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ACCESSIBILITY

MASTER'S THESIS

TITLE OF REPORT	DATE
Experimental Investigation of Moisture Migration in Tiled Bathroom Walls	May 25th 2023
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AUTHOR Morten Brodahl	SUPERVISOR Dimitrios Kraniotis

IN COLLABORATION WITH	CONTACT PERSONS
SINTEF Community	Lars-Erik Fiskum Sverre B. Holøs

SUMMARY / SYNOPSIS

Experimental laboratory research has been performed, assessing moisture migration behavior in tiled bathroom walls with different tile adhesive trowel patterns. Three 2.4 m x 1.8 m walls have been constructed and exposed to water through a shower head, in different time intervals, with the longest accumulated water exposure of 2 920 minutes, equivalent to an 8-minute daily shower for one year. The horizontal wet zone definition of 1 meter provided in TEK17 has been evaluated against the water exposure and found to be sufficient within the scope and parameters establish herein. The longest moisture migration during the experiment was 899 mm. A prediction model is established, estimating that the wet room zone to be reached within 4 - 7 years with a prediction accuracy between 89 % and 92 %.

KEYWORDS
Experimental laboratory research
Tiled bathroom walls
Moisture migration

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Sincerely, *Morten Brodahl*

ABSTRACT

Moisture related damage to buildings are a continuously increasing trend regarding both occurrences and indemnity cost. More and more knowledge is available in the industry; however, the negative trend continues. This master's thesis is a contribution to turn the trend, providing insight into moisture migration in the grout and tile adhesives in tiled bathroom walls.

Several research questions and hypotheses are established, challenged, and answered. The main objective of this experiment is to observe and assess moisture migration behavior in cementitious tile adhesive and grout, when tiled walls are exposed to a range of water cycles using a commercial shower head. This is done to evaluate if the wet zone definition in TEK 17 provides sufficient moisture safety in dwelling bathrooms. The research is performed in an experimental laboratory setting with emphasize on a realistic setup, providing a visual presentation and assessment of moisture migration, supported by data acquisition including weight-, temperature-, water flow rate- and relative humidity measurements.

Three 2.4 m x 1.8 m walls comprising lightweight wooden framework, mounted with 30 mm wet room boards with RH-sensors attached, have been constructed. The walls are clad with a mix of 150 mm x 150 mm glass- and ceramic tiles in an approx. 9: 10 ratio. Cementitious tile adhesive and grout are used to install the tiles, with emphasis on leaving trowel groove patterns in two orientations in the tile adhesive, both horizontal and curved. A sorption experiment on four different tile adhesives are performed, contributing with parameter input to the main experiment.

Moisture migrates differently in the two types of tile adhesive trowel patterns, where the furthest moisture migration occurred in curved trowel pattern. After 2 920 minutes of water exposure, distributed in different exposure increments, equivalent to a daily 8-minute shower for 365 days, there was measured a fully saturated area of 1.68 m^2, with the furthest horizontal moisture migration being 899 mm. The water exposure is concentrated on one specific point during the whole experiment. This concludes that a tiled bathroom wall, applied with cementitious tile adhesive and grout behaves like a sponge, yet the defined wet zone is not reached by moisture within the scope of this experiment.

Prediction models for future moisture migration has been developed, estimating that the 1-meter wet zone will to be reached by moisture after 4 -7 years incl. prediction accuracies between 89 % and 92 %.

SAMMENDRAG

Fuktrelaterte skader i bygninger er en stadig økende trend innen både antall forekomster og erstatningskostnader. Mer og mer kunnskap er tilgjengelig, likevel fortsetter den negative trenden. Denne masteroppgaven er et bidrag til å snu trenden ved å gi en innsikt i hvordan fukt transporteres og oppfører seg i fugemasse og flislim i flislagte baderomsvegger.

Tre forskningsspørsmål og tre hypoteser er etablert, utfordret og besvart. Hovedmålet med dette eksperimentet er å observere, samt evaluere fukttransporten i et sementbasert flislim og fugemasse, når flislagte vegger utsettes for ulik vanneksponering gjennom et kommersielt tilgjengelig dusjhode. Dette gjøres for å vurdere om våtsonedefinisjonen i TEK 17 gir tilstrekkelig fuktsikring på et baderom. Forskningen utføres gjennom eksperimentelt laboratorieforsøk med fokus på et realistisk oppsett, som gir en visuell presentasjon og vurdering av fukttransporten, støttet av datainnsamling av bl.a. vekt-, temperatur-, vannstrømnings- og relativ fuktighetsmålinger.

Det har blitt bygget 3 vegger a 2,4 m x 1,8 m bestående i et rammeverk av konstruksjonsvirke med påmonterte 30mm våtromsplater. Veggene er flislagt med en blanding av 150 mm x 150 mm glass- og keramikkfliser i et forhold på 9:10. Sementbasert flislim og fugemasse er brukt til å installere flisene, med fokus på å etterlate tanningsmønstere i to orienteringer i flislimet. Et sorpsjonseksperiment med fire forskjellige flislim er også gjennomført og bidrar som parameterinput til hovedeksperimentet.

Fuktigheten transporteres forskjellig i de to forskjellige tanningsmønsterne i flislimet, der den lengste fukttransporten oppstod i det buede tanningsmønsteret. Etter en akkumulert 2 920 minutters lang vanneksponering, fordelt på ulike eksponeringsintervaller, tilsvarende en daglig 8-minutters dusj i 365 dager, ble det målt et fullstendig fuktmettet område på 1,68 m^2, med den lengste horisontale fukttransporten på 899 mm. Vanneksponeringen var konsentrert på ett bestemt punkt gjennom hele eksperimentet. Dette konkluderer med at en baderomsvegg, bestående av baderomsflis, sementbasert flislim og fugemasse, oppfører seg som en svamp. Men den definerte våtsonen blir ikke nådd av vann eller fukt innenfor de definerte parameterne og rammene i dette eksperimentet.

Prognosemodeller for fremtidig fukttransport er utviklet, og anslår at våtsonen i horisontallengde på én meter blir nådd etter 4 - 7 år, med en konfidenskoeffisient mellom 89 % og 92 %.

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NOMENCLATURE & SYMBOLS

Description of symbols and units are found in Table 1. These are usually presented in equations, or in a mathematical context.

Table 1 Nomenclature and Symbols Described and Used in this Document

Symbol	Description	Unit
A	In equations: calculation variable input	none
B	In equations: calculation variable input	none
d	Material thickness	m
EXP_{Time}	Exposure time	min
g	Acceleration of gravity	$[m / s^2]$
h	In equations: Height	m
Hz	Frequency - hertz	s^{-1}
m	Mass, sometimes provided with a contextual subscript. meter	kg or g m or cm or mm
MM_{Right}	Moisture migration to the right	mm
μ	Water vapor resistance factor	-
p	Current vapor pressure	Pa
ϕ	Relative Humidity (RH)	%
P_S	Porosity	%
P_{sat}	Vapor pressure at saturation	Pa
ψ	Moisture volume pr material volume	$[m^3 / m^3]$
R^2	Coefficient of determination	- or %
r	Radius	m

Symbol	Description	Unit
ρ	Density, sometimes provided with a contextual subscript.	[kg / mm^3]
S	Saturation	-
σ	Surface tension	[N / m]
S_d	Vapor resistance - Equivalent air thickness layer	m
t	time	year, month, day, hour, minute, second
T	Temperature	°C
θ	Contact angle	degrees °
u	Water mass ratio or Moisture mass as weight percentage	[kg / kg] [g / kg]
U	Flow rate	[l / m]
V_{VS}	Void Space Volume	m^3 or mm^3
V_S	Specimen Volume	m^3 or mm^3
w	Moisture mass pr volume	[kg / m^3]
w/b	water/binder ratio	-
W	Water vapor permeability	[kg / m^2sPa]
Z	Water vapor resistance	[m^2sPa / kg]
Ø	Geometric diameter	m or mm

ABBREVIATIONS, ACRONYMS AND TERMS DEFINITIONS

Most of the utilized materials, equipment and data acquisition tools are written with each word capitalized. This is intentional to highlight significant tools and equipment, and to be concise in terms and expressions. Other expression might also be presented in in the same way to highlight a title or expression. The composition of defined assemblies are described in Table 3 and Table 6.

Some expressions are written in *Italic* font, to highlight a name, term, or by any other reason to clarify an expression.

Content of Table 2 describes letters, acronyms and abbreviations not having any symbolic context, compared to what is presented in Table 1.

<u>List of Terms and Expressions used Interchangeably throughout the Document</u>

- "EUT #1, #2 & #4" and "Wall #1, #2 & #3"
- "Parameters" and "Variables"
- "Fluid" and "Liquid"
- "Pores", "Voids" and "Cells"
- Capillary Force, Effect, Action, Suction, Transport are all used interchangeably.
- "Clay tiles" and "Ceramic tiles"

Table 2 Abbreviations and Acronyms Described and Used in this Document

Abbr. & Acr.	Definition
°C	Degrees Celsius
Abbr.	Abbreviations
Acr.	Acronyms
Approx.	Approximately

Abbr. & Acr.	**Definition**
Assy	Assembly
Base Walls	Main experimental walls comprising a wooden structural frame, wet room boards with taped seams and pre-drilled holes for the Support Legs and Wall Hoisting Assembly
BBR	The Swedish National Board of Housing, Building and Planning
BVN	The Norwegian Wet Room Norm
Byggforsk	SINTEF Building Research Design Guides (SINTEF Byggforsk)
CC	Condition Class
Ch.	Chapter
cm	Centimeter
CM	Configuration Management
CoG	Center of Gravity
Complete Walls	Main experimental walls comprising the Base Walls plus tiles, grout and tile adhesive
DAQ	Data Acquisition System
DiBK	The Norwegian Building Quality Directorate
e.g	exempli gratia / for example
ea	Each, pieces, units, etc.
EAD	European Assessment Document
EN	European Union (In relation to ISO-std)
EOTA	European Organisation for Technical Assessment
Etc.	Et cetera (and so forth)
EUT	Equipment Under Test

Abbr. & Acr.	Definition
FFV	The Faculty for Wet rooms
FHI	Norwegian Institute of Public Health
g	Grams
Gb	Gigabytes
GBR	Golvbranschen Riksorganisation
h	Hour
H_2O	Water molecule
HAM	Heat Air & Moisture
HBM	Brand name (Hottinger Brüel & Kjær (HBK))
HSE	Health, Safety & Environmental
i.e	id est / that is
ID	Identification
incl.	Including
ISO	International Organization for Standards
KDD	Municipal and District Department
kg	Kilograms
kN	Kilonewton
l	Liter (sometimes "ltrs")
m	Meter
$m^{(2, 3)}$, $mm^{(2, 3)}$	Square- or Cubic measurements
M8	Drill bit of size 8 mm.

Abbr. & Acr.	**Definition**
Maturing time	For tile adhesives: Time between mixing and ready for use
Min	Minute
Misc.	Miscellaneous
mm	Millimeter
Moisture	Umbrella term for both water vapor and liquid water. Other words included in this term is humidity, moistness, and dampness.
MoM	Minutes of Meeting
MP	Mega Pixels
mV	Millivolt
μV	Microvolts
MVRA	Multivariate Regression Analysis
N/A	Not Applicable
N_2	Nitrogen molecule
NBKF	The Norwegian Association for Building Ceramics
No.	Number
NOK	Norwegian Kroner
NS	Norwegian Standard
O_2	Oxygen molecule
Open time	For tile adhesives: Maximum time between mixing and ready for use
Pa	Pascal
pc	Pieces, units, a number of something
PDCA	Plan Do Check Act

Abbr. & Acr.	**Definition**
PhD	Doctor of Philosophy
Pot-life Pot life	For tile adhesives: Maximum time after application prior to tile placement
PRV	Swedish Patent Database
QA	Quality Assurance
ref	Refer to
RH	Relative Humidity
s	Second
SAK10	Regulations relating to building applications
SBS	Sick Building Syndrome
Sect.	Section
SEWS	Sanitary Engineering and Wetroom Systems
SINTEF	In Norwegian: Stiftelsen for industriell og teknisk forskning
SotA	State of the Art
Std	Standard
Support Legs	Assembly for supporting the Wall during exposure
SW	Software
TEK17	Regulations on technical requirements for construction works (In Norwegian: "Byggteknisk forskrift - TEK17")
TG	In relation to CC: "Tilstandsgrad" Other: Technical Approvals
UK	United Kingdom

Abbr. & Acr.	Definition
V	Volt
v.	Version
w/	with
w / b	water / binder ratio
Wall Hoisting Assembly	All required misc. equipment to be able to hoist the walls using the Pulley

1 INTRODUCTION

1.1 OVERVIEW

In addition to the need for practical and functional buildings, humans have appreciated architectural- and structural esthetics for thousands of years. To satisfy the desire for visually pleasing surroundings in a day-to-day setting, people have shown a keen interest in colorful tiles and tilework for more than 6000 years [1]. In modern times, tiles have found their place both on the exteriors and interiors of buildings. In Norway, tiles are most commonly found indoor, mainly in kitchens and bathrooms.

To install tiles on a surface, some kind of adhesive is required. Historically, tiles were adhered with materials such as gypsum or volcanic ash, but in modern time, a form of dry-mix mortar, usually in the form of a cementitious tile adhesive is the most common option [2]. The global annual consumption of cementitious tile adhesive is approx. 50 million tons [3], making it a significant market share.

Bringing tilework into bathrooms, combined with buildings being continuously more complex with time, leads to higher risk of issues and damage, especially related to moisture. Occurrences of moisture related damage is high globally speaking, as well as in Norway. Due to this, Norway even has a dedicated statistical tool for exclusively water related damages, developed by Finans Norge (VASK) [4]. This is a frequently cited source in literature presenting the occurrences and amount of indemnity costs related to moisture damage. The latest statistics from VASK points to an annual indemnity cost of NOK 5.3 Billion both in 2021 and 2022, and a damage occurrence of approx. 90 000 in 2022. Both trends have been increasing since 2008, however a 14% reduction in occurrences are registered from 2021 and 2022, causing reason for optimism. The moisture related damages, highest in both indemnity cost and occurrences, comes from exterior factors such as floods causing water to enter the building envelope. Still, a high portion of issues originates from water coming from inside the buildings.

Evaluations regarding the origin of moisture related damage is provided through several sources. A Swedish damage assessment report made by Polygon was released in 2017, evaluating different construction types of tiled walls [5]. A 2017 study evaluating the cause of damage and errors related to moisture and dampness in 10 112 Norwegian dwellings [6], and the most recent study performed by Menon in 2022 [7], highlighting the extent of construction related errors in Norwegian buildings. The trend and commonalities in these studies and statistical tools presents a rather bleak impression, created by the dimension of issues related to moisture damages. The building envelope and building details gets more and more complex, causing issues not being detected for a long time. Additionally, there is revealed a relatively high rate of construction issues related to not being according to the Norwegian Regulations On Technical Requirements For Construction Works (TEK17) (in Norwegian: "Byggteknisk forskrift") [8].

Norway, along with many other countries, has a building law being the overall governing regulation related to construction and building design. Several regulations on different levels are subordinate to the building law, providing everything from generic construction guidelines to specific construction detail instructions. Even with technically approved products and solutions that are tested according to Norwegian requirements and international standards, through SINTEF's technical approvals (TG). The continuously increasing complexity of building details and dense building envelopes are causing inspections to be more challenging. However, requirements regarding easy access in critical solutions in bathrooms, and other requirements ensuring inspection possibilities exist in the available literature.

The crux of the matter, regarding indoor tilework combined with water sources, are how to combine the demand for esthetics in combination with conscious design and workmanship, with proper moisture safety based on realistic research in complex structures. Increasingly available knowledge is accessible as time advances; however, statistics still shows that there is a great challenge related to handling moisture safety in buildings, and all trends points towards a further negative future.

This master's thesis aim to contribute to the knowledge needed to turn the trend, providing a future of less issues related to moisture damage. The main part of this document describes the experimental research performed in a laboratory, exposing multiple tiled walls to water using a commercially available shower head. The novelty of this research is based in combining a visual presentation of the moisture migration in the tile adhesive in tiled walls, in addition to assessing and analyzing the moisture behavior. Further prediction of moisture migration over time is discussed, in addition to evaluations into which parameters affects the moisture behavior.

By having a visual focus combined with a moisture behavioral assessment, the author's goal is to be a contributor to reduce the trend of increasing indemnity cost. Additionally, decrease the potential of mold and moisture issues causing negative long-time effects on people and buildings.

1.2 SCOPE AND MOTIVATION

The overall motivation of this master's thesis is presented above; however, it is also a contribution to a 23-year-old topic originating from one of Europe's largest, being Norway's largest independent research organization, namely SINTEF. Through the institute named SINTEF Community, which also provides SINTEF Building Research Design Guides (SINTEF Byggforsk), a project named 'Healthy Energy-efficient Urban Home Ventilation' (Urban Ventilation) is the top-level initiator and collaborator for this master's thesis. From this project, the overall proposal of a master's thesis was collaboratively created between the research manager in the department of Sanitary Engineering and Wetroom Systems (SEWS) at SINTEF Community and the author of this master's thesis, supported by the internal supervisor and the work package manager (no. 3) in Urban Ventilation.

The research manager performed an experiment in the year 2000, looking into moisture penetration in grout and ceramic tiles in a tiled wall [9]. From this experiment, both questions and discussions emerged surrounding the complex tiled construction, but not least how moisture behaves in a tiled wall. In 2022, the need- and demand for performing a full-scale laboratory experiment, looking into moisture migration, was established. Through the Urban Ventilation project, and an eager research manager with available research funds of NOK 150 000.-, it was possible to establish a master's thesis for executing the required full-scale laboratory experimental research.

Three 2.4 m x 1.8 m walls comprising a lightweight, wooden framework, constructed with 30 mm wet room boards with RH-sensors attached are made. The walls are tiled with a mix of 150 x 150 mm glass tiles and ceramic tiles in an approx. 9: 10 ratio. Cementitious tile adhesive and grout are used to install the tiles. Throughout a total period of three months, the walls have been exposed to water, followed by a drying- and monitoring period. Several parameters have continuously been measured through data acquisition, and forms the total dataset used for post analysis.

Further details into the background for the motivation of this master's thesis is found in the State of the Art (SotA) chapter (Ch. 3). The chapter presents the current knowledge, as well as highlighting the request and desire for further knowledge from the literature.

1.3 RESEARCH QUESTIONS AND HYPOTHESES

The main purpose of this master's thesis is to assess the moisture behavior in the tile adhesive behind the tiles in a bathroom wall, as realistically as possible. Emphasized by workmanship errors seen in the industry, this forms a worst-case basis that can be challenged. A combination of the unknown moisture migration combined with a problematic workmanship consequences is highly relevant for evaluating the moisture safety in existing technical regulation. To do this, a collection of overall research questions, as well as a selection of hypotheses have been established and are presented in section 1.3.1.

A detailed background for the research questions are described in the SotA, Ch. 3.

1.3.1 Research Questions

- How does water and water vapor behave in the tile adhesive in a tiled bathroom wall during- and after being subjected to showering?
- Is the perimeter definition of the wet room zone provided by TEK17 sufficient to prevent moisture from migrating outside the wet room zones?
- How are the moisture migration affected by insufficient tile adhesive coverage, causing trowel pattern grooves in the tile adhesive?
    - Should the wet room zones defined in TEK17 be modified to handle the risk related to moisture migration in the trowel grooves?

Hypotheses

- Cement based tile adhesive behaves as a sponge due to material properties, soaking up applied water and surrounding water vapor. The sorbed moisture needs several months to dry out.
- Trowel pattern grooves in the tile adhesive will affect the moisture migration, causing expressways for moisture to migrate beyond boundaries of the wet zone.
    - Liquid water will migrate faster in saturated (RH = 100%) grooves than non-saturated groves (RH < 100%). Especially horizontal grooves are thought to cause moisture to migrate rapidly to the sides.
- A mix of soapy water will cause a more rapid moisture content increase in the tiled walls as well as faster moisture migration in the grout and tile adhesive.

1.4 LIMITATIONS

The following overall research limitations have been identified:

- To be able to provide a visual presentation of the moisture migration, glass tiles have been the main type of cladding on the walls. The differences in moisture migration behavior in glass tiles and ceramic tiles have been of interest during the experiment. With the assumption of different behavior, uncertainties regarding a real-life wall fully clad with ceramic tiles compared to this experiment is thoroughly discussed herein.
- Ambient conditions have not been controlled in the laboratory. However, daily registration of temperature and Relative Humidity (RH) have been done to establish a full overview of the conditions.
- Constraints and assumptions related to finance, schedule and equipment are presented in sect. 4.10.
- Challenges and limitations experienced during the research period is presented in sect. 6.4

1.5 DOCUMENT OVERVIEW

This section provides an overview of the structure and overall content of this master's thesis.

Chapter 1: Provides an overview of the document, including scope, motivation, and the research questions to be evaluated.

Chapter 2: Presents the necessary theory to be able to understand the technical content herein.

Chapter 3: Highlights the current knowledge and previous research serving as an input to this document.

Chapter 4: Provides a highly detailed description of the research methods that has been utilized. The chapter gives an overview of all construction, equipment and data acquisition that have been used and executed. Additionally, the plan, schedule and constraints are presented.

Chapter 5: Presents all results from the research. Some result specific discussion are also provided.

Chapter 6: Discusses the results and findings from the experiment, synthesizing all results and observations providing a solid evaluation of the research questions compared to the research questions and hypotheses.

Chapter 7: Provides the overall conclusion of the master's thesis rooted in the research questions.

Chapter 8: Presents a short summary of recommendations to future actions and research based on the described results and findings.

Chapter 9: Displays all references.

Eleven appendices are provided at the end of the document. All appendices are referred to in applicable chapters and sections below.

2 THEORETICAL BACKGROUND

2.1 INTRODUCTION

The science of how moisture behaves both in air and materials are elaborate and quite complex. There are many details necessary to evaluate when handling moisture migration, especially when evaluating experimental results. This chapter presents the required theoretical background to be able to understand the main concepts and core principles of what is presented in this document. There is much more details and in-depth theory available regarding all topics than what is presented. However, this chapter is limited to presenting the most relevant topics and information related to this master's thesis. The information is primarily divided into applicable material properties and moisture migration mechanics.

Moisture and moisture migration is divided into two main categories in this document: liquid water and water vapor. The term 'moisture' is the umbrella term comprising both water and water vapor described herein. The main transport mechanic for liquid water is through capillarity and the main mechanic for transporting water vapor is diffusion. In the main experiment presented in this document, the diffusion mechanism serve as a supporting mechanism to the main transport mechanism, being the capillarity.

A generally accepted definition of moisture is the presence of water molecules in a material, being a gas or a solid. In solid materials, the structure of the material is deciding for the moisture behavior in the material. In this master's thesis, cementitious tile adhesive and grout is the main material, structurally relatable to mortar and concrete.

'Fluid' and 'liquid' are used interchangeable in this chapter, and the experiments are mainly executed using water as liquid. A mix of soapy water has also been used, however for a very short time. Additional terms being used interchangeably is 'pores', 'voids' and 'cells'.

This chapter is divided into the following categories, where the content is distributed into individual sections and sub-sections:

- Moisture in air and materials, ref section 2.2
- Material properties, ref section 2.3
- Moisture migration mechanisms, ref section 2.4

2.2 MOISTURE IN AIR AND MATERIALS

2.2.1 Relative Humidity

As seen through much of the investigated literature, Relative Humidity (RH) is one of the key parameters to be able to predict moisture behavior in materials and air. RH is expressed by the ratio of current water vapor content in a gas to the maximum water vapor capacity at saturation, applicable for the same temperature and is commonly represented as a percentage [%], ref eq. (1). The unit of RH is presented in percent [%] in this document. RH is easily explained in air whereas the ratio is presented using the actual vapor pressure to the saturated vapor pressure. The pressure is derived from the ideal gas law [10, 11].

$$\phi = \frac{p}{p_{sat}} * 100\% \tag{1}$$

Where

ϕ = Relative humidity [%]

p = current vapor pressure [Pa]

p_{sat} = vapor pressure at saturation [Pa]

RH is also present in numerous materials and can be measured. For RH to be present in a material, the material needs to be a hygroscopic, meaning porous and permeable to moisture. The effects of RH related to hygroscopicity, porosity and permeability are explained in more detail below.

2.2.2 Absolute Humidity and Moisture Content

Absolute Humidity (AH) and Moisture Content (MC) is a measure of the quantifiable amount of water vapor and liquid water in a material. AH, or the mass concentration of water vapor, is a measurement of presenting water vapor usually in terms of weight pr volume [kg / m^3] or weight by weight [g / kg].

Utilizing models such as Tetens equation [12, 13] and Mollier's diagram [14] are valid methods for calculating and finding AH.

There are also several ways of calculating moisture content in building materials, using either ratios of weight- or volume in both dry and wet material conditions.

1. Moisture mass as weight percentage (u), unit: [kg / kg]
2. Moisture mass pr volume (w), unit: [kg / m^3]
3. Moisture volume pr material volume (ψ), unit: [m^3 / m^3]
4. Saturation between moisture volume and pore volume (S), unit: [-]

The most common quantifiable presentation of the water amount is the mass ratio of water to dry matter, listed as number 1. Above [10, 15]. Mathematical expression is presented in eq. (2).

$$u = \frac{m_w}{m_d} = \frac{m_{tot} - m_d}{m_d} \left[\frac{kg}{kg}\right] \quad (2)$$

Where

u = water mass ratio

m_w = mass of water

m_d = mass of dry material

m_{tot} = mass of moist material

Water mass ratio (u) is multiplied with 100 % and called moisture content ratio further in this document. Where only 'moisture content' is used, it refers to the amount of moisture in grams [g].

2.3 MATERIAL PROPERTIES – GENERAL

A hygroscopic material is defined by being a material that can uptake, withhold, transport and release water and water vapor [10, 11]. In cementitious materials, porosity and permeability are derived from the hygroscopic properties of a material. Both properties are described in sections below.

The material characteristics of a cementitious material is highly dependent on the ratio between water and cement (w/c), and water and binder (w/b) [16]. Binder is a common term for all dry ingredients in a concrete- or mortar mix, including the cement. In this master's thesis, w/b will be used consistently, as the isolated w/c ratio is outside of scope.

2.3.1 Porosity

An abundance of materials are porous in their structure. Meaning that there is a cell structure within the material, causing air filled voids in the material. This includes the tile adhesives as well as the ceramic tiles described in this master's thesis. Examples of materials not being porous are metals and glass having a closed pore structure [17]. Thus, the glass tiles used in the experimental research has a closed pore structure, hence no capability of absorbing fluid.

The hygroscopic behavior of a material is affected by several parameters, being highly dependent on individual pore size, the geometric shape, how the pores are connected and the orientation and layout of the pores. The number of pores (porosity), being the total volume of air voids inside the material determines the moisture holding capacity, i.e the total amount of water a material can hold. Moreover, the orientation, connectivity and layout of the pores affects the penetrability and transportability of water and water vapor, which is known as *permeability*. The term is explained in more detail further down, ref 2.3.2. If the material has a relatively open pore structure, with tunnels causing easy transfer of water and water vapor between the pores, it will probably cause it to have a high permeability. If a material is denser, with overlapping sheets of solids and no easy access between pores and voids, this will likely cause a lower permeability. Examples of different void layouts are seen in Figure 1.

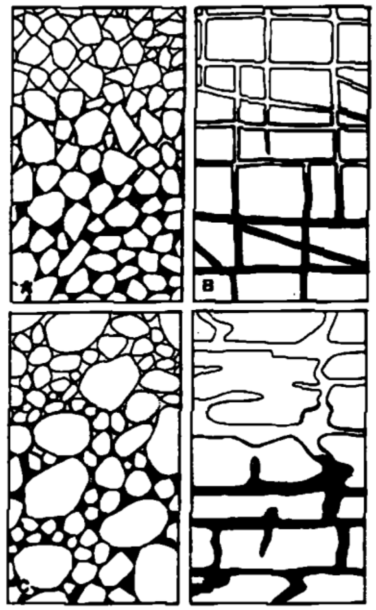

Figure 1 Porosity Layouts Showing Two Kinds of Round Voids (A & C) and Two Kinds of Cracks and Tunnels (B & D)[18]

Porosity can be calculated through several methods. The method applicable for this master's thesis is according to eq. (3).

$$P_S = \frac{V_{VS}}{V_S} * 100\ \% \qquad (3)$$

Where

P_s = Porosity

V_{vs} = Void Space Volume

V_s = Specimen Volume

2.3.2 Permeability

There are several different permeabilities within science. For this master's thesis two types of permeability will be touched upon. Water vapor permeability and liquid permeability. Generally, for the two, the property describes the flow rate of-, or the ability of transmitting either a gas or liquid in a porous material. In other words, the property describes the ability of gasses and liquid to flow through a material. A higher permeability rating means higher flow rate, hence the higher permeability number the easier it is for gasses or fluid to enter-, and flow through a material.

The permeability also relates highly to the w/b in a cementitious material. The higher the w/b ratio, the higher the permeability, due to the permeability increases as the RH increase in the material. This phenomenon can be seen in relation to the moisture adsorption in the voids in a material, described through sorption curves discussion in section 2.4.1.

Within liquid permeability (denoted as 'k' with SI-unit [m^2]), the most common definition is presented through Darcy's law, being an expression for permeability through a relationship between e.g. the flow rate and physical fluid properties in porous materials [19]. Another important parameter regarding liquid permeability is the hydraulic conductivity (denoted as 'K' with SI-unit [m/s]), which is defined as a global constant representing conductivity in regard to water flow through a porous material [20]. None of these expressions are used further in this master's thesis, however, they are highlighted due to creating the relationship between liquid- and water vapor permeance. Water vapor permeability is used further in this document and will be presented in more detail below. The same logic within the same parameter relationships having a permeability number and a conductivity number applies.

2.3.2.1 Water Vapor Permeability and Water Vapor Resistance

Water vapor permeability is usually denoted with the letter W, defined by an area, time, mass, and pressure with the SI-unit of [kg / m^2sPa] and describes a materials ability to let water vapor through the material through diffusion.

Water vapor resistance is usually denoted with the letter Z and is the reciprocal of the water vapor permeability (W), thus being presented with the SI-unit [m^2sPa / kg]. The water vapor resistance describes a materials ability to resist diffusion of water vapor.

Both water vapor permeability and resistance is described using numbers in the order of magnitude of $1.0 \times 10^{\pm 12}$, which is not particularly intuitive. Therefore, a much more perceptible term for expressing water vapor resistance through a building detail is commonly used within the industry, called equivalent air layer thickness or S_d-value, with unit given in meters [m]. The S_d-value can be presented as a product of the water vapor resistance and water vapor permeability of air; however, an easier approach through a water vapor resistance factor is more common.

The S_d-value is derived through Fick's first law through a unit called the water vapor resistance factor (μ) - equivalent air thickness layer. Through the derivative process of μ, a resistance factor for stagnant air is generated, hence the name equivalent air layer thickness. Through the use of water vapor resistance factor, the S_d-value is presented by the product of μ and the thickness d of the specific building material, according to eq. (4). The higher μ or d the higher the resistance of a material, or combinations of materials to water vapor through diffusion [10, 11, 21].

$$S_d = \mu * d \ [m] \tag{4}$$

The water vapor resistance factor is material specific and is determined through experimental research. Details regarding the origin of μ and how it is derived from Fick's first law is not significant for understanding the content herein, thus simply a general explanation is provided.

2.4 MOISTURE MIGRATION

For pure water vapor migration to occur, RH- needs to be below 40 %. Therefore, in real life situations, with fluctuating conditions throughout a broad specter of RH, moisture sorption and migration happens in a combination of water vapor and liquid water. Section 2.4.1 describes the overall moisture migration concept with the introduction to applicable technical terms, where the central concepts are presented further in sections below.

2.4.1 Overall Behavior of Moisture in Building Materials

2.4.1.1 Sorption

When describing a material's hygroscopic properties, usually it is the sorption which is described. Sorption is a collective term for both adsorption and absorption. Adsorption happens in two different forms which is applicable to this master's thesis. Either on the exterior surface of a material, being the outside of tiles or grout, or on the surface of the pores inside the material itself. There is rare that adsorption and absorption happens fully isolated from each other, thus the umbrella term sorption is mostly used [10, 17, 21].

A simplification of the explanation between the two terms follows below:

Adsorption

- The non-penetrable moisture stuck to a material surface, i.e. moisture attached to an external surface of a material.
- Moisture, usually water vapor, that sticks to the surface of the voids inside a material.
- Adsorption is defined as a surface phenomenon, as the moisture is taken up by the internal- and external surface of a material.

Absorption

- The penetrable moisture (in the form of water molecules in the context of this master's thesis) which transfer and dissolve into a material. The outer border of the absorption phenomenon is created by the outer surface of the material.
- Exposed surface area, pressure and concentration of moisture are all variables affecting the rate of absorption.
- Absorption is defined as a bulk phenomenon, as the moisture is taken up by the volume and pore structure of a material.

Sorption Curves

A sorption curve can roughly be divided into 3 or 4 zones, depending on the referred literature. Figure 2 below, shows a sorption curve for timber exemplified by 4 zones A-D. When the RH in the pore structure is high enough, a meniscus is created (explained in detail 2.4.2). At RH < 20 %, a single layer of water vapor molecules is present on the surface of the cell walls in the material (A), and a marginal meniscus is established. Further transport of moisture happens through a combination of both capillary transport and diffusion between RH = 20 % and 60 %, creating multiple layers of moisture (B). When RH becomes very high, between 60 % and 97 %, the meniscus becomes interconnected in the cells (C), causing more rapid moisture transport.

Beyond this point of RH = 97 % it is solely liquid water which is the dominant moisture migration force, and the effects of diffusion is marginal (D). Any RH above 95 % is seen as volatile, due to marginal control on the presence of water vapor and liquid water [10, 11, 17, 21]. At point (D), the air voids in the material is filled with water, and the capillary effect is triggered. As the practical experiments in this master's thesis primarily is influenced by liquid water, the main moisture transport mechanism is defined as the capillary effect, while diffusion is defined as a supporting mechanism. The two moisture migration mechanisms are described in more detail below, ref 2.4.2 and 2.4.3.

Tile adhesive, being a cementitious material with a number of additives, is mixed using individual w/b ratios, making it very hard to produce general sorption curves with specific values applicable for a selection of material compositions. Additionally, individual pore structures and layouts will form for each batch, potentially causing different material properties, making creation of general curves challenging. An example from SINTEF Byggforsk is presented in Figure 3, showing a specific moisture content of u = 2.5 in weight percentage (equal to 0.025 kg / kg) [22]. Due to individual material compositions and w/b ratios, the RH could be somewhere between 35 % and 90 %, making it very hard to estimate any value. Recommendations is therefore to measure the RH and document when critical RH is achieved in a specific situation. Tests according to NS-EN ISO 12571:2021 could be done, however due to structural irregularities in cementitious materials it is hard to perform accurate measurements [15].

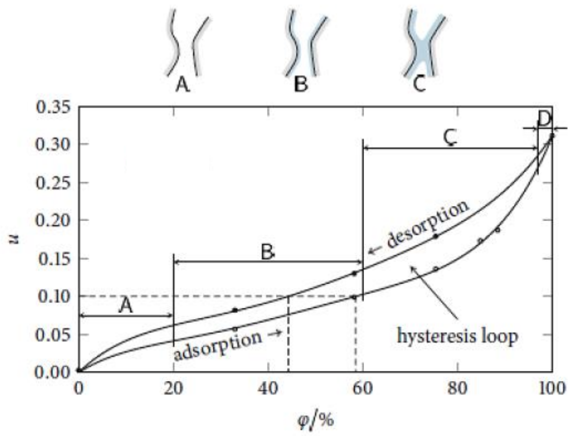

*Figure 2 Sorption Curve for Timber with Development of Meniscus within each Segment, ref Fig 4.9, p. 113 [10].**

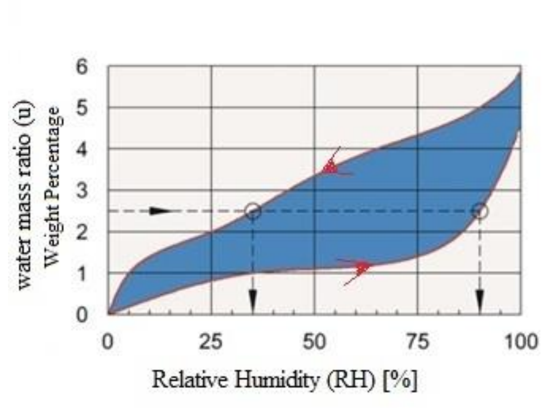

*Figure 3 Sorption Curve for Concrete Showing Variety of Possible RH at a specific Moisture Concentration, here 2.5, ref Fig. 56 [22].**

* Note: When establishing a sorption curve, it is important to have a stable temperature [15].

2.4.1.2 Hysteresis

The text in Figure 2, within the C-section states "hysteresis loop", between the "desorption" curve pointing downwards and "adsorption" curve in B-section, pointing upwards. Hysteresis is of high relevance to how moisture behaves in a material. It is an irreversible adsorption and release behavior in materials, where moisture content changes depending on whether moisture is being absorbed or desorbed at a specific RH. The behavior has in most cases significance for moisture gain, drying and moisture transportation.

From what is presented in Figure 3, where water content of u = 2.5 can either be 35 % or 90 % depends on the moisture history of the material, hence, the material is measured while gaining moisture (adsorption) or drying out (desorption). Transferring adsorption and desorption arrows from Figure 2 to Figure 3, shows that if the material is measured while drying, the RH will read 35 %, while if RH measurement happens during adsorption, the RH measurement will show 90 %. This can also be evaluated the other way around, RH reading at e.g. 50 %, means than the moisture content in the measured location is between u = 1.1 and 3.4 [10, 11, 17].

