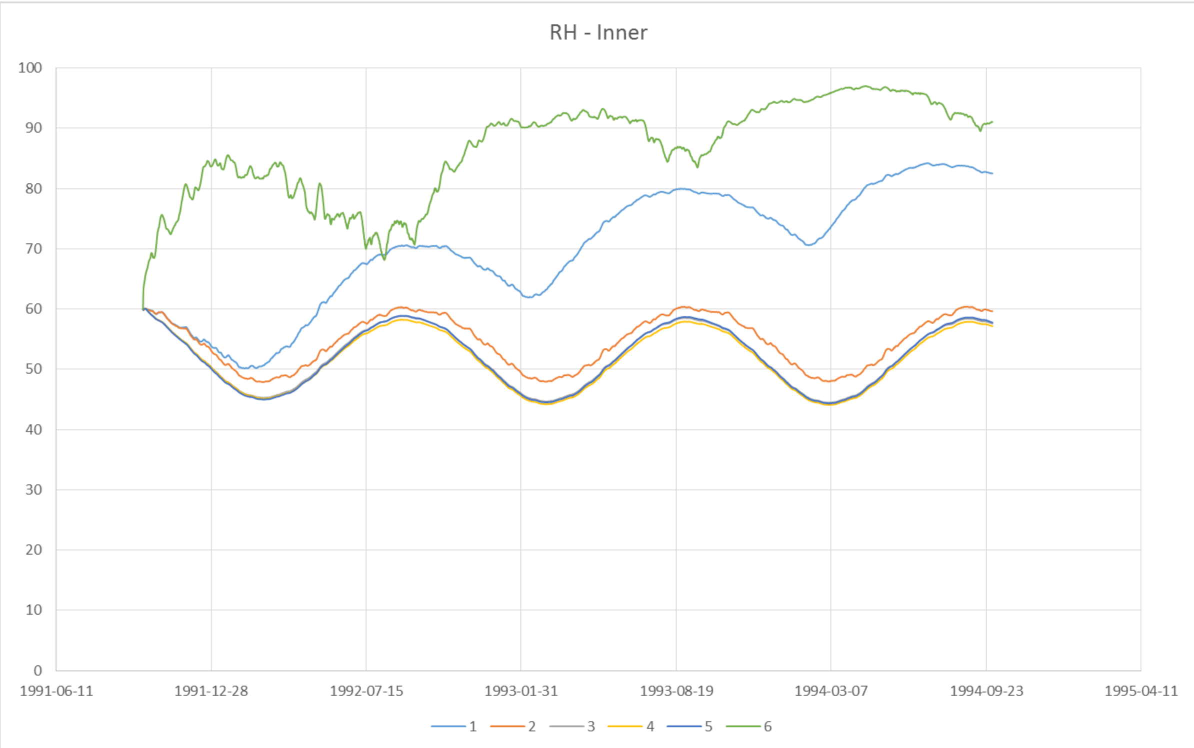


Figure 10, relative humidity, inner point, type 1-6

Temperature

Figure 11-18 shows the temperature in the specified points for each type of wall.

