“FEELING GOOD IN ONE'S OWN SKIN”

A PROPOSAL TOWARDS BIOBASED AND BREATHABLE DESIGN FOR HEALTHIER RESIDENTIAL ARCHITECTURE

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Keywords.

Vapour-open, Biobased, Timber structures, Health and well-being, Residential architecture, Sick Building Syndrome (SBS), Indoor air quality (IAQ).

Abstract.

This research investigates the potential of biobased and vapour-open construction principles with the objective to increase health and well-being in residential architecture. Conventional building materials and airtight construction methods often contribute to poor indoor air quality, leading to issues such as the Sick Building Syndrome (SBS). By contrast, biobased materials, and vapour-open façade designs allow for natural moisture regulation, improved air circulation, and reduced indoor pollutants. Through literature review, a case study, most notably the Hemphouse project, and performance simulations, this study examines the technical feasibility and environmental benefits of these sustainable building practices. Findings suggest that vapour-open structures can passively manage indoor humidity levels, reduce mould risks, and enhance overall occupant comfort. Additionally, the integration of locally sourced, renewable materials aligns with climate-conscious design strategies, supporting both ecological sustainability and healthier living environments here in The Netherlands. The results advocate for a shift in residential architecture, promoting breathable and nature-inspired design solutions as viable alternatives to conventional building methods.

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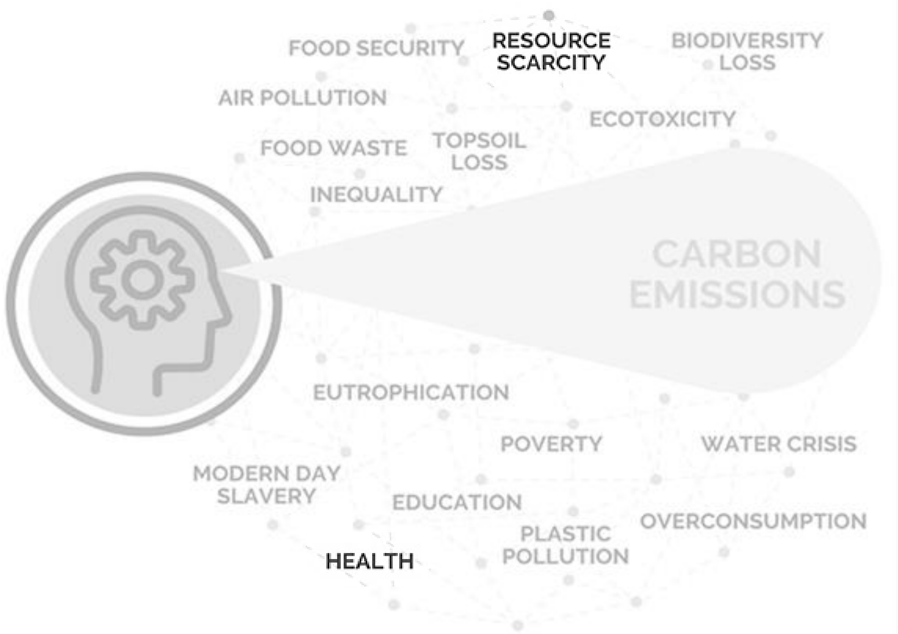
Introduction.

Six years ago, Dutch tv producer VPRO broadcasted an inspiring documentary about the timber revolution (Rozinga & de Bruijn, 2019). Just last month the VPRO broadcasted another documentary, now about building in collaboration with the farmer. The story that the VPRO presented was that there is a large variety building materials produced by local farmers. Farmers who abandoned their cattle for nitrogen reasons, and invested in a switch to grow crops to supply the built environment. Farmers who contribute to climate action and the housing scarcity. Farmers who are ready to scale up.

> Estimations conclude that $1/3^{rd}$ of Dutch farmers strives to keep their cattle. $1/3^{rd}$ of all farmers has ambitions to sell their business and$1/3^{rd}$ of local farmers is ready to pioneer and grow crops for sustainable and biobased development (Rozinga & de Bruijn, 2024).

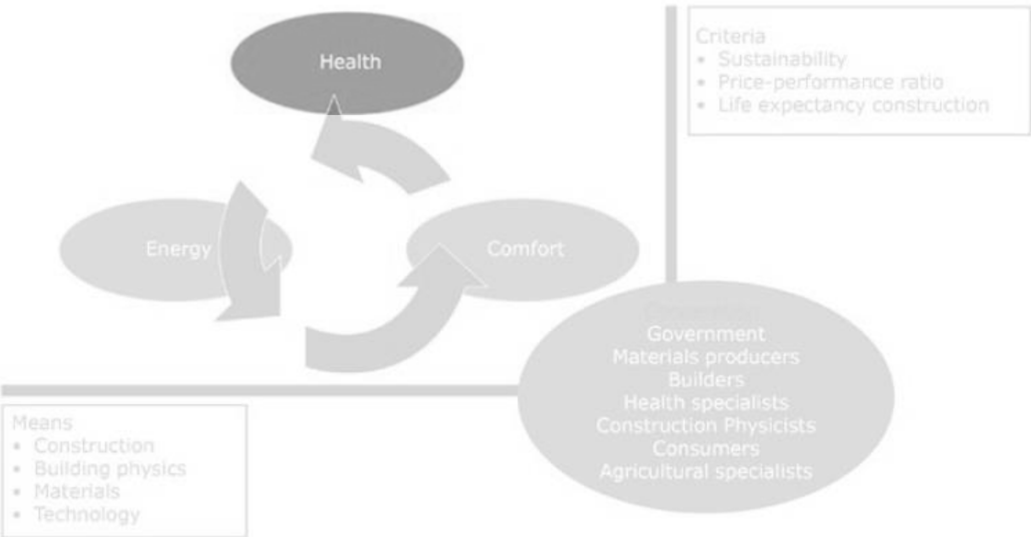
With a very prominent nitrogen- and housing crisis in The Netherlands and the Metropolitan Region of Amsterdam initiatives like this cannot go underutilised. Building with locally grown and renewable materials has the potential to reduce resource depletion, carbon emissions and logistical movements and the potential to improve local economy, indoor- and outdoor climate, as well as resident numbers.

The Sick Building Syndrome (SBS) poses significant challenges in residential architecture, affecting occupant health and well-being (Van Dongen & Phaff, 1989). Many residents report symptoms such as headaches, breathing complications and fatigue, which can be linked to poorly designed and managed indoor environments. Common causes of SBS in homes include poor ventilation, leading to a lack of fresh air circulation and the accumulation of indoor pollutants. Additionally, the use of indoor chemical pollutants, such as volatile organic compounds (VOC's) emitted from synthetic building materials, paints, and cleaning products, contributes to these health issues. Biological contaminants, such as mould, thrive in poorly maintained spaces (Al horr et al, 2016, p8). Lastly, inadequate temperature and humidity control can create uncomfortable living conditions, further impacting the quality of life. Addressing these factors is crucial for creating healthier, more sustainable residential environments.



[Fig. 01: *Carbon tunnelvision* (Jan Koneitzko, via 3R Group, 2022).]

Biobased and vapor-open construction principles present promising ways to enhance health and well-being in residential architecture. Conventional building methods can restrict air flow and trap moisture, vapour and other impurities, potentially harming indoor air quality and occupant health. By contrast, biobased materials and vapour-open techniques support ventilation and humidity management. Research in Nancy, France, concluded a 12% energy saving by applying breathable hempcrete in combination with a classical ventilation system, thus providing a comfortable indoor climate with less consumed energy (Tran Le et al., 2010). Another study concluded that vapour-conducting and vapour-accumulating materials reduce relative humidity swing to a stable level between 43 and 59% (Woloszyn et al., 2009). The Wageningen University continued on these studies and implied in their proposition that biobased materials with the correct hygrothermal properties have potential to promote health, energy savings and living comfort (De Visser et al, 2015, p36).



[Fig. 02: Proposition for biobased building materials (*De Visser et al, 2015, p36*).]

This research explores how these sustainable design concepts can improve residential health and well-being, aiming to highlight potential benefits in modern housing design. This can be achieved through finding a scientific answer to the following research question:

> *How can biobased and vapour-open construction principles increase health and well-being in residential architecture?*

Sub question's will set out the path to a clear conclusion to the main question. In total, there are five sub questions with each their individual contribution to a clear and convincing answer to the research question. These five sub questions are as follows:

I. *What is the difference between vapour and moisture and what means are required to manage them in a healthy residential environment?*
II. *What physical events occur when vapour travels through a solid façade component?*
III. *How are vapour-open construction principles applied in existing residential architecture?*
IV. *What materials could be applied in vapour-open construction and how do the alternatives perform?*
V. *Wat are benefits of vapour-open principles to the indoor climate and the overall health and well-being of the resident?*

Timber is outperforming conventional structural materials in modern sustainable development on topics like renewability, flexibility and energy efficiency (Dufourmont & van der Lugt, 2021). The many advantages of Timber don't need to be summed up to explain this trend. Despite this clear revolution there are still important steps to be made. This research aims to question why timber architecture is still detailed as if it is still designed with concrete or steel. Biobased building materials, this includes mass- and engineered timber, don't transfer heat and are very much capable of safely diffusing vapour. To wrap them in plastics is the safe position, but is it the optimal choice?

The use of locally grown and biobased materials in combination with renewable structural elements is innovative but not unknown. Design and engineering for breathable buildings can be complex. However, cases from existing projects prove the technical feasibility. What remains to be discovered is the added value for the user.

The hypothesis is that by utilising a completely biobased façade composition and by discarding the vapour barrier there is the potential to improve the indoor climate in residential buildings the way nature intended them to be. With an estimated 1/3rd of the local farmers interested in replacing their cattle for crops suitable for the built environment (Rozinga & de Bruijn, 2024) the topic of biobased and breathable architecture becomes increasingly relevant. The philosophy is underexplored in bigger scale but the recourses are available and growing. A breathable building does not solve symptoms of SBS by default but the connection and the possible improvement for the indoor climate and the health and wellbeing of the user can prove a serious motivation to consider vapour-open architecture.

To combat previously mentioned challenges, the use of biobased materials and vapor-open detailing is hypothesised to significantly enhance indoor environments. Biobased materials have lower, if not negative, emissions and contribute to healthier air quality. Vapour-open detailing allows for passive humidity management and, in contrary to common assumptions, is believed to prevents mould growth. This design philosophy creates a breathable envelope that, together with adequate ventilation, enhances the indoor environment. Together, these approaches have the possibility to improve overall health and well-being, fostering a more comfortable and sustainable living space for residents.

Methodology.

To come to a quality conclusion and answer the research question it is important to follow methods that allow for a clear and convincing conclusion. The methods that utilized in the process are literature reviews expanded by expert interviews, a case study and performance simulations. In addition to the more theoretical methods, physical models will be made in addition to the simulations.

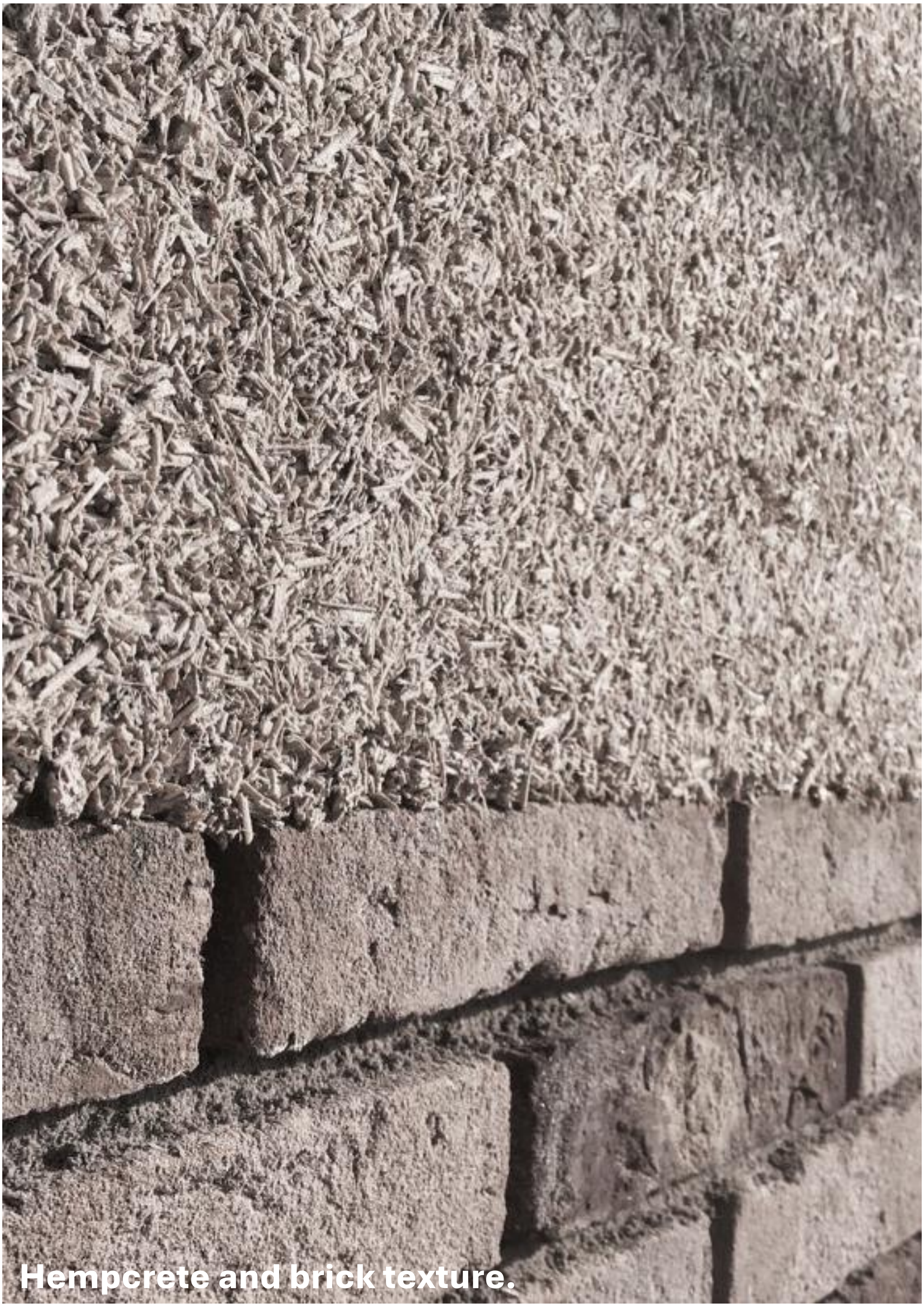
The first, second and fifth sub question are theoretical questions. This means they will be answered by means of literature review. Principles important for a better understanding of vapour open construction have been studied in the past. These outcomes will be analysed and interpreted to conclude the theoretical sub questions. In order to guarantee the right interpretation in the context of the built environment, a building physics expert will be interviewed. The expert will be Dr.ir. M.J. Tenpierik. Dr.ir. M.J. Tenpierik tutors in various courses in the bachelors Architecture, Urbanism and Building Sciences program, is intensively affiliated with the master's program Building Technology and is part of the section for Environmental & Climate Design.

In advancement towards the third sub question a case study will be performed. As soon as theoretical principles about moisture, vapour and its physical properties are established a more practical example is introduced. The case that will be studied is called Hemphouse and was Designed by Werkstatt, an architecture studio based in Eindhoven. Hemphouse is located in a rural environment in Oudega Friesland. The design consists of two residential houses with similar properties.

[Fig. 03: *Hemphouse by Werkstatt.*]

In the following phase of the research the previously studied design principles will be tested and compared. A variety of simulation will be run to establish how vapour travels through different façade compositions. These simulations will provide drying times and condensation risk as well as thermal performances. The simulations will be based on a selection of different construction and isolation methods. This will include the materials and methods utilised in the president. To ensure design freedom the exterior cladding is not included in the simulations.

The complete methodology and its relations were visualised in figure 23 which is included in Appendix 01.


Hempcrete and brick texture.

Interior load-bearing structure.

01. Vapour production.

In residential architecture, understanding the distinction between vapour and moisture is fundamental to creating healthy and durable living environments. While often used interchangeably, these terms represent distinct phenomena that require different approaches in order to keep the indoor environment balanced. This section examines the fundamental differences between vapour and moisture, setting the stage for understanding the measures necessary to ensure a healthy and well-functioning dwellings. Ventilation is essential for a well-functioning dwelling. This doesn't change when the building envelope is designed to be breathable. Mechanical ventilation and vapour-open construction principles work in collaboration.

To further specify the distinction between vapour and moisture we call upon the Cambridge Dictionary. The Cambridge dictionary defines moisture and vapour as follows:

> **Moisture**, noun [U] : A liquid such as water in the form of very small drops, either in the air, in a substance, or on a surface.

> **Vapour**, noun [C or U] : Gas or extremely small drops of liquid that result from the heating of a liquid or solid.

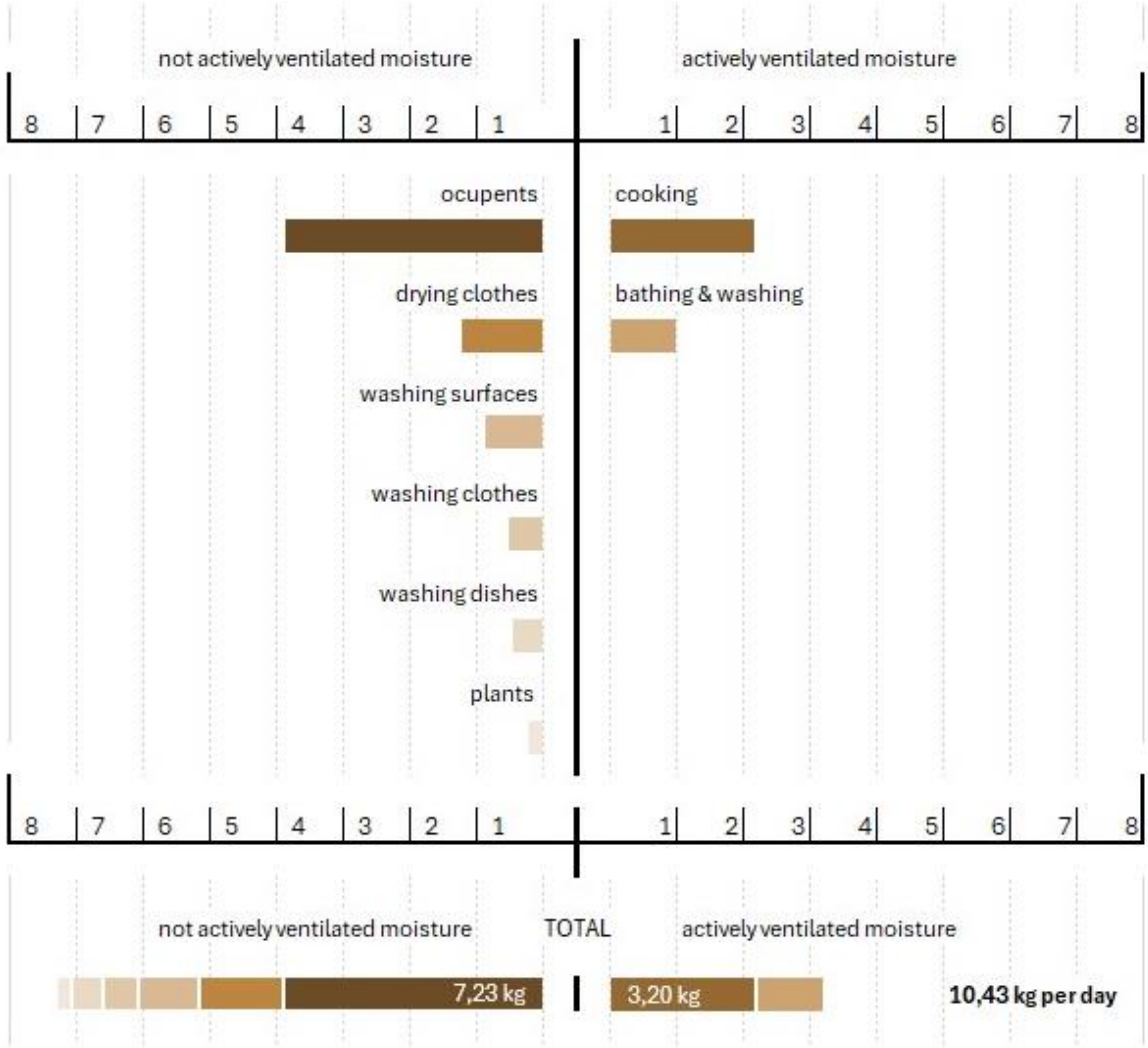
The biggest distinction is that moisture is still described as a liquid while vapour is described as a gas. In addition moisture can also form in substances or on surfaces, these conditions are not mentioned in the description of vapour. In the description of vapour the influence of temperature and heating is mentioned.

The Art & Architecture Thesaurus® (AAT) is a globally used polyhierarchical vocabulary for organizing and accessing architectural, art, and cultural heritage collections (Getty Research Institute, RDK Research). Originally developed by the Getty Research Institute, and now widely adopted by many institutions, the AAT is a standard for multilingual collection access to information for art, architecture, and other material culture. The Art & Architecture Thesaurus (AAT) made the following statement on water vapour.

> **Water vapour**: The dispersion of water molecules into the air, as produced by evaporation at ambient temperatures rather than boiling.

An important element of the definition by the AAT is the distinction between ambient and boiling temperatures. The Arts & Architecture Thesaurus mentions evaporation at ambient rather than at boiling temperatures. This distinction between evaporation temperatures can be the dividing factor. Water produced inside a residence at ambient temperatures and without the use of any heating device is considered vapour. Water that is produce with the aid of external heating can be defined as moisture.

Moisture production in dwellings is highly dependent on various different factors. However, this can be generalised into two: the dwelling occupants and their daily behaviour. Most of this moisture production is transported by means of mechanical ventilation, some transported through openable elements and small fractions of moisture are (temporarily) stored in the building fabric (Oreszczyn & Pretlove, 2015, p7). The diagram of figure 03 visualizes the amount of moisture produced based on the average behaviour of a family of 4 occupants.



[Fig. 04: *Typical moisture production for a family of four in kg/day.* Source: (Oreszczyn & Pretlove, 2015, p6).]