There are several theories that are discussed regarding the occurrence of hysteresis and the differences in RH at same moisture content, or different moisture content at same RH. Two theories can be presented supporting the reason for the hysteresis phenomenon:

- Water needs to "push" N_2 and O_2 away from the pores, demanding more energy during adsorption. While from wet condition moisture and H_2O molecules are present in the pores, having an abundance of water vapor present. [11]
- Pore size affects the possibility of the capillary effect happening due to adhesion force* between the pore walls and surface tension*. If a vertical pore is too wide, and the pore is empty (moving upwards along the adsorption curve) the adhesion force is not strong enough to create the necessary capillary force* within the pore. On the contrary, if water is present in the pore, the adhesion force (moving downward along the desorption curve) is strong enough to overcome the gravitational force [17].

* Note: Adhesion force, surface tension, and capillary force are explained below, ref section 2.4.2.

2.4.2 Capillarity

The capillary force is dependent on the material properties presented above, in addition to moisture concepts being introduced below. Surface tension is the most prominent force regarding moisture migration; however, an in-depth chemical explanation is not necessary to understand the content of this master's thesis. Thus, a principal explanation will be provided.

Capillary transport, also known as capillary force, capillary action, or capillary suction, is a transport mechanic where a fluid is moving through a material without the assistance of external forces. The different capillary expressions are used interchangeably in this document. The capillary action happens both laterally and vertically, even acting against the gravitational force [10, 23].

Capillary transport happens mainly due to three forces:

- Cohesion force
    - Intermolecular reaction between the same type of molecules

- Adhesion force
    - Intermolecular reaction between different types of molecules
- Surface Tension
    - Created by the cohesion force in the water molecules, at the interface between air.

The surface tension is affected by the cohesion force between the water molecules on the surface of a liquid, causing a meniscus (the curved surface created on the top of a fluid) to be formed. Surface tension is the energy required to stretch a unit change of surface area. The higher the tension, the less willing the liquid is to bind to external surfaces. Lower tension causes easier flow, as the intermolecular forces is lower, making it easier to bind to external surfaces. Hence, where adhesion forces are greater than the surface tension caused by the cohesion forces, the water will migrate in the pore structure.

Surface tension is also affected by water density and water temperature. The density of water at 38 °C is 993 kg / m^3 [24]. For this experiment, the accuracy of assuming 1000 kg / m^3 is deemed sufficient. To be able to measure or calculate the ratio between these parameters throughout an experiment becomes very complex. In the experiment presented herein, water temperature will likely change throughout the material in the tiled walls. For this master's thesis the focus on the moisture migration will be presented in a theoretically simplified way, not considering the surface tension dependencies in detail.

One specification regarding surface tension is still worth mentioning, based on the hypothesis regarding soapy water causing easier moisture penetration through the grout and migration in the tile adhesive. Soap does not change the surface tension of water, however, modifies it to be approx. half its value for pure water. Water at 20 °C has a surface tension at approx. 0.07 N / m while soapy water at 20 °C has a value of approx. 0.03 N / m depending on the water-soap ratio [25]. As lowering surface tension causes easier flow, the hypothesis was established.

The main dependency for the capillary force to act is the diameter of the pores. The smaller the diameter of a tube, tunnel, or pore, the higher a fluid will rise, and the further a fluid will migrate. In cementitious materials, such as concrete, mortar or cementitious tile adhesives, the pores are very small relatively speaking. With surface tension being the prominent force regarding capillary dependency, the combination with small pore diameter provides excellent moisture migration conditions [10, 17]. This is also seen mathematically in eq. (5), where the radius (r) of a tube, crack or void affects the height (h) greatly compared to the other parameters.

$$h = \frac{2\sigma * \cos(\theta)}{\rho g r} \qquad (5)$$

Where

h = height of liquid [m]

σ = surface tension [N / m] (Approx. 0.07 N / m @ 20 °C)

θ = contact angle (θ = 0 for clean surface) **

ρ = density of liquid [kg / m^3] (approx. 1000 kg / m^3 for water)

g = acceleration of gravity [m / s^2] (most common value is 9.81 m / s^2)

r = radius of tube or crack [m] (often within magnitude of µm)

**Note: Contact angle being the angle between the meniscus or droplet relative to the surface of the material, which for most building materials are equal to θ = 0, causing cos (θ) = 1, providing fairly reliable estimates in moisture migration at different pore sizes. However, realistically this is much more volatile both regarding migration direction and actual pore diameter. Other mathematical presentations are also relevant when discussing capillary transport, however this master's thesis has a more practical approach, and detailed calculations are not presented herein. Hence, further in-depth theoretical details are not provided.

If a cementitious material is mixed with a specific w/b, and there are large air voids and pores scattered throughout the material, this will affect the moisture migration. Large pores prevents the capillary effect from happening, due to the adhesion forces not being strong enough, causing liquid water to take detours. However large pores do not prevent the water vapor migration from happening through diffusion, making the to mechanics work in harmony.

2.4.3 Diffusion

Water vapor diffusion is defined as the movement of water vapor from a higher density region to a region of lesser density. Density can also be presented as mass concentration of water vapor or water vapor pressure. Diffusion happens mainly due to differences in water vapor pressure and water vapor's pursuit for attaining equilibrium [10, 21, 22].

The properties related to diffusion in a material fluctuates with RH. This relates also to the steady state vs transient calculations highlighted in State of the Art (Ch. 3) as a conscious evaluation to be made when performing experiments or design calculations etc. Diffusion values are often calculated through steady state settings, however it is recommended to calculate diffusion as a function of RH for a more valid calculation. Multidimensional and transient or dynamic diffusion is quite complex, therefore steady state calculation is often used.

2.4.4 Evaporation

Evaporation can be presented as water vapor diffusion in the material which evaporates when the water vapor has migrated to the surface of e.g. the grout in a tiled wall. Evaporation is generally the transition between liquid state into vapor state. Evaporation happens within the scope of the ambient conditions. The hotter and drier the ambient conditions are in the vicinity of the evaporation, the higher capacity the surroundings have of holding the evaporated water vapor. Evaporation from a building material means that liquid water and water vapor are migrating in- and away from the material, making the material lighter with less moisture content.

3 STATE OF THE ART

3.1 INTRODUCTION AND OVERVIEW

The overall reason for this chapter is to provide the reader with the current knowledge and status in the applicable areas for this master's thesis. In addition, provide a sufficiently detailed background for the research questions and hypotheses presented in section 1.3. This chapter is based on literature reviews and information gathering performed both during a preliminary study (pre-study) and the writing of this master's thesis.

The chapter is divided into two main parts:

- Section 3.2: A summary and highlights from the pre-study report written by the author of this master's thesis, completed during the course MABY5010 at OsloMet during fall of 2022 [26], including a presentation of the current state of today's research and knowledge regarding moisture handling in bathrooms and structures. This is supplemented by specific topics related to design and workmanship of bathroom walls, supported by governing guidelines that are available to ensure a solid and safe structure.

- Section 3.3: A presentation of the defined key parameters to be used in the research experiment, including literature background.

3.2 LITERATURE REVIEW

3.2.1 Overview

During the pre-study, literature from 16 countries were investigated. Additionally, further research was done during the writing of this master's thesis. Based on the findings, four main topics will be highlighted.

- Negative human- and structural effects, ref. 3.2.3.
- Standards and guidelines, ref. 3.2.4.
- Experiments and research methods, ref. 3.2.5.
- Design and workmanship 3.2.6.

3.2.2 Literature Review Summary

This section 3.2.2 presents a total summary of all details presented from section 3.2.3 until section 3.3.

Pre-Study Literature Summary

The overall conclusion from the pre-study highlights an industry that suffers from a high occurrence of issues and damage with high consequences and high indemnity cost. A general "trial-by-use" mentality, combined with the need to do more realistic experiments are also big topics. Realistic experiments should contribute to the standards and regulations which are governing in the building industry. Moreover, some of the articles states that the results from realistic experiments should be utilized as input for simulation tool SW, for better to be able to provide a solid set of input- and output parameters, as a measure to reduce occurrence of errors. Additionally, several of the reviewed documents describes the need for more knowledge, also across borders. Local climate and local governing rules are of course fundamental in a country's rules and regulation, but several papers highlight the positive gain of being able to utilize knowledge from foreign countries. One conclusion was emphasis on the concern of being subjected to a false impression of control, when an established technical baseline parameter exist as a governing requirement. It is always important to do enough research with realistic experiments prior to a regulation enactment, as well as not being blinded by the existence of a setpoint value which might be arbitrary and proves to be inadequate.

Master's Thesis Investigation Summary

The overall conclusion from the investigations done during the writing of this master's thesis highlights a building industry that has issues predominantly related to moisture. Damages and issues related to poor quality and workmanship, in addition to not being according to TEK17, is found to be above 60%. Laws, regulations, guidelines, and recommended solutions are well established, however buildings become more and more complex. Combining this with workmanship shortcuts and not enough research and knowledge regarding the current constructions, it becomes a challenging situation. From VASK statistics presented introductorily, there are increasing occurrences of damages, causing high indemnity cost. Even though the industry gain more knowledge in the field of moisture related damage in buildings as time progresses. This is a finding that should be reflected on and contribute to establishing a different approach regarding research, solutions, and attitude in the building industry.

3.2.3 Negative human- and structural effects

During the writing of this master's thesis, the author sent out a survey to a selection of relevant people and organizations within a broad specter of specialties, ranging from insurance companies, to building surveyors and microbiologists. The reason being to map out the damages which can be traced back to moisture in bathrooms that has gone astray. The survey asked for experience from situations with moisture that have affected wooden door frames, window frames or other structural materials negatively in the form of rot, mold, etc. Seven responded to the survey, where five had experience with the described issues. However, none of the respondents had any documented findings.

One respondent showed the author pictures from their own house, where water had been absorbed into the doorframe outside the defined wet zone (Wet zone is defined in section 3.2.4). The other respondents shared their experience with the author confirming the issue, and described moisture being present in doorframes and window frames outside the wet zone, either through professional or private circumstances. Preliminary conclusion based on the narrow sample rate is a frequent occurrence which resonates with the statistics.

Consequences from moisture affecting materials not being susceptible to moisture loads, cause high stress on both people and building materials. Many studies have pointed to Sick Building Syndrome (SBS) being a severe issue to people's health. SBS have been proven to cause a range of respiratory illnesses, even cancer and other highly serious conditions [6, 27-32]. SBS is often related to mold issues due to moisture in buildings. Mold and bacteria have even been found to grow in cementitious materials under highly unfavorable conditions for growth [33, 34], making mold potentially hard to discover.

An elaborate study was done in Norway in 2017, where 10 112 houses were investigated for issues and damages. The study was a collaboration between SINTEF, Norwegian Institute of Public Health (FHI) and The Norwegian Labor Inspection Authority (In Norwegian: "Arbeidstilsynet"). The research dataset was based on professional inspection reports and dweller self-reporting. Findings were defined as condition classes Condition Classes (CC) CC1, CC2, and CC3 (in Norwegian: "Tilstandsgrad" (TG)). Grade CC3 require repair and improvement, while CC2 should be repaired or improved. The study concluded with 31 % of the houses having damage or issues related to moisture with CC2 or CC3 [6]. This study also described the issues related to SBS, and the potential risks of living in a mold afflicted building. According to the study, there has been a decline in revealed damages in houses built from the 1980s. However, the article speculates in this being a false impression due to more dense and more complex structures in modern buildings, causing a challenges in revealing issues.

Moreover, a large report establish from an inquiry made by DiBK and the Municipal and district department (KDD) to survey the magnitude of construction errors in Norway. The project was performed in collaboration between Menon Economics, Multiconsult and Mycoteam between May 2021 and November 2022. The report revealed several harsh conditions related to constructional issues, concluding with half of people buying new houses reporting issues or damage. 70 – 85 % of the highlighted issues are related to moisture. A rather interesting and dismal finding in the report is that there are equally many issues related to wear and tear over time, as there are issues related to immediate situations to what the report calls carelessness and poor workmanship [7].

The main conclusion from the report by Menon et al. is that 75 % of buildings constructed between 2010 and 2020 has at least one building issue or error. 60 % of the revealed moisture damages are related to construction not being according to requirements in TEK17. The document specifies that bathrooms are the room with the highest frequency in reported errors, with a magnitude of 26.3 %. The report makes a remark regarding rectification cost of the identified issues related to neglecting requirements in TEK17 to be an average of approx. NOK 39 000, - pr case. The average indemnity cost related to moisture damage generally is estimated to be between NOK 60 000 to 95 000, -. The total annual indemnity cost related to the findings described in the report totals 500 Million NOK.

The final conclusion from the Menon-report clearly states that more knowledge and more knowledge distribution regarding the identified issues creates a much-needed awareness of the scope and magnitude. This might help to contribute where necessary to reduce the number of issues. Hence reducing risk of SBS, damage to property and excessive indemnity cost. From what is presented in this master's thesis, more knowledge as time progresses has yet to prove effective compared to number of issues.

3.2.4 Standards & Guidelines

The current applicable technical rules and regulations for erecting a building in Norway, is TEK17. These regulations are derived from The Planning and Building Act (Building Law) (in Norwegian: "Plan- og bygningsloven"), with DiBK being a central authority. In addition to the technical information provided in TEK17, regulations relating to building applications (SAK10) (in Norwegian: "Byggesakforskriften") is an equally important governing document called out by the DiBK [8, 35, 36].

TEK17 and SAK10 complements the Building Law and describes the minimum requirements regarding inspections, approvals, and quality control (SAK10) and the technical design and construction of a building (TEK17), to be legally allowed to erect a structure in Norway. SAK10 is mainly a planning and processing regulation and will not be discussed further herein.

As the requirements and guidelines provided in TEK17 is somewhat general in their description, a more specific and tangible set of guidelines are provided by SINTEF Byggforsk. Approx. 800 guidelines and building instructions are governed by SINTEF, providing proven and factual solutions to an abundance of structural building detail alternatives. The Byggforsk guidelines are not mandatory, however, some of the strengths of utilizing Byggforsk is the reference to- and ensuring accordance with applicable standards, as well as providing tested and validated solutions (in Norwegian: "Preaksepterte ytelser"). Additionally, SINTEF provides technical approvals of products, making sure they pertain to applicable standards as well as all Norwegian requirements (TG).

Wet Zone Definitions in Bathrooms

Figure 4 shows the definition of the wet zone described in TEK17, further detailed in the Byggforsk series. One part of the research question to be challenged is the horizontal length of the wet zone. As seen in the figure, the wet zone is defined by the directly affected showering or bathing area, in addition to 1.0 meter outside the specific installation. The requirement in this zone is to install a water-tight membrane with an equivalent water vapor resistance value of $S_d \geq 10$ m. If the room is below $4m^2$, all walls are considered wet zone.

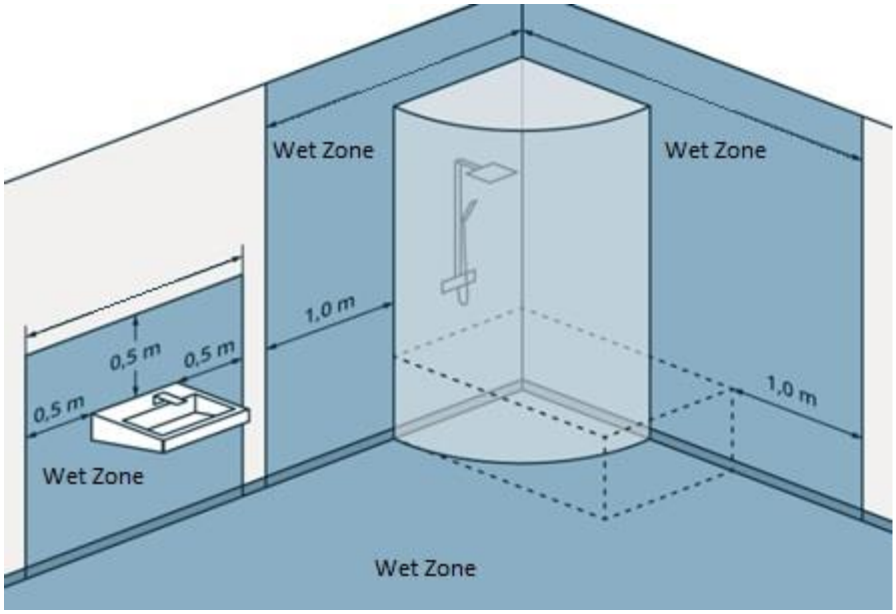

Figure 4 Wet Zone Definition in Bathrooms with a Larger Floor Area than 4m². English Version Based on TEK17 § 13-15 Figur 1[37]

An additional, and equally important set of specific guidelines and instructions for wet rooms, is The Norwegian Wet Room Norm (BVN) (In Norwegian: "Våtromsnormen") [38]. Byggforsk provides a certain level of details in wet room design and solutions, however the BVN specifies necessary details to be sure everything conforms with TEK17 in a more detailed way. BVN focus exclusively on wet rooms and sanitary installations and provides information to secure solid workmanship and technically valid solutions. The BVN was released in 1994 and has been continuously updated since. The guideline is a collaboration between SINTEF and The Faculty for Wet rooms (FFV) (in Norwegian: "Fagrådet for våtrom").

Additionally, there are numerous standards and guidelines for wall construction, tiles, tile adhesive, grout, workmanship etc. that must be evaluated when designing and constructing a bathroom. The specific documents being applicable for this master's thesis are described further below, in addition of being specified throughout the method chapter, Ch. 4 where applicable.

3.2.5 Experiments and Research Methods

Through the literature review a clear request for more realistic verification methods and proven, governing standards have been called out by multiple authors. Both regarding the ISO-standards describing verification methods, as well as standards describing design calculations for Heat, Air and Moisture (HAM) [28, 39-41]. The literature that have provided the most applicable input for realistic experiments and realistic usage of standards are presented in sub-sections below. The highlighted research papers also form the fundamental basis for evaluating the authors experiment setup and parameter input.

3.2.5.1 Swedish Research

Anders Jansson and other people connected to Lund University in Sweden has done several experiments regarding both evaluation of governing setpoint values regarding moisture safety in structures, as well as evaluating the verification methods themselves. Two main experiments performed by A. Jansson can briefly be highlighted:

In 2005 Jansson and his team evaluated if two vapor barriers are plausible in connection with constructing bathroom walls, one on each side of the building board mounted to the framework. Through this experiment, mainly being done using a Software (SW) simulation tool, they evaluated if the building codes provided be the Swedish Building Law related to water vapor diffusion resistance (Z), and the S_d-value, were sufficient and reasonable. The guidelines from The Swedish National Board of Housing, Building and Planning (BBR) (in Swedish: "Boverets Byggregler") from 2006:12, states an S_d-value of minimum 25 m [42], while the simulation by Jansson concluded with a minimum required S_d-value of 37.5 m, preferably 50 m to prevent moisture related damage to framework, building boards and adjacent structures. Additionally, Jansson concluded with having double vapor barriers is risky but plausible as long as the barrier located furthers inside the structure has the highest Sd-value [43]. For comparison, the Norwegian TEK17 has a minimum requirement of S_d = 10 m and a single vapor barrier closest to the indoor environment [37]. This is interesting as the climate and many of the building regulations are relatively similar in both Norway and Sweden.

In 2006, Jansson and his team used the data from the 2005 study to perform a practical experiment to evaluate the vapor resistance values that were recommended in the 2005-study. A full-scale practical experiment was performed, comprising four constructed tiled walls with eight different commercially available vapor barriers. The test duration was three and four months for individual walls respectively, where the walls were subjected to showering through a series of nozzles providing a shower sequence of 15 min twice pr day, with a water flow rate of 5 l / min at approx. 40 °C. A conclusive remark made by Jansson, states that water which has penetrated the grout and started accumulating in the ceramic tiles, caused the walls to need six months to completely dry out [44]. In addition, there is stated that saturation and RH = 100% can always be assumed in the tile adhesive when using a normal, daily showering cycle.

The vapor barriers were tested using a transient approach to evaluate the actual vapor resistance. This is not relevant to the scope of this master's thesis and will not be addressed further. The experiments done by Jansson is not directly transferrable to the research question described herein regarding vapor resistance. However, regardless of having a different research focus, the literature by Jansson provide valid and applicable knowledge regarding challenges with established requirement values that remain unchallenged. Additionally, providing inspiration for input to the experiment setup and parameters described herein.

Another research example is done by the Swedish business sector called Golvbranschen Riksorganisation (GBR). Golvbranschen performed an experiment, exposing a tiled wall for water for 30 minutes each 12th hour, using a shower head, for a duration of five months. The tiled wall was 4 m x 3 m in size, joined by a 1 m deep floor mockup in the bottom corner. 32 moisture sensors were installed in the wall on strategic locations to be able to map the RH. The tiles used in the experiment was 150 mm x 150 mm ceramic tiles, which were adhered to the wall using tile adhesive and grout [45].

The Swedish wet zone definitions are the same as the Norwegian ones, related to the defined 1-meter limit described in Figure 4. The experiment done by Golvbranschen focused on logging the RH from all sensors and evaluating if the sensors towards- and outside the 1 m wet zone was increasing beyond critical values. According to the study, the RH-sensors at the 1 m wet zone limit, and beyond did not reach any critical values.

The research performed by Golvbranschen provided insight into possible RH-sensor positioning, as well as input to be evaluated regarding showering duration, tiles, and overall setup.

3.2.5.2 SINTEF Grout Experiment

SINTEF Byggforsk conducted experimental research looking into different grout and their behavior when subjected to water during showering. The purpose of the experiment was to observe moisture behavior in the grout, and to map the penetration rate of moisture transport into the tile adhesive in addition to observe how the ceramic tiles absorb water. The report from the experiment is archived as a local file in the SINTEF Configuration Management system. As it is archived locally, most of its content is paraphrased in Appendix K and the overall highlights are presented below [9]. This is done as citing is challenging due to the archiving circumstances.

A test rig comprising a wall clad with 150 mm x 150 mm x 5.8 mm ceramic tiles and grout width of 3mm and 5 mm was built in five different configurations. The number of tiles in width was five, and the number of tiles in height was six, providing a total tiled area of 0.67 m^2. Total grout length is stated to be 738 cm. The rear of the walls were transparent, providing possibility to observe the water penetration through the grout, ref Figure 6. Overall setup is presented in Figure 5.

Figure 5 Grout Experiment Setup with Shower Head Aimed at the Tiled Wall

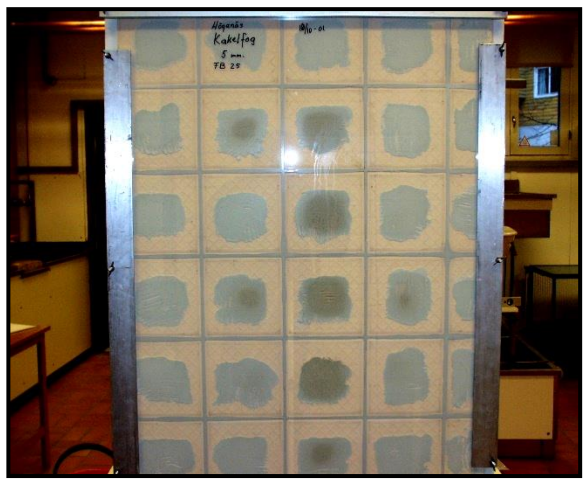

Figure 6 Tiled Wall Seen from the Rear Showing Tiles and Tile Adhesive.

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Three types of grout was used, where type 1 was a single component cementitious grout and type 3 was an epoxy variant. One type of tile adhesive was used in all configurations, being a single component cementitious tile adhesive. The tiles were not adhered using full adhesive coverage, instead the tiles were mounted with approx. 50 % coverage, with the tile adhesive centered on the tile, seen in Figure 6.

The flow rate was 6 l / min with water temperature of 20 °C. The tiled walls were exposed to water for 60 minutes, and the following results are presented:

- Type 1 with 5 mm grout width had first visible moisture in the rear after only 9 seconds, where all tiles where visibly wet after 15 minutes
- Type 3 with 5 mm grout width showed no moisture after 60 minutes.

The results from the report can be concluded with a relatively high permeability for the type 1 grout, following a rather quick moisture uptake in the tiles. However, the epoxy version is defined as totally water-tight within the duration of the experiment.

The findings from this SINTEF experiment can also be connected to a study performed in 1986, where cementitious grout was compared to silicone- and acrylic grout. The study focused on moisture saturation in grout, where it concluded with recommendations towards grout including silicone and acrylic additives, compared to single component cementitious grout regarding watertightness. The tested single component grout reached saturation at 9 minutes and acrylic at 1 200 minutes [46].

3.2.6 Design and Workmanship

This section is based on science and knowledge from all associations and guidelines mentioned above, in addition to other contributors where specifically described below. Whenever 'the industry' is used, it refers to a collaborative term including all mentioned contributors, as well as other providers within the field of products, craft industries, guidelines, and suppliers within the scope of this master's thesis.

3.2.6.1 General

In addition to TEK17, SINTEF Byggforsk and BVN, there are other providers with the intention of supplying guidelines to ensuring high quality design and workmanship in Norway. Where BVN is derived from TEK17 and SINTEF Byggforsk, intended as a specified norm applicable only to wet rooms, Norway also has a further specified sector association which specializes in tiles, natural stone, slate, tile adhesive, grout etc. intended for wet rooms and public swimming pools. The Norwegian Association for Building Ceramics (NBKF) (in Norwegian: "Norsk Byggkeramikkforening") was established in 1988, derived through a project in SINTEF. NBFK is now a large association comprising more than fifty industry members and several research collaboratives providing solid knowledge and availability in their field. The contributions from NBFK will be discussed below.

3.2.6.2 Tiled Wall Structure

A shower wall panel or glass shower wall (in Norwegian: "dusjnisje") is a common construction detail when installing a shower in a tiled bathroom. Figure 7 shows a typical glass shower wall installed on the surface of a tiled bathroom wall. Figure 8 shows the same method from top view with the tile adhesive having an unhindered access on both sides of the glass wall. This is a solid solution, however, might be vulnerable if knowledge of moisture migration in the tile adhesion is limited. The awareness regarding moisture being able to migrate in the tile adhesive behind the shower wall is identified in some guiding documents and books [47, 48]. However, to the author's knowledge and according to discussions with several people in the industry, the extent of the migration has not been presented in a particularly perceptive way prior to the experiments performed in this master's thesis. One of the main gaps in current research is therefore to highlight the moisture migration that occur from inside the water exposed area, outside the visible borders in a shower zone.

Figure 7 Glass Shower Door Installed on a Tiled Bathroom Wall [49]

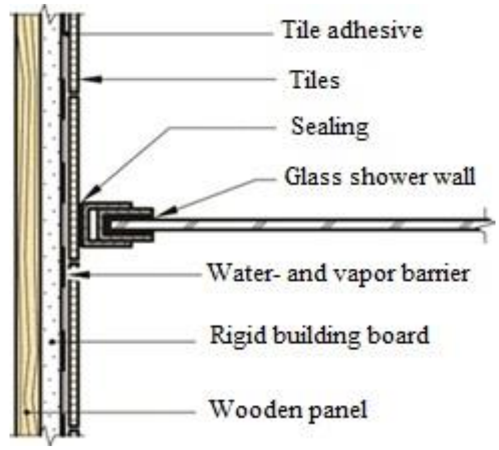

Figure 8 Glass Shower Door in Top View. English Figure Version based on Byggforsk 543.506 Fig. 15 a [50]
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The structure and buildup of a tiled bathroom wall is provided in several guidelines from SINTEF Byggforsk. In addition, there are several standards and guidelines that are applicable when designing a tiled bathroom wall. All standards and guidelines deemed pertinent for the construction of the walls in this master's thesis are called out and presented in sufficient details in Ch. 4.

3.2.6.3 Tile Installation and Materials

Suitable tiles needs to be adhered to an appropriate building board using some sort of tile adhesive. There are an abundance of different types to choose from on the market, from several providers. As presented introductorily, Mapei AS has been a contributor and collaborator at the start of this master's thesis period. They have provided a selection of tile adhesives from Mapei's product line, where the chosen types are presented in detail in Ch. 4.

Sufficient tile adhesive coverage between the applicable surface and tiles are critical to ensure proper installation, structural integrity and to make sure the tiles last throughout their whole lifetime. Tile adhesive coverage is a crucial factor in the construction of a tiled wall. As specified by NS3420:2019, part N, there is a high necessity of complete tile adhesive coverage between the tiles and mounting surface in industrial wet rooms and swimming halls, however dwelling wet rooms are not specifically described [51]. Anyway, Arne Nesje states in a NBKF article that required adhesion force is critical in all installations, and insufficient pressure on the tiles during installation might cause issues. Following this, the risk of trowel grooves in the tile adhesive is imminent [52]. Mr. Nesje is a specialist in tiles and tile constructions and has also worked as the General Manager for NBKF for several years.

Documentation of the recommended trowel direction of the tile adhesive is scarce, however, based on conversation with several people in the industry, especially craftsmen, there is a broad consensus of applying the trowel pattern of the tile adhesive vertically on the applicable surfaces. This is seen as a solid solution, both during installation and the fact that the whole floor is defined as a wet zone according to TEK17. Hence, a correctly designed and built floor solution according to Byggforsk 541.805 will make sure that water are safely handled and will be routed towards the floor drain [53].

The most relevant documentation of the trowel pattern orientation is found in articles written by senior researcher Mr. Nesje. He writes that a good workmanship rule is to pull the tile adhesive application vertically, providing water with a way of escaping from the grooves. If moisture is trapped in horizontal trowel pattern, this may lead to water and moisture reaching doorframes etc. outside the shower zone or wet zone [47]. In both new construction and repairs, horizontally trowel pattern is seen, ref. Figure 10, in addition to the curved trowel pattern, also identified by Byggforsk in Figure 9.

Figure 9 Curved Tile Adhesive Trowel Pattern, Ref Fig 64a - Byggforsk 543.301[54] Copyright © SINTEF Byggforsk - Published in Agreement with SINTEF Byggforsk

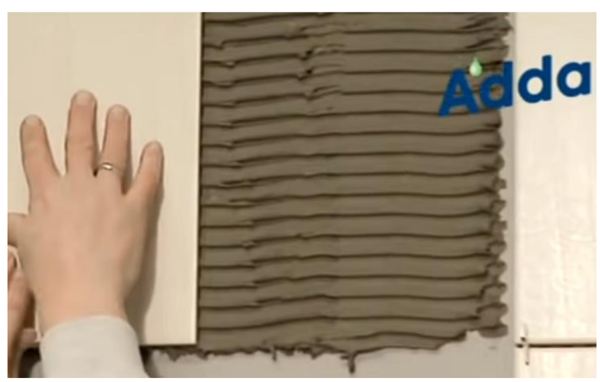


Figure 10 Horizontal Trowel Pattern in Tile Adhesive during Tile Installation [55]

In the monthly technical article released April 2022 by NBKF, a discussion whether a hollow noise, indicating potential missing adhesive coverage, hence potential grooves in the adhesive should be defined as a negative Condition Class (CC2 or CC3) or just a characteristic state [52]. This indicates that the industry has not yet concluded whether the described issue is an issue at all. However, Norwegian Standard NS3420:2019, part N, describing workmanship of tile work, clearly states that the work needs to be executed in a way which secures full adhesive coverage between the tiles and foundation / building board etc. [51].

An example of poor tile adhesive coverage is seen in Figure 11 and Figure 12, causing trowel pattern grooves, which may lead to moisture being transported outside the defined wet zones, resulting in property damage.

Figure 11 Visible Trowel Pattern in the Tile Adhesive due to Insufficient Tile Installation Pressure (I) - ref [52]

Figure 12 Visible Trowel Pattern in the Tile Adhesive due to Insufficient Tile Installation Pressure (II) - ref [56]

3.3 KEY PARAMETERS

This section describes the key parameters that lay the foundation for scheduling and planning a realistic execution of the practical experiment.

3.3.1 Shower Water Flow Rate

Several product webpages, scientific literature and other literature have been reviewed to establish a reasonable shower flow rate. Based on the reviewed sources, the typical shower provides a flow rate of between 8 to 16 liters pr minute. The so-called economy shower heads available in the market has a flow rate of 6 l / min, while showers defined as generous, has a usage of 16 l / min. Test standards in the European Assessment Document (EAD) series regarding watertightness testing provided by the European Organisation for Technical Assessment (EOTA), is at the absolute high end of the spectrum with a flow rate of 18 l / min [57]. Based on the reviewed products and literature, flow rates of 10 l / min and 11 l / min has been identified as the most common [58, 59].

The results from the collected literature sources establish the foundation for the planned flow rate in the experiment and conclude with a target value of 10 l / min ± 2 l / min.

3.3.2 Shower Water Temperature

The background for establishing the applicable water temperature for the main experiment is based on a mix of scientific and non-scientific literature. The shower temperature that most sources define as comfortable ranges from 35.0 °C to 40.2 °C [59-62]. Many commercially available shower faucets has a safety function, preventing the user from adjusting the temperature to an unsafe temperature. This mechanism is usually found between 38 °C and 40 °C.

The findings from the reviewed literature establish the foundation for the planned water temperature in the main experiment, and concludes with a target value of 38 ± 3 °C.

3.3.3 Shower Duration

The literature background for establishing the applicable shower duration is a mix of non-science forums, as well as journal articles. The advantage of using non-scientific forums are that they provide information on a grassroot-level directly from the general population. The negative side might be non-controlled responses and a missing peer review of the data. The results from two polls from the Norwegian webpage kvinneguiden.no were utilized:

- Based on 235 votes, the highest average of 37 % answered 6-9 minutes [63].
- Based on 196 votes, the highest averages being 28 % and 30 % answered 0 - 10 minutes and 11-15 minutes correspondingly [64]

Based on a survey performed by YouGov, 2000 adults replied to the survey. There were some varieties between the respondents showing an average of 8 minutes for women and 7 minutes for men. Additionally, it was shown that younger adults ranging in the age between 18 and 24 had an average shower length of 11 minutes 26 seconds [65].

A survey done in the United Kingdom (UK) has also been evaluated as input. The study is quite elaborate going into much detail regarding hygiene and the frequency of how people shower. More than 70% of the responders said they shower 7 or more days during a week [66]. Additionally, a questionnaire performed by Opinion with an unknown number of respondents shows that 80% showers approx. 10 minutes every day. Around 30% of the respondents showers approx. 5 minutes every day. [67]

The results from the collected literature sources establish the foundation for the planned shower cycles in the main experiment and conclude with a duration of 8 minutes each.

4 METHODS & METHODOLOGY

4.1 INTRODUCTION AND OVERVIEW

Within scientific research, it is important to document and provide sufficient information regarding an experiment to be able to ensure research integrity and reproducibility. It is critical to establish a thorough experiment baseline to be able to recreate the experiment at any time with as much detail as possible. The holistic intention of this chapter is to present a solid understanding into how the research and experiments are planned and executed to be able to answer the research questions and the hypotheses. Chapter 4 presents the overall methodology and applicable methods, with emphasis on describing details into how the experimental research is set up and executed. This chapter also describes the schedule, plan, and experiment procedures in addition to all necessary information to substantiate decisions and choices made prior to- and during the research. Several data acquisition processes are established and described, which serves as input for further analysis.

Two laboratory experiments are performed and described herein:

Main Experiment

- Water exposure on 3 tiled bathroom walls in two different stages:
    - Stage 1: Un-saturated, i.e. RH < 100%
    - Stage 2: Saturated, i.e. RH = 100%

Supporting Experiment

- Water sorption experiment
    - Water sorption measurement in 4 different tile adhesives and 1 type of ceramic tile.

4.1.1 Chapter Overview

Chapter 4 is divided into the following sections:

4.1 – Presenting a holistic introduction to chapter 4.

4.2 – Describes the evaluated quality management incl. configuration and safety & health.

4.3 – Presenting the facility and laboratory which has been used during the experiment.

4.4 – Describes an early phase prototyping, establishing a foundation for the main research. The presentation of this research is included in the Method chapter and not the Result chapter due to being an input to the main research.

4.5 – Detailing the design and construction of the walls, defined as the Equipment Under Test (EUT).

4.6 – Presents the installation and setup of the EUT in the laboratory.

4.7 – Describes all utilized data acquisition and equipment in addition to the defined calibration regime.

4.8 – Defines and presents the experiment plan and schedule.

4.9 – Presents the experimental procedures performed during the laboratory work.

4.10– Describing applicable assumptions and known limitations.

4.1.2 Prepared Documents and Register Forms

To be able to establish a solid design baseline of the experimental research, as well as ensuring that evaluation of the research questions and hypotheses are possible, several documents have been established. Detailed experiment procedures, design documents and data collecting documents have been composed, and reviews have been conducted between the author, supervisors, and other stakeholders. All necessary content for sufficiently understanding the setup, method, experiment execution, data logging, registering etc. have been extracted from the specified documents and presented in this Chapter 4.

A simplified version of the Experiment Procedure is found in section 4.8, and the full version is found in Appendix A. The design document for the EUTs are found in Appendix B. The remaining documents (e.g. Logbooks or data collection templates) are not provided individually as they are presented satisfactorily in the main part of this document.

The following documents have been established and serve as a key contributor to the completion of the master's thesis:

Experiment Procedures

- Describing the procedures regarding experiment setup and the daily measurements to be done throughout the experiment period.

Design Documents

- EUT design including construction- and assembly instructions.
- RH-sensor design layout.

Logbooks

- Experiment logbook for the main water exposure on the EUTs.
- Experiment logbook for the supporting water absorption experiment.
- Experiment log for observation, photo mapping and daily actions to be followed up.
- Experiment log for all measurements related to RH-logging.

Minutes of Meeting Template

- To be utilized for all conducted meetings between author, supervisors, and other stakeholders.