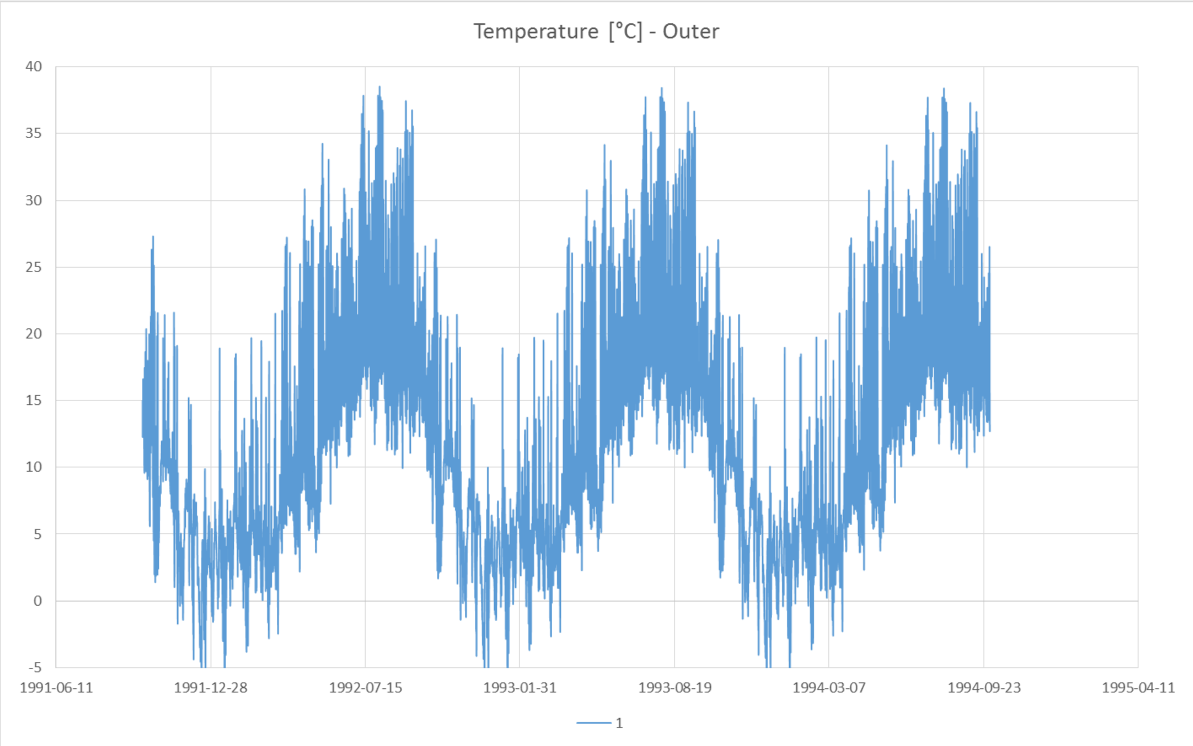


Figure 11, temperature, outer point, type 1

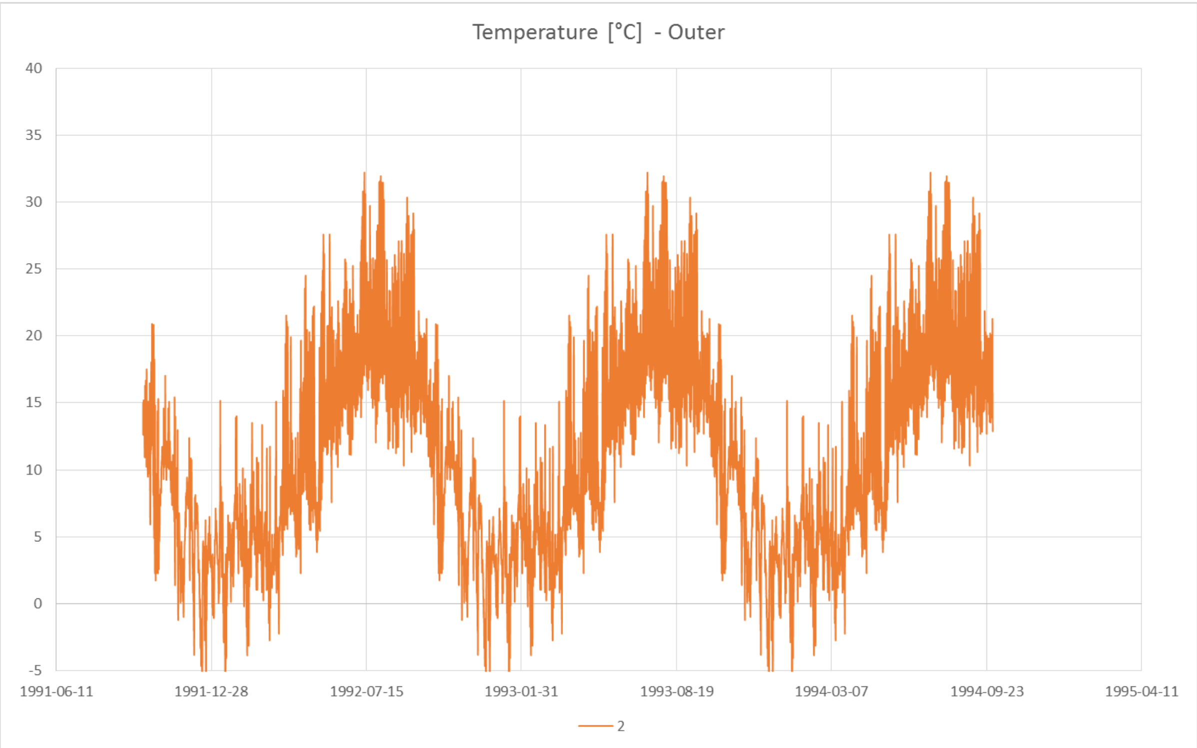


Figure 12, temperature, outer point, type 2

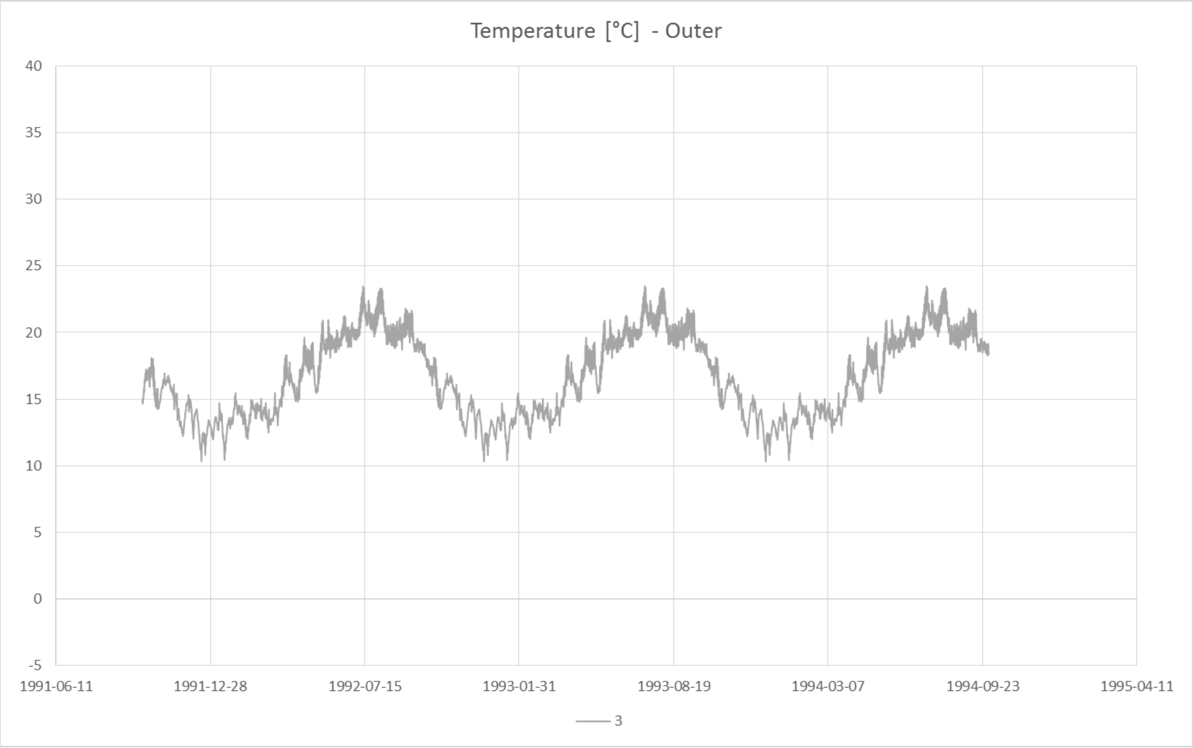


Figure 13, temperature, outer point, type 3

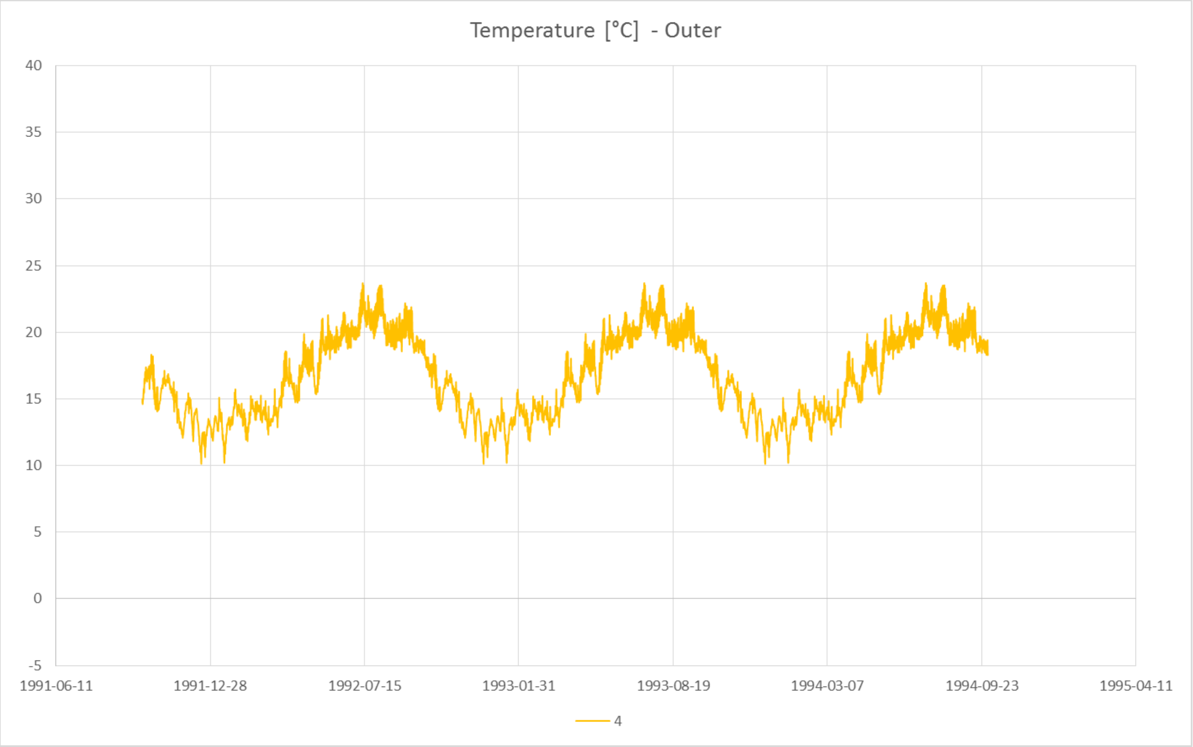


Figure 14, temperature, outer point, type 4

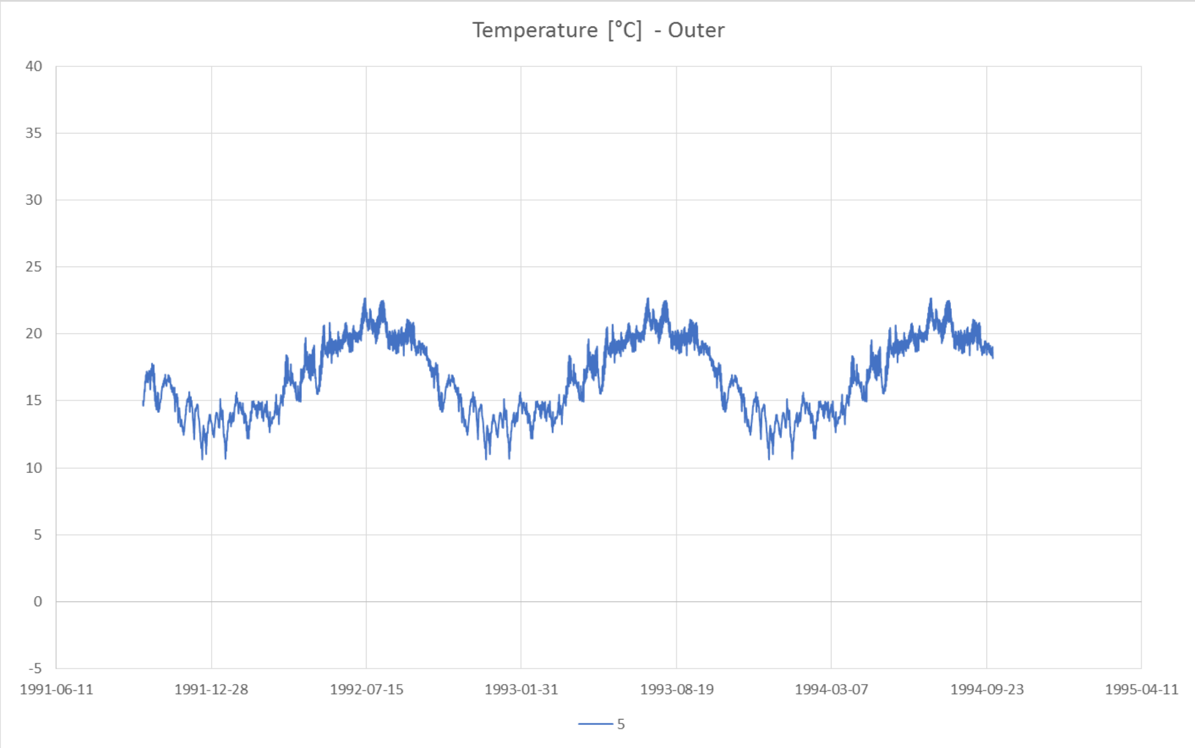


Figure 15, temperature, outer point, type 5

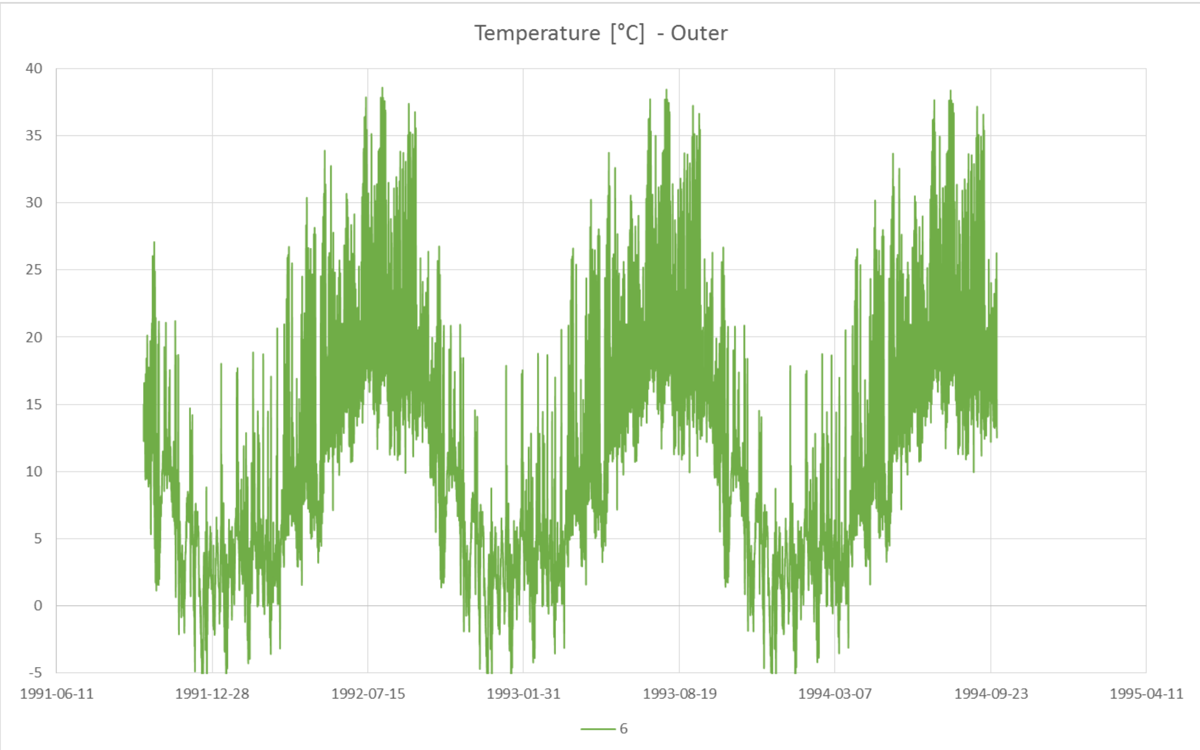


Figure 16, temperature, outer point, type 6

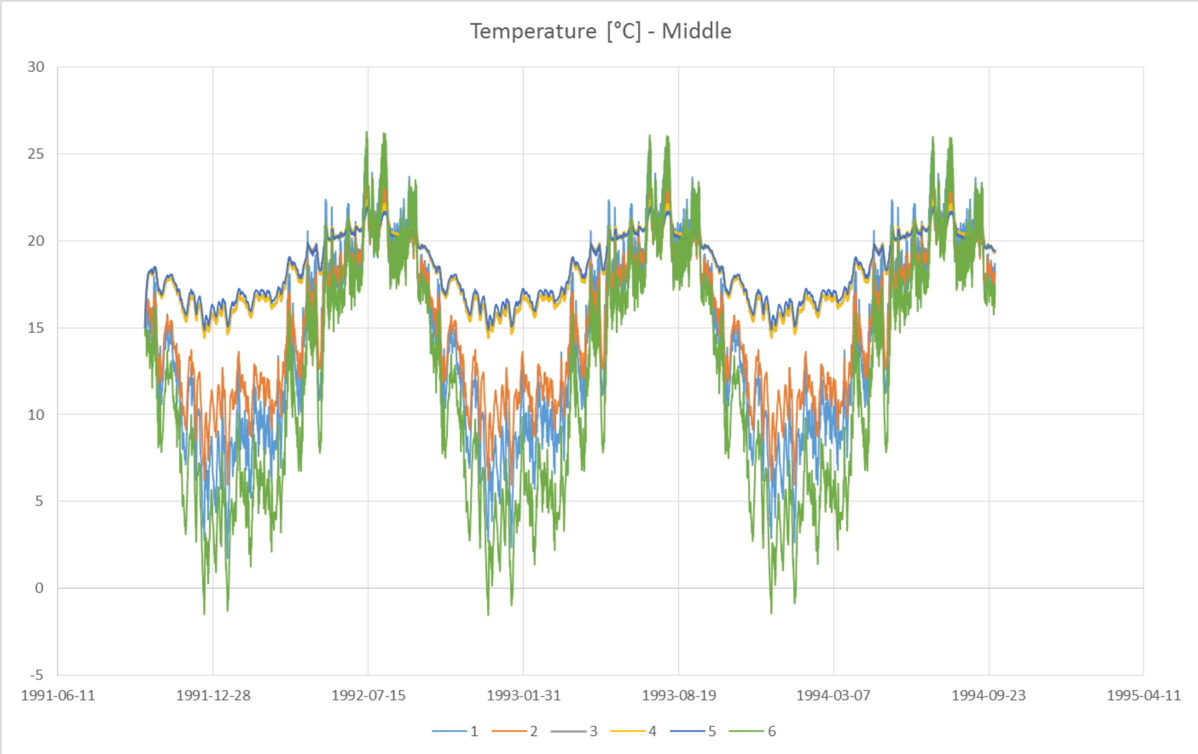


Figure 17, temperature, middle point, type 1-6

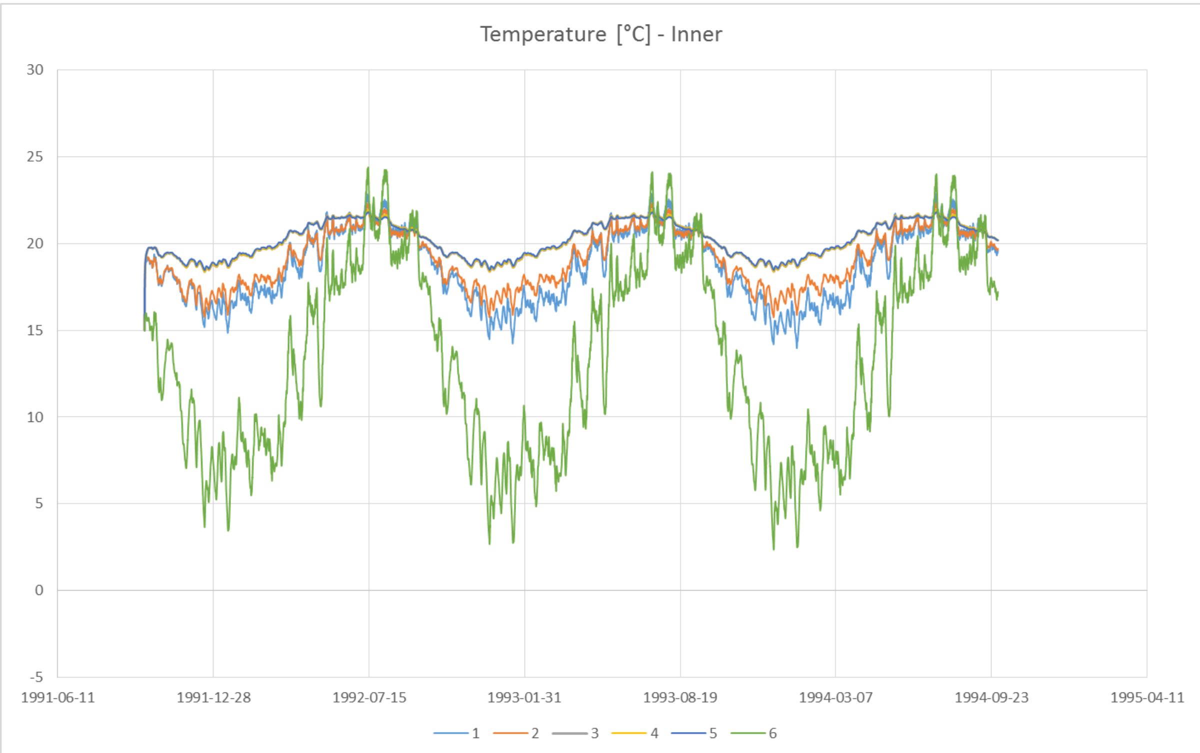


Figure 18, temperature, inner point, type 1-6

Water content

Figure 19-23 present the water content in the specified points. Observe that the y-axis have different scale in the figures. In some points the water content differ so the information needs to be presented in different figures.

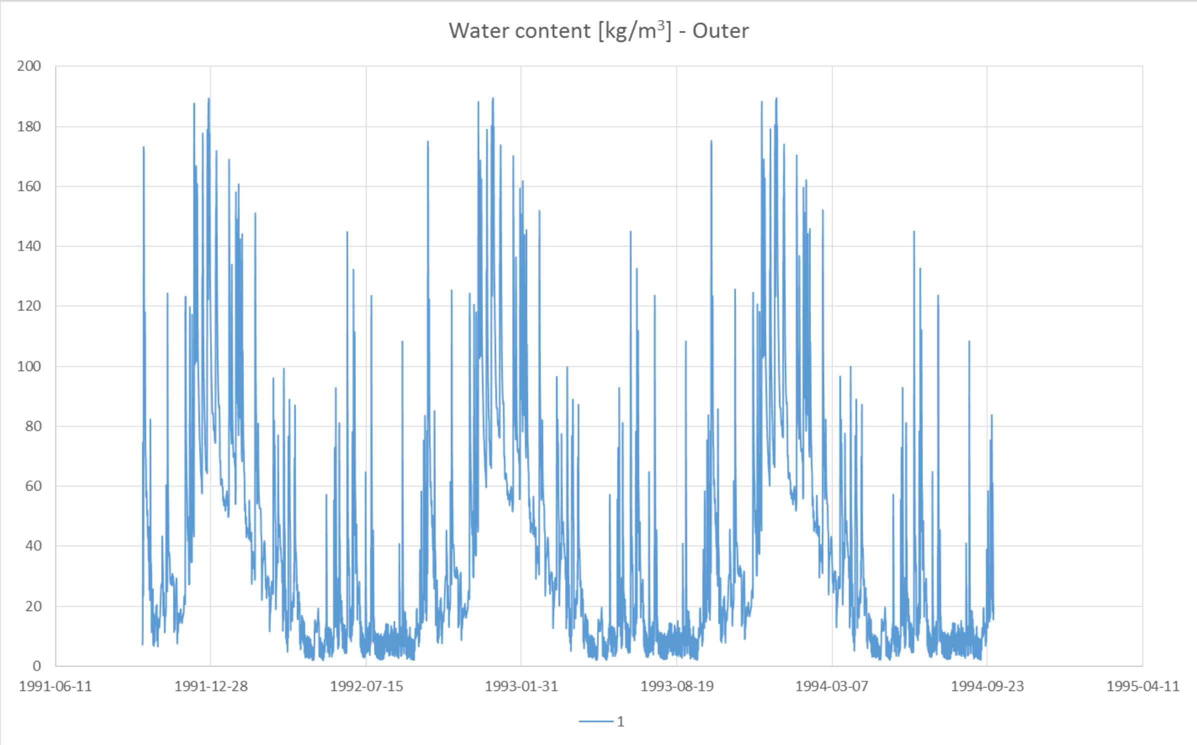


Figure 19, water content, outer point, type 1

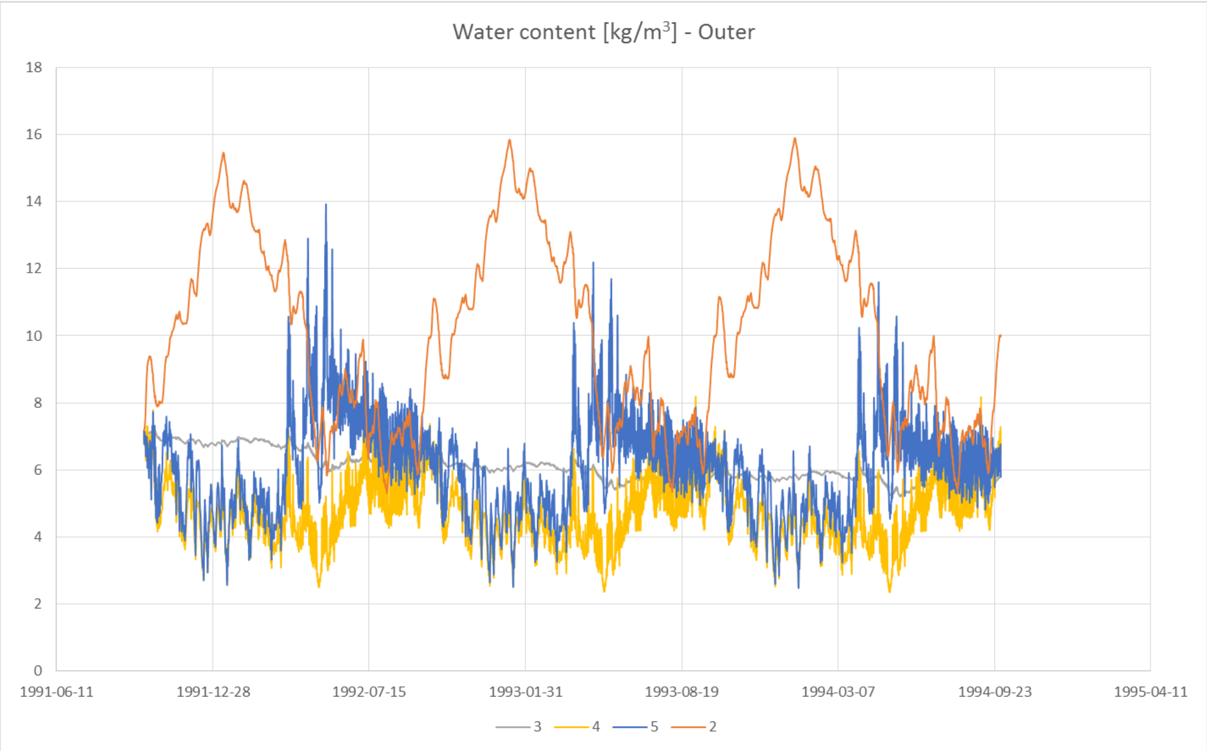


Figure 20, water content, outer point, type 2-5

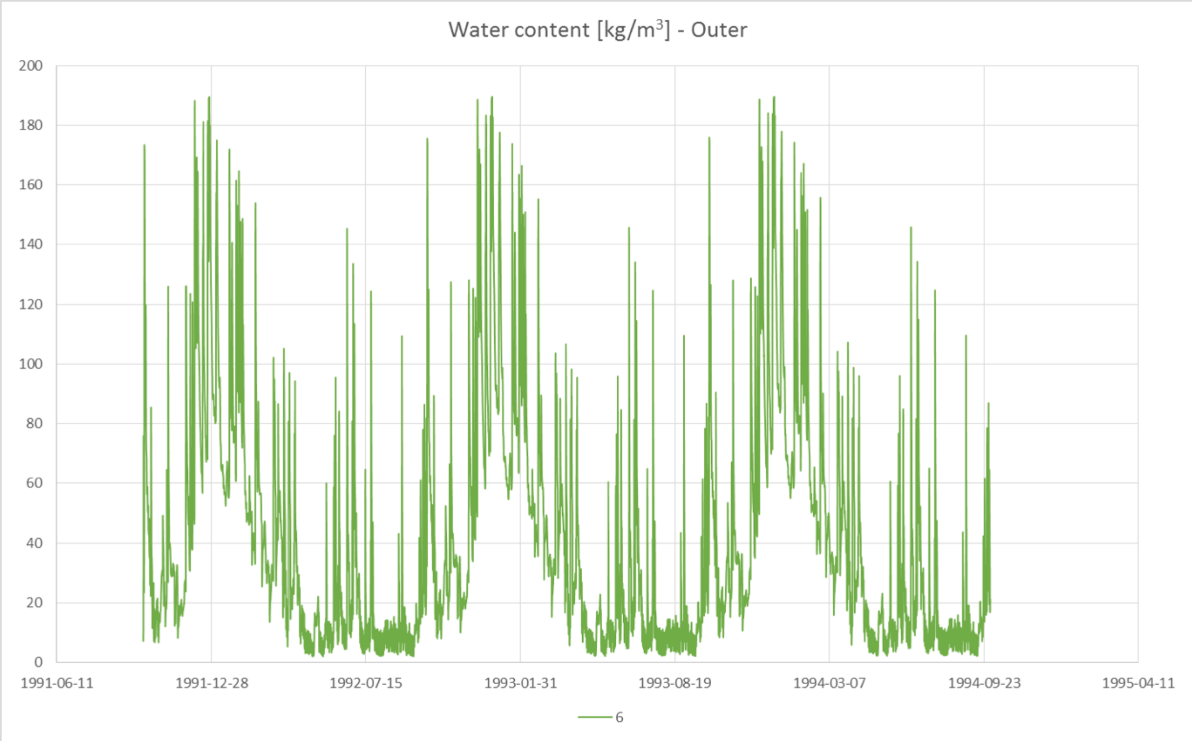


Figure 21, water content, outer point, type 6

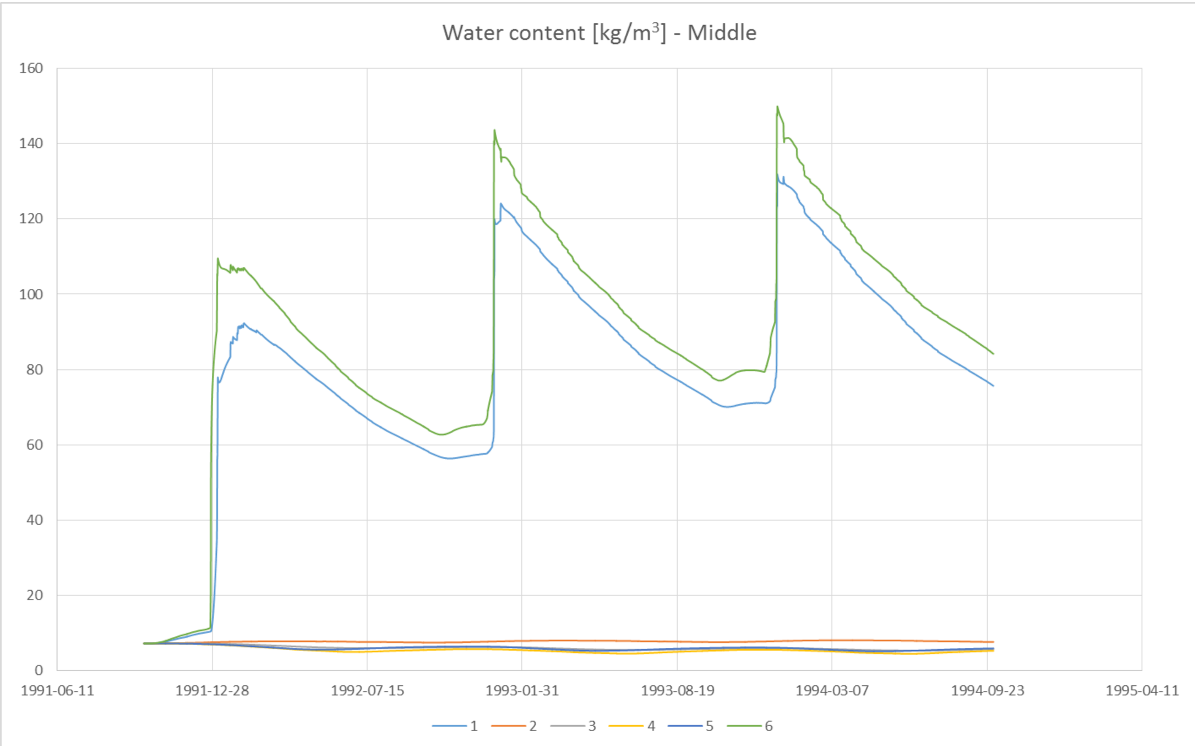


Figure 22, water content, middle point, type 1-6

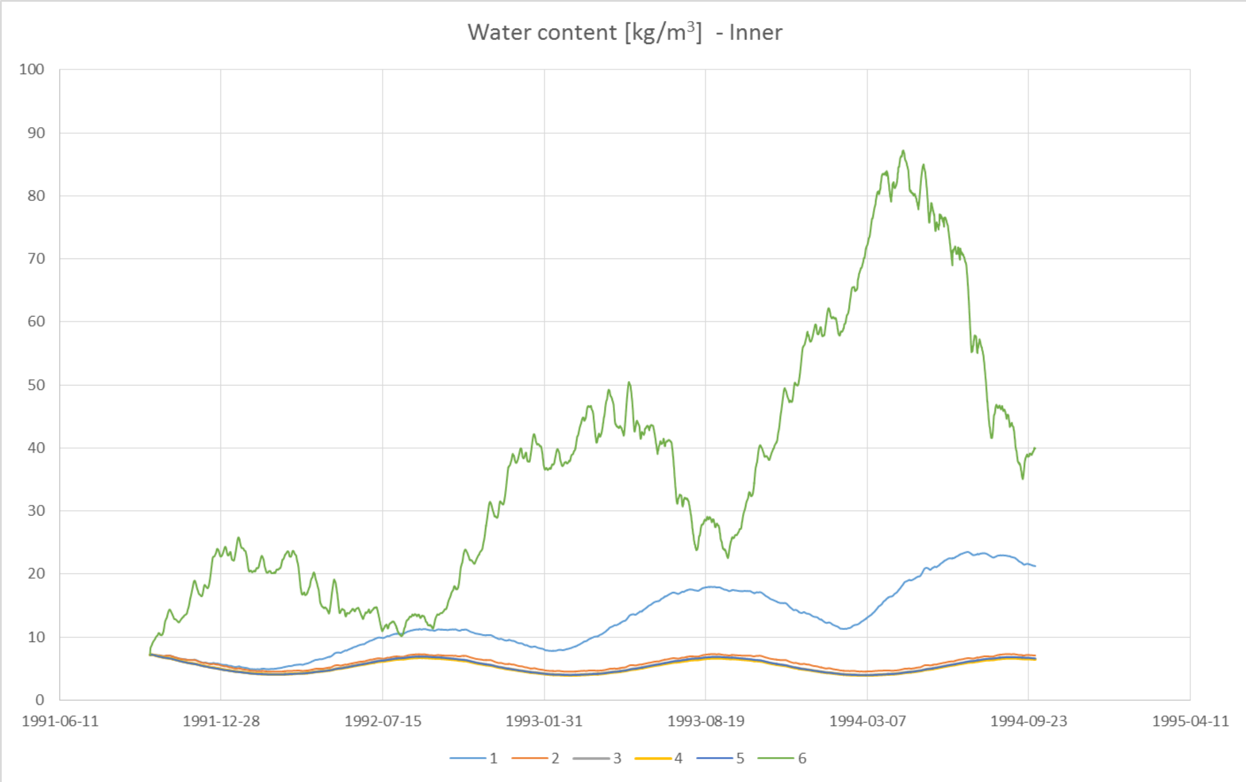


Figure 23, water content, inner point, type 1-6

Frost damage control

The following figures show plots of the temperature against the water content. The orange line is set as a risk zone for frost damages. The level of critical water content is 90% of the saturated free water content.

The results are just presented for wall number 1 and number 6. In the other wall types the brick are covered and horizontal rain will not connect directly to the brick.

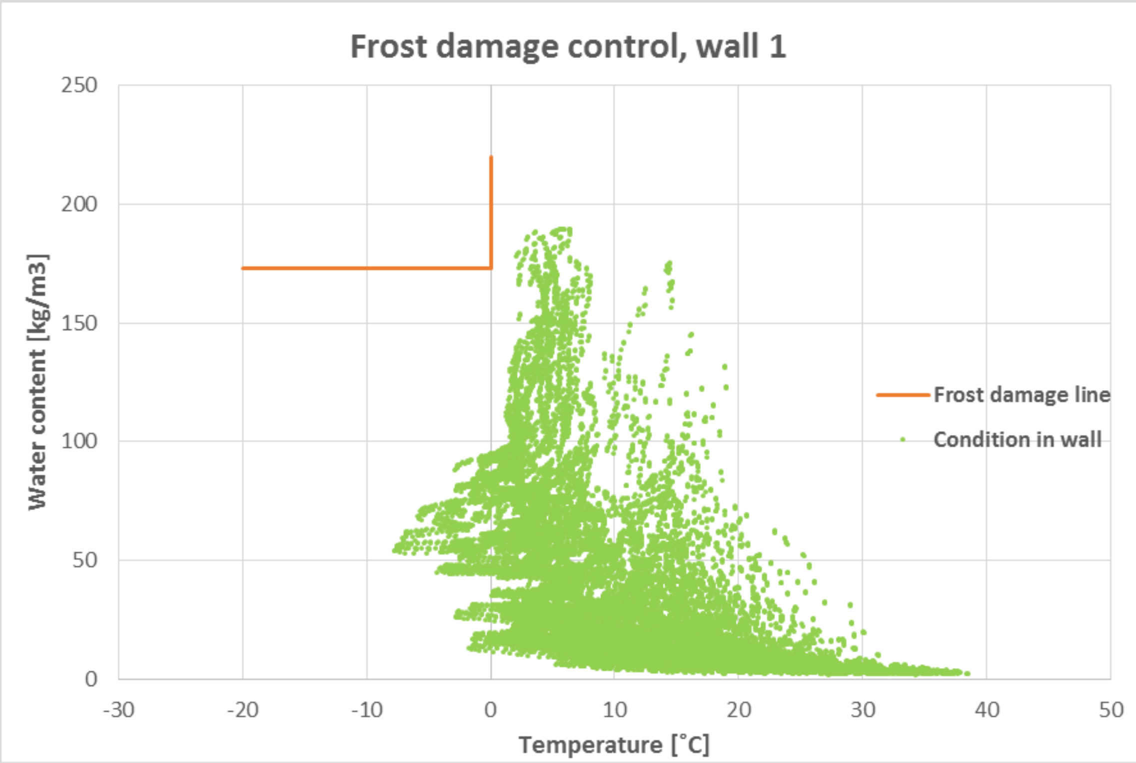


Figure 24, Frost damage control, wall 1

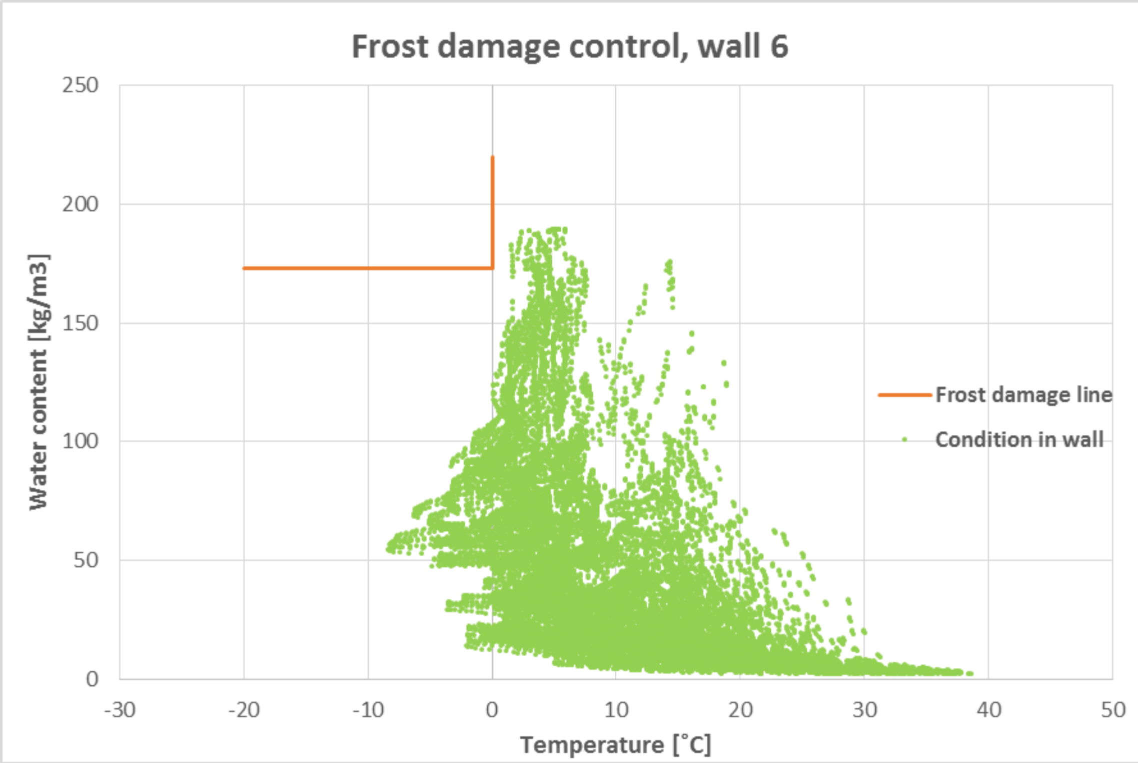


Figure 25, Frost damage control, wall 6

Appendix IV

Hygrothermal simulations

Support of slab in wall, WUFI

Contents

Wooden beam, support in brick wall

This appendix presents the data and the results for simulations in WUFI of beam end supports in brick walls. The simulations show the relative humidity in the wooden beams over a period of three years. To see the risk of mould growth a plot with the relative humidity against the temperature is made. The results are indicating which kind of solution that is beneficial for the beam support depending on the relative humidity and the temperature in the wood. Totally 7 different types are studied:

1. Original beam support with non-insulated 1.5 brick walls with an internal stucco layer
2. Beam support with non-insulated brick wall with internal and external stucco layer
3. Beam support with 1.5 brick wall insulated with 50 mm exterior EPS layer with 15 mm stucco
4. Beam support with 1.5 brick wall insulated with 50 mm exterior mineral wool with 15 mm stucco
5. Beam support with 1.5 brick wall insulated with 50 mm exterior mineral wool with non-ventilated air layered steel façade
6. Beam support filled with polyurethane foam (closed cells) and non-insulated 1.5 brick wall
7. Beam support with 50 mm internal mineral wool and gypsum board

Observe that the aim of the simulations is to give an indication of the effect of the different types of beam supports. For a certain case, precise geometry and material parameters need to be deeper investigated.