The diagram visualizes the average amount of moisture produced per person per day in kilograms. The graph shows a distinction between moisture that is actively ventilated and moisture that is not actively ventilated at production. This distinction is important because it shows where breathable facades can have a significant effect.

The right side of the central axes of the diagram often represents a large quantities of moisture produced in a short period of time. This allows it to be ventilated in an energy efficient way and prevents large amounts of condensation on the interior surfaces of the dwelling. The left side of the central axes represents moisture where the production is often spread over longer periods of time, or consistently throughout the day. Mechanically ventilating the moisture is incredibly energy inefficient and with relatively low influence on the indoor environment. In practice, this means that the moisture on the left side is passively transported through openings in the building envelope or not managed at all.

The moisture with a high peak production falls outside of the scope of the research. Moisture with a low and consistent production is better described as vapour. The definition of vapour has to most to do with the concentration of water molecules in the air of the indoor environment. Water quickly produced in high concentrations will result in moisture and water slowly produced in lower concentrations will result in vapour in the indoor climate of the dwelling. The mentioned average of 7,23 kg of vapour can, with the right design strategies, be managed without the need for openings in the facades and the risk of damage. The continuation of the research will elaborate on possible design strategies, their performance and the effect on the health and well-being of the resident.

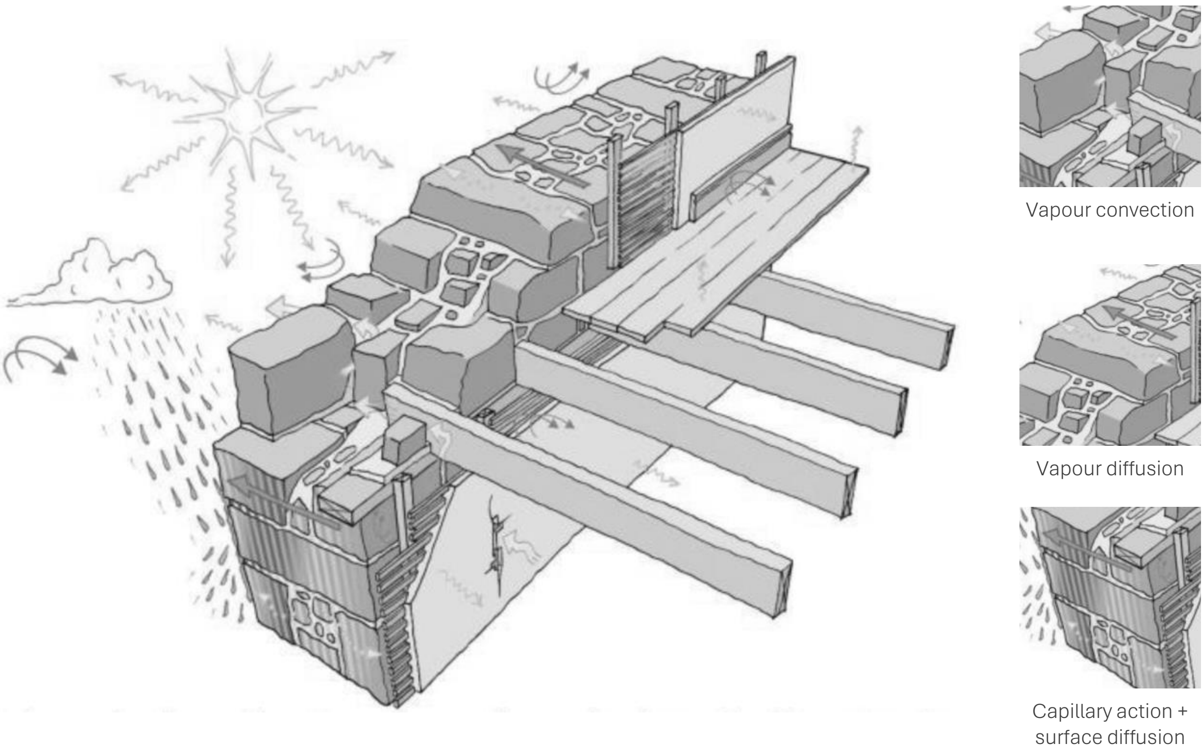
02.

Physical vapour transfer.

Hygrothermal building physics is concerned with heat and vapour transport, which are connected in both directions. Heat transport is influenced by vapour, and, conversely, vapour transport is influenced by heat. (Little et al, 2015, p18). This transportation process needs a medium for it to be experienced. In the context of the built environment this medium often is the air and the building fabric.

Air contains approximately 78% nitrogen and 20 % oxygen. The final 2% of the air consists of a large variety of other gasses including a variable amount of gaseous water (Little et al, 2015, p20). Outside of highly controlled laboratory conditions, air is never completely dry. Air exists outdoors, within building spaces, and within the pore structure of materials. Because these pores are generally very small, air movement within materials is rather restricted. In a building context this can result in two likely transport scenarios. The first scenario would be air transport of by opening a door or window. The second would be air transport through cracks and other small openings in the building envelope, see figure 04. This mechanism is called vapour convection.

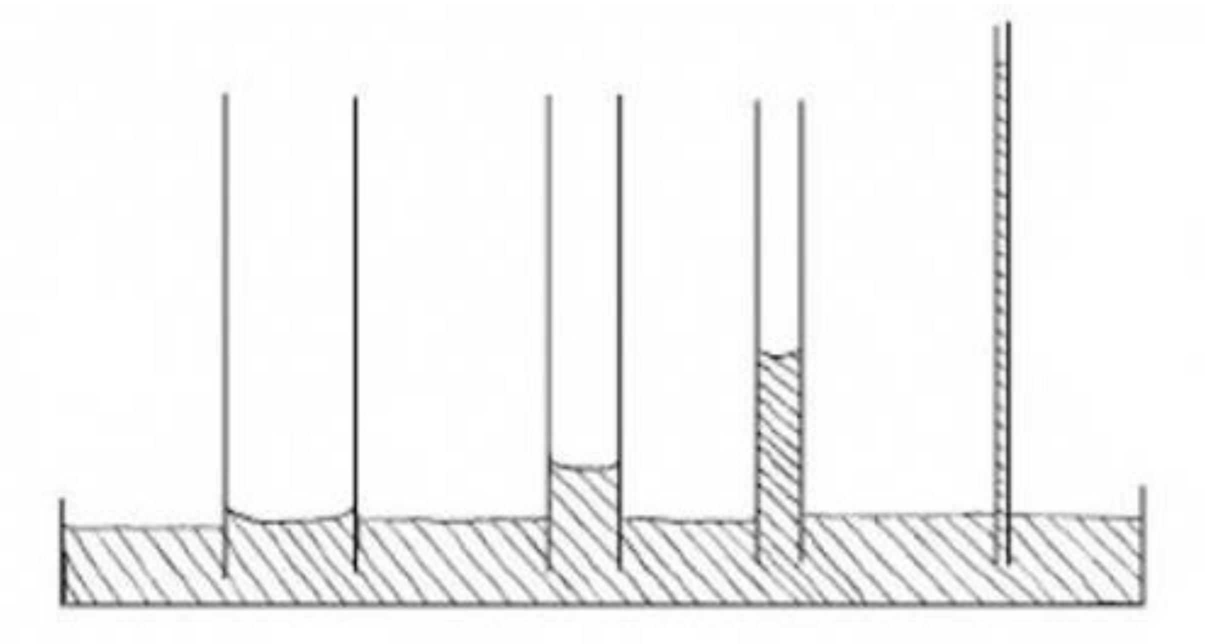
Air, including the water vapour it naturally contains, is not confined to the spaces within a building's interior but also penetrates the majority of construction materials. This occurs because most building materials possess a porous structure, meaning they comprise not only solid mass but also microscopic pores. The characteristics of this pore structure, which vary significantly between materials, play a critical role in determining the extent and ease with which air and vapour can move into, out of, and through these materials. These movements are called vapour diffusion.



[Fig. 05: *Mechanisms of heat transfer and moisture transport* (Little et al, 2015 p.19, fig.1).]

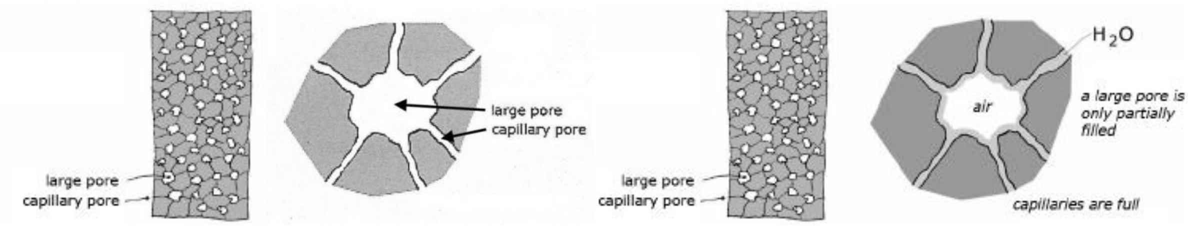
2.1. Capillary action.

Capillary transport refers to the process by which liquid is drawn through the pore structure of a material, filling the pore spaces entirely. This mechanism operates independently of, and in some cases contrary to, external forces such as gravity. The phenomenon underlying this process, known as capillary attraction or capillarity, describes the capacity of water to move through the material in this manner (Little et al, 2015, p52). The concept of capillarity is visualised in figure 05.



[Fig. 06: *Liquid water risen vertically due capillary transport, illustrated graphically* (Torraca, 2009, p.81, fig. 3.17).]

Materials containing a significant number of pores are referred to as porous, while those with few or no pores are classified as non-porous (Little et al, 2015, p27). The majority of building materials are porous, with only a small subset exhibiting sufficiently low porosity to be considered non-porous. Examples of non-porous materials include glass, metals, and certain plastics. Organic materials, such as timber or thatch, are typically porous.



[Fig. 07: *Sketch illustrations of a material's pore structure: the right illustration is a magnification of the left, showing a large pore with connected capillary pores* (Torraca, 2009, p.82, fig. 3.19).]

In figure 06 the composition of mass and pores are sketched. The image visualizes how building materials look on a cellular level. In the sketches three important properties of a material are visible. The size of the solids in the material composition determine the density, the number and size of the pores determine the porosity and the size difference between the large- and capillary pores determine the permeability of the material (Little et al, 2015, p48).

2.2. Vapour diffusion.

In predominantly cool climates, such as that of the Houthaven area in Amsterdam, interior spaces are maintained at warmer temperatures than the outdoor air for much of the year. This warmer indoor air has the capacity to contain more vapour. The concentration of vapour molecules results in a higher vapour pressure within the building than outside for most of the year, driving vapour outwards through the thermal envelope (Little et al, 2015, p47). At the same time even in Spring, but obviously more often in summer, periods occur when the external surface temperature of a wall or roof is higher than the room temperature due to solar radiation. This temperature differential can reverse the direction vapour is moving through the thermal envelope temporarily. Thus, the combination of the vapour pressure and temperature differentials are the driving force for vapour transport by diffusion through the thermal envelope.

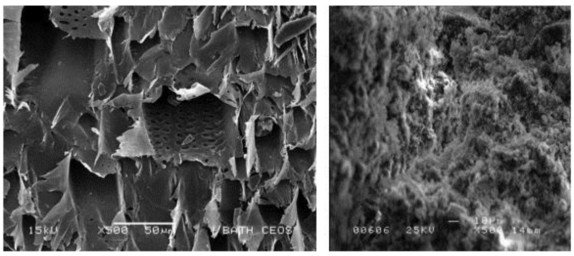
The difference in vapour pressure is the driving force for vapour diffusion (Little et al, 2015, p47). Vapour diffusion and vapour pressure are inextricably linked. Vapour diffusion will always aim to distribute vapour molecules to equalize vapour pressure in open or enclosed space.

2.3. Vapour diffusion resistance factor (μ-value).

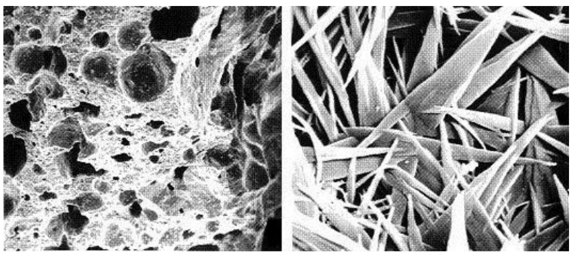
Vapour moves through all materials unless they are truly vapour impermeable: the latter group is surprisingly small. The amount of vapour that permeates into and migrates through a vapour permeable material varies depending on its vapour diffusion resistance factor and thickness. A more vapour-closed material, i.e. one with a high μ-value, ensures less vapour diffusion than a more vapour-open material. The thicker a material, the more difficult it is for vapour to migrate through. Therefore, a material that has a high μvalue and is of great thickness will ensure even less vapour diffusion.

The vapour diffusion resistance factor itself is based on the material density, porosity and the permeability (Little et al, 2015, p26). Building materials often have tiny pores, the smallest being invisible to the naked eye. These pores are cavities within the cellular composition of a material. The size of the solids define the density, the amount of pores describe the porosity and the size of the pores describe the permeability of a material. These three factors contribute to the resistance vapour encores when it is transported through a material.

When a material comes into contact with vapour the capillary pores fill up. If the size difference between the capillary and the regular (large) pores are too big, the vapour struggles to fill the large pore and air will be trapped. Vapour cannot continue to diffuse and condensation happens on the surface of the material. The permeability is too low. In a case where the capillary pores are bigger, more frequent and the solids are smaller, capillary action continues to occur throughout the complete pore structure of the material. This allows vapour to reach the other side of the material. Because the vapour pressure is lower on this side, vapour evaporates back into the dryer air. In a scenario where all of the vapour is transported through the pores, vapour diffusion has happened (Little et al, 2015, p48).



[Fig. 08: *electron microscope photograph of hemp shiv fibres (left photo) and lime plaster (right photo), both at 250 x magnification.* Image: University of Bath]



[Fig. 09: *electron microscope photograph of aerated concrete with 22 x magnification (left) and 11,000 x magnification (right).* Image: Fraunhofer-Gesellschaft]

The images of figure 07 and figure 08 four pictures are shown (Little et al, 2015, p25). Figure 07 show the composition of hemp and lime fibres zoomed at 250 x magnification. In Figure 08 aerated concrete is studied. Here, at 22 x magnification, the largest pores are already very clearly visible. However, in order to find the first fibres a zoom of 11.000 x magnification is necessary. These examples further proves that all materials are porous. However, the specific properties might not match the requirements for diffusion to occur safely in a residential scenario.

2.4. Hygroscopicity and vapour barriers.

Continuing on the example of the aerated concrete in figure Y, its hygroscopic properties will cause vapour diffusion to go slow or prevent diffusion completely. Therefore, collecting vapour on the surface of the material until condensation occurs. This can be harmful for the material and the indoor environment and thus vapour barriers are introduced (WHO, 2011). Vapour barriers are thin layers placed right behind the interior and exterior finish of the building envelope. Their function is to block vapour and rain and prevent it from entering the inner layers of the facades (BRON). By doing so, vapour cannot collect in these layers where it might end up trapped. Instead, vapour remains in an environment where it stays air bound until it is released by means of natural or mechanical ventilation.

When biobased materials are used like in the example of figure 07, pores are bigger which makes vapour diffusion a faster and safer process. Therefore, risk of condensation due to high vapour production is reduced when the materials with similar properties as the example of figure 07 are applied. This reduced risk of condensation then reduces the importance of vapour barriers. If designed and built correctly, vapour barriers can be considered completely unnecessary. In this scenario the resistance is designed to diffuse vapour through the building envelope towards space with the lowest relative humidity without condensation. In chapter 03 this concept will be studied in depth.

03. The Hemphouse.

The Hemphouse, designed by Werkstatt, is a sustainable home in The Netherlands built with hempcrete. A breathable, CO_2-absorbing material offering excellent insulation and fire resistance. The design maximizes energy efficiency through passive solar principles, large glass facades, and strategic overhangs to regulate temperature. A zinc-clad roof with 26 photovoltaic panels enables the house to be energy-positive. Natural ventilation and a rocket stove-based heating system further enhance sustainability. This chapter explores the innovative design and construction methods of the Hemphouse, demonstrating its potential as a model for breathable- and healthy residential architecture

Project data:

Location: Oudega, Friesland, The Netherlands.
Year completed: 2019.
Architect: Werkstatt.
Designers: Raoul Vleugels, Niels Groeneveld.
Project title: Hemphouse.
Function: Residential + Lodging
Space: 200 + 100 m^2

Werkstatt focusses on context and culture when they first approach a new project (Junte, 2018). Werkstatt describes hemp as a forgotten recourse. The leaves are used in textile and paper industry. The stems however, are considered a waste product. Hemp crop has a short harvesting cycle and is therefore an appropriate intercrop. Hemp crop contains embodied carbon due to photosynthesis. In addition to CO^2, hemp crop also extracts nitrogen from its environment in the growing process. Hemp fibre is a product perceived to be nitrogen neutral or depending on the species, nitrogen negative (Junte, 2020).

[Fig. 10: *Site drawing of the Hemphouse in Oudega, Friesland.*]

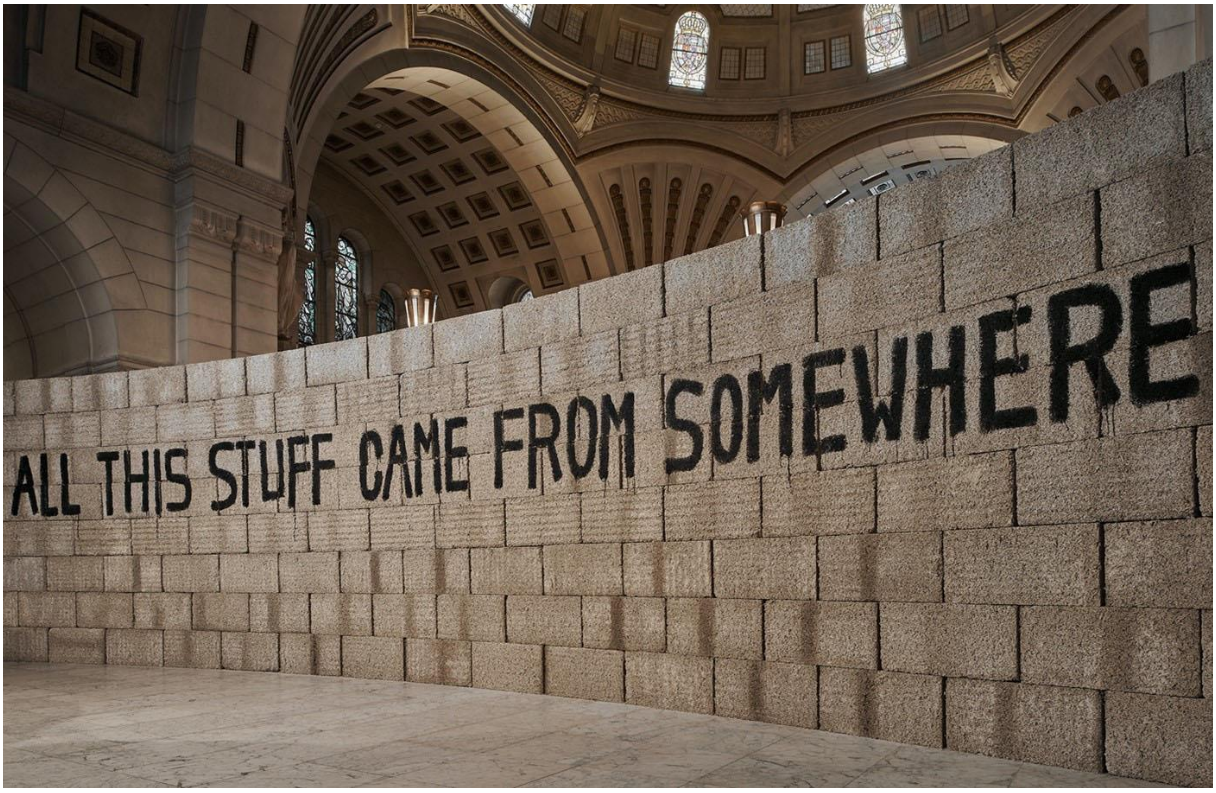
3.1. Design ambition.

The program of the project featured two freely positioned volumes. One being four bedroom residence and the other being a more compact two bedroom recreational residence. The family home housed the client. The additional volume was meant to be used by family or other guests who visit the vibrant cultural village in which the Hemphouse, or Hemphouses, are situated. Werkstatt is an office with a serious ambition to build naturally (Junte, 2018). This resulted in an interesting composition of timber, hemp and lime.

[Fig. 11: *Hemp crop field.*]

[Fig. 12: *hemp crop applications after harvesting.*]

Designers Raoul Vleugels and Niels Groeneveld meant building naturally literally. Together with a progressive local contractor the two young architects participated in a speed course hempcrete construction hosted by international craftsman from the south of Europe (Giele, 2022). The design process featured conventional methods like sketching, computational drafting and modelmaking in combination with extensive material studies and prototyping (Junte, 2018). The outcome was a truly unique work of architecture.



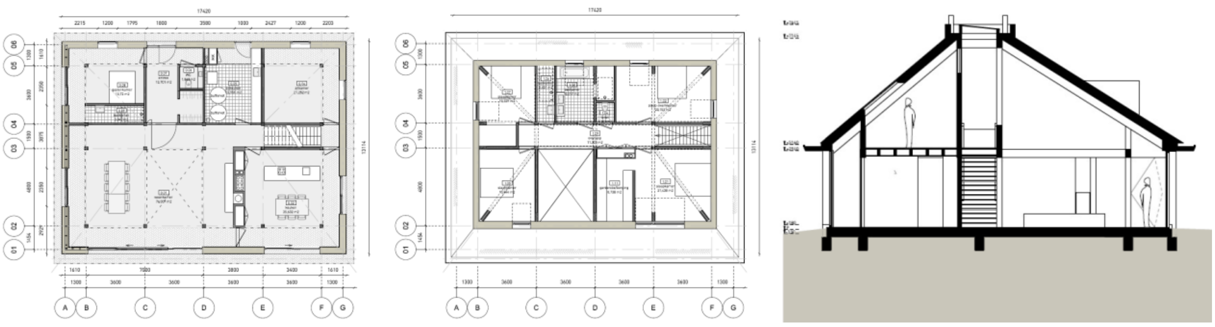
[Fig. 13: *Werkstatt's search for a new ecological aesthetic: Principles Poetics of Plenitude. Exhibition at the Rotterdam townhall, 26th of august 2022.* Image: Max Hart Nibbrig.]