4.2 QUALITY MANAGEMENT

When planning and executing experimental research, there are many evaluations to be made regarding best practice of the research. To be able to ensure full research control and integrity, considerations related to parameter control, setup, system calibration, assumptions, intention, etc. needs to be thoroughly evaluated. There has been evaluated several uncertainties and constraints related to the setup, as well as governing assumptions. An extensive effort has been put into evaluating the accuracies regarding the experiment setup itself, in addition to logging- and measuring equipment. Actions taken to mitigate risks and setup uncertainties, as well as establishing the accuracy in the logging equipment are described in sections below.

All equipment for data acquisition and logging purpose have been calibrated, either individually or in a complete system intended for a specific experiment setup. All evaluated setup mitigations and calibration handling are described in more detail in sections below.

This section describes the evaluations made regarding Quality Assurance (QA), Configuration Management (CM) and Health, Safety & Environment (HSE).

4.2.1 Quality Assurance

This master's thesis is based on the scientific method, with the process of having an established research question with hypotheses, as presented in 1.3, performing an experiment, analyze the data and present the findings [68]. With the author of this master's thesis having several years of experience within QA engineering, it is natural to utilize some of this experience during the master's thesis. There is a tried-and-true QA approach within verification and experimental work that is derived from the scientific method, named the Plan-Do-Check-Act (PDCA) cycle [69].

Using the PDCA approach stimulates a thorough thinking process regarding the plan, intention, and the execution, not least having continuous control throughout the experiment. Prior to- and during the experimental research, there has been taken extensive measures to ensure QA in all research steps.

4.2.2 Configuration Management

To ensure a satisfactory CM, all choices and applicable documentation governing the design, planning and execution has been part of a review process. Either by peer-review followed by formal review, or formal review only. The object applicable for a review was initiated and established by the author, and the relevant personnel was summoned for the review. The external- and internal supervisors were always present during the reviews, and additional personnel was summoned based on applicability. Following a solid QA-approach regarding communication between stakeholders, Minutes of Meeting (MoM) has been produced and followed up by the author to make sure that agreements, plans, and actions are handled accordingly both from reviews and other meetings.

4.2.3 Human Safety & Environment

As part of HSE, there was performed an inspection of the laboratory and experiment setup where possible hazards were identified and mitigated. The inspecting party consisted of a SINTEF Safety Representative and the author. A risk evaluation document was established by the author of this master's thesis, where the identified risks were listed. The document was signed by both parties and hung on the entrance door to the laboratory.

The signed document is found in Appendix D.

4.3 EXPERIMENT FACILITY AT SINTEF

The laboratory identified as U60, in the SINTEF Community building in Børrestuveien 3, has been dedicated to the practical experiments of this master's thesis. The laboratory is located relatively secluded with only one entry point, with a small number of people entering the lab. Active ventilation is installed in the ceiling, and the temperature is fairly stable at approx. 22 °C throughout the day. The RH was measured at a stable 11 % in the days leading up to the experiment startup. This is quite low; however, no actions have been taken to control the RH in the lab. As seen throughout the experiment, the RH fluctuates between 10% and 30% due to higher concentration of water vapor during water exposure on the tiled walls.

As the experiment requires a drain to lead away the excess water from the shower use, this laboratory is a great fit as it has an approx. 300 mm wide gutter running alongside the edge of the wall. Above the gutter, there is a concrete support beam which is used for mounting the EUTs. In addition, the laboratory has cold and warm water access through a common faucet, and a traditional sink. All-in-all the laboratory is highly functionable for the intention of the experiment with every defined necessity within close proximity.

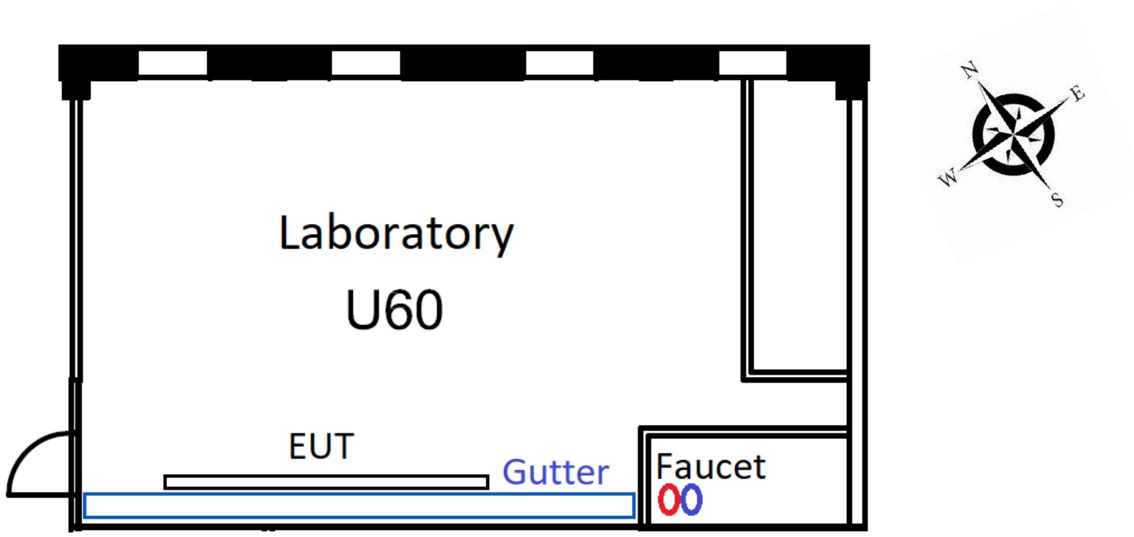


Figure 13 Planview of Laboratory U60 Used for All Experiments incl. Faucet, Gutter and EUT Location. Global Orientation to Magnetic North is Shown Top Right

4.4 PROTOTYPING

An early-stage prototype of a tiled wall was built to be able to gather information regarding adhesive drying time as well as establishing an expectation of moisture migration in the tile adhesive. A simple glass door was clad with ceramic tiles using a similar single component cementitious tile adhesive and a similar grout as used in the EUTs. One side was grouted and the other one was not. All tiles used on this wall was the same ceramic tiles as the ones used in the main water exposure experiment. The main setup of the glass door and the water exposure is found in Figure 14 and Figure 15. Both sides of the prototype was scheduled for an 8-minute shower cycle using cold water. After the 8 minutes of exposure was finished, an estimation of water accumulation was done.

Figure 14 Prototype Water Exposure Setup without Grout between Tiles

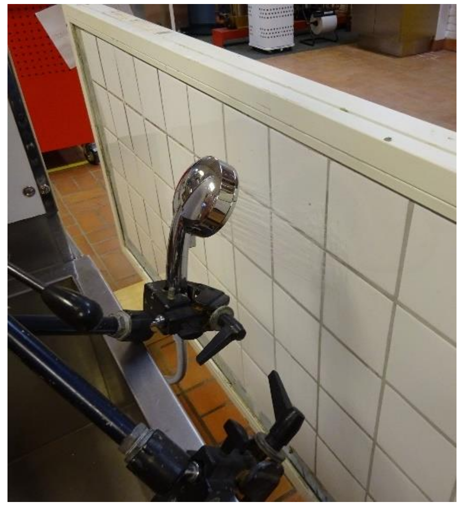


Figure 15 Prototype Water Exposure Setup with Grout between Tiles

4.4.1 Prototype Results

Results from both of the exposed sides of the prototype is described below.

4.4.1.1 Without Grout

The side without grout had the first occurrence of visible moisture immediately in the total exposed area, towards the bottom of the wall. The moisture accumulated area measured approx. 500 mm in width and approx. 1200 mm in height. After 8 minutes of water exposure, the total area affected by moisture measured 800 mm x 1200 mm with numerous occasions of horizontal and vertical capillary transport behind the tiles. An additional observation can be mentioned regarding water transport. Between the glass and the tile adhesive, a considerable amount of running water was observed. See results after 8 minutes in Figure 16.

4.4.1.2 With Grout

The side with grout had the first occurrence of visible moisture immediately on the bottom part of the wall. This was expected due to the layout of the wall, and the capillary effect at the bottom. After 2 minutes, the first observation of visible water in the tile adhesive was present at the water impact area. After 8 minutes of water exposure, several areas had visible moisture in the tile adhesive. A vertical capillary transport of approx. 200 mm was observed from the bottom, and the area largest in visible moisture was approx. 100 mm x 100 mm in size, in addition to two smaller areas. See results after 8 minutes in Figure 17.

Figure 16 Water Exposure after 8 min – Without Grout between the Tiles

Figure 17 Water Exposure after 8 min – With Grout between the Tiles

4.5 TILED WALLS - EQUIPMENT UNDER TEST

The 4 tiled walls, defined as EUT, is structurally divided into Base Walls and Complete Walls. This section describes the design and construction of both. The design of the Base Walls were planned in collaboration between SINTEF and the author, while the construction of the Base Wall framework was done by SINTEF personnel. The design of the Complete Walls were done by the author, continuously discussed with the supervisors. Much consideration is put into the design of the walls, making sure the purpose and aim of the experiment is achieved. In addition, aiming to fulfill the standards and guidelines which has been defined as applicable for this experiment is of high importance. SINTEF Byggforsk, BVN and NBKF have been chosen as the governing guidelines for the structural buildup of the EUTs. The EUT design is structurally inspired by a combined from Figure 18 and Figure 19.

Supplementary images from the construction process is found in Appendix F.

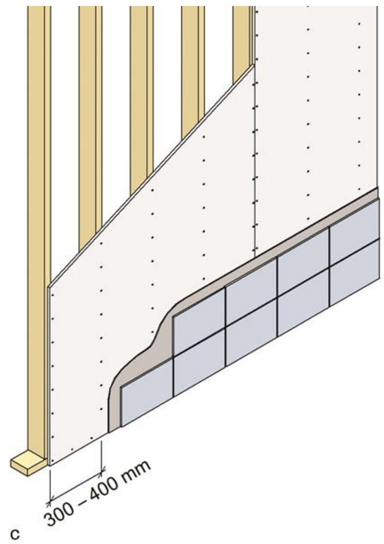


Figure 18 Stable Base for Tiles w/ One Building Panel on Wooden Frame w/ cc = 300–400 mm. Ref Fig 54c [54]

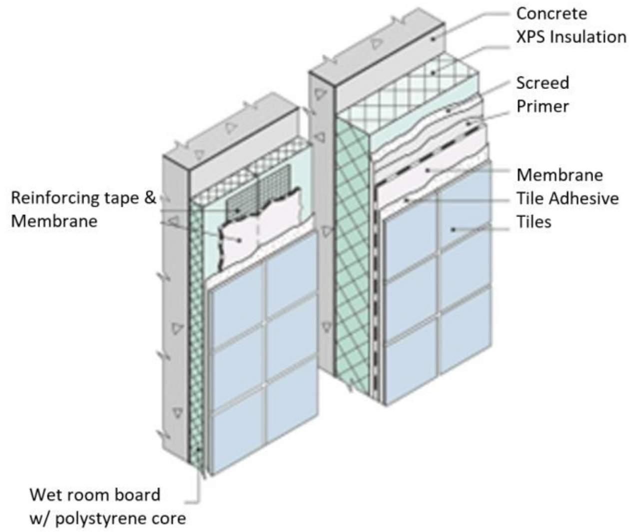


Figure 19 Example of Exterior Concrete Wall w/ some Interior Insulation. English Figure Version based on Fig. 55 [70]

Overall description of the design and construction are given in sections 4.5.1 and 4.5.2, while detailed technical information regarding geometrics, data of the materials and equipment are provided in Table 3 in section 4.5.1.

4.5.1 Base Walls

The 4 Base Walls comprise 3 Litex wet room boards joined by Litex sealing tape, mounted to a wooden frame using Litex mounting screws w/washers. All bolts were sealed with the same sealing tape as the boards to prevent moisture intrusion during the experiment. To ensure both financial budget control, ease of construction, as well as handling of the walls, a standard size of building boards were chosen. Using standard sizes of the wet room boards and supporting materials, also ensured control regarding research questions and the possibility to evaluate all established hypotheses. Details regarding materials are found in Table 3. See Figure 20 and Figure 21 for the assembled Base Walls.

Figure 20 Front side of Base Wall Showing Litex Boards and Litex Tape

Figure 21 The Rear of the Base Wall Showing the Framework w/ Attached Litex Boards

The wooden frame is drilled with two holes on top, equally spaced from the center, and one at each side towards the bottom end, with an M8 drill bit. The holes are intended for mounting the Wall Hoisting Assembly and the Support Legs for stabilizing the EUT. See Figure 22 and Figure 23.

Figure 22 Support Legs Bolt Used for Stabilizing the Wall

Figure 23 Wall Hoisting Assembly Bolt for Mounting Wall to Ceiling

RH-sensors are attached to the Litex wet room boards as part of the Base Walls. The sensors are placed based on the Sensor Location design document presented in section 4.1. The final Base Wall with the mounted sensors are shown in Figure 24. The sensors are strategically positioned based on the hypotheses and the assumption of moisture migration behavior, to be able to capture the fluctuation in RH as the experiment is progressing. In addition, it is important to establish a foundation for being able to collect data of RH towards the edge of the imitated wet zone of 1 meter. Through this data collecting it is also possible to predict further moisture migration behavior outside the time allocated for this master's thesis experiment duration. The identification of the sensors are unique to each EUT, with a sequential integer logic:

Sensor ID "SX-y", where S = "Sensor", X is the unique EUT ID, and y is the sensor numbers between 1 and 10. See sensor identification for EUT#1 in Figure 25. The "Shower" in Figure 25 shows the location of the water exposure target area.

The sensors and accompanying equipment are described in further detail in section 4.7.3.

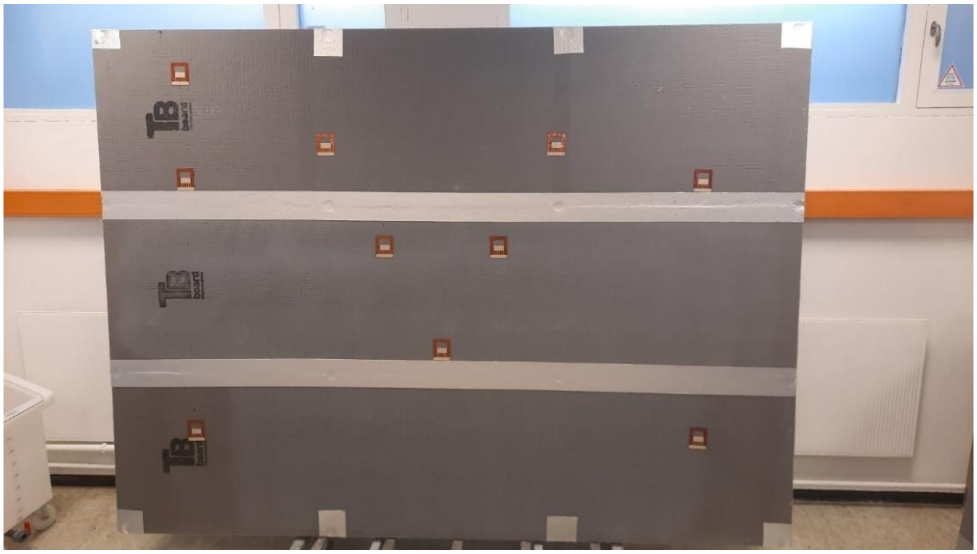


Figure 24 Overview of the RH-Sensor Locations Attached to the Based Wall

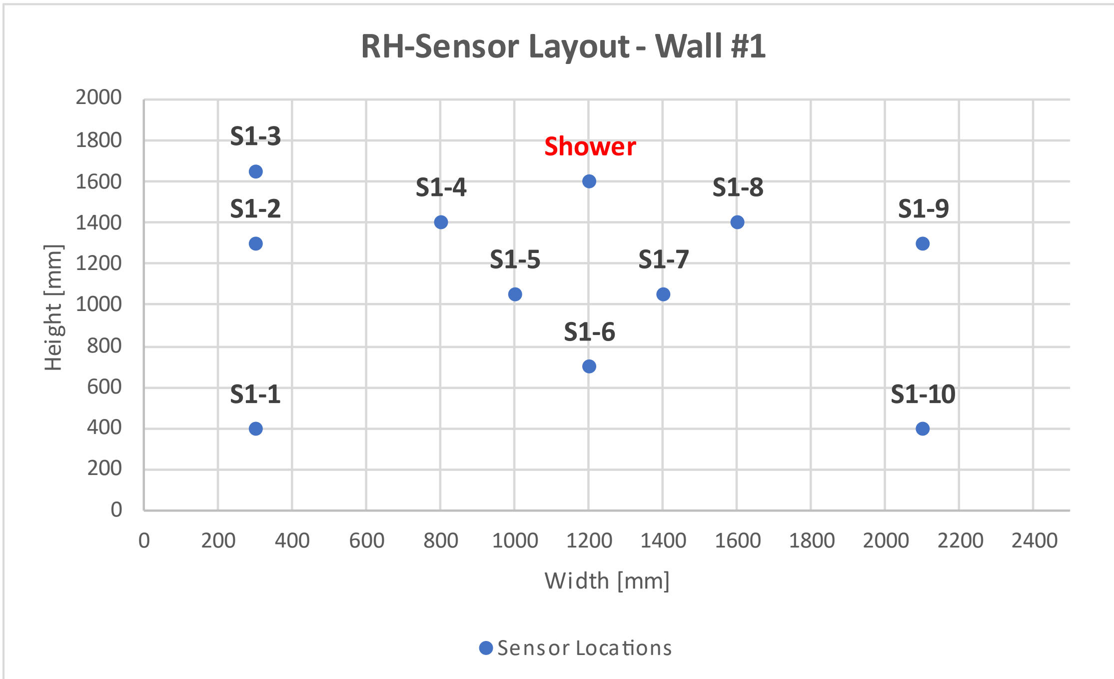


Figure 25 Overview of the Sensor Identification and Locations for EUT #1

4.5.2 Complete Wall

After the Base Walls are completed, construction of the Complete Walls are the next step in the process. The Design Document for the EUT design is the governing document for the Complete Walls. All 4 EUTs are similarly structured, with one difference: EUT #1 and EUT #2 are built with horizontal trowel pattern and EUT#4 is built with 'random' trowel pattern. The random pattern is inspired from the curved finishing pulls which occurs at the top of the wall, when the recommended vertical trowel pattern is applied, in addition to the more vertical curved pattern, presented in Figure 9, p. 33. The pattern is created by repeating the finishing pull of the trowel in three rows vertically. The design of EUT #4 is presented in Figure 26, showing all necessary measurements and data to be able to construct the tiled wall.

The remaining EUT designs are presented in Appendix B.

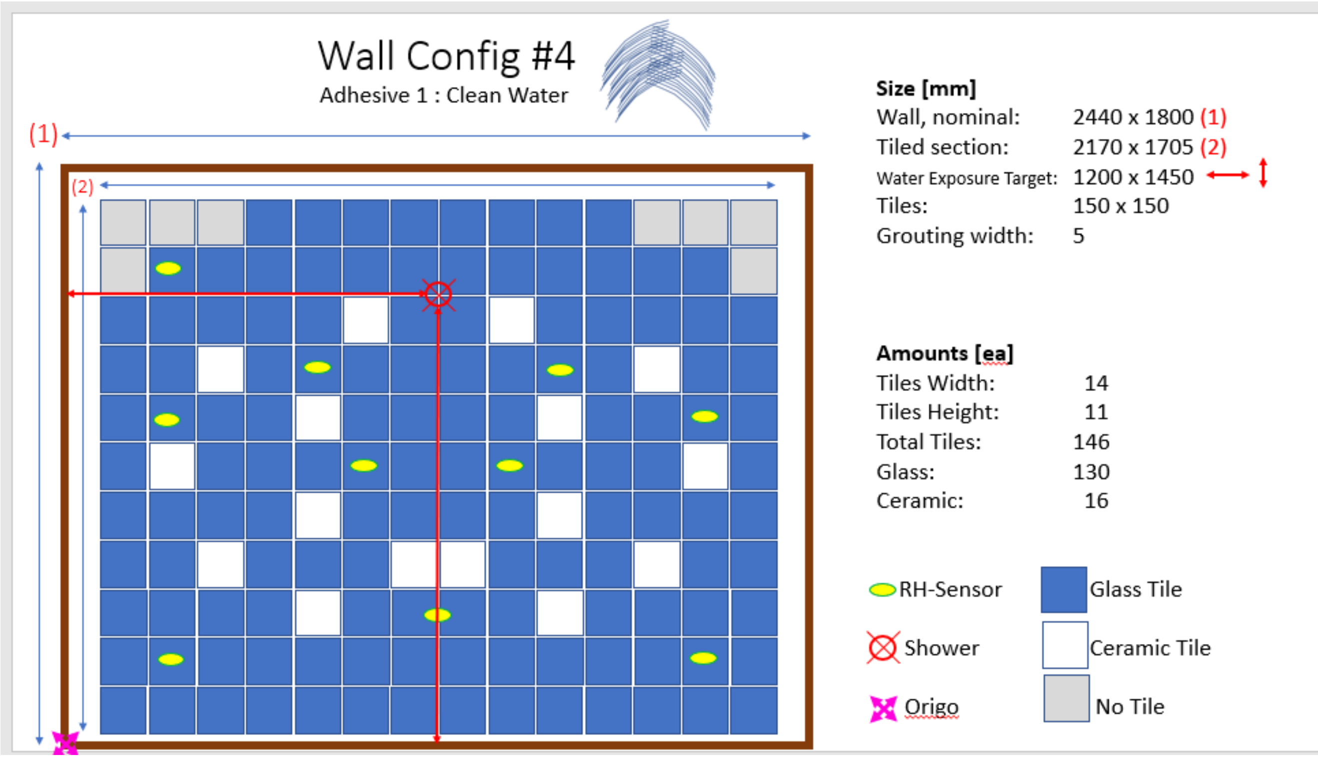


Figure 26 Design of EUT #4, showing Geometrics, Layout of Tiles, Tile Adhesive and other Measurements

Key information for each EUT:

- Total wall area: 4.4 m^2
- Total tiled area: 3.5 m^2
- Total number of tiles: 146 pc
    - Number of ceramic tiles: 16 pc
    - Number of glass tiles: 130 pc
- Number of RH-Sensors: 10 pc

4.5.2.1 Tile Adhesive and Grout

As presented introductorily, one of the key drivers of choosing materials and methods in this experiment is realism. Therefore, the tile adhesive and grout is chosen based on being the highest seller and the most commonly used, also supported by other criteria presented herein. Similar grout as type 1 from the SINTEF experiment and the single component from the Kung study are used for the experiments in this master's thesis [9, 46]. Specifications and supporting tables for this section is found in Appendix C. Data sheets are found in Appendix H.

<u>Tile Adhesive</u>

According to market investigation and information from Mapei personnel, the tile adhesive being in accordance with the experiment intention and requirements, is the cementitious single component called Megalite S1. Coincidentally this product is also one of the cheapest adhesives in the Mapei product lineup. All tile adhesives are categorized in a classification system called out by NS-EN 12004-1:2017. The classification of the tile adhesive used in the EUTs are C2TE S1, Class E. The tile adhesive identification describes requirements of adhesion strengths, reaction to fire and release of dangerous substances. In addition, the standard describes a broad range of requirements for tile adhesives intended for use in the industry, e.g. maturing time, pot-life, and open time. It does not, however, describe any hygroscopic- or moisture absorption properties [71].

Therefore, a sorption experiment is performed as part of this master's thesis, to establish a baseline for the sorption properties of the tile adhesives. From what the author has found, ISO 13007-1:2014 describes grouts and adhesives, and might have relevant information about moisture properties, however access to the standard has not been provided. Regardless, a self-executed sorption experiment contributes to a broader understanding of the moisture sorption in tile adhesives.

The sorption experiment setup is described in detail in section 4.6.2, where three types of tile adhesive was tested in addition to the Megalite S1. The four types of tile adhesive has different degree of theoretical water sorption properties due to their material composition, as well as differences in mechanical- and adhesion properties. The four types of tile adhesive are listed below.

Mapei Ultralite S1 (ID: #1)

- Single component, cementitious tile adhesive with added synthetic resin to make it lighter.
- NS-EN 12004-1:2017 Classification: C2TE S1
  - C2TE S1: An improved deformable cementitious adhesive with reduced slip properties and extended open time.

Mapei Megafix (ID: #2)

- Single component, cementitious tile adhesive with added synthetic resins and special additives.
- NS-EN 12004-1:2017 Classification: C2TE
  - C2TE: An improved cementitious adhesive with reduced slip properties and extended open time.

Mapei Megarapid 2K Plus (ID: #3)

- Two-Component silica sand and synthetic latex rubber tile adhesive
- NS-EN 12004-1:2017 Classification: C2FTE S2:
  - C2FTE S2: An improved and fast setting, highly deformable cementitious adhesive with reduced slip properties and extended open time.

Mapei Ultrabond ECO PU 2K (ID: #4)

- Two-Component polyurethane with catalyzer tile adhesive
- NS-EN 12004-1:2017 Classification: R2T
  - R2T: An improved reaction resin adhesive with reduced slip properties.

Tile Adhesive Mixing and Application

There is provided a min / max-ratio on all of the adhesive- and grout products provided by the industry. For the Ultralite S1 (ID: #1), applicable ratios was stated as 7.5 l – 8 l water pr 15 kg dry material. This equals a w/b ratio between w/b = 0.50 to 0.53. The w/b ratio of the adhesive was consciously established based on the intention of ensuring the ability of leaving grooves made by the adhesive trowel. Simultaneously maintaining a good workability being within the recommendations of the producer. A test spread of the mixed adhesive was done on one Litex XPS board. Using the lowest w/b ratio, the adhesive behavior and material inertia were observed when placing two tiles to the adhesive. Evaluation whether the required behavior of the adhesive was adequate or not was done by the author and the contractors. As the Mapei contractors have many years of experience handling this type of adhesive, it was necessary to get their subjective view whether the experiment's properties were being ensured using the tested ratio, in addition to being governed by the intention of ensure firm enough adhesive to retain the grooves. Pictures from the trial installation is found in Appendix F.

After evaluating the test spread, confidence in choosing a w/b = 0.5 was made, and the ratio was meticulously weighed for each mixed batch. Each 15 kg bag was divided into two batches to make sure *pot life*, and *open time* of the adhesive was within acceptance. Figure 27 is showing the dry component of the tile adhesive (a) being weighed, followed by the water (b), and mixing the two components (c).

The adhesive trowel tooth size was selected as 6 mm. Tabell 55 in Byggforsk 573.114 calls out 6 mm being applicable for tiles up to 200 mm x 200 mm adhered to a semi-rough surface [72]. This definition is relatable to the size of the tiles as well as the surface on the Litex wet room boards.

a) b) c)

Figure 27 a, b, c - a: Dry Material Measuring of 7.505 kg, b: Water weighing of 3.750 kg, c: Mixing Finish Adhesive

Grouts

The grout Megafug G 113 is selected based on the same experiment criteria as the tile adhesive related to being a producer bestseller and the most commonly used. In addition, it was important that the chosen grout resembled the grout identified as 'Type 1' in the experiment done by SINTEF, ref 3.2.5.2. It was mixed according to the instructions on the bag without any modification, supported by the product data sheet. Applicable ratios was stated as 3.6 l – 4.0 l water pr 20 kg dry material. This equals a w/b ratio between w/b = 0.18 to 0.20. The chosen w/b ratio is 0.18 for the experiment and divided over two mixed batches to be within the required open time. Figure 28 presents the same principal regarding weighing and mixing as for tile adhesive, using other ratios.

a) b) c)

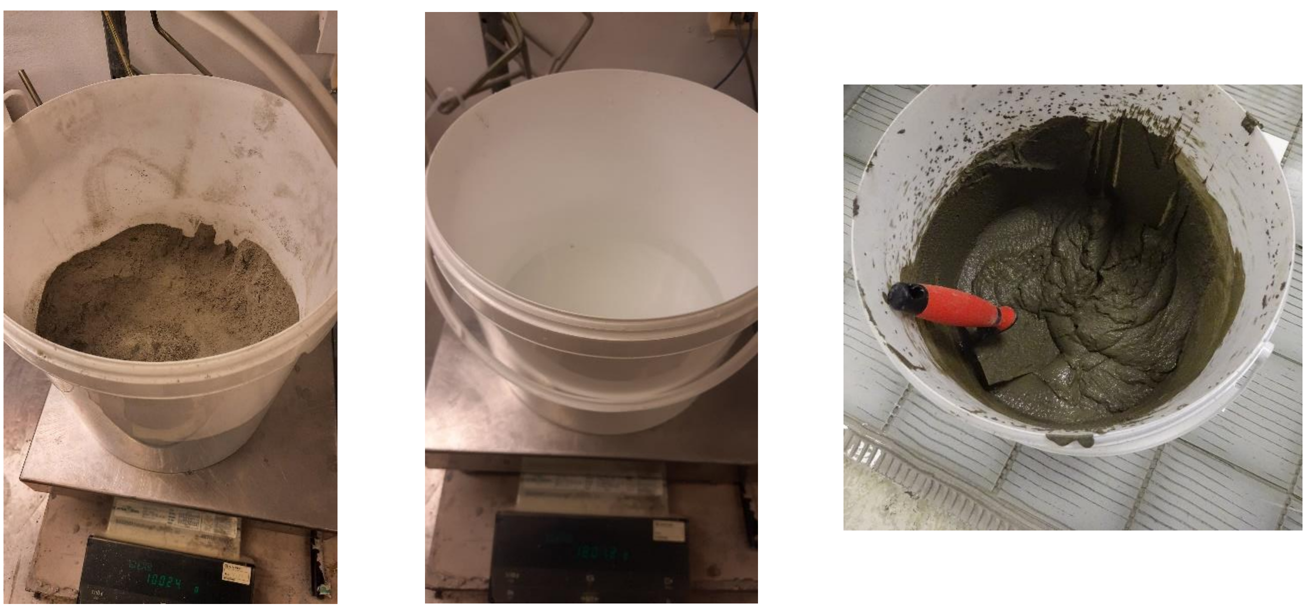


Figure 28 a, b, c. a: Dry Material Weighing of 10 024 g, b: Water Weighing of 1 801.2 g, c: Finished and Mixed Grout based on the Two Measurements a and b.

Similarly, as the tile adhesive, there is not much information regarding moisture absorption properties in applicable product data sheets. However, there is a test method description in EN 12808-5:2008 and a classification system provided in EN 13888-1:2022 related to the moisture characteristics of grouts:

Megafug G 113

- Single component, polymer modified cementitious grout.
- EN 13888-1:2022 Classification: CG2WA
    - CG2WA: An improved cementitious grout with reduced water absorption compared with a non-improved grout.

A direct comparison between non-improved and improved grouting related to moisture absorption is provided by Mapei in Appendix C [73].

NS3420-N:2019 is the governing standard for tile- and brick work, describing the choices to be evaluated regarding grouts and grout line widths. There is not established a standard definition of a specific grout width in any specific scenario. Instead, there is specified acceptable deviations to the grout widths in different tile- and structure configuration and orientations. In addition, several evaluations needs to be made based on type of tile, type of grout, required drying properties, tile chamfer profiles, building materials, esthetics, and other industry recommendations [51]. In the experiment research described herein. the grout line width was set to a nominal 5 mm. The applicable tolerance for the grout width is states as 20 % in NS3420-N, which translates to:

5 mm x 0.20 = ± 1 mm.

The selection of grout width was made based on information gathered from NS3420-N, the book "Alt om Flislegging", information available at NBKF and discussion with personnel at Mapei AS [48, 51, 74].

4.5.2.2 Tiles

Two types of tiles are used in this experiment, i.e glass tiles and clay tiles with a ceramic surface. 'Clay tiles' and 'ceramic tiles' are used interchangeably throughout the document. The main intention of using glass tiles are to provide a visual impression of the moisture migration in the tile adhesive. The reason for using scattered ceramic tiles on the walls are to investigate the potential difference in moisture migration in the area of the tiles. In addition to observe any specific behavior as the tiles are hygroscopic. Classification of different ceramic tiles are provided in ISO 13006:2018, however due to uncertainties regarding markings and identification on the tile packaging, no investigation was done into defining the correct classification. The primary property of interest is the moisture absorption, that are established through the supporting sorption experiment.

Figure 29 A Stack of 150 mm x 150 mm x 4 mm Glass Tiles used in All Wall

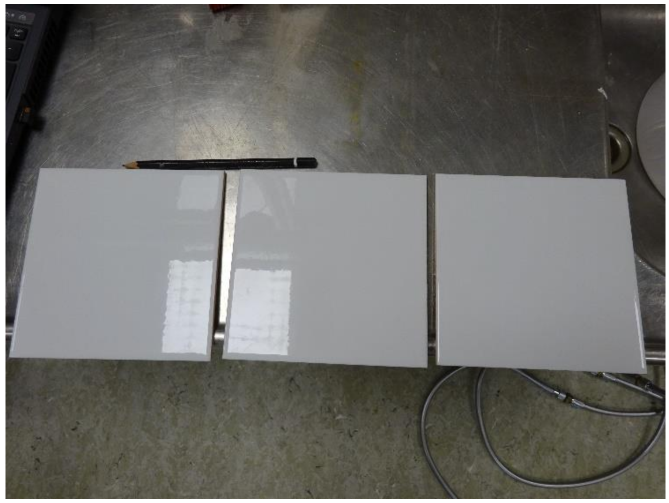


Figure 30 150 mm x 150 mm x 5 mm Ceramic Tiles used in All Walls

Due to the production method of the glass tiles, individual differences up to ± 1 mm are observed in width and height. A couple of exceptions are observed, where tiles have differences of up to 5 mm in size difference. All size deviations are mitigated through the design and construction of the walls, and tiles with the most deviation are placed at the edges of the tiled area. As presented in the *Grouts* - section, NS3420-N states ± 1 mm tolerance of the grout. Worst case regarding distance between tiles, causes a potential of ± 2 mm. This occurrence is seen at a couple of location on the EUT; however, the tolerance of ± 1 mm is predominant throughout the EUTs. The few occurrences of tolerance being outside of the provided guidelines are deemed neglectable.

Ceramic tiles have a natural water sorption property due to the material composition being a porous material. The glass tiles have no moisture sorption properties having a closed pore structure. Investigation into how moisture migration is affected by the sorption properties of the ceramic tiles compared to the glass tiles are of interest in the experiment. Additionally, another reason for using a selection of ceramic tiles in the design of the EUTs were the finite number of glass tiles available for the experiment. This was due to financial budget limitations, and the intention of comparing the results of all 4 EUTs in the best way possible.

An assumption was made towards both the glass- and ceramic tiles having the same adsorption properties on the exterior surface facing the water exposure side, i.e approx. the same smoothness. An additional assumption was made regarding the water would be caught in the grout rather than on the tiles due to the smoothness of the tiles, at the end of each water exposure. This was confirmed during the early stages of the experiment. Therefore, no additional measurements were performed regarding adsorption properties for the two different tile types.

The experiment establishing the water sorption properties in the clay tiles, are performed along with a selection of several tile adhesives, including the main tile adhesive used in the EUTs. The experiment is described in section 4.6.2.

4.5.2.3 Tile Adhesive Application, Grouting and Tile Installation

The construction- and assembly of the 4 EUTs are done by professional contractors from Mapei AS. The contractors provide every necessity for completing the tile work on the walls, being materials, tools, and equipment. By using professionals from Mapei, overall quality regarding workmanship is ensured. Part NH in NS 3420-N:2019, regarding description of proper tile work, is followed and verified throughout the tile work process [51]. A couple of modifications are made from the description in the standard; e.g using glass tiles potentially causing less adhesive force and ensuring the formation of grooves in the tile adhesive as governed by the research questions.

The same personnel is used for both the tile adhesive application, tile work and grout. Great care is put into workmanship to ensure quality control along each step of the construction- and assembly process. The contractors from Mapei did an excellent job of doing as instructed as well as providing invaluable continuous feedback and proposals of improvement related to the design choices of the wall assemblies, based on their experience.

The tile adhesive application and the installation of the tiles were executed within one full workday (December 6th 2022) for all 4 EUTs. For the walls to be able to dry out sufficiently, the walls were left in storage for 34 days prior to grouting, which was done January 9th 2023 and left to dry for 30 days. The grouting was done within a time slot of approx. 3 hours for all EUTs, using the same batch of grout. The process of grouting and working the grout into the grooves were done by the same person using the same approach and tools for all walls. Confidence is therefore high regarding consistency in application and uniformity of grout characteristics in all EUTs.

See Figure 31, Figure 32, Figure 33, and Figure 34 for tile adhesive and grouting progress pictures.

Figure 31 Horizontal Tile Adhesive Grooves, while Installing Tiles on EUT #1

Figure 32 Random Tile Adhesive Grooves shown during Construction of EUT #4

Figure 33 Grouting of EUT #1

Figure 34 Grouting of EUT #4

4.5.3 Wall Construction Equipment

All materials and equipment used for construction and assembly of the Base Walls and Complete Walls, concluding the EUT design and construction, is according to Table 3.

Table 3 Wall Construction - Materials and Equipment

Description	Type
Wall Components	
Structural Frame & Support Legs	Structural Lumber 36 mm x 48 mm
Construction Boards	LITEX TB Wet Room XPS Boards Size: 2 400 mm x 600 mm x 30 mm
Tape	LITEX Wet Room Board Tape Width: 100 mm
Screws, Bolts and Washers	LITEX mounting screw w/ washers Size: ~5 mm x 32 mm
Glass Tiles	Size: 150 mm x 150 mm x 4 mm
Clay Tiles	White Ceramic Glazed Size: 150 mm x 150 mm x 5 mm
Tile Adhesive	Mapei Ultralite S1 Batch No. F 070622 0265 Batch No. F 210322 0985 Batch No. 211419 24102022 0578
Grout	Mapei Megafug G 113 Batch No. 213326 171122 0357
Wall Construction Equipment	
Adhesive Trowel	Steel Trowel 6mm
Grout Spunge	Standard Generic

Description	Type
Concrete Float	Standard Generic
Chalk line	Standard Generic
Misc. tile work tools	Standard Generic
Additional Tile Adhesives	
Mapei Megafix	Batch No. 212918 101122 2629
Mapei Megarapid 2K Plus 1st Component	Batch No. 214266 291122 0773
Mapei Megarapid 2K Plus 2nd Component	Batch No. 19.10.2022 263 PB: 211431
Mapei ULTRABOND ECO PU 2K Comp: A	Batch No. 05-12-22 2
Mapei ULTRABOND ECO PU 2K Comp: B	Batch No. 06-09-22

4.6 EXPERIMENT SETUP

This section gives an overall description of the main- and supporting experiment setups. Details regarding the specific equipment and further setup- and utilization information is found in section 4.7.