Software

The software used for the simulations is WUFI 2D version 3.3. WUFI is a software based on finite volumes and handles transient heat and moisture transports of 2-dimensional geometries. WUFI allows you to add driving rain and heat and moisture sources, which is relevant in this case.

Geometry

Figure 1 and 2 show the basic geometry of the supports in the brick wall. Table 1 shows the dimension of the geometry. The geometry is based on an average geometry. In other words, the geometry can differ from house to house. The marked areas in figure 1 show the points (edge and middle) where the relative humidity and the temperature are measured. The wooden beam is laying in the cavity with a bituminous paper in between the beam and the brick.

Figure 3 shows the five different geometries with each materials marked.

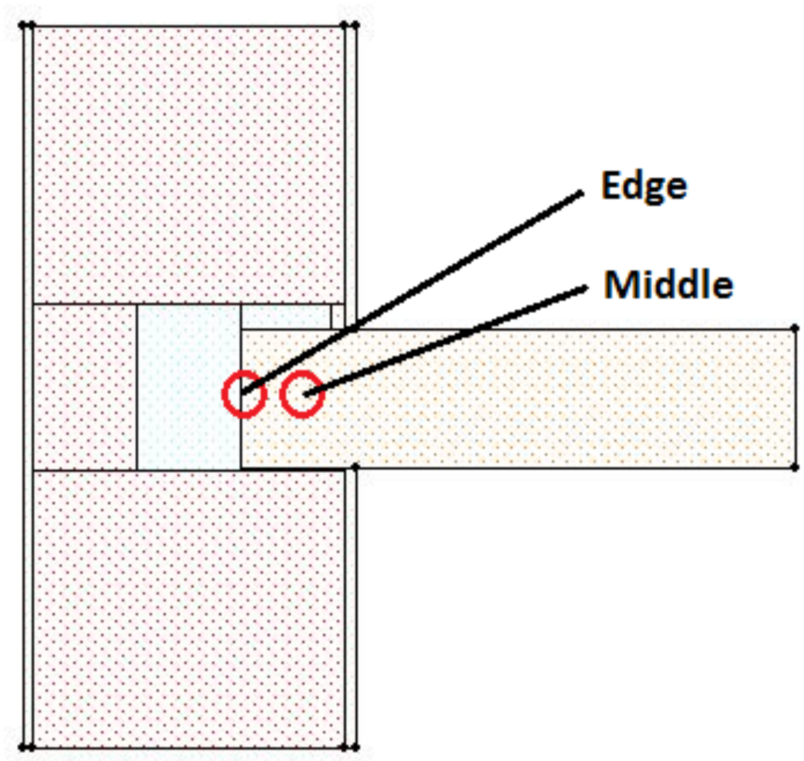


Figure 1, basic geometry and measuring points

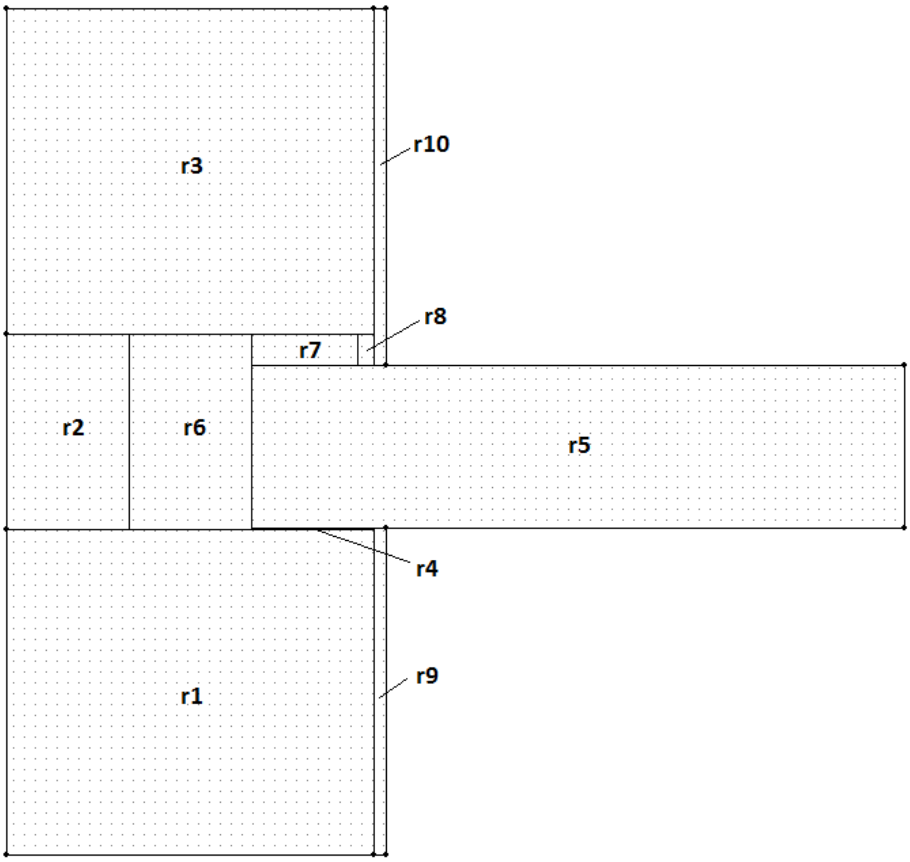


Figure 2, basic geometry with box numbers

Table 1, basic geometry, box sizes

Box	**X [mm]**	**Y [mm]**	**X_0 [mm]**	**Y_0 [mm]**
r1	450	400	200	0
r2	150	240	200	400
r3	450	400	200	640
r4	150	2	500	400
r5	800	200	500	402
r6	150	240	350	400
r7	130	38	500	602
r8	20	38	630	602
r9	15	402	650	0
r10	15	438	650	602

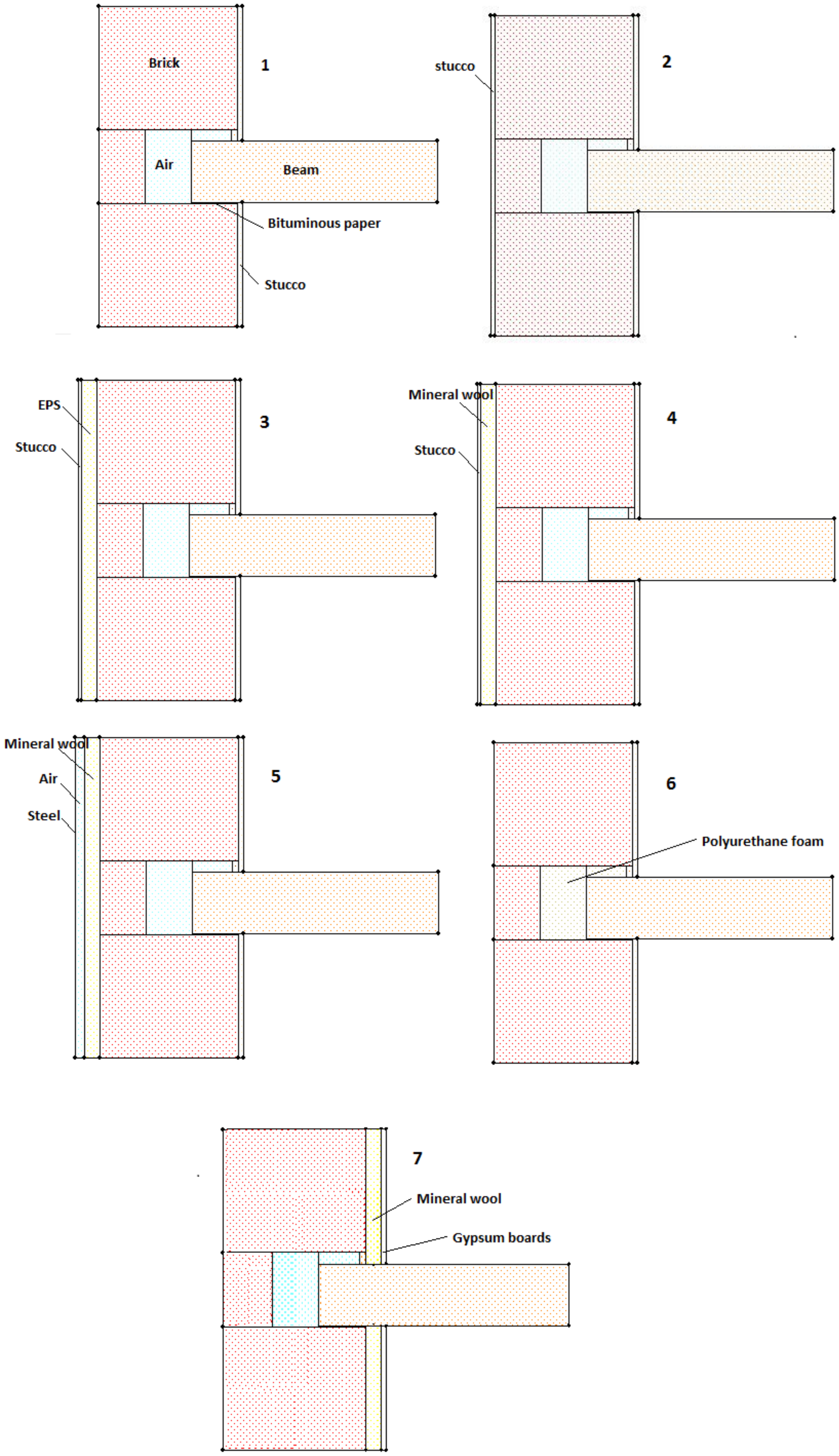


Figure 3, types of geometries, 1-7

Boundary conditions and initial conditions

Three boundary conditions are used and are described below. Figure 4 shows the boundary conditions in the geometry.

Out:

- Climate, Gothenburg

	Temperature [°C]	Relative humidity [%]
Mean	8.8	74
Maximum	27.8	94
Minimum	-12.2	19

- Façade facing south
- Heat transfer coefficient, 25 W/(m^2*K)
- Short- and long-wave radiation absorptivity and emissivity depending on material
- Rain water absorption factor, 0.7

In:

- Climate, medium moisture load, indoor (21±1 °C, 50±10 RH)
- Heat transfer coefficient, 7.7 W/(m^2*K)

Adiabatic:

- Adiabatic system border.

Initial conditions:

- 15°C and 60% relative humidity in all materials. Start value is set based on the month where the calculation is started.

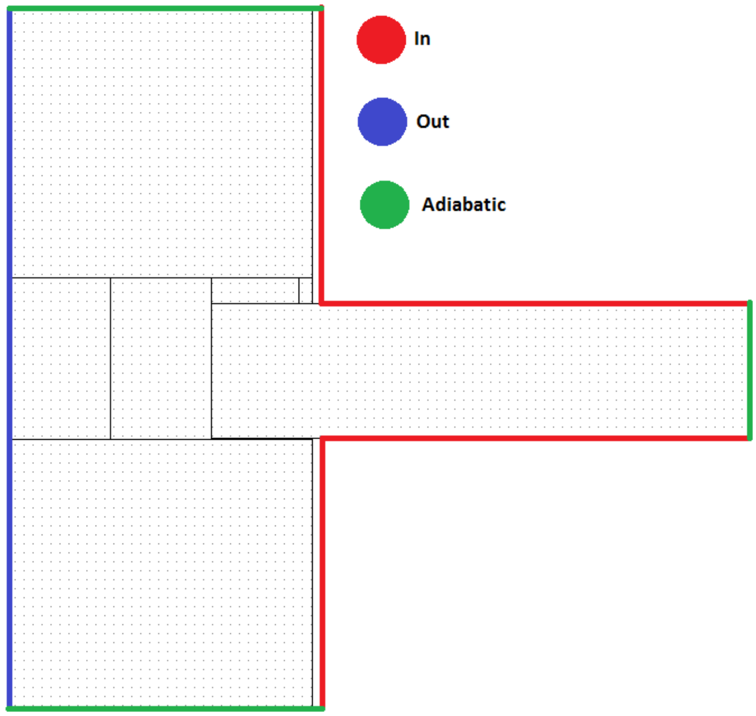


Figure 4, Basic geometry with boundary conditions

Materials

The materials used in the simulations are chosen from the material database in WUFI. The materials, with relevant data are showed in table 2.

Table 2, material data

Material	Bulk density [kg/m^3]	Porosity [m^3/m^3]	Spec. heat capacity [J/KgK]	Thermal conductivity [W/m*K]	Water vapour diffusion resistance factor [-]
Solid brick masonry	1900	0.24	850	0.6	10
Bituminous paper	715	0.001	1500	4	993
Spruce, longitudinal	455	0.73	1500	0.23	4.3
Spruce, radial	455	0.73	1500	0.09	130
Mineral plaster (stucco)	1900	0.24	850	0.8	25
EPS	30	0.95	1500	0.04	50
Mineral wool	60	0.95	850	0.04	1.3
Sprayed polyurethane foam, closed cell	39	0.99	1470	0.025	88.9
Air gap 40 mm (including convection and radiation)	1.3	0.999	1000	0.23	0.38

Air gap 150 mm (including convection and radiation)	1.3	0.999	1000	0.94	0.07
Air gap 20 mm (including convection and radiation)	1.3	0.999	1000	0.13	0.56

Results

Relative humidity

Figure 5 and 6 show the relative humidity over the three calculated years in the points marked in figure 1 for each of the seven types of beam supports.

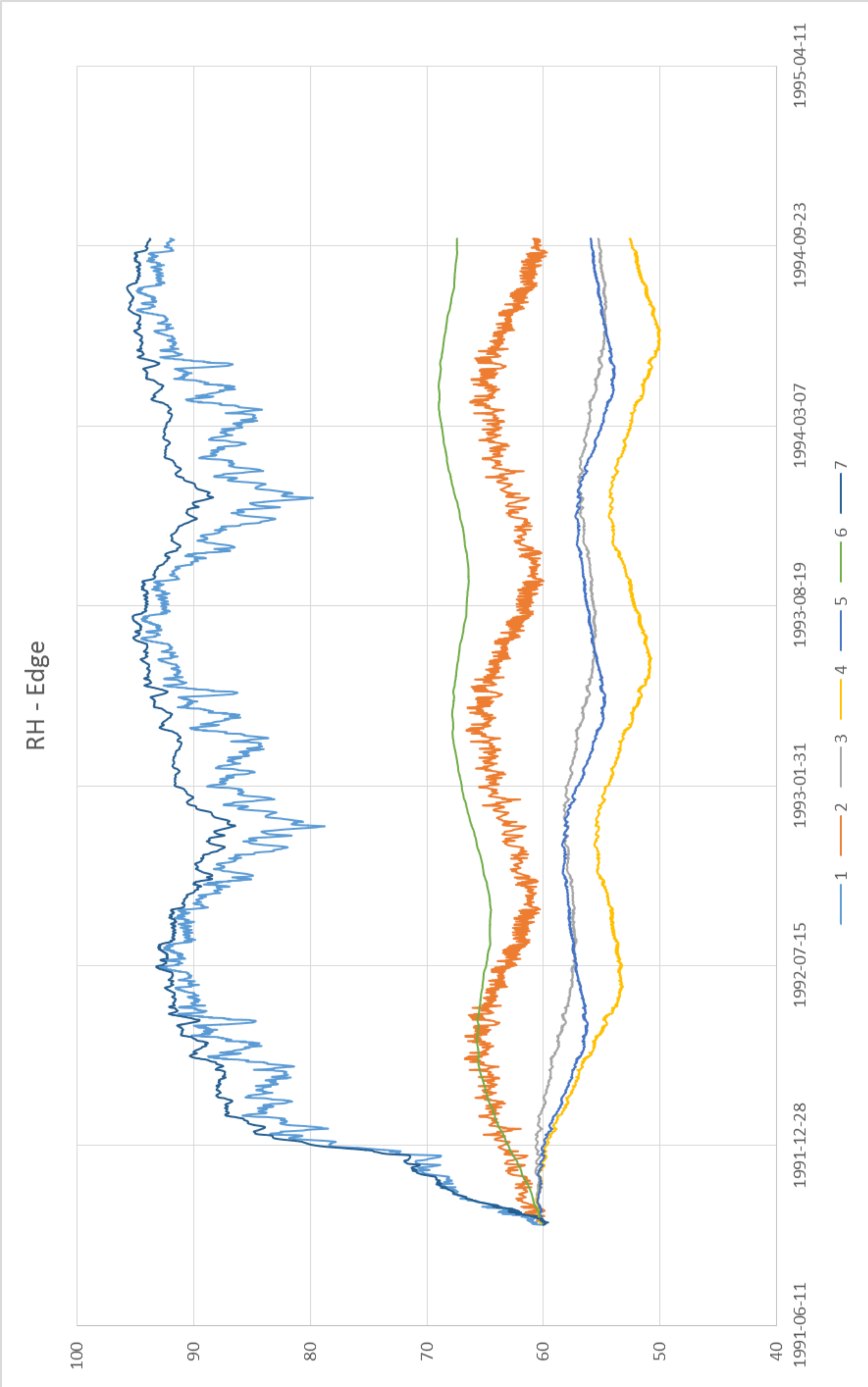


Figure 5, Relative humidity in beam edge

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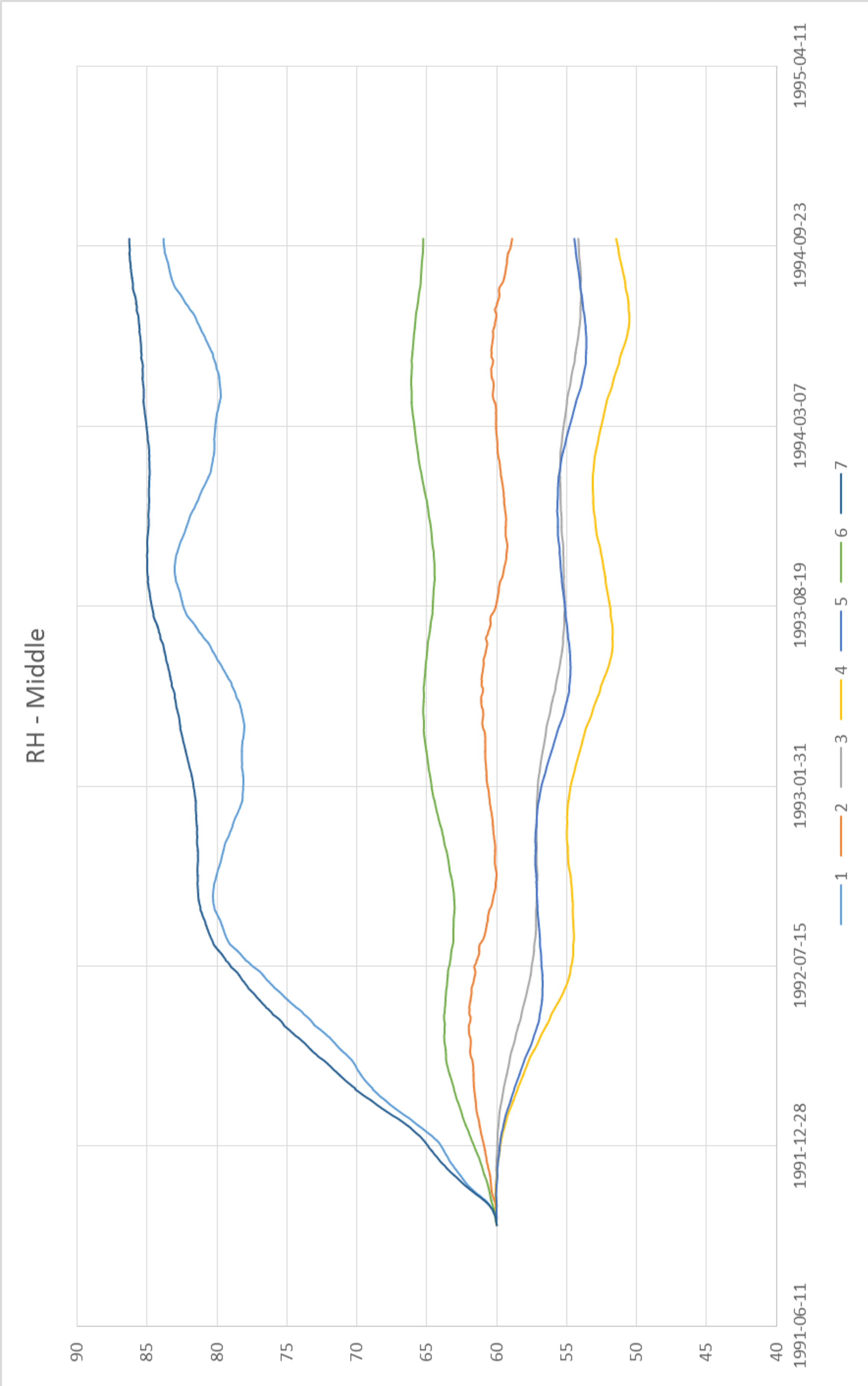

Figure 6, Relative humidity in beam middle

Hygrothermal conditions

The following figures show the plots of the temperature against the relative humidity (hygrothermal conditions). When the plot is outside the red dotted line, there is a risk of mould growth.

