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BACHELOR'S THESIS

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Preface

This thesis marks the end of my bachelor's study in constructional engineering at the University of Stavanger. The thesis was written in the spring of 2021.

With a long-standing background as a carpenter, my experience is that the issue is very relevant to the construction industry. With a limited knowledge of moisture that can occur in buildings before writing the thesis, it has been very interesting and instructive to dive deeper into the problem areas the dissertation looks at.

Moisture in buildings is a large and comprehensive topic, where the area extends from microscopic pores in materials, to challenges and changes in climate. Trying to compress the findings and the relevant theory into something that provides a basic assessment of the challenges the thesis problem refers to has been both instructive and challenging.

I would like to thank my supervisor, Samindi Samarakoon, who has patiently answered inquiries, questions and suggestions I had to ask. It has been a security and a great help to have someone with such great knowledge in the subject to provide feedback.

Abstract

This thesis has looked at and assessed the various challenges with moisture and moisture damage in Norwegian residential buildings.

In this relation, a review has been made of current statistics and reports within building damages, in order to uncover the causes and extent of the damages. Furthermore, a review has been made of instructions found in Byggforskserien, guidelines for relevant regulations, as well as relevant theory. The purpose of this has been to form an overview of which moisture-related challenges occur, why these occur, how they can be improved and how they can be avoided, and to substantiate these issues with relevant theory. The amount of available information and data on the thesis problem is large, and ranges from microscopic pores in materials, to climate change. It has therefore been important to assess which findings are relevant to the thesis and not, and to what extent these are relevant, in order to address the thesis' problem as specifically as possible.

The results show that the proportion of moisture-related building damages have been stable in recent decades, but that moisture damages resulting from precipitation has increased significantly. Statistics show that more than 70% of all building damages are moisture-related, and that as many as one third of all Norwegian residential buildings have moisture problems. These damages cost society billions of NOK every year, in addition to being a strong contributing factor to health problems such as respiratory disorders, according to several studies done in recent years.

A demanding Norwegian climate places strict demands on design and execution in order to avoid complications and challenges with moisture over time. Several of the injuries that occur could have been avoided. This is supported by the fact that damages resulting from building moisture and moisture from inside the building, have been significantly reduced as the focus on moisture in buildings has increased, along with requirements for building density becoming stricter.

The example studies in this thesis show some of the challenges one has related to moisture in homes, where a theory of why the damage occurs is presented. The damages that have occurred in all of the three studies must be said could have been avoided with sufficient knowledge. This is in line with statements from experts in the industry, where most of the damages that occur are due to errors in design and / or execution.

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1 Intro

1.1 Introduction

Every year, building damages in Norway cost society billions of NOK. The annual costs for repairing process-caused damages alone are estimated to be around 4 - 6% of the total investment costs in new buildings [1]. Of these, it is estimated that as much as 75% of the damages are due to moisture or the effects of moisture [2]. The total extent of moisture problems in Norwegian residential buildings, however, seems to be significantly greater, where it is estimated that as much as one third of the buildings have challenges with moisture [3].

However, the consequences of moisture related damages are not just economical. Moisture damages often lead to reduced quality of the indoor climate, and can result in favorable growth conditions for fungus. This can lead to health related issues for residents, with an increased risk of both allergies and respiratory disorders, like asthma, bronchitis and eczema, to mention a few. A number of studies have been done that go a long way in suggesting that problems with moisture in buildings are not only a contributing factor to cases of asthma, but a major cause [4].

The proportion of moisture damages has been stable in recent decades [5], but increased focus on building physics and moisture in buildings as well as stricter requirements for construction and the building's air tightness over the last couple of decades [6], seem to have changed the distribution of damages. Since 1993, there has been a significant reduction in moisture damages resulting from building moisture and moisture from within [5]. At the same time, moisture damages resulting from precipitation has almost doubled during the same period [5], with precipitation today accounting for more than 40% of the damage. This indicates ever-increasing challenges with a changing climate, where more rain and heavier rainfall is predicted to increase further in the coming decades [7].

Many of the damages that occur must be said to be avoidable. Poor craftmanship and a lack of knowledge seems to be a common denominator for a many of the damages that occur. Several news articles and expert opinions support this:

"As many as 43 per cent of the appraisers surveyed in the in-depth survey from the Norwegian Appraisal Association believe that more than half of the cases in which they reduce the degree of condition are due to poor craftsmanship." (AT) [8]

"Previous studies conducted by SINTEF Byggforsk have concluded that as much as 65 to 70 percent of all building damages are due to moisture. Svein Bjørberg, professor at NTNU and R&D manager at Multiconsult, confirms that poor craftsmanship is the problem in the vast majority of cases. - The cause is construction defects, and construction defects are due to poor work by designers and contractors, he says." (AT) [8]

"Last year (2016), 4610 water damages attributed to poor craftmanship was registered in Norway. This corresponds to 12 water damages every single day, according to statistics from Finans Norge." (AT) [8]

"Around 75 % of the damages documented by the institute, are due to moisture. More than half come from problems during precipitation, moisture from within, water in the ground and building moisture. Most of the damages can be traced back to faults and defects during the design; design omissions and incorrect design." (AT) [9]

In older buildings, moisture problems are largely due to the building customs of the time, with basements in particular being exposed, where previously there was no drainage on the outside. However, there are also many moisture damages in older buildings that are due to construction defects during renovation and/or re-insulation. The challenges of building moisture-resistant buildings are many, but knowledge indicates that with the right design and by following recommendations and requirements, one can virtually eliminate moisture-related damages in buildings. With the high cost to society of such damages, both financially and in terms of health, the potential benefits of a sharp reduction in building damage are significant.

1.2 Goal of Thesis

The goal of this thesis is

- To uncover which moisture related damages occur most frequent
- What the cause of these damages are and how they occur
- How these damages can be avoided
- How we can repair these damages, and prevent them from occuring in the future
- What the cost of these repairs are

The thesis will also look at possible consequences and challenges regarding rehabilitation and post-insulation of older buildings, and how these damages can be avoided.

1.3 Limitations

The thesis addresses moisture related damages to buildings. It will be looking at wooden buildings, and the subject area of the work of the carpenter. The focus has mainly been on the execution of the different building elements, but projected and chosen solution is looked at and commented where this is found necessary.

Furthermore, the limitations of the thesis stretches to dealing with buildings of measure class 1, and the following types of wooden dwellings:

- Detached house
- House with 2 dwellings

This is due to these types of dwellings being the most common in Norway. However, the difference in recommended and executed solution is insignificant in most types of dwellings, and so the discoveries of the thesis will be applicable to most wooden dwellings.

1.4 Structure of thesis

The thesis consist of a total of 8 chapters.

Chapter 1 gives an introduction to the subject and goal of the thesis, as well as it's limitations.

Chapter 2 provides general information about residential buildings in Norway. First an introduction to the different classes of relevant dwellings, then information about the Norwegian climate, followed by the structural challenges the climate provides.

Chapter 3 addresses the relevant theory needed to assess the subject of the thesis. The first part consists of basic moisture mechanics. This is then followed by explaining how moisture can transport through both materials and constructions, and how the two react in contact with moisture. The second part gives an overview of the recommended execution of exterior walls and roofs within a wood frame dwelling. It also looks at some of the recommended and required properties of the different materials used in these constructions.

Chapter 4 gives an overview of the methodology used to assess the thesis problem.

Chapter 5 looks at the different challenges and requirements related to moisture in buildings. Furthermore, it gives an overview of indicators of moisture damages, their causes, and how to improve such damages. It also addresses the owner's rights related to this matter.

Chapter 6 consists of three case studies. Each study is represented with general information about the building or building part damaged. Then issue, cause and solution is discussed, along with a cost evaluation of the damage. The final part of the chapter addresses the similarities of the cases.

Chapter 7 consists of a summary and conclusion.

Chapter 8 holds a list of figures and referances.

1.5 Definitions

- **Process related damages -** Damages that occur during the construction phase.

- **TEK17 -** The Norwegian building code.

- **SINTEF -** One of Europe's largest independent research organisations.

- **AT -** Authors translation.

- **NOK -** Norwegian currency.

- **Climate shield -** The buildings exterior protection against weather.

- **Saturation point -** The stage which the maximum amount of something has been absorbed.
- **Moisture -** Water in vapor form.
- s_d **-** A measure of how vapor open a product is.
- **Condensation -** Water vapor converting into liquid form.
- **Mold -** A type of fungus.
- **Re-insulation -** When adding insulation to an existing home.
- **Weight percentage -** The amount of substance contained in a material, relative to it's weight.
- **Moisture meter -** Device used to measure the moisture content in a material.
- **Financial Complaint Board -** A Norwegian board solving disputes between finance companies and customers.
- **Norsk Standard -** Norwegian standards for construction, petroleum etc.

2 Residential buildings in Norway

As of 2018, there is a total of approximately 2.5 million residential buildings in Norway, according to public statistics [10]. Of these, approximately 1.3 million are detached houses [10].

On average, approximately 27,000 residential buildings are built every year [9], where statistics show that this accounts for approximately 25 % of the total number of residential buildings being sold on the open market in Norway every year [11], of which the average sales price is approximately 40,000 NOK per m^2 for new residential buildings [12], and 26,000 NOK per m^2 for used residential buildings [12].

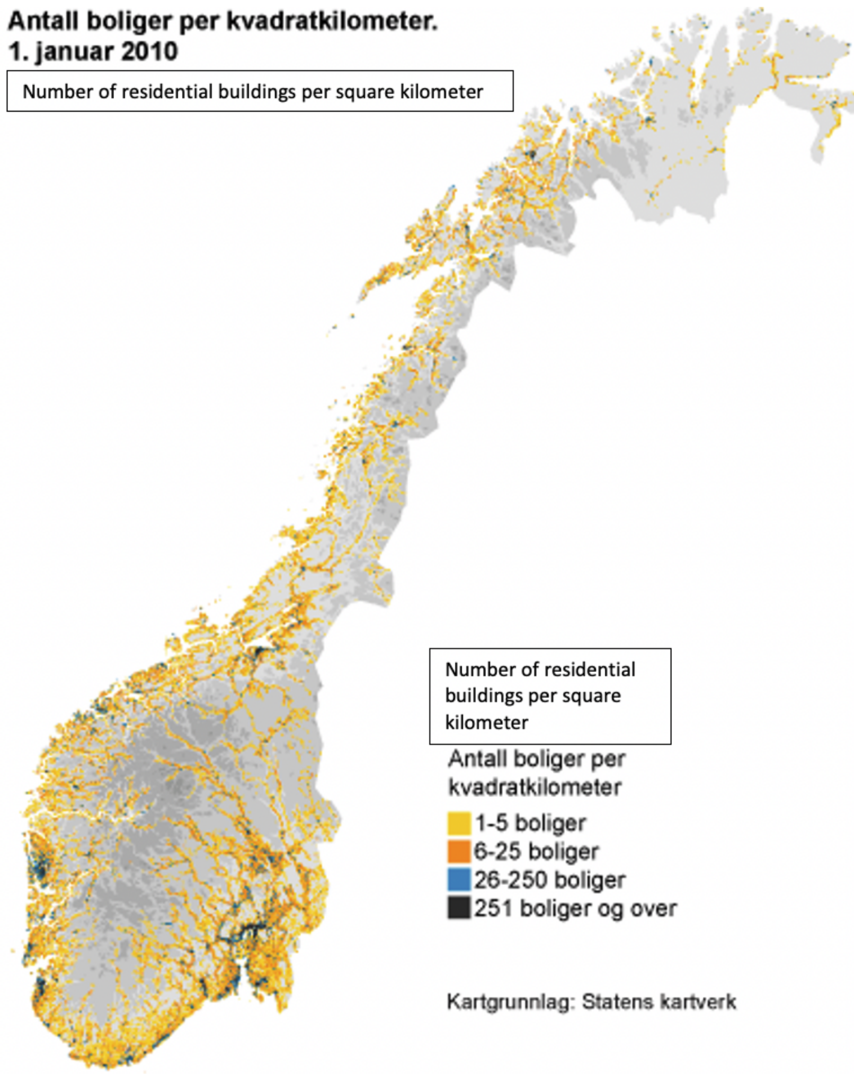

Figure 1: Density of residential buildings in Norway per km^2 [10].