4.6.1 Main Experiment Setup – Water Exposure on the Tiled Walls

An expansion bolt was installed in one of the concrete support beams just above the gutter, which is described in section 4.3. An eyebolt was installed in the beam and the Wall Hoisting Assembly together with the Pulley, Load Cell and Strap were assembled and mounted, see Figure 49. The intention of the setup was to make it as interchangeable as possible for the different EUTs. With only the two bolts for the Wall Hoisting Assembly, and the two bolts for the Support Legs being mounted for each new EUT, this was seen as a success. Due to minor differences in the Center of Gravity (CoG) (drilled hole locations, tile setup, tile adhesive configuration, etc.) in the individual EUTs, the necessity of making individual adjustments was required. This was handled through adjusting the lifting strap, mounting, and utilizing the Support Legs and using a level for verification. When installing and mounting each EUT, the pitch, roll and yaw (rotation around the x-, y-, and z- axis) was stabilized and levelled, see

Figure 35 and Figure 36. Throughout the experiment, sampling verifications were performed to make sure the setup was according to plan.

Figure 35 Levelling of x- and y-Axis Using the Hultafors Level

Figure 36 Levelling of the z-Axis Using the Hultafors Level

To be able to have a stable and reproducible setup for the EUTs in elevation, initial experiment phase measurements concluded with a distance of 200 mm being a perfect fit. This ensured the intention of the experiment being followed, with enough clearance from the floor and the Pulley, see Figure 38. The chains in the Pulley were marked using a sharpie, and the alignment was validated each time the individual EUTs were hoisted. See Figure 37.

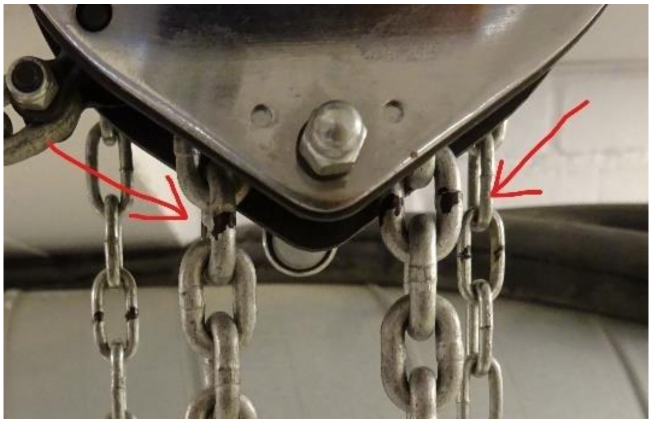


Figure 37 Pulley Markers for Verifying Correct EUT Height Above Ground

Figure 38 Correct EUT Positioning Elevated 200 mm from the Floor

A steel stand and tape markers on the floor were used to ensure a stable and reproducible verification setup for the water exposure during each shower cycle. The same approach regarding floor tape markers were used for tripod for photo setup. The metal stand comprise a modular and highly versatile steel square extruded piping system and a clamping fixture for the shower head. A GoPro-fixture was mounted to the stand for the possibility of timelapse photos throughout the experiment. See Figure 39 and Figure 40.

Figure 39 Shower- and GoPro Stand in front of EUT#1

Figure 40 Steel Stand Positioning showing Floor Tape Markers for Repetitive Measurements

Thermal and Weight Data Acquisition

The thermocouple and signal cable for the Load Cell were routed along the top edge of the wall, with the temperature measuring probe aligned with the center of the water exposure target area. The cables were connected to applicable equipment on the Data Acquisition Hub. See Figure 41 and Figure 42.

The Data Acquisition Hub is described further down.

Figure 41 Cable Routing for Load Cell and Thermocouple on top of EUT #1

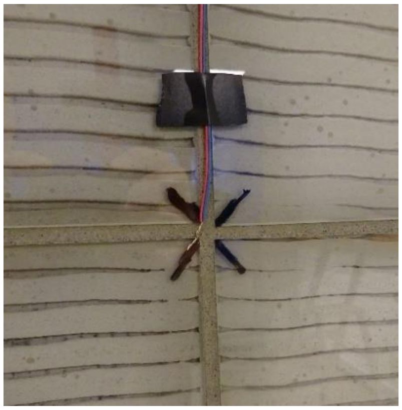


Figure 42 Thermocouple in Center of Water Exposure Target Area

The overall setup, with the shower head installed in the stand, is shown in Figure 43. A system for routing the excess water towards the gutter has been constructed below the wall (blue area), and a safety cordon is erected to prevent intrusion or trespassing into the experimental area. The cordon helps with defining a clear separation between the experimental area, with no access for unauthorized personnel, and the rest of the area.

Figure 43 Overall Experiment Setup incl. Safety Barrier Surrounding the Setup

Data Acquisition Hub

A trolley table was used as a Data Acquisition Hub, where all applicable equipment was strategically located. This secured a streamlined experiment setup, minimizing time wasted doing measurements and gathering of data. The Data Acquisition Hub was also the storage area for generic tools and equipment for repairs and necessary experiment adaptation.

Figure 44 Data Acquisition Hub Showing all Critical Data Acquisition Equipment

4.6.2 Supporting Experiment Setup – Water Sorption

As part of establishing the material characteristics related to water sorption in the tile adhesive, a custom experiment was designed and executed. The experiment was constructed inspired from descriptions in NS-EN 12004-2:2021, NS-EN 13888-2:2022 and NS-EN ISO 12571:2021 [15, 75, 76], regarding methodology, methods, and stabilization criteria. The tile adhesive used in all EUTs, along with three different tile adhesives presented in section 4.5.2.1, with its individual characteristics and properties were investigated. In addition, the water sorption characteristic for the ceramic tiles were measured.

When logging the weight of the specimens described in sections 4.6.2.1 and 4.6.2.2, attention was made to the surface of the specimens, making sure that no excessive water was present on any surface. There will always be a minor presence of adsorption on the specimens, however making sure the specimens are patted down equally thoroughly each time prior to weighing, will ensure consistency and minimize the risk of unintended differences in the measurements.

4.6.2.1 Water Sorption – Tile Adhesives

Four prisms, with nominal measurements of 25 mm x 25 mm x 150 mm (width x height x length) was molded and smaller cubes were cut from the main prisms. Three specimens of each tile adhesive was produced, measuring nominally 25 mm x 25 mm x 30 mm, ready for measurements, ref Figure 45, Figure 46, Figure 47 and Figure 48. Detailed measurements are presented in Table 4.

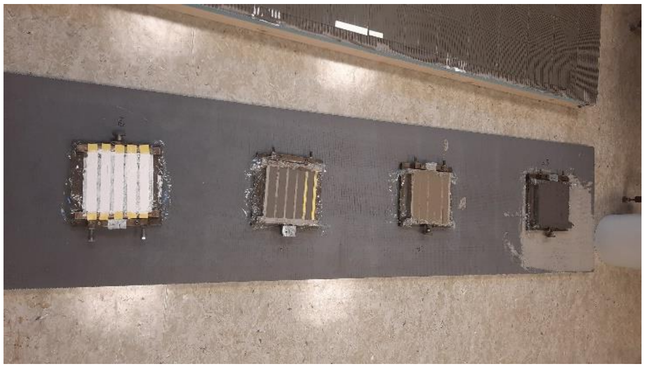


Figure 45 Four Different Tile Adhesives in Prism Molds

Figure 46 All Tile Adhesive Specimens Finalized and Identified – Ready for Sorption Experiment

Figure 47 All Tile Adhesive Specimens Submerged in Water

Figure 48 Weighing Tile Adhesive Specimen 2-1

Specimens were measured and marked using a sharpie prior to being placed in a vise. Further, the specimens were cut using a hacksaw, and finished using a 120-grit sandpaper. The specimens were then measured using a digital caliper capable of measuring within $1\ x\ 10^{-2}$ millimeter with an accuracy of $\pm\ 3\ x\ 10^{-2}$ millimeters. As the specimens were machined and processed manually, two diagonal measurements, along the edge of the calipers were performed on all sides, averaging the values. The average measurement error was approx. ± 0.15 mm. Based on the average measurements of each side of the specimen, this translates to a measurement uncertainty of:

- Length = 1 %
- Width = 0.4 %
- Height = 0.02 %

The author has confidence in the method being accurate enough for the purpose of this experiment.

Table 4 Tile Adhesive Specimen Measurements incl. Geometrics and Dry Values

ID	Length [mm]	Width [mm]	Height [mm]	Volume [mm^3]	Weight Dry [g]	Density Dry [kg / m^3]
1-1	29.75	24.58	25.10	18 354.50	20.00	1 089.65
1-2	29.80	24.56	25.15	18 406.98	19.80	1 075.68
1-3	29.45	24.55	25.05	18 111.09	19.50	1 076.69
2-1	28.95	24.75	24.95	17 876.99	22.20	1 241.82
2-2	29.00	24.54	24.80	17 649.17	22.20	1 257.85
2-3	28.85	24.65	24.76	17 608.14	22.30	1 266.46
3-1	28.55	24.99	26.45	18 871.14	25.50	1 351.27
3-2	29.95	24.98	26.61	19 908.30	27.00	1 356.22
3-3	28.78	25.00	26.65	19 174.68	26.30	1 371.60

ID	Length [mm]	Width [mm]	Height [mm]	Volume [mm^3]	Weight Dry [g]	Density Dry [kg / m^3]
4-1	28.92	24.94	25.01	18 038.83	27.70	1 535.58
4-2	29.81	24.95	25.18	18 727.86	28.70	1 532.48
4-3	28.72	24.89	25.09	17 935.36	27.60	1 538.86

4.6.2.2 Water Sorption - Tiles

The sorption of the ceramic tiles are measured to be able to predict the water uptake in the tiles, comparing it to grout and tile adhesive. As previously described, the intention is to form a baseline for the different moisture migration behavior during experimental research. Table 5 presents the geometrics and dry measurements of the specimens.

Table 5 Ceramic Tile Sorption Measurements – Geometrics and Dry Weight

ID	Length [mm]	Width [mm]	Height [mm]	Volume [mm^3]	Weight Dry [g]	Density Dry [kg / m^3]
1	150.00	150.00	4.75	106 875.00	209.30	1 958.36
2	150.00	150.00	4.75	106 875.00	210.00	1 964.91
3	150.00	150.00	4.75	106 875.00	212.10	1 984.56

4.7 EXPERIMENT EQUIPMENT

In every experiment, test, or research there is usually a lot of equipment required to be able to setup, monitor, measure and observe what has been defined according to scope. Some of the equipment are enrolled in a calibration regime, as it is critical to have documented margin of error or accuracy, as well as ensuring functionality. All equipment that is part of the calibration routine at SINTEF, has annual intervals. This means that the column "Last Calibration" in Table 6 needs to be within 1 year for it to be valid. All equipment required for calibration are either used for data acquisition or related to safety (e.g pulley, lifting strap etc.). Most of the equipment presented in Table 6 are not part of any calibration, as its intended use is not critical in any way, or datasheets have been provided from suppliers with required data.

The Scale in Table 6 is presented with two calibration dates. On the calibration tag on the Scale, it is stated that calibration is valid through 03/2022. No measurements were done in the period between March 31st and April 3rd 2023. All other measurements were done by the end of April 2023.

Table 6 lists all equipment and Software (SW) that has been utilized throughout the experiment. The table is divided into relevant categories regarding the established parameters of interest in this experiment. All defined categories or equipment otherwise seen as critical for establishing the result baseline is presented in more detail in sub-sections below the table. In each sub-section there is a section dedicated to calibration for each logging system.

Table 6 Data Acquisition & Experiment Equipment

Description	Type	Part Number	Serial Number / ID	Last Calibration
Wall Weight Logging Equipment (ref. section 4.7.1)				
Load Cell	HBM U2A 2 kN (2 mV / V)	H 03743 K	SINTEF ID-4987	2. Dec 2022
Load Cell Data Acquisition System (DAQ)	HBM Quantum X w/ Amplifier	MX 840 B	SINTEF ID-10652 9E5015BAC	Custom*

Description	Type	Part Number	Serial Number / ID	Last Calibration
Battery Pack for DAQ	CLA HBM 120 Wh	CLATEC2LY	SINTEF ID-10653 000O060/2001S4/005	N/A
DAQ SW	HBM CatmanEasy	v.5.4.2.11	N/A	Custom*
Laptop	Acer Aspire 5	A515-55-31V3	NXHSGED00C119141134600	N/A
Interconnecting Cables	Ethernet, RS-422, Power	N/A	N/A	N/A
Pulley	Tractel Tralift	250 kg 4 x 12	L802651/2008	11/2022
Lifting Strap	Carl Stahl 1m – Polyester Green EN1492-2	04/2014 30210875	N/A	11/2022
Wall Hoisting Assembly	Bolts, nuts, shackles, eyebolts.	N/A	N/A	N/A
Temperature Logging Equipment (ref. section 4.7.2)				
Thermal Logger w/ SW	HIOKI LR8431-20 MEMORY HiLOGGER	LR8431-20	200143869	Custom*
Thermal Logger SW	Version 1.11	N/A	200143869	N/A
Thermal Wires	TE Wire and Cable TEW&C Type-T	N/A	N/A	Custom*
Thermal Calibration Unit	Hart Scientific	9105	SINTEF ID-3671 71411	04.08.2022

Description	Type	Part Number	Serial Number / ID	Last Calibration
Relative Humidity Logging Equipment (ref. section 4.7.3)				
Humidity Sensor	InviSense StandardSensor	v. 2.1	N/A	N/A
Humidity Sensor Scanner	InviSense	N/A	I60-F-A079	Continuous**
Humidity Sensor Scanner App	v. 6.1.2	N/A	N/A	11/2022
Mobile Device	Samsung Galaxy A51	SM-A515F/DSN	N/A	N/A
Water Exposure Equipment (ref. section 4.7.4)				
Shower Head	Grohe Generic	N/A	N/A	Continuous**
Stand for Shower	Square Steel Module Stand	N/A	N/A	N/A
Adjustable Shower Stand	Manfrotto	143	D1590480	N/A
Water Hose w/ couplings	4.5m, Ø = 0.5"	N/A	N/A	N/A
Saturation Equipment	Plastic Container	N/A	N/A	N/A
Bucket	Generic 10 ltrs	N/A	N/A	N/A
Photo and Video Equipment				
Photo Camera	Sony Cybershot AVCHD 18.2MP	DSC-WX350	3213016	N/A
GoPro Camera	HERO 8 Black	SPJ81	C3331352631705	N/A

Description	Type	Part Number	Serial Number / ID	Last Calibration
Thermal Camera	FOTRIC 346A	346A-L25	Z1S3LYB3007	Jan 2023
Tripod for Camera	Velbon VGB-3	891450	N/A	N/A
Miscellaneous Equipment				
Scale	Mettler Toledo "0 – 32,100 grams"	SG32001 DeltaRange	SINTEF M.nr 5489 S/N: 1120481123	08.03.2022 03.04.2023
Water Tub	Generic 40 ltrs	N/A	N/A	N/A
Soap	Orkla Lano	N/A	N/A	N/A
Tape	Electrical, Duct, Paper	N/A	N/A	N/A
Folding Rule	Hultafors 2m	N/A	N/A	N/A
Stopwatch	COMET Digital 3-button	N/A	N/A	N/A
Memory Stick	Kingston USB stick 32 Gb	N/A	N/A	N/A
Soap Spray Bottle	Generic w/ pump handle	N/A|	N/A	N/A
Level	Hultafors GDS 60	N/A	N/A	N/A
Ambience Log (°C / RH)	Cotech Hygrometer / Thermometer Temp ± 0.5 °C RH ± 1 %	E0119TH	N/A	N/A

Description	Type	Part Number	Serial Number / ID	Last Calibration
Analysis SW	MS Excel NCSS Digimizer	Office 365 v. 23.0.1 Version 6	N/A	N/A

* Note: Custom calibration performed with the specified equipment. Details are presented below.

**Note: Calibration is done several times each day. Details are presented below.

4.7.1 Wall Weight Logging Equipment

To be able to measure the weight of the water content in the wall as the experiment progresses, a setup comprising a 2 kiloNewton (kN) Load Cell and a laptop with CatmanEasy logging SW was established, ref Figure 50 and ref Figure 52. The Load Cell is attached to the hook of the Pulley, Figure 49, and the signal cable is routed topside of the wall towards the data acquisition hub together with the thermocouple, as shown in Figure 41. The signal from the Load Cell to the Laptop running the CatmanEasy SW, is routed through a signal amplifier and the HBM Quantum X DAQ for signal processing, ref Figure 51.

Wall Weight Calibration

The Load Cell had valid calibration and the Pulley and Lifting Strap both came calibrated and approved regarding safety. In addition to the Load Cell being externally calibrated, an alignment calibration between the Catman Software used for logging and the Load Cell was needed. The Load Cell was imported into Catman SW, and the calibration was performed ending in an offset of - 0.02974 kN for the specific Load Cell.

To establish a baseline regarding measuring uncertainties, several long-term measurements were performed, i.e. two 36 h periods and one 40 h period. The results of these measurements showed a measuring deviation of +/- 80 g which was deemed acceptable within the required measurements. The deviation is likely due to both inertia in the lifting strap, the bolt connection in the wooden frame, orientation in the shackles between the wooden frame and the lifting strap, and potential ambient conditions in the laboratory affecting the measurement.

Figure 49 EUT Hanging from the Ceiling in a Load Cell and Pulley Setup

Figure 50 Load Cell with Eyebolt for Measuring the Weight of the Wall

Figure 51 Quantum X used for Weight Logging Signal Processing

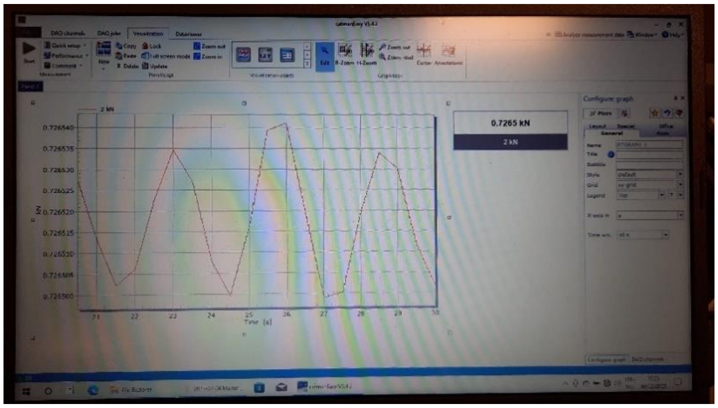


Figure 52 CatmanEasy Software used for Weight Logging

4.7.2 Temperature Logging Equipment

The HIOKI LR8431-20 MEMORY HiLOGGER (HIOKI) is a multi-channel (10 isolated analog channels) logger used for measuring and logging the temperature of the water in the water exposure target area through a measuring probe. The unit is capable of a sampling rate of 100 Hz, (1 / 0.01s) making it very accurate. For this experiment, 2 channels with a sampling rate of 1 Hz (1 / 1s) is utilized and deemed sufficient for the purpose of the experiment. As the HIOKI unit has no local storage, a memory stick (USB stick) is used for data storage during logging and transfer to a computer after logging.

The HIOKI is used in combination with two measuring probes. The probes are a dual metal wire configuration comprising copper and constantan (copper-nickel alloy), defined as a Type-T thermocouple. The thermocouple wires measures the voltage which the HIOKI translates to a temperature presented in Celsius. The accuracy of the thermocouple is 43 µV / °C, equivalent to approx. 0.75 %. Data sheet for the probes are found in Appendix H.

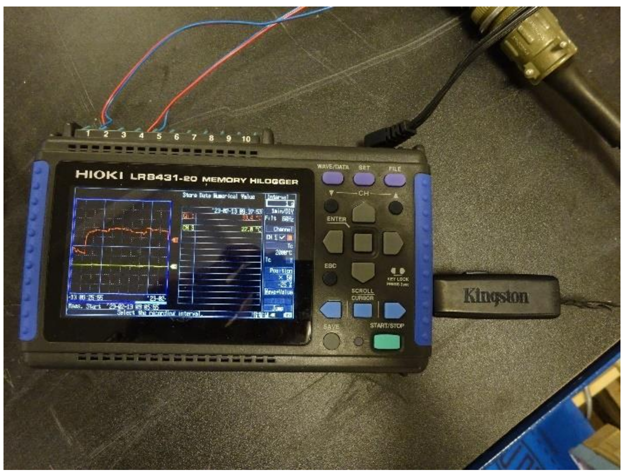


Figure 53 HIOKI LR8431-20 w/USB stick

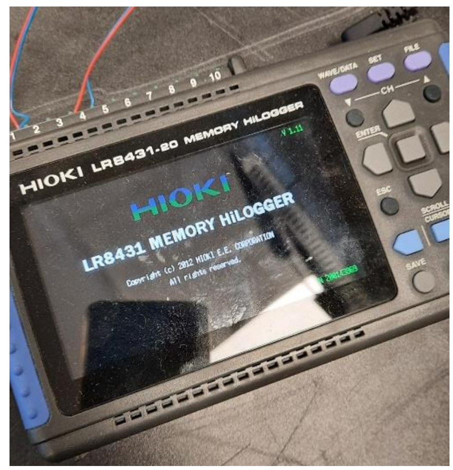


Figure 54 HOIKI Version Details

Temperature Data Acquisition Calibration

To mitigate some of the accuracy deviation and to calibrate the actual experiment setup, calibration was performed consisting of the actual probes used, the applicable HIOKI unit, at the specific temperature intended for the experiment. A Hart Scientific Calibration Unit was utilized for the calibration of the temperature measuring setup, see Figure 55. Calibration temperature was set at 38.00 °C and the temperature probes were inserted into the unit. A continuous log were run for 30 minutes to set the baseline for the calibration. An average accuracy of +/- 0.1 °C for both probes was measured during the calibration period which is deemed acceptable for the experiment. As presented in the section 3.3.2, the target temperature of the water is within 38 +/- 3 °C, hence the deviation is well within any potential issues regarding calibration values. Figure 56 shows the two thermocouples measuring 37.9 °C and 38.0°C. The graph of the temperature calibration is found in Appendix E

Figure 55 Hart Scientific Thermal Calibration Unit

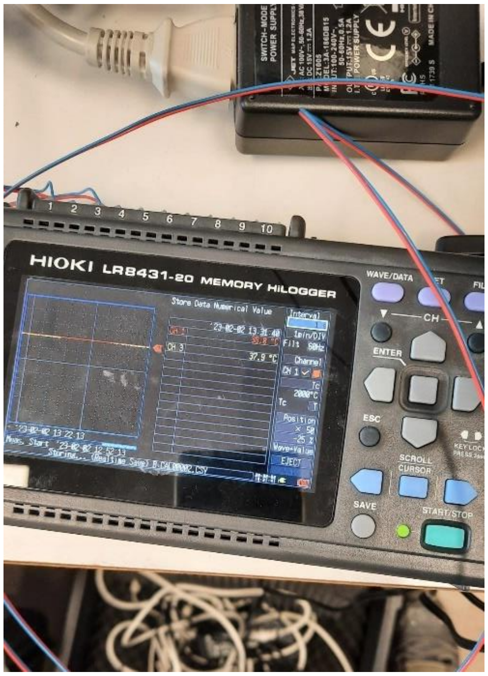


Figure 56 HIOKI Unit during Temperature Calibration

4.7.3 Relative Humidity Logging Equipment

To be able to establish a quantifiable data set from the RH in the tile adhesive, a Swedish producer named InviSense was selected as the provider of applicable sensors. Their sensors are patented under the Swedish Patent Database (PRV) as SE 1750183-4 and SE 1750182-6 [77]. As shown in Figure 24, the sensors were installed on the Litex wet room boards according to the Sensor Location design document described in 4.1.2. The sensors measure approx. 70 mm x 100 mm and are shown in Figure 57, below.

The RH Logging Equipment consists of a set of 10 RH-sensors in each EUT, a scanner and a phone application. All parts of the system was provided with a thorough description and user guide, for easy setup and handling. All the specified units are described in further detail below. InviSense also has a cloud-based setup- and storage system, capable of establishing an online project for continuous logging and data processing. For the experimental research described herein, the user mode 'quick scanning' with no cloud storage was utilized through the scanner. The measured RH-values was registered in a spreadsheet established by the author, and data was processed locally. The InviSense RH measurement equipment was a very easy and streamlined measuring system.

<u>InviSense Sensors</u>

The RH-sensors are meant to be installed inside walls and are highly applicable for the experiment setup. They can be covered with different building materials with two exceptions, and still be functional with the scanner. As the scanner operates using inductive measurements, there is specified in the provided white paper that installation of the sensors need to be done outside close proximity to metals or other high conductive materials. In addition, there is specified that the sensors cannot be cast in concrete and get a valid reading. According to SINTEF, they have had previous experience with on/off sensors, which triggered at a specified RH. The sensors from InviSense were specified to be able to measure continuous integers of RH in unit [%]. The sensors are also capable of measuring liquid. The RH is measured within the range of 20% – 95% with high accuracy [78]. As "high accuracy" is not a scientific amount, the author reached out InviSense for a more specific accuracy. According to the in-house verification tests performed by InviSense, they state an accuracy of RH = +/- 3 %. The measuring accuracy also applies when measuring liquid. InviSense provided an installation guide which were thoroughly reviewed by the author prior to installation to make sure installation risk mitigation was fulfilled.

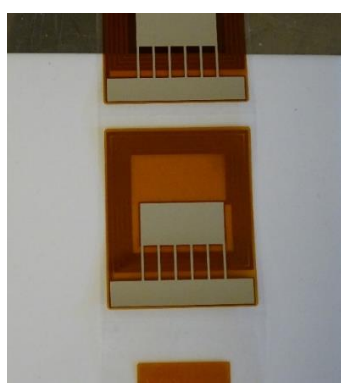


Figure 57 InviSense Sensor ready for Application

InviSense Scanner

The InviSense Scanner is a handheld device connected by Bluetooth to a mobile device, see Figure 58. The scanner is highly usable and worked as intended through the experiment. During the early stages of the experiment, the highest accuracy and solid value consistency in measurements were established when scanning the sensors at a distance of approx. 10mm from the surface of the EUTs.

According to the product's white paper, the sensors register the number of H_2O-molecules within the measuring area of the sensor. The number of H_2O-molecules are mapped to a specific frequency range, which is interpreted by the InviSense Moisture Scanner. The Sensors is also able to provide measurements beyond RH = 95 %. The Sensors and Scanner provides values up to RH = 100 in percent [%]. When RH = 100 %, the scanner app must be set into "Water mode" to be able to measure the amount of liquid. When in Water Mode, the Sensor provides the Scanner with values based on the dielectric constant of the material in the Sensor, and the capacitance which occurs when water gets in contact with the copper in the Sensor. The maximum achievable value in Water Mode is 140 % [78].

InviSense Mobile Phone Application

To be able to use the Scanner, an InviSense App was installed on the author's mobile device. After an initial setup of the app, the Scanner needed to be connected to the app using Bluetooth. When connected, measurements could be performed for all sensors. When the sensors were located by the scanner, the RH-measurements were shown real-time on the mobile device. Individual sensor results were logged in the RH logbook.

Figure 58 InviSense Scanner used for RH-Sensor Readings

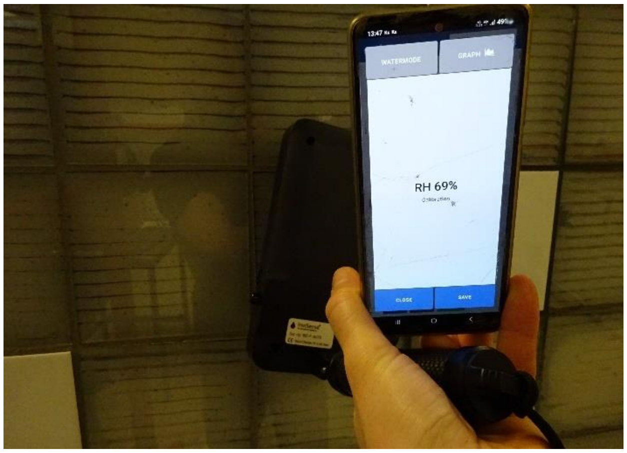


Figure 59 Measuring RH = 69% using the Scanner and App

RH-Measuring Calibration

Each time the scanner is connected to the app via Bluetooth, it needs to be calibrated prior to scanning any RH sensors. The app calls out the calibration to be performed in an open space, with anything interfering line of sight of 1 meter in all directions, see Figure 60. When the calibration is performed, it presents the user with a graph as shown in Figure 61. For the first 15 calibrations, a screen dump was taken to document the calibration curve. All curves was close to identical within minimal deviations; therefore, the curve signature was continuously verified on-screen during the upcoming calibrations only. See Curve I and Curve II in Figure 61 and Figure 62 for two individual examples taken February 6th and February 7th respectively.

Figure 60 InviSense Calibration, Making Sure no Obstacle is within 1 Meter in all Directions

Figure 61 InviSense Caibration Curve I

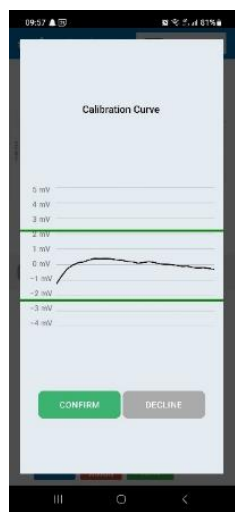


Figure 62 InviSense Caibration Curve II

4.7.4 Water Exposure Equipment

A water exposure shower system comprising hoses, couplings and a shower head was mounted to the modular extruded steel square stand. The Shower Head was securely mounted in the adjustable clamping fixture during water exposure. The black clamping fixture was set at a height and angle ensuring an approx. 60-degree shower stream orientation relative to the horizon, while hitting the center of the water exposure Target area. The shower system was directly connected to a temperature adjustable faucet using 1/2" couplings and hoses. The setup provided a steady water source with a stable water flow rate and relatively steady temperature, according to specification. The setup provided the water cone in the water exposure target area to be approx. 140 mm in width and 200 mm in height. See Figure 63 and Figure 64.

As presented in Chapter 3.3, parameters regarding both flow rate and temperature are defined as key parameters. Control of the flow rate was made through the established calibration regime described below. Temperature control was established using the HIOKI unit presented in 4.7.2.

Figure 63 Shower Water Exposure Target Area Impacting the EUT

Figure 64 Fixture Positioning for Shower Head in an Approx. 60° Angle

As part of the water exposure equipment, the selected soap can also be highlighted. The suspicion that both remains from soap, but also skin residue might lead to growth of mold in wall, in addition to altering the water behavior was evaluated [33]. For this experiment, skin residue is not included, however soapy water is planned for EUT #2. The soapy water mixture comprised Lano and water in a 1:10 (10%) ratio. 50 g Lano soap pr 500 g water. The mixture is sprayed in- and immediately around the water exposure area.

<u>Water Exposure Calibration</u>

The flow rate of the shower head is calibrated at least once pr day at the specific temperature established for the experiment. A designated calibration area for the flow rate was setup in the sink and a dedicated bucket is used for weighing the water. The empty bucket is used to establish the tare weight on a desiccated scale.

The shower head is removed from the stand and aimed at the thermocouple in the sink, ref Figure 65. Adjustments to the water temperature is done through the faucet. When temperature of 38 +/-1 °C is reached, immediately proceed to fill the bucket for flow rate measurement, letting the water flow for 30 seconds, controlled by a timer. When the bucket has been filled for 30 seconds, weigh the bucket, and utilize eq. (6) to establish the flow rate, see example weighing in Figure 66:

$$U = (m_w * \rho_w) * 2 \text{ [l / m]} \qquad (6)$$

Where,

U = Flow rate

m_w = Mass of water in kg pr 30 seconds

ρ_w = Density of water at 38 °C in kilograms pr liter

Figure 65 Flow Rate Calibration Timing of 30 Seconds

Figure 66 Water Weight of 4 636 Grams after 30 Seconds of Water Flow

4.7.5 Data Processing- and Analysis Software

Several SW is used to compile and analyze the registered data acquisition, as well as analyze the results. Common SW tools in Microsoft (MS) Office is used the most, with Excel being the core SW being used for all data processing. In addition, an image processing tool called Digimizer is used for analyzing a selection of the photos, and a statistical analysis SW called NCSS. The latter is utilized for the regression analysis presented in the results.

4.8 EXPERIMENT PLAN AND SCHEDULE

This section presents the executed experiment plan and schedule of the master's thesis. The section provides the reader with a fairly detailed overview of the executed plan, as well as the schedule for the experiment. All further details and the full execution with results are presented in Ch. 5. A detailed description of the research timeline in addition to a Gantt chart is presented.

Limiting factors related to schedule is presented in section 4.9.

The experiment plan and schedule changed rather drastically during the research period based on observations during the experiment. The change in plan and execution are connected to the QA aspect regarding the PDCA-cycle. From what was seen during the experiment, and the experiment goal not being achieved doing as initially planned, changes needed to be made. QA was assured throughout the entire process, implementing proper PDCA approach. The changes are presented in section 4.8.3.

To ensure the content and progress of the experimental research, as well as have an established platform for discussions, weekly status meetings were conducted between the author, supervisors, and other stakeholder during the experimental research period.

4.8.1 Experiment Plan

Based on the research questions, the hypotheses and what is presented in Ch. 2 and Ch. 3, all EUTs were planned for a 2-stage experiment. Key parameter baseline was according to what is presented in section 3.3, and the main research focus was evaluation of moisture migration behavior both prior to- and after moisture saturation. To be able to do this, two experiments were planned and executed, according to sub-sections below.

4.8.1.1 Main Experiment – Water Exposure Plan

The two stages applicable for the main experiment was defined as the following:

- Stage 1: Un-saturated moisture migration with water temperature $T = 38 \pm 3$ °C
- Stage 2: Saturated moisture migration with water temperature $T < 38$ °C

The intention of Stage 1 was to measure, observe and evaluate the water- and moisture behavior in the grout, tile adhesive and tiles where RH < 100 %. The water exposure during Stage 1 are planned to be done in a more realistic way, distributing the shower cycles evenly throughout the day.

Stage 2 include the same intention as Stage 1, where the tile adhesive is fully saturated at RH = 100 % also with water present. The water exposure during Stage 2 are accelerated, and continuous water exposure is applied within the allocated time. Different focus during Stage 2 for EUT #1 and EUT #4 were established. EUT #1 was planned for a more realistic distribution of cycles, while EUT #4 was planned for a more concentrated and accelerated water exposure in Stage 2.

The total exposure time for both Stage 1 and Stage 2 for all EUTs are listed below:

EUT #1 is subjected to clean water exposure:

- Stage 1:
  - 5 days of 9 to 12 shower cycles
- Stage 2*:
  - 4 days of 9 to 12 shower cycles
  - 2 days of 1 shower cycle beyond 8 minutes
- Total exposure time: 664 minutes (11h4m)
- Total number of shower cycles: 83
- RH- and weight measurements to be done after water exposure.

* Note: after exposure, initiate 4 days of artificial water saturation with the EUT laying on the floor.

EUT#2 is subjected to soapy water exposure:

- Stage 1:
  - 1 day of 12 shower cycles
- Total exposure time: 96 minutes (1h36m)
- Total number of shower cycles: 12

EUT#4 is subjected to clean water exposure:

- Stage 1:
  - 4 days of 12 shower cycles
- Stage 2:
  - 13 days of 1 shower cycle beyond 8 minutes
- Total exposure time: 2920 minutes (48h40m)
- Total number of shower cycles: 365
- RH- and weight measurements to be done after water exposure.
- In-depth analysis of moisture migration to be performed after water exposure.

4.8.1.2 Supporting Experiment – Water Sorption Plan

The water sorption experiment for the tile adhesive specimens and tiles are planned and executed based on the standards described in 4.5.2 in addition to others [15, 75, 76]. The duration of the experiment are governed by a stabilization criteria for the valid maximum weight value, i.e. saturated weight:

3 sequentially measured values being identical each 24 hours to an accuracy of 0.1 grams.

Whenever the stabilization criteria is met, the specific cube or tile can be removed from the experiment having fulfilled its purpose. The same acceptance criteria applies for both the tile adhesive specimens and the tiles. Further calculations for moisture content shall be done using dry basis, using mass of water and mass of dry solids.

4.8.2 Schedule

The initial meetings between the internal supervisor, SINTEF and the author were held during October 2022. Establishing the scope of the master's thesis and as the experiments itself were the primary content of these preliminary meetings. The first activity having dependency on further activity was the design of the EUT. During November and December 2022, the final design of the walls were reviewed and finalized. The Base Walls were constructed by SINTEF in the last week of November 2022, and all walls were clad and constructed according to specification of the complete wall design December 5th

and 6th 2022. The walls were left to dry until January 9th 2023, where they were grouted and finalized prior to experiment startup February 6th 2023. The experiment research phase was originally planned from February 6th 2023 until April 5th 2023, ended up with lasting until April 28th 2023.

During the period of January and first week of February 2023, planning and detailing regarding experiment setup was the main activity. Also, during this period, the main part of the governing documents highlighted in 4.1.2 was produced, reviewed, and finalized.

A complete and detailed Gantt chart showing the complete schedule is found in Appendix G.