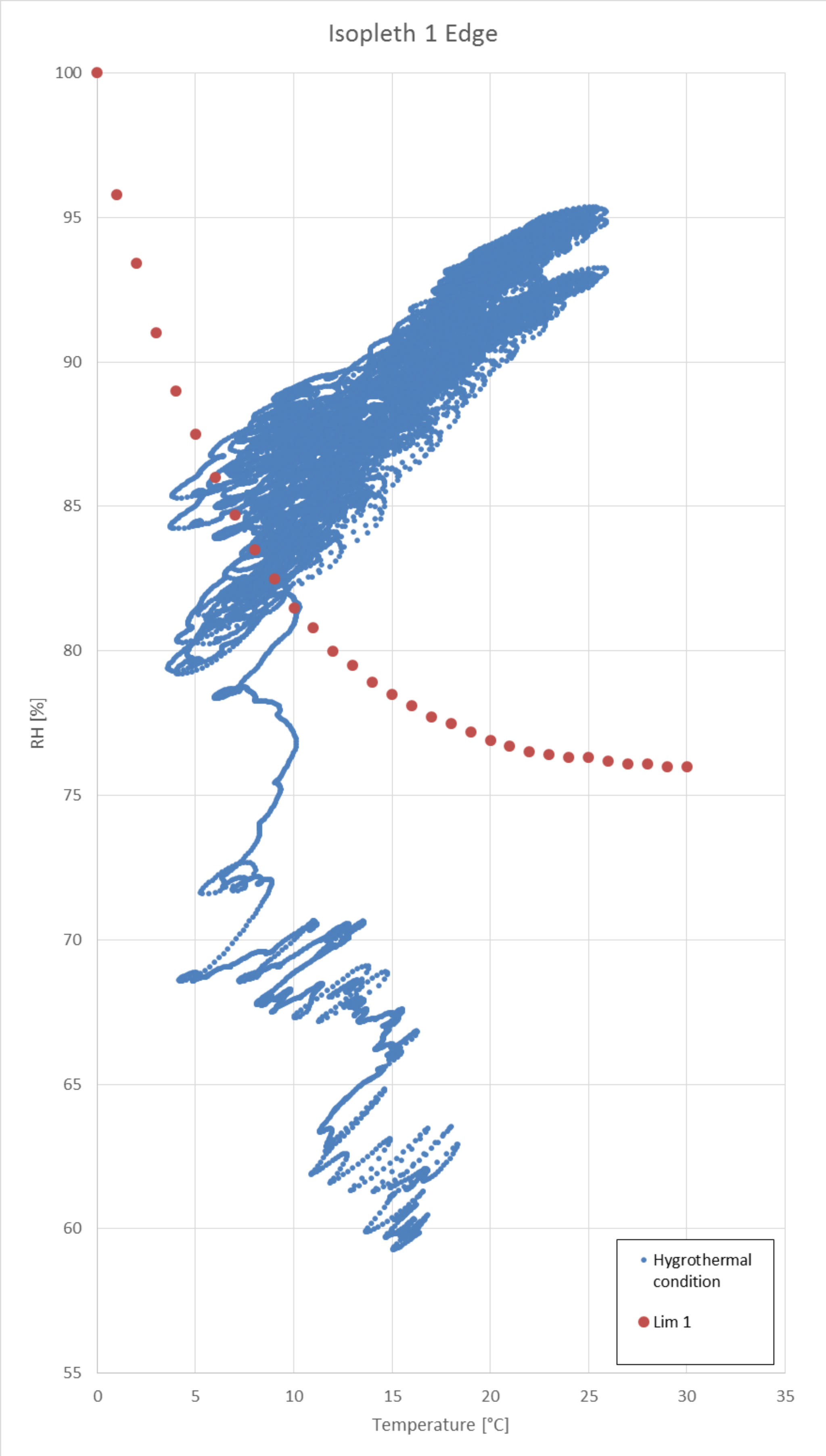

Figure 7, Type 1, edge

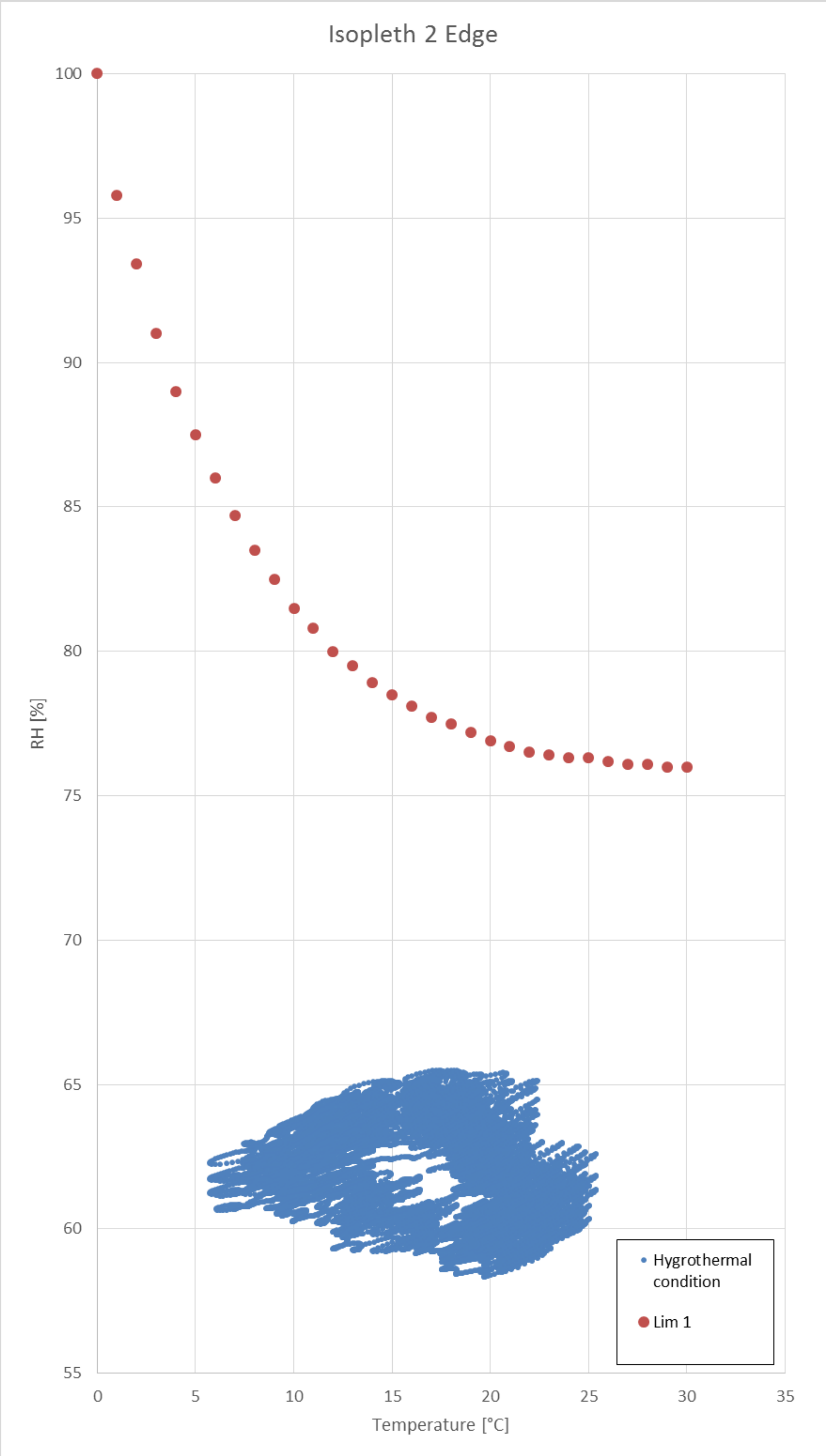

Figure 8, Type 2, edge

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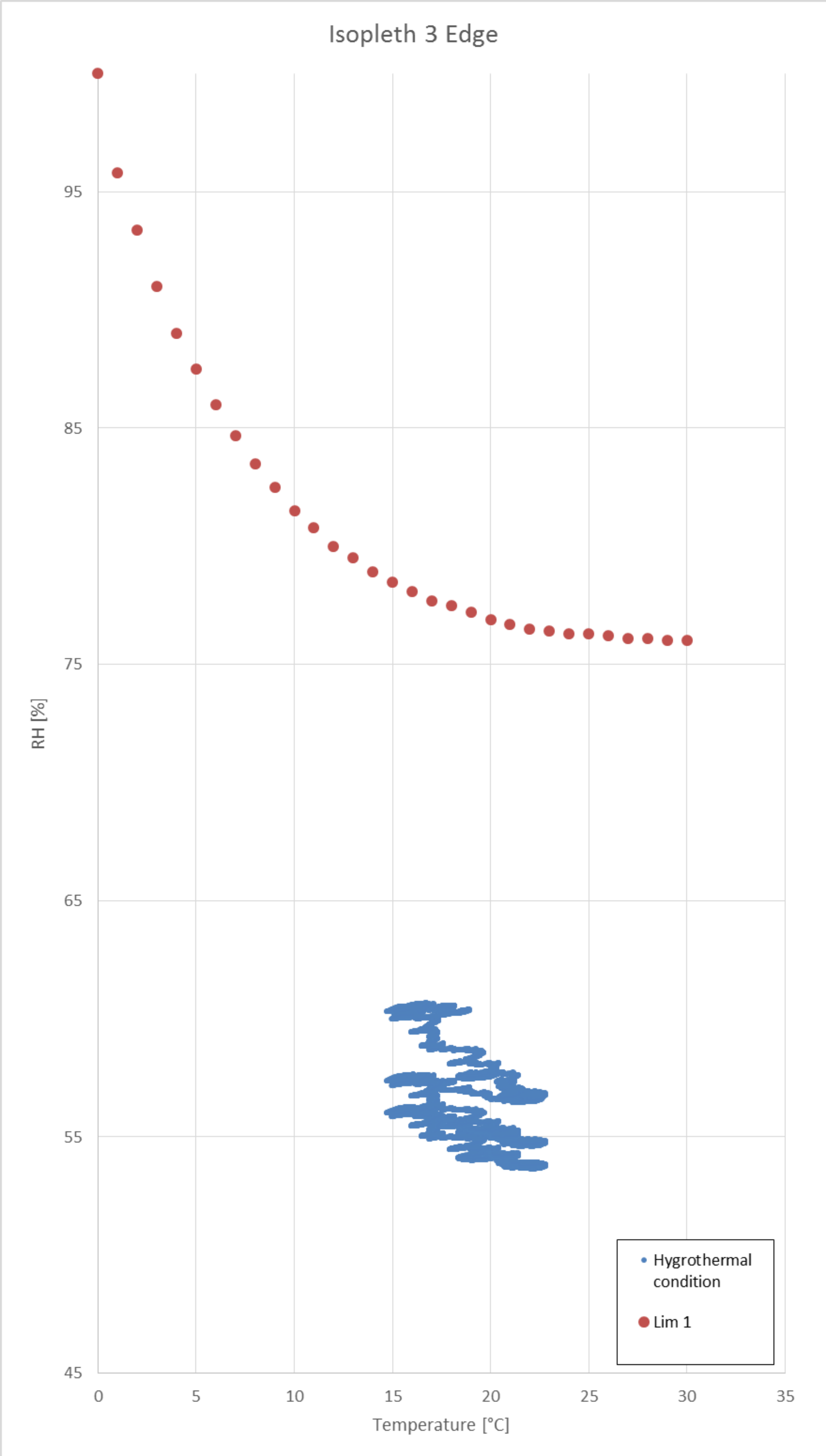

Figure 9, Type 3, edge

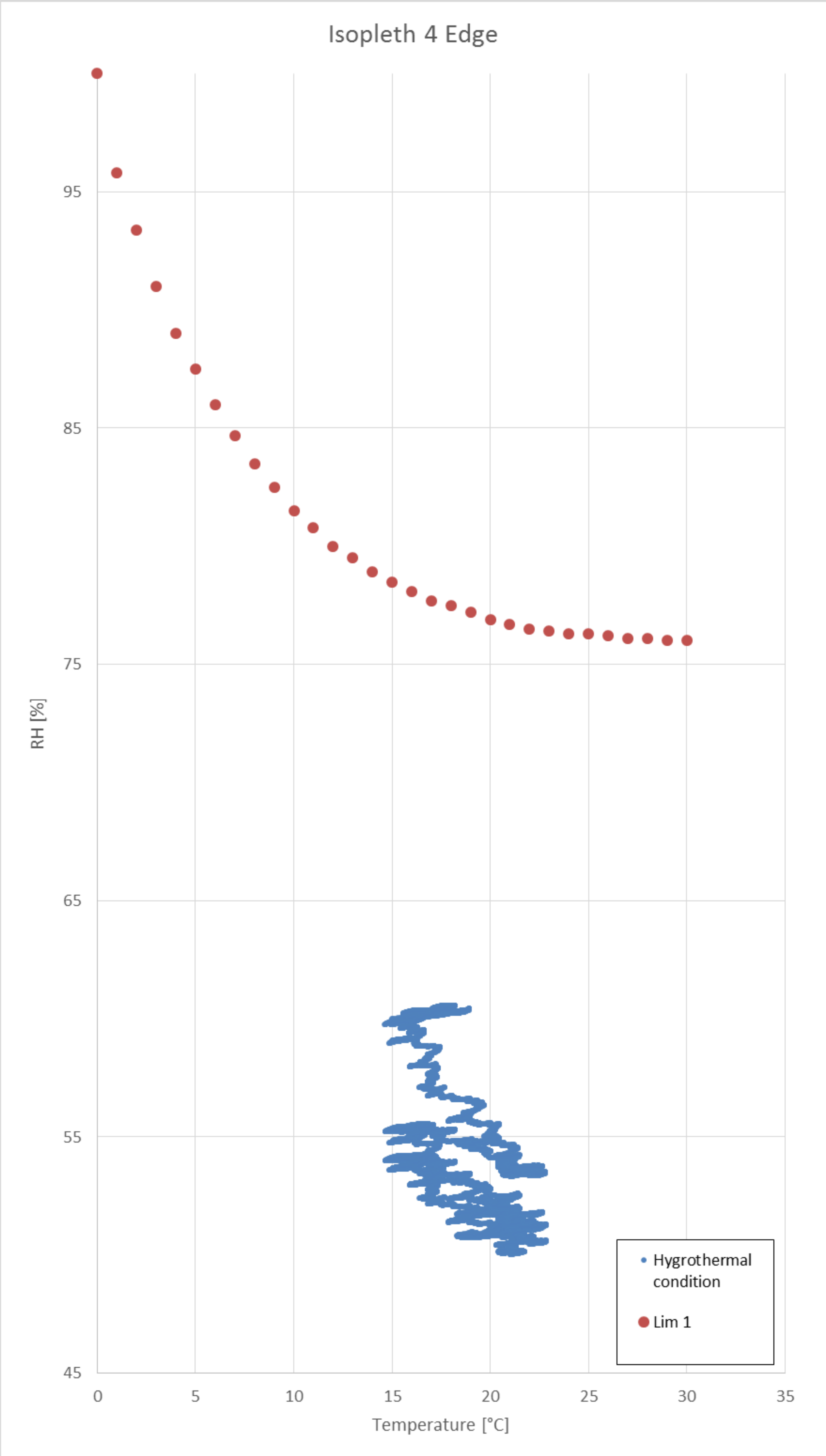

Figure 10, Type 4, edge

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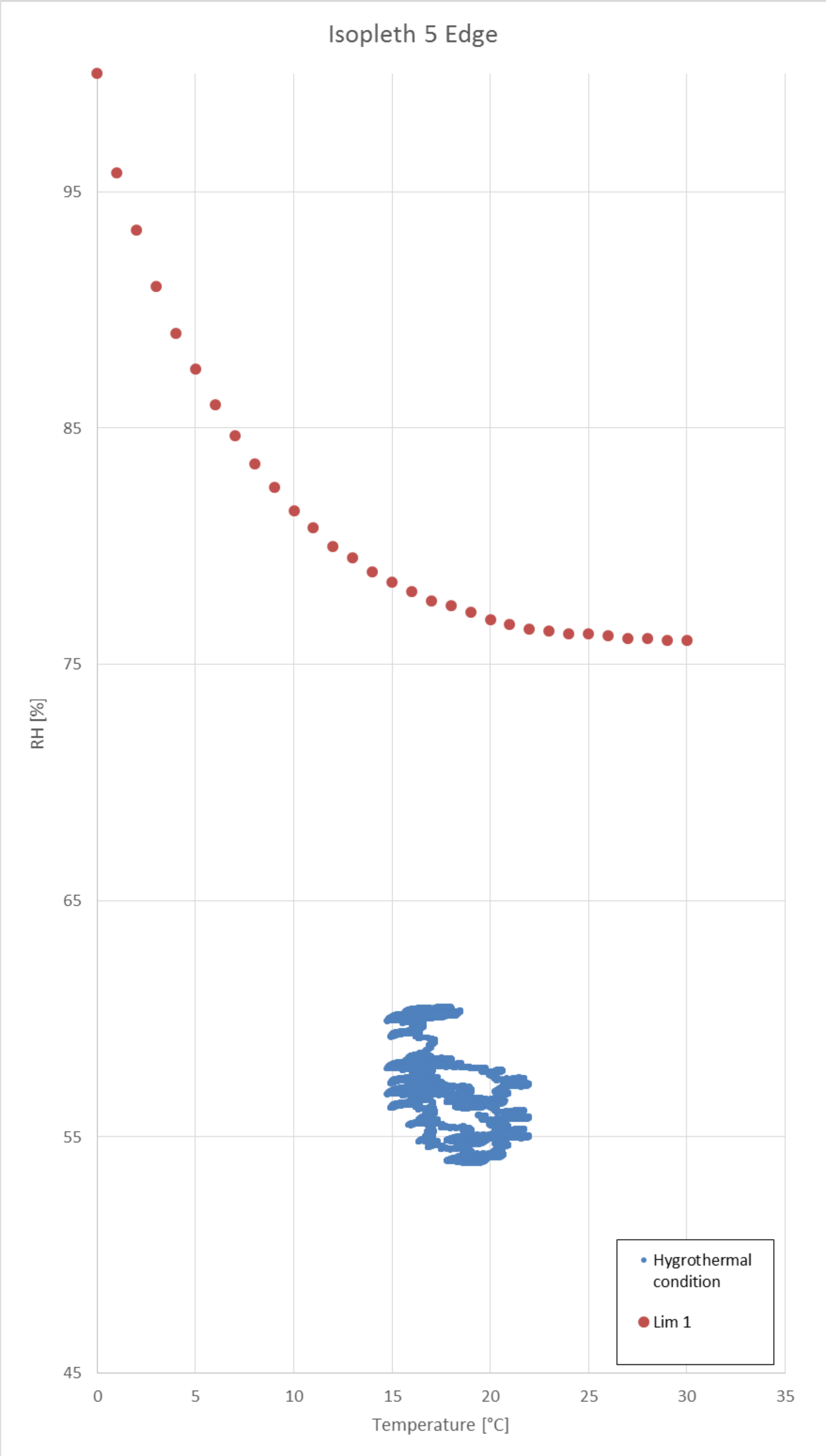