3.2. Technical execution.

The client wanted a cast-on-site application on the facades. This with the objective to show the craftsmanship and detail that went into mixing, casting and stamping every layer (Mans, 2016).

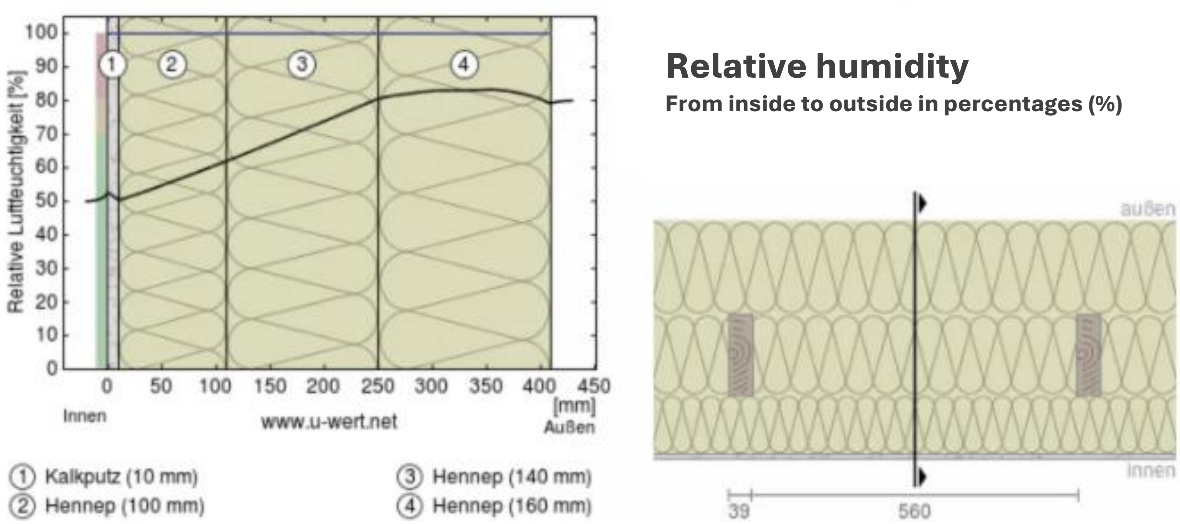
> *"That material is super strong; that didn't seem to be the problem for us. It is a mix of lime and the stalk of hemp plants, which contains a lot of silicon and therefore has an almost stone-like quality." mentioned Raoul Vleugels to architectuur.nl (*Junte, 2020*).*

As mentioned, the project was designed with a Timber structure and a hemp and lime paste also known as hempcrete. The timber structure was a traditional post and beam framework from solid oak. Solid hempcrete was used on the facades. On the inside the hempcrete was cladded with clay plaster. On the outside the hempcrete was not covered. It was pigmented and treated with oils to create a material that fulfilled structural, thermal and aesthetic properties. Another important benefit of the façade being composed of just two materials was the fact that this made the façade structure completely vapour-open. Hemp fibres were also applied to insulate the roof- and floor structures.



[Fig. 14: *ground floorplan, first floorplan and section of the Hemphouse, by Werkstatt.*]

Hempcrete has a direct positive impact on the indoor climate of residents (Junte, 2020). According to Vleugels, it is a breathable material that, unlike the airtight insulation of modern homes, naturally regulates humidity and temperature. The Hemphouse functions like a Gore-Tex jacket, creating a healthier living environment for its users. These concepts were thoroughly tested before construction started. Simulations were run to calculate vapour content within the different levels of density of the cast in place hemp-lime mixture. In Figure 13 the results of the simulation are shown. Outcomes were that relative humidity rises very consistantly towards levels on the outside of the building envelope. Further proving hempcrete's high performance in vapour-open façade composition.



[Fig. 15: *Ubakus simulation results executed by Werkstatt.*]

3.3. Lessons learned.

At the moment of application the hempcrete is a heavy mass of wet lime. This can take a long time to dry. At the scale of the Hemphouse the contractor advised to start interior finishing three months after the walls were casted (Junte, 2020). Due to its breathable nature hempcrete dries according to the conditions of its context. Construction in summer benefits drying and creates a better result in shorter time. On the contrary, casting in rainy seasons is ill-advised. Not only does this extend drying, extensive rain might compromise the hemp-lime recipe creating inconsistencies in density, texture and aesthetic. In extreme cases this can create mould during drying.

Hemphouse designer Raoul Vleugels described hempcrete as stonelike. However, Vleugels is very aware it is not the same as concrete (Junte, 2020). Vleugels speaks about a case of extreme hail falling in winter, causing cosmetic damages to the exterior of the residence.

> *"The surface will then start to fray slightly. This does not cause any structural issues, but not everyone likes such signs of use." mentioned Raoul Vleugels to architectuur.nl (*Junte, 2020*).*

For this reason Vleugels and Groeneveld introduced a brick foundation going up to about half a metre above ground level. This subtle intervention created some distance between the hempcrete and the splashing rain which improves its durability and lifespan drastically.

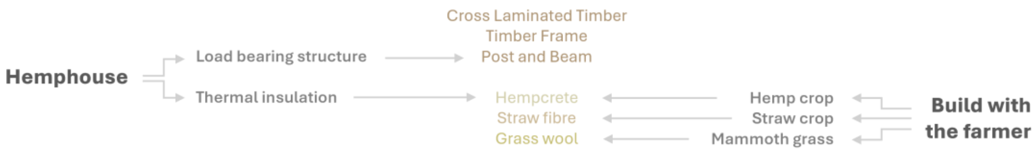
[Fig. 16: *Designers and founders of architecture office Werkstatt. On the right: Niels Groeneveld and on the left: Raoul Vleugels.*]

04. Performance simulations.

One of the core principles for vapour-open construction philosophies is that the materials used are biobased (Rose, 2019). This however, leaves designers with a massive pool of possibilities. In the context of this research this pool is initially narrowed down to one specific façade composition. The results from chapter 03 established how hempcrete in combination with an oak post and beam structure is able to create a functional and vapour-open façade in combination with aesthetic architecture. Verifying it's thermal and hygroscopic performance in a simulation would be redundant. However, comparing its performance to possible alternatives is expected to be of considerable value.

4.1. Design.

The simulations are based on two important influences. The first being the case study described in chapter three. On the other side the alternatives are based on crops that are locally grown. This is shown in Figure 15. Recent research done by Dutch broadcaster VPRO concluded in their documentary 'Bouwen met de Boer' that local farmers are ready to change their cattle to crops (Rozinga & de Bruijn, 2024). Farming livestock on large scales is polluting and therefore the Dutch government is trying to scale down this practice. Farmers who are willing to cooperate with this initiative have shown interest in using their land and facilities for growing crops to supply the built environment. By doing this these farmers refrain from emitting nitrogen and instead, retract carbon dioxide from our environment. To support this local initiative this study will incorporate local, innovative and biobased materials grown by farmers in The Netherlands. This selection of crops including hemp, as used in the Hemphouse, form the origin of alternative compositions with hempcrete, straw fibre and grass wool insulation.

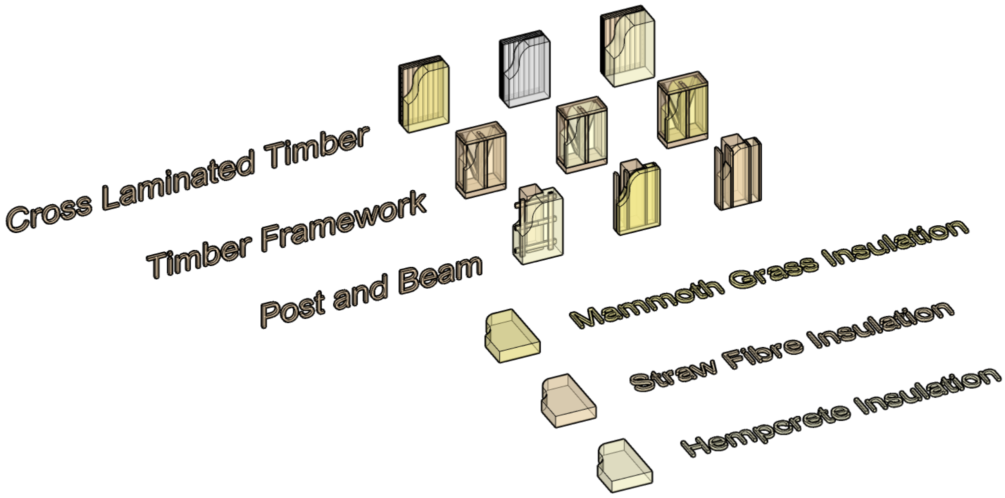


[Fig. 17: *diagram visualising the origin of the alternative façade compositions.*]

In addition to the insulating layer the structural element of the composition is also varied. The case study shows how a post and beam structure with a solid wall element is integrated into a functional composition but different insulation methods can benefit from different structural systems. Therefore all of the insulation principles are also tested in collaboration with a CLT (cross laminated timber) slab and a timber frame as a structural component. This creates a total of nine alternatives to simulate.

Due to practical circumstances the composition consisting of a CLT structure in combination with straw fibre insulation is excluded. Straw fibre requires an enclosed support system that is filled with individual fibres. A CLT slab does not have any enclosed spaces. Therefore combining CLT with straw fibre would require additional framework with the sole purpose of enclosing the straw insulation. This alternative is not realistic and therefore excluded.

Figure 16 shows the remaining eight compositions that have been simulated. The compositions include both the structural and the thermal element as well as the basic construction methods that they require. The middle composition in the top row is not coloured because of the exclusion in the simulation process.



[Fig. 18: *diagram visualising the eight feasible façade compositions.*]

4.2. Software and simulation parameters.

The simulations as discussed in paragraph 4.1 have been run in German building physics software Ubakus. Ubakus has a detailed material catalogue. With this catalogue designers can select materials and edit dimensions and properties if necessary in order to simulate a fragment of a component they have designed. Ubakus will respond by defining thermal resistance values, possible condensation and ecological footprint.

Location		De Bilt	National meteorological institute
		Outside	Inside
Conditions	Temperature	-5 °C	20 °C
	Humidity	50%	80%
Output	thermal resistance	m^2K/W	
	Drying times	days	
	Ecological footprint	kg CO_2 q./m^2	

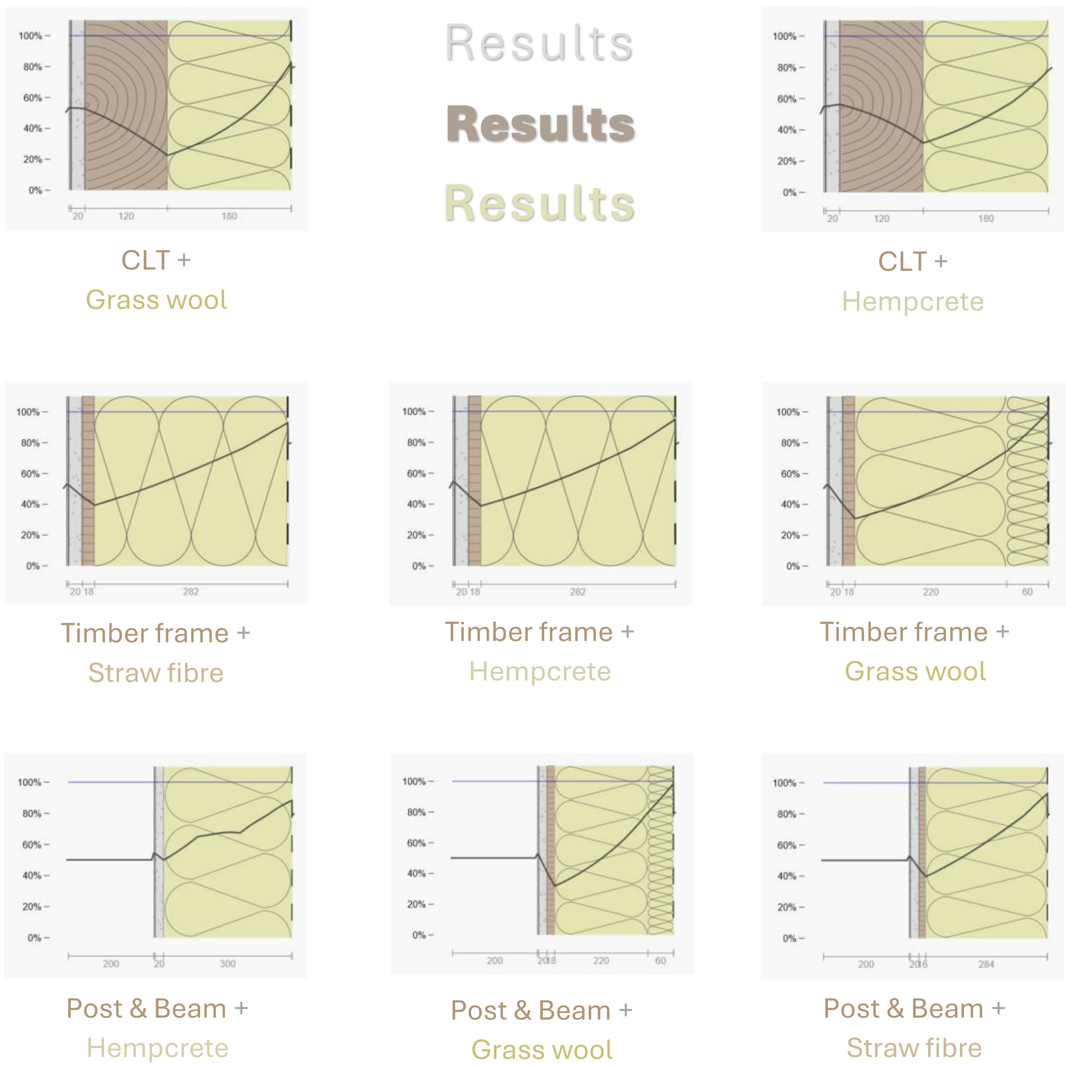
[Fig. 19: *parameters used by Ubakus.*]

The ecological footprint of the simulations is an interesting and important aspect of its performance. However, in the context of the research topic and question it is not as relevant. For this reason the ecological footprint is not included in the results of this chapter.

4.3. Simulation results.

The graphics of figure 18 show a simplified version of the final results of the simulations performed in Ubakus. This simplified version shows the material function, dimensions and vapour content from inside on the left, and outside on the right. The horizontal axis represents the dimensions of the material in millimetres (mm) and the vertical axes represent the relative humidity in percentages (%). More detailed input and outcomes are available in appendix 03.

It is important to note that all simulations contain a plasterboard with clay plaster finish on the inside, and a breathable membrane (with the exception of the hempcrete alternatives) on the outside. To specify the dimensions and ratio's between materials a combined thickness (structural system + insulation) of 300 millimetres was applied.



[Fig. 20: *Ubakus simulation results.*]

The only composition to encounter condensation is the timber frame + grass wool composition. The condensation however, is minimal and will only take a single day to dry. Other crucial findings were that where hempcrete was used within the 300 mm specification it did not meet the standards for thermal resistance according to Dutch building regulations. This means more material will be necessary in order to compete with the other insulating methods.

05. Health and well-being.

Humans spend on average 90% of their lifetime indoors, of which around 70% in their own residence (De Visser et al, 2015, p8). This leads to the characteristics of a building to be of great importance for the overall quality of life . According to a study performed by the Organization for Economic Co-operation and Development (OECD), living in satisfactory housing conditions is among the most important aspects of people's lives (OECD. n.d.). This is partially instinctively since our houses provide shelter. However, it's also very much a rational due to the feeling of privacy and an emotional need for a sense of 'home'. An individuals wellbeing is proven to be connected to the special quality of the environment they find themselves in (Al horr et al, 2016, p2).

The conditions of the air was one of the investigated factors influencing the special quality of a dwelling. Problems with the air conditions are often summarised as the Sick Building Syndrome or SBS (Al horr et al, 2016, p5). Building design and materialisation, interior materials and resident behaviour all play important roles in the complications caused by SBS. Uncomfortable temperature and humidity, chemical and biological pollution, physical condition, and psychosocial status are some of the factors identified as root causes of SBS (Al horr et al, 2016, p5). Consequently, long term exposure to SBS symptoms can have a variety of consequences, some already mentioned in the introduction of this document. Health issues can start as innocent as irritation to eyes and airways, but have the possibility to get as severe as certain forms of cancer (Allen et al, 2017 p11). In addition to strictly medical concerns, SBS is connected to psychological problems like depression (Al horr et al, 2016, p5) and to severe forms of performance issues such as lack of concentration, focus and sometimes burn-outs (Allen et al, 2017, p9).

5.1. Volatile Organic Compounds.

The term volatile organic compounds (VOC's) refers to a diverse group of organic molecules that occur in paints, coatings and resins (De Visser et al, 2015, p10). Objects containing VOC's have a high vapour pressure which causes them to slowly emit harmful toxins in gaseous form into the air (Allen et al, 2017, P11). In an indoor environment VOC's can come from building materials like caulk and sealants, adhesives and pressed wood products. However, VOC's are also highly common in personal products such as cleaners and disinfectants, air fresheners and cosmetics. Finally, resident activities like smoking, gas cooking, open-hearth heating and printing can increase indoor air pollution (ALA, 2024).

Preventing the introduction of pollution sources into a building is always recommended. However, in many cases this is practically not feasible. Therefore standard measures like ventilation can help circulating polluted air out of the residence (De Visser et al, 2015, p10). In addition to ventilation the application of insulation materials of natural origin could also assist in creating a more healthy indoor environment (De Visser et al, 2015, p10).

5.2. Risks of mould growth.

Increased insulation standards due to energy efficiency have caused the relative air humidity in many dwellings to be high, thus giving rise to growth of moulds (De Visser et al, 2015, p8). Harmful moulds can appear in environments with a relative humidity as low as 70%. In standard conditions dwellings in the Netherlands fall slightly below this level. However according to reports 9% of residences in the

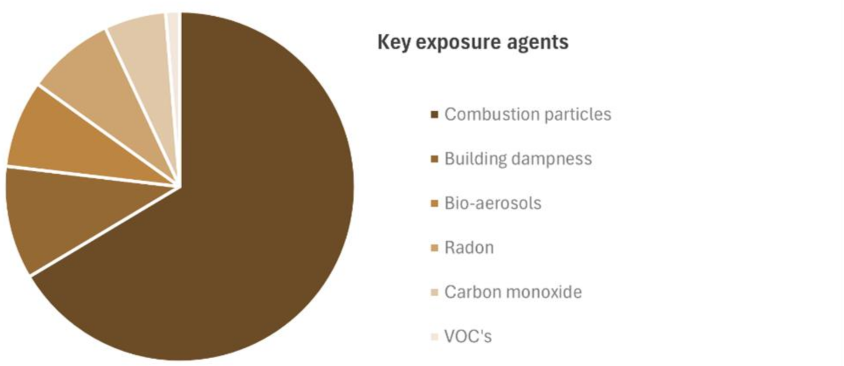
Netherlands have problems with humidity directly resulting in mould growth (Ginkel et al, 2012). The Wolds Health Organisation, commonly known as the WHO, have issued guidelines on indoor air quality (WHO, 2010, De Visser et al, 2015, p9). The guidelines state a strong connection between humidity problems and mould risks causing health issues.

Mould extracts moisture from the substance on which it's growing and from the air where its present. Therefore, both the surface properties and indoor conditions are important factors in growth potential. Mould has more growing potential on hygroscopic surfaces such as wood or leather (Oreszczyn & Pretlove, 2015, p3). Surfaces that do not absorb moisture such as glass or ceramics require condensation. This would come down to a relative humidity of 100% instead of the previously mentioned 70%. For surfaces covered with wallpaper or paint the relative humidity for mould growth is 80% (Oreszczyn & Pretlove, p4).

This would conclude that biobased hygroscopic materials have the biggest risk of mould growth, which is technically true. However, as established in Chapter 02 of this paper, when these materials are applied in such a way that vapour diffusion can take place the chances of humidity staying at high levels, as simulated in Chapter 04, for a long enough time to lead to mould growth are negligible. These principles do not apply when non-hygroscopic materials are utilised. If circumstances allow humidity to rise these materials will not be able to process the vapour, creating it to collect and cause damage and serious health risks over time (Al horr et al, 2016, p5).

5.3. Influences of breathable architecture.

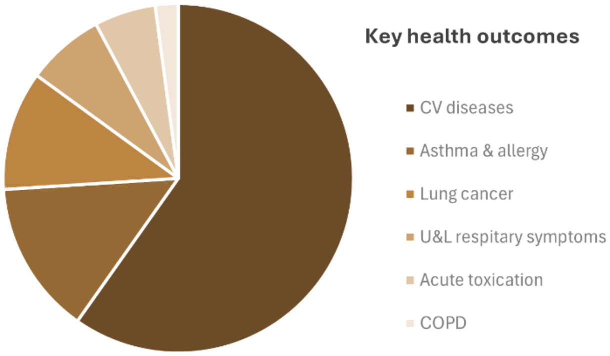
Sick Building Syndrome symptoms are 30 – 200% more frequent in mechanically ventilated buildings (Al horr et al, 2016, p5). Mechanically ventilated spaces often require more maintenance and knowledge to keep the indoor air quality up to standard in comparison to naturally ventilated spaces. The increase in thermal performance for better energy efficiency however have caused indoor vapour- and moisture production to rise and therefore ventilation norms to become outdated (Borsboom & Jacobs, 2019, p22). Dutch research organisation TNO suggested solutions such as increasing ventilation rates, terminating thermal bridges and decreasing vapour production (Borsboom & Jacobs, 2019, p48). Figure 19 shows the studied agents responsible for compromised indoor air quality, showing building dampness as the second most impactful source.



[Fig. 21: *The indoor air quality (IAQ) associated burden of disease (BoD) attributed to key exposure agents*. Data: IAIAQ, 2011.]