Experiment Schedule Overview

- EUT#1 Water Exposure- and Drying Period
  - Water Exposure w/ Daily Measurements: February 6th – February 20th
  - Drying Period w/ Daily Measurements: February 21st – March 17th
  - Drying Period w/ Weekly Measurements: March 24th – April 28th
- EUT#2 Water Exposure Period
  - Water Exposure w/ Daily Measurements: February 13th
- EUT#4 Water Exposure Period
  - Water Exposure w/ Daily Measurements: February 20th – March 17th
  - Drying Period w/ Weekly Measurements: March 24th – April 28th
- Sorption Experiment Period
  - Daily measurements: February 23rd – March 16th

4.8.3 Changes in Schedule and Scope

Based on observations from initial experiments with the prototype wall, reviewed literature, and general assumptions to moisture migration, the EUTs was scheduled for 1.5 weeks of water exposure each. In addition, time allocation for additional supplementary experiments and unforeseen issues and problem-solving were scheduled.

There was challenges regarding progressing into Stage 2 for EUT #1 within the allocated experiment schedule. After the first week of water exposure, an attempt to accelerate the saturation was made by placing EUT #1 on the floor, soaking it for 4 days. After the accelerated saturation attempt was finished, EUT #1 was subjected to an additional 5 days of water exposure. Further description of the saturation attempt is described in section 5.3. After the water exposure, EUT #1 is scheduled for continuous RH-measurements to establish a data set for the drying period.

A second issue causing change in schedule and scope of the experiment were made after soapy water observations on EUT #2. The assumptions regarding moisture migration being much faster using soap, did not occur. Therefore, a decision was made to cancel further experiment using soapy water and focus on more long-term experiments with clean water. The decision was reviewed by the supervisors and stakeholders, and consensus was reached to move forward with the new plan, focusing on EUT #4.

EUT schedule and experiment scope was changed, and the final iteration of the schedule was finalized.

4.9 EXPERIMENTAL PROCEDURE

To be able to have a proper experimental setup, in addition to establishing a framework for gathering all necessary data required to establish a solid foundation result evaluation, an experimental procedure is utilized. This section describes the daily procedures for the water exposure experiment and the water sorption experiment. The experimental procedures were established prior to startup and was adjusted in the early parts of the experiment to establish a more effective, functional, and streamlined process. The procedures are established governed by the research questions, the hypotheses, and the intention of ensuring sufficient data collection.

4.9.1 Main Experiment - Water Exposure Procedure

A simplified procedure of the water exposure procedure is presented below, with focus on the daily logging performance. The complete and detailed experiment procedure, as utilized during the experiment, is found in Appendix A. The detailed version also include the full setup description of the EUTs in the laboratory.

Daily Experiment procedure:

Prerequisites

EUT installed correctly in the Pulley and Hoisting Equipment, with all applicable logging equipment and data acquisition connected and ready. RH-sensors are ID-marked using a sharpie.

Procedure

1. Register start-up time
2. Register ambient temperature and ambient relative humidity
3. Perform weight logging of the EUT while the support legs are stowed
4. Tilt the support legs making sure the EUT is level in roll, pitch and yaw
5. Perform RH-sensor measurements
6. Take pre-exposure pictures
7. Perform water temperature calibration
8. Perform flow rate measurement
9. Position shower stand with the installed shower head in the dedicated experiment location.
10. Start temperature logging
11. Start timer and turn on the faucet simultaneously, while the shower head is aimed at the target area.
12. Let the water run for a predefined time while observing EUT for potential findings

a. If soapy water is planned, apply the mixture soap in the water exposed area every 2 minutes

13. Stop timer and turn off the faucet simultaneously
14. Stop temperature logging
15. Take post-exposure pictures
16. Perform RH-sensor measurements
17. Perform weight logging of the EUT while the support legs are stowed
18. Register ambient temperature and relative humidity

The primary data acquisition were performed prior to-, after, or during the water exposure of the experiment. A compressed overview of the different data acquisitions are described in Table 7.

Table 7 Experiment Procedure – Main Data Acquisition Timing

ID	Description	Prior	During	Post
1.	Ambient Conditions	X		X
2.	Measure Wall Weight	X		X
3.	Temperature Measurement	X	X	
4.	Relative Humidity Measurement	X		X
5.	Video	X	X	X
6.	Photo	X	X	X
7.	Timelapse Photo		X	

4.9.2 Supporting Experiment - Water Sorption Experiment

The full experiment procedure for the tile- and tile adhesive water sorption experiment is presented below. A simple procedure was established based on test methods described in several standards, and the author's experience within verification and testing [15, 75, 76].

Daily Experiment Procedure:

Prerequisites

Tiles and tile adhesive specimens are submerged in the dedicated water tub, fully covered in water.

Procedure

1. The water tub containing the tile adhesive cubes and the tiles shall be positioned within short distance to the scale.

2. Verify the scale being zeroed at 0.0 grams.
3. Remove one cube or tile at a time from the water tub, drying off any excess water on the surface.
4. Placed the cube or tile on the scale and registered the weight.
5. Repeat measuring steps for all cubes and tiles.

Evaluation whether stabilization criteria is met shall be done at the end of each weighing period.

4.10 CONSTRAINTS AND ASSUMPTIONS

4.10.1 Financial Constraints

SINTEF had a total budget of NOK 150 000.- available for the experimental research executed during this master's thesis. The main expense in the budget was the construction labor of the tiled walls as well as material cost, with the cost of the glass tiles being the largest. Additionally supporting equipment, assistance from lab personnel, rental of experiment equipment, and consumption items was part of the budgeted expenses.

4.10.2 Schedule Constraints

The allocated time for this master's thesis was between the first week of January 2023 with hand-in May 25th 2023. This was not sufficient to be able to plan, design, construct, execute and evaluate the experimental research. To mitigate the time constraints, the planning, design, and construction of the research was started in October / November 2022 as part of the preliminary study course MABY5010 at OsloMet. One of the main issues to handle was the construction of the 4 tiled walls for the main experiment. Based on the literature review and experience from the industry, a relatively long drying time was required for the tile adhesive to reach low enough RH prior to experiment startup. As the drying also applied to the grout, two separate activities needed to be planned and executed. All in all, the tiled walls got 34 days of drying after tile adhesive application and 30 days drying time after grout. After performing the first measurements of RH, the values was deemed acceptable.

4.10.3 Equipment Constraints and Assumptions

4.10.3.1 RH-Logging Equipment

The RH logging equipment, described in detail in section 4.7.3, was not available to the author until a couple of days prior to experiment startup. Therefore, no measurements of the RH has been done to track progress during the drying period for the 4 tiled walls. Due to the late delivery of the last batch of sensors, only EUT #1, EUT #2 and EUT #4 was installed with RH-sensors.

RH-sensor ID S1-9 does not provide any readout when utilizing the scanner. In conversation with the producer InviSense, the conclusion of the sensor being malfunction was reached without any way of rectifying within the experiment time frame. The location of the sensor (top right) has been shown to be of little relevance during the experiment, hence this is seen as a minor issue.

4.10.3.2 Moisture Diffusion Resistance not According to Requirements in TEK17

To be in accordance with the requirements in TEK17 §13 regarding moisture- and water vapor safety in a bathroom wall, a membrane should be applied to the Litex TB Wet Room XPS Boards to achieve a Moisture Diffusion Resistance of S_d = 10 m. According to the supplier of the chosen Litex boards, they have an S_d value of 1.25 m pr 10 mm, concluding a total of S_d = 0.030 * 125 = <u>3.75 m</u> for the 30 mm boards. An evaluation was done, and a conscious decision was made to deviate from establishing realistic parameters at every levels. Due to the established research questions does not include any evaluation to be done for moisture- or water migration into the structure. In addition, sideways moisture migration was the key parameter to evaluate during the experiment. Also, evaluation regarding financial- and time-wise constraints were done, in addition to uncertainty regarding RH-sensor installation combined with the membrane.

Based on the above, the author remains confident in ensuring full integrity and safeguarding of the research questions with no membrane applied to the wet room boards. The main purpose of the experiment is to evaluate moisture migration in the tile adhesive in the constructed walls; hence the lower moisture diffusion resistance across the building detail is deemed acceptable.

4.10.3.3 Wall Weight Uncertainties due to Excess Water Accumulation

During water exposure there is accumulated some water in the bottom part of the tile adhesive. A small amount of water is also present on the surface of the tiles, or located elsewhere in the wall structure which is deemed outside of the applicable water exposed area. However, as seen in the results chapter 5, a steady increasing weight trend is seen from measurements. The uncertainty regarding accumulated water is considered minor and confidence in the setup remains by the author.

Based on sorption data for the tile adhesive from the supporting experiment, a quantifiable estimate has been done to find the disregarded amount of accumulated water:

Average volume and weight calculation of the water in the lower parts of the walls, where exposed tile adhesive is present, averaged between EUT #1 and EUT #4, is found in eq. (7) and (8):

$$Volume = \frac{width * height * depth}{2\ (due\ to\ trowel)} = \frac{1\ 395 * 50 * 6}{2} = \underline{209\ 250\ mm^3} \tag{7}$$

$$Weight = 220\ 875\ mm^3 * \rho = \ 209\ 250\ mm^3 * 1\ 375.15 \frac{kg}{m^3} = \underline{287.75\ grams} \tag{8}$$

The width is based on an averaged estimate between the earlier stages and the later stages of water exposure. As time progress, more and more water is accumulated in the exposed tile adhesive. The average is estimated to be approx. 9 tiles in width. Each tile and adjacent grout is 155 mm. An additional estimate of the water stuck to the surface of the tiles are 50 grams. However, this number is highly uncertain, as some of this water might have dried up between the last water exposure and the execution of the weighing.

Assuming 1000 kg / m^3 = 1 kg / liter for water concludes with a weight of 288 g + 50 g to be subtracted from any water weight calculation.

5 RESULTS

5.1 INTRODUCTION

Chapter 5 presents the results from the experimental research. The sections in this chapter are divided into presenting individual EUT results from the main experiment including the *main parameters* in sections 5.2 - 5.5. In section 5.6 the *control parameters* are presented for all EUTs combined, and section 5.7 describes the supporting experiment.

All highlighted sections introduce general information in addition to the following details:

Main parameters

- Moisture migration
- Relative humidity
- Wall weight

*Control parameters**

- Water temperature
- Water flow rate
- Laboratory ambient conditions

*Note: Control parameters are controlled and registered, however, not influenced in any way other than making sure they are within the applicable scope. Both water temperature and flow rate were part of the key parameters presented in section 3.3.

The main scope in this master's thesis, based on the research questions, are to evaluate the moisture migration in the tiled walls. This is done through the implementation of the defined key parameters, in addition to the presented data acquisition tools. All results presented below establish the baseline for the overall discussion in chapter 6, however, specific result discussions are found in this chapter (Ch. 5). The holistic discussion, synthesizing all results and observations are presented in chapter 6.

Wall #4 is presented more in depth than the other EUTs and will be analyzed in more detail. Both linear- and multivariate regression have been utilized using Microsoft Excel and NCSS Statistical Analysis and Graphics Software (NCSS) 2023, in addition to photo analysis and further evaluation of the data acquisition. The results for Wall #4 are found in section 5.5.

5.2 GENERAL RESULT INFORMATION

Due to the selected color of the tile adhesive and the grout, there is a relatively high color contrast between wet and dry material. The dry material is shown as light grey, and the wet material is shown as dark grey in all presented photos.

A common measurement used in this chapter for describing the accumulation of moisture, either in the grout or tile adhesive, is provided in the number of wet tiles. Either lengthwise or area-wise, being contextually explained when presented. If one whole tile is visibly wet, this is counted as 1.0, and estimate to the nearest 0.1 is done.

The size of the tiles are 150 mm x 150 mm, and the grout width is 5 mm, leading to one tile-width being 155 mm, and the area of one tile being approx. 155 mm x 155 mm = 24 025 mm^2.

Overall shower cycle description is presented in sections below. Details regarding the specific distribution of the shower cycles for each EUT found in Appendix I, identified as 'Exposure Details'.

5.3 WALL #1 RESULTS

5.3.1 General

Wall #1 was exposed to showering cycles for a total of 10 days, followed by 9 weeks of drying with continuous RH data collecting. The time distribution was as follows:

- Stage 1: 4 days = 328 minutes
- Stage 2: 6 days = 336 minutes
- Stage 1 + Stage 2: 10 days = 664 minutes
- Drying: 67 days = 96 480 minutes

Each showering exposure cycle was 3 x 8 min separated by an approx. 2 min break between each cycle throughout both Stage 1 and Stage 2, with data acquisition measurements according to plan and experiment procedure. There was executed three or four 3 x 8 min cycles during each day of exposure, with three exceptions being day 1 with two cycles and day 9 and 10 with only one 3 x 8 min cycle.

After 328 min, EUT #1 was placed on the floor and continuously soaked using rags and water containers for approx. 96 hours. Due to challenging water containment control on the lying wall caused water to migrate towards the edges and beyond. See Figure 69 for the visual result just after the 96-hour soaking period. The two most conspicuous moisture migrations are highlighted in red circles.

5.3.2 Moisture Migration

As a general observation, the moisture migrates in the grout prior to the tile adhesive. Figure 67 shows the result after only 8 minutes of water exposure, where moisture can be seen in the grout as wide as 6 tiles in the center of the wall, and approx. 8.5 tiles in the bottom row. As Wall #1 is exposed to water, moisture slowly but steadily builds up in the tile adhesive. Figure 68 shows the result after the last exposure in Stage 1 at 328 min, where moisture is seen saturating tile adhesive at the water exposure target area as well as a total of approx. 4.5 tiles towards the bottom of the wall. Moisture has started to migrate into the tile adhesive from the grout, as seen from the thicker dark grey grout lines.

Uncertainty regarding moisture content in the ceramic tiles is relatively high in the early phases of water exposure. However, as moisture can clearly be seen surrounding most of the ceramic tiles in the center, assumption is made towards the tiles being saturated at 328 min. The general moisture behavior is backed up from the supporting experiment, with results presented in 5.7, and discussion regarding moisture sorption in both ceramic tiles and tile adhesive are found in Ch. 6.

The maximum sideways moisture migration during Stage 1 is approx. 8 tiles, corresponding to approx. 1 240 mm (approx. 640 mm to each side) with most of the moisture being in the grout.

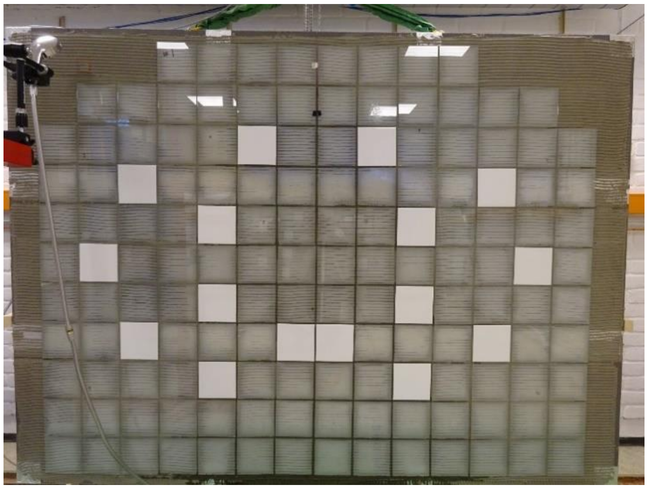


Figure 67 Showing EUT #1 during Stage 1 after 8 min of Water Exposure

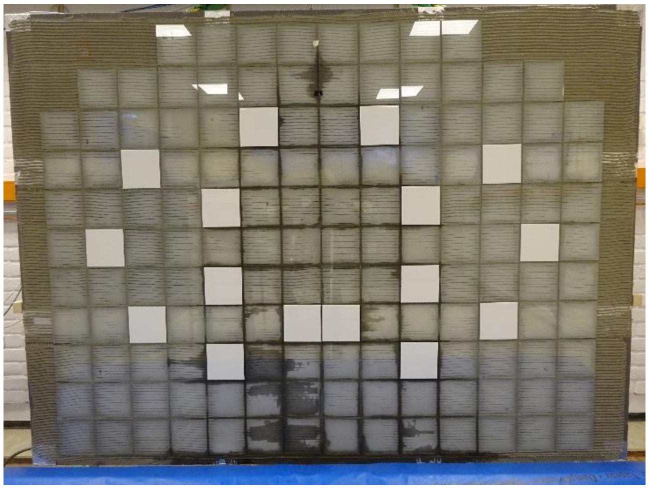


Figure 68 Showing EUT #1 during Stage 1 after 328 min of Water Exposure

After the artificial saturation, Wall #1 was further exposed to an incremental cycle of 3 x 8 min shower exposure for an additional 336 minutes. Comparing Figure 70 and Figure 71, distinct signs of further moisture migration is seen moving from the center towards the edges, as well as moisture being filled in the center tiles. Also, the two spots subject to involuntarily soaking, highlighted in Figure 69, has started to dry up.

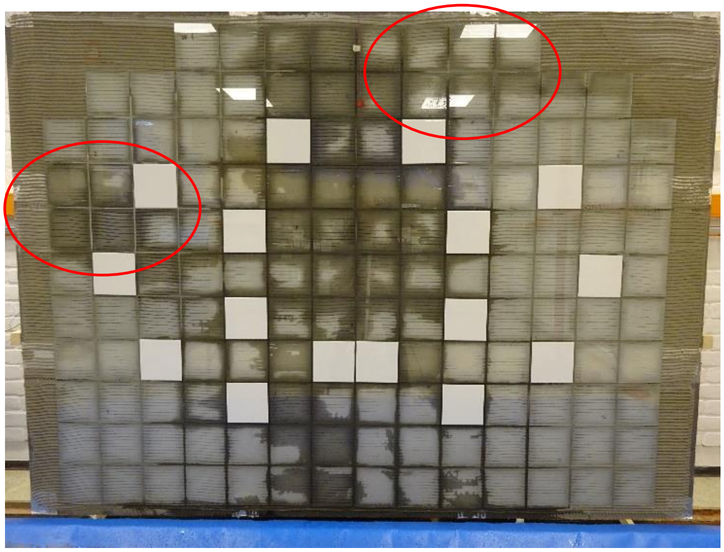


Figure 69 EUT #1 after 328 min and 96 Hours of Soaking

Figure 70 EUT #1 after a Total of 424 min of Water Exposure incl 96 hours of Soaking

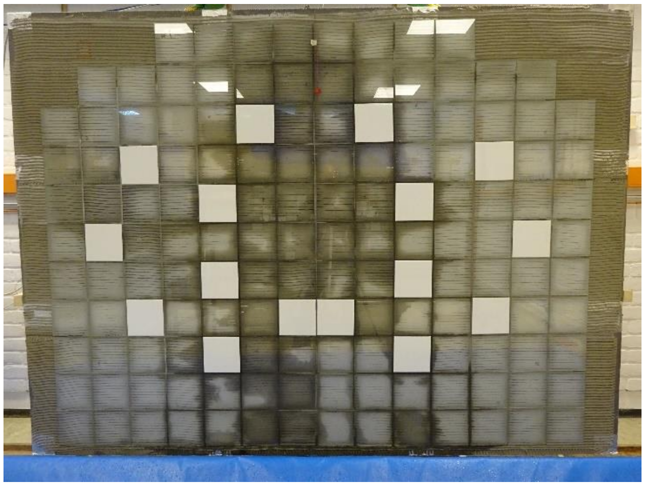


Figure 71 EUT #1 after a Total of 664 min of Water Exposure incl 96 hours of Soaking

Additional pictures of the moisture migration is found in Appendix I.

5.3.3 Relative Humidity

Note: Refer to Figure 25, page 48 for RH-sensor ID overview.

Throughout the scheduled water exposure, RH was measured and logged according to plan. The data is compiled into a graph, ref Figure 72. Water vapor saturation levels at RH = 100% is indicated by a red circle and a black, dashed line, and liquid water is present above, towards RH = 140 %. Sensor ID S1-9 is not part of the presentation as it was broken and does not provide any readouts.

From the first shower exposure, sensor S1-6 shows a steady climb from the start, passing saturated levels and into liquid water at 72 minutes, ref Figure 72. The sudden climb in RH makes sense as the sensor is located just below the water exposure target area. Sensors S1-5 and S1-7 started climbing at 48 min, however, not as rapid as S1-6. The artificial saturation period is seen at timestamp 328 min indicated by a red arrow. Due to challenging water containment control on the lying wall, high levels of RH and liquid water is seen in the outer sensor perimeter sensor S1-2. The remaining sensors shows relatively stable values between 21 % and 50 % between timestamp 328 min (end of Stage 1) and 664 min (end of Stage 2).

After water exposure was finished, Wall #1 was stored upright, > 85° relative to the horizon, in laboratory U60. The RH-sensors in the wall was measured with a 24 - hour increment for 25 days, except 3 occurrences where measurement increments were 48 and 72 hours. After the initial 25 days, 6 additional measurements were made with intervals of 7 ± 1 days, concluding with a drying period of 67 days. X-axis in Figure 72 is divided into both minutes and days, where the separation happens at 640 min / 1 day, indicated by a dashed, red line. A separate figure showing the drying period in more detail and a more realistic timeframe, is presented in Figure 73.

During the drying period, a decrease in RH is observed due to evaporation. The sensors being at peak value of 140 % (S1-2, S1-4, S1-5, and S1-7) starts to decrease after 10 days with the first sensor being S1-6, followed by S1-7, S1-5, and S1-4. The first sensor dropping below saturated levels, i.e. RH = 100 %, is S1-7, which happened after 32 days. The last sensor dropping below saturation levels are S1-4 after 46 days. The remaining sensors also decrease, stabilizing between 21 % and 50 %.

During the drying period, the ambient temperature was between 22.2 °C and 23.0 °C, while the ambient RH was between 10 % and 30 %.

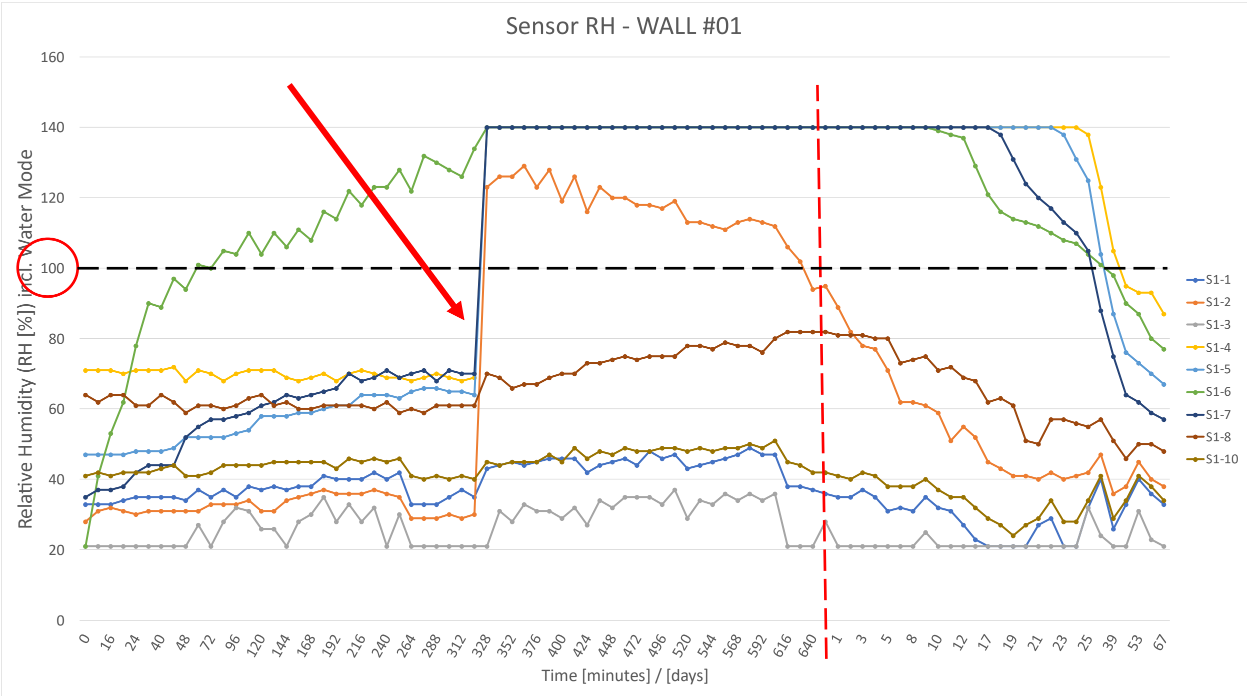


Figure 72 Wall #1 – Collected RH Data Showing Total Exposure Time and RH, incl. Water Exposure (664 min) and Drying Period (67 days) with the Rise and Descend of RH Sensor Values

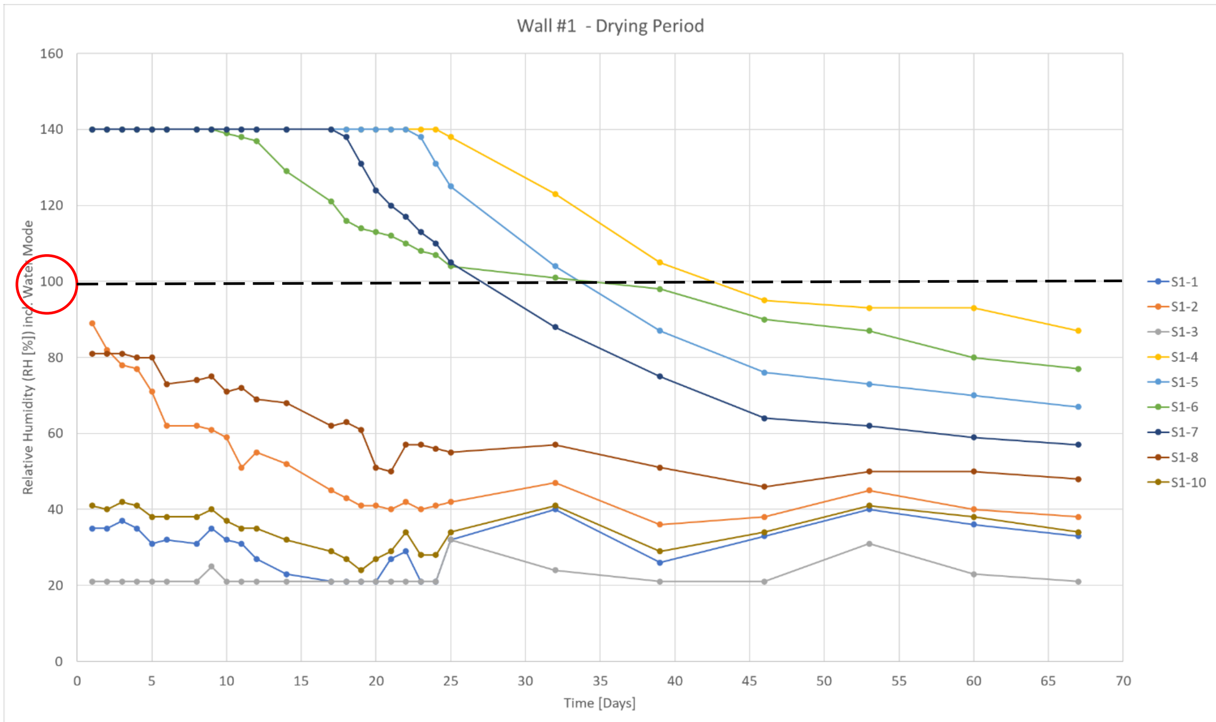


Figure 73 Wall #1 – Collected RH Data Showing Drying Period (67 days) with the Descend of RH Sensor Values throughout the Total Period

5.3.4 Wall Weight

Throughout the scheduled water exposure, weight measurements were registered and logged according to plan. Figure 74 shows the registered weigh of Wall #1 throughout the exposure period. Each timestamp in the x-axis (time) has one y-value (weight). At time = 0 the dry weight of the wall of 73.381 kg is presented. The following data points are collected after the last water exposure of the day for the remaining y-values. The trend line for the registered weight is presented as linear. This is only due to the artificial saturation, causing a rise in weight at Time = 328. Prior to this, the trend can vaguely be observed as the onset of having a natural logarithmic signature, which makes sense as the moisture holding capacity converge towards the maximum capacity value for the tile adhesive.

The total weight increase of Wall #1, measured from dry wall weight to the final measurement of 75.002 kg was 1.621 kg. Subtracting the estimate of disregarded weight as described in section 4.10.3.3, including the accuracy deviation described in 4.7.1 concludes with an applicable total water weight of 1.283 kg ± 0.080 kg.

All registered values are found in table form in Appendix I.

Figure 74 Weight Data of Wall #1 - Daily Post Water Exposure Weight Measurements

5.4 WALL #2 RESULTS

The results for Wall #2 is not structured in the same way as for Wall #1 and Wall #4. This EUT was subjected to water exposure only for 1 day, before being terminated and put into storage.

- Stage 1: 1 day = 96 minutes
- Total = 96 minutes

Wall #2, scheduled for water exposure mixed with soap, underwent a much shorter exposure than originally planned. The assumptions regarding soap making water migration much more rapid, was not confirmed. Based on the accumulated water exposure for Wall #2, the same, rather slow behavior as for Wall #1 was concluded. Figure 76 shows the moisture being in the grout only, extending a total width of approx. 8.5 tiles at the widest. With the expectation of seeing a noticeable difference in water migration compared with Wall #1, the experiment was redirected into focusing on Wall #4, performing a more long-term experiment period.

Figure 75 EUT #2 Being Applied with Soap

Figure 76 EUT #2 after 96 min of Water Exposure Showing Wet Grout

5.5 WALL #4 RESULTS

5.5.1 General

Wall #4 was exposed to showering cycles for a total of 17 days, followed by 6 weeks of drying with continuous RH data collecting and weight registration. The time distribution was as follows:

- Stage 1: 4 days = 384 minutes
- Stage 2: 13 days = 2 536 minutes
- Stage 1 + Stage 2: 17 days = 2 920 minutes
- Drying: 42 days = 43 800 minutes

Each showering exposure cycle was 3 x 8 min separated by an approx. 2 min break between each cycle throughout Stage 1. During Stage 2, an accelerated and continuous water exposure was applied ranging from between 96 min (1h 36min) and 300 min (5h 00m). Data acquisition measurements was executed according to plan and experiment procedure.

5.5.2 Moisture Migration

During water exposure of Wall #4, the typical moisture migration behavior was the following:

Moisture migrated in the grout, followed by moisture penetrating the grout and migrating into the tile adhesive. As seen in Figure 77, after 8 minutes of exposure, the grout is moist at an approx. 4 tile-width to each side, while only a small occurrence of capillary transport in the lower part of the wall, as well as three capillary transport affected areas, in addition to a gravitational transport in the center of the wall. The typical behavior between the moisture migration in the grout and tile adhesive are further presented and discussed in section 5.5.2.1.

After the immediate moisture migration in the grout, further expansion in the grout happens very slowly. This behavior is clearly seen in Figure 78, presenting results after 384 minutes, where moisture can be seen in the grout far out to the sides, very close to the final migration results after 2 920 minutes, seen in Figure 79. The noticeable difference is that the tile adhesive, within the boundaries of the grout, is not nearly as saturated at 384 min compared to the final 2 920 min.

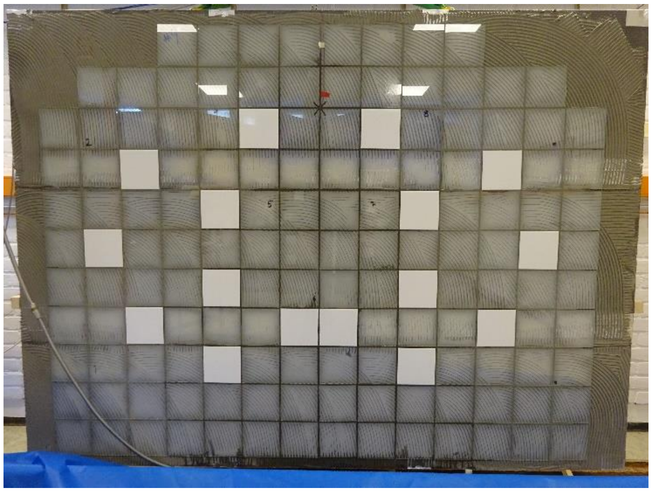


Figure 77 Wall #4 - Moisture Migration during Start of Stage 1 after 8 min

Figure 78 Wall #4 - Moisture Migration at the End of Stage 1 after 384min

Figure 79 shows Wall #4 after 2 920 minutes of accumulated water exposure. The total wet area is approx. 1.68 m^2. The final visual signature of the wet tile adhesive area forms close to an expected normal distribution area with a slight shift to the right. The shift to the right is reasonable due to the orientation and layout of the tile adhesive trowel pattern, causing less moisture resistance towards the right than the left side. The water exposure target area is located centered on the upper part of the wall, and the water runs down the wall due to gravitation. The orientation of the trowel pattern curves from top left in a smooth arc towards the lower right. As the water hits the top left of the tile adhesive curve first, it migrates relatively easily in the downward directed trowel arc affected by the gravitational force. In addition to the gravitational force, the moisture migration is amplified by the capillary force acting in the tile adhesive from the bottom of the arc through the grout. As described before, the moisture migrates in the grout prior to the tile adhesive, hence moisture is already present below to tile, where moisture is pulled upwards due to the capillary effect merging with the moisture coming from above.

Additional pictures of the moisture migration, and the moisture development throughout most timestamps are found in Appendix I.

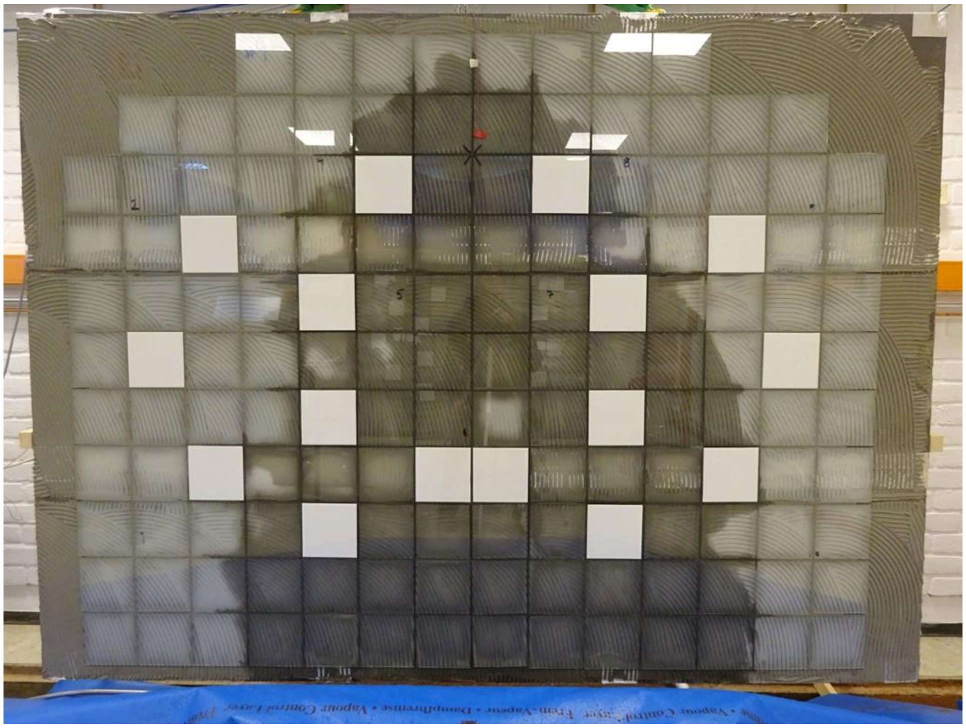


Figure 79 Wall #4 - Moisture Migration Result after Stage 1 and Stage 2 – Totalling an Accumulated Time of 2 920 min of Water Exposure

5.5.2.1 Moisture Migration Ratio between Grout and Tile Adhesive

Figure 80 shows the moisture migration in the tile adhesive, and Figure 81 shows the grout. The columns are stacked presenting the combined total values, showing the migration towards the right side in blue and to the left side in orange, presented in millimeters. Figure 82 compares the total moisture migration in the two materials. Tile adhesive expansion shows a slower buildup than in the grout, supporting the previously stated observations. After the initial moisture migration in the grout of 1 519 mm, migration extension happens at an average rate of only 0.5 % throughout the experiment.

Maximum tile adhesive moisture migration peaks just below 1 600 mm, while the grout peaks just above 1 600 mm on several occasions.

Figure 81 and Figure 82 presents a conspicuous dip in moisture migration in the grout at timestamp 1105 minutes. No correlation between any of the parameters have been found to explain this. As seen in both the RH-measurement in 5.5.4, and weight data presented in 5.5.5, no particular deviation are noticed at the specific timestamp. Ambient conditions, flow rate and water temperature have also been found to be comparable with other exposure days. From the post water exposure picture at 1 105 min, it seems that the moisture in the grout have had time to dry out towards the edges. This might indicate that the photo has been taken a long time after finished exposure. However, the file properties of the image confirms the picture being taken within 10 min of finished water exposure.