2.1 Dwellings

Buildings in Norway are classified according to the function of the building [13]. The class of dwellings consists of all housings, which include detached houses, houses with two dwellings, holiday houses and more. The most common residential buildings in Norway are detached houses, which account for roughly 50 % of the total number of residential buildings [10].

All residential buildings that are built in Norway are subject to requirements that provide certain guidelines for how the residential building can and should be designed through Plan- og bygningsloven (PBL)(Planning and building act) [14] and TEK17 (The building code) [15]. Among these are requirements for fire safety, insulation, air tightness, and sizes of rooms and escape routes, to name a few.

The requirements for the building's air tightness and insulation capacity are something that can be directly related to the problem of the thesis. Along with increased insulation requirements to promote more energy-efficient and environmentally friendly buildings, the requirements for building air tightness have also increased [16]. This is to achieve even better insulation capacity by minimizing air leaks in the home, but also because larger amounts of insulation increase the risk of condensation resulting from these air leaks. This is explained in more detail in chapter 3.

2.2 Climate

The Norwegian climate can be challenging on buildings, and the predicted climate changes with increasing temperatures and more extreme weather puts great demands on the design of these buildings and the execution during the building process [17].

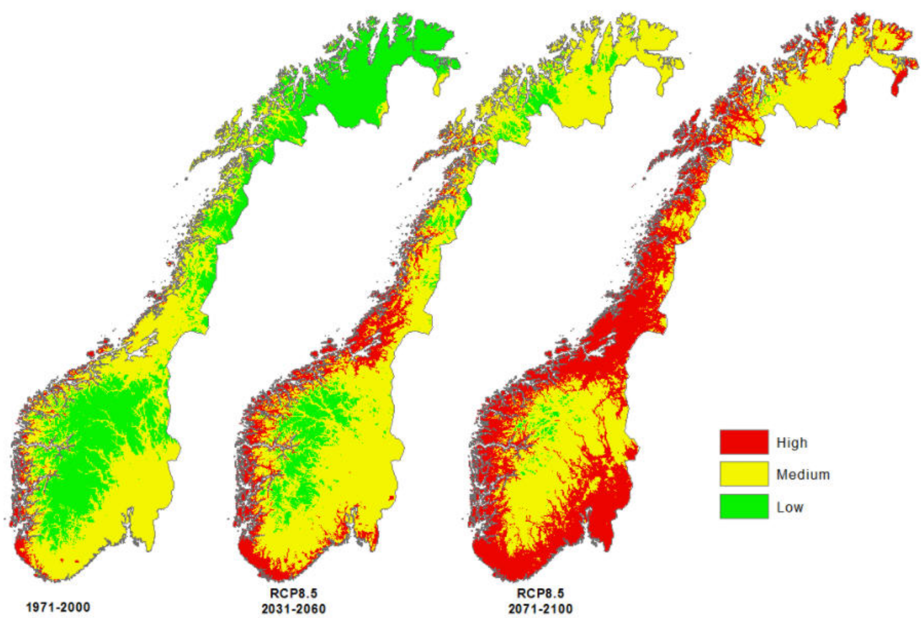

Figure 2: Historic and predicted risk of wood decay in Norway [18].

Today, approximately 615,000 buildings are located within regions of Norway where the risk of wood decay is considered high [7]. In 2100, it is estimated that this number could rise to as many as 2,4 million buildings [7]).

When comparing the predicted risk of wood decay in figure 2 with the location of buildings seen in figure 1, the importance of constructing robust buildings that can withstand both the climate of today and the predicted climate of the future, becomes visible.

2.2.1 Structural challenges

Climate stresses, such as rain, snow, wind and temperature changes, demands that the building's climate shield must be robust enough to minimize the wear and tear this entails. The importance of ensuring that the climate in general, as well as the the local climate, is taken into account when designing and building, is shown in figure 8 on page 28 that shows the proportions of damages on residential buildings in Norway, where a significant amount of damages that occur are due to rain. This requires knowledge of the correct use of exterior materials, the correct execution of installation of these materials, and the correct execution of sealing in transitions and around openings for, among other things, windows and doors.

Increase in both temperature and the intensity of the rain falls [7] can result in better growth conditions for mold and rot fungi [19], with the intense rainfalls in combination with extreme wind loads in exposed areas also leading to challenges due to torrential rain [7]. This will require increasingly more of the buildings climate shield.

3 Theory

3.1 Mechanics of moisture

3.1.1 Airs water content and dew point

Air consists of a mixture of gases, of which water vapor (H_2O) make up a small part of. At higher temperatures, the kinetic energy in the water molecules increase, resulting in the molecules breaking the bonds to one another, allowing the water to stay in vapor form. When the air is cooled, the kinetic energy of the water molecules is reduced, making it possible for them bond again, releasing condensation into the air. The temperature at which the condensation occurs is called the dew point [20].

At a given temperature, the air can hold on to a certain amount of water vapor. When this amount is reached, the air is said to be saturated and it's relative humidity (RH) = 100 % [20]. Given a constant amount of water vapor in the air: By increasing the temperature of the air, the RH decreases (the air can 'hold on' to more water), and by cooling the air, its RH increases (the air's potential to hold on to water decreases).

Table 1: Water vapors steam pressure and density at saturation point at different temperatures [20].

Metn.trykk = Saturation Pressure, Fuktinnh. = Moisture Saturation Point

Temp. (°C)	Metn.trykk (N/m²)	Fuktinnh. (g/m³)	Tem. (°C)	Metn.trykk (N/m²)	Fuktinnh. (g/m³)	Temp. (°C)	Metn.trykk (N/m²)	Fuktinnh. (g/m³)
30	4245	30,36	10	1228	9,40	-10	260	2,14
29	4005	28,78	9	1147	8,83	-11	238	1,97
28	3780	27,24	8	1072	8,28	-12	225	1,81
27	3565	25,80	7	1001	7,76	-13	199	1,66
26	3360	24,40	6	935	7,27	-14	181	1,52
25	3170	23,04	5	872	6,80	-15	166	1,39
24	2985	21,80	4	813	6,37	-16	151	1,27
23	2815	20,60	3	757	5,96	-17	137	1,16
22	2640	19,45	2	705	5,57	-18	125	1,06
21	2485	18,35	1	656	5,20	-19	114	0,97
20	2335	17,29	0	611	4,84	-20	104	0,88
19	2195	16,33	-1	563	4,48	-21	94	0,80
18	2060	15,40	-2	517	4,13	-22	85	0,73
17	1935	14,50	-3	475	3,82	-23	78	0,67
16	1818	13,65	-4	437	3,52	-24	71	0,61
15	1703	12,82	-5	402	3,24	-25	64	0,55
14	1596	12,09	-6	368	2,99	-26	58	0,50
13	1496	11,37	-7	338	2,75	-27	52	0,46
12	1400	10,68	-8	310	2,53	-28	47	0,41
11	1311	10,03	-9	284	2,33	-29	42	0,38
						-30	37	0,34

Table 1 shows the moisture saturation point in g/m^3 of air at a given temperature. We can see that the air's capacity to keep water in vapor form drops significantly when the temperature decreases, with the saturation point dropping approximately by half for every 10 °C decrease in temperature. Simply put: Air with a temperature of 20 °C has the capacity to hold on to approximately twice as much moisture before reaching the saturation point, compared to air with a temperature of 10 °C.

3.1.2 Diffusion

Moisture in vapor form can transport through materials by diffusion. This is when the water vapor transfers from areas with high concentration of vapor, to areas with lower concentrations [20], where the concentration is the amount of vapor per volume unit of the substance (material or air). Within a building, this will normally lead to moisture moving towards the outside of the construction.

The amount of water vapor actually being transferred through the construction via diffusion, is dependant on which materials the layers of the construction consists of. A material's ability to lead this water vapor diffusion is called water vapor permeability [20].

3.1.3 Convection

Convection is when the difference in air pressure causes the air to move and/or circulate [20]. When air is heated, its pressure increases, forcing it towards areas where the air pressure is lower. Since the heated air also becomes lighter [21], it rises upwards. This leaves the roof of the building particularly exposed to convection-related damages.

3.1.4 Capillary suction

Capillary suction is when the pores of a material sucks and transports moisture, with a smaller radius of pores creating the greater suction effect [22]. This happens when RH $> 98\%$, which is usually when the material is in contact with water [22]. Capillary suction can continue until the capillary saturation point of the pores is reached.

3.1.5 Vapor pressure

The air has a potential to hold on to a certain amount of water in vapor form. As the amount of water vapor in the air increases, the vapor pressure of the air also increases, until the air's saturation point is reached [20]. This saturation point is dependant on the air's temperature. The higher the temperature of the air, the larger its potential to hold on to water vapor before saturation point is reached.

3.1.6 Examples with calculation

Note: All examples are simplified calculations of theoretical scenarios, meant to provide an idea of how temperature and RH affect each other. In reality, a number of factors come in to play, such as the rooms ventilation and the temperature of surrounding rooms, to mention a few.

Using the table shown in table 1 on page 10, we can calculate the amount of water being released per m^3 of air when the temperature decreases enough to reach RH = 100 %.

Example 1
Considering a starting temperature of 20 °C and RH = 40 %:

$$\textit{Saturation point} = \textit{17,3 } g/m^3$$
$$\textit{Vapor content at } 20\,^{\circ}\mathrm{C} = \textit{17,3 } g/m^3 * \textit{40 \%} = \textit{6,92 } g/m^3$$

Here we can see that when the temperature drops to just above 5 °C (Saturation point of 6,8 g/m^3), dew point is reached.

Example 2
If temperature continues to drop to 0 °C, the airs saturation point is approximately 4,85 g/m^3.

$$\textit{6,92 } g/m^3 - \textit{4,85 } g/m^3 = \textit{2,07 } g/m^3$$

When reaching this temperature, the air now releases 2,07 grams of water per m^3.

Example 1 and 2 could be a likely scenario during winter or autumn, when we might choose not to heat a room at night to save energy.

Example 3
We can also calculate at what percentage of RH at room temperature the dew point will occur on a surface with a given temperature. Given a room temperature of 20 °C and a surface temperature of 8 °C at a certain point:

$$\textit{Saturation point at } 20\,^{\circ}\mathrm{C} = \textit{17,3 } g/m^3$$
$$\textit{Saturation point at } 8\,^{\circ}\mathrm{C} = \textit{8,27 } g/m^3$$

$$\frac{8,27 g/m^3}{17,3 g/m^3} * \textit{100 \%} = \textit{47,8 \%}$$

At given room temperature of 20 °C, dew point at surface point where the temperature is 8 °C is reached when the rooms RH reaches 47,8 %.