According to data from the IAIAQ, building dampness is responsible for about 11% of the burden of disease (Jantunen et al, 2011). Vapour-open construction philosophies could assist with two of the presented solutions. Due to its completely biobased nature, and therefore decreased thermal conductivity, the compositions tested in chapter 04 are less likely to contain any thermal bridges. In addition, vapour diffusion will passively manage indoor relative humidity.

Insulation materials of biological origin have the ability to accumulate vapour towards op to 30% of their own weight and release it again over time (De Visser et al, 2015, p17). Physically this process, explained in chapter 02, is called vapour diffusion. In an architectural context this phenomenon is often called vapour buffering. Building materials of chemical or mineral origin do not have the same accumulative properties. When these synthetic materials are utilised and spaces are not adequately ventilated vapour and moisture can be trapped causing mould growth and a polluted indoor environment. This with serious long term health effects. Data collected by IAIAQ (Jantunen et al, 2011) shows a direct relationship between exposure agents and health outcomes (Borsboom & Jacobs, 2019, p28). TNO came to the important conclusion that symptoms of SBS and the early effects the occupants health and well-being, like headaches and fatigue, often are underestimated and not followed by medical professionals. This can, over longer termes, lead to more serious medical complications. Research by the IAIAQ studied quantities of the complications (Jantunen et al, 2011). The results are shown in figure 20.



[Fig. 22: *The indoor air quality (IAQ) associated burden of disease (BoD) attributed to the key health outcomes.* Data: IAIAQ, 2011.]

Complex material connection.

Complete material composition.

Conclusion.

Increasing residential health and well-being can come in many forms and scales. The introduction highlighted complications regarding the Sick Building Syndrome due to mistakes in design, execution and making use of a residence. This problem has many faces and therefore the solution will not have one. This research explored the impact of biobased and vapour-open construction principles on health and well-being in residential architecture. This is achieved through finding a scientific answer to the following research question:

> *How can biobased and vapour-open construction principles increase health and well-being in residential architecture?*

The findings indicate that vapour-open materials facilitate passive humidity management, reducing risks of mould and other SBS associated complications. The Hemphouse case study in chapter 03 demonstrated the feasibility of these materials in practice, while simulations confirmed their ability to manage indoor humidity effectively. Through performance comparisons, it was established that different biobased materials offer viable alternatives to conventional construction methods. The results suggest that vapour diffusion, when properly integrated into architectural design, can contribute to healthier indoor environments. Additionally, the use of locally sourced biobased materials supports environmental sustainability and aligns with climate-conscious design strategies.

This does not position vapour-open philosophies as a one size fits all solution. Breathable facades design is one of many elements responsible for quality indoor environments and therefore increased health and well-being. An important characteristic is that vapour diffusion does not require specific behaviour or energy in its use. Results in chapter 02 proved that vapour diffusion is managed my nature. When understood and applied correctly its positive effects do not stop.

While vapour-open design is not a universal solution for all residential health challenges, it presents a compelling case for reconsidering current construction standards. This research reinforces the importance of integrating breathable materials and passive moisture management into modern housing design, paving the way for healthier, more sustainable built environments.

Discussion.

The results of this study provide strong theoretical and practical arguments for biobased and vapour-open design. However, one of the more striking observations from the simulations was the high similarity in performance across different biobased façade compositions. While all tested materials demonstrated promising vapour diffusion, the variations between them were relatively low. While vapour-open design appears beneficial in principle, the marginal differences in diffusion suggest that other factors, such as cost, availability, and ease of construction, may also play a significant role in determining the most suitable approach for implementation.

Another key consideration is the link between vapour-open construction and resident health and well-being. While the study highlights several potential benefits, such as reduced risks of mould growth, better indoor air quality, and passive vapour regulation, these effects remain indirectly linked to health rather than being scientifically proven as direct outcomes of vapour-open design. Existing literature supports the idea that improved indoor air quality contributes to overall well-being, but long-term medical studies are required to establish a direct causal relationship between vapour-open housing and resident health.

Despite these uncertainties, the study emphasises the importance of integrating breathable materials and passive humidity management into modern residential architecture. While vapour-open design is not a standalone solution for all indoor environmental issues, its potential role in promoting healthier living conditions makes it a compelling area for further research. This study contributes to the growing knowledge on breathable and nature-inspired renewable design. While more scientific validation is necessarily, the concept of vapour-open architecture offers a promising direction for creating healthier and more sustainable residential architecture.

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Appendix

01.

Methodology diagram

"FEELING GOOD IN ONE'S OWN SKIN"

RESEARCH METHODS

LITERATURE | INTERVIEWS | CASE STUDY | SIMULATIONS | MODEL MAKING

RESEARCH QUESTION

How can biobased and vapour-open construction principles increase health and well-being in residential architecture?

SUB-QUESTIONS

SUBQUESTION
I. What is the difference between vapour and moisture and what means are required to manage them in a healthy residential environment?

OUTCOME
SQ I. Clear theoretical framework on the scope of the research objective.

SUBQUESTUIN
II. What physical events occur when vapour travels through a solid façade component?

OUTCOME
SQ II. Increased knowledge and understanding on vapour diffusion which is beneficial for SQ IV and the design process in MSc4.

DISCUSSION
SQ II. The outcome of SQ I and SQ II will be discussed with a field expert to confirm or contest conclusions.

SUBQUESTION
III. How are vapour-open construction principles applied in existing residential architecture?

OUTCOME
SQ III. Reference projects will function as a practical example of the studied theory. In addition, it will be the starting reference for SQ IV.

REQUIREMENTS
- ☑ biobased
- ☑ vapour-open
- ☑ wooden structure
- ☑ residential
- ☐ mass timber
- ☐ parasitic
- ☐ amphibious

DISCUSSION
SQ III. The architect will be introduced to get a deeper insight on their ambitions regarding vapour-open building methods and the expected health- and comfort effects on the resident.

SUBQUESTION
IV. What materials could be applied in vapour-open construction and how do the alternatives perform?

OUTCOME
SQ IV. A boarder variety of material compositions and their performance to help optimise the detailing in MSc4.

REQUIREMENTS
- ☑ CLT + Insulation panels based
- ☑ Wooden framework + fibre based
- ☑ Post & beam + hemp based

OUTCOME
SQ IV. Models will be made to increase the understanding and performance of the façade composition.

REQUIREMENTS
- ☑ Scale range: 1:1 – 1:5
- ☑ Authentic materials
- ☑ Realistic assembly methods
- ☑ Visualised vapour behaviour

SUBQUESTION
V. What are the benefits of vapour-open principles to the indoor climate and the overall health and well-being of the resident?

OUTCOME
SQ V. Literature should provide clear scientific proof on the effects of vapour-open building principles for the indoor climate of residential buildings.

At this point of the research there is understanding of the physics of vapour-open facades. Existing examples have been studied, and alternatives have been explored and evaluated. Literature has come with factual statements and experts provided the opportunity to elaborate with their individual experience on the topic. This process has all potential for a strong and compelling answer to the research question. The outcomes of the research will be applied during the different design phases in MSc4. The research will allow an increased density by utilising timber structures and optimising façade performance for an improved indoor climate.

CONCLUSION

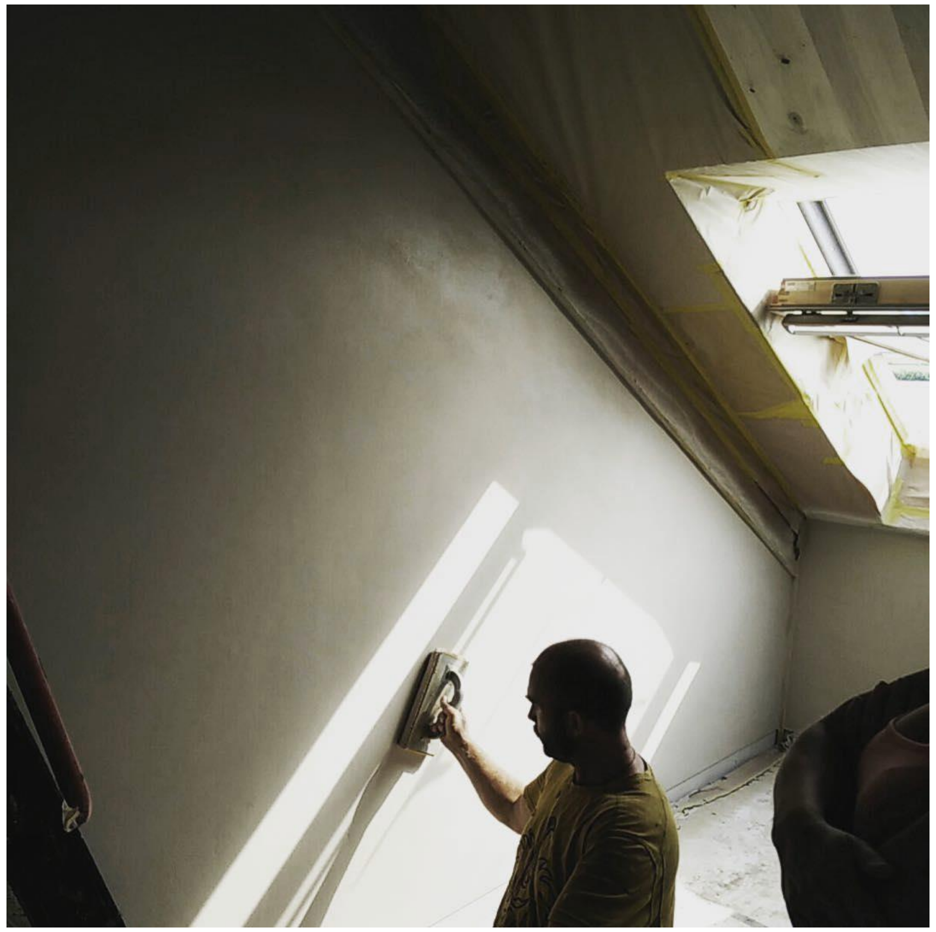
[Fig. 23: *Methodology diagram.*]

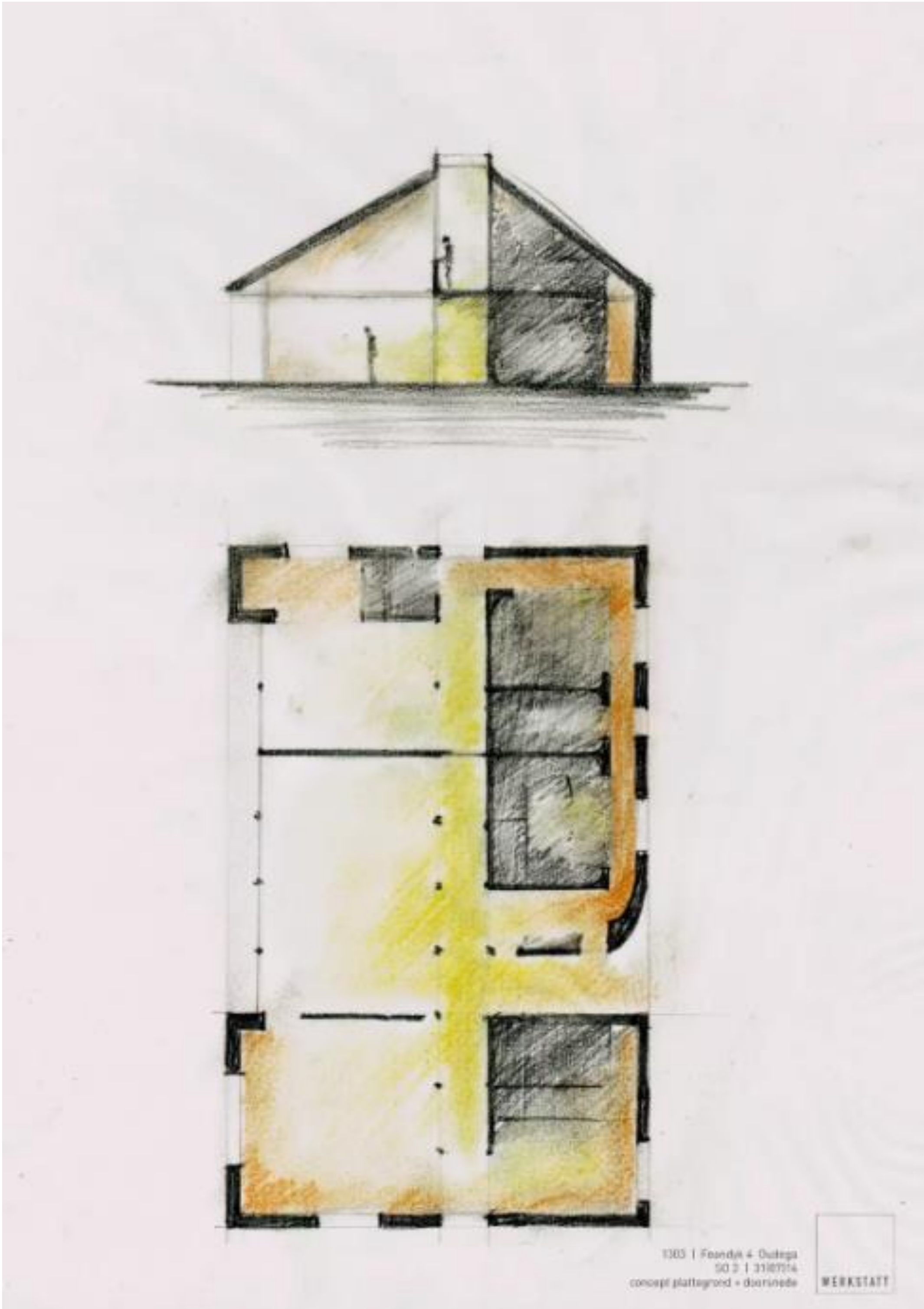
Appendix

02.

President: The Hemphouse

WERKSTATT

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YOSIMA
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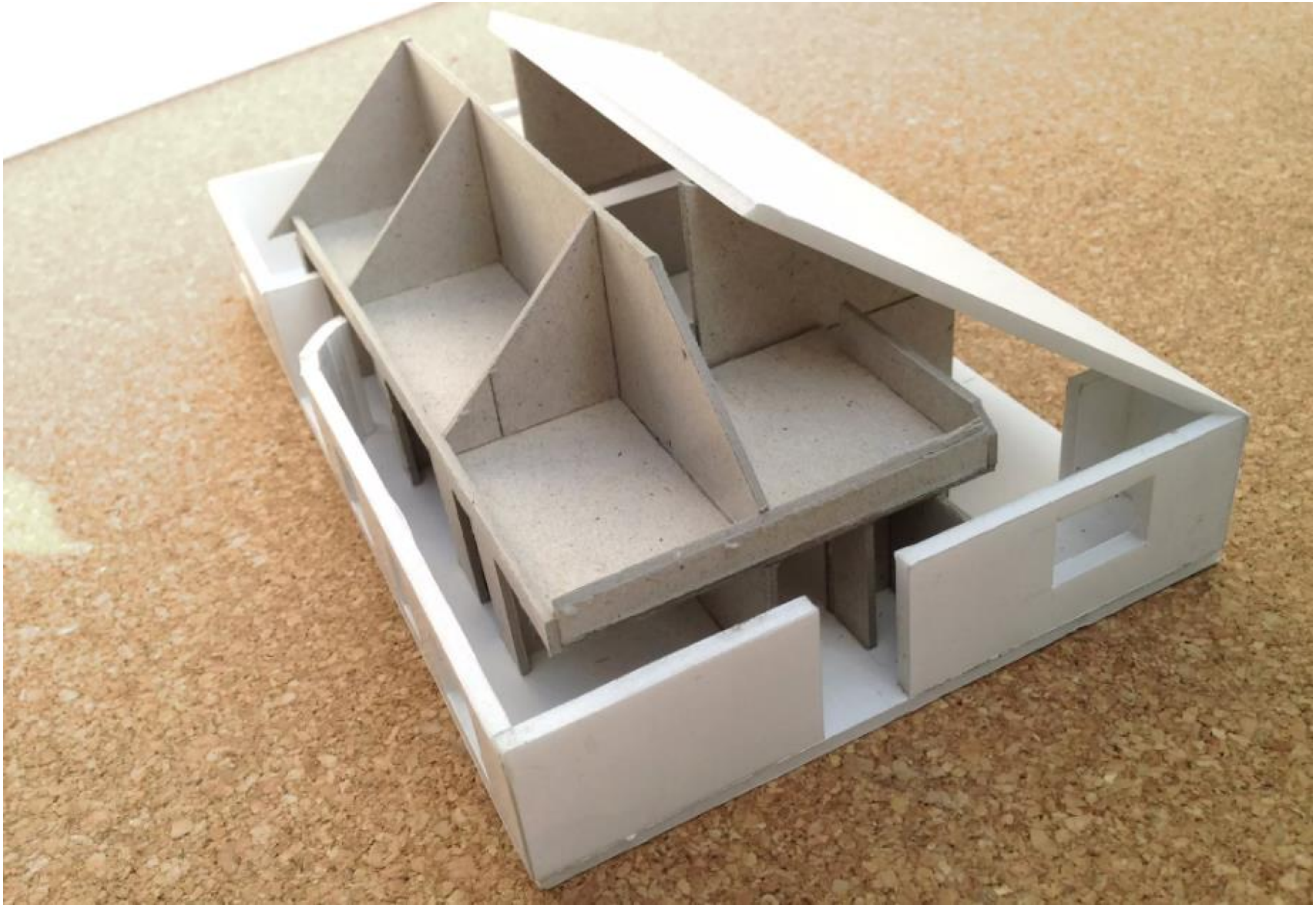