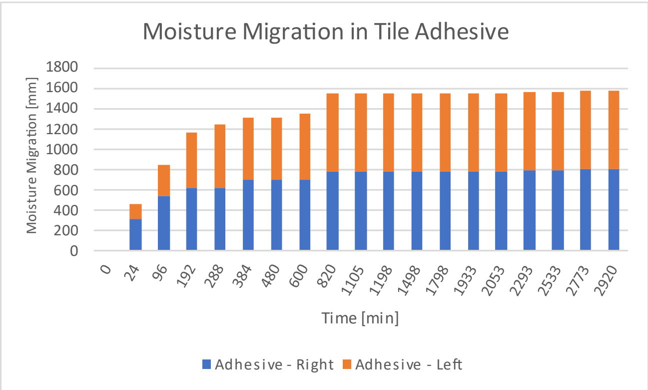


Figure 80 Moisture Migration in Tile Adhesive between 0 min to 2 920 min of Water Exposure

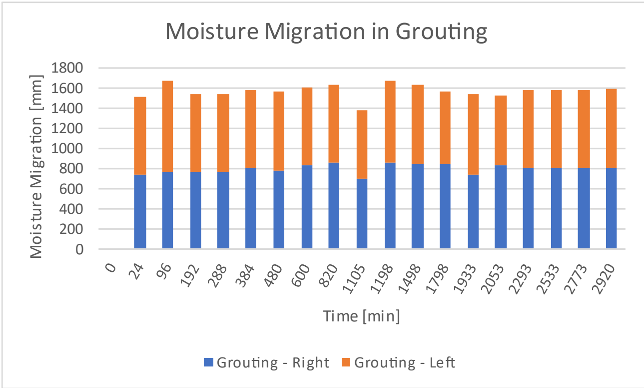


Figure 81 Moisture Migration in Grout between 0 min to 2 920 min of Water Exposure

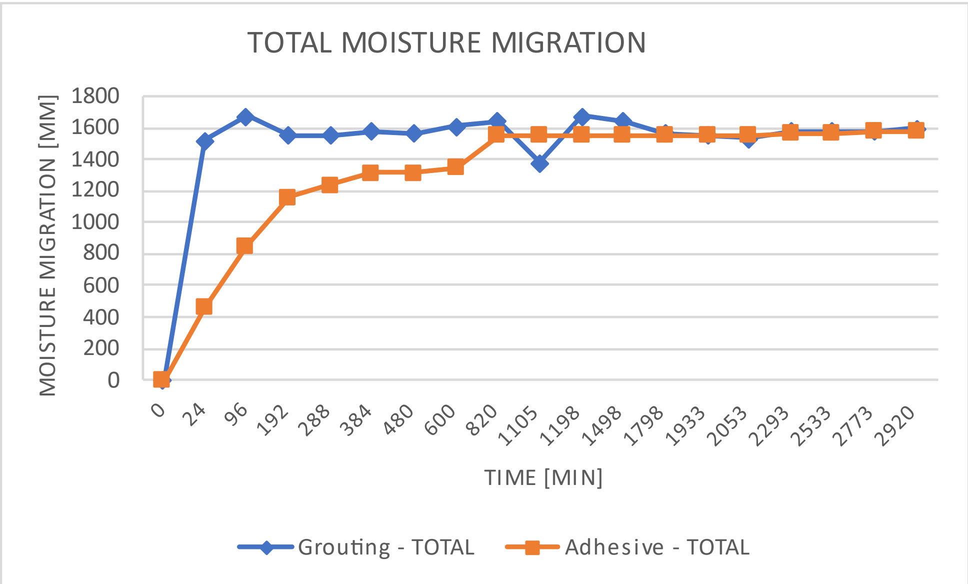


Figure 82 Comparing Total Moisture Migration in Tile Adhesive and Grout between 0 min to 2 920 min of Water Exposure Time

The longest moisture migration, during the total 2 920 minutes exposure time, from center of the water exposure target area is according to Table 8, and the moisture migration after the final water exposure at 2 920 min is presented in Table 9. As the data shows, moisture travels a bit further in the grout than in the tile adhesive, and this has been the consistent trend throughout the experiment. The defined wet zone of 1 meter (1 000 mm) was not reached during the experiment, however it was only 101 mm away compared to the longest moisture migration.

Table 8 Longest Moisture Migration during 2 920 minutes of Water Exposure

Description	Left [mm]	Right [mm]	Total [mm]	Up [mm]	Down [mm]
Moisture migration in the tile adhesive	775	806	1 581	276	1 450*
Moisture migration in the grout	899	868	1 767	283	1 450*

Table 9 Longest Moisture Migration at Final Exposure after 2 920 minutes of Water Exposure

Description	Left [mm]	Right [mm]	Total [mm]	Up [mm]	Down [mm]
Moisture migration in the tile adhesive	775	806	1 581	276	1 450*
Moisture migration in the grout	791	806	1 597	283	1 450*

* Note: The water migrated all the way to the lower end of the wall

5.5.3 Moisture Migration Analysis

Detailed moisture migration analysis is performed on Wall #4, where evaluation of which experiment parameter has the highest impact on the moisture migration. The words 'variables' and 'parameters' are used interchangeably throughout the section.

A combination of Multivariate Regression Analysis (MVRA) using the NCSS 2023 statistical SW, linear regression analysis in NCSS and MS Excel, and photo analysis have been done.

5.5.3.1 Moisture Migration Analysis Parameter Overview

A relationship between variables affecting the moisture behavior in the wall has been established. Identification of dependent and independent variables have been done through distinguishing between the registered & measured variables (dependent), and the controlled variables (independent). The following variables have been identified, and presented in more detail below the list:

Dependent Parameters

- Wall Weights
  - Accumulative
  - Incremental
- Wet Tile Area
  - Accumulative
  - Incremental

Independent Parameters

- Overall Experiment Elapsed Time
- Flow Rate
- Water Exposure Time
- Liter of Water
- Water Temperature
- Ambient Temperature
- Ambient RH
- Grout Moisture Migration

<u>Dependent Variable – 'Wall Weights'</u>

The applicable wall weights dependent variables were divided into accumulative weight of the wall after final daily exposure, called 'Weight Post' and the incremental water weight for each exposure day, called 'Weight Delta Pre-Post'. The latter is calculated as the delta between last weight measurement (Weight Post) and the first weight measurement done prior to the first exposure of the day, called 'Weight Pre'. Figure 83 shows the pre- and post weight of the wall in kilograms, using blue line with circular dots and red line with triangle dots for each timestamp. The 'Weight Delta Pre-Post' is presented as yellow columns, where the weight is provided in grams. The numbers used in NCSS is found below each timestamp 24 minutes to 2920 minutes on the x-axis, additionally in Appendix J.

Isolated results of the weight measurements are presented in further detail in section 5.5.5.

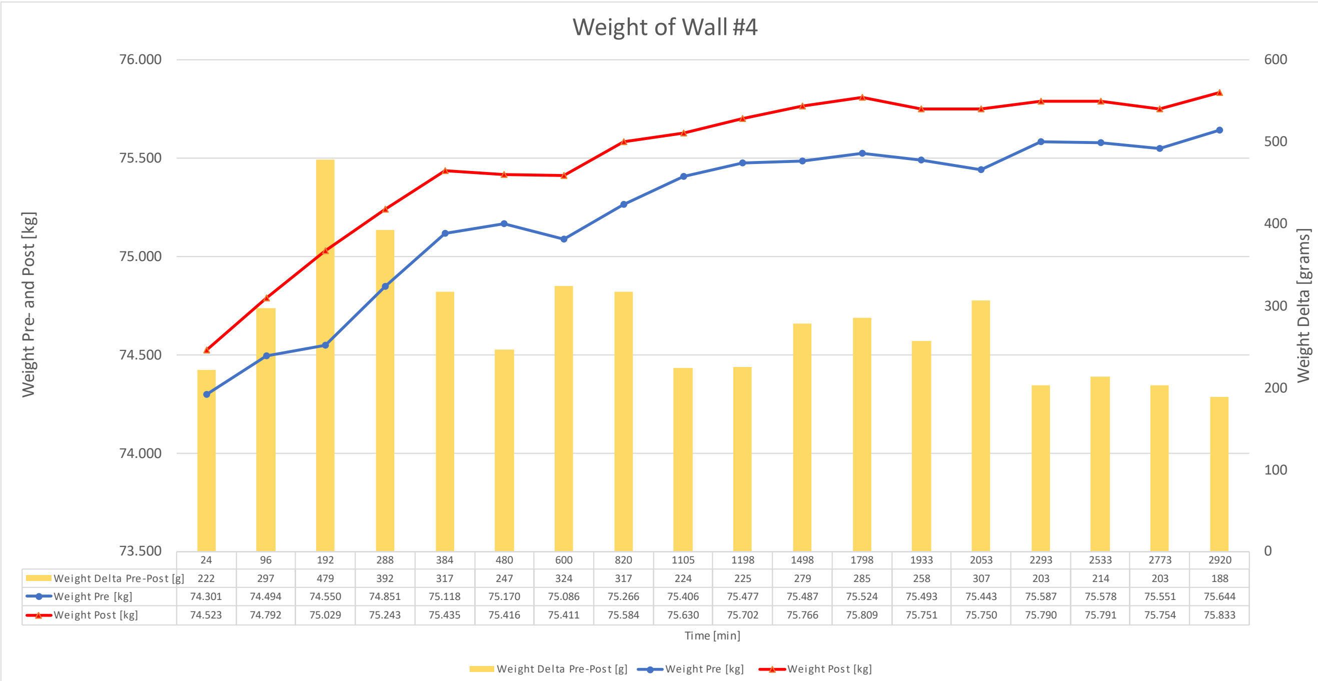


Figure 83 Weight of Wall #4 - Measurements Prior to Daily Exposure and After Daily Exposure (blue- and red line) Shown in kg, and in Delta Weight (columns) Shown in Grams

Dependent Variable – 'Wet Tile Area'

To evaluate the progression and expansion of the wet area in the tile adhesive as time advanced throughout the experiment, the photos taken at each main timestamps 24 minutes through 2 920 minutes were inspected. The wall was divided into a number of tile rows, to be able to analyze the moisture migration in sufficient resolution using the quantified measure of number of wet tiles described introductorily, ref. section 5.2. Figure 84 shows the accumulation of wet tiles during the experiment. 'ROW 1' is the top row of tiles on the wall, counting downwards towards 'ROW 11'. The accumulated amount in each color section corresponds to the sum of visible moisture in each tile. It is based on visual observation of the photos after the final water exposure for all 17 days. The stacked columns shows the total accumulation in the whole wall throughout all timestamps.

Source data for the table is found in Appendix I.

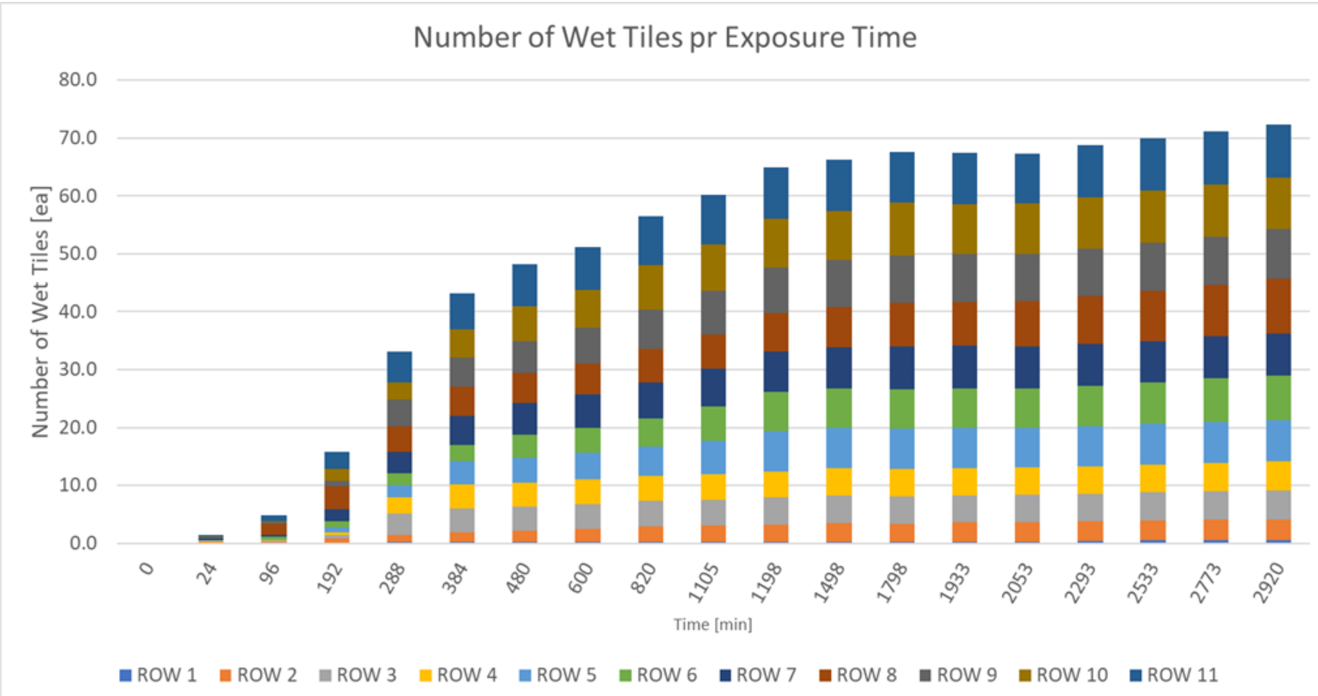


Figure 84 Number of Wet Tiles during Water Exposure in Wall #4 between Timestamps 0 minutes and 2 920 minutes

5.5.3.2 Moisture Migration Analysis - Statistical Software (NCSS 2023)

Multivariate regression analysis is a rather complex statistical analysis tool, however a great way of describing the relationship between a dependent variable and one or more independent variables. To be able to utilize this in depth requires much more dedicated time for training and use than the scope of this master's thesis allowed. An effort has been made to utilize the SW with available support to the best of the author's ability within a reasonable timeframe [79-81].

This section is meant to provide a summarized overview of the work that has been done with NCSS 2023. A more in-depth explanation into how the SW have been utilized and how the SW variable validity has been evaluated is found in Appendix J. Overall results and experience with the regression modelling in NCSS 2023 is summarized in sub-section 5.5.3.5.

5.5.3.3 Moisture Migration Analysis – MVRA

There are two analyses that can be highlighted. Both are found in more detail in Appendix J, and one is discussed below, being identified as analysis no. 2 in Appendix J.

#2 - Dependent Variable: Incremental 'Weight Delta Pre-Post'

This analysis showed promising results with both water temperature and ambient temperature being variables having the highest impact on the incremental weight (moisture content) in the wall. Five iterations were run in total. On paper, this analysis seemed plausible, however due to risk of multicollinearity and the author's expectations towards other variables having higher correlation, led to further inspection of the dataset.

5.5.3.4 Moisture Migration Analysis Discussion

Analyzing the above dataset in more detail using MS Excel showed a seemingly correlation between the registered incremental wall weight ('Weight Delta Pre-Post') and the registered water temperature ('Water Temperature'). Plotting the investigated dataset and adding a trendline, a clear collinearity is observed in Figure 85 between the delta weight (blue line) and the water temperature (orange line), being close to parallel. Both variables decrease as time progresses. Even a relative convergence is observed between the two. Based on this finding, it is understandable that the NCSS SW interpret these variables as pertinent regarding moisture migration.

Adding a daily exposure time (red line) to the graph shows an increasing trend. This variable was included in the investigation due to being the hypothesized variable causing most effect on the moisture migration. Understandably, it makes no logical sense that an increasing water exposure trend cause less delta water weight in the wall. There is obviously a different variable, material property and a combination of the two that are the root cause of the weight increase and wet tile development.

The discussion points and conclusions of these findings require input from other results in different chapters and sections as well. Hence, the content will be synthesized in Ch. 6.

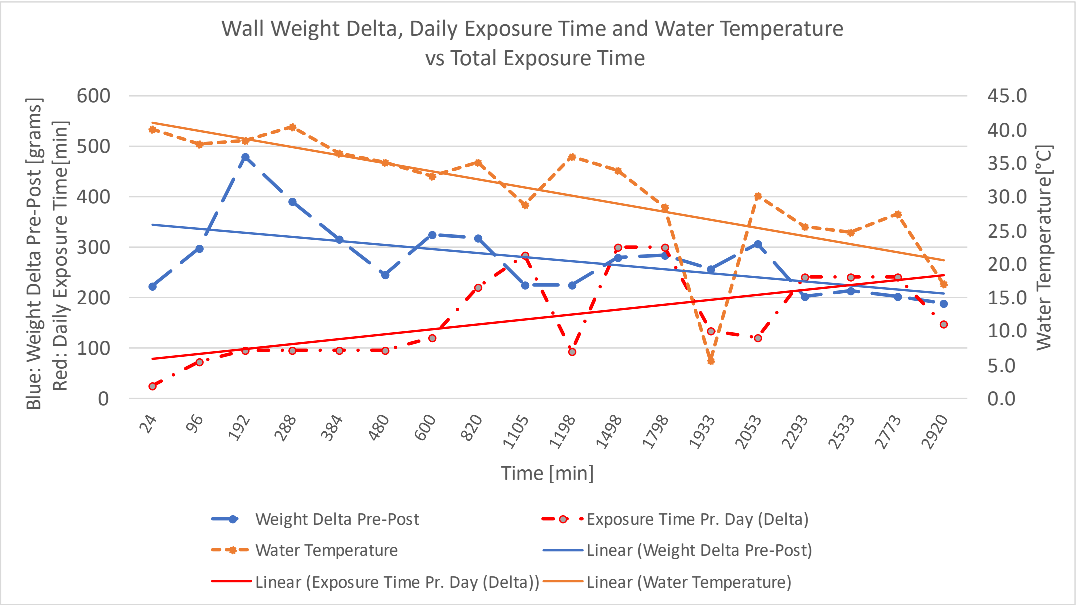


Figure 85 Analysis of Trendlines for Delta Weight, Water Temp, and Daily Exposure Time along Time Axis of Accumulated Time

5.5.3.5 Moisture Migration Analysis Conclusion

For a multivariate regression analysis to be effective, a "correct" and valid data set needs to be established. One of the challenges regarding using the parameters previously defined as control parameters, is that no effort has been taken into influencing these, other than to make sure they are within the defined setpoint. The parameters were established based on literature, to find the most realistic set of parameter values, and not part of any strategical and iterative analysis approach.

Additional challenges are autocorrelation (or serial correlation) and multicollinearity. The dataset clearly shows a correlation from the same variable between two sequential timestamps (autocorrelation) and two independent variables show high degree of collinearity (multicollinearity). None of these phenomenon should be present in a regression analysis to provide a reliable and valid result. As both incidents exists, there are little to no confidence in the performed analysis [82-84]. In the context of the research question and scope of this master's thesis, the available dataset suffers from being garbage in, garbage out, as the analysis was not planned from the start [85].

However, using MVRA through the NCSS 2023 SW was a great tool for critical thinking regarding the existing dataset, being able to analyze the data using a different approach. Possibly assisting in revealing connections that might not else have been drawn.

5.5.3.6 Future Moisture Migration Prediction through Extrapolation Modelling

A moisture migration expansion prediction is done based on the dataset from the moisture migration presented in 5.5.2, Models for predicting one daily 8-minute shower for 15 years is performed through a logarithmic curve fitting based on data from the moisture migration towards the right side for each main timestamp 24 min to 2 920 min, presented in 5.5.2.1. The two models are based on the following:

1. Logarithmic curve fitting in MS Excel based on expression from the built in trendline function in MS Excel.
    - Equation (9)

2. Logarithmic curve fitting in the NCSS SW based on the right-side moisture migration values.
    - Equation (10)

The applicable dataset and corresponding trendline are presented in Figure 86. Figure 87 shows the extended trendline for the whole calculation period of 2 - 15 years, where the blue dots to the left is the same graph as seen in Figure 86, but compressed due to the different scale. Recall that one shower exposure is defined as 8 minutes, hence 15 years equals only 43 800 min in this context.

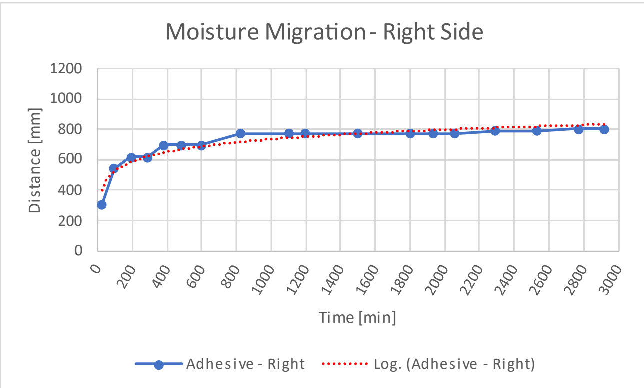


Figure 86 Moisture Migration to the Right in Tile Adhesive from 24 min to 2 920 min

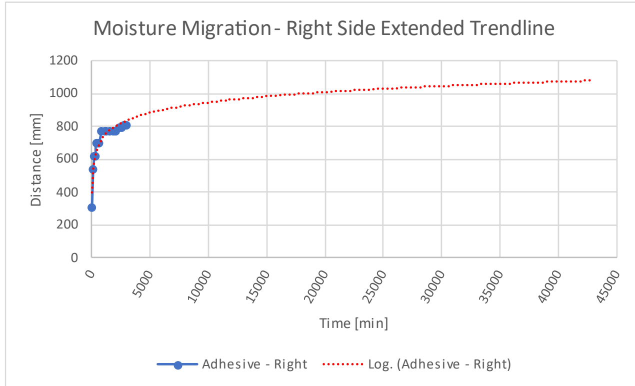


Figure 87 Extended Trendline Based on Moisture Migration from 24 min to 43 800 min

The model based on MS Excel trendline, eq. (9), has a coefficient of determination value $R^2 = 0.92$ (prediction accuracy is 92 %) while the NCSS model, eq. (10), has an $R^2 = 0.89$ (prediction accuracy is 89 %) [86].

$$MM_{Right} = B * ln(Exp_{Time}) + A \ [mm] \tag{9}$$

$$MM_{Right} = B * ln(Exp_{Time} - A) \ [mm] \tag{10}$$

Where

	Equation (9)		**Equation (10)**
A =	105.250	A =	1.092
B =	91.306	B =	107.467

Exp_{Time} = 24 min → 2 920 min and 24 min → 43 800 min in annual increments

MM_{Right} = Moisture Migration to the Right Side

There is always a degree of uncertainty regarding this kind of curve fitting. Utilizing the R^2 - values, there can be predicted a future moisture migration with a degree of accuracy for the two models. The moisture migration values are calculated and plotted based on eq. (9) and eq. (10) for each annual timestamps during the upcoming 2 – 15 years. Both models are matched to the trendline from MS Excel in Figure 88 and Figure 89.

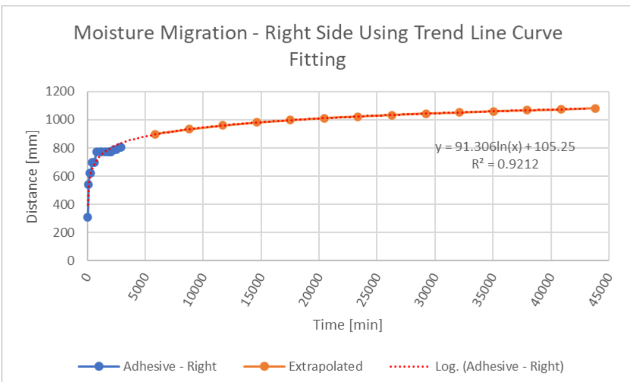


Figure 88 Moisture Migration in Tile Adhesive from 24 min to 43 800 min using Trend Line Equation for Curve Fitting, eq. (9)

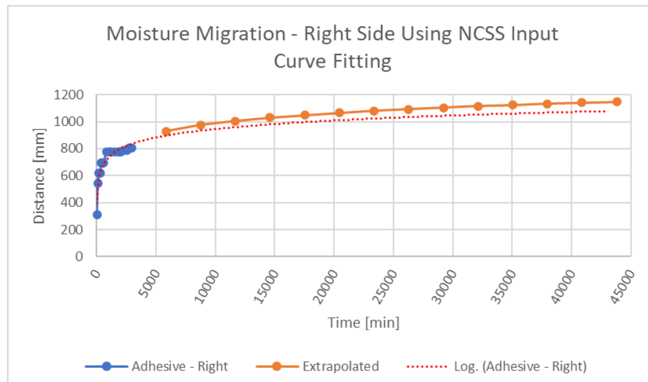


Figure 89 Moisture Migration in Tile Adhesive from 24 min to 43 800 min using NCSS Equation for Curve Fitting eq. (10)

The two models gives the following prediction into when the wet zone definition of 1 meter is reached:

- Model 1, eq. (9) predicts that moisture crosses the 1-meter wet zone after 7 years. Including the prediction accuracy of 92%, the prediction becomes between 3 – 16 years.
- Model 2, eq. (10) predicts that moisture crosses the 1-meter wet zone after 4 years. Including the prediction accuracy of 89%, the prediction becomes 2 – 12 years.

Based on the wet tile counting presented above and the moisture development in the different rows, it is most likely that the moisture will migrate furthest in ROW 8 throughout the upcoming years.

5.5.4 Relative Humidity

Throughout the scheduled water exposure, RH was measured and logged according to plan. Figure 90 show the registered measurements throughout both the water exposure period and the following drying period. The x-axis in Figure 90 is divided into both minutes for the water exposure period and days for the drying period, where the separation happens at 2 920 min / 7 days, indicated by a vertical, dashed, red line. Having two x-axis scales in one plot might provide a misconception, hence the drying period is separated in Figure 91, using a uniform minutes scale, giving a better visual impression. The first timestamp in Figure 91 is the last water exposure timestamp at 2 920 minutes. The point of saturation at RH = 100 % is indicated by a red circle and a black, dashed line in both graphs.

During exposure period, RH-sensors S4-6, S4-7, S4-5 are the first ones to initiate a steady climb, having presence of liquid water at 48 min, 120 min and 384 min accordingly. At approx. 1 200 min both S4-4 and S4-8 has a sudden rise in RH, indicating that liquid water is migrating further to the sides. S4-8 registers liquid water at 2 278 min, and S4-4 drops off before liquid water is measured indicating that the moisture is suddenly migrating in another direction. The remaining sensors shows relatively stable RH-values between 21 % and 40 %. When the experiment entered Stage 2, at timestamp 384 min, the sensors showed a more sawtooth signature. This is due to longer water exposure periods, causing higher concentrated increase and higher concentrated decrease in RH.

After the scheduled water exposure was finished, Wall #4 remained hanging in the Wall Hoisting Assembly in laboratory U60. The RH-sensors were measured with a 7 ± 1 day increment for a total of 42 days. During the drying cycle, the ambient temperature was between 22.4 °C and 22.8 °C, while the ambient RH was between 13 % and 29 %. During the drying period, the sensors being at peak value of 140% (S4-6, S4-7, and S4-5) starts to descend with S4-6 going below 140 % after 27 days, followed by S1-7 after 42 days. No sensor has dropped below water vapor saturated levels (RH = 100 %) after 42 days of drying.

An observation can be made regarding sensor S4-8: After water exposure has stopped at 2 920 min, the RH climbs from 109 % to 122 % in 7 days. This indicates that liquid water present in the tile adhesive migrates several days through water vapor diffusion after water exposure has stopped.

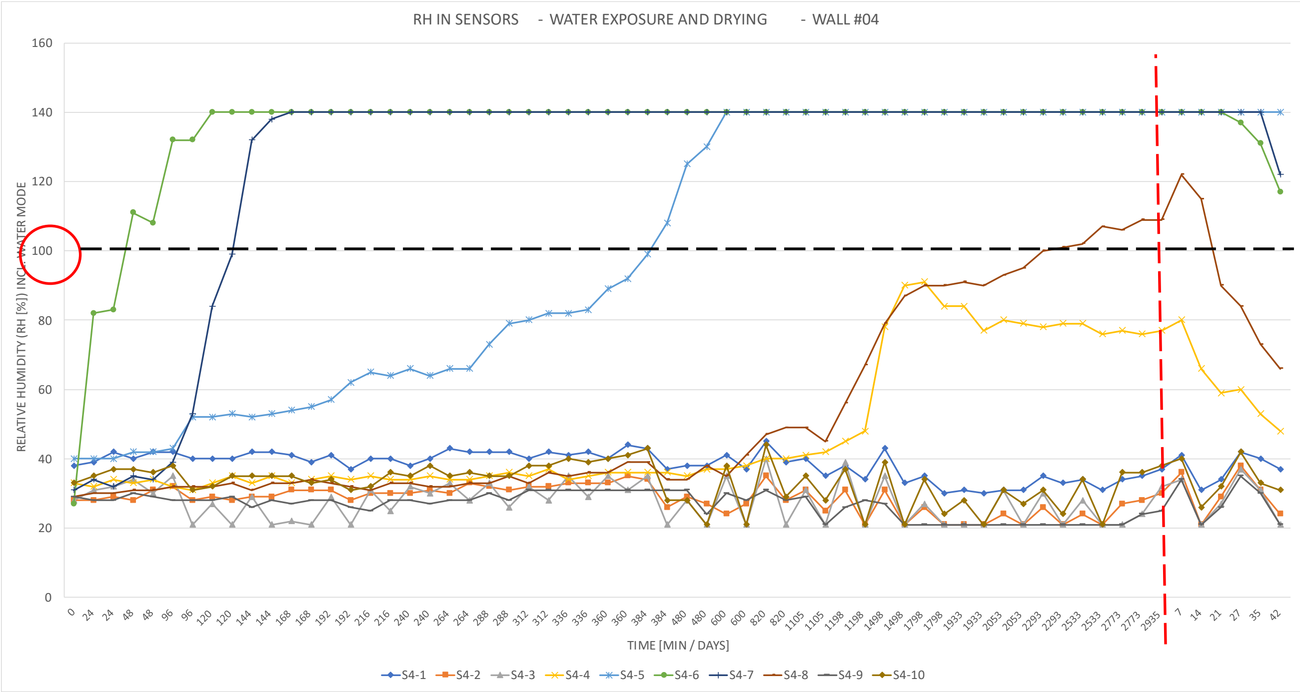


Figure 90 Wall #4 – Collected RH Data Showing Total Exposure Time and RH, incl. Water Exposure (2 920 min) and Drying Period (42 days) with the Rise and Descend of RH Sensor Values

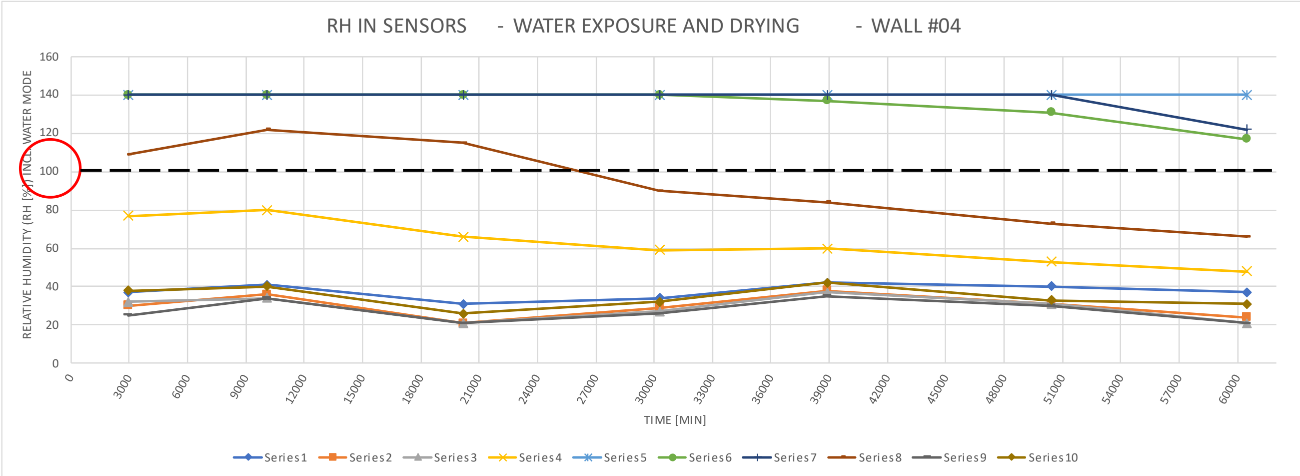


Figure 91 Wall #4 – Collected RH Data Showing Drying Period (42 days) with the Descend of RH Sensor Values throughout the Total Period

5.5.5 Wall Weight

Throughout the scheduled water exposure, weight measurements were registered and logged according to plan. Figure 92 shows the registered weigh of Wall #4 throughout the exposure period ('Weight'), including the following drying period ('Drying'). Each timestamp in the x-axis (time) has two y-values (weight), both being weight registration prior to daily water exposure and after. The trend line should have gone from t = 0 min. However, due to logarithmic calculation with values approaching 0 being challenging due to *ln (0) = undefined*, the first value in the graph is based on the pre-weight value after the first 3 x 8 min = 24 min exposures, weighing 74.494 kg. This only affects the first point in the visualization and the visualized trend line. The dry weight of the wall was 74.301 kg, causing a difference of 193 grams for the first registered weight point in the graph visualization.

The total weight increase of Wall #4, measured from dry weight to the highest registered weight of 75.833 kg, was 1.532 kg. Subtract the estimate of disregarded weight, as described in section 4.10.3.3, including the accuracy deviation described in 4.7.1, concludes with a total accumulated water weight of 1.194 kg ± 0.080 kg.

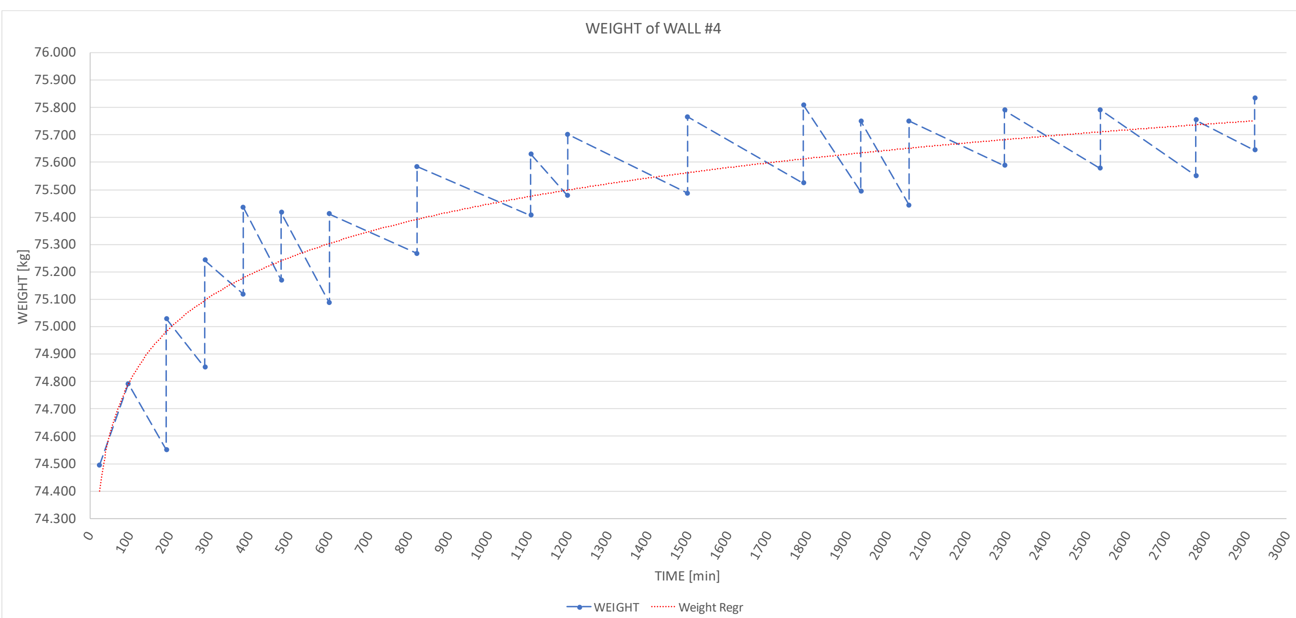


Figure 92 Weight Data of Wall #4 – Daily pre- and post Water Exposure Weight Measurements Including Trendline

Figure 93 shows the drying period for a total of 60 480 minutes (42 days). The first value in the 'Drying' series is the last point of the 'Post Weight' in Figure 92. The y-axis showing the weight is in the same scale, however, notice the time difference in the x-axis. The total amount of water and water vapor still present in the wall after 42 days of drying is 368 grams ± 80 grams. The number is calculated subtracting the last value during the drying period (after 42 days) from the dry wall weight measurement:

74.669 kg – 74.301 kg = 0.368 kg = <u>368 grams</u>

The assumption of all accumulated water weight being trapped behind the tiles, as the disregarded moisture in the lower end of the wall has evaporated during the first days of drying cycle applies.

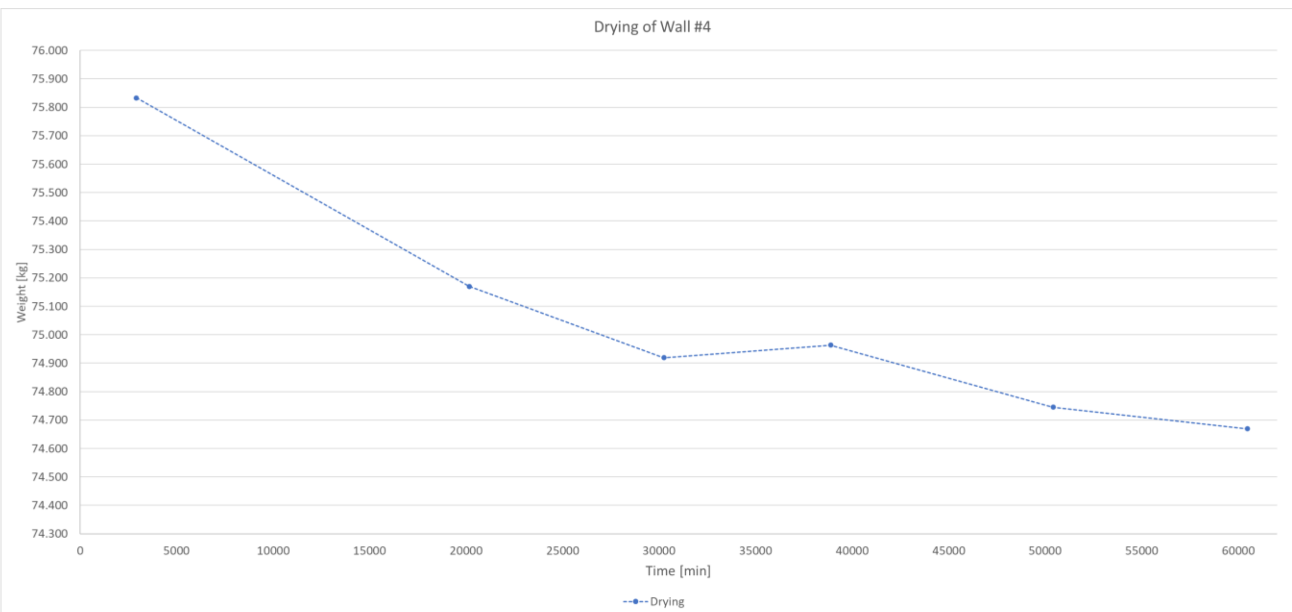


Figure 93 Weight Data of Wall #4 –Drying Period between 0 and 42 days (60 480 minutes)

All registered values regarding weights are found in table form in Appendix I.