Example 4

Using the same scenario as in example 3, and knowing that mold starts to develop at RH => 80 % [19], we can calculate when mold will start to develop at the given surface point with a temperature of 8 °C and saturation point of 8,27 g/m^3:

$$80\ \%\ *\ 8{,}27\ g/m^3\ =\ 6{,}6\ g/m^3$$

This means that when the vapor content of the room's air reaches 6,6 g/m^3, mold potentially starts to develop at the given surface point with a temperature of 8 °C. This happens when the RH of the room's air reaches 38,2 %, as shown in the calculation below.

$$80\ \%\ *\ 100\ \%\ =\ 38{,}2\ \%$$

3.2 Transportation of moisture in materials

Any type of material has a certain ability to allow water vapor to pass through it. This is referred to as the material's water vapor permeability, and is expressed as δ_p, and has unit $g/mhPa$ [20].

When divided by the thickness of the layer of the material, we get the layers water vapor permeance [20]:

$$\frac{\delta_p}{d} = W_p = \textit{water vapor permeance of layer, with unit } g/m^2hPa$$

where

$$\delta_p = \textit{water vapor permeability of material } (g/mhPa)$$
$$d = \textit{thickness of material layer in meters } (m)$$

where *"water vapor permeance is a special coefficient of the vapor conductivity for a defined material layer of a certain thickness, while permeability is a general material coefficient." [20]*

To find the amount of water vapor transported through a given material layer, we multiply the water vapor permeance of the layer with the difference in vapor pressure between the two sides of the material [20]. So,

$$\frac{\delta_p}{d}\ *\ (P_1 - P_2) = W_p\ *\ \Delta P\ =\ G$$

where

$$P_1\ \&\ P_2 = \textit{vapor pressure on different sides of material layer } (Pa)$$
$$\Delta P = \textit{the difference in vapor pressure between the two sides of the material}$$
$$G = \textit{amount of water vapor transported through the layer}$$

giving us a final expression in g/m^2h, which gives us the amount of water in grams passing through each square meter of the material per hour.

δ_p for a material might vary due to different factors, such as the material's moisture content and internal variations in the material [23]. It is therefore useful to refer to what is called a "normal value", a frequently occurring value within a reference area (an area covering lowest value through highest value measured when testing the materials vapor permeability) when measuring a material's δ_p, when calculating water vapor transportation through a material [20].

Furthermore, a material's water vapor resistance can be found by finding the inverse of the material's water vapor permeance [20], giving;

$$\frac{1}{\frac{\delta_p}{d}} = \frac{1}{W_p} = Z_p$$

where Z_p is the water vapor resistance of the material. This is especially useful when calculating water vapor transportation through a construction consisting of several layers of materials, each with different thickness and water vapor handling abilities.

3.2.1 Example with calculation

Given mineral wool insulation, which has a δ_p = 0,00054 $g/mhPa$ [20], of thickness 198 mm, and a difference in vapor pressure between the two sides of the insulation of ΔP = 200 Pa:

$$G = 0,00054 \ \frac{g}{m * h * Pa} \ * \frac{1}{0,198m} \ * \mathit{200\ Pa}$$

$$= \mathit{0{,}5454} \ \frac{g}{m^2 * h}$$

results in a total of 0,5454 grams of water vapor transporting through each m^2 of the insulation every hour.

3.3 Transportation of moisture in constructions

Moisture can occur in or be transported into and through a construction in several ways:

- Diffusion
- Convection
- Capillary action
- Built-in moisture

- Water leakage (from exterior sources or water pipes within the building)

Considering an exterior wall: within the building, the water vapor content and the temperature is normally higher than on the outside. This is especially true during winter, when there are large differences between the temperatures inside and outside the wall. Comparing the water vapor content with an inside temperature of 20 °C and an RH of 30 % versus an outside temperature of −10 °C and an RH of 90 %, the water vapor content of the inside air is greater than the saturation point of the outside air, with 5.26 g/m^3 and 2.13 g/m^3 respectively. In this scenario, if the vapor barrier is not sufficiently air tight, water vapor from the warm inside air will be transported into the construction through diffusion. At a given point within the wall where the temperature is significantly lower, the water vapor starts to condense, increasing the risk of the formation of mold.

Also, if the wall is not sufficiently air tight, air within the insulation will start to circulate by forced convection. The warmer air found closest to the warm side of the wall rises within the construction, effectively forcing it towards the much colder wind barrier when reaching the top of the wall.

Figure 3: Mold on the inside of roof sarking in cold loft [24].

Figure 3 shows the development of mold, likely caused by a lack of vapor barrier in the joists between the loft and the floor below.

Furthermore, areas within the construction where the insulation is not sufficient, either due to poor craftsmanship or otherwise, can result in surface areas of the interior of the wall with significantly lower temperatures than other areas. This could lead to water vapor condensing on said surfaces, and also increasing the risk of mold. It is worth noticing that this can occur on the backside of the material used as a wall surface, leaving the damage hard to discover.

A similar issue can occur with thermal bridges, especially if the surface of thermal bridge is significantly colder than the air it is being exposed to. The thermal bridges can have the same effect on the surfaces as the lack of insulation, but even with otherwise sufficient insulation surrounding the thermal bridge. The surface of the thermal bridge itself could be cold enough to cause condensation within the wall. This is especially a potential problem when the material of the thermal bridge has a high thermal conductivity - the materials ability to conduct heat - such as steel or concrete. Compared to wood-frames (lower ability to conduct heat), where the studs and sills often cover the entire width of the wall, a material such as steel require that it is insulated sufficiently from the colder side of the wall to prevent or reduce the material's surface from cooling.

Figure 4: Mold and fungus appearing on interior wall found behind furniture [25].

Figure 4 shows the development of mold on the surface of an interior wall. A likely cause is the surface of the wall being significantly colder than the room temperature, due to lack of or poor insulation. The furniture prevents the surface area of the wall to heat, resulting in a cold surface being exposed to the warm inside airs vapor content.

Through capillary suction, materials can soak up water. This can happen when the RH of the surrounding air or material is above 98 % , which usually occurs when the material is in direct contact with water [22]. The pores of the material fill with water, with narrower pores causing more suction than wider pores [22]. Therefore, to prevent capillary suction in the different materials of a construction, it is necessary to use a material with either much wider pores as a membrane layer, or a membrane that is waterproof. A typical example of this is the sill membrane used to separate the wood sill from the concrete foundation, as concrete can transport water from the ground via capillary suction [20], potentially exposing the bottom sill to water.

Figure 5: Decaying bottom sill caused by capillary suction [26].

Figure 5 shows how a lack of sill membrane allows the material to absorb moisture from the floor.

Due to the presence of water in air regardless of temperature, moisture within the wall will occur to some degree. How much, will generally vary with different seasons and temperatures. As the temperatures and subsequent RH of the outside air drops, the moisture within the wall "pushes" towards the wind barrier. By using a vapor open wind barrier, the moisture within the wall is more easily transported away from the wall.

3.3.1 Example with calculation

To calculate the amount of water vapor being transported through a construction, we first need to summarize the water vapor resistance of all the individual layers of material of the construction [20].

Table 2: Material layers of exterior wall.

Material	Thickness (d) in mm	δ_p	$\frac{\delta_p}{d} = W_p$	$\frac{1}{W_p} = Z_p$
Chipboard	12	0,000027	0,00225	444
Mineral wool	48	0.00054	0.01125	89
Vapor barrier	0,15		0,00001	100 000
Mineral wool	148	0.00054	0.00365	274
Asphalt imp. board	12	0.00001728	0.00144	694
Wind barrier				36
Total				**101 537**

Table 2 shows materials used in an exterior wall following modern recommendations and requirements [27], from inside and outwards, with their respectable water vapor abilities. For both the vapor barrier and the wind barrier, the Z_p value is given in the material documents. δ_p is the normalized value for the material.

Table 3: Water vapor values of air at given temperatures on both sides of exterior wall.

	Temperature	RH	Pa
Inside	20 °C	35 %	818
Outside	−10 °C	90 %	234
ΔP			**584**

If the exterior wall from table 2 is subjected to the values found in table 3, we can calculate the amount of water vapor transporting through the entire construction using the following formula:

$$G = \frac{\Delta P}{Z_p}$$

which gives us

$$G = \frac{584}{101537} = \mathit{0.00575}\ g/m^2 h$$

This means that 0.00575 grams of water vapor will transport through each m^2 of the wall every hour.

We can also see that by removing the vapor barrier, our Z_p decreases dramatically, while G increases [20]:

$$G = \frac{584}{(101537 - 100000)} = \mathit{0.38}\ g/m^2 h$$

By excluding the vapor barrier, the amount of water vapor being transported through the wall is now 0.38 g/m^2h; an increase of more than 60 times the amount when including the vapor barrier.

3.4 Construction

3.4.1 Roof

The roof is the part of the building that is most exposed to climate most of the year. In addition, it is the part of the structure that is most exposed to condensation damage, in that warm indoor air rises upwards and can find its way into the roof structure through leaks. Due to the large amount of insulation required (in the region of 350 mm) to fulfill the U-value requirements of the roof or the building as a whole [28], the outer parts of the construction will be significantly colder than the inside air on average. These are important factors to take into account when designing and building a roof structure to prevent potential future moisture problems.

According to SINTEF, roofs can be divided into three main types based on the structure [29]:

- **Compact roof**. The structure consists of one or more layers that lie close together, where the insulation is usually installed on the upper side of the construction.
- **Roof with insulated surfaces and ventilated roofing.** The most common solution in modern residential buildings. Here, the insulation is installed between the roof barriers or trusses, and an air gap is created between the insulation and the underlayment. This means that moisture will largely be transported away from the roof. An alternative solution is to install a combined underlayment and wind barrier. Such a solution removes the need for an air gap [29].
- **Roof with cold attic.** The insulation is installed between the attics floor beams, which makes the attic room cold. Such roofs can be ventilated in two ways: By ventilating the entire attic space with outdoor air that flows in via air gaps along the eaves and via valves in the gable, or by the attic being sealed and the ventilation taking place between the wind barrier and the roof covering.