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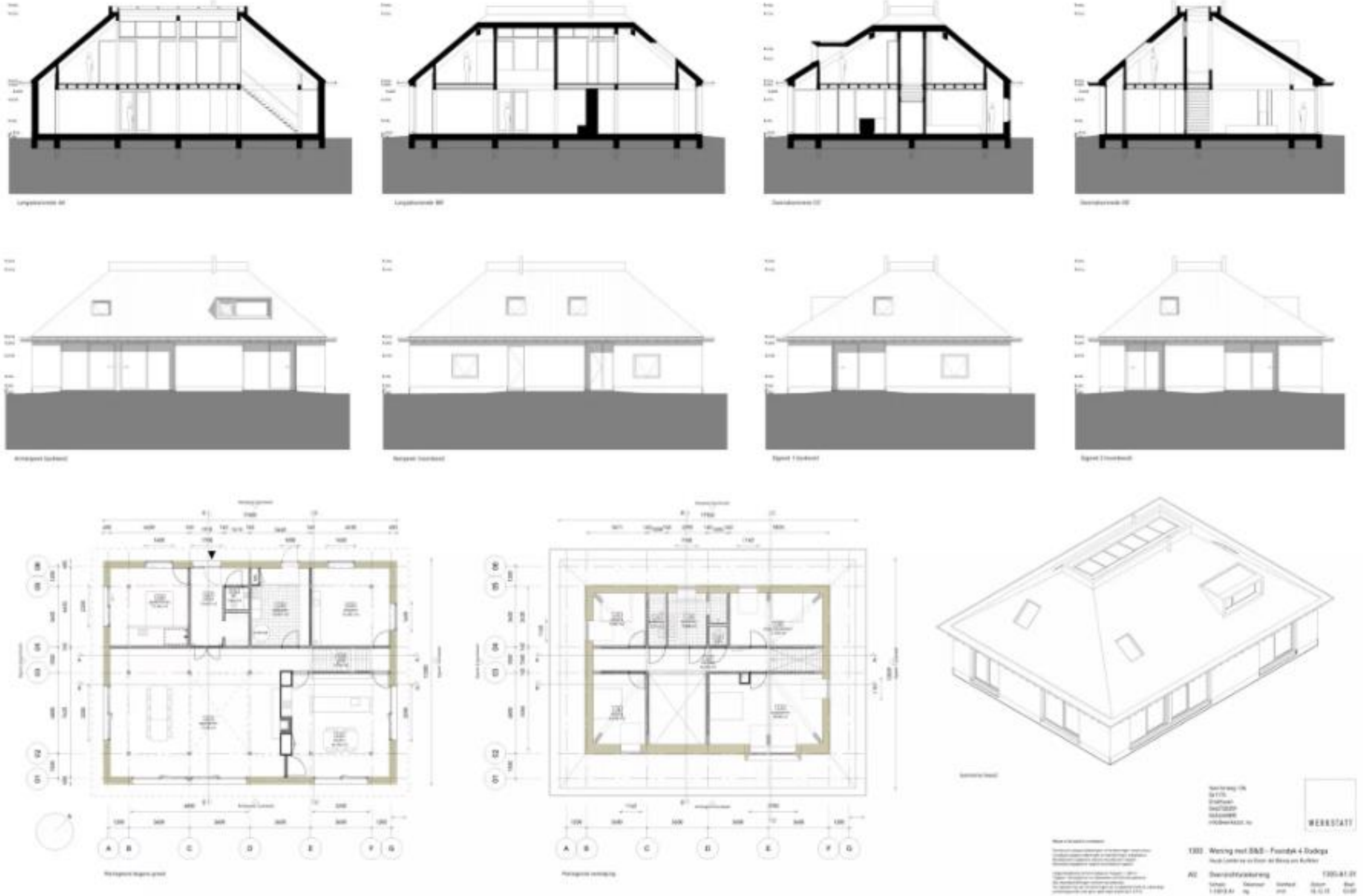
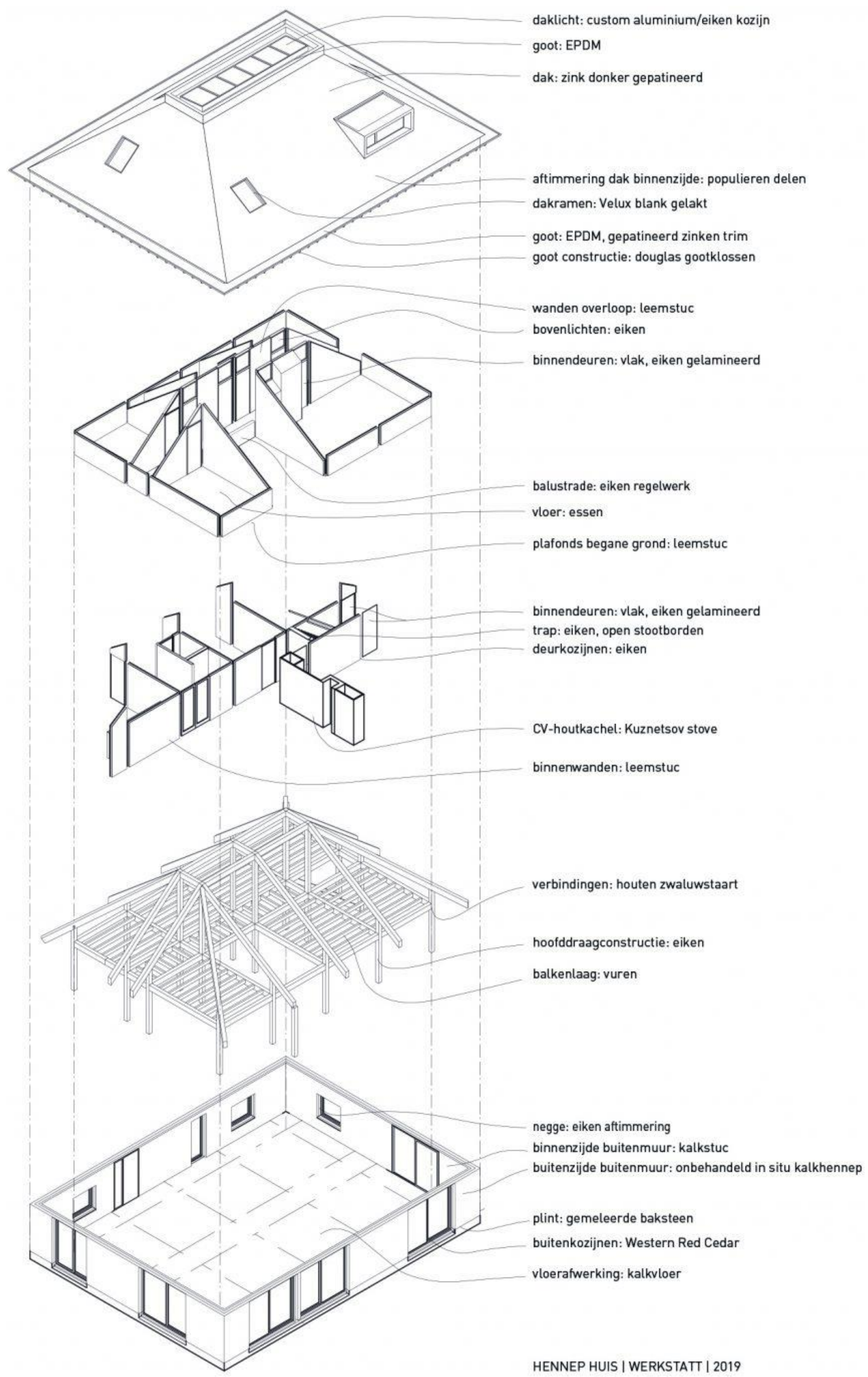
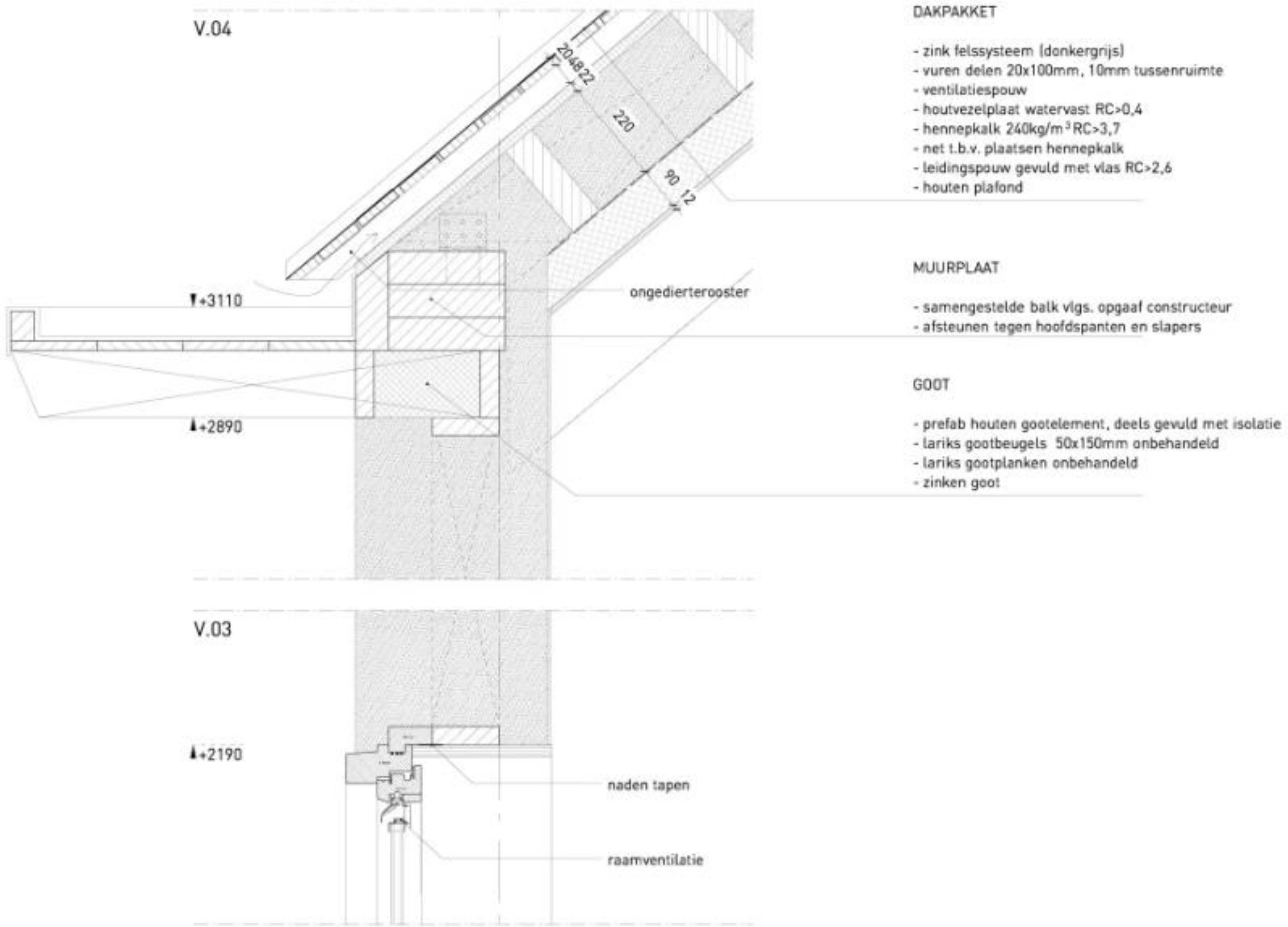
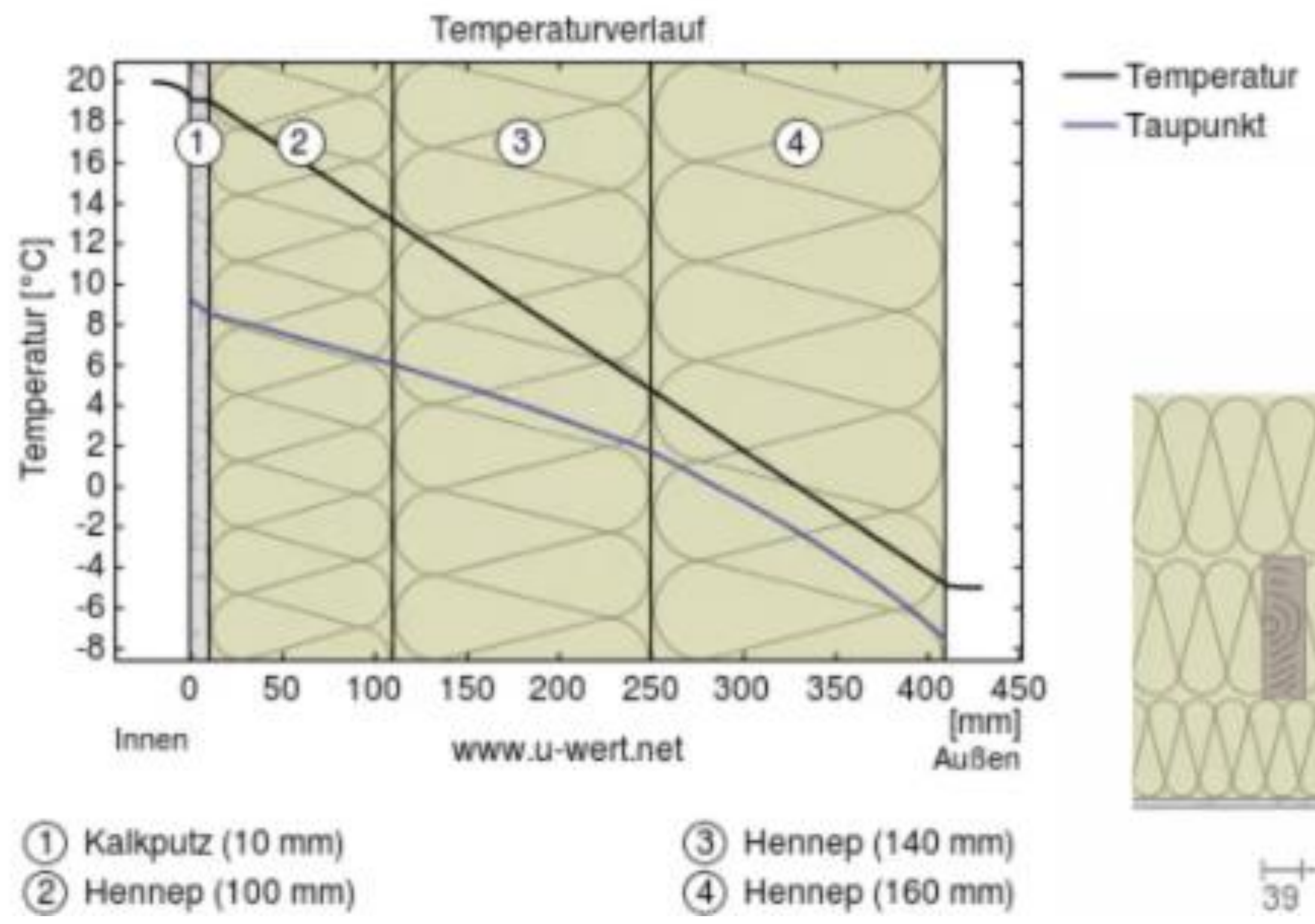
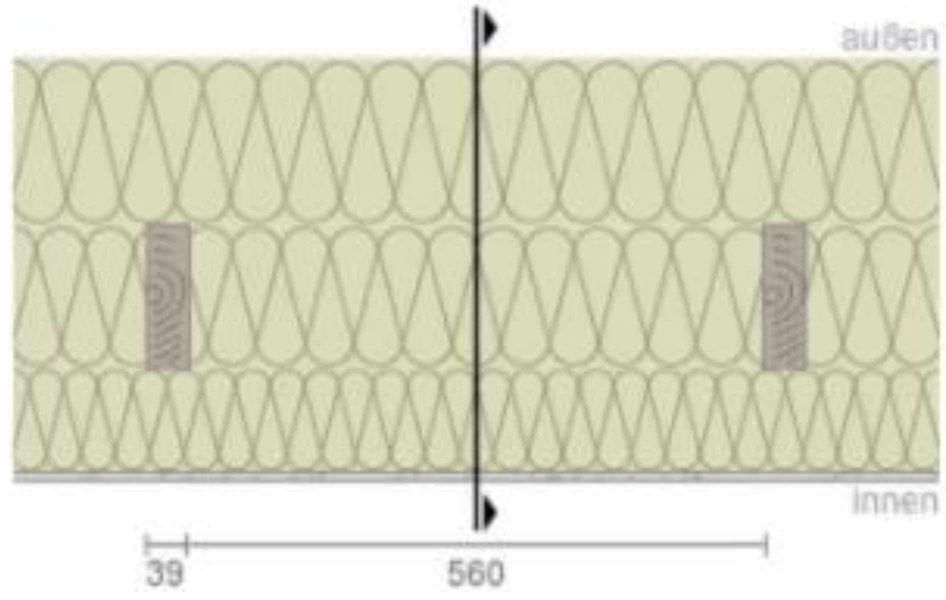

WERKSTATT

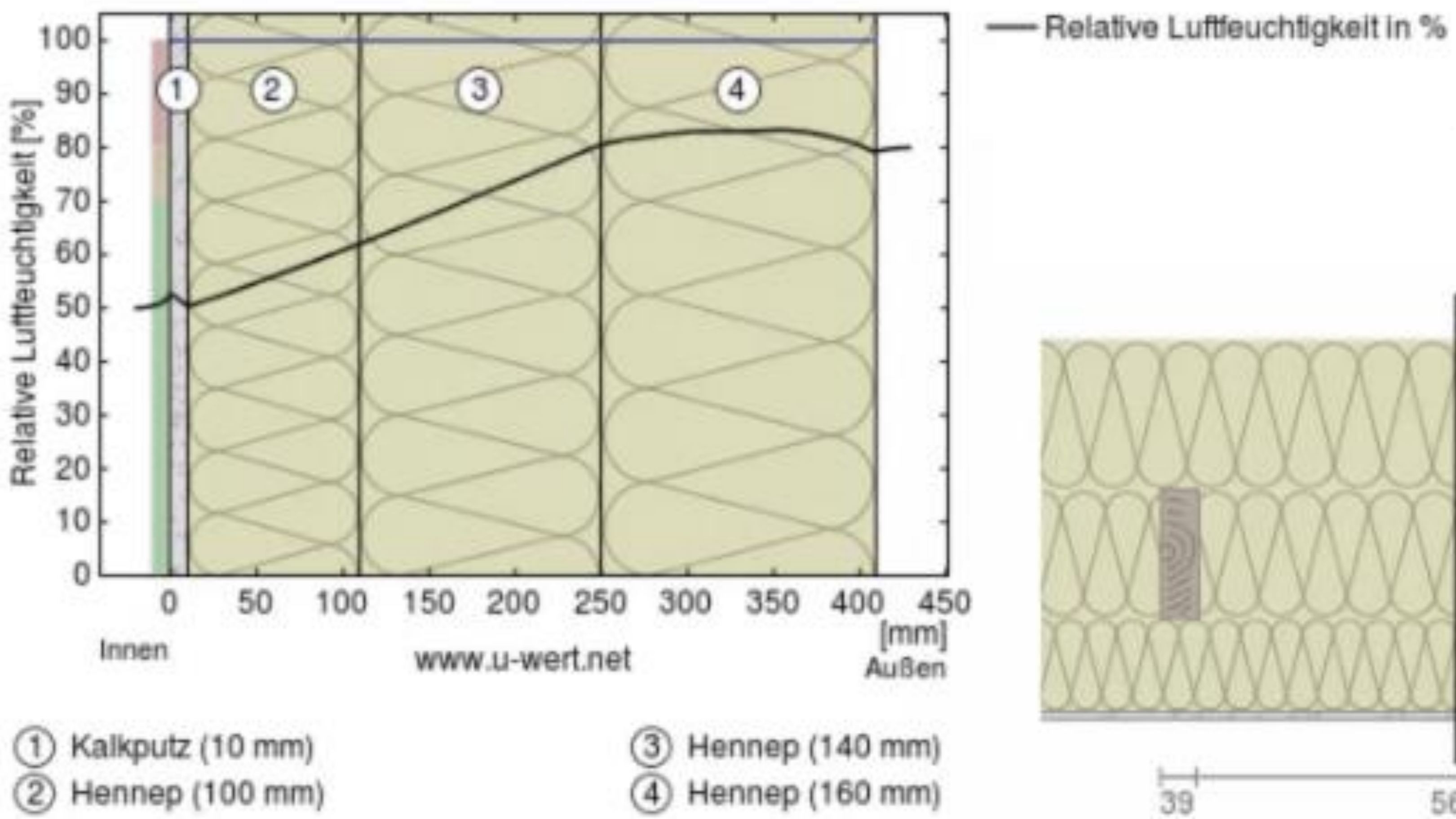


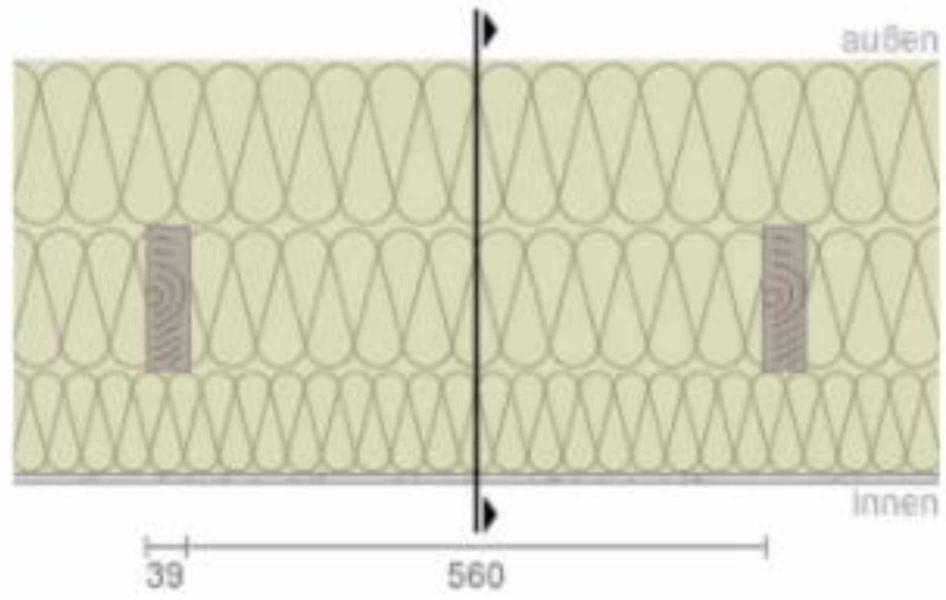
HENNEP HUIS | WERKSTATT | 2019


V.04
204822
220
90 12
+3110
+2890
ongedierterooster
DAKPAKKET
- zink felssysteem (donkergrijs)
- vuren delen 20x100mm, 10mm tussenruimte
- ventilatiespouw
- houtvezelplaat watervast RC>0,4
- hennepkalk 240kg/m³ RC>3,7
- net t.b.v. plaatsen hennepkalk
- leidingspouw gevuld met vlas RC>2,6
- houten plafond
MUURPLAAT
- samengestelde balk vlgs. opgaaf constructeur
- afsteunen tegen hoofdspanten en slapers
GOOT
- prefab houten gootelement, deels gevuld met isolatie
- lariks gootbeugels 50x150mm onbehandeld
- lariks gootplanken onbehandeld
- zinken goot
V.03
+2190
naden tapen
raamventilatie


Temperaturverlauf
Temperatur
Taupunkt
Temperatur [°C]
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
0
50
100
150
200
250
300
350
400
450
[mm]
Innen
www.u-wert.net
Außen
① Kalkputz (10 mm)
② Hennep (100 mm)
③ Hennep (140 mm)
④ Hennep (160 mm)


außen
innen
39
560


Relative Luftfeuchtigkeit in %
Relative Luftfeuchtigkeit [%]
100
90
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
400
450
[mm]
Innen
www.u-wert.net
Außen
① Kalkputz (10 mm)
② Hennep (100 mm)
③ Hennep (140 mm)
④ Hennep (160 mm)


außen
innen
39
560


PATAGONIA

Appendix

03.