Figure 81, Type 5, edge

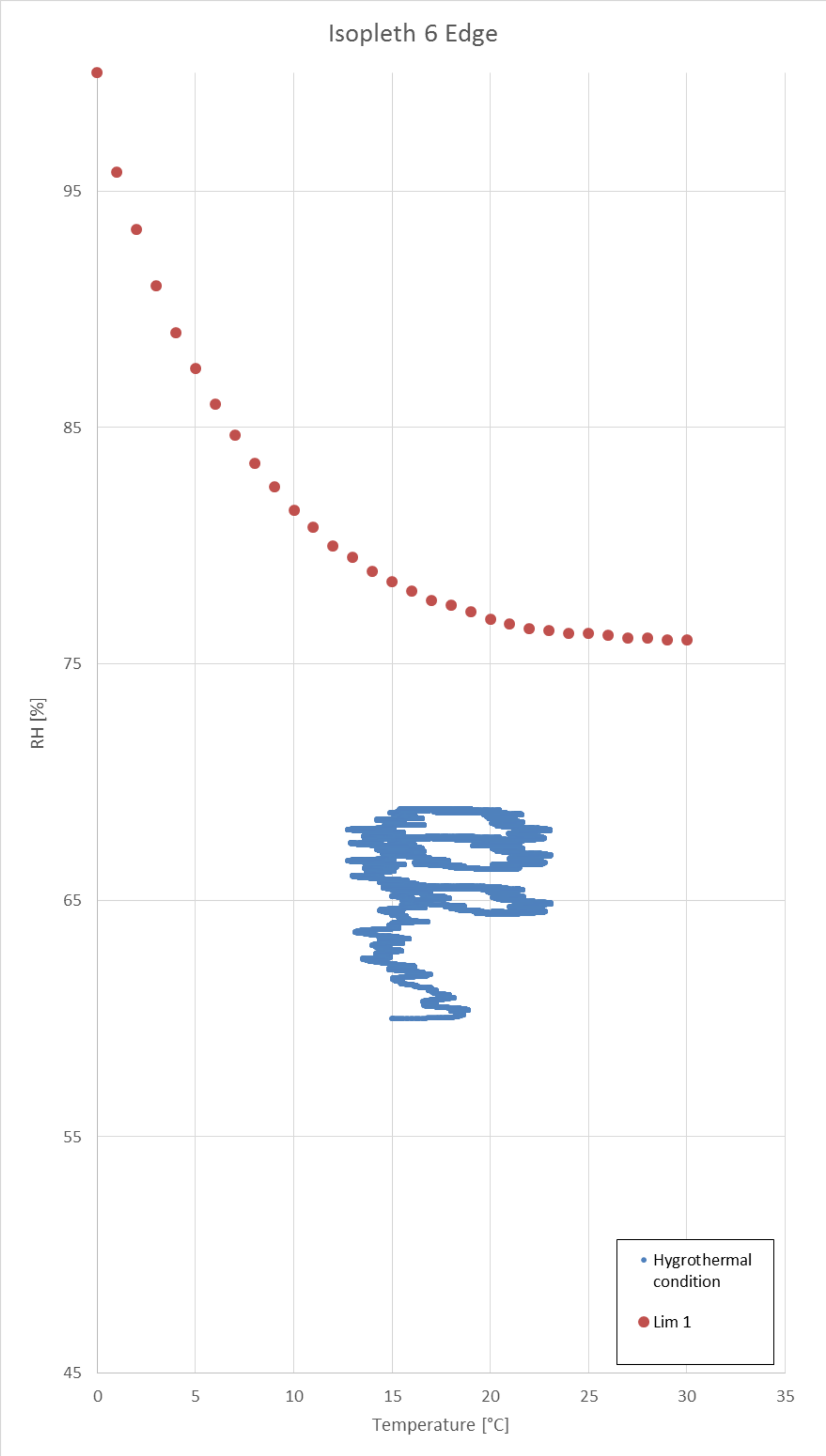

Figure 92, Type 6, edge

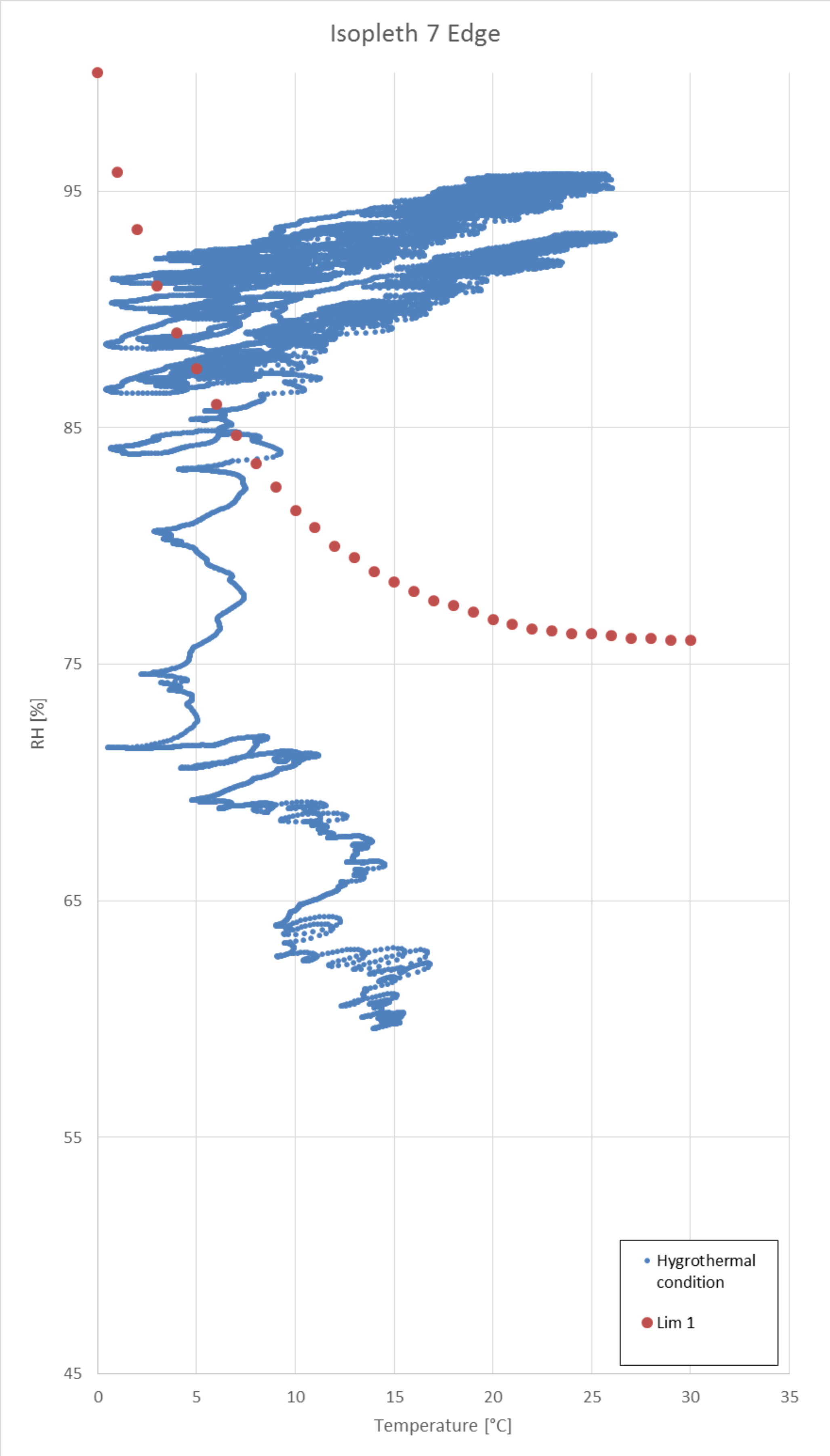

Figure 103, Type 7, edge

Type 6, six years simulation

Type number six is a method of how to improve the climate for the wooden beam. In the results for the three years long simulation, the curve shows no stabilized results. To see if the type will reach the risky climate a six years simulation is made. The results is presented below.

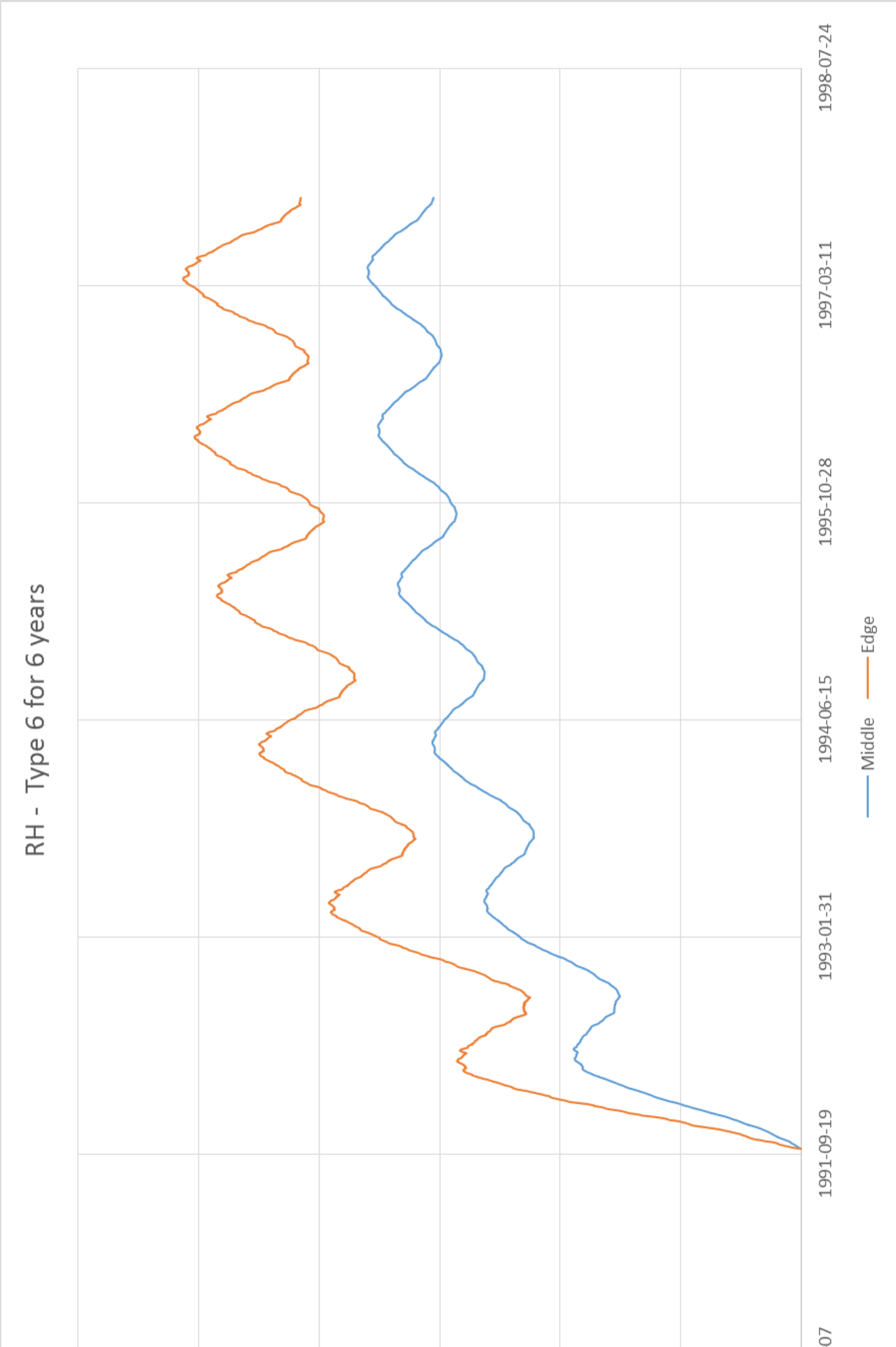

Figure 14, relative humidity, type 6, for 6 years

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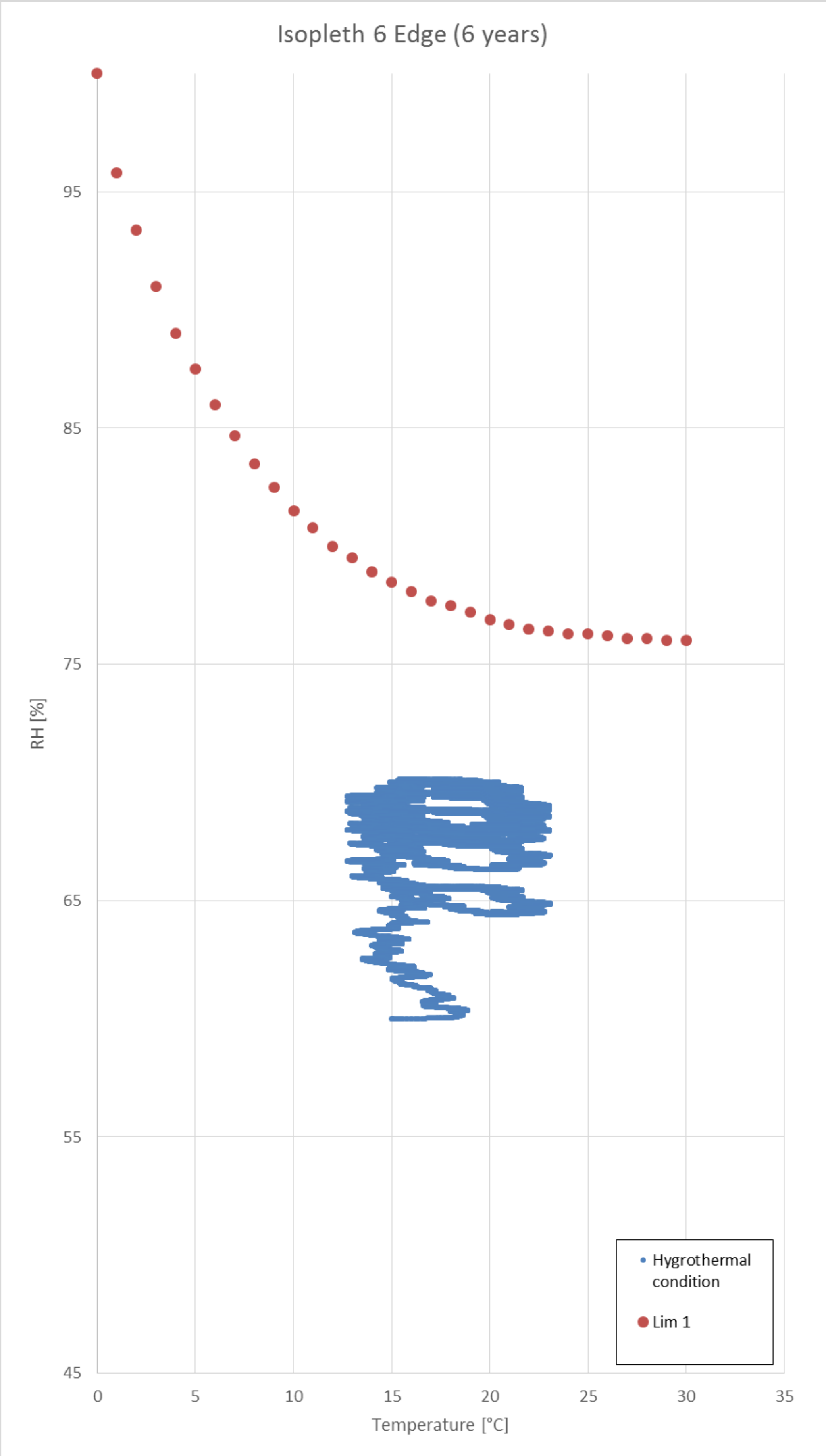
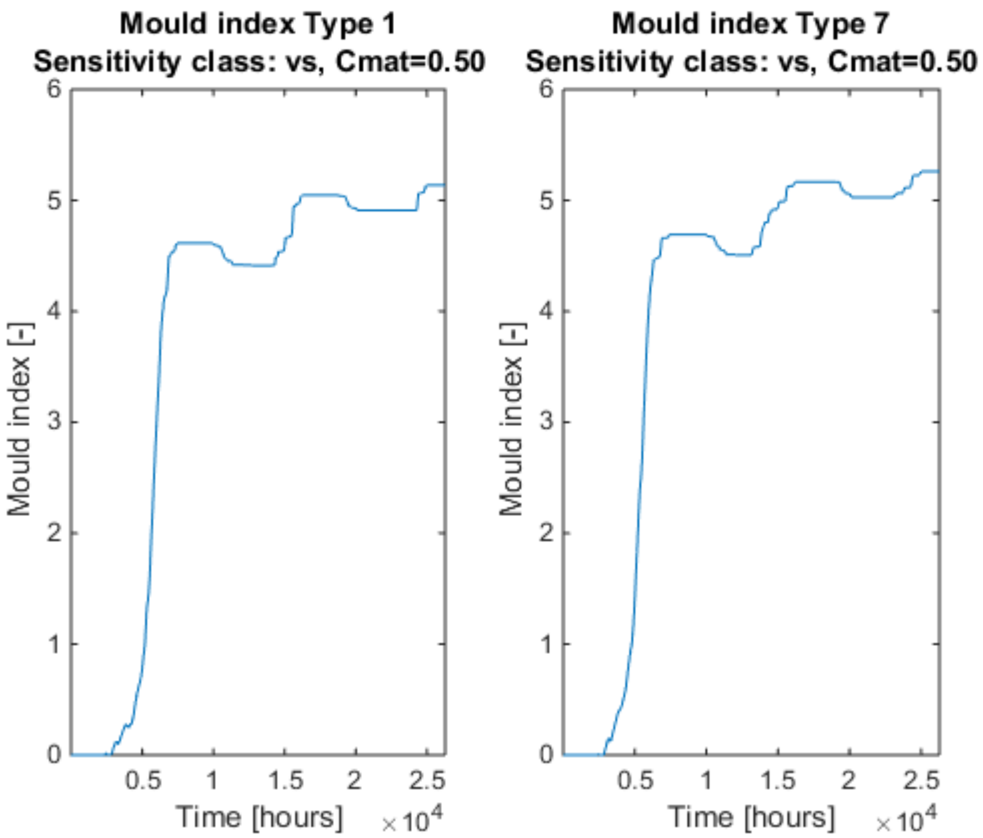


Figure 1511, Type 6, edge

Mould Growth Index

The evaluation of results that can be considered as critical above follows. Type number one and seven was further considered and Mould Growth Index was computed. Type number one was the situation where noting was added to the original wall structure and type number seven was the situation where internal insulation was added. The results follows.



Appendix V

Hygrothermal simulations

Roof – wall

Contents

Connection roof-wall

This appendix presents the data and the results for simulations in WUFI of the connection where the roof meets the exterior wall. The simulations show the relative humidity in the wooden beams over a period of three years. To see the risk of mould growth a plot with the relative humidity against the temperature is made. The results are indicating which kind of solution that is beneficial for the connection depending on the relative humidity and the temperature in the wood. The results also indicates the influence of an overhang of the roof. The base model is composed of a 1-stone wall, width 300mm, which meets the roof truss. The exterior wall was modelled to experiences different amount of rain, depending on how large overhang the roof has. This is controlled by changing the rain water absorption factor in WUFI. The connection where the beam meets the wall was designed according to the other beam supports that has been simulated, see separate appendix. In the models where insulation was assigned, an air cavity has also been considered. This cavity was modelled to be un-ventilated. The insulation was modelled to be located on the interior side of the roof.

Totally four different types are studied:

1. Insulation on the interior side of the roof. The model was simulated with a large overhang, which were considered by using a rainwater absorption factor equal to zero.
2. Same situation as above, with a difference of the length of the overhang or the rain absorption factor. The factor was in this case set to 0.3.
3. In this simulation was the rain absorption factor set to 0.7 to simulate a situation where the overhang does not exist at all and the wall are fully exposed to the rain. Otherwise, same conditions as above.
4. A reference case, where no insulation was added to the roof construction. The rain absorption factor was set to 0.7 and the temperature on the inside of the attic was set to be equal to the outside temperature.

Observe that the aim of the simulations is to give an indication of the effect of the different types of overhangs and the influence of the insulation. For a certain case, precise geometry and material parameters need to be deeper investigated.

Software

The software used for the simulations is WUFI 2D version 3.3. WUFI is a software based on finite volumes and handles transient heat and moisture transports of 2-dimensional geometries. WUFI allows you to add driving rain and heat and moisture sources, which is relevant in this case.

Geometry

The pictures and table below illustrate and describe the geometry used in the simulations. There are mainly two basic models that has been used, one with and one without insulation.

The air that makes the distance between the insulation and the outer layer of the roof is set to be 20mm consistently.

The geometry of the insulation was designed such as that a 300mm layer was obtained.

The geometry is based on an average geometry. In other words, the geometry can differ from house to house.

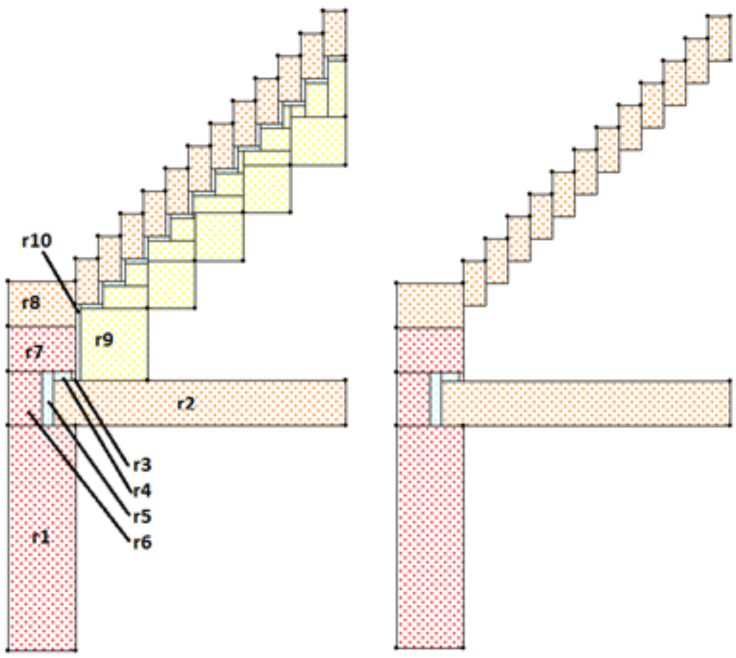


Figure 1, basic geometry with box numbers

Table 1, basic geometry, box sizes

Box	**X [mm]**	**Y [mm]**	**X_0 [mm]**	**Y_0 [mm]**
r1	300	1000	200	-600
r2	1300	200	400	402
r3	20	38	480	602
r4	80	38	400	602
r5	50	240	350	400
r6	150	240	300	400
r7	300	200	200	640
r8	300	200	200	840
r9	300	318	520	602
r10	20	338	500	602

The marked areas in the figure below show the points (edge and middle) where the relative humidity and the temperature are measured.

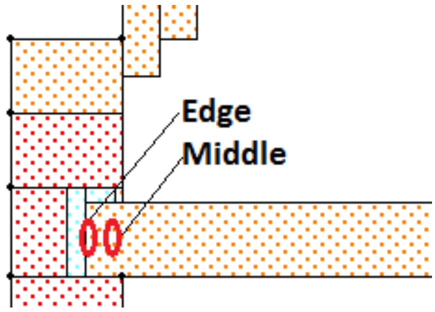


Figure 2, measuring points

Following illustration describes what material that has been assigned where in the models.

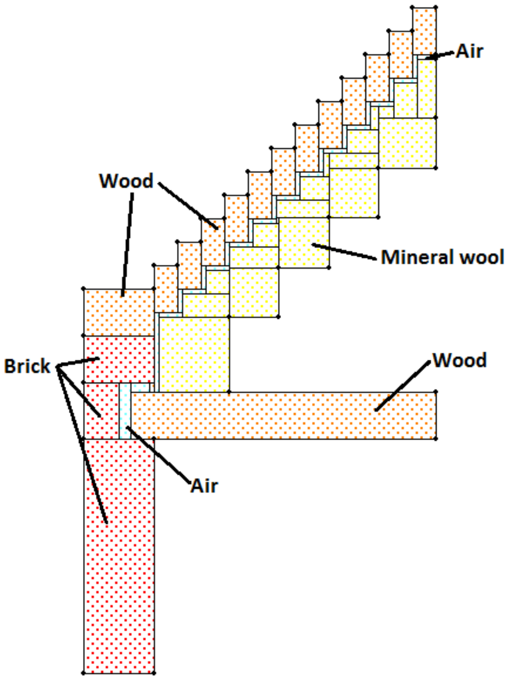


Figure 3, assigned materials

Boundary conditions and initial conditions

Three boundary conditions are used and are described below. Following figure shows the boundary conditions in the geometry.