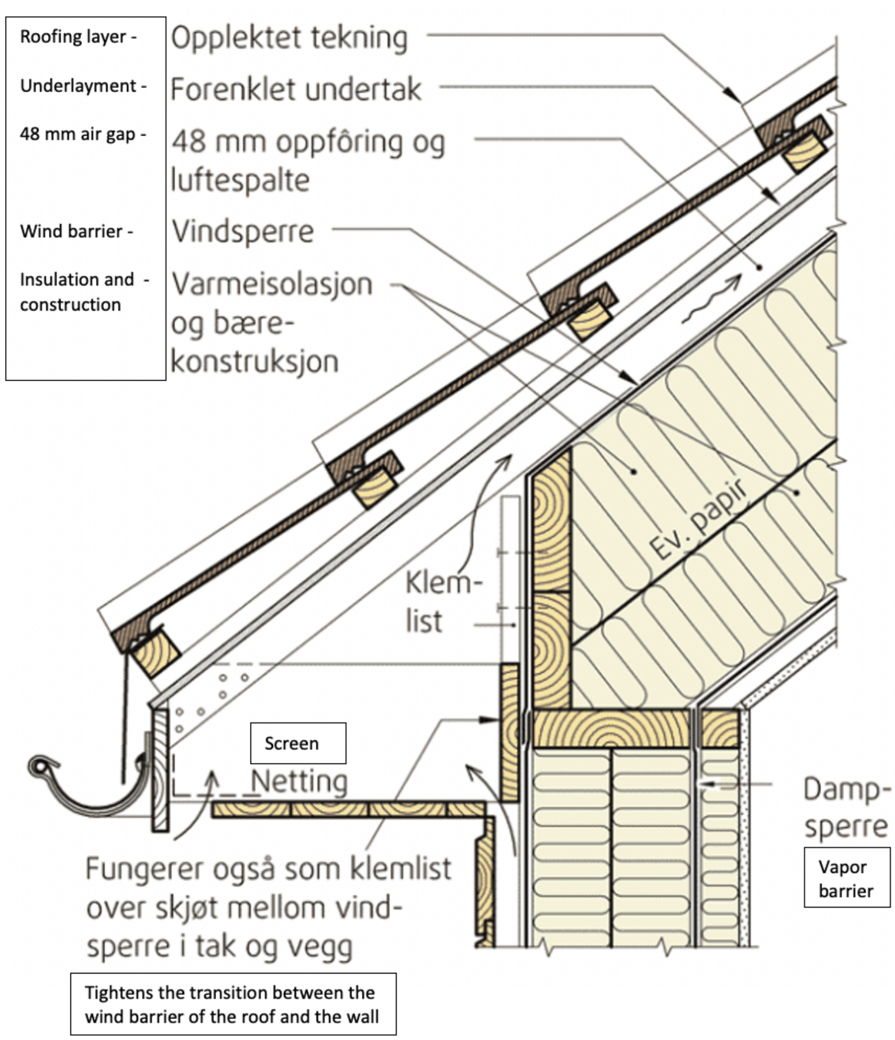

Figure 6: Example of roof with insulated surfaces and ventilated roofing [29].

3.4.2 Exterior wall

The exterior wall, like the roof, is exposed to great stresses from the climate, where heavy rain in combination with wind can cause water and moisture to penetrate the wall. In order to obtain adequate protection of the wall, it is therefore most often built with what is called a two-stage seal [27]. This consists of a separate exterior climate shield, such as wood cladding, and a wind barrier, where these layers are separated by an air gap. The air gap drains out and dries moisture that may find its way through the climate shield, in addition to moisture that may arise inside the structure itself being transported away from the wall.

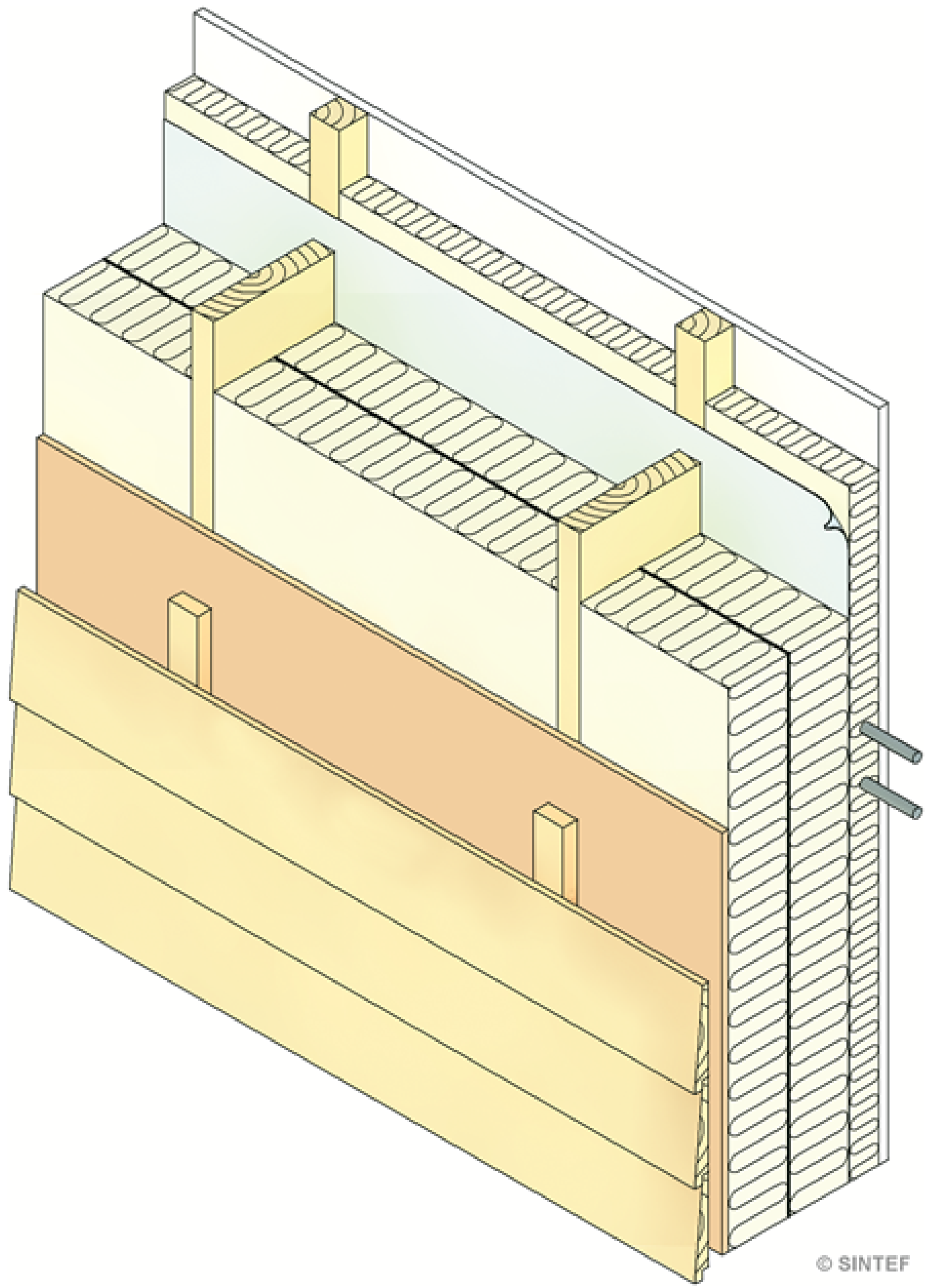

Figure 7: Construction of traditional exterior wall with two-stage seal [27].

3.4.3 Cladding

The wall's exterior layer provides protection from weather and climate, and perhaps especially torrential rain. The most common cladding used for this purpose on dwellings in Norway is wooden cladding. Brick cladding and concrete are also used frequently, but this type of cladding is mostly used on larger buildings.

3.4.4 Wind barrier

The purpose of the wind barrier is to prevent circulation of air within the insulation, which would reduce it's insulation capacity, as well as protecting both the insulation and the timber framing from weather during the building of the construction. It also prevents moisture that has found its way into the air gap behind the cladding from reaching inside the wall and potentially causing damages.

Since there is always a risk of some moisture naturally occurring within the wall, it is important that the wind barrier is as vapor open as possible so that moisture within the wall can transfer more easily towards the outside air. The maximum recommended vapor resistance, s_d, of the wind barrier is 0,5 [27].

The most common wind barriers are boards, like asphalt impregnated and plaster boards, and wind barrier paper rolls. The latter leaves very few joints on the building's wind barrier, and is often installed over wind barrier boards giving a double wind barrier. In these cases, it is important to make sure that the combined vapor resistance of the two layers of wind barrier is not higher than the maximum recommended 0,5 s_d [27], in order to allow moisture from within the construction to be transported out of the wall.

3.4.5 Insulation

There are different types of insulation being used in Norwegian dwellings. Most common is the mineral wool, which is made from melted sand, rock or glass. It is most commonly used due to it's light weight and easy installation. Layers of mineral wool thick enough to satisfy the requirements in modern buildings, however, require the installation of a vapor barrier [27], as they are incapable of absorbing moisture, which over time could cause consequential damage to the surrounding materials.

Other types of insulation, such as cellulose insulation and wood fiber insulation, are also used, though not as frequently as mineral wool. The main benefits of these types of insulation is their capacity to absorb moisture, reducing the risk of moisture related damages to surrounding materials [30].

Also, the increasing thickness of required insulation in residential buildings over the years means that the construction consist of more wood, increasing the time it takes to dry the construction [31].

3.4.6 Thermal bridges

A thermal bridge is defined as *"an area with increased loss of heat in the connection between two or more building parts. At least one of the building parts are included in the climate shield and separates the buildings inner climate against outer climate."* [32]

Thermal bridges can have low surface temperatures depending on where they occur, increasing the risk of condensation and the development of mold near areas where the temperature of the air and its RH is higher. In worst case scenarios this leads to the formation of mold, which can result in significant damages within the wall structure.

3.4.7 Vapor barrier

In calculating the water vapor diffusion through the exterior wall in table 2 page 16, the importance of the vapor barrier becomes clear. Without the drop in vapor pressure caused by the vapor barrier, the potential of moisture damages within the construction increases dramatically.

The minimum recommended vapor resistance of the vapor barrier is $s_d =$ 10m [23], but it is common to use polyethylene film of 0,15 mm with a vapor resistance many times this [33] as a vapor barrier. This is due to a thicker vapor barrier being far more robust and not as prone to damages during installation.

In addition to a traditional vapor barrier which holds a constant vapor resistance, vapor barriers with an adaptable vapor resistance also exists. In certain circumstances, typically when the RH of the surroundings exceed 70 % [16], these vapor barriers become more or less vapor open, enabling moisture from within the construction to transfer into the building.

Another option is what is referred to as a vapor break. Considering that a traditional vapor barrier has a vapor resistance that exceeds the minimum recommendations by a large degree, a vapor break has a much lower vapor resistance [33]. The idea is that this will allow the construction to dry in both directions [16], but tests show that this has little to no impact on the amount of time it takes for the wall to dry, compared to a traditional solution [33].

When installing the vapor barrier, it is important to make sure the joints are sufficiently air tight by using aging-resisting tape to prevent convection and diffusion [27]. In addition, the vapor barrier should be installed before the building is heated [27] to prevent warm air with higher RH to transport through the construction, as well as making sure the construction is dry enough (¡ 20 weight percentage) before installation [27].

To prevent penetrations due to technical installations within the construction, the vapor barrier can be recessed into the wall, leaving space for the installations between the vapor barrier and the inner surface of the wall. However, as a general rule, at least 3/4 of the insulation should be installed on the colder side of the vapor barrier [16], in order to prevent the surface of the vapor barrier reaching temperatures low enough to cause condensation or mold.

3.4.8 Rehabilitation and post-insulation

Older homes are usually poorly insulated or not insulated at all, which may make it desirable to re-insulate the building. In such cases, it is important to consider what such measures will mean for the building as a whole, so that future problems with moisture are not created. Buildings that were built without insulation have a natural ventilation through all the building's surfaces, which means that there are often few or no additional air gaps in these constructions, as this was deemed unnecessary. An uninsulated wall will also be warmer on the outside due to heat leakage from the inside, which means that problems with moisture resulting from condensation will rarely occur. When re-insulating such a building, the natural ventilation in the building will potentially be sealed, also causing the temperature at the exterior of the construction to be lowered significantly. This can lead to problems with condensation damage if not done properly. With such measures, it is therefore important to ensure that it is carried out so that moisture and condensation do not occur, by getting a good overview of how the building is built.