5.6 CONTROL PARAMETERS

The results from three categories of control parameters are presented below. Results from both Wall #1 and Wall #4 are presented within each section. Wall #2 is not part of these sections as its exposure time was limited to 96 minutes, with no comparable results between the other EUTs.

5.6.1.1 Water Temperature

The shower water temperature was measured according to the experimental procedure both for calibration and during the shower exposure. The applicable value for each exposure was found by averaging the dataset from the HIOKI logger for the specific exposure. The values below presents the highest and lowest average, as well as the average of all temperatures during exposure, called 'Average Average'.

Wall #1

Stage 1

- Maximum Average 38.1° C
- Minimum Average 34.9° C
- Average Average 37.0 ° C

Stage 2

- Maximum Average 37.9° C
- Minimum Average 34.5° C
- Average Average 36.6 ° C

Wall #4

Stage 1

- Maximum Average 40.5° C
- Minimum Average 34.2° C
- Average Average 37.3 ° C

Stage 2

- Maximum Average 35.9° C
- Minimum Average 5.6° C
- Average Average 27.8 ° C

All daily average temperature values are found in Appendix I

5.6.1.2 Water Flow Rates

<u>Wall #1</u>

Flow rates were measured twice pr day for 6 out of 10 days and once pr day 4 out of 10 days. Average flow rate for Wall #1 throughout the experiment was 9.579 l / min.

<u>Wall #4</u>

Flow rates were measured once pr day for all 17 days of water exposure. Average flow rate for Wall #4 throughout the experiment was 9.529 l / min.

All daily flow rate values are found in Appendix I.

5.6.1.3 Laboratory Ambient Conditions

The temperature- and RH ambient conditions in the laboratory during the experiment was registered prior to- and after all water exposure cycles. The registered RH was done just prior to exposure and within 15 minutes after exposure. Elevated values in RH after water exposure makes sense due to the exposure of temperature of approx. 38 °C, causing water vapor to be present in the air surrounding the wall. The following values and averages were registered during the experiment:

Wall #1

<u>Temperature average</u>

- Prior to shower cycle: 22.5 °C
- After shower cycle: 22.6 °C

<u>Relative humidity average</u>

- Prior to shower cycle: 16.2 %
- After shower cycle: 24.2 %

Wall #4

<u>Temperature average</u>

- Prior to shower cycle: 22.6 °C
- After shower cycle: 22.6 °C

<u>Relative humidity average</u>

- Prior to shower cycle: 11.1 %
- After shower cycle: 20.3 %

For values registered prior to- and after each shower cycle, see Appendix I.

5.7 SUPPORTING EXPERIMENT - WATER SORPTION RESULTS

From the custom water sorption experiment, results from both the tile adhesives and ceramic tiles are presented in sub-sections below.

Applicable for both Table 10 and Table 12: The columns 'Density Sat' and 'Weight Sat' are selected as the maximum value in an array of data points, where measurements have been done each 24 hours for a total period of 21 days. The column 'Time' specifies the number of days required to achieve the stabilization criteria, ref 4.8.1.2.

5.7.1 Water Sorption – Tile Adhesives

Table 10 shows the dry and saturated weight and density of the tile adhesive cubes, as well as the maximum moisture content and ratio.

For tile adhesive series 4-X, where X = 1-3, stabilization criteria was achieved after the 3 first days. However, measurements for 4-X were continued along with the remaining specimens for an extended period of time. During the experiment a delta weight of 0.1 g was observed and logged. As tile adhesive series 4-X is a 2-component polyurethan adhesive, there is no water sorption in the adhesive itself. The author has confidence in concluding with the small delta in being due to small surface inconsistencies, especially on the cut surface, due to manual machining using the hacksaw and grinding paper. This might lead to surface voids, where a minor amount of moisture is absorbed.

From the sorption data, it is clear that the single component cementitious tile adhesive, which is used in all EUTs, have the highest moisture content ratio, averaging 26.86 % between the three specimens.

Table 10 Tile Adhesive Moisture Content Measurements

ID	Density Dry [kg/m^3]	Density Sat [kg/m^3]	Weight Dry [g]	Weight Sat [g]	Moisture Content [g]	Time [days]	Moisture Content Ratio (u) [%]
1-1	1 089.65	1 372.96	20.0	25.2	5.2	21	26.00%
1-2	1 075.68	1 363.61	19.8	25.1	5.3	20	26.77%

ID	Density Dry [kg/m³]	Density Sat [kg/m³]	Weight Dry [g]	Weight Sat [g]	Moisture Content [g]	Time [days]	Moisture Content Ratio (u) [%]
1-3	1 076.69	1 385.89	19.5	25.1	5.6	20	28.72%
2-1	1 241.82	1 504.73	22.2	26.9	4.7	19	21.17%
2-2	1 257.85	1 541.15	22.2	27.2	5.0	19	22.52%
2-3	1 266.46	1 544.74	22.3	27.2	4.9	19	21.97%
3-1	1 351.27	1 504.94	25.5	28.4	2.9	21	11.37%
3-2	1 356.22	1 496.86	27.0	29.8	2.8	19	10.37%
3-3	1 371.60	1 512.41	26.3	29.0	2.7	19	10.27%
4-1*	1 535.58	1 546.66	27.7	27.9	0.2	3*	0.72%
4-2*	1 532.48	1 537.82	28.7	28.8	0.1	3*	0.35%
4-3*	1 538.86	1 544.44	27.6	27.7	0.1	3*	0.36%

*Note: Tile adhesive series 4-X had two occurrences where stabilization criteria was met, as explained above the table.

Based on the measured water weights, the porosity is calculated through the formula presented in section 2.3.1. Assumption for water density of 1 000 kg / m^3 = 1 kg / liter applies, and the conversion of 1 000 kg / m^3 = 1.0×10^{-3} g / mm^3 leads to 1 gram = 1 000 mm^3. This assumption is used for finding the total volume of the *Void Space Volume* in the tile adhesive. An average porosity of 29.35 % was measured between the three specimens 1-1, 1-2, and 1-3, presented in Table 11.

The differences in moisture content ratio (u) and porosity (P_s) in tables Table 10 and Table 11 indicates that the void space has additional moisture content capacity. However, this was not achieved due to the stabilization criteria being reached. Hence, if the specimens had been submerged for a longer time, the moisture content would have converged to the maximum capacity, i.e. the porosity value.

Table 11 Tile Adhesive Porosity Calculation

ID	Specimen Volume (V_s) [mm³]	Bulk Density (ρ_b) [kg/m³]	Moisture Content [g]	Void Space Volume (V_{vs}) [mm³]	Porosity (P_s) [%]
1-1	18 354.50	1 089.65	5.2	5 200.0	28.33%
1-2	18 406.98	1 075.68	5.3	5 300.0	28.79%
1-3	18 111.09	1 076.69	5.6	5 600.0	30.92%

The weight of specimens 1-1, 1-2, and 1-3 are presented in Figure 94. A moisture content increase of 1.9 g after 2 hours, and an additional 1.9 g increase after 25 hours is measured. For the remainder of the experiment, elapsing for a total of 526 hours ≈ 22 days, an average incremental increase of 0.1 g is measured at each timestamp. With a marginal weight increase towards the end of the experiment period, it indicates that the specimens converge towards maximum moisture content at full saturation.

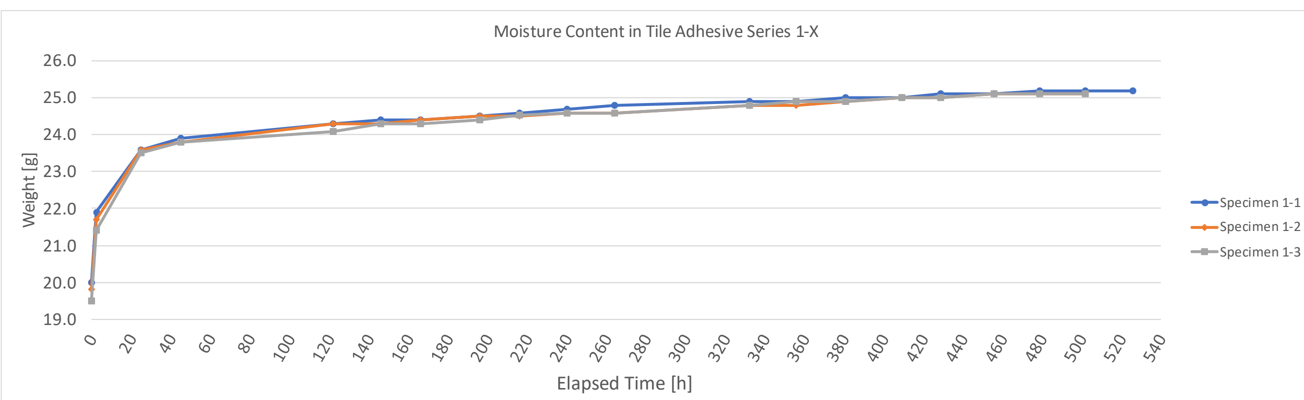


Figure 94 Moisture Content in 1-X Series Tile Adhesive – Weight Increase over 526 hours

5.7.2 Water Sorption – Ceramic Tiles

Table 12 shows the dry and saturated weight and density of the ceramic tiles, as well as the maximum moisture content and ratio. The column 'Time' specifies the number of days required to achieve the stabilization criteria. The average moisture content ratio (u) between the three specimens are 16.68%.

Table 12 Ceramic Tiles Moisture Content Measurements

ID	Density Dry [kg / m³]	Density Sat [kg / m³]	Weight Dry [g]	Weight Sat [g]	Moisture Content [g]	Time [days]	Moisture Content Ratio (u) [%]
1	1 958.36	2 292.40	209.3	245.0	35.7	17	17.06%
2	1 964.91	2 289.59	210.0	244.7	34.7	16	16.52%
3	1 984.56	2 311.11	212.1	247.0	34.9	16	16.45%

The weight of the different tile specimens 1 - 3 are presented in Figure 95. A large moisture content increase of 26.7 g after 2 hours is observed, slowing down significantly after 25 hours with a moisture content increase of only 2.1 g. For the remainder of the experiment, elapsing for a total of 409 hours ≈ 17 days, an average incremental moisture content increase of 0.5 g is measured each time. With a marginal increase towards the end of the experiment period, it indicates that the specimens converge towards maximum moisture content at full saturation. The sudden increase in moisture content during the first 2 hours, indicates that the tiles have a high permeability.

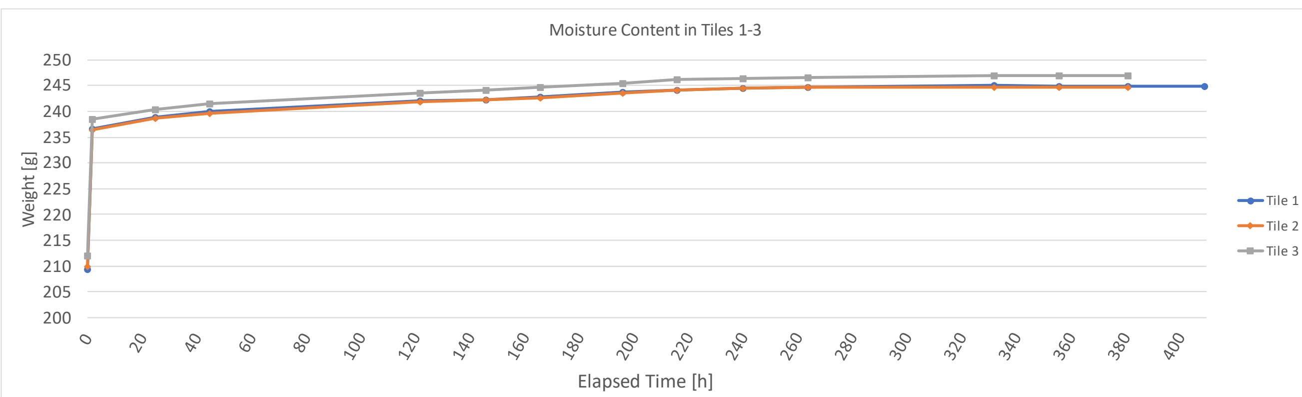


Figure 95 Moisture Content in Three Tile Specimens – Weight Increase over 409 hours

The calculated porosity is presented in Table 13, averaging 32.84 % between the three specimens.

Table 13 Porosity Calculation for Ceramic Tiles ID 1 - 3

ID	**Specimen Volume (V_s) [mm^3]**	**Bulk Density (ρ_b) [kg / m^3]**	**Moisture Content [g]**	**Void Space Volume (V_{vs}) [mm^3]**	**Porosity (P_s) [%]**
1	106 875.00	1 958.36	209.3	35 700.0	33.40%
2	106 875.00	1 964.91	210.0	34 700.0	32.47%
3	106 875.00	1 984.56	212.1	34 900.0	32.65%

The differences in moisture content (u) and porosity (P_s) in tables Table 12 and Table 13 indicates that the void space has only been occupied by water for approx. half its capacity within the established stabilization criteria. Hence, if the tiles had been submerged for a longer time, the moisture content would have converged to the maximum capacity, i.e. the porosity value.

6 DISCUSSION

6.1 GENERAL

The overall purpose of this chapter is to synthesize and discuss the observations and results related to the research questions and hypotheses. Additionally, a short discussion regarding uncertainties, challenges and limitations, based on acquired knowledge and experience during the experiment period, is presented in Section 6.4.

Chapter 6 is divided into a set of main discussion points and supporting discussion points, ref. sections 6.2 and 6.3. The supporting points are secondary compared to the main moisture migration synthesis, however highly applicable towards the final conclusion.

Some results and figures previously presented are repeated in this chapter for easy reading.

6.2 MAIN DISCUSSION POINTS

The primary discussion point in this master's thesis is the synthesis of all findings related to the moisture migration and the evolution over time, mainly in EUT #4. A few specific discussion points will be presented in sections 6.2.1 and 6.2.2, while the overall synthesis is compiled in section 6.2.3.

6.2.1 Exposed Water vs Incremental Water Weight Increase Divergence

Figure 96 presents the incremental water exposure on Wall #4 in liters (red line with circles) plotted against the incremental weight increase of the wall in grams (blue line with triangles). This graph is derived from the figure discussed in 5.5.3.4. The number of liters instead of incremental exposure time is both derived from the flow rate; hence, both are valid regarding comparison of the moisture behavior in the wall.

Observing the two graphs, they can obviously be seen as having the same signature from 0 min towards approx. 600 min. Meaning increasing the amount of water exposure leads to increase in incremental delta weight and vice versa. From the first exposure at 24 minutes, until the exposure at 600 minutes, the two graphs have the same trend within a varying delta distance. However, at timestamp 820 minutes, the two graphs diverge. From this point towards the end point at 2 920 min, a difference up to water exposure of 2 178 liters results in a relatively stable delta weight of approx. 240 grams, even with a decline in water absorption from timestamp 2 053 towards the final exposure at 2 920 minutes.

Evidently, material properties and moisture migration mechanics affects the delta weight response due to water exposure as the experiment advances in time.

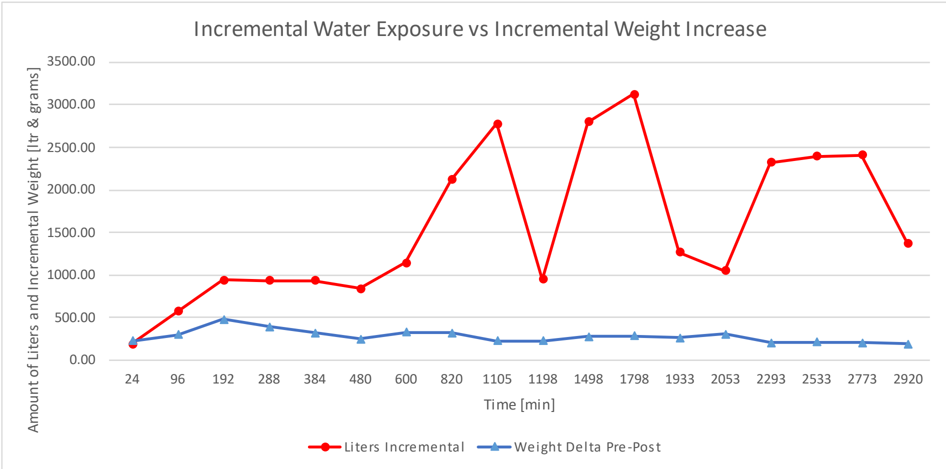


Figure 96 Amount of Incremental Water Exposure in Liters compared to the Incremental Weight Increase in Wall #4

6.2.2 Dynamic Capillary and Diffusion Behavior

A general observation throughout the experiment is the combination effect of capillary forces and the water vapor diffusion. After a break in the water exposure, either being between the daily 8 min exposures, or in between days, the material is more susceptible to the new moisture. Based on theory from the different zones in the sorption curves, it is known that at higher levels of RH, moisture migrates faster and the capillary effect initiates. At certain points in time, the diffusion behavior was also captured by the RH-sensors, clearly indicating moisture migration through water vapor diffusion in between water exposures.

The theory behind diffusion makes it a solid contributor to the expansion of moisture migration, as diffusion can only happen in the opposite direction laterally from the saturated tile adhesive material, moving from denser to less dense moisture concentration. The observation is visualized in Figure 97 and Figure 98 showing capillarity and diffusion in different degrees of color contrast. The two zones are indicated with a red sharpie on the glass tile.

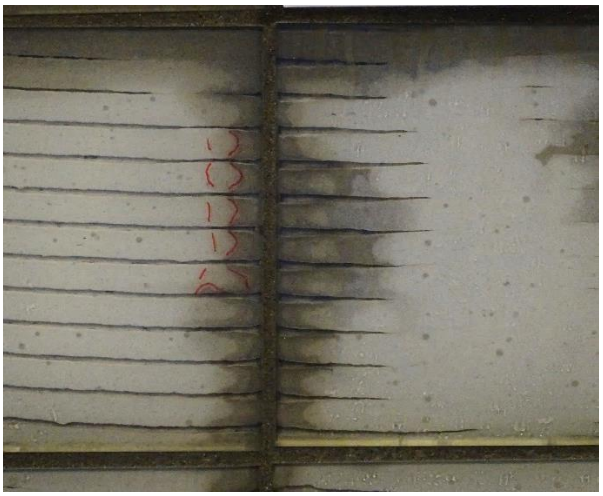


Figure 97 Moisture in Tile Adhesive where Moisture has Migrated from a Saturated Area to an Unsaturated Area through Diffusion

Figure 98 Moisture in Tile Adhesive Showing Saturation (RH = 100 %) in Dark Grey and RH<100 % due to Diffusion in Light Grey

6.2.3 Moisture Migration Results Compilation and Synthesizing

Synthesizing all presented datasets and observations, a description of moisture migration behavior can be made. There are several connections and dependencies to address to be able to generate a solid coherence from this research. Section 6.2.3.1 provides the overall moisture migration behavior while section 6.2.3.2 calls out the specific technical inputs for establishing the main research synthesis.

6.2.3.1 Overall Moisture Migration Behavior Description within Total Experiment Duration

The total moisture migration scope starts from timestamp t = 0 minutes, where water from the shower hits the exposure target area on the wall with an approx. 140 mm x 200 mm water cone impact area. The water runs down the wall in a width of approx. two tiles plus a 5 mm grout on each side. From this exposure width of approx. 155 mm to each side, the moisture migrates more than 800 mm to each side due to the combination of material properties and moisture migration mechanics. This happens throughout the total accumulated time exposure, until timestamp t = 2 920 minutes.

The moisture sourcing from the water exposure target area establishes an outer perimeter by the migration pattern in the grout after only 24 minutes, ref red lines in Figure 100. At timestamp 192 min, the absorption rate and expansion rate in the tile adhesive catches up with the moisture absorption capacity in the grout, ref Figure 99, starting to saturate the tile adhesive inside the perimeter created by the grout. At timestamp 820 min, Figure 99 shows the tile adhesive reaching the migration extension perimeter created by the grout moisture. Between timestamp 820 min towards the end at 2 920 min, sideways migration in both tile adhesive and grout are highly correlated, at a total distance of approx. 1600 mm. Until the final water exposure at 2 920 min, the tile adhesive increase its moisture content limited to its porosity, within the perimeter established by the grout at approx. t = 24 min.

From timestamp t = 2 533 min, a periodic and cyclic behavior is observed between the migration extension of the tile adhesive and grout, indicating the onset of a slow expansion of the perimeter, most likely to continue as water exposure and time progresses.

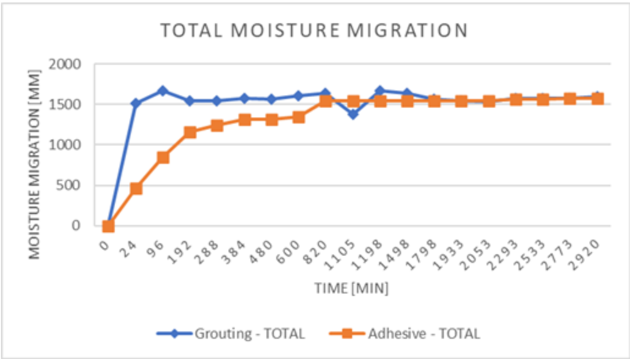


Figure 99 Total Moisture Migration in Tile Adhesive and Grout

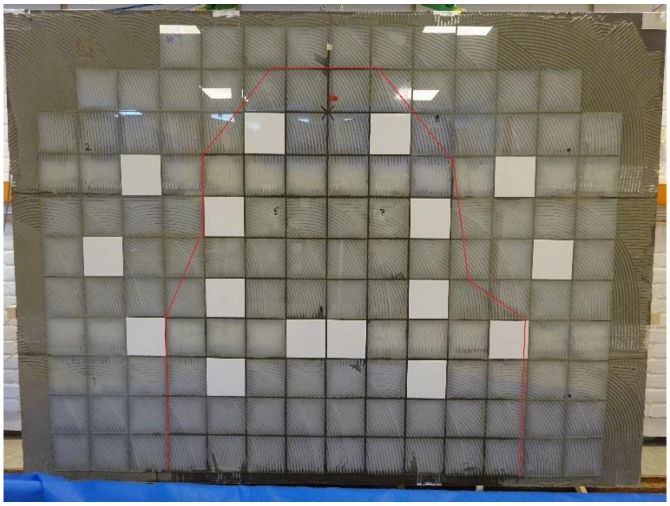


Figure 100 Wall #4 – Outer Moisture Perimeter Created by Saturated Grout

6.2.3.2 Synthesizing all Observations and Parameters

Mapping the number of wet tiles, which represents an area of moisture in the wall, against the total moisture migration in absolute numbers, both over the total exposure time, concludes with two parameters having a similar signature, showing correlation. Figure 101 presents this using two applicable scales for y-axis, number of wet tiles (stacked columns), and moisture expansion in mm (solid line). This correlation is sensible due to moisture migrating inertia in the wall based on material properties and how moisture mechanics affect the moisture in the wall over time towards saturation of the affected area, moving into a slow expansion of the wet area.

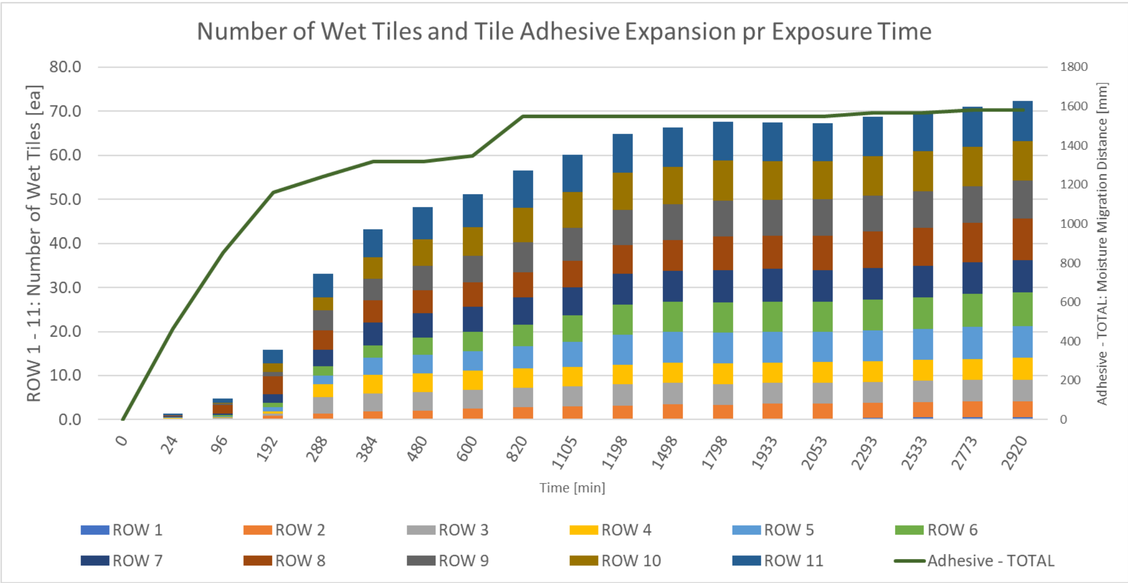


Figure 101 Number of Wet Tiles & Moisture Migration Expansion Distance for each Timestamp 0 min – 2 920 min Showing Similar Signature

Inspecting the data from the applicable parameters presented in the results Chapter 5 and the discussion within this Chapter 6, there can be argued that a rational behavior in the moisture migration based on theory and expectations exists. A high correlation relating to the moisture behavior progression and expansion, and why the registered measurements behave as they do, are mainly proven in the timestamp area of 820 min to 1 198 minutes.

Key points that are observed from the data from this point in time (820 min to 1 198 minutes):

- Accumulated and incremental weights starts to flatten out indicating the convergence towards maximum moisture content in the pores of the tile adhesive and grout in the affected area.
- Sideways moisture migration expansion in both grout and tile adhesive are converging from this point in time and has a high parallel behavior in migration expansion from this point onwards.
- The exposed water amount and the amount of absorbed water starts to diverge, also becomes highly independent towards the end of exposure time, indicating convergence towards saturation due to material properties within the perimeter created by the grout and tile adhesive moisture.
- The number of wet tiles, and the total wet area rate slows significantly down and stabilizes at a slow expansion rate towards the convergence value being the maximum saturation point for the whole wall. The rate of further expansion also matches the behavior of further moisture migration extension.
- RH readings from sensors SX-4 and SX-8 starts to increase rapidly, indicating the presence of moisture through capillary effect and diffusion further to the sides, indicating an expansion.

Overall, the moisture migration progress is highly dependent on time, both backwards and forwards, in addition to the moisture content capacity of the materials. Due to slow drying rate, the tile adhesive has RH values in the upper part of the sorption curve (RH > 60 %), causing a hysteresis loop within the boundary created by the saturated grout, and eventually the tile adhesive.

6.3 SUPPORTING DISCUSSION POINTS

6.3.1 Comparing Moisture Migration in Different Trowel Patterns

A side-by-side comparison between Wall #1 and Wall #4 at two similar timestamps are made below. Figure 102 and Figure 104 shows Wall #1 after 328 minutes of water exposure, compared with Figure 103 showing Wall #4 after 288 minutes and Figure 105 after 384 minutes. Already at 40 minutes less exposure, Wall #4 shows a much more aggressive moisture migration, and most likely a higher moisture content. This can also be seen in the relative weight difference between the two, with a difference of 220 grams. However, a discussion regarding moisture content is found in section 6.3.2.

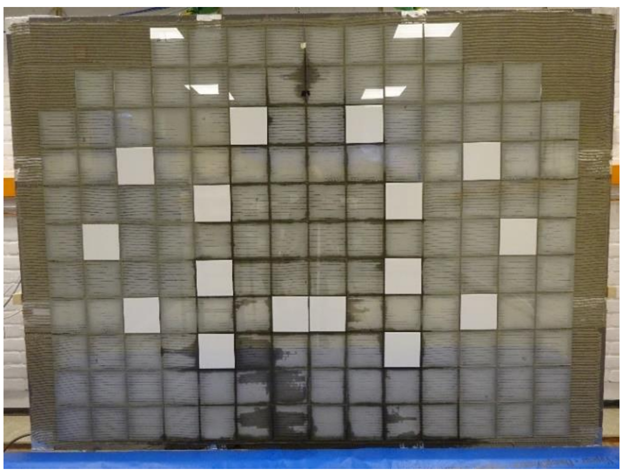


Figure 102 Wall #1 Visible Moisture Content after 328 min Water Exposure

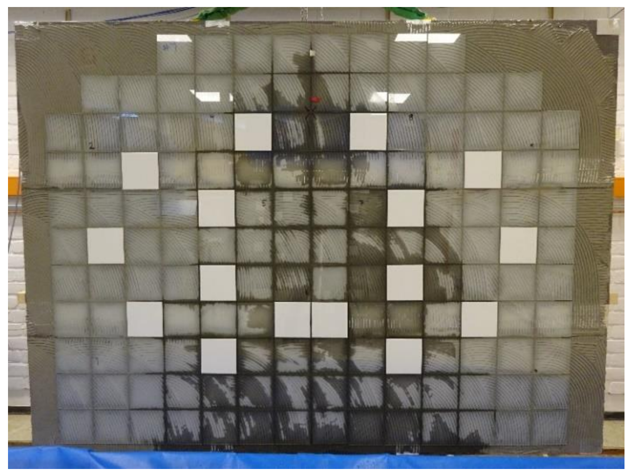


Figure 103 Wall #4 Visible Moisture Content after 288 min Water Exposure

During the experiment, observations were made regarding the moisture migration in saturated- compared to non-saturated grooves made no difference. Naturally, capillary effect happens when moisture is present in the grooves, however there were unhindered flowing water in un-saturated grooves as well as in saturated grooves. This indicates that the flow rate is higher than the absorption capacity on the surface of the tile adhesive.

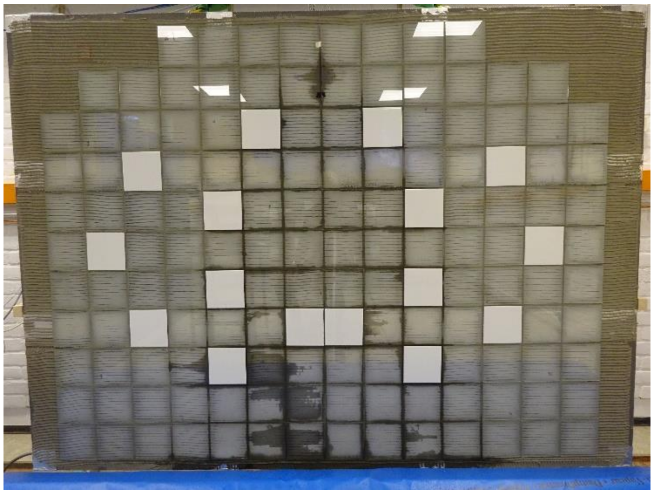


Figure 104 Wall #1 - Visible Moisture Content after 328 min of Water Exposure (same as Figure 102. Only for Comparison with Figure 105)

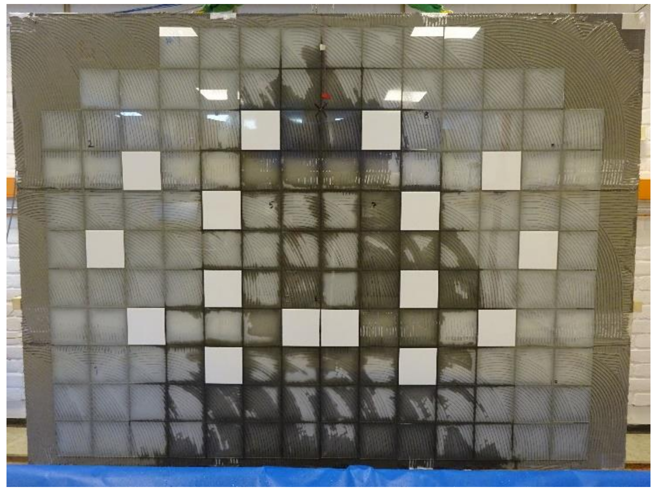


Figure 105 Wall #4 - Visible Moisture Content after 384 min of Water Exposure

6.3.2 Weight Comparison between Wall #1 and Wall #4 with Different Moisture Visuals

An interesting finding is observed comparing the weight between Wall #1 and Wall #4, ref. Figure 106 and Figure 107. Wall #1 has a water content of 723 grams and Wall #4 has a water content of 728 grams, which could be considered equivalent. However, comparing the two figures visually, it seems that Wall #4 holds much more water. One plausible reason might be that moisture migrates better between the glass and tile adhesive due to higher adhesion force and molecular attraction to the silica in the glass, than the inwards capillary effect within the tile adhesive. This potentially causes a more aggressive meniscus between the water and glass tiles, than the water in the tile adhesive pores. Hence, the visible moisture in Figure 107 is mainly in the surface between tile adhesive and glass tile and has not yet started to migrate inwards. However, from theory it is known that the small radius of pores in the tile adhesive serves as great conditions for moisture migration due to capillary force.

A final conclusion is hard to draw from these findings.

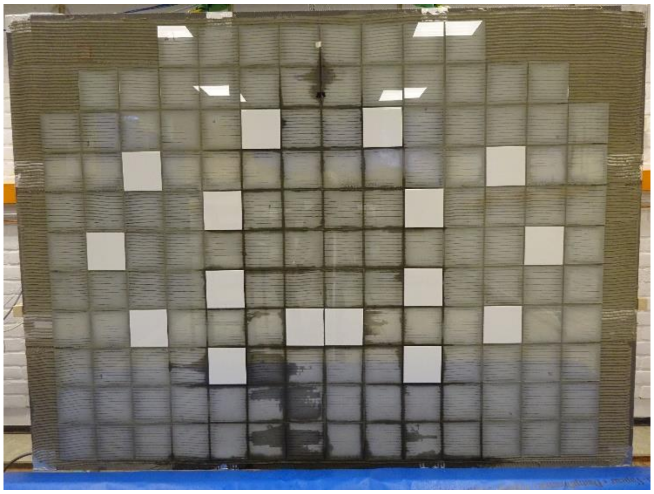


Figure 106 Wall #1 after 328 min of Water Exposure with Water Content of 723 grams

Figure 107 Wall #4 after 192 min of Water Exposure with Water Content of 728 grams

6.3.3 Permeability in Grout, Tile Adhesive and Ceramic Tiles

The porosity is found to be approx. 12 % higher in the ceramic tiles compared to the tile adhesive. From theory it is known that porosity is not directly related to moisture penetration, however it concludes with higher moisture content capacity in the tiles. From the supporting experiment it was evident that the tiles had a far more rapid moisture content increase than the tile adhesive between the two first measurements. Also, a much lower moisture content delta between the timestamps after the two initial measurements. This indicates that the tiles have a higher permeability than the tile adhesive. According to this, it is fairly safe to assume that the tiles are saturated at timestamp 328 minutes for EUT #4, as described in section 5.3.2

Speculation into differences in permeability between tiles and grout is hard due to no established empirical data. Differences in permeability between the grout and tile adhesive is also hard to differentiate. It is obvious that the water exposure hits the grout first, and moisture is being transported on the surface of the wall due to a combination of gravity and absorption in the grout. Moreover, as the grout has some depth to it, (equal to trowel size of 6 mm minus the installation pressure of the tiles), it takes time for the grout to saturate. Both grout and tile adhesive have individual w/b content, therefore, assumed different density and porosity. With all this, it seems fair that moisture migrates in the grout prior to entering the tile adhesive.

6.4 RESEARCH UNCERTAINTIES, CHALLENGES AND LIMITATIONS

Several uncertainties, challenges and limitations emerged during the experiment. The main concerns are presented in sections below.

6.4.1 Glass Tiles Effects vs Real Life Ceramic Tiled Walls

From the results of the ceramic tiles sorption experiment an average porosity of 32.84 % and a total moisture content of 35.10 grams were measured, causing a moisture content ratio at stabilization criteria equal to 16.68 %. From these results, an assumption of a real wall, comprising only ceramic tiles would result in a slower moisture migration. However, as seen comparing the moisture content rates between tiles and tile adhesive, the tiles have a tremendous willingness to absorb water very fast when fully surrounded by water, compared to the tile adhesive. Moreover, due to the material properties in the ceramic tiles, the drying would take much longer.

As seen in this experiment, RH values needed 46 days before dropping below saturation point of RH = 100 % in Wall #1, and water was present indicated by values above RH = 100 % for quite some time. Extending this knowledge into predicting drying time for a real tiled wall, absolutely supports the findings in literature, where drying times up to 6 months are mentioned [33, 44].

Throughout the experiment, the ceramic tiles have behaved as local sponges, or local moisture hubs. Observations were made both early in the experiment, but also after more than a month of drying. Figure 108 and Figure 109 clearly shows that after a relatively long drying time, the ceramic tiles still has a high moisture content, based on observations of the surrounding grout being very dark in color. This indicates that the tiles have a high moisture holding capacity over time in the given circumstances.