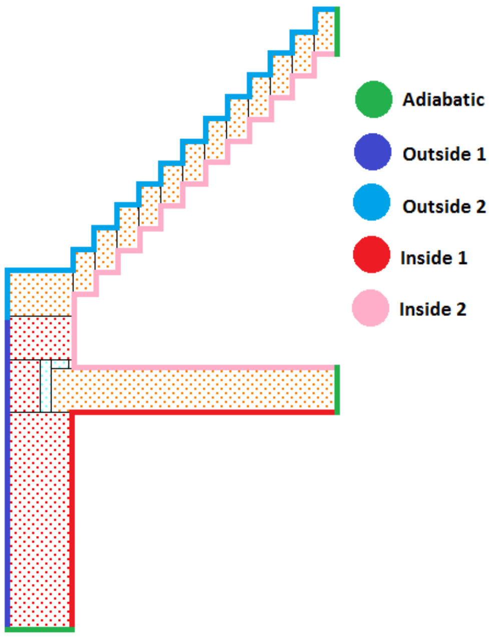


Figure 4, basic geometry with boundary conditions

Outside:

What differs “Outside 1” from “Outside 2” is the rain water absorption factor, they are otherwise identical.

- Climate, Gothenburg

	Temperature [°C]	Relative humidity [%]
Mean	8.8	74
Maximum	27.8	94
Minimum	-12.2	19

- Façade facing south
- Heat transfer coefficient, 25 $W/m^{2*}K$
- Short- and long-wave radiation absorptivity and emissivity depending on material
- Rain water absorption factor:
    - Outside 1: 0, 0.3 or 0,7
    - Outside 2: 0

In:

What differs “Inside 1” from “Inside 2” is that in simulation 4 “Inside 2” is equal to outside climate without any rain.

- Climate, medium moisture load, indoor (21±1 °C, 50±10 RH)
- Heat transfer coefficient, 7.7 $W/m^{2*}K$

Adiabatic:

- Adiabatic system border.

Initial conditions:

- 15 °C and 60% relative humidity in all materials. Start value is set based on the month where the calculation is started.

Materials

The materials used in the simulations are chosen from the material database in WUFI. The materials, with relevant data are showed in table 2.

Table 2, material data

Material	Bulk density [kg/m^3]	Porosity [m^3/m^3]	Spec. heat capacity [J/KgK]	Thermal conductivity [W/m*K]	Water vapour diffusion resistance factor [-]
Solid brick masonry	1900	0.24	850	0.6	10
Spruce, longitudinal	455	0.73	1500	0.23	4.3
Spruce, radial	455	0.73	1500	0.09	130
Mineral wool	60	0.95	850	0.04	1.3
Air gap 40 mm (including convection and radiation)	1.3	0.999	1000	0.23	0.38
Air gap 150 mm (including convection and radiation)	1.3	0.999	1000	0.94	0.07
Air gap 20 mm (including convection and radiation)	1.3	0.999	1000	0.13	0.56
Air gap 100 mm (including convection and radiation)	1.3	0.999	1000	0.59	0.15
Air gap 50 mm (including convection and radiation)	1.3	0.999	1000	0.28	0.32

Results

Relative humidity

Figure 5 and 6 show the relative humidity over the three calculated years in the points marked in figure 2 for each of the four types of roof-wall connection.

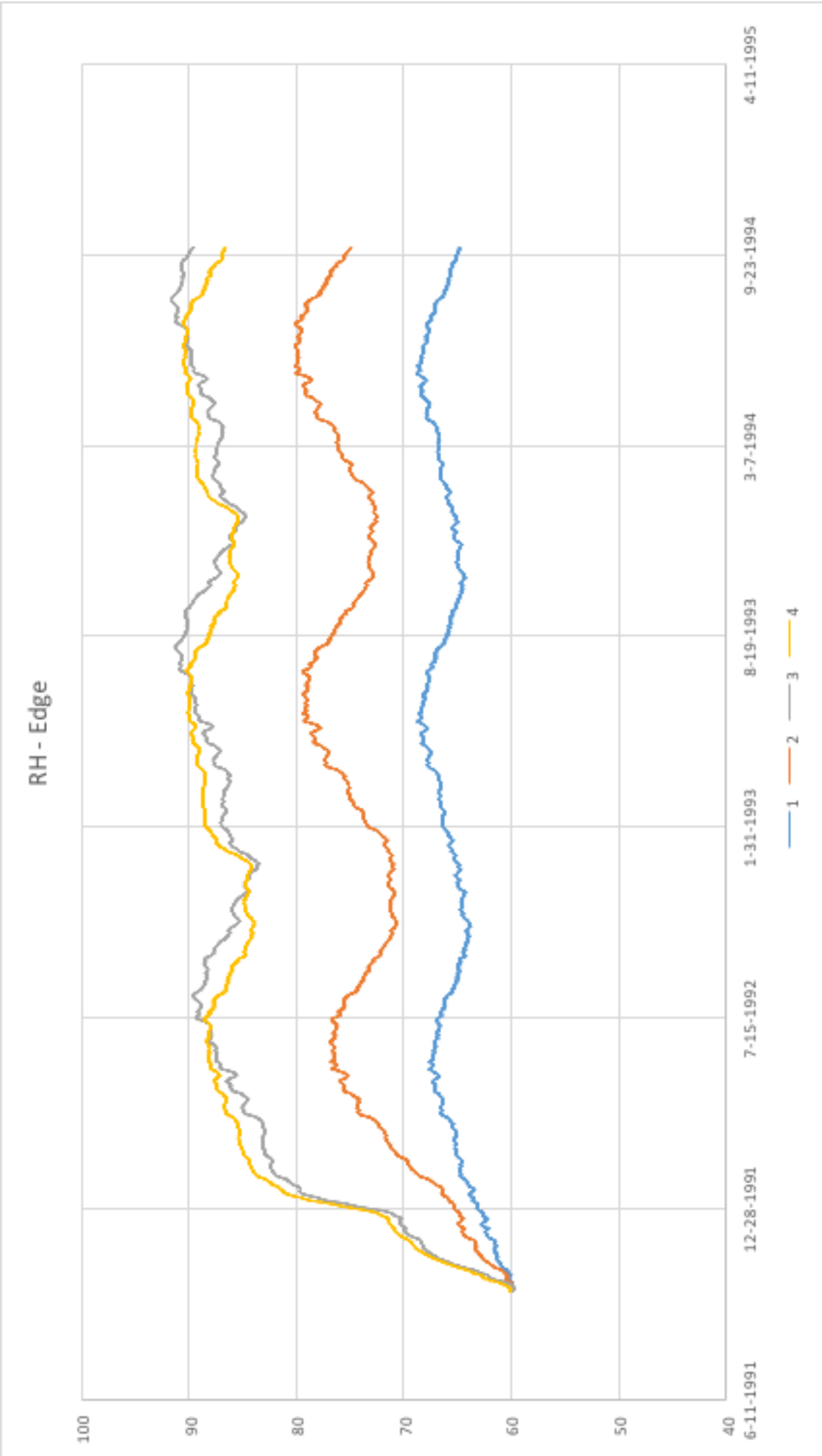


Figure 5, Relative humidity in beam edge

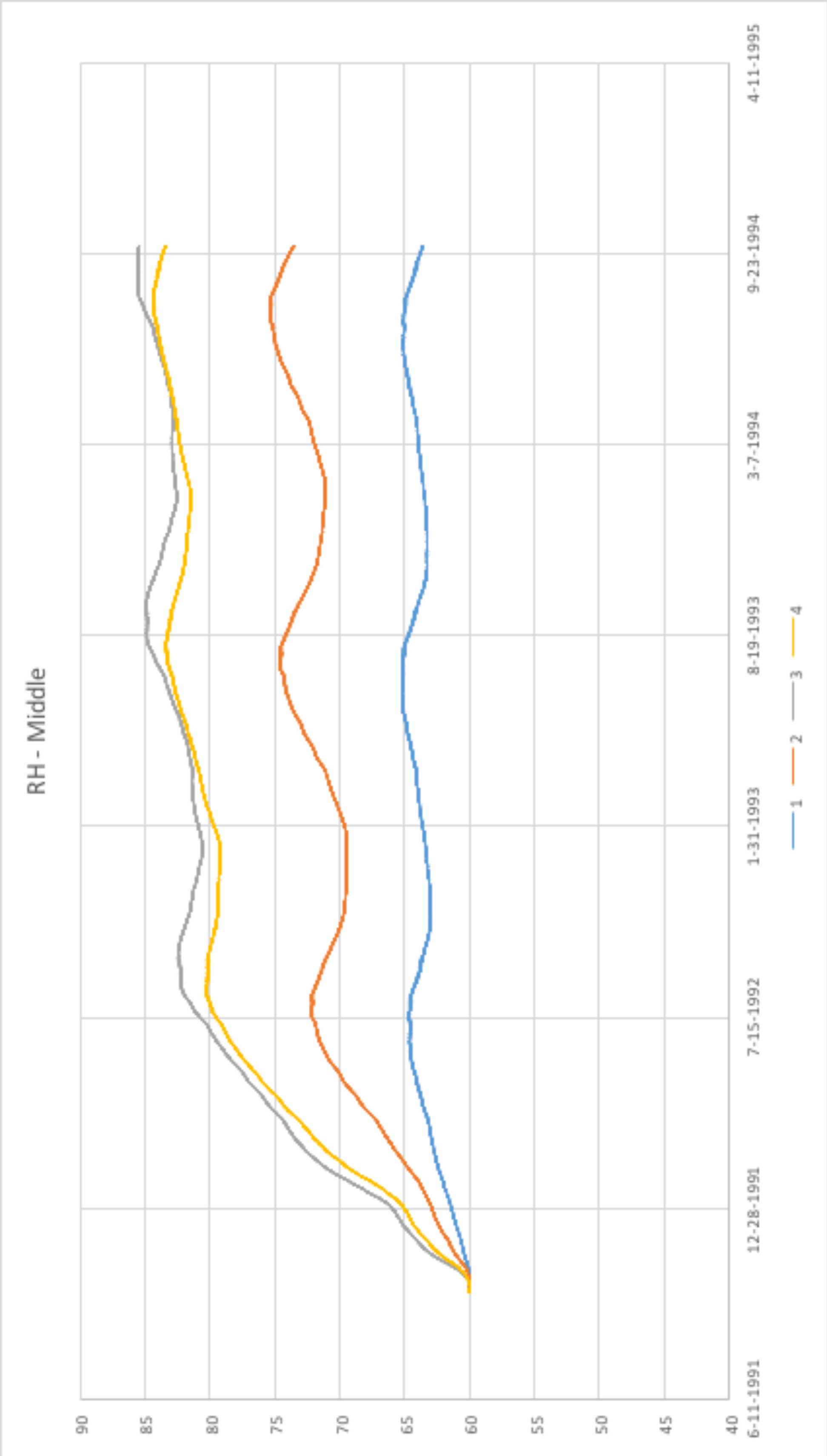


Figure 6, Relative humidity in beam middle

Hygrothermal conditions

The following figures show the plots of the temperature against the relative humidity (hygrothermal conditions). When the plot is outside the red dotted line, there is a risk of mould growth.