Re-insulation of exterior walls
Common ways to re-insulate exterior walls, are:

- **Blown-in insulation**. This is done by blowing insulation into the exterior wall, either from the inside or the outside. A big advantage of this is that it avoids costs such as new cladding and new surfaces on the inside. On the outside, however, the construction and cladding become colder and more humid, which makes it important to make sure the air gap and ventilation behind the cladding is sufficient [34].

- **Re-insulation on the outside**. In this scenario, the desired amount of insulation is added on the outside of the existing construction. This can be a favorable solution both in terms of moisture safety and insulation effect, as it virtually eliminates thermal bridges, and reduces the risk of moisture damage since the construction becomes warmer and drier [34]. It is recommended to remove the cladding before re-insulating the outside, as any air gap behind the cladding will add cold air to the construction and reduce the insulation effect [34]

- **Re-insulation inside**. An alternative may be to re-insulate from the inside, where, as with external re-insulation, the desired amount of insulation is added on the inside of the existing construction. However, such a solution means that the construction itself becomes colder and more humid, which makes it less moisture-proof [34].

- **Insulation of the structure**. If the wall is to be opened in any case, either internally or externally, in connection with the replacement of cladding or internal surfaces, it is easy to insulate the construction at the same time. This can also be combined with re-insulation inside or outside as mentioned above, to achieve a higher insulation effect.

Regardless of which solution is chosen, it is important to get a good overview of the construction of the wall. By insulating the exterior wall, the air circulation and the naturally occurring ventilation of the building, will change. Some of the solutions when re-insulating also provide a colder exterior construction, and this results in the construction and cladding becoming more moist [34]. In such cases, it is important to make sure that there is sufficient ventilation on the outside to transport away the moisture that occurs. Exterior wind barriers must also be sufficiently installed to prevent air circulating in the construction, as well as the wind barrier installed having as low of a vapor resistance as possible [34]. One should also consider whether the measures require additional ventilation in the building, as an increased amount of insulation results in a denser building. Insulated exterior walls should in principle have a vapor barrier [35], but experience indicates that it is possible to re-insulate older exterior walls without installing a new vapor barrier [34].

Re-insulation of roof

Re-insulation of roof structures can, as with re-insulation of external walls, be carried out in several ways:

- **Re-insulation on the outside**. Here, either all or most of the insulation is installed above the roof construction. This makes the construction warmer and drier, which in turn provides higher moisture safety. Older roofs often have vapor-tight roof underlayment [36], and this can therefore act as a vapor barrier. Such a solution makes it easier to get the roof sufficiently windproof. If roof underlayment and sarking is removed, insulation can be installed between the rafters from the outside. It is then important that the new sarking and/or underlayment is as vapor-open as possible, preferably by using a combined underlayment and wind barrier [36].
- **Re-insulation inside**. Perhaps the most common solution for post-insulation of roofs is to install the insulation from the inside. In such cases, it is important to ensure that there is sufficient ventilation between the insulation and the sarking, by establishing an air gap of at least 48 mm [36]. Installing insulation from the inside makes it possible to install a new vapor barrier over the entire ceiling surface, which will prevent warm, humid air from being transported out into the construction, which will now be colder due to the insulation.
- **Blown-in insulation**. Older homes often have wood-paneled sarking, which can be both beneficial and economical to preserve. As with post-insulation of the exterior wall, the roof can therefore also be insulated by blowing insulation into the construction. It is then important that existing sarking and/or underlayment are not vapor-tight, and if not, that they are replaced with a vapor-open product [36].

Re-insulation of roofs is one of the measures that can potentially create the greatest challenges with moisture if it is not carried out correctly. A colder outer part of the construction makes this area more vulnerable to air leaks from the inside, and insufficient insulation and ventilation, as well as a leaky vapor barrier, can therefore have major consequences over time.

4 Methodology

The thesis issue can be evaluated with the help of different research methods. This chapter will address the methods that are used and explain why these are chosen, and also briefly compare used methods to alternative methods.

4.1 Qualitative and quantitative methods

A research is based mostly on two types of data: qualitative and quantitative.

Qualitative method consists of gathering and analyzing qualitative data, which usually come in the form of text [37]. This can be interviews, participating observation, content analysis or case studies [37]. This method is most suitable when in-depth knowledge is wanted within a specific subject or category, and is based on a large amount of data on a single issue [37].

For research that includes several subjects, quantitative method is largely the preferred method [38]. Here the research is based on limited amounts of data on each subject, where one acquires an overview of the more general conditions within an issue [38].

In this thesis qualitative method is mainly used, since it is desirable to achieve in-depth knowledge on the issue through case studies and content analysis. However, quantitative method has been used in order to gain an overview of the scope of the thesis issue, before narrowing the focus of the research.

4.2 Research gathering

To assess the thesis issue, the following have been conducted:

- Literature review
- Review of existing data
- Case studies

4.2.1 Literature review

There is a large amount of literature available on the subject of challenges with moisture in residential buildings. In order to understand what causes these challenges and what the consequences are, the author has read available literature and news articles containing expert opinions on climate challenges, climate changes, the influence of craftsmanship on the issue, and the overall opinion of the scope of moisture damages.

To assess the challenges and damages related to moisture in residential buildings, the author has read publications and recommendations from SINTEF, which is considered the leading authority on the subject area and one of Europe's largest independent research organisations. In addition, mechanics of moisture has been studied to understand the physics that relates to the challenges and damages found during the research.

4.2.2 Review of existing data

Data showing the scope and development of challenges with moisture in residential buildings has been reviewed, in order to understand the scope of the issue, as well as how the issue has changed and developed over time. In doing so, public statistics and statistics published by authorities on current areas, has been reviewed.

4.2.3 Case studies

Case studies have been performed in order to illuminate some of the challenges and issues regarding moisture in residential buildings, with the mentioned case studies being assessed using theory and reviewed material found during the research.

5 Moisture in buildings

In 2015 the Norwegian national institute for public health, Folkehelseinstituttet (FHI), conducted a study aimed to map the scope of moisture related problems within the Norwegian residential building stock [3]. This study revealed that close to one third of the building stock had one or more issues related to moisture, with the majority of these occuring in basements, foundation/drainage, bathrooms and undecorated attics.

The study also showed that the amount of residential buildings experiencing moisture related problems drops consistently when the building is built post-1980s, with the period of 2010 - 2015 by far representing the lowest amount of buildings experiencing these problems. This could be due to several reasons:

- It takes time for moisture related problems to become visible and measurable, hence the newer buildings have not yet developed significant enough signs of moisture problems.
- More moisture robust buildings are built due to an increased focus on the problems with moisture over the last few decades.
- Stricter requirements regarding drainage surrounding the foundation of the building (especially affects the numbers related to moisture problems in basements).

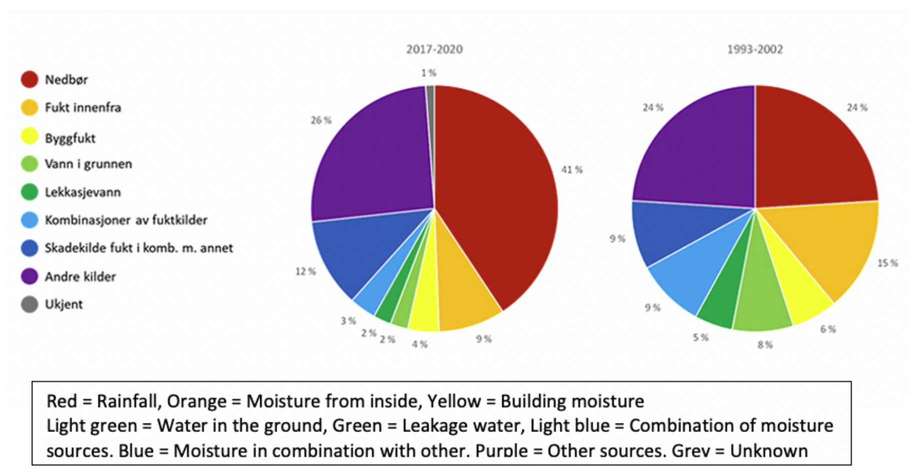

Figure 8: The distribution of damages on buildings from the periods 1993 - 2002 and 2017 - 2020 [5].

Figure 8 show a stable proportion of damages caused by moisture when comparing the periods of 1993 - 2002 and 2017 - 2020, while the most significant change being the near doubling of damages caused by rainfall (red colour in the figure).

5.1 Requirements

In the Norwegian technical regulations, TEK17, there are several requirements related to moisture in buildings [15]. The general requirements found in paragraph 13-9, are:

- Water and moisture should not be able to enter the construction potentially causing moisture damages.
- The building should be projected and constructed in such a way that rainfall, snow and ice do not lead to damages on the building.
- Necessary measures are to be made in order to divert flowing water away from the foundations of the building.
- The building should be projected in such a way that problems with moisture due to water vapor from the inside air does not occur.
- Materials should be dry enough when closing the construction so that the formation of fungus and the decomposing of the materials do not occur. The requirements are a maximum value of 20 weight percent of moisture in wood [15], with a maximum value of 15 weight percent if the construction has a low ability to dehydrate [15].
- Wet rooms are to be constructed in such a way that damages due to water related to the use of the room do not occur.

In addition, the recommended RH values of the inside air is between 20 % and 50 % [39]. These values are mostly health and comfort related, but an RH of above 60 % should be avoided due to the possible formation of fungus if this air reaches colder surfaces [40].

Furthermore, it is required that the moisture content of the wood frame is $< 20\%$ weight percentage before closing the construction [41], as well as any other material within the construction being sufficiently dry [41].

"The moisture content of timber is given as a percentage of the total weight of the material in dry condition:

$$u = \frac{(m_v - m_0)}{m_0} \times 100\%$$

where

$$u = \textit{moisture content in percentage of dry weight}$$
$$m_v = \textit{the mass (water and timber) at given moisture content}$$
$$m_0 = \textit{the mass of dry timber"}$$ [41]

5.2 Common challenges and damages

When comparing the periods of 1993 - 2002 and 2017 - 2020, the proportion of damages caused by moisture is the same at approximately 75 % [5]. However, from figure 8 on page 28, we see that the number of damages caused by rainfall have nearly doubled, from 24 % in 1993 - 2002 to 41 % in 2017 - 2020. Other damages caused by moisture have been reduced, with damages caused by moisture from within the building dropping from 15 % in 1993 - 2002 to 9 % in 2017 - 2020, a drop of 40 %. Building moisture - the moisture left over in the buildings materials from the building process - have also dropped from 6 % to 4 %, a reduction of 33 %.

These numbers suggest that an increased focus on moisture and moisture transportation within buildings [42] have been successful, with the raised requirements regarding the buildings air tightness effectively forcing a more thorough assembly of the vapor barrier and the wind proofing.

However, the significant increase in damages caused by rainfall indicates how challenging the Norwegian climate is when it comes to designing and constructing buildings.