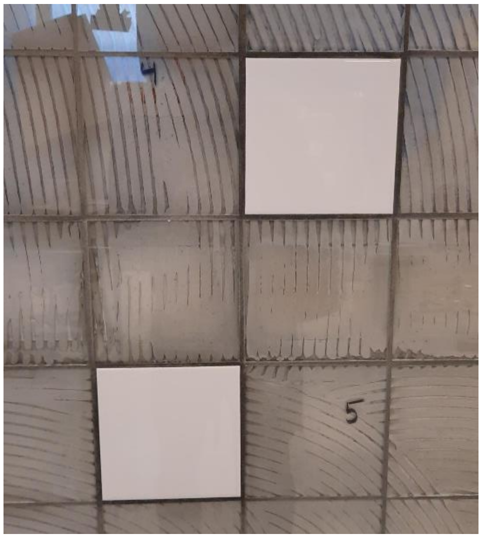


Figure 108 Wall #4 - Ceramic Tiles Functioning as Moisture Hubs Showing Moisture after 42 Days of Drying

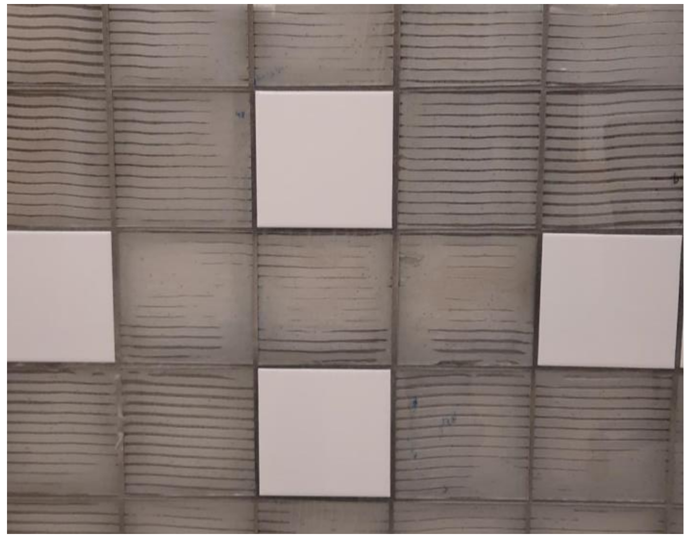


Figure 109 Wall #1 - Ceramic Tiles Functioning as Moisture Hubs Showing Moisture after 53 Days of Drying

All-in-all, the setup in this experiment most likely results in faster moisture migration and quicker drying times compared to a totally ceramic tile setup due to the presence of glass tiles. However, due to a relatively dry tile adhesive and grout prior to experiment start, moisture expansion onset might happen at a slower rate compared to real life. When tiled walls are constructed in bathrooms, they rarely gets to dry out prior to being exposed to shower use. As seen in this experiment, supported by theory, moist materials, especially from RH > 60 % expands and accelerates the moisture migration considerably. With this to mind, it is fair to assume that the moisture migration is more severe from the get-go compared to what has been seen in the experiment.

6.4.1.1 Moisture Migration Prediction Model

Uncertainties regarding the model predicting future moisture migration presented in 5.5.3.6 is highly affected by the current setup in this experiment. As discussed above, there is a dominant difference in the theoretical moisture behavior in ceramic tiled wall and glass tiled wall. If assumption regarding inertia in a ceramic tiled wall is correct, the time until moisture reaches the wet zone of 1 meter takes longer than the 7 years (3 – 15) and 4 years (2 – 12) predicted herein. However, it is certain that the wall will remain moist for a longer time, and observations regarding moisture hubs in the ceramic tiles might affect in spreading the moisture more effective.

6.4.2 Moisture Migration - Speed and Distance

Based on prototype testing and the investigated literature, the established expectation of the tile adhesive being saturated much quicker than what became the case, especially for Wall #1 and Wall #2. Originally four walls were built and planned as part of the experiment with equal amount of allocated time, planned for a conclusive comparison between the moisture behavior in the different EUT configurations. Based on the findings during the experiment, the moisture content accumulation and moisture migration took much longer than anticipated, making direct comparison challenging due to allocated time and the other scheduled activities. How the different trowel patterns affect the moisture migration provides a fairly confident outcome, however if direct comparison between all 4 EUT had been possible, a more viable comparison result could have been made.

Additionally, RH-sensors were placed based on the same migration rate expectations. The RH sensors towards the edges of the walls, should have been placed closer to center to be able to utilize the RH-data in a better way. If RH-measurements could have been utilized throughout the whole width of the wall, the data could have been applied towards the synthesis of moisture migration to a greater extent than what was the final results herein.

6.4.3 Grout Sorption Experiment and Moisture Migration

There was not performed any practical experiment considering the grout, however, literature [9, 46] and the prototype testing were the basis for the expectation of moisture migration. In hindsight there should have been prioritized and allocated time to cast grout cubes in addition to the tile adhesives for the sorption experiment. If so, there could have been established a more scientific and unambiguous input to the variable evaluation regarding moisture migration. However, through continuous photos, and manual post analysis, the behavior of the moisture migration in the grout has been mapped out. The author remains confident that the current results based on the opted methodology contributes to the overall conclusion regarding moisture migration.

Additionally, awareness of the classification systems regarding moisture absorption rating for grouts was not evaluated until close to delivery of the thesis. Assumptions towards the grout being used in the prototype testing and in literature giving the impression of very rapid moisture penetration in the grout, might have been a so-called non-improved grout, like the Megafug G-113 is. As seen in the moisture characteristics table in Appendix C and in the data sheet in Appendix H, the Megafug having the W-characteristic indicates a lower permeability. A nominal 60 % decrease in moisture absorption is presented by Mapei in table in Appendix C. Water absorption amount reduced from 5 grams to 2 grams pr 30 min of exposure. The test method behind the numbers are unknown to the author.

6.4.4 Supporting Experiment Baseline Stability Conditions

According to ISO 12571:2021 it is required to dry the applicable specimens to constant mass to have full control of weight and RH at start of experiment [15]. This was not done for the adhesive specimens, however, they were stored in laboratory U60 for several weeks prior to experiment startup; hence, the specimens have been in ambient surroundings consisting of temperature = 22.5 ± 0.4 °C and RH = 15 ± 5 % which is seen as relatively stable. The results from the sorption experiment clearly provides trends and actual numbers that can be utilized confidently; however, the moisture content ratio would probably been somewhat higher. If the experiment had been repeated, the author would have prioritized complete control of the starting conditions using a drying oven.

6.4.5 Supporting Experiment – Selection of Tile Adhesive

The one-component cementitious tile adhesive used in all wall configurations had the highest moisture content ratio at the conclusion of the sorption experiment. Both two-component version had significantly less moisture content, whereas ID #4 had practically none. During the main experiment there was evidence that moisture migration happens at the same rate in the grooves, independently of degree of saturation. With this it could be reasonable to state that it is recommended to use a tile adhesive with less moisture capacity, as long as full tile adhesive coverage is ensured.

A groove is equally challenging and causes easy moisture migration independently of tile adhesive type. When full tile adhesive coverage is ensured, a two-component tile adhesive seems preferred related to moisture safety.

7 CONCLUSION

This master's thesis has performed an investigation of the moisture migration behavior in tiled bathroom walls through experimental laboratory research and post analysis. Three 2.4 m x 1.8 m walls comprising a lightweight, wooden framework, constructed with 30 mm wet room boards with RH-sensors attached have been made. The walls were tiled with a mix of 150 x 150 mm glass tiles and ceramic tiles in an approx. 9: 10 ratio. Cementitious tile adhesive and grout have been used to install the tiles, with emphasis on leaving trowel groove patterns in the tile adhesive. All walls were subjected to different water exposure scenarios and the main data acquisition has been wall weight, RH measurements in the wall, water flow rate and water temperature in addition to ambient condition.

All research questions and hypotheses have been answered and challenged. The main purpose of this experiment was to observe and document the moisture migration behavior in the tile adhesive and evaluate if the wet zone defined in TEK 17 provides sufficient moisture safety in dwelling bathrooms with a floor area less than 4 m^2:

Within the parameters and scope of this master's thesis, based on an accumulated 2 920 minutes of water exposure, equivalent to a daily 8-minute shower for 365 days centered on one spot on the wall, there was measured a fully saturated area of 1.68 m^2, with the furthest moisture migration being 899 mm; hence, the wet zone perimeter was not reached by moisture. Extrapolation through mathematical models was performed predicting the wet zone to be reached after 4 -7 years with prediction accuracies between 89 % and 92 %, estimating a continuation of the same variables as the initial 365 days. Uncertainties regarding the glass tiles used in this experiment versus solely ceramic tiles to be used in real bathrooms have been described and discussed in regard to model accuracies.

A tiled wall subjected to the described shower cycles can be considered as a sponge that is continuously saturated and needs months to dry out if exposure stops. For all practical purposes, under normal showering conditions, a tiled bathroom wall can be assumed fully saturated at all times. Special care needs to be taken during construction to ensure full tile adhesive coverage, as moisture travels fast in trowel grooves. The moisture migration is dependent on the orientation and layout of the trowel grooves, showing faster and further migration in curved grooves. Additionally, reliable and robust moisture safety solutions needs to be ensured in the presence of biological materials inside the wet zone or in immediate proximity, as moisture is highly likely to reach these areas.

8 FUTURE RECOMMENDATIONS

Valuable knowledge has emerged during the experimental research described herein. However, there are big possibilities of extending and synthesizing additional research, either in collaboration with other parties in the industry, or internally at SINTEF.

A big advantage with the setup described in this master's thesis is the EUTs capabilities of being dried up to the point where they can re-used for additional- or extended experiments. However, there are also some experiments that are recommended by the author, requiring construction of additional walls.

Some reflections and ideas for experiments worth highlighting:

- Having established a visual assessment of the moisture migration, the next step could be to establish a setup, disregarding the glass tiles, being able to better predict the moisture migration for the upcoming e.g. 15 years.
    - Clad a similar wall structure with exclusively ceramic tiles, establishing the foundation for further assessment, and develop a more precise mathematical prediction model, utilizing the knowledge from the moisture migration presented herein, with even more realistic settings.
- Repeat the experiment using the same input parameters and framework, except creating a tiled wall ensuring full tile adhesive coverage. This can be combined with assessment of moisture behavior in cornered walls or in connection to a tiled floor. Evaluating how a saturated tiled floor affects the capillarity effect in the wall.

A broader approach for further utilization of this research data could be a contribution to evaluate if moisture properties should get a more central part in data sheets and standards, especially for tile adhesives. Currently, there are few descriptions or relations to moisture parameters in these documents. Having easy access to moisture characteristics for both grouts (as in EN 13888-1 and EN 12808-5) and tile adhesives could provide vital input for designers and tile workers, ensuring better decision making and moisture safety in bathrooms and wet rooms.

9 REFERENCES

[1] Harry. "THE HISTORY OF CERAMIC TILES YOU SHOULD KNOW." UniqueTiles Limited. https://www.uniquetiles.uk/the-history-of-ceramic-tiles-you-should-know (accessed 11. Nov, 2022).

[2] J. Michalak, "Ceramic Tile Adhesives from the Producer's Perspective: A Literature Review," *Ceramics*, vol. 4, no. 3, pp. 378-390doi: 10.3390/ceramics4030027.

[3] M. Intelligence. "DRY MIX MORTAR MARKET SIZE & SHARE ANALYSIS - GROWTH TRENDS & FORECASTS (2023 - 2028)." https://www.mordorintelligence.com/industry-reports/dry-mix-mortar-market (accessed May 22nd, 2023).

[4] FinansNorge. "Vannskadestatistikk (VASK)." Finans Norge. https://www.finansnorge.no/statistikk/skadeforsikring/vask/ (accessed May 22., 2023).

[5] P. Brander and J. Winther, "Fuktsäkerhetsprojektering av 8 våtrumsväggar," Polygon, 2017.

[6] R. Becher, A. H. Høie, J. V. Bakke, S. B. Holøs, and J. Øvrevik, "Dampness and moisture problems in Norwegian homes," *International journal of environmental research and public health,* vol. 14, no. 10, p. 1241, 2017, doi: doi:10.3390/ijerph14101241.

[7] S. Pedersen *et al.*, "Omfang av byggfeil i Norge," in "Menon-publikasjon nr. 146/2022," November 1st 2022. [Online]. Available: https://www.menon.no/publication/omfang-av-byggfeil-i-norge/

[8] DiBK_TEK17. "Tek17." Norwegian Building Authority. https://dibk.no/regelverk/byggteknisk-forskrift-tek17/ (accessed 25. Nov, 2022).

[9] L.-E. Fiskum, "Vanntette dusjvegger," SINTEF, SINTEF Local Archives, Experimental Research Report 2000.

[10] M. Pinteric, *Building physics From physical principles to international standards*, 1st ed. Springer International Publisher AG, 2017.

[11] S. Geving and J. V. Thue, *Håndbok 50 - Fukt i bygninger*, 1st ed. Norsk byggforskningsinstitutt, 2002.

[12] A. L. Buck, "New Equations for Computing Vapor Pressure and Enhancement Factor," pp. 1527-1532, December 1st 1981, doi: "https://doi.org/10.1175/1520-0450(1981)020<1527:NEFCVP>2.0.CO;2".

[13] S. Norge, "Hygrothermal performance of building components and building elements. Internal surface temperature to avoid critical surface humidity and interstitial condensation. Calculation methods," NS-EN ISO 13788:2012, 2012. [Online]. Available: https://standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=626361

[14] M. Lampinen, M. E. H. Assad, and E. F. Curd, "4 - PHYSICAL FUNDAMENTALS," in *Industrial Ventilation Design Guidebook*, H. Goodfellow and E. Tähti Eds. San Diego: Academic Press, 2001, pp. 41-171.

[15] *Hygrothermal performance of building materials and products - Determination of hygroscopic sorption properties*, NS-EN ISO 12571, S. Norge, November 2021.

[16] T. J. Rønnes, "Fuktforhold i kjellervegger av betong under grunnvannstand," Master's Thesis, Bygg- og miljøteknikk, Norges teknisk-naturvitenskapelige universitet (NTNU), 2015.

[17] E. Brandt, L. L. B. Raunkjær, Ed. *Fugt i bygninger* (SBi-anvisning 224). Statens Byggeforskningsinstitut, Aalborg Universitet, 2013.

[18] P. Gravesen and N. Kelstrup, "Grundlæggende geologi og grundvand," ed: Miljø- og Energiministeriet. Miljøstyrelsen, 2001, p. 75.

[19] M. K. Hubbert, "Darcy's Law and the Field Equations of the Flow of Underground Fluids," no. SPE-749-G, pp. 222-239, December 1956, doi: https://doi.org/10.2118/749-G.

[20] C. Hall and A. N. Kalimeris, "Water movement in porous building materials—V. Absorption and shedding of rain by building surfaces," *Building and Environment*, vol. 17, no. 4, pp. 257-262, Jan 1st 1982, doi: https://doi.org/10.1016/0360-1323(82)90018-X.

[21] S. Geving, *Praktisk Bygningsfysikk*. Vigmostad & Bjørke AS, 2021.

[22] S. Byggforsk. "421.132 Fukt i bygninger. Teorigrunnlag." Byggforsk. https://www.byggforsk.no/dokument/3044/keramiske_fliser_paa_innvendige_vegger_materialer_planlegging_og_underlag (accessed May 11th, 2023).

[23] J. Lstiburek. "BSI-123: Capillarity Sucks." Building science.com corporation. https://buildingscience.com/documents/building-science-insights-newsletters/bsi-123-capillarity-sucks (accessed May 17th, 2023).

[24] T. E. Toolbox. "Water - Density, Specific Weight and Thermal Expansion Coefficients." https://www.engineeringtoolbox.com/water-density-specific-weight-d_595.html (accessed April 1st, 2023).

[25] T. E. Toolbox. "Surface Tension." https://www.engineeringtoolbox.com/surface-tension-d_962.html (accessed May 16th, 2023).

[26] M. Brodahl, "Moisture Challenges in Buildings - Preliminary Study," Oslo Metropolitan University, 30. Nov, 2022.

[27] Y. Saijo, Y. Nakagi, T. Ito, Y. Sugioka, H. Endo, and T. Yoshida, "Relation of dampness to sick building syndrome in Japanese public apartment houses," *Environmental Health and Preventive Medicine*, vol. 14, no. 1, pp. 26-35, Jan 1st 2009, doi: 10.1007/s12199-008-0052-y.

[28] S. Mundt-Petersen and L.-E. Harderup, "Moisture safety in wood frame constructions–What do we know today?–A Literature overview," in *Sustainable Building Conference 2013–SB13, 22-24 May, 2013, Oulu, Finland*, 2013.

[29] W. Liu, C. Huang, Y. Hu, Z. Zou, L. Shen, and J. Sundell, "Associations of building characteristics and lifestyle behaviors with home dampness-related exposures in Shanghai dwellings," *Building and Environment*, vol. 88, pp. 106-115, June 1st 2015, doi: https://doi.org/10.1016/j.buildenv.2014.10.028.

[30] S. M. Joshi, "The sick building syndrome," *Indian journal of occupational and environmental medicine*, vol. 12(2), pp. 61-64, 2008, doi: 10.4103/0019-5278.43262.

[31] K. Engvall, C. Norrby, and D. Norbäck, "Sick building syndrome in relation to building dampness in multi-family residential buildings in Stockholm," (in eng), *Int Arch Occup Environ Health*, vol. 74, no. 4, pp. 270-8, May 2001, doi: 10.1007/s004200000218.

[32] R. I. Adams *et al.*, "Microbes and associated soluble and volatile chemicals on periodically wet household surfaces," (in English), *MICROBIOME*, vol. 5, SEP 26 2017, Art no. 128, doi: 10.1186/s40168-017-0347-6.

[33] G. Bok and P. Johansson, "Microbial growth behind tiles in bathrooms," *E3S Web of Conferences*, vol. 172, 2020, doi: 10.1051/e3sconf/202017220003.

[34] N. Hamada and T. Fujita, "Growth rate of fungi in bathrooms Experimental survey," *Mycoscience*, vol. 41, no. 4, pp. 297-301, 2000.

[35] Lovdata. "Lov om planlegging og byggesaksbehandling (plan- og bygningsloven)." https://lovdata.no/dokument/NL/lov/2008-06-27-71 (accessed 26. Nov, 2022).

[36] DiBK_SAK10. "Sak10." Norwegian Building Authority. https://dibk.no/regelverk/sak (accessed May 23., 2023).

[37] DiBK_TEK17. "§ 13-15. Våtrom og rom med vanninstallasjoner." Norwegian Building Authority. https://dibk.no/regelverk/byggteknisk-forskrift-tek17/13/vi/13-15/ (accessed May 14th, 2023).

[38] Våtromsnormen. "Byggebransjens våtromsnorm, BVN." FFV - Fagrådet for våtrom. https://ffv.no/vatromsnormen (accessed 10. Nov, 2022).

[39] D. Mumovic, I. Ridley, T. Oreszczyn, and M. Davies, "Condensation risk: comparison of steady-state and transient methods," *Building Services Engineering Research and Technology*, vol. 27, no. 3, pp. 219-233, 2006.

[40] R. Slávik and M. Čekon, "Hygrothermal Loads of Building Components in Bathroom of Dwellings," in *Advanced Materials Research*, 2014, vol. 1041: Trans Tech Publ, pp. 269-272.

[41] H. M. Künzel, *Simultaneous Heat and Moisture Transport in Building Components*. Fraunhofer Institute of Building Physics: Fraunhofer IRB Verlag, 1995, p. 102.

[42] Boverket. "Boverket – the Swedish National Board of Housing, Building and Planning." Boverket. https://www.boverket.se/en/start/ (accessed 26. Nov, 2022).

[43] A. Jansson, "Dubbla tätskikt i våtrumsytterväggar med keramiska plattor," SP Swedish National Testing and Research Institute, 2005.

[44] A. Jansson, "Tätskikt bakom kakel i våtrumsytterväggar," in "SP Rapport," 02845172 (ISSN), 2006. [Online]. Available: http://urn.kb.se/resolve?urn=urn:nbn:se:ri:diva-4740

[45] Golvbranschen, "Kapillärsugning och fuktfördelning i fästmassa," Golvbranschen, GBR, golvbranschen.se, 2017. [Online]. Available: www.golvbranschen.se

[46] J. Kung, G. Mould, and W. F. Williamson, "Moisture Penetration Through Ceramic-tile Shower Walls," *Nat. Res. Counc. Can. Build Res. Note BRN 236 1986; Can. Build. Abstr.(Jul)*, p. 2, 1986.

[47] A. Nesje, "Håndverkertips for flislegging av vegger.," no. 2 - 2016, p. 5. [Online]. Available: https://www.norskbyggkeramikkforening.no/phocadownload/artikler/Faktablad-2-2016.pdf

[48] A. Nesje, H. J. P. Larsen, T. Kvande, L.-I. Alnæs, S. K. Nilsen, and H. Stemland, *Alt om flislegging*, 2nd ed. SINTEF akademisk forlag, 2018.

[49] K. Haugholt. "Glass Shower Door on Tiled Bathroom Walls." (accessed May 14th, 2023).

[50] S. Byggforsk. "543.506 Våtromsvegger med fliskledning." Byggforsk. https://www.byggforsk.no/dokument/3243/vaatromsvegger_med_fliskledning# (accessed May 14th, 2023).

[51] *Specification texts for building, construction and installations Part N: Masonry and rigid tile work*, NS3420-N, S. Norge, December 1st 2019.

[52] A. Nesje, "Bomlyd under fliser," no. 4 - 2022, p. 5. [Online]. Available: https://www.norskbyggkeramikkforening.no/phocadownload/teknisk-informasjon/2022/faktablad_04-2022.pdf

[53] S. Byggforsk. "541.805 Golv i bad og andre våtrom." SINTEF Byggforsk. https://www.byggforsk.no/dokument/468/golv_i_bad_og_andre_vaatrom#changes (accessed May 18th, 2023).

[54] S. Byggforsk. "543.301 Keramiske fliser på innvendige vegger. Materialer, planlegging og underlag." Byggforsk. https://www.byggforsk.no/dokument/3044/keramiske_fliser_paa_innvendige_vegger_materialer_planlegging_og_underlag (accessed April 2nd, 2023).

[55] A. B. AS. "Instructional video for tile installation." Adda Byggkjemi AS. https://www.youtube.com/watch?v=4xDG0VFvIwQ (accessed April 10th, 2023).

[56] A. Nesje, "Limdekning under fliser," no. 1 - 2017, p. 4. [Online]. Available: https://www.norskbyggkeramikkforening.no/teknisk-informasjon/202-limdekning-under-fliser

[57] *Liquid applied watertight covering kits for wet room floors and/or walls*, E. A. Document, January 2019. [Online]. Available: https://www.eota.eu/download?file=/2017/17-03-0352/ead%20for%20ojeu/ead%20030352-00-0503_ojeu2020.pdf

[58] Bad.no. "Sparedusj - Products." Allier Gruppen. https://bad.no/collections/sparedusj (accessed April 15, 2023).

[59] Fjordkraft. "Hvor mye koster en dusj?" https://www.fjordkraft.no/strom/stromprat/stromforbruk/hvor-mye-koster-en-dusj/ (accessed April 15, 2023).

[60] T. S. Drapes. "What's Your Average Shower Temperature?" https://showerdrape.com/whats-your-average-shower-temperature/ (accessed May 14th, 2023).

[61] T. Ohnaka, Y. Tochihara, and Y. Watanabe, "The effects of variation in body temperature on the preferred water temperature and flow rate during showering," *Ergonomics,* vol. 37, no. 3, pp. 541-546, March 1st 1994, doi: 10.1080/00140139408963669.

[62] S. Byggforsk. "361.215 Sanitærutstyr og plassbehov." SINTEF Byggforsk. https://www.byggforsk.no/dokument/142/sanitaerutstyr_og_plassbehov (accessed May 14th, 2023).

[63] svas. "Hvor lenge skal man dusje?" https://www.diskusjon.no/topic/1198276-hvor-lenge-skal-man-dusje/ (accessed April 15, 2023).

[64] Bruker-93156. "Hvor lenge dusjer dere?" https://www.diskusjon.no/topic/761677-hvor-lenge-dusjer-dere/ (accessed April 15, 2023).

[65] mira. "REVEALED: What Brits are really getting up to in the bathroom." https://www.mirashowers.co.uk/blog/trends/revealed-what-brits-are-really-getting-up-to-in-the-bathroom-1/ (accessed April 15, 2023).

[66] M. Pullinger, A. Browne, B. Anderson, and W. Medd, "Patterns of Water: The water related practices of households in southern England, and their influence on water consumption and demand management.," University of Lancaster, Lancaster, United Kingdom, Final report of the ARCC-Water/SPRG Patterns of Water projects, March 2013.

[67] J. Regnström. "Nakne tall – Så lenge dusjer vi." https://www.elskling.no/presserom/nakne-tall-sa-lenge-dusjer-vi (accessed 26th Nov, 2022).

[68] J. Hugh G. Gauch, *Scientific method in practice*, 1st ed. Cambridge University Press, 2003.

[69] R. Moen and C. Norman, "Evolution of the PDCA cycle," presented at the 7th ANQ Congress, Tokyo, 2006.

[70] S. Byggforsk. "527.204 Bad og andre våtrom." Byggforsk. https://www.byggforsk.no/dokument/419/bad_og_andre_vaatrom (accessed April 2nd, 2023).

[71] *Adhesives for ceramic tiles, Part 1: Requirements, assessment an verification of constancy of performance, classification and marking*, NS-EN 12004-1, S. Norge, May 1st 2017.

[72] S. Byggforsk. "573.114 Lim, fugemasser og fugeprofiler til keramiske fliser." SINTEF Byggforsk. https://www.byggforsk.no/dokument/4119/lim_fugemasser_og_fugeprofiler_til_keramiske_fliser (accessed April 1st, 2023).

[73] Mapei. "Types of tile grout for tile and stone works." Mapei AS. https://www.mapei.com/sg/en/blog/detail/tech-talk/2020/10/28/understanding-tile-grouts-and-its-standards-for-tile-and-stone-works (accessed May 24th, 2023).

[74] A. Nesje, "Flisfuger - Fugebredder, storformatfliser og leggeteknikker," no. 3 - 2016, p. 4. [Online]. Available: https://www.norskbyggkeramikkforening.no/teknisk-informasjon/267-flisfuger-2

[75] *Adhesives for ceramic tiles, Part 2: Test Methods*, NS-EN 12004-2, S. Norge, February 2017.

[76] *Grouts for ceramic tiles - Part 2: Test Methods,* NS-EN 13888-2:2022, S. Norge, September 2022.

[77] P.-o. r. PRV. "Sensk Patentdatabas." Patent- och registreringsverket PRV. https://tc.prv.se/spd/search?lang=sv&tab=1 (accessed March 31, 2023).

[78] InviSense, "InviSense sensor Whitepaper," ed: InviSense, 2020.

[79] NCSS. "NCSS Documentation." NCSS, LLC. https://www.ncss.com/software/ncss/ncss-documentation/ (accessed April 30th, 2023).

[80] NCSS. "Videos." NCSS, LLC. https://www.ncss.com/videos/pass/ (accessed April 30th, 2023).

[81] NCSS. "Support." NCSS, LLC. https://www.ncss.com/support/ (accessed April 30th, 2023).

[82] D. E. Farrar and R. R. Glauber, "Multicollinearity in Regression Analysis: The Problem Revisited," *The Review of Economics and Statistics*, vol. 49, no. 1, pp. 92-107, 1967, doi: 10.2307/1937887.

[83] J. Frost. "Multicollinearity in Regression Analysis: Problems, Detection, and Solutions." Jim Frost. https://statisticsbyjim.com/regression/multicollinearity-in-regression-analysis/ (accessed May 20th, 2023).

[84] S. Glen. "Finding and Fixing Autocorrelation." Tech Target, Inc. https://www.datasciencecentral.com/finding-and-fixing-autocorrelation/ (accessed May 20th, 2023).

[85] T. Rose, Edd, and K. Fischer, "Garbage In, Garbage Out: Having Useful Data Is Everything," *Measurement*, vol. 9, pp. 222-226, 10/01 2011, doi: 10.1080/15366367.2011.632338.

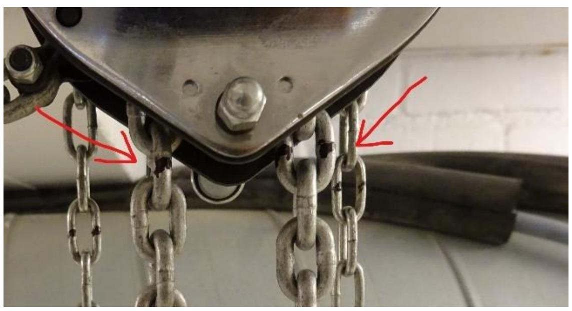
[86] N. J. Nagelkerke, "A note on a general definition of the coefficient of determination," *Biometrika*, vol. 78, no. 3, pp. 691-692, 1991. [Online]. Available: https://www.cesarzamudio.com/uploads/1/7/9/1/17916581/nagelkerke_n.j.d._1991_-_a_note_on_a_general_definition_of_the_coefficient_of_determination.pdf.

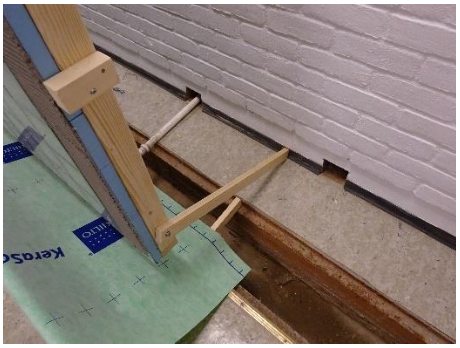
APPENDICES

Appendix A

Detailed experiment procedure that was followed during every water exposure day.

<table>
<tr><th>ID</th><th>Description</th><th>Verification</th></tr>
<tr><td colspan="3">CAUTION:
Due to non-optimal adhesion force of the tiles, take special care when handling the walls:
- Use smooth motion when handling the walls.
- Be sure not to make sudden moves when handling the walls.</td></tr>
<tr><td colspan="3">Note: Read the whole Test Step ID prior to executing the content, making sure full understanding of what is to be done during execution.</td></tr>
<tr><td>1.</td><td>If GoPro is recording time lapse:
- Stop recording and save file
If GoPro is not recording, goto ID 2.</td><td>GoPro is stopped</td></tr>
<tr><td>2.</td><td>Mount applicable Wall (#1 - #4) using the established hoist setup including pulley, shackle, lifting strap and loading cell.
Mount the support legs on the wall using the M8 bolts and nuts.
 </td><td>Every bolt and fastening mechanism is tightened and the wall is secured in the pulley.</td></tr>
</table>

ID	Description	Verification
3.	Setup the stand for shower head and GoPro equipment. - Aim the shower head at the point marked with a black 'X', positioned @ 30cm between wall and center of shower head in depth direction and 60 degrees parallel to the ground. - Use tape, sharpie etc. to be able to recreate setup.	Document setup using photo (Once pr wall)
4.	Hoist the wall using the pulley and align the height according to the markers on the chain: 	Wall is verified at 20cm +/- 1cm above ground.
5.	Stabilize the wall	Wall is not swaying
6.	Start Catman logging setup for load cell and document the weight of the wall. - 2Hz measuring rate - Catman logger is running for 30s or stabilized @ +/- 0.0001 kN	Save file as Excel .xml Document Average-values in: "Water_Exposure.xlsx"
7.	Document ambient temperature and RH	Document value in: "Water_Exposure.xlsx"

ID	Description	Verification
8.	Level the x, y and z-direction using the support feet 	Level wall in x, y and z – axis Document once pr wall config (#1 - #4) using a level and pictures.
9.	Document the RH sensors using the InviSense scanner, scanning < 20mm from the surface, not touching the surface. - If calibration of the scanner is required, save the calibration data for each wall config (#1 - #4). - If RH > 95%, perform measurement using WATERMODE in the scanner application.	Document values in: "Sensor_Location.xlsx"
10.	Setup GoPro with 1080p 30fps video or 2 images / min timelapse. - Prioritize video when saturation starts to show. Do continuous evaluations if video or timelapse should be used for each wall config (#1 - #4)	GoPro is setup and ready to go
11.	Setup temperature measurement at the wall aimpoint and in the water temperature calibration area (sink) using thermocouple connected to the Hioki. - Start the logger and make sure it is working and memory stick is inserted.	Sensor is installed Logging is correctly setup using memory stick

<table>
<tr><th>ID</th><th>Description</th><th>Verification</th></tr>
<tr><td colspan="3">Note: During the first day of water exposure on each wall, perform detailed measurements according to ID 23 through ID 26 after each 8min increment. Perform detailed measurements after the total 24min exposure for the remainder of experiment for each wall.

IF full saturation is reached during the first day, evaluation needs to be done.</td></tr>
<tr><td>12.</td><td>Adjust/Verify water temperature to 38 +/-3°C while the shower head is removed from the stand and located in the water temperature calibration area (sink).

- Aim the shower at the thermocouple in the corner of the sink.
- When temperature is reached, immediately proceed to Test Step ID 13

Note: Only to be done prior to each 24 min cycle.

</td><td>Document the average temp from the thermal gauge measurement in:

"Water_Exposure.xlsx"</td></tr>
</table>

ID	Description	Verification
13.	Measure the flow rate using the calibrated temperature in a bucket for weighing. Let the water flow for 30 seconds into the bucket, weigh the bucket and multiply by 2. Assume 1l = 1kg and note the flow rate in liters / minute. **Caution: Make sure to set TARE on the scale for the bucket** Note: Only to be done prior to each 24 min cycle. 	Document the value in: "Water_Exposure.xlsx"
14.	Install/Verify the shower head into the stand and secure it using the tightening screw. - @ Approx. 30cm distance and 60 degrees 	Shower head is fixed in placed and directed at the aimpoint on the wall

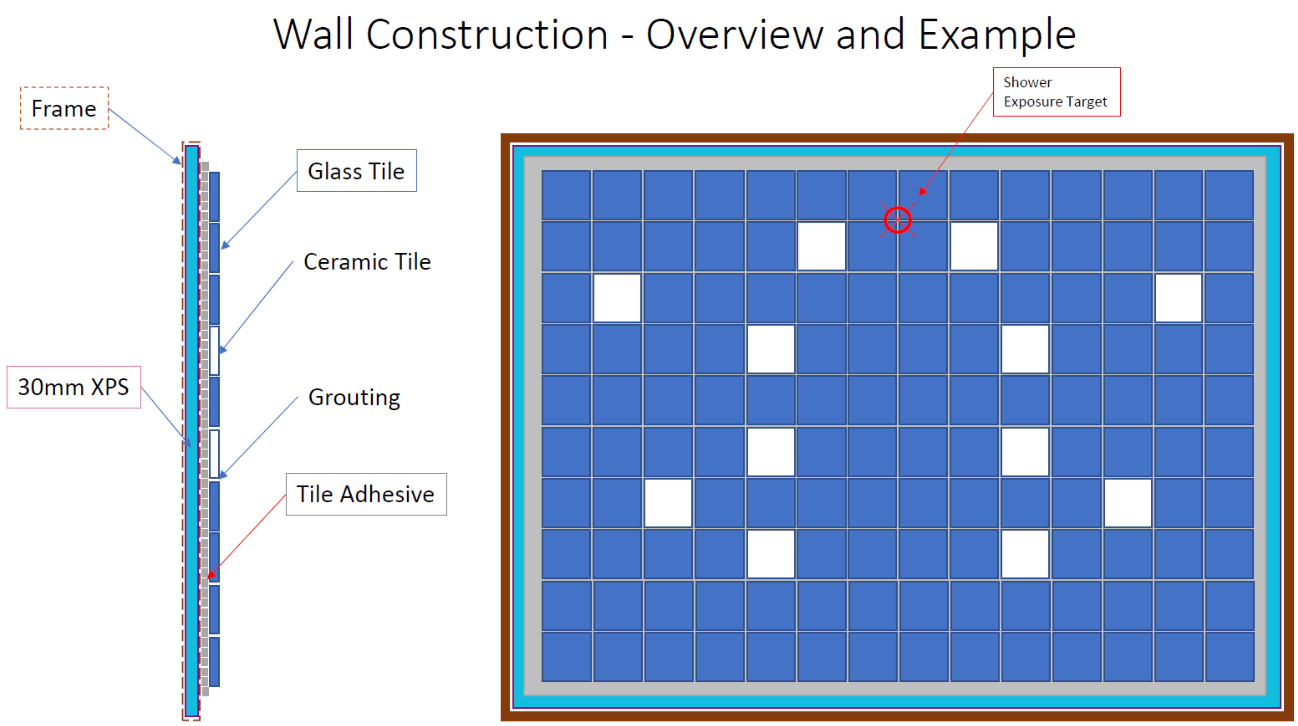
ID	Description	Verification
15.	Prepare a stopwatch or timer for 8 / 24 min. If Soap: Prepare stopwatch or timer for 1 min, then 2 min intervals	
16.	Start temperature logging	Hioki is logging and saving data
17.	Press record on GoPro	GoPro is recording
18.	Start waterflow and timer simultaneously. - Adjusting the water flow @ 10+/- 1 l/min - Perform continuous temp adjustments as needed. - Observe the water exposure zone to be approx. 140mm x 200mm - Observe behavior throughout the experimental period and document observations using photos / video. Base observations on research question, hypotheses, and other questions introductorily. - Let the water run for 8 / 24 min. - Document using a Thermal Camera sporadically **IF SOAP (i.e wall ID #2 and #4):** - Apply soap mixture to the water exposed area of the wall after 1 minute, then each 2 minutes. - To be applied in a random manner within the wet area, as well as along the edges of the water exposed area. Note for soap: Shortly stop water exposure if necessary	Water is flowing, timers are running, and soap is applied as specified. Observations are done and documented accordingly. Thermal Camera is used to document moisture migration. Document water impact zone once pr wall in: "Water_Exposure.xlsx"
19.	Stop water after 8 / 24 min	Document the exposure time in: "Water_Exposure.xlsx"
20.	Stop temperature logging	Hioki stops and saves data