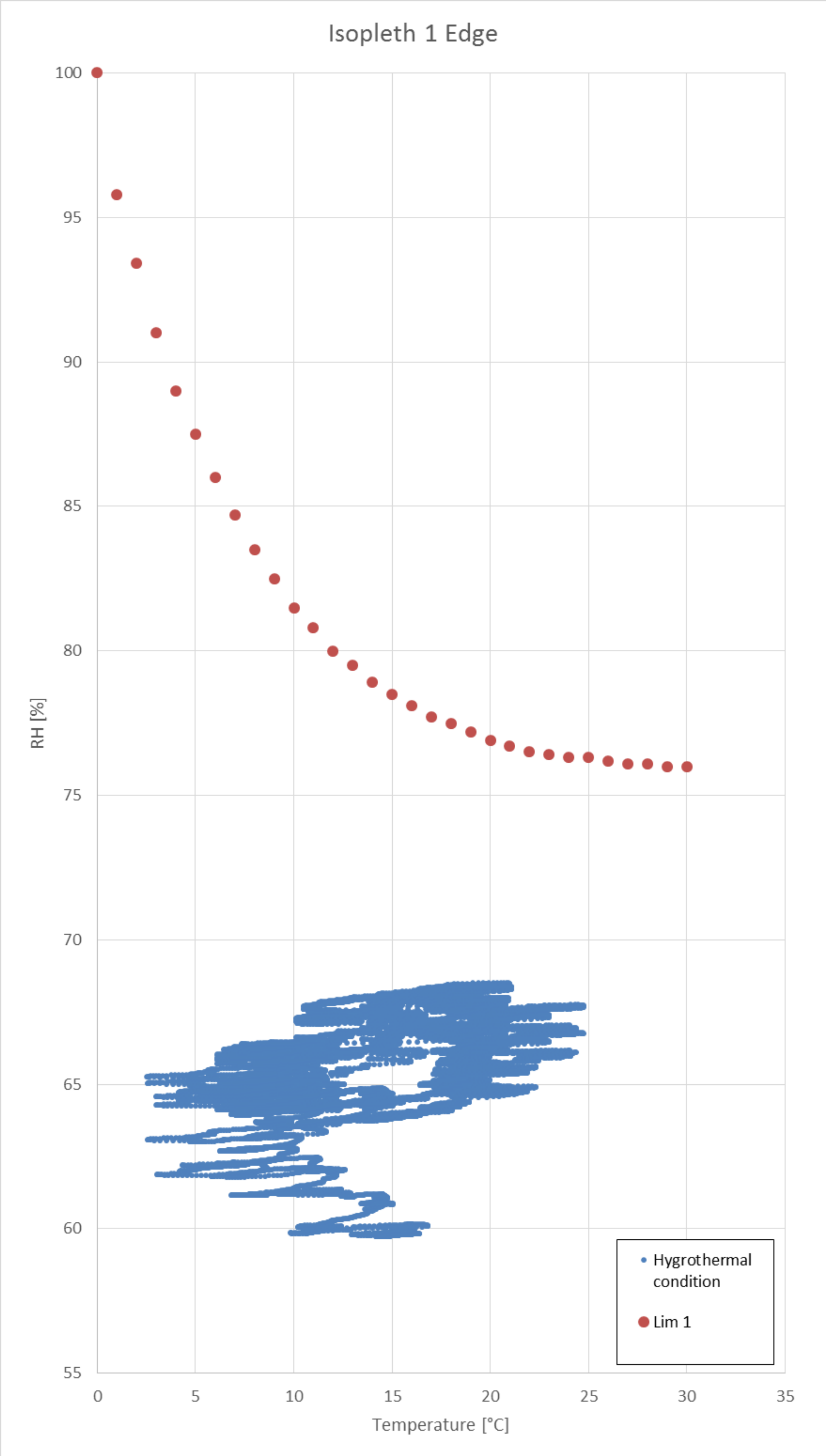


Figure 7, Type 1 edge

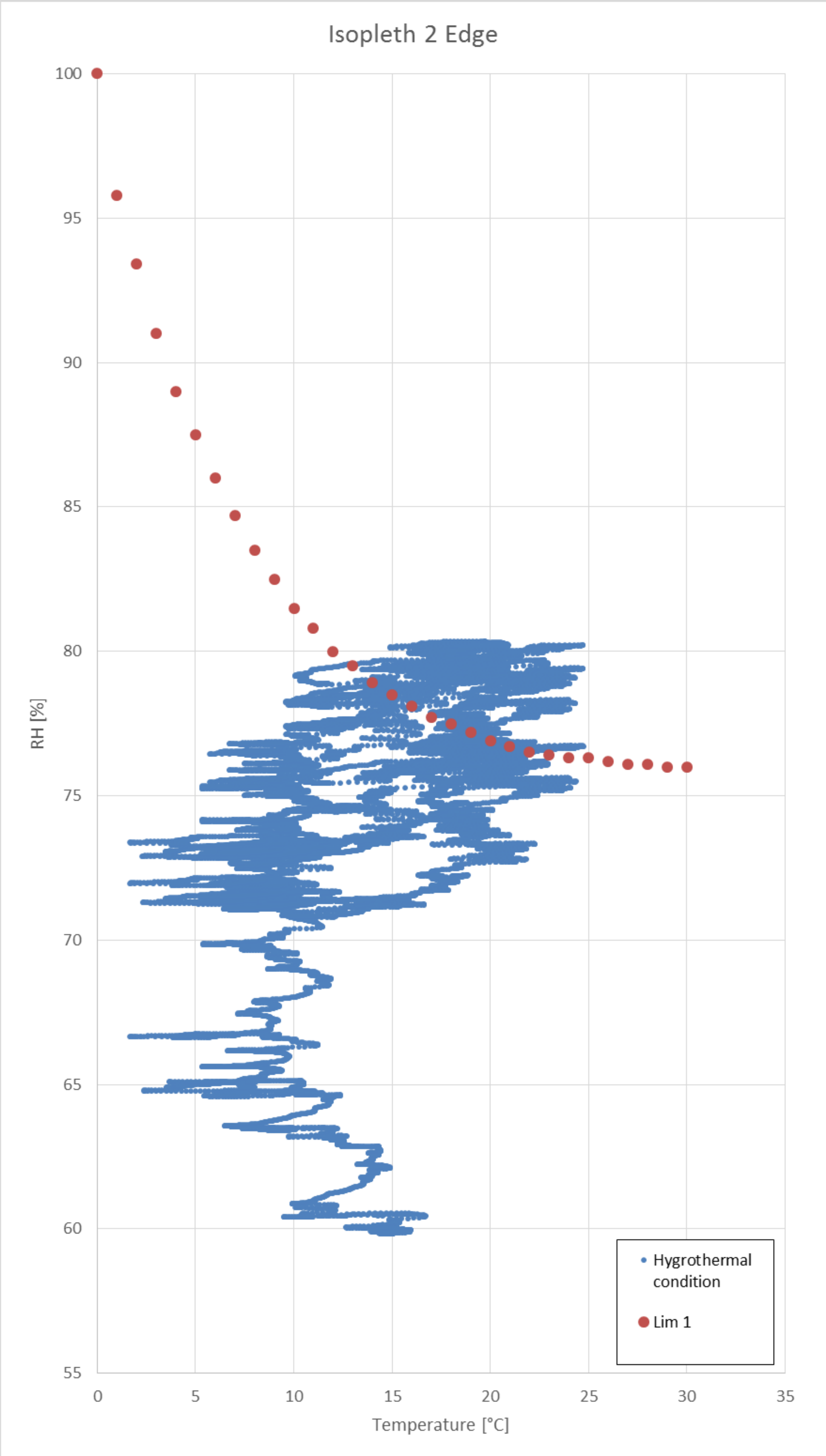


Figure 8, Type 2 edge

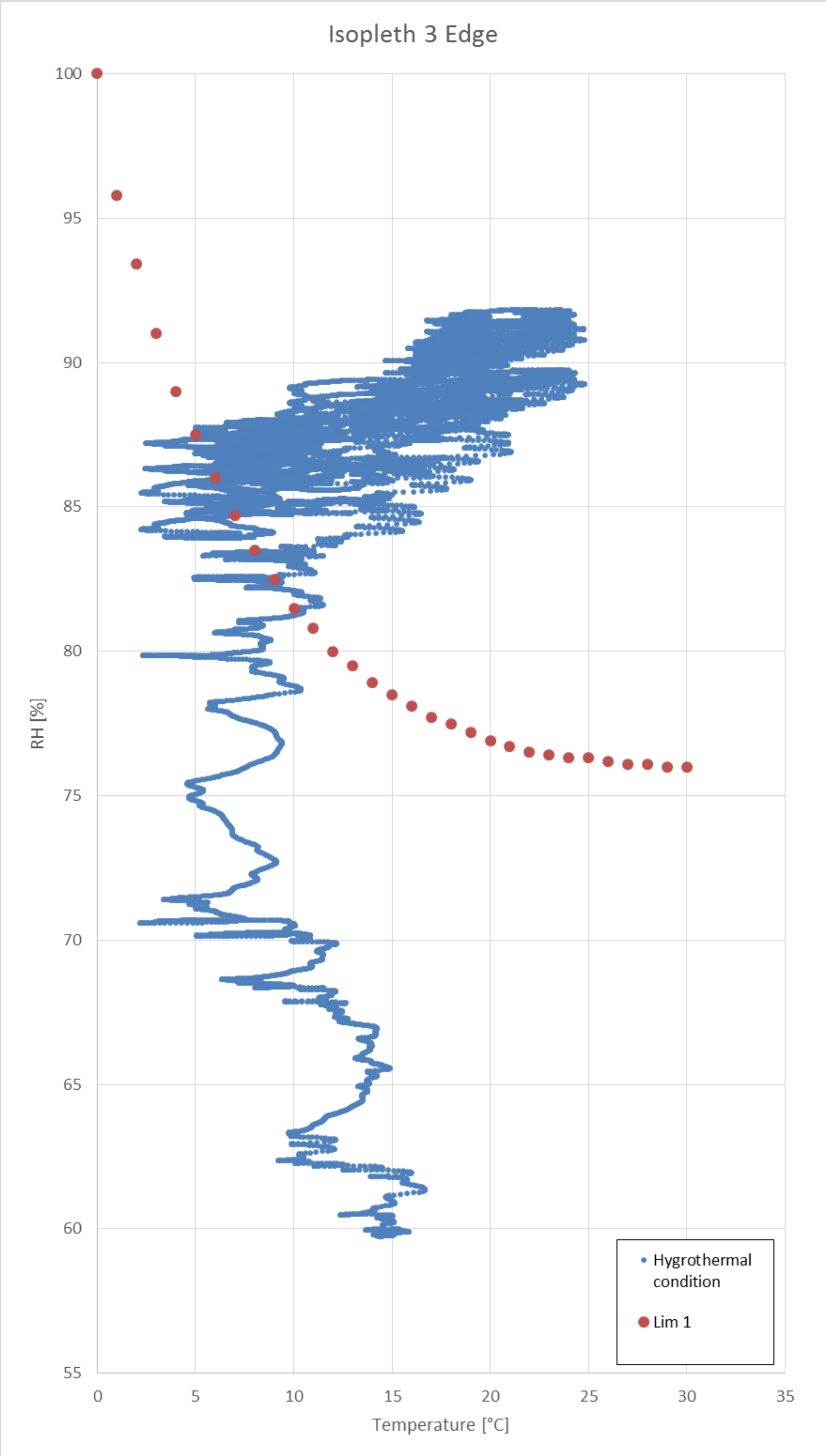


Figure 9, Type 3 edge

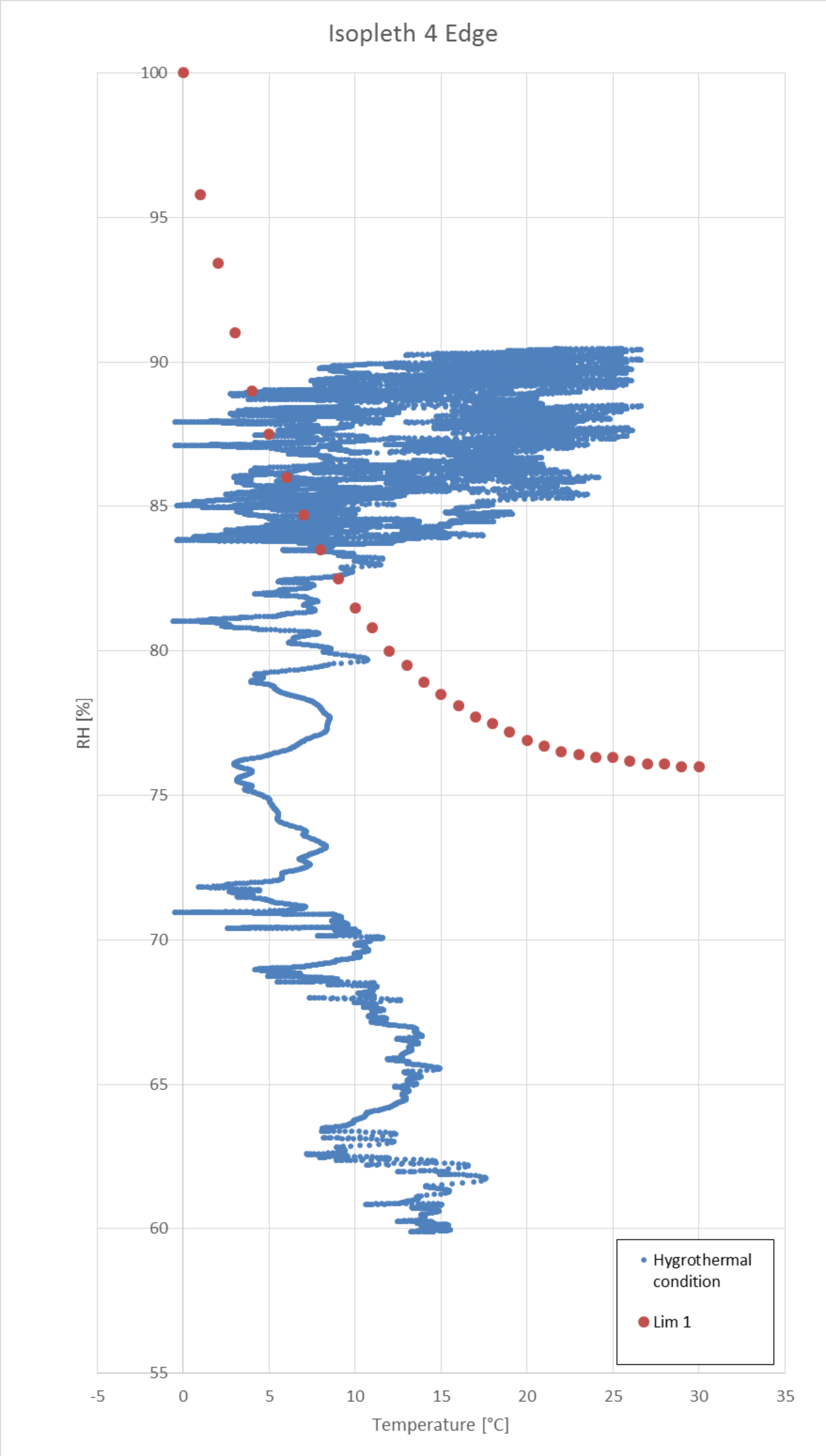
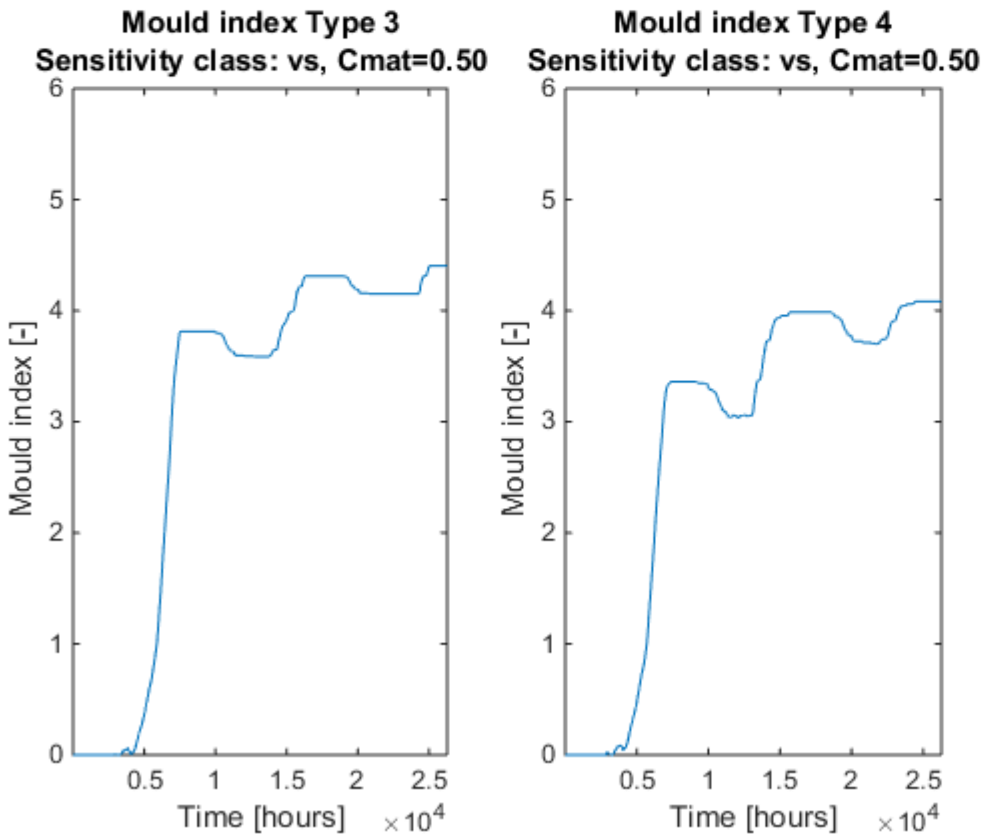


Figure 80, Type 4 edge

Mould Growth Index

The evaluation of results that can be considered as critical above follows. Type number three and four was further considered and Mould Growth Index was computed. Type number three was the situation where rain water absorption factor was set to 0.7 and type number seven was the situation where no insulation was added. The results follows below.



Appendix VI

Energy readings

Energy saving calculations

Contents

Energy readings

Energy readings from the district heating are made for all the buildings to get an overview of the energy consumption. These values are compared with the values from the EPC. All the values in the figures below are corrected with the average year according to Boverkets författningssamling 2013:16.

Year	Building 1 [kWh/m^2]	Building 2 [kWh/m^2]	Building 3 [kWh/m^2]	Building 4 [kWh/m^2]	Building 5 [kWh/m^2]
2005	104	123	121	128	154
2006	116	133	139	141	150
2007	99	126	134	141	147
2008	98	128	134	137	152
2009	99	121	126	136	147
2010	94	105	102	119	135
2011	101	123	81	128	153
2012	100	117	101	121	134
2013	100	135	117	144	161
2014	107	129	99	137	152
2015	112	117	91	127	147
Energideklaration	107	130	142	117	159

2008 the windows in building 3 were renovated. The windows were covered with painted aluminium and an extra glass pane was added on the interior. To see how the energy consumption are affected from the renovation, the energy readings before and after the renovation are controlled.

The average energy consumptions are calculated for the years before and after the renovation year. 2011 seems to be unrepresentative. 2011 is considerably lower than the others. Therefore, the savings are calculated both when 2011 is included and also when it is excluded. The savings are presented in the tables below.

Savings calculated for the years after and the years before.	
Average before 2008	131
Average after 2008	103
Savings:	22%

Savings calculated for the years after and the years before excluding 2011.	
Average before 2008	131
Average after 2008	106
Savings:	19%

Energy saving calculations

Below follows in total eleven (eight and three) pages of energy saving calculations.

Calculations of U-value for floor and roof

Calculation of U-value of the ground construction

$A_1 := 710\ m^2$ $P_1 := 146\ m$

$A_2 := 460\ m^2$ $P_2 := 70\ m$

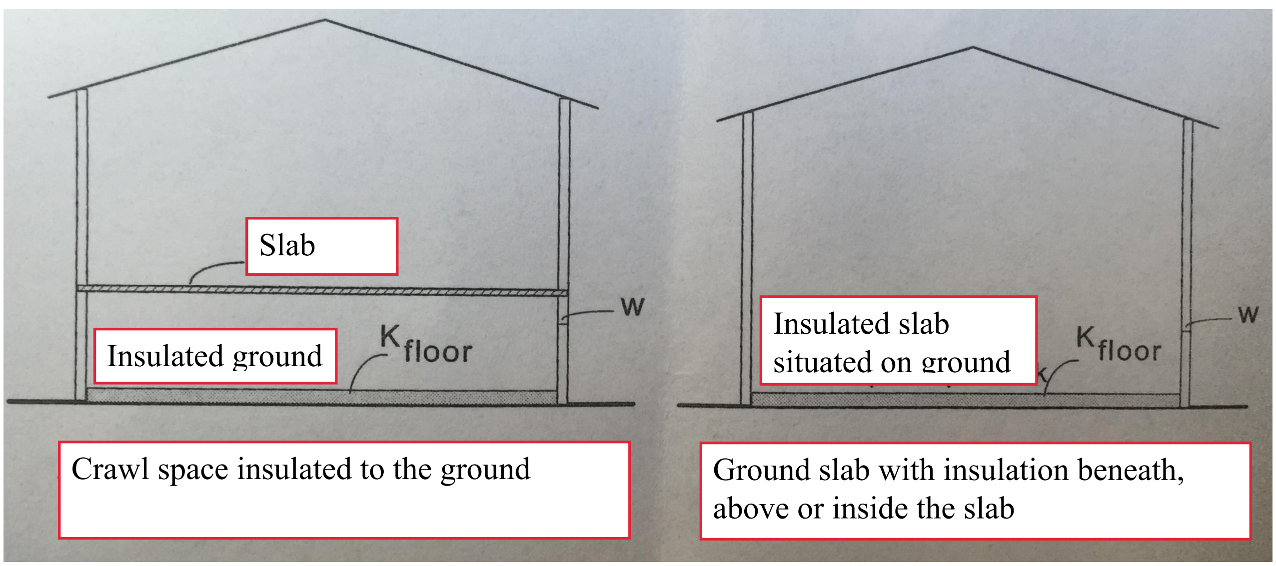
$A_3 := 180\ m^2$ $P_3 := 62\ m$

$A_4 := 580\ m^2$ $P_4 := 103\ m$

$A_5 := 310\ m^2$ $P_5 := 82\ m$

$$A_{mean} := \frac{A_1 + A_2 + A_3 + A_4 + A_5}{5} = 448\ m^2$$

$$P_{mean} := \frac{P_1 + P_2 + P_3 + P_4 + P_5}{5} = 92,6\ m$$



Heat transfer coefficient in (Table 9.2)

$$\alpha_{si} := 5,88\ \frac{W}{m^2\ K}$$

Heat transfer coefficient out (Table 9.2)

$$\alpha_{se} := 25\ \frac{W}{m^2\ K}$$

Area inside the foundation wall

$A := A_{mean} = 448\ m^2$

Circumference inside the foundation wall

$P := P_{mean} = 92,6\ m$

Thickness of the foundation wall (all material layers)

$w := 0,6\ m$

Thermal conductivity of the ground (Table 9.1)

$\lambda_{ground} := 2\ \frac{W}{m\ K}$

Thermal conducticity of the concrete

$\lambda_{conc} := 1,7\ \frac{W}{m\ K}$

Thickness of the concrete

$t_{conc} := 0,1\ m$

Characteristic dimension of foundation slab (9.31)

$$B := \frac{A}{\frac{1}{2} \cdot P} = 9,676\ m$$

Conductance of foundation slab

$$K_{insul} := \frac{\lambda_{conc}}{t_{conc}} \cdot A = 7616\ \frac{W}{K}$$

Eqvivalent thickness (9.32)

$$a := \frac{1}{\alpha_{si}}$$

$$c := \frac{1}{\alpha_{se}} \qquad b := \frac{A}{K_{insul}}$$

$$d_t := w + \lambda_{ground} \cdot (a + b + c) = 1,1378\ m$$

Conductance of the floor (9.33 and 9.34)

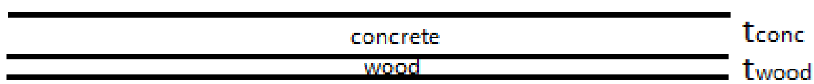
$$K_{floor} := \text{if } d_t \geq B \quad A \cdot \frac{\lambda_{ground}}{0{,}457 \cdot B + d_t} \quad \text{else} \quad A \cdot \frac{\left(2 \cdot \lambda_{ground}\right)}{\pi \cdot B + d_t} \cdot \ln\left(\frac{\pi \cdot B}{d_t} + 1\right) = 188{,}7722 \; \frac{W}{K}$$

$$U := \frac{K_{floor}}{A} = 0{,}42 \; \frac{W}{m^2 \; K}$$

Calculation of U-value for the roof

$$R_{si} := \frac{0{,}1 \; m^2 \; K}{W}$$

$$R_{se} := \frac{0{,}04 \; m^2 \; K}{W}$$



$$t_{wood} := 30 \; mm$$

$$t_{conc} := 50 \; mm$$

$$\lambda_{wood} := 0{,}14 \; \frac{W}{m \; K}$$

$$\lambda_{conc} = 1{,}7 \; \frac{W}{m \; K}$$

$$R_{wood} := \frac{t_{wood}}{\lambda_{wood}} = 0{,}2143 \; \frac{m^2 \; K}{W} \qquad R_{conc} := \frac{t_{conc}}{\lambda_{conc}} = 0{,}0294 \; \frac{m^2 \; K}{W}$$

$$U := \frac{1}{R_{si} + R_{wood} + R_{conc} + R_{se}} = 2{,}61 \; \frac{W}{m^2 \; K}$$

Typical geometry and calculation of Um

Area, windows

$A_{win1} := 450\ m^2$

$A_{win2} := 220\ m^2$

$A_{win3} := 145\ m^2$

$A_{win4} := 360\ m^2$

$A_{win5} := 180\ m^2$

Area, walls

$A_{w1} := 2250\ m^2$

$A_{w2} := 1370\ m^2$

$A_{w3} := 655\ m^2$

$A_{w4} := 1100\ m^2$

$A_{w5} := 1010\ m^2$

Area, ground floor

$A_{f1} := 710\ m^2$

$A_{f2} := 460\ m^2$

$A_{f3} := 180\ m^2$

$A_{f4} := 580\ m^2$

$A_{f5} := 310\ m^2$

Area, roof

$A_{r1} := 710\ m^2$

$A_{r2} := 460\ m^2$

$A_{r3} := 180\ m^2$

$A_{r4} := 580\ m^2$

$A_{r5} := 310\ m^2$

$BOA_1 := 2407\ m^2$

$BOA_2 := 2085\ m^2$

$BOA_3 := 1108\ m^2$

$BOA_4 := 1880\ m^2$

$BOA_5 := 1456\ m^2$

$LOA_1 := 1742\ m^2$

$LOA_2 := 285\ m^2$

$LOA_3 := 193\ m^2$

$LOA_4 := 810\ m^2$

$LOA_5 := 211\ m^2$

Heated area

$A_{temp1} := 5091\ m^2$

$A_{temp2} := 2634\ m^2$

$A_{temp3} := 1657\ m^2$

$A_{temp4} := 4075\ m^2$

$A_{temp5} := 2084\ m^2$

Average areas

$$A_{win} := \frac{A_{win1} + A_{win2} + A_{win3} + A_{win4} + A_{win5}}{5} = 271\ m^2$$

$$A_{w} := \frac{A_{w1} + A_{w2} + A_{w3} + A_{w4} + A_{w5}}{5} = 1277\ m^2$$

$$A_{f} := \frac{A_{f1} + A_{f2} + A_{f3} + A_{f4} + A_{f5}}{5} = 448\ m^2$$

$$A_{r} := \frac{A_{r1} + A_{r2} + A_{r3} + A_{r4} + A_{r5}}{5} = 448\ m^2$$

$$BOA := \frac{BOA_1 + BOA_2 + BOA_3 + BOA_4 + BOA_5}{5} = 1787{,}2\ m^2$$

$$LOA := \frac{LOA_1 + LOA_2 + LOA_3 + LOA_4 + LOA_5}{5} = 648{,}2\ m^2$$

$$A_{temp} := \frac{A_{temp1} + A_{temp2} + A_{temp3} + A_{temp4} + A_{temp5}}{5} = 3108{,}2\ m^2$$

Original U-values

$$U_{winORIG} := 2{,}8 \ \frac{W}{m^2 K}$$

$$U_{w1ORIG} := \left(\frac{1{,}06 + 1{,}43}{2}\right) \frac{W}{m^2 K} = 1{,}245 \ \frac{W}{m^2 K}$$

$$U_{w2ORIG} := \left(\frac{1{,}06 + 1{,}43}{2}\right) \frac{W}{m^2 K} = 1{,}245 \ \frac{W}{m^2 K}$$

$$U_{fORIG} := 0{,}43 \ \frac{W}{m^2 K}$$

$$U_{rORIG} := 2{,}6 \ \frac{W}{m^2 K}$$

$$A_{tempORIG} := 1 \cdot A_{temp}$$

Total average original U-value

$$U_{mORIG} := \frac{A_{win} \cdot U_{winORIG} + 0{,}5 \cdot A_w \cdot U_{w1ORIG} + 0{,}5 \cdot A_w \cdot U_{w2ORIG} + A_f \cdot U_{fORIG} + A_r \cdot U_{rORIG}}{A_{win} + A_w + A_f + A_r}$$

$$U_{mORIG} = 1{,}5164 \ \frac{W}{m^2 K}$$

U-value per A.temp

$$\frac{U_{mORIG}}{A_{tempORIG}} = 0{,}0005 \ \frac{\frac{W}{m^2 K}}{m^2}$$

New windows

New U-values

$$U_{winNEW} := 1,2 \frac{W}{m^2 K}$$

$$U_{w1NEW} := U_{w1ORIG} = 1,245 \frac{W}{m^2 K}$$

$$U_{w2NEW} := U_{w2ORIG} = 1,245 \frac{W}{m^2 K}$$

$$U_{fNEW} := U_{fORIG} = 0,43 \frac{W}{m^2 K}$$

$$U_{rNEW} := U_{rORIG} = 2,6 \frac{W}{m^2 K}$$

$$A_{tempNEW} := \frac{6}{6} \cdot A_{temp} = 3108,2 \; m^2$$

Total average new U-value

$$U_{mNEW} := \frac{A_{win} \cdot U_{winNEW} + 0,5 \cdot A_w \cdot U_{w1NEW} + 0,5 \cdot A_w \cdot U_{w2NEW} + A_f \cdot U_{fNEW} + A_r \cdot U_{rNEW}}{A_{win} + A_w + A_f + A_r}$$

$$U_{mNEW} = 1,339 \frac{W}{m^2 K}$$

U-value per A.temp

$$\frac{U_{mNEW}}{A_{tempNEW}} = 0,0004 \frac{\frac{W}{m^2 K}}{m^2}$$

Saving excluding A.temp

$$\frac{U_{mORIG} - U_{mNEW}}{U_{mORIG}} = 12 \; \%$$

Saving including A.temp

$$\frac{\frac{U_{mORIG}}{A_{tempORIG}} - \frac{U_{mNEW}}{A_{tempNEW}}}{\frac{U_{mORIG}}{A_{tempORIG}}} = 12 \; \%$$

100 mm insulation to the courtyard (half the wall area)

New U-values

$U_{winNEW} := U_{winORIG} = 2,8 \frac{W}{m^2 K}$

$U_{w1NEW} := \frac{0,32 + 0,29}{2} \frac{W}{m^2 K} = 0,305 \frac{W}{m^2 K}$

$U_{w2NEW} := U_{w2ORIG} = 1,245 \frac{W}{m^2 K}$

$U_{fNEW} := U_{fORIG} = 0,43 \frac{W}{m^2 K}$

$U_{rNEW} := U_{rORIG} = 2,6 \frac{W}{m^2 K}$

$A_{tempNEW} := \frac{6}{6} \cdot A_{temp} = 3108,2 \; m^2$

Total average new U-value

$$U_{mNEW} := \frac{A_{win} \cdot U_{winNEW} + 0,5 \cdot A_w \cdot U_{w1NEW} + 0,5 \cdot A_w \cdot U_{w2NEW} + A_f \cdot U_{fNEW} + A_r \cdot U_{rNEW}}{A_{win} + A_w + A_f + A_r}$$

$U_{mNEW} = 1,2708 \frac{W}{m^2 K}$

U-value per A.temp

$$\frac{U_{mNEW}}{A_{tempNEW}} = 0,0004 \frac{\frac{W}{m^2 K}}{m^2}$$

Saving excluding A.temp

$$\frac{U_{mORIG} - U_{mNEW}}{U_{mORIG}} = 16 \; \%$$

Saving including A.temp

$$\frac{\frac{U_{mORIG}}{A_{tempORIG}} - \frac{U_{mNEW}}{A_{tempNEW}}}{\frac{U_{mORIG}}{A_{tempORIG}}} = 16 \; \%$$

50 mm insulation to the court yard (half the wall area)