Full simulation data

Ubakus input

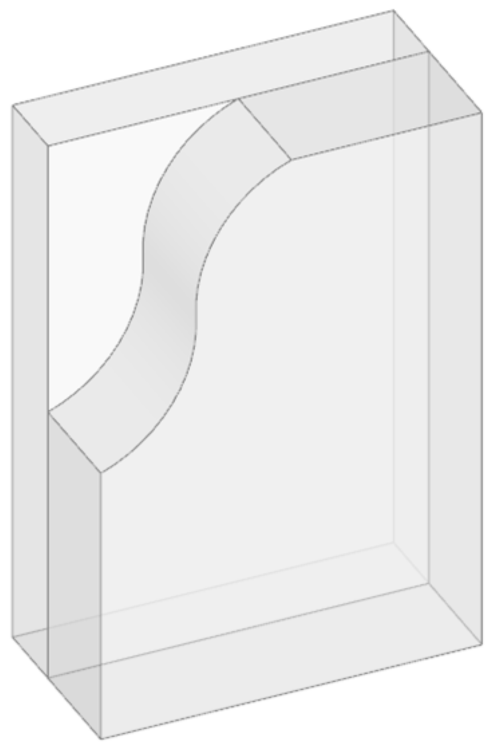
Fragment drawing

Visualisation of the material function by hatch and colour, the material dimensions and positioning

Structural system
+
Insulation material

Humidity gradient

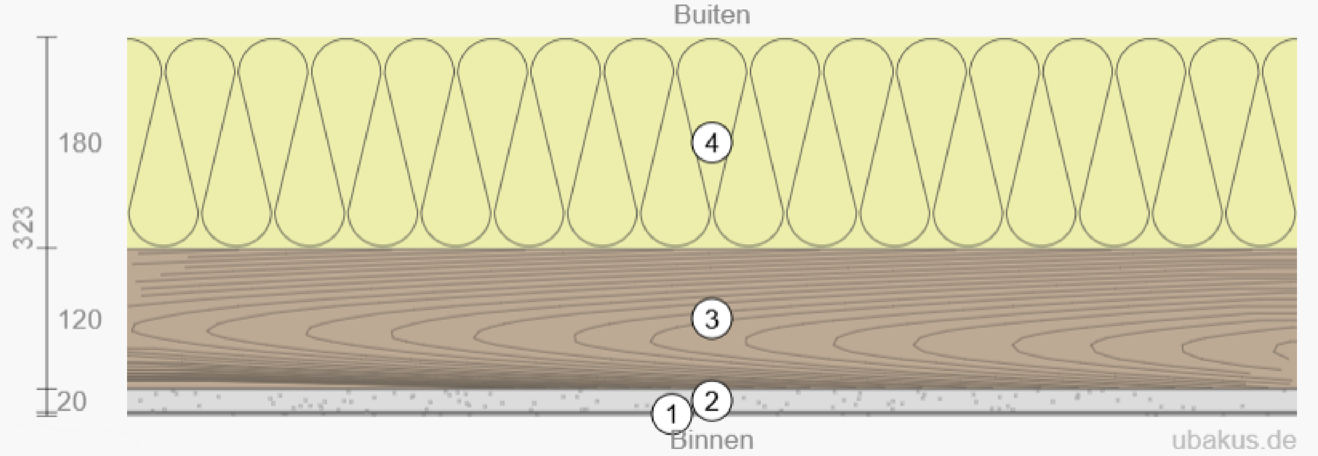
Vapour content in percentages (%) visualised by means of a gradient trough the façade composition

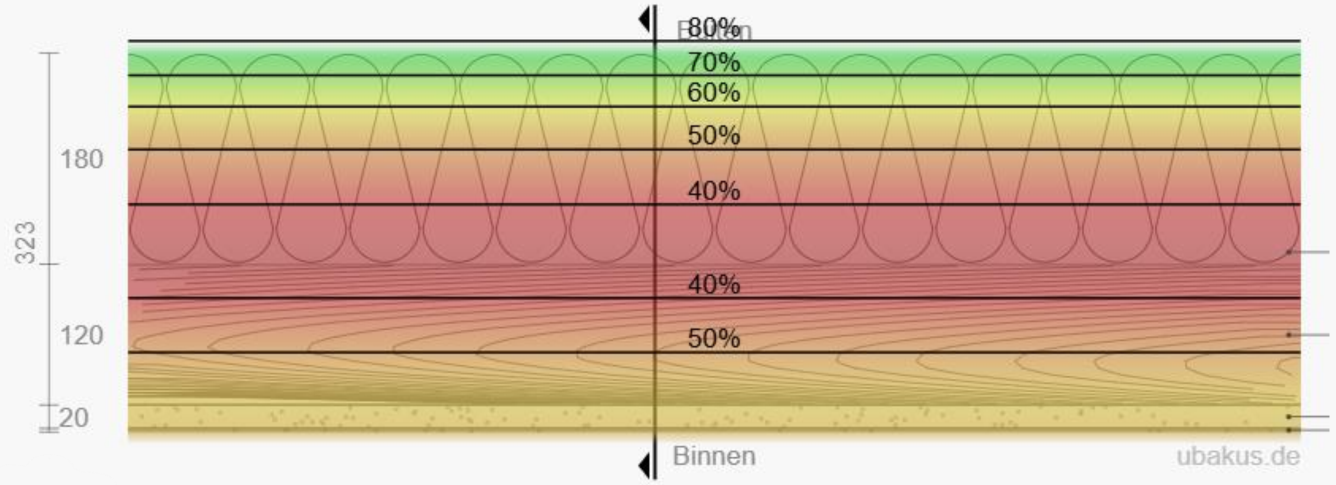


Relative humidity chart

Visualisation of the relative humidity changes in percentages (%) through the façade composition

Binnen:	Beperkte luchtcirculatie	20 °C	50 % Luchtvochtigheid	Rsi...
	Van binnen naar buiten: omkeren	Dikte	Breedte	Afstand
1	Claytec Lehmkleber	3 mm		
2	Claytec Lehmbauplatte	20 mm		
3	best wood CLT Brettsperrholz	120 mm		
4	IsoHemp Hempcrete "in situ" met Pro	180 mm		
5		mm		
Buiten:	Directe overgang naar buitenlucht	-5 °C	80 % Luchtvochtigheid	Rse...

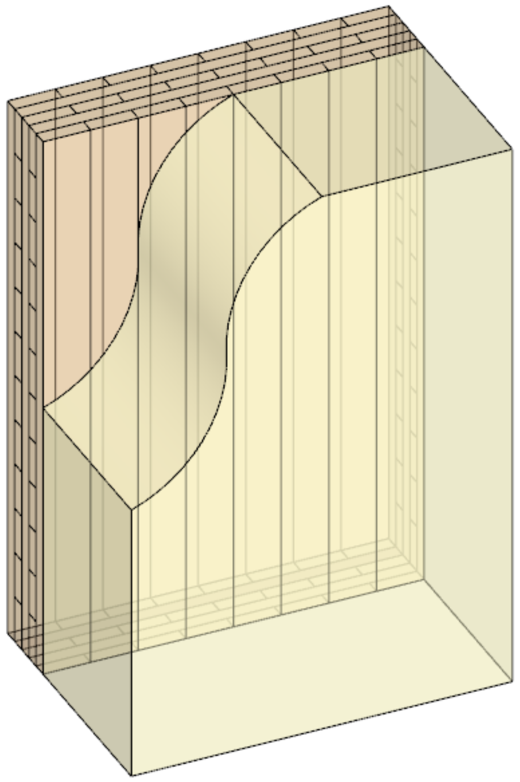




Cross Laminated Timber

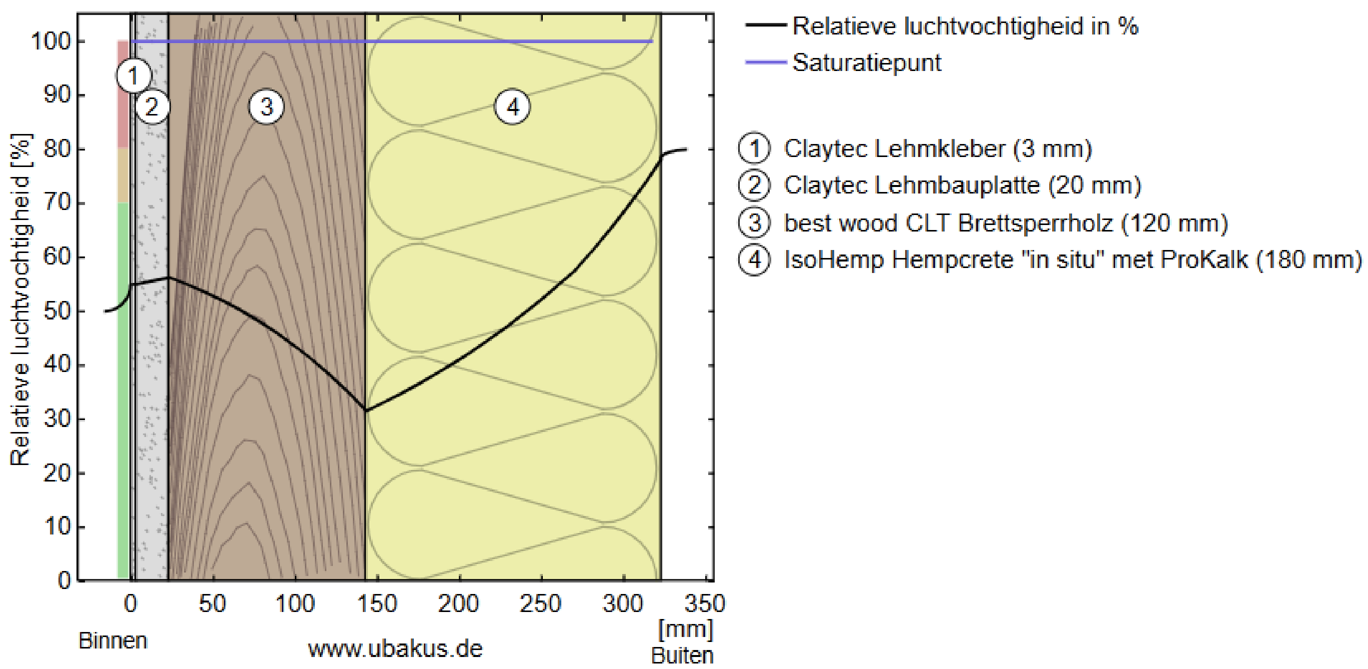
+

Hempcrete



Vochtbestendige bescherming (via de 2D-Finite element methode van u-wert.net)

Het volgende diagram toont de luchtvochtigheid binnenin de component, 100% = condensatie.

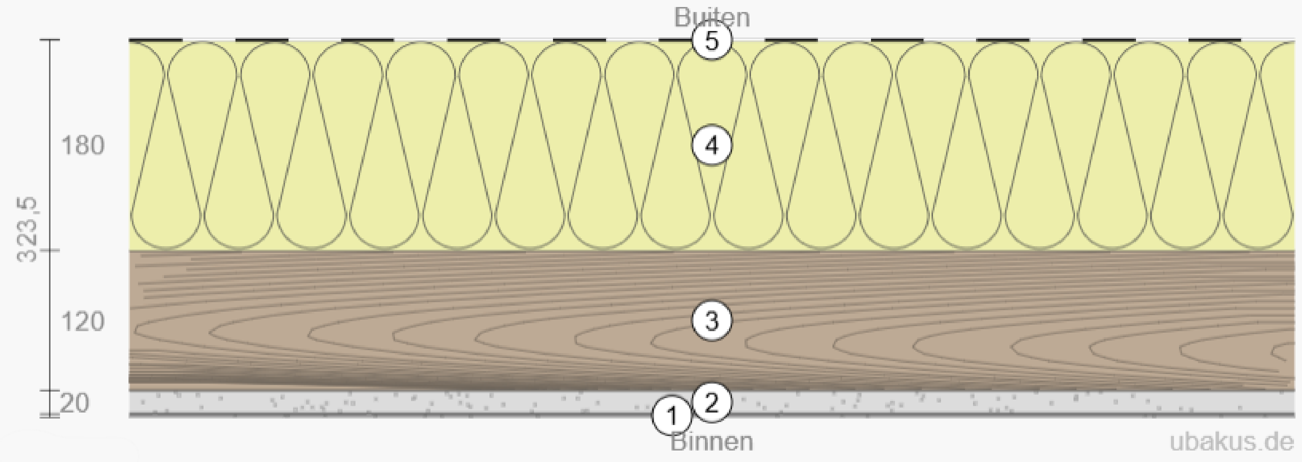


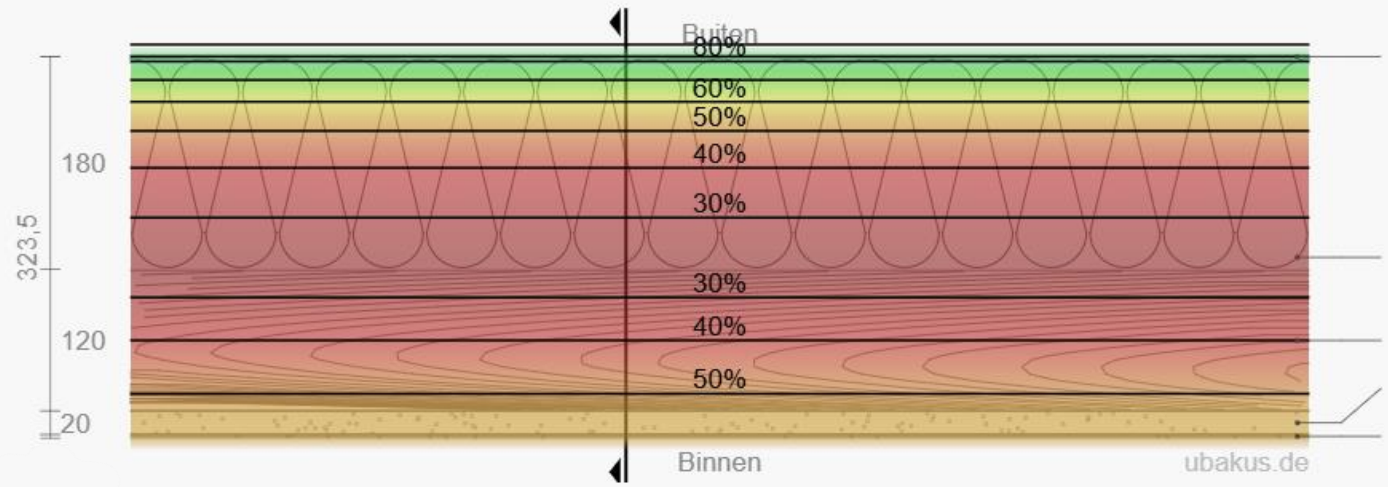
Binnen: Beperkte luchtcirculatie ▼ | 20 °C | 50 % Luchtvochtigheid | Rsi...

Van binnen naar buiten: omkeren

	Laag	Dikte		Breedte	Afstand ▾
1	Claytec Lehmkleber ▼	3	mm		
2	Claytec Lehmbauplatte ▼	20	mm		
3	best wood CLT Brettsperrholz ▼	120	mm		
4	Thermo Jute 100 ▼	180	mm		
5	Waterkerende dampdoorlatende folie ▼	0,5	mm		
6	▼		mm		

Buiten: Directe overgang naar buitenlucht ▼ | -5 °C | 80 % Luchtvochtigheid | Rse...

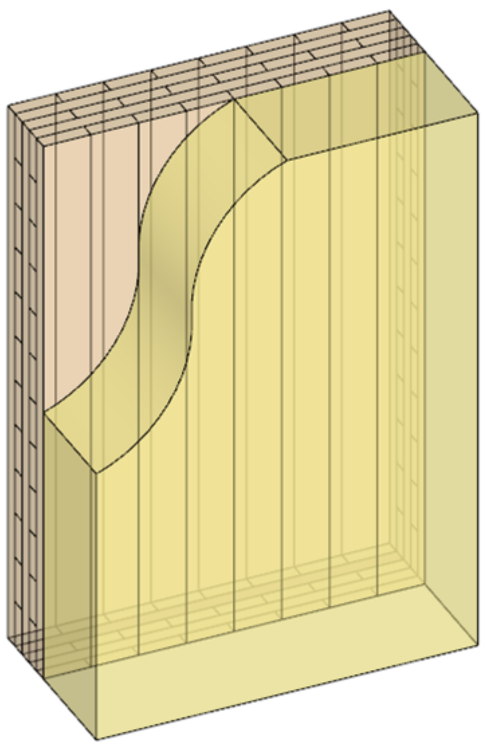




Cross Laminated Timber

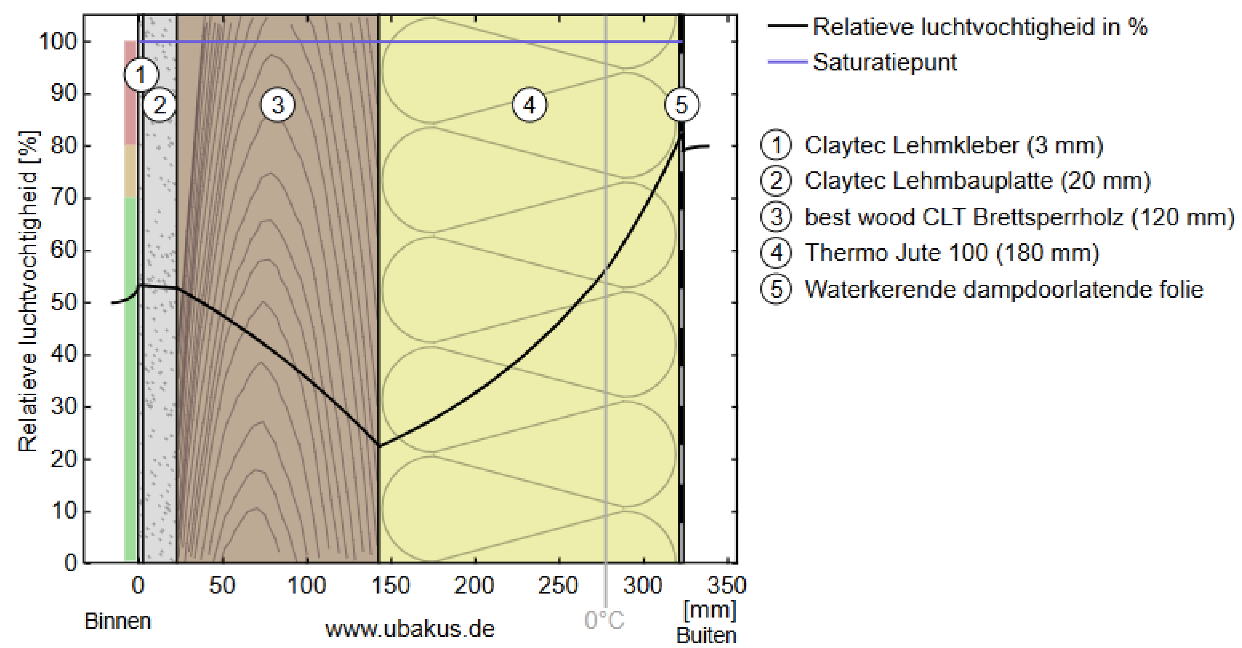
\+

Grass wool

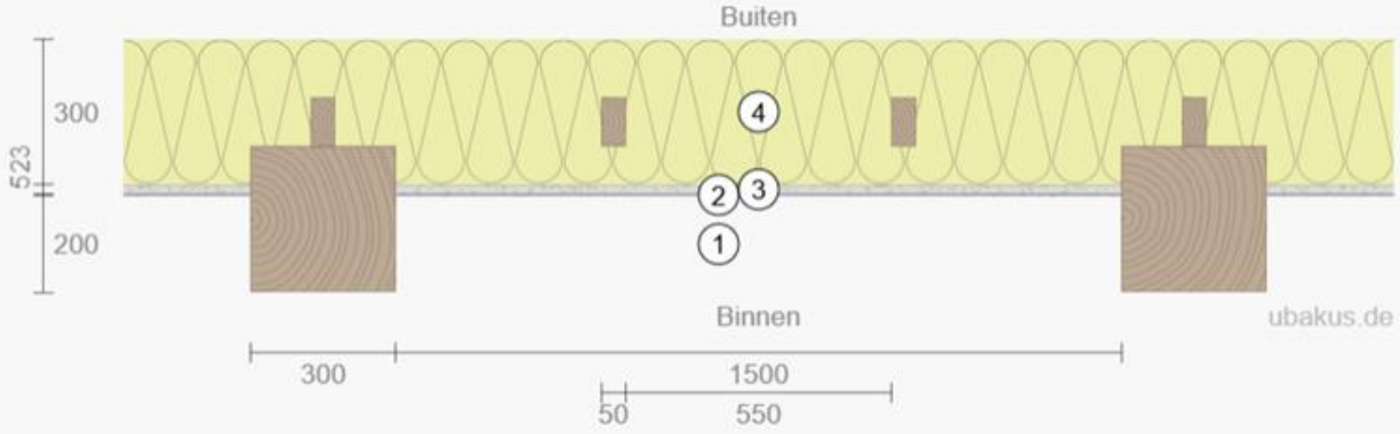


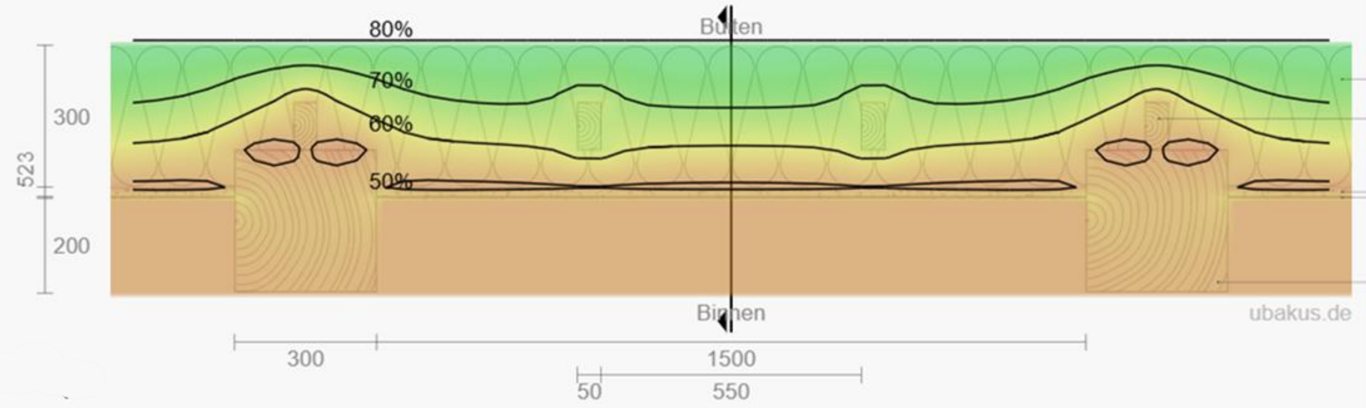
Vochtbestendige bescherming (via de 2D-Finite element methode van u-wert.net)

Het volgende diagram toont de luchtvochtigheid binnenin de component, 100% = condensatie.



Binnen:	Beperkte luchtcirculatie	20 °C	50 % Luchtvochtigheid	Rsi...	
	Van binnen naar buiten: omkeren	Dikte	Breedte	Afstand	
1	Sterk geventileerde luchtlage (binnen	200 mm			
	Spar	300 mm	300 mm	150(mm	
2	Claytec Lehmkleber	3 mm			
3	Claytec Lehmbauplatte	20 mm			
4	IsoHemp Hempcrete "in situ" met Pro	300 mm			
	Vuren	100 mm	50 mm	550 mm	
5		mm			
Buiten:	Directe overgang naar buitenlucht	-5 °C	80 % Luchtvochtigheid	Rse...	