5.2.1 Indicators of moisture damages

There are several indicators of moisture related problems or damages within a building. Among the most common are:

- **High humidity**. RH values considerably higher than the recommended values of 20 - 50 % could indicate [39], in addition to there being a possible problem related to the buildings ventilation, a not yet visible problem such as for example a water leakage inside the construction of the building.
- **Condensation**. Condensation occurring on the buildings surfaces could be due to high humidity [22], lack of/unsatisfying insulation within the construction, or thermal bridges, among others.
- **Mold, black fungus and/or the smell of mold**. This indicates good growth conditions for mentioned fungi, which implies an RH of around 80 % [22] over longer periods of time. This is achievable on surfaces without a noticeable high humidity elsewhere in the building, as the surface could be colder in certain areas due to insufficient insulation, thermal bridges etc. The smell of mold [43] without a visible indicators indicates that there is mold hidden within the construction.
- **Damp spots**. Spots on surfaces [43]. This is often where mold and black fungus start to grow.
- **Measurable moisture within the construction** [44]. Often related to bathrooms, where it takes longer for the damages to become visible due to more moisture robust surface material, such as for example tiles. This can be measured with a moisture meter [44].

- **Uneven or "soft" floors** [43]. This is especially true in older buildings where wooden floors often are built directly on top of concrete floors. With insufficient vapor barriers beneath and/or above the concrete floor, the concrete will transport moisture from the ground and upwards by capillary suction, exposing the wooden floor to water. When "soft" floors are detected elsewhere in the building, this might indicate a water leakage either from water pipes or from external water finding its way inside the building.

5.2.2 Cause

As seen in figure 8 on page 28, rainfall is a considerable cause of moisture related damages in buildings. With heavy rainfall in combination with heavy winds, water potentially forces its way inside the construction. This mostly happens in and around transitions between different materials and building parts [1]:

- Between different layers on the roof. Examples are in and around the chimney, between metal barges and roof tiles, along the ridge of the roof, in and around the gutters, or through open areas where roof tiles, barges etc. are missing.
- Around windows and doors. Water is potentially forced between the trim and the cladding, window or door.
- Roof to wall intersections. The wind is forcing the rain vertically, resulting in the construction being exposed to water.
- Heavy wind damaging the climate shield of the building, exposing areas to rainfall.

Choice of materials and the projected solution also has a certain impact on how moisture robust the building is. With untreated cladding, the outer layers of the building are being exposed to higher moisture content [45]. This could lead to more ideal growth conditions for fungus and the decomposing of materials if the moisture is not sufficiently transported away from the construction via the air gap behind the cladding. Furthermore, shorter (or the lack of) eaves, will increase the buildings exposure to rainfall.

Within the building, human activities contribute to the amount of moisture in the air [22]. Cooking, showering, laundry and breathing can represent several liters of water added to the inside air of the building every day. If this water is not sufficiently transported out of the building through ventilation, the air's RH will potentially be high enough to cause moisture related problems within the building.

5.2.3 How to improve

When moisture damages have occurred, it is important to improve both the damage itself and its underlying cause. Necessary improvements will be forced by the scope of the damage. If for example there are visible signs of significant moisture damages, like decaying or wet material, chances are that the damage goes beyond what is visible. In these cases, opening the construction to reveal the scope of the damage is likely necessary. How to improve such damages also depends on the scope of the damage, but:

- Decaying material should be replaced [43]
- Material with unsatisfying RH should be replaced [43], but in some cases it is possible to reach acceptable RH values by drying the material using a dehumidifier [31] [43]
- Fungus on surfaces can in most cases be removed by thoroughly cleaning the area [46]

Since damages and challenges due to moisture are indicators of a problem, it is equally important to look at what causes the damage, otherwise the damage might reoccur. Examples of how to improve the cause of the damages could be:

- If mold or fungus or other signs of high RH are visible, make sure moisture transportation out of the room is increased by installing ventilation [45]
- Making sure moisture can't penetrate the construction from the outside [45], by for example lack of drainage or damage to outside cladding or roof
- Making sure the construction is rebuilt following requirements to avoid condensation within the construction due to diffusion and convection

5.3 Owners rights

When purchasing a residential building in Norway, there are two main laws governing the agreement between buyer and seller; Bustadoppføringslova (The law of constructing of houses (AT)) [47] and Avhendingslova (The law of transfer (AT)) [48].

Bustadoppføringslova governs the *"agreement between entrepreneur and a consumer about the constructing of a new residential building."* [47] (AT)

This law goes into effect when the following criteria are met [47];

- the *"agreement on the constructing of a building for the purpose of housing, and the agreement on the work being done directly as part of such constructing"* (AT), and also
- the *"agreement on the right to real estate with housing when the work done by the entrepreneur, is yet to be finished on the agreement date."* (AT)

Avhendingslova governs *"the rights and duties between buyer and seller when transferring real estate by voluntarily sale"* (AT) between both professional and private person [48].

The parties involved in the agreement are more or less free to agree on any terms related to the disposing of the real estate, unless else is specified.

However, the law seeks to govern the rights of a private person being the buyer, with the law stating that when *"the buyer is a physical person who is not mainly buying as part of business, the law can in some cases not deviate to the harm of the consumer."* [48] (AT)

5.3.1 Right of complaint

According to both Bustadoppføringslova and Avhendingslova, *"a defect can not be made applicable later than five years after the takeover."* [47] [48](AT).

Furthermore, *"any defect should be made applicable within reasonable time after the consumer discovered or should have discovered the defect"*[47](AT) and *"as soon as possible."* [47] (AT)

However, it is possible for a defect to be made applicable after the initial five years have passed, if the entrepreneur or seller responsible *"has proceeded grossly negligently or in violation of heathens and otherwise good faith."* [49](AT)

Both laws also protect the buyer from hidden errors or defects. However, this is more common when buying used housings. What can be regarded as a hidden defect is referred to as a defect that *"the seller has to have known about our should have known about."* [47] (AT)

5.3.2 Who covers the costs

For moisture damages or defects covered by the "right of complaint"-law, where seller/entrepreneur are deemed liable for the damages, the latter will be required by law to cover the costs related to improving said damage or defect [48] [47].

For damages not covered by Avhendingslova or Bustadoppføringslova, the owners insurance company might cover the cost. To what degree the cost will be covered, and which type of damage the insurance covers, depends on the which level of insurance the owner has. Most of the well known insurance companies offer both a standard and an extended option as building insurance [50] [51] [52].

Damages due to water, for example heavy rain resulting in water finding its way into the building via the terrain or flood, and damages due to leaking and/or broken pipes within the house, are covered by most insurance companies in their standard policy [50] [51] [52].

However, for damages caused by leaky outer roofs, outer walls, wet rooms, and/or damages caused by or involving fungus or decay, the extended option is required [50] [51]. Several insurance companies offers this extended insurance through Norsk Hussoppforsikring (Norwegian House Fungus Insurance (AT)) [53], which is the only Norwegian insurance company specializing in insurance for rot damages and pests [54].

Common for insurances is that for the policy holder to have a claim for compensation, the event needs to be a "sudden event" [55].

This is by the Financial Complaint Boards defined as *"happening within a limited time frame"* (AT), and further that *"time frames surpassing one day, is not deemed a "sudden event."* [55] (AT)

In the chance of disagreement between the insurance company and the policyholder, the policyholder can bring the issue forward to and be assisted by the Financial Complaints Boards [55].

6 Case studies

Each of the following case studies are of buildings located in the western part of Norway, in the northern part of Rogaland county.

6.1 Case study A

Figure 9: Moisture damage in the roof construction.

6.1.1 General information

- Built in 2004
- Approximately 110 m^2
- Damage located in roof behind knee wall
- Damaged area approximately 9×3 meters (27 m^2)

The building is built with modern wood frame walls and a wooden roof construction with an external covering consisting of shingel. The shingel is laid directly on top of horizontally fixed wooden boards, which in turn have a ventilated air space of approximately 5 centimeters underneath that stretches along the vertical lengths of the roof construction. Between the roof beams, cardboard wind barriers are installed on top of the insulation. On the inside of the roof, wooden panel is installed directly on to the roof beams, with a plastic vapor barrier in-between the panel and the beam. Within the loft of the cabin, there are knee walls with a height of 50 centimeters. Behind the knee walls, there is an inaccessible attic along the length of the cabin. Directly beneath the knee wall, there is a bathroom and a washing room. The surfaces of both rooms consist of wooden panel.

6.1.2 Issue

Figure 10: Knee wall located above bathroom and washing room. Visible is the lack of vapor barrier on the ceiling behind the knee wall.

The owner noticed water occasionally dripping from the interior roof of the hall. Opening the knee wall in the area above the hall and removing the roof insulation within the attic shows significant signs of moisture damages. Large areas of the wood sarking have turned black, with several places showing signs of decomposing (figure 12). There is also a certain amount of fungus visible.

Figure 11: Visible signs of moisture and water on the wind barrier of the roof.

6.1.3 Cause

Figure 12: Visible fungus and mold on the inside of the roof sarking, as well as material starting to decay.

Insulation has been installed between the roof beams along the entire length of the beams. The same is done for the floor beams. The roofs vapor barrier, however, has been installed on the spars and down the inside of the uninsulated knee wall (figure 10). There is no vapor barrier within the attic itself, along with no ventilation. This allows the heat from the loft to warm up the attic, and the warm air from the attic to transport through the construction of the roof. This air potentially has a moisture content high enough to cause a RH of above 85 % on the surface of the wooden sarking. In addition, the cardboard wind barriers are squeezed up against the sarking in several places, effectively reducing the air flow within the air space.

The bathroom and washing room directly beneath the attic are also likely big contributors to the damages. The surfaces of these rooms were not opened, and it is therefore difficult to conclude with how much of the damage is due to heat and/or water vapor from mentioned rooms rising up to the attic. However, if the vapor barrier of both rooms is not sufficiently air tight in the transition between the ceiling and the wall [27] [22], large amounts of water vapor could find its way into the attic and out through the roof construction. Traditionally, these rooms are kept warmer than the rest of the building, enabling the air within them to hold on to more water in vapor form [22], increasing the steam pressure against the ceiling [22]. When using the shower and/or the washing room, the air's temperature and water vapor content rises, adding to the steam pressure [22]. There is an electrical fan installed in the bathroom that will reduce the amount of steam pressure on the ceiling [56], but there is no air vent elsewhere in the room. Electrical fans often require the addition of an air vent, usually installed on or under the door leaf, to be able to optimize the circulation of air in the room [56]. In the washing room, there is only one mechanical air vent. When washing clothes or storing outside clothing in this room, the air's RH will increase, again adding to the steam pressure against the ceiling.

6.1.4 Solution

In this case, the majority of the exterior layers of the roof needs to be replaced:

- The wooden boards with visible damages from rot and mold as well as unsatisfying moisture content, should be replaced entirely. It would be possible to dry parts of the material naturally or with a dehumidifier [31], but this would be time consuming and not very cost effective, since the roof needs to be opened from the outside regardless.
- The cardboard wind barriers should be replaced to some degree.
- The roof insulation should be checked while removing the wind barrier, with any part of the insulation visually damaged by moisture being replaced, as moisture reduces its insulation capacity [31].
- The knee wall should be removed to be able to install the vapor barrier continuously along the length of the roof [57].
- Air vents should be installed on both sides of the attic [56].
- Parts of roof beams should be replaced if decomposing has occurred [43]. Potential fungus can be removed using chemicals if cost effective [43], and high moisture content can possibly be reduced by letting the beams dry mechanically [31].
- Extra air vents should be installed in both the bathroom and the washing room [56]. In addition, an electrical air vent should be considered in the washing room.