New U-values

$$U_{winNEW} := U_{winORIG} = 2,8 \ \frac{W}{m^2 K}$$

$$U_{w1NEW} := \frac{0,52 + 0,46}{2} \ \frac{W}{m^2 K} = 0,49 \ \frac{W}{m^2 K}$$

$$U_{w2NEW} := U_{w2ORIG} = 1,245 \ \frac{W}{m^2 K}$$

$$U_{fNEW} := U_{fORIG} = 0,43 \ \frac{W}{m^2 K}$$

$$U_{rNEW} := U_{rORIG} = 2,6 \ \frac{W}{m^2 K}$$

$$A_{tempNEW} := \frac{6}{6} \cdot A_{temp} = 3108,2 \ m^2$$

Total average new U-value

$$U_{mNEW} := \frac{A_{win} \cdot U_{winNEW} + 0,5 \cdot A_w \cdot U_{w1NEW} + 0,5 \cdot A_w \cdot U_{w2NEW} + A_f \cdot U_{fNEW} + A_r \cdot U_{rNEW}}{A_{win} + A_w + A_f + A_r}$$

$$U_{mNEW} = 1,3192 \ \frac{W}{m^2 K}$$

U-value per A.temp

$$\frac{U_{mNEW}}{A_{tempNEW}} = 0,0004 \ \frac{\frac{W}{m^2 K}}{m^2}$$

Saving excluding A.temp

$$\frac{U_{mORIG} - U_{mNEW}}{U_{mORIG}} = 13 \ \%$$

Saving including A.temp

$$\frac{\frac{U_{mORIG}}{A_{tempORIG}} - \frac{U_{mNEW}}{A_{tempNEW}}}{\frac{U_{mORIG}}{A_{tempORIG}}} = 13 \ \%$$

100 mm insulation (all walls)

New U-values

$$U_{winNEW} := U_{winORIG} = 2,8 \ \frac{W}{m^2 K}$$

$$U_{w1NEW} := \frac{0,32 + 0,29}{2} \frac{W}{m^2 K} = 0,305 \ \frac{W}{m^2 K}$$

$$U_{w2NEW} := \frac{0,32 + 0,29}{2} \frac{W}{m^2 K} = 0,305 \ \frac{W}{m^2 K}$$

$$U_{fNEW} := U_{fORIG} = 0,43 \ \frac{W}{m^2 K}$$

$$U_{rNEW} := U_{rORIG} = 2,6 \ \frac{W}{m^2 K}$$

$$A_{tempNEW} := \frac{6}{6} \cdot A_{temp} = 3108,2 \ m^2$$

Total average new U-value

$$U_{mNEW} := \frac{A_{win} \cdot U_{winNEW} + 0,5 \cdot A_w \cdot U_{w1NEW} + 0,5 \cdot A_w \cdot U_{w2NEW} + A_f \cdot U_{fNEW} + A_r \cdot U_{rNEW}}{A_{win} + A_w + A_f + A_r}$$

$$U_{mNEW} = 1,0253 \ \frac{W}{m^2 K}$$

U-value per A.temp

$$\frac{U_{mNEW}}{A_{tempNEW}} = 0,0003 \ \frac{\frac{W}{m^2 K}}{m^2}$$

Saving excluding A.temp

$$\frac{U_{mORIG} - U_{mNEW}}{U_{mORIG}} = 32 \ \%$$

Saving including A.temp

$$\frac{\frac{U_{mORIG}}{A_{tempORIG}} - \frac{U_{mNEW}}{A_{tempNEW}}}{\frac{U_{mORIG}}{A_{tempORIG}}} = 32 \ \%$$

50 mm insulation (all walls)

New U-values

$$U_{winNEW} := U_{winORIG} = 2,8 \ \frac{W}{m^2 K}$$

$$U_{w1NEW} := \frac{0,52 + 0,46}{2} \frac{W}{m^2 K} = 0,49 \ \frac{W}{m^2 K}$$

$$U_{w2NEW} := \frac{0,52 + 0,46}{2} \frac{W}{m^2 K} = 0,49 \ \frac{W}{m^2 K}$$

$$U_{fNEW} := U_{fORIG} = 0,43 \ \frac{W}{m^2 K}$$

$$U_{rNEW} := U_{rORIG} = 2,6 \ \frac{W}{m^2 K}$$

$$A_{tempNEW} := \frac{6}{6} \cdot A_{temp} = 3108,2 \ m^2$$

Total average new U-value

$$U_{mNEW} := \frac{A_{win} \cdot U_{winNEW} + 0,5 \cdot A_w \cdot U_{w1NEW} + 0,5 \cdot A_w \cdot U_{w2NEW} + A_f \cdot U_{fNEW} + A_r \cdot U_{rNEW}}{A_{win} + A_w + A_f + A_r}$$

$$U_{mNEW} = 1,1219 \ \frac{W}{m^2 K}$$

U-value per A.temp

$$\frac{U_{mNEW}}{A_{tempNEW}} = 0,0004 \ \frac{\frac{W}{m^2 K}}{m^2}$$

Saving excluding A.temp

$$\frac{U_{mORIG} - U_{mNEW}}{U_{mORIG}} = 26 \ \%$$

Saving including A.temp

$$\frac{\frac{U_{mORIG}}{A_{tempORIG}} - \frac{U_{mNEW}}{A_{tempNEW}}}{\frac{U_{mORIG}}{A_{tempORIG}}} = 26 \ \%$$

Attic apartments

New U-values

$$U_{winNEW} := U_{winORIG} = 2{,}8 \ \frac{W}{m^2 K}$$

$$U_{w1NEW} := U_{w1ORIG} = 1{,}245 \ \frac{W}{m^2 K}$$

$$U_{w2NEW} := U_{w2ORIG} = 1{,}245 \ \frac{W}{m^2 K}$$

$$U_{fNEW} := U_{fORIG} = 0{,}43 \ \frac{W}{m^2 K}$$

$$U_{rNEW} := 0{,}13 \ \frac{W}{m^2 K}$$

$$A_{tempNEW} := \frac{7}{6} \cdot A_{temp} = 3626{,}2333 \ m^2$$

Total average new U-value

$$U_{mNEW} := \frac{A_{win} \cdot U_{winNEW} + 0{,}5 \cdot A_w \cdot U_{w1NEW} + 0{,}5 \cdot A_w \cdot U_{w2NEW} + A_f \cdot U_{fNEW} + A_r \cdot U_{rNEW}}{A_{win} + A_w + A_f + A_r}$$

$$U_{mNEW} = 1{,}0636 \ \frac{W}{m^2 K}$$

U-value per A.temp

$$\frac{U_{mNEW}}{A_{tempNEW}} = 0{,}0003 \ \frac{\frac{W}{m^2 K}}{m^2}$$

Saving excluding A.temp

$$\frac{U_{mORIG} - U_{mNEW}}{U_{mORIG}} = 30 \ \%$$

Saving including A.temp

$$\frac{\frac{U_{mORIG}}{A_{tempORIG}} - \frac{U_{mNEW}}{A_{tempNEW}}}{\frac{U_{mORIG}}{A_{tempORIG}}} = 40 \ \%$$

Appendix VII

Protocol for inspection of visited buildings

Contents

Protocol for inspection of buildings

Below follows the protocol that was used during inspection of the visited buildings.

Adress:		**Date:**
Evaulation of building elements	**Comment 1**	**Comment 2**
Windows		
Window ledges		
Facade		
Internal surfaces		
Roof		
Basement		
Attic		
Moisture:		
Foundation wall		
Basement floor slab		
Elements in roof construction		
Basement floor		
Attic floor slab		
Attic beams		

Temperatures		
Facade without insulation		
Facade with insulation		
Draught:		
Windows		
Doors		
Joints		

Appendix VIII

Climate conditions from WUFI

Contents

Climate conditions

Below follow climate conditions for inside and outside climate.

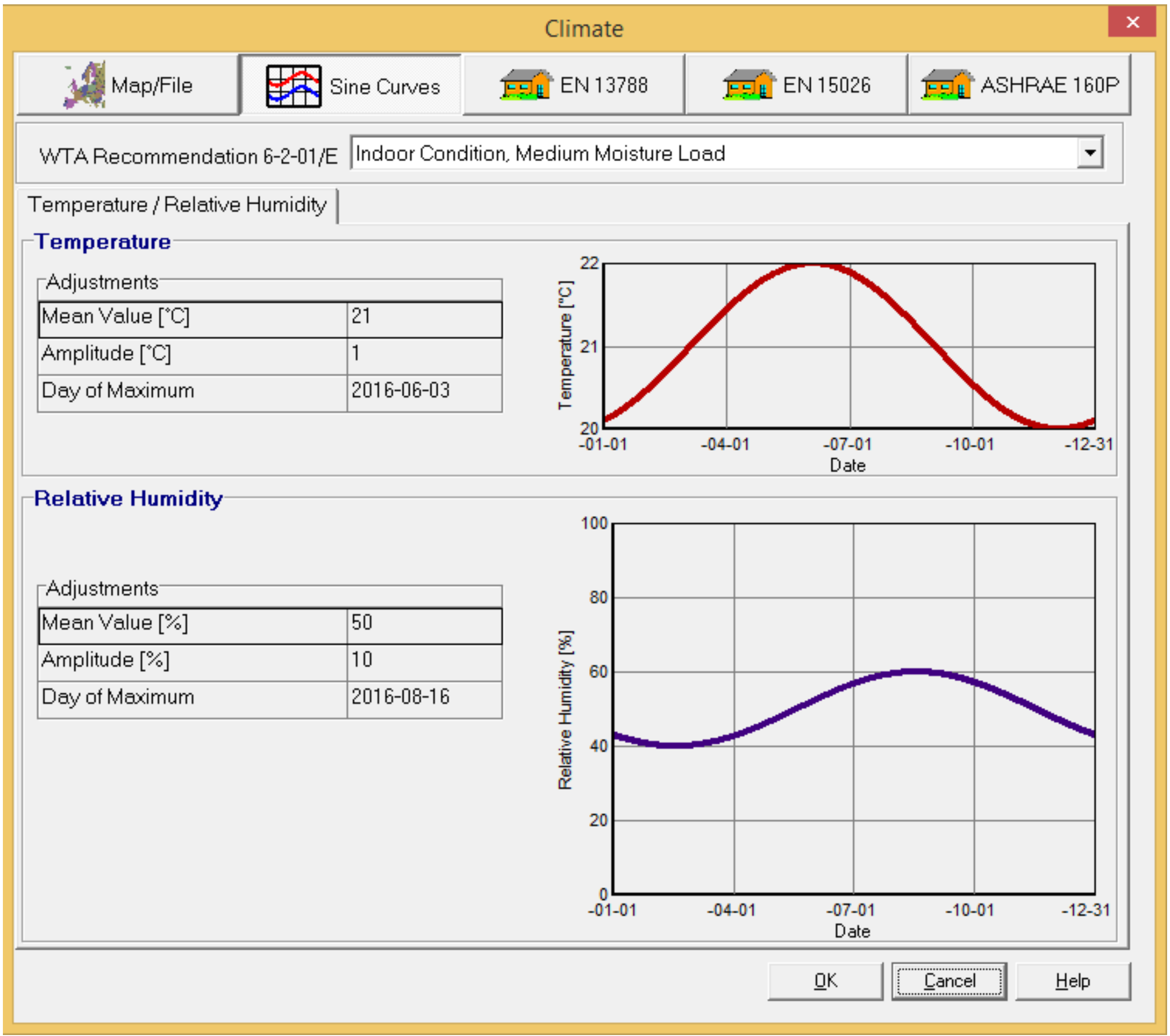


Figure 1, Indoor climate in Wufi.

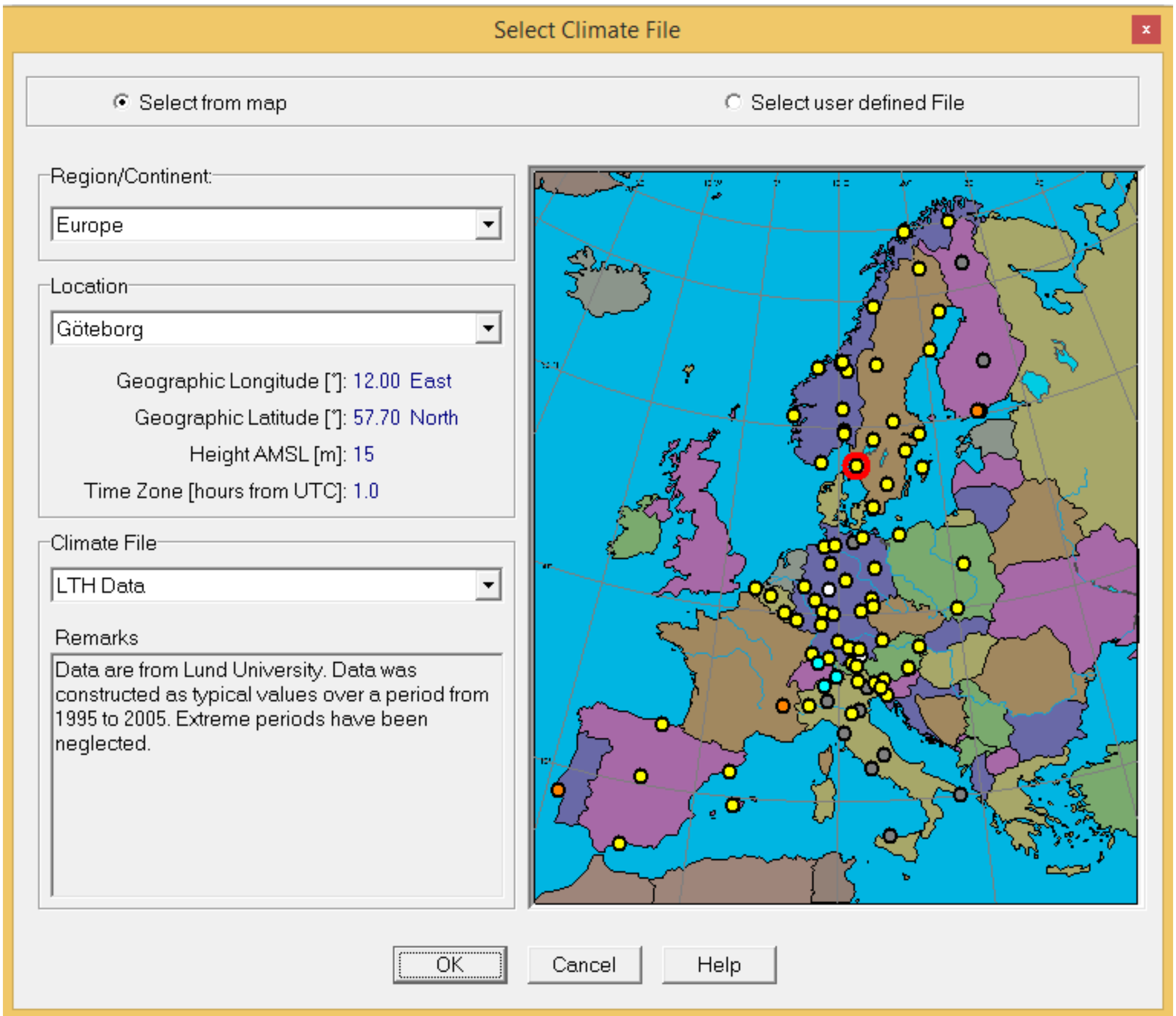


Figure 2, Gothenburg outdoor climate in Wufi with map.

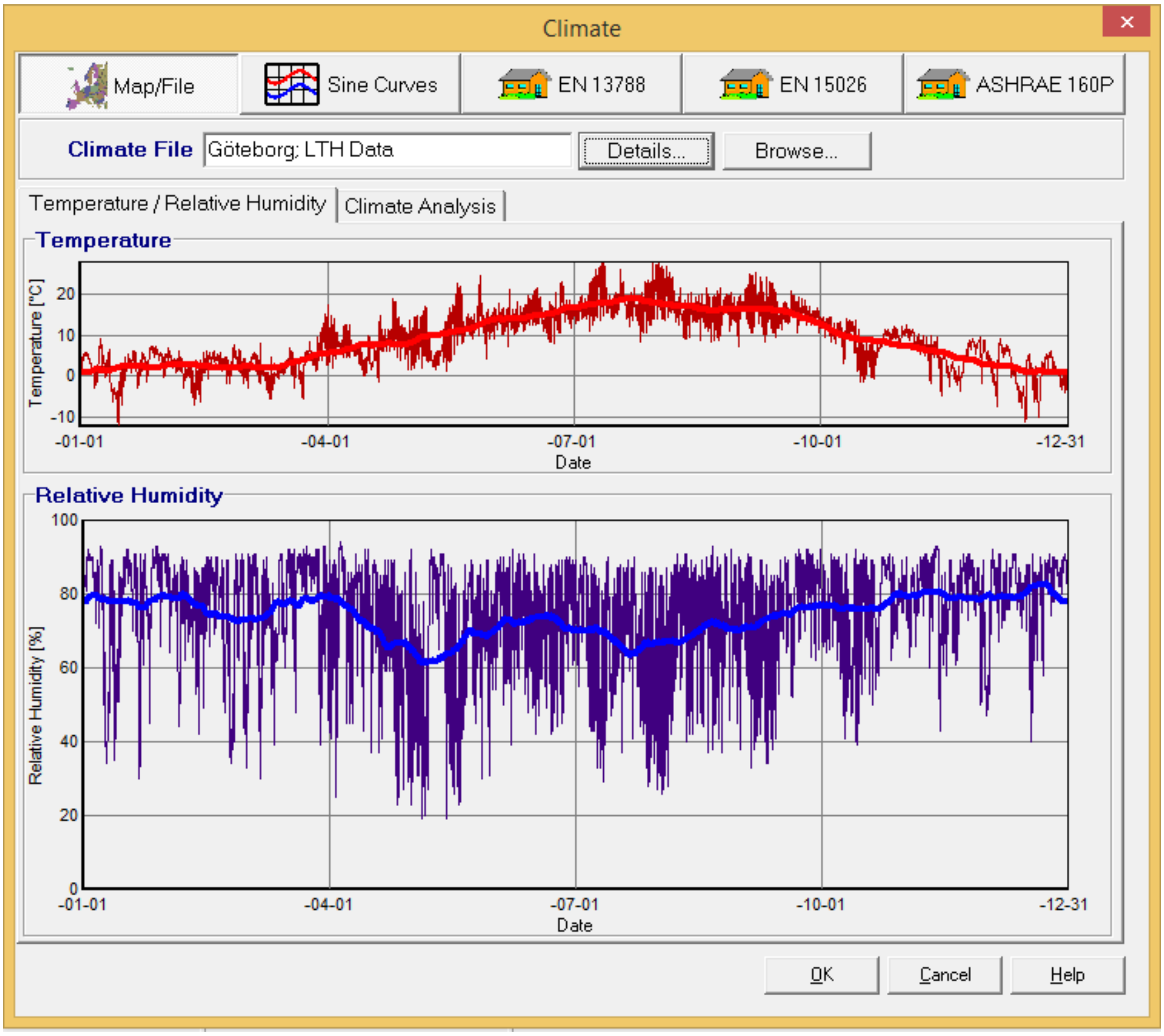


Figure 3, Gothenburg outdoor climate in Wufi.

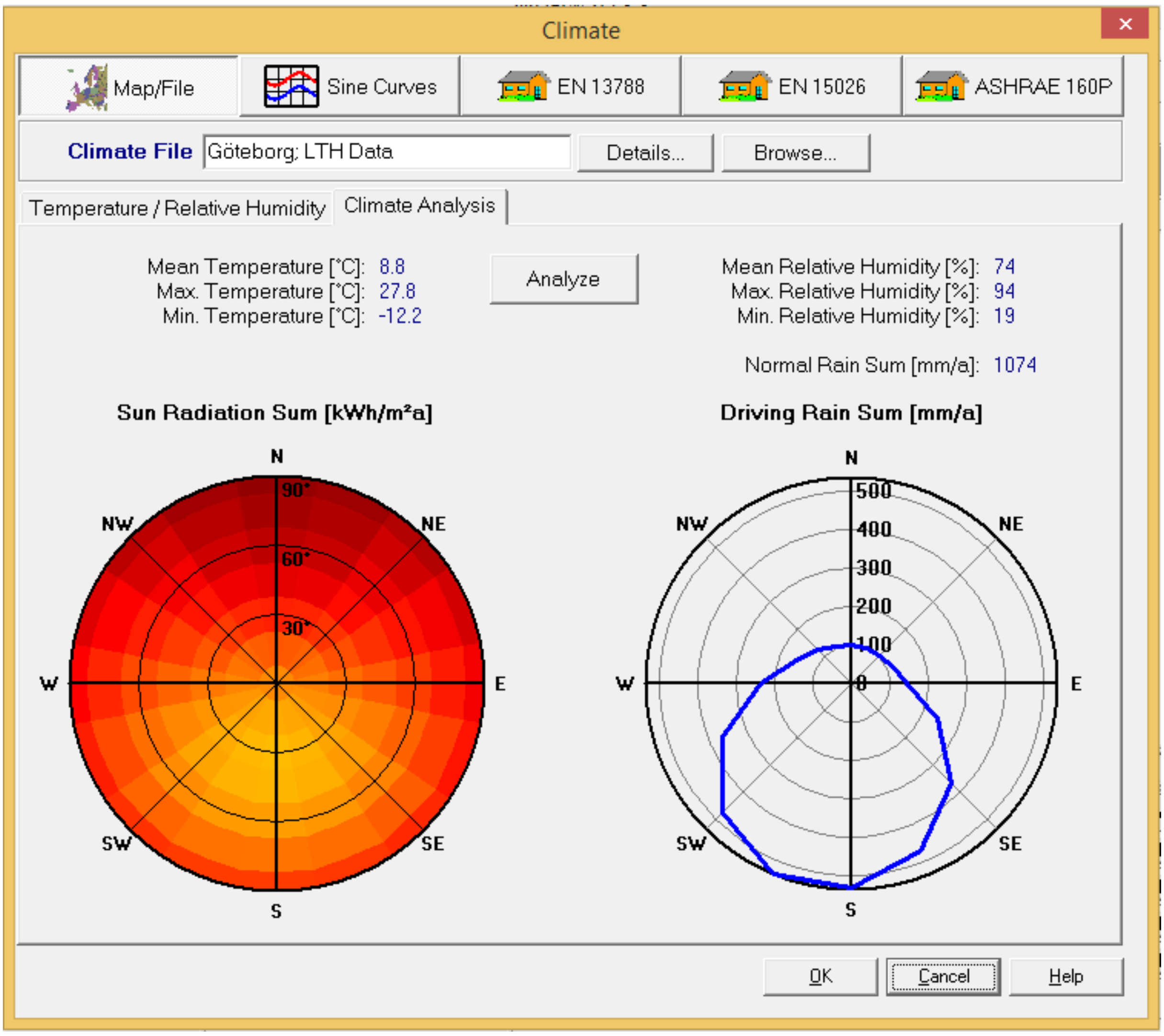


Figure 4, Gothenburg outdoor climate, sun radiation and driving rain.