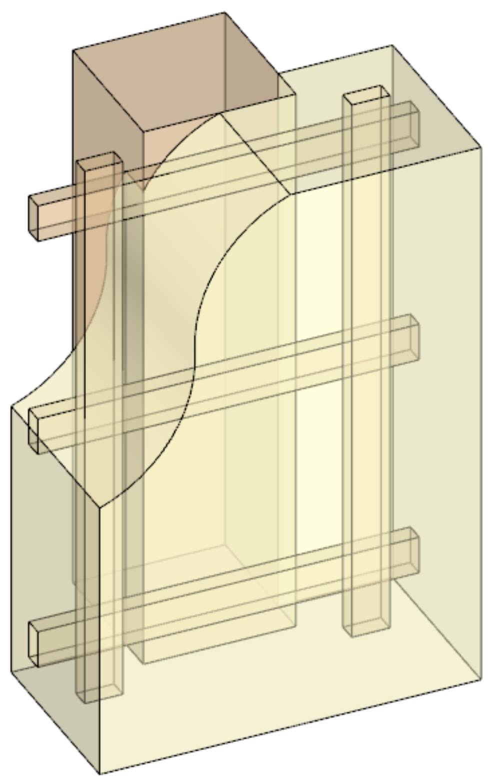




Post and Beam

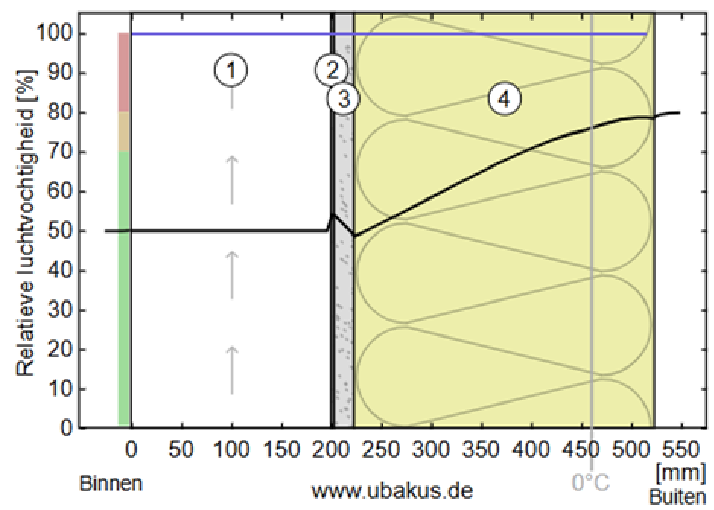
+

Hempcrete

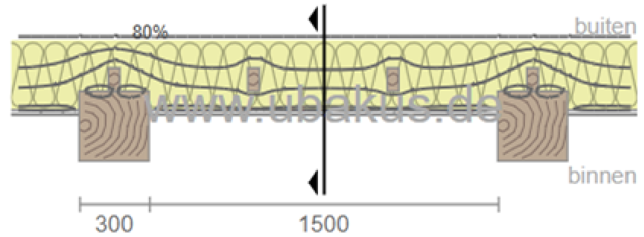


Vochtbestendige bescherming (via de 2D-Finite element methode van u-wert.net)

Het volgende diagram toont de luchtvochtigheid binnenin de component, 100% = condensatie.

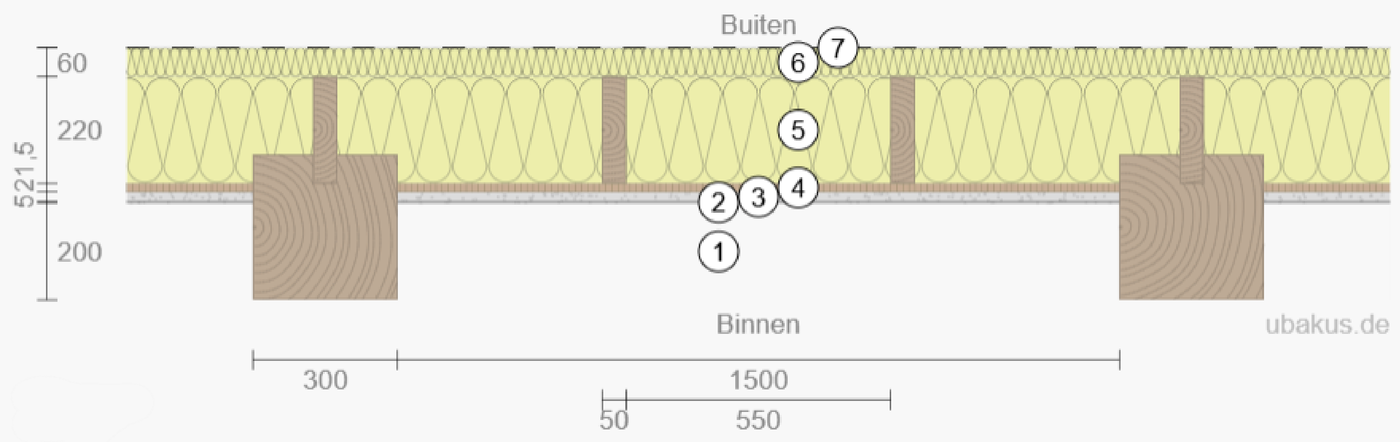


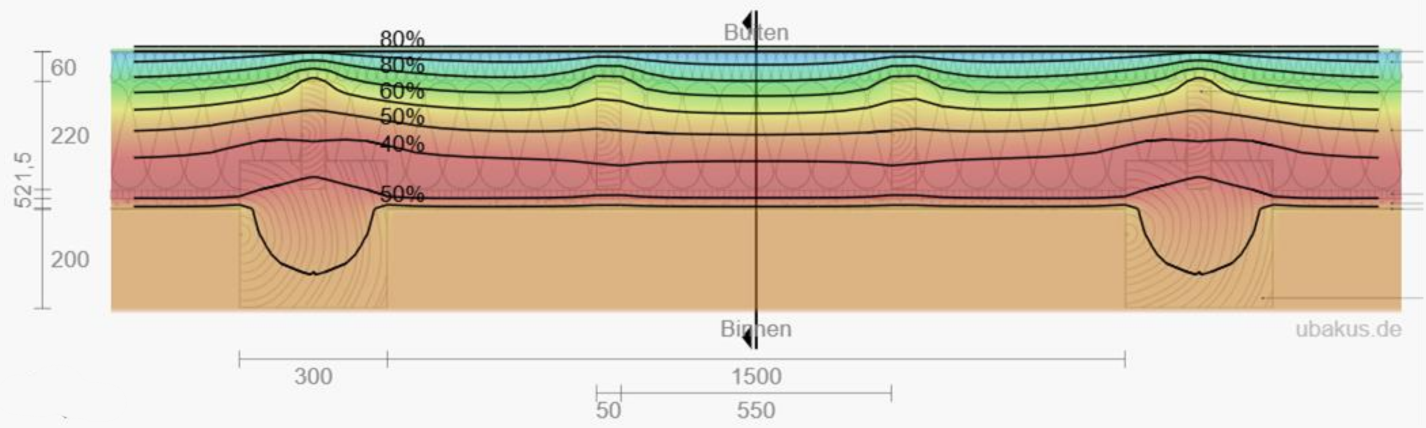
— Relatieve luchtvochtigheid in %
— Saturatiepunt



(1) Kamerlucht (200 mm)
(2) Claytec Lehmkleber (3 mm)
(3) Claytec Lehmbauplatte (20 mm)
(4) IsoHemp Hempcrete "in situ" met ProKalk...

			Dikte		Breedte		Afstand	
Binnen:		Beperkte luchtcirculatie	20	°C	50	% Luchtvochtigheid		Rsi...
		Van binnen naar buiten: omkeren						
1		Sterk geventileerde luchtlage (binnen	200	mm				
		Spar	300	mm	300	mm	1500	mm
2		Claytec Lehmkleber	3	mm				
3		Claytec Lehmbauplatte	20	mm				
4		Spaanplaat	18	mm				
5		Thermo Jute 100	220	mm				
		Vuren	220	mm	50	mm	550	mm
6		Thermo Jute 100	60	mm				
7		Waterkerende dampdoorlatende folie	0,5	mm				
8				mm				
Buiten:		Directe overgang naar buitenlucht	-5	°C	80	% Luchtvochtigheid		Rse...

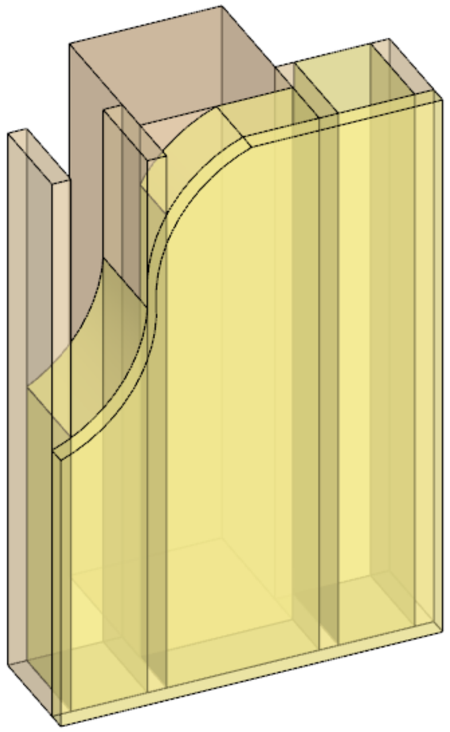




Post and Beam

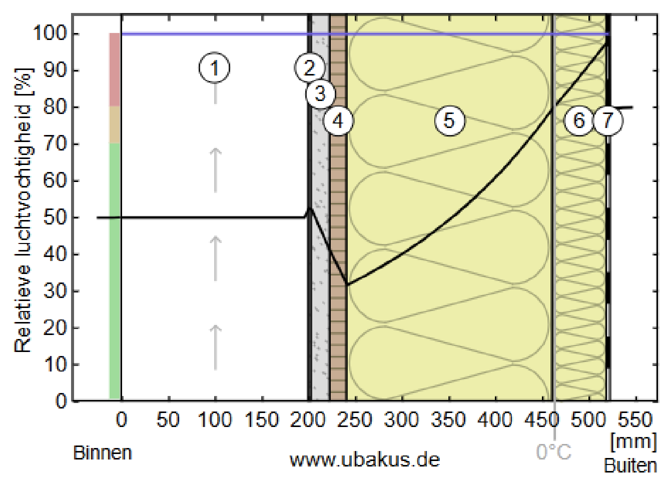
+

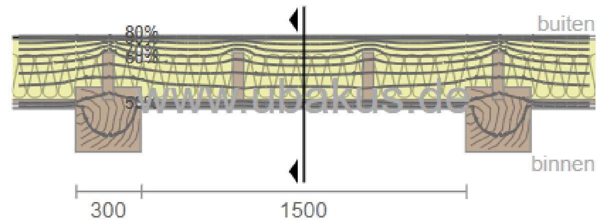
Grass wool



Vochtbestendige bescherming (via de 2D-Finite element methode van u-wert.net)

Het volgende diagram toont de luchtvochtigheid binnenin de component, 100% = condensatie.



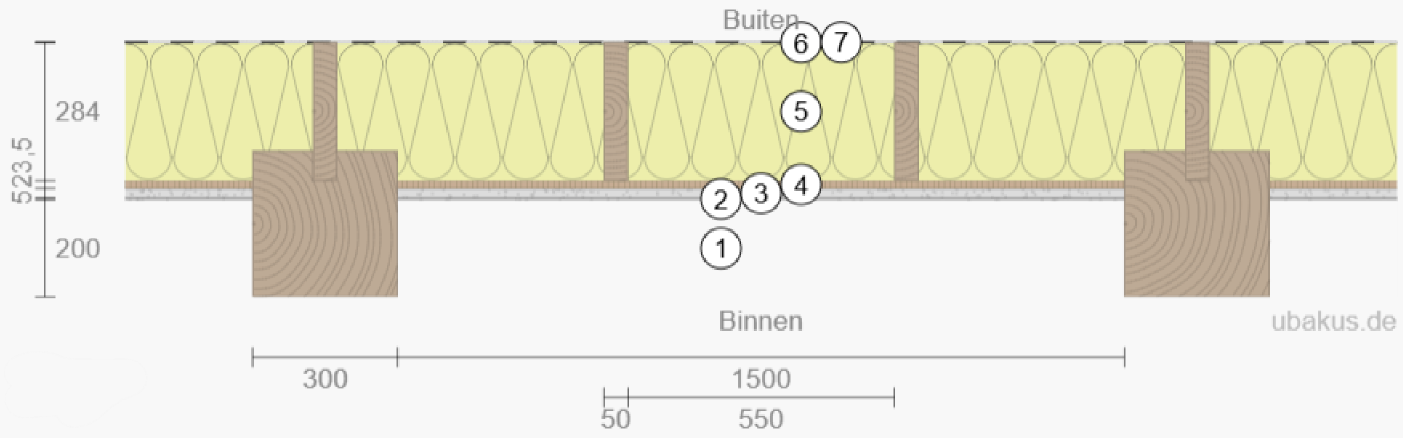


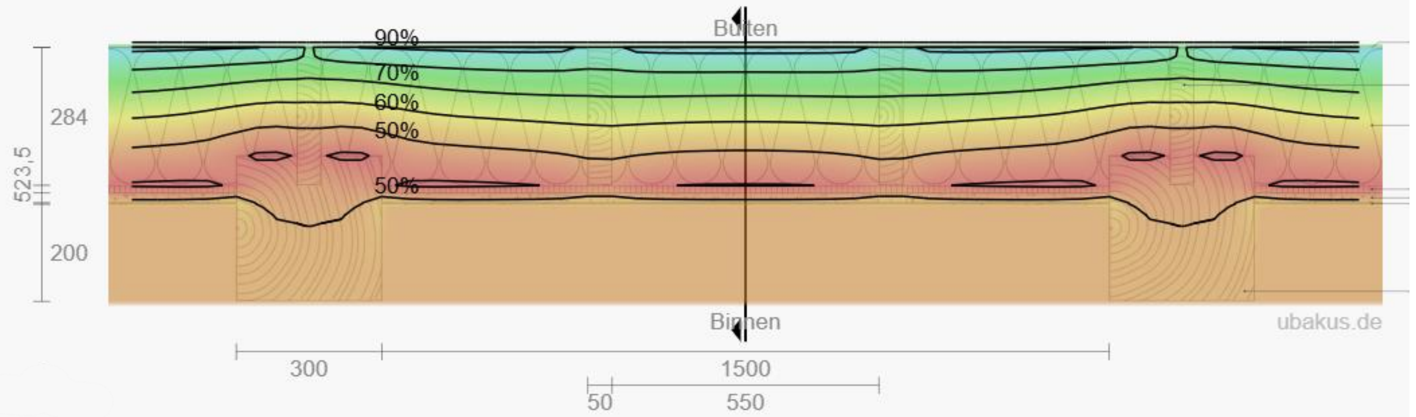
① Kamerlucht (200 mm)
② Claytec Lehmkleber (3 mm)
③ Claytec Lehmbauplatte (20 mm)
④ Spaanplaat (18 mm)
⑤ Thermo Jute 100 (220 mm)
⑥ Thermo Jute 100 (60 mm)
⑦ Waterkerende dampdoorlatende folie

Binnen: Beperkte luchtcirculatie | 20 °C | 50 % Luchtvochtigheid | Rsi...

Van binnen naar buiten: (omkeren)		Dikte	Breedte	Afstand
1	Sterk geventileerde luchtlage (binnen	200 mm		
	Spar	300 mm	300 mm	1500 mm
2	Claytec Lehmkleber	3 mm		
3	Claytec Lehmbauplatte	20 mm		
4	Spaanplaat	16 mm		
5	ISO-Stroh Einblasdämmung	284 mm		
	Vuren	284 mm	50 mm	550 mm
6	Strohplatte (Leicht)	0 mm		
7	Waterkerende dampdoorlatende folie	0,5 mm		
8		mm		

Buiten: Directe overgang naar buitenlucht | -5 °C | 80 % Luchtvochtigheid | Rse...

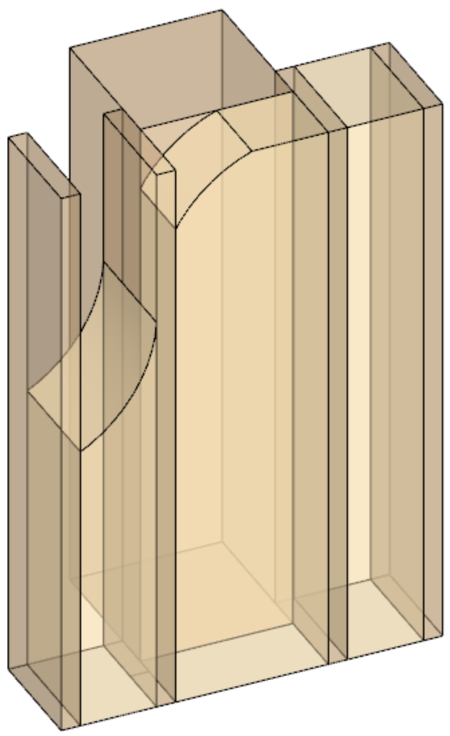




Post and Beam

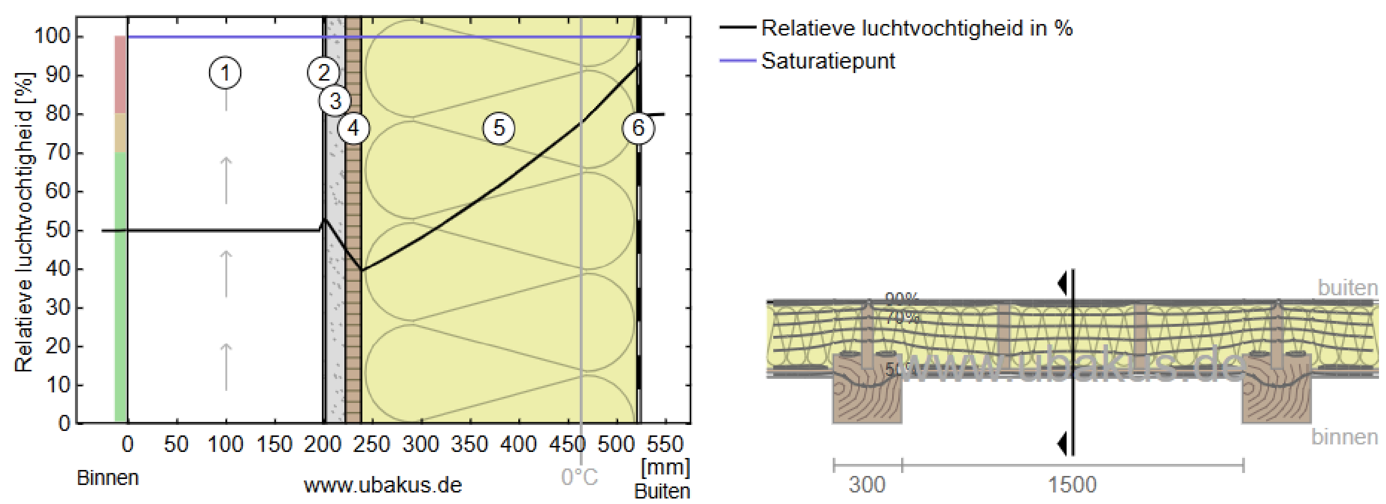
+

Straw fibre



Vochtbestendige bescherming (via de 2D-Finite element methode van u-wert.net)

Het volgende diagram toont de luchtvochtigheid binnenin de component, 100% = condensatie.



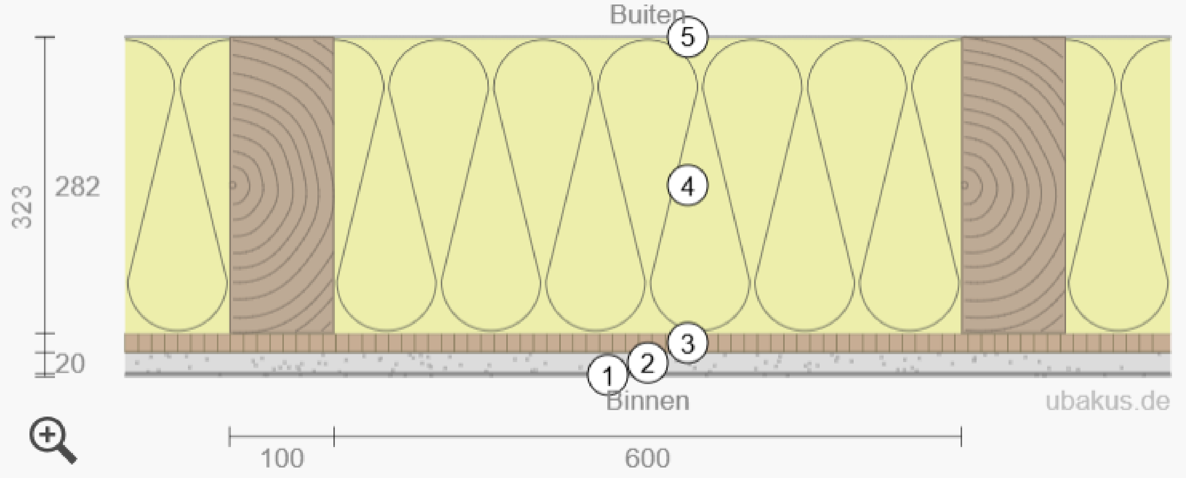
① Kamerlucht (200 mm)
② Claytec Lehmkleber (3 mm)
③ Claytec Lehmbauplatte (20 mm)
④ Spaanplaat (16 mm)
⑤ ISO-Stroh Einblasdämmung (284 mm)
⑥ Waterkerende dampdoorlatende folie

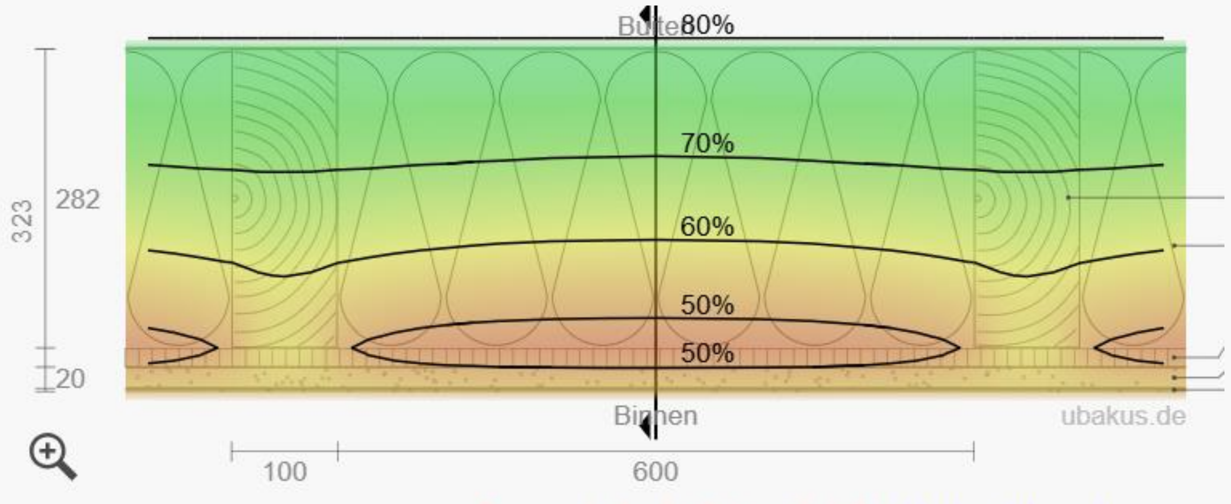
Binnen: Beperkte luchtcirculatie | 20 °C | 50 % Luchtvochtigheid | Rsi...