In addition, the insulation between the floor beams should be removed in order to be able to evaluate the condition and installation of the vapor barrier of the bathroom and the washing room.

6.1.5 Cost evaluation

Estimated cost of repairs and improvement:

- **Work:** A total of approximately 90 hours of work at a cost of 550 NOK + VAT per hour, amounting to approximately 61,000 NOK.
- **Materials:** Approximately 44,000 NOK.
- **Total:** 105,000 NOK.

Estimated cost include improving damaged areas of the building, and the installation of vapor barrier in the attic where this was missing prior to the damage.

6.2 Case B

Figure 13: Moisture damage in bedroom.

6.2.1 General information

Figure 14: The wall consists of wooden panel, 2×2 studs and sills, 50mm mineral wool insulation, and a vapor barrier installed directly on concrete blocks.

- Built in early 1960s

- Appendage build in early 2000s
- Approximately 90 m^2
- Damage located in room within appendage, approximately $1,9 \times 3,3$ meters (6,27 m^2)
- Damaged area approximately 4×2 meters (8 m^2)

There are visible moisture damages on the surfaces of the room (figure 13). Due to the room being partly under ground, two of the walls are built in concrete Leca blocks. There is no drainage on the outside of mentioned walls. The remaining walls are wood frames. On the inside of the concrete walls, 48x48 mm sawn timber studs are fixed against the walls, with a thin (likely 0,06 mm) plastic layer in-between. There is 5 cm glass wool insulation within the walls. The interior surfaces of the room consist of wooden panel. The floor of the room consist of laminate flooring on top of a plastic vapor barrier and a concrete floor.

6.2.2 Issue

Figure 15: Visible condensation on the vapor barrier when removing the insulation.

The room has visible moisture damages on the surface of one of the corners of the room (figure 13). The wooden panel has heavy discoloration, and has started to decompose in smaller areas near the floor. Upon opening the wall, several signs of moisture related problems are visible (figure 14). The sill has started to decompose in the corner where the damage was visible on the surface (figure 13), as well as there being several areas of mold, fungus and discoloration (figure 15). The plastic layer between the studs and the concrete blocks are covered in both moisture and mold over the majority of the wall (figure 15).

6.2.3 Cause

There is no drainage or insulation on the outside of the concrete wall, making it possible for water and ground moisture to transport through the concrete blocks [58]. Here, moisture reaches the bottom sill and the wooden panel, which then absorbs a significant portion of the moisture through capillary suction.

The lack of insulation on the outside of the concrete wall effectively turns the entire part of the wall into a thermal bridge [59]. The inside temperature of the concrete blocks is therefore potentially lower than the temperature of the room, and significantly lower during the colder seasons. Further, the small quantity of insulation on the inside of the wall leads to a relatively large heat loss towards the outside. This in turn potentially leads to issues with condensation on the (much) colder surface of the plastic film covering the concrete blocks [32].

The choice and use of plastic vapor barrier can also be a causal part of the damage. With no vapor barrier on the inside of the wood frame, the water vapor of the air found in the room is transported through the wall [22]. When reaching the much colder surface of the plastic film covering the concrete blocks, the air quickly condensates [60]. Since moisture most likely has been added continuously to the room due to the lack of outside drainage in addition to already existing moisture in the room, it is assumable that the RH within the room is relatively high. A plausible line of events could be:

1. Moisture is added to the room due to lack of outside drainage.
2. Part of the moisture vaporizes due to room temperature, increasing the air's RH.
3. The warm air with its high RH transports through the wall due to both convection and diffusion.
4. When reaching the (much) colder surface of the plastic vapor barrier covering the concrete blocks, the water in air condenses.

In this line of events, the condensation occurring on the vapor barrier can potentially add to the moisture content of the construction and the decomposing of the wooden materials of the wall.

This would be in addition to the warm air already found in the room transporting through the construction, until condensing on the colder vapor barrier.

Further, if the concrete floor does not have a capillary-breaking layer, it can add to the moisture content of the room via capillary suction [58].

6.2.4 Solution

Figure 16: Overview of the room after opening the construction and removing moisture damaged parts of the walls.

In order to stop moisture from reaching the room, it is important to install a drainage system on the outside of the concrete walls [58]. In addition, the outside of the concrete wall should be insulated to reduce the thermal bridge-effect [58], increasing the temperature of the inside of the concrete blocks enough to stop condensation.

Further, all materials covering the concrete wall should be removed along with any part of the remaining walls where damages are visible and/or suspected. This will enable the process of drying out the moisture of the room and materials until acceptable values are achieved [43].

When rebuilding the room, the vapor barrier on the wall should be installed on the inside of the wood construction [61]. Insulation can also be installed on the inside if it is not possible/preferable to add all the necessary insulation on the outside [61]. However, no less than 50 % of the insulation should be on the outside of the wall [58]. The inside of the concrete wall should be added a concrete finish before installing the insulation [58]. Contact between wooden materials and the concrete needs to be avoided bu using a capillary-breaking layer [58].

6.2.5 Cost evaluation

Estimated cost of repairs and improvements:

- **Work:** A total of approximately 60 hours at a cost of 550 NOK + VAT, amounting to approximately 43,000 NOK.
- **Materials:** 14,000 NOK, only including interior materials.
- **Total:** Approximately 57,000 NOK.

Included in these estimated costs, are the hours and materials needed to rebuild the interior of the room. Estimates do not include exterior work necessary to prevent the damage from occurring again. The cost of improving the exterior drainage is estimated to cost 3500 - 7000 NOK per meter [62], giving a total cost estimate in the area of 20,000 - 40,000 NOK for the exterior drainage. The addition of exterior insulation where needed would bring the estimated cost higher.

6.3 Case C

Figure 17: Moisture damage due to condensation in post-insulated roof.

6.3.1 General information

- Built in early 1960s
- Approximately 120 m^2
- Damage located along the ridge of the roof

- Damage area approximately $9 \times 1,5$ meters on both sides of ridge, an area total of 27 m^2

The roof consist of concrete roof tiles over roof battens, and roofing felt installed on top of timber boards. The roof was post-insulated from the inside with 150 mm insulation approximately 2005. Here, the insulation was installed directly towards the timber boards, with no air gap between the two. Further, there was no vapor barrier installed on the inside of the roof during post-insulation.

6.3.2 Issue

Figure 18: Signs of decaying material on the upper part of the roof beams.

During the laying of new roof tiles, signs of moisture damages became visible. The roof battens and the roofing felt near the ridge of the roof showed significant signs of decaying. Beneath the roofing felt, the timber boards in this part of the roof are rotten. There is no ventilation installed in the loft, mechanical or otherwise.

6.3.3 Cause

Warm air will rise upwards within the building due to convection [22]. The warmer air can be found at the highest point in the building [22], which in this case is the inside of the ridge. This can be seen by the damage in Figure 17. This warmer air has a vapor content potentially higher than the saturation point of the outside air. Since there is no vapor barrier installed, the warm air with higher vapor content is able to transport freely towards the outside of the roof

[22]. In this case, this happens both due to diffusion (air with higher content of vapor move towards air with lower content of vapor) and convection (warmer air with higher pressure move towards colder air with lower pressure).

Figure 19: Significant decay along the entire length of the roof.

When the inside air reaches the outer parts of the roof, the water vapor starts to condense on the colder surfaces [22] where the air's saturation point is reached, in this case the timber boards and the outer parts of the beams. Since there is no air gap between the insulation and the timber boards, moist air is not being transported away from the construction [29]. This is further amplified by a roofing felt that is not very vapor open being installed directly on top of the timber boards [36].

6.3.4 Solution

Figure 20: Overview of roof after opening the construction.

It is necessary to make sure that all parts of the construction that is rotten, decayed or showing significant signs of decay, are removed, along with the insulation found in the damaged area [43]. The beams could potentially be dried naturally until satisfying moisture content of ¡ 20 % is reached [43], if this is cost effective [43] and practically achievable. Considering the scope of the visible damages due to moisture, the entire outer part of the roof should be removed.

An ideal solution is the inside of the roof being opened, allowing for the installation of a vapor barrier [29]. In this case it is important to make sure that a sufficient air gap is created between the insulation and the roof sarking [29]. Since the entire outside of the roof is removed, this can be achieved by installing a vapor open wind barrier across the roof beams, and raising the roof on top of the beams to create a sufficient air gap between the wind barrier and the roof tiles. This solution will allow for larger amounts of insulation to be installed, compared to if the air gap is created from the top of the beams down to the insulation [36]. It is, however, possible to install a combined underlayment and wind barrier which is as vapor open as possible without the addition of a vapor barrier [36].

6.3.5 Cost evaluation

Estimated cost of repairs and improvement of the damage:

- **Work:** A total of approximately 150 hours at a rate of 550 NOK + VAT, amounting to approximately 104,000 NOK.
- **Materials:** 32,000 NOK.
- **Total:** 136,000 NOK.

Included in these estimations are the work hours and materials needed to repair the damaged area of the roof, as well as replacing the old sarking with a vapor open sarking to prevent similar consequences and damages in the future.

6.4 Discussion

In all three cases, the damages must be said to have been avoidable if requirements and recommendations were followed. The consequences in all three cases are significant, especially compared to how relatively easy they could have been avoided. In case B the damage and cause seems to be slightly more complex, with both condensation and water leakage from the outside causing the damage. In cases A and C, the cause of the damages seem to be entirely, or at least primarily, caused by condensation within the construction due to the lack of a vapor barrier. As seen in chapter 3.3.1, the exclusion of a vapor barrier results in significant amounts of moisture transporting through a construction. All three cases also show signs that the damage has evolved over several years, showing that these types of damages are difficult to spot before they have evolved into significant and costly damages.

6.4.1 Similarities

In cases A and C, the importance of using a vapor barrier becomes visible. In both cases, condensation alone has caused severe damages to the construction, with both cases also showing significant signs of wood decay within the construction. There are no signs of exterior leakages from rainfall or snow, leaving it likely that all damages are caused by convection and diffusion, with warm inside air forcing its way through the construction. Case B shows similar mechanics at play, where there are signs of damages caused by condense due to warm inside air transporting outwards. In cases A and C, the (correct) installation of a vapor barrier would likely have prevented the damage, or at least dramatically decreased the scope of the damage. This is also true for case B, but here the main cause of the damage is likely due to water finding its way into the construction from outside due to lack of drainage.

6.4.2 Cost evaluation

The cost estimations of cases A and C show how costly moisture damages in roofs can potentially become. As such damages often require a significant amount of work done on the exterior part of the construction, in order to reveal the scope of the damage as well as making sure the roof is water proof after improving the damage, costs of such damages could become significant. For case B, the estimated cost for the interior improvement of the damage is significantly lower than in cases A and C, but this is only true if one excludes the necessary work on the outside regarding drainage and recommended insulation. If this is included, all three cases have relatively similar cost estimates, ranging from roughly 100,000 - 150,000 NOK. Considering for example case A, where the likely main cause of the damage is the lack of (or insufficient installation of) a vapor barrier over a relatively small area, the consequence of an easily avoidable mistake highlights the importance of sufficient knowledge and craftsmanship.

7 Conclusion

The purpose of the thesis has been to assess the various challenges related to moisture that can arise throughout the life cycle of a residential building. The focus has been on the challenges caused by moisture that arise due to the transport of air through constructions.