Van binnen naar buiten: omkeren

	Laag	Dikte		Breedte		Afstand	
1	Claytec Lehmkleber	3	mm				
2	Claytec Lehmbauplatte	20	mm				
3	Spaanplaat	18	mm				
4	IsoHemp Hempcrete "in situ" met Pro	282	mm				
	Spar	282	mm	100	mm	600	mm
5	Thermo Hanf PREMIUM	0	mm				
6			mm				

Buiten: Directe overgang naar buitenlucht | -5 °C | 80 % Luchtvochtigheid | Rse...

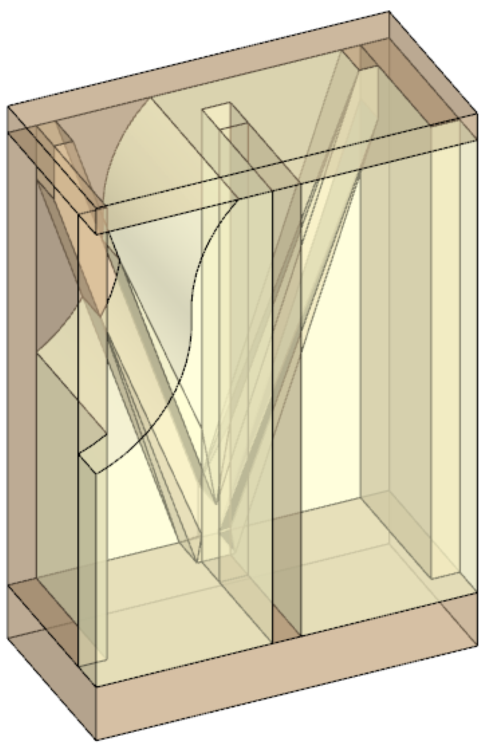




Timber Frame

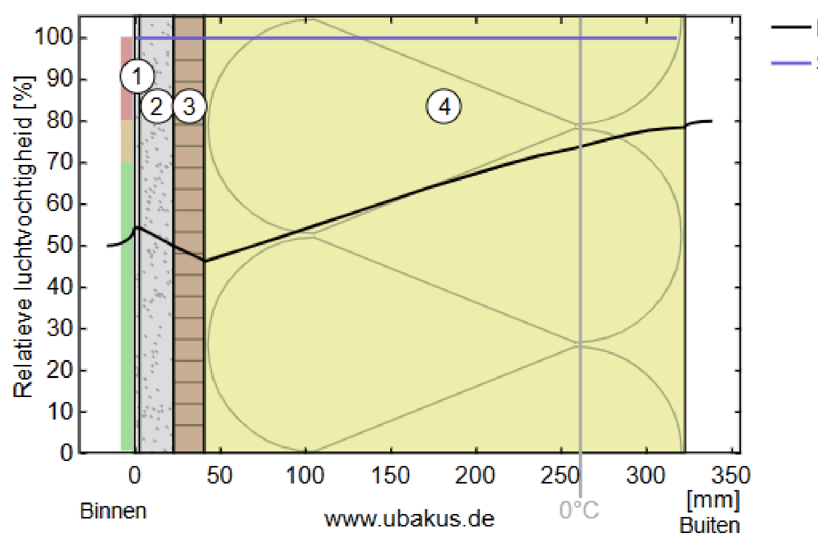
\+

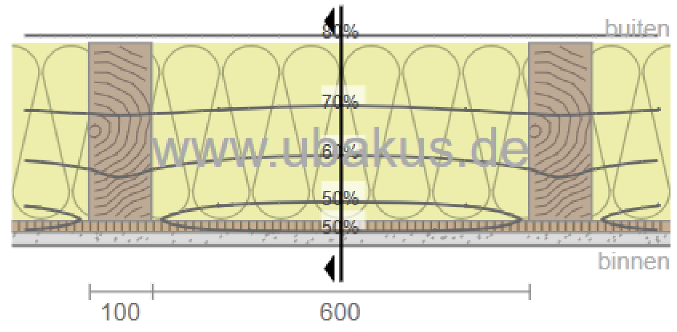
Hempcrete



Vochtbestendige bescherming (via de 2D-Finite element methode van u-wert.net)

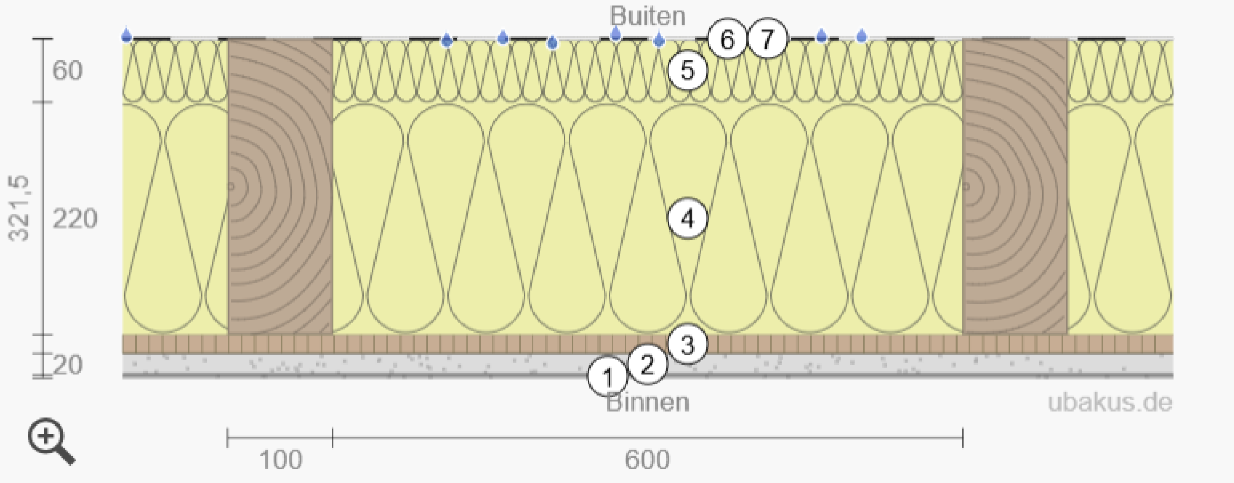
Het volgende diagram toont de luchtvochtigheid binnenin de component, 100% = condensatie.

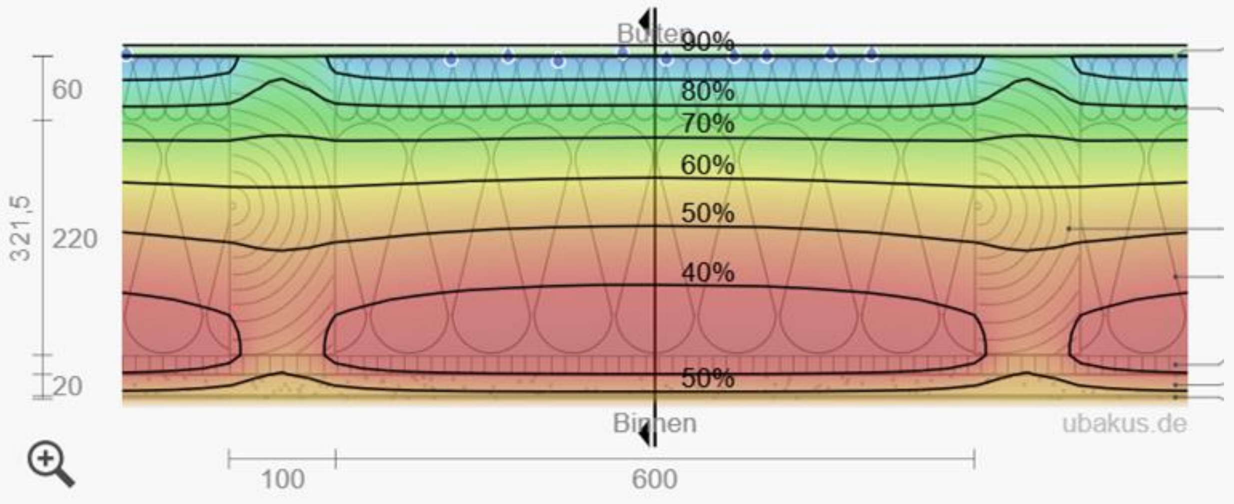




① Claytec Lehmkleber (3 mm)
② Claytec Lehmbauplatte (20 mm)
③ Spaanplaat (18 mm)
④ IsoHemp Hempcrete "in situ" met ProKalk...

Binnen:	Beperkte luchtcirculatie	20 °C	50 % Luchtvochtigheid			Rsi...
	Van binnen naar buiten: omkeren	Dikte	Breedte	Afstand		
1	Claytec Lehmkleber	3 mm				
2	Claytec Lehmbauplatte	20 mm				
3	Spaanplaat	18 mm				
4	Thermo Jute 100	220 mm				
	Spar	280 mm	100 mm	600 mm		
5	Thermo Jute 100	60 mm				
6	PAVATEX PAVABOARD	0 mm				
7	Waterkerende dampdoorlatende folie	0,5 mm				
8		mm				
Buiten:	Directe overgang naar buitenlucht	-5 °C	80 % Luchtvochtigheid			Rse...

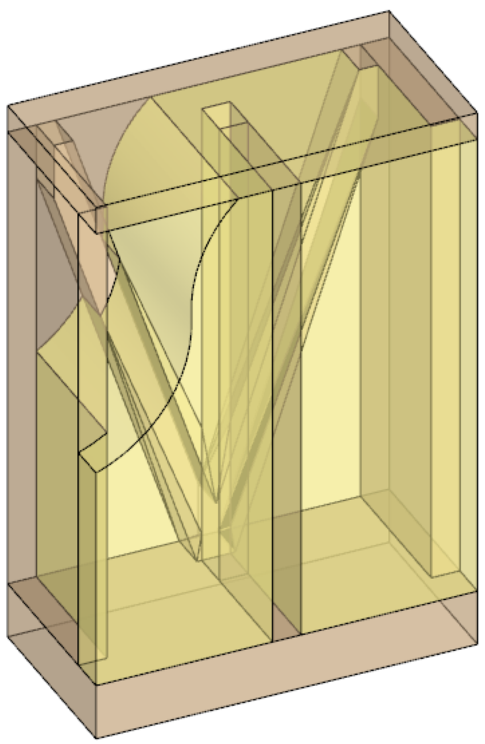




Timber Frame

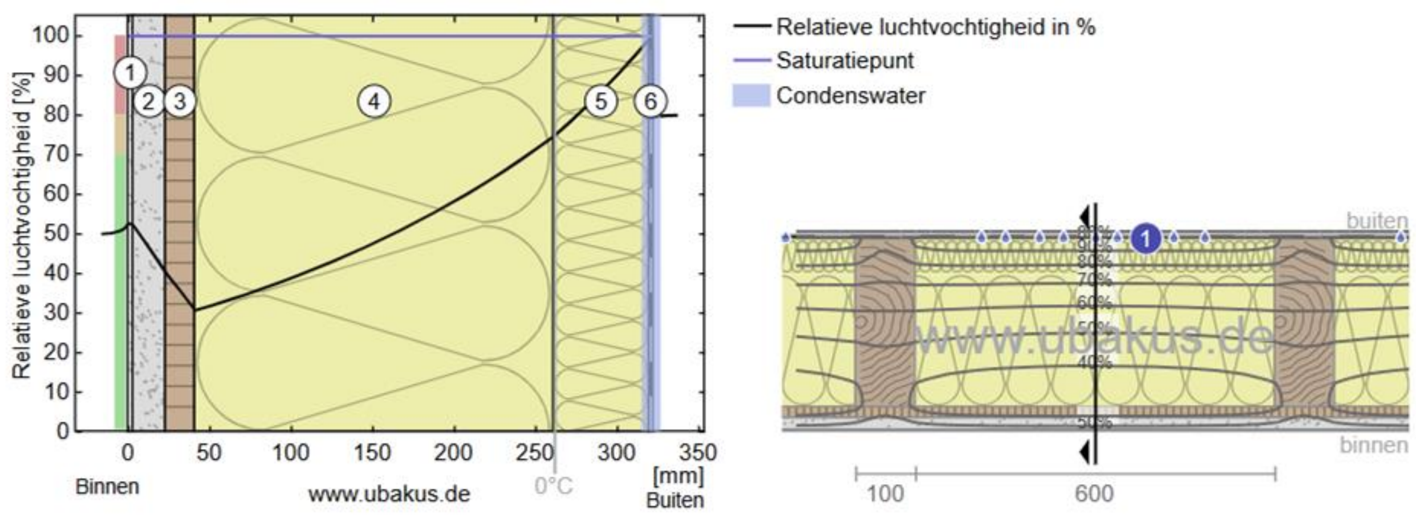
+

Grass wool



Vochtbestendige bescherming (via de 2D-Finite element methode van u-wert.net)

Het volgende diagram toont de luchtvochtigheid binnenin de component, 100% = condensatie.

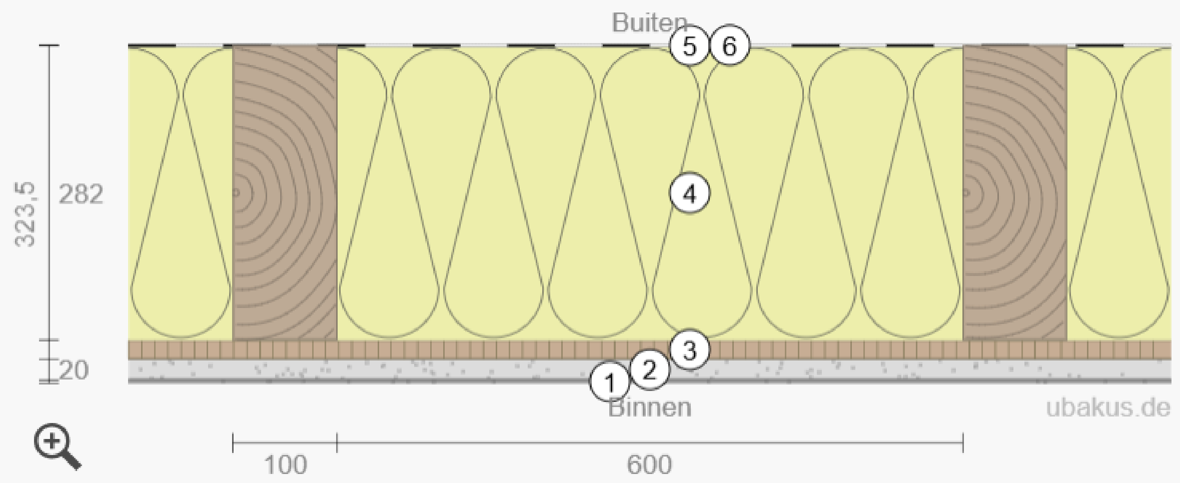


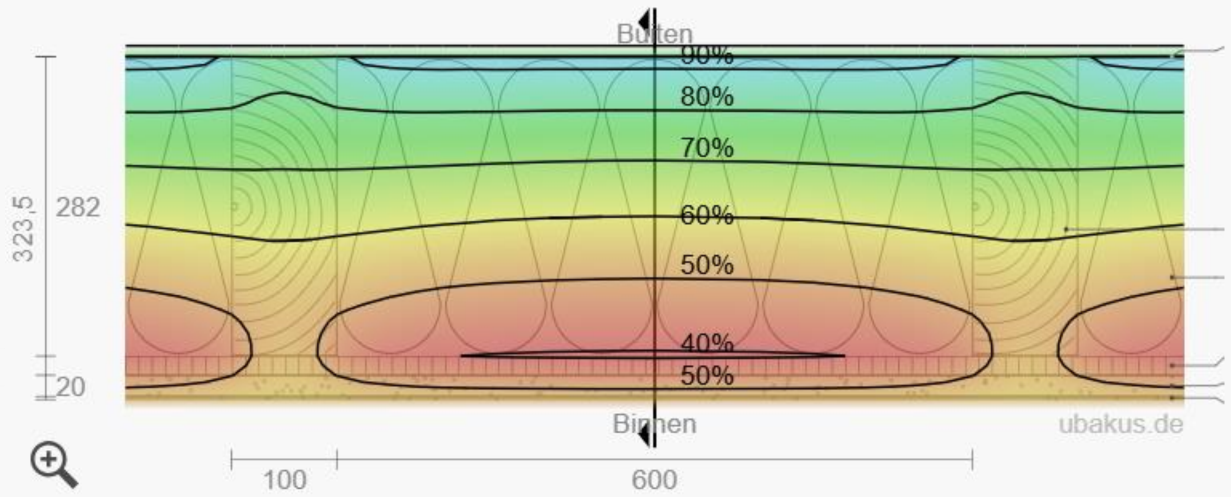
① Claytec Lehmkleber (3 mm)
② Claytec Lehmbauplatte (20 mm)
③ Spaanplaat (18 mm)
④ Thermo Jute 100 (220 mm)
⑤ Thermo Jute 100 (60 mm)
⑥ Waterkerende dampdoorlatende folie

Binnen: Beperkte luchtcirculatie | 20 °C | 50 % Luchtvochtigheid | Rsi...

Van binnen naar buiten: (omkeren)		Dikte	Breedte	Afstand
1	Claytec Lehmkleber	3 mm		
2	Claytec Lehmbauplatte	20 mm		
3	Spaanplaat	18 mm		
4	ISO-Stroh Einblasdämmung	282 mm		
	Spar	282 mm	100 mm	600 mm
5	Thermo Hanf PREMIUM	0 mm		
6	Waterkerende dampdoorlatende folie	0,5 mm		
7		mm		

Buiten: Directe overgang naar buitenlucht | -5 °C | 80 % Luchtvochtigheid | Rse...

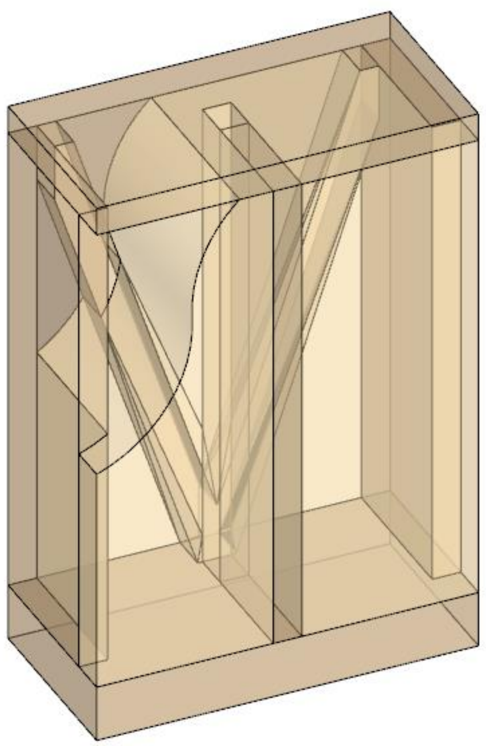




Timber Frame

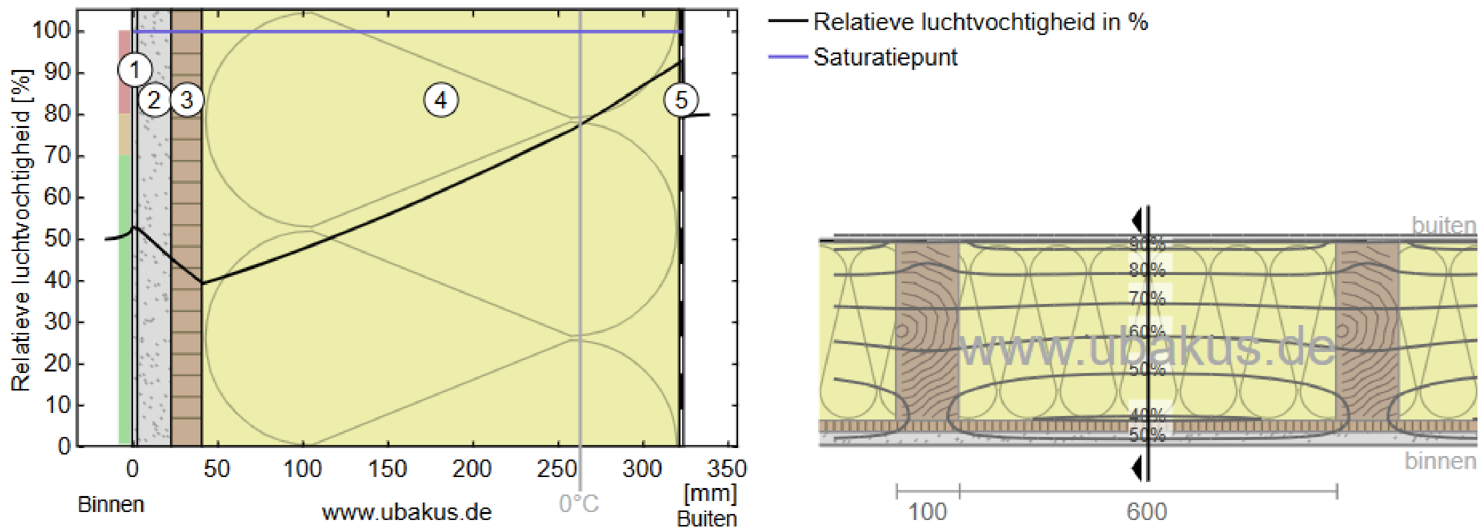
+

Straw fibre



Vochtbestendige bescherming (via de 2D-Finite element methode van u-wert.net)

Het volgende diagram toont de luchtvochtigheid binnenin de component, 100% = condensatie.



① Claytec Lehmkleber (3 mm)
② Claytec Lehmbauplatte (20 mm)
③ Spaanplaat (18 mm)
④ ISO-Stroh Einblasdämmung (282 mm)
⑤ Waterkerende dampdoorlatende folie

“Feeling good in one’s own skin”

A PROPOSAL TOWARDS BIOBASED AND BREATHABLE DESIGN FOR HEALTHIER RESIDENTIAL ARCHITECTURE

22 January 2025

Carlos Damberg
5437288

Architectural Wood | Timber for Urban Density
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