To assess the problem of the thesis, the following has been studied:

- The extent of moisture damages and moisture problems in Norwegian residential buildings, and the consequences of these
- Cause of these damages
- Moisture theory to explain how moisture behaves within a building and a construction
- Recommendations and requirements for buildings to reduce / avoid problems with moisture
- How these damages can be repaired and what costs it entails

Statistics show that moisture damage and damage resulting from moisture account for approximately 75 % of all building damage in the country. The large number of moisture damages has increased the focus on, and provided stricter requirements for, both design and execution, and this seems to have had an impact on what causes the moisture damage in recent decades. Nevertheless, the proportion of moisture damage is stable at approximately 75 %, mainly due to a sharp increase in damages resulting from precipitation, where increased rainfall and heavier rainfall in recent decades is a probable cause. A changing climate that is predicted to become even more challenging for the design and construction of buildings, means that having a focus on making both future and current buildings moisture-robust is perhaps more important than ever.

Of moisture damage that occurs in new buildings, the damages in the majority of the cases are due to errors in design and execution, and these are damages that can be avoided if recommendations and requirements are followed. The consequences of such errors cost the Norwegian society billions of NOK annually, in addition to the potential health damage it causes to the users of the buildings. Many of the moisture damages don't become visible until long after the completion of the building, and this means in many cases that the extent of the damage is significantly greater than if it was discovered at an earlier time. The formation of fungi resulting from bad indoor air and / or incorrect execution during the construction of the home will potentially be difficult to detect before many years have passed.

Of all residential buildings in Norway, about one-third have problems with moisture. In most cases, it is moisture in basements, which is mainly due to older building customs where external drainage around the foundation wall was not common. In addition to bathrooms or other wet rooms, which are often the rooms where moisture damage is expected to occur, unfurnished attics are also a place where many homes have problems with moisture. This is due both to the fact that moisture penetrates from the outside, and that moist air from the building rises to the attic, cools down and forms condensation. The latter scenario is especially a problem if re-insulating the joist in the attic without also installing a vapor barrier. In older buildings, where the amount of insulation was minimal or non-existent, post-insulation can have major consequences if not done properly. The air transportation in the building changes, and in many cases it is completely clogged. Example study C clearly shows the consequences it can have when the post-insulation is not carried out in accordance with recommendations.

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A Appendix

Cost estimation case study A

Task	Hours
Rigg	**6**
Scaffolding	2
Remove shingel	8
Remove sarking	6
Improve beams	5
Remove wind barriers	2
Remove insulation	2
New insulation	3
New wind barrier	6
New sarking	6
New shingel	24
Handling of material	4
Interior work	8
Waste handling	3
Exterior moldings	4
Total work hours	89

Hourly rate	kr	550,00
inc. VAT	kr	687,50
Total work cost	**kr**	**61 187,50**

Material	Amount	Unit	Cost pr. unit	Total	
Insulation	18	m2	140	kr	2 520,00
Cardboard wind barriers	16	stk	40	kr	640,00
Vapor barrier	1	stk	300	kr	300,00
Sarking	500	m	17	kr	8 500,00
Shingel	58,5	m2	190	kr	11 115,00
Ridge shingel	9	stk	1175	kr	10 575,00
Miscellanous	1	stk	4000	kr	4 000,00
Underlayment roof	3	stk	950	kr	2 850,00
Interior wood panel	48	m	25	kr	1 200,00
Waste fee	1	stk	1500	kr	1 500,00
Flashing	3	stk	330	kr	990,00
Material total cost				**kr**	**44 190,00**

Estimated total cost		
Work	kr	61 187,50
Materials	kr	44 190,00
Total	**kr**	**105 377,50**

Cost estimation case study B

Task	Hours
Remove wood panel	5
Remove floor	4
Remove insulation	1
Remove vapor barrier	2
Remove studs	3
New stdus and sills	5
Insulation	3
Wood panel	16
Moldings	4
New floor	8
Waste handling	2
Handling of material	4
Rigg	5
Total work hours	62

Hourly rate	kr	550,00
inc. VAT	kr	687,50
Total work cost	**kr**	**42 625,00**

Material cost	Amount	Unit	Cost pr. unit	Total	
Insulation	13,2	m2	70	kr	924,00
Studs and sills	13	m	15	kr	195,00
Wood panel	113	m	25	kr	2 831,40
Vapor barrier (floor)	1	stk	300	kr	300,00
Floor	6,9	m2	300	kr	2 069,10
Miscellaneous	1	stk	4000	kr	4 000,00
Moldings	33	m	50	kr	1 650,00
Underlay floor	6,9	m2	100	kr	689,70
Waste fee	1	stk	1500	kr	1 500,00
Material cost				**kr**	**14 159,20**

Estimated total cost		
Work cost	kr	42 625,00
Material cost	kr	14 159,20
Total cost	**kr**	**56 784,20**

Cost estimation case study C

Task	Hours
Rigg	8
Scaffolding	5
Remove roof tiles	8
Remove gutters	3
Remove roof moldings	3
Remove roof battens	8
Remove underlayment	3
Remove sarking	8
Waste handling	3
Material handling	5
Improving beams	6
New insulation	5
New sarking	22
New roof battens	22
Gutters	5
New roof tiles	32
New roof moldings	5
Total work hours	**151**

Hourly rate	kr	550,00
ink. VAT	kr	687,50
Total work cost	**kr**	**103 812,50**

Materials	Amount	Unit	Cost pr. unit	Total	
Sarking	85,05	m2	120	kr	10 206,00
Insulation	37,8	m2	140	kr	5 292,00
Roof battens 23 mm	168,3	m	11	kr	1 851,30
Roof battens 30mm	297	m	12	kr	3 564,00
Gutters	18	m	300	kr	5 400,00
Miscellaneous	1	stk	4000	kr	4 000,00
Beams	34	m	28	kr	952,00
Eaves moldings	18	m	22	kr	396,00
Roof moldings	36	m	22	kr	792,00
Materials total				**kr**	**32 453,30**

Estimated total cost		
Work	kr	103 812,50
Materials	kr	32 453,30
Total	**kr**	**136 265,80**

Invoice, case study A

Ryfylke-bygg AS
Birkelandsvegen 74
4200 SAUDA
Foretaksregisteret: NO 993 485 136 MVA
Telefon: 52 78 59 20
E-post: lillian@ryfylkebygg.no

FAKTURA

Fakturanr.:
Fakturadato: 2020-05-14
Kundenr:

Betalingsinformasjon
Forfallsdato: 2020-05-24
Kontonummer:
KID:
NB! Oppgi alltid KID ved elektronisk betaling.

Prosjekt: 1022
Leveransested:

Beskrivelse	*Antall*	*Enh.pris (eks. mva)*	*Beløp (eks. mva)*	*Mva (25%)*	*Beløp (inkl. mva)*
Tømrerarbeid			52 920,00	13 230,00	66 150,00
TAKSHINGEL S SKIFERGRÅ ISOLA 2,95 M2 PR PAKKE	19	463,814	8 812,47	2 203,12	11 015,59
MØNEPR LUFTER 15-60 SK.GRÅ ISOLA LENGDE: 1 LM INKL FESTEMATR	8	936,508	7 492,06	1 873,02	9 365,08
KLEBELAPP ISOFLEX S SK.GRÅ ISOLA	2	216,475	432,95	108,24	541,19
TAKFOT/MØNEPL SKIFERGRÅ ISOLA 66 STK. PR. PAKKE	1	1 207,65	1 207,65	301,91	1 509,56
SONETILLEGG	1	81,90	81,90	20,48	102,38
HENTETILLEGG	1	455,00	455,00	113,75	568,75
G-F 18X120 UNDERPANEL RUPANEL ENDEPLØYD	511,89	10,894	5 576,53	1 394,13	6 970,66
UNDERLAG ISO-D 1X25M ISOLA	2	771,76	1 543,52	385,88	1 929,40
GRAN 48X198 K-VIRKE C24 KONSTRUKSJON FALLENDE LENGDER	2,47	40,587	100,25	25,06	125,31
PAPPSPIKER 2,5X35 FZV A-1200 A1200	1	216,41	216,41	54,10	270,51
PAPPSPIKER 15GR 3,0X32 FZV RØR COIL TRÅDBÅNDET RØR A-1200	1	260,73	260,73	65,18	325,91
FURU 19X148 CUIMP REKTKLED KL1 REKTANGULÆR CU-IMPREGNERT TØRKET	22,5	23,92	538,20	134,55	672,75
GRAN 48X048 UHØVLET TREKANTLEKT DIAGONALSKÅRET TREKANTLEKT BH	22	14,963	329,19	82,30	411,49
BORDTAKSBESLAG C-87 SORT FOR TAK-PAPP, SHINGEL OG PLATETAK	4	97,28	389,12	97,28	486,40

FUGEMASSE 0,31 LTR TUBE ISOLA	5	166,14	830,70	207,68	1 038,38
LUFTESPALTE HVIT ISOLA	6	44,902	269,41	67,35	336,76
Øreavrunding	1	0,61	0,61	0,15	0,76
Søppel i flg vedlegg	1	1 485,12	1 485,12	371,28	1 856,40
BORDTAKBESLAG PLAST BP9-11 SORT BMI 2M LENGDE	3	264,42	793,26	198,32	991,58
Fakturagebyr	1	26,00	26,00	6,50	32,50
Øreavrunding	1	0,33	0,33	0,08	0,41
BORDTAKSBESLAG C-87 SORT FOR TAK-PAPP, SHINGEL OG PLATETAK	-4	97,28	-389,12	-97,28	-486,40
UNDERLAG ISO-D 1X25M ISOLA	1	771,76	771,76	192,94	964,70
PAPPSPIKER 15GR 3,0X19 FZV RØR COIL TRÅDBÅNDET RØR A-2160	1	395,47	395,47	98,87	494,34
GRAN 12X120 SKYGGESKRÅ NAT PANEL SKYGGE UBEHANDLET NATUR	7,36	14,755	108,60	27,15	135,75
GLAVA PROFF 34 RULL 150X570X3200MM 2 STK 3,65 M2/PK	1	382,98	382,98	95,75	478,73
Øreavrunding	-1	0,01	-0,01	0,00	-0,01
Sum			85 031,09	21 257,79	106 288,88
Betales til bankkonto , KID:				**NOK**	**106 288,88**

Ryfylke-Bygg AS
Birkelandvegen 74

4200 SAUDA

Foretaksregisteret: NO 993 485 136 MVA
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E-post: lillian@ryfylkebygg.no
Bankgiro:

Invoice, case study C

Fakturanr: **2794**
Fakturadato: **24.09.2014**
Forfallsdato: **04.10.2014**

Leveringsdato:

Faktura

		Antall	Pris	Rab	Mva	Beløp
	Skifte av tak					
101	Sum i flg vedlegg	1,00	119 945,30		25%	119 945,30

Grunnlag 25% mva	Merverdiavgift	Avgiftsfritt	Avrunding	Totalsum
119 945,30	**29 986,33**	**0,00**	**0,00**	**149 931,63**

Etter forfall beregnes det renter

0,00

04.10.2014

Fakturanr: 2794
Kundenr:

Fakturasum:	149 931.63
Oppgjort beløp:	149 931.63
Rest å betale:	0.00

Ryfylke-Bygg AS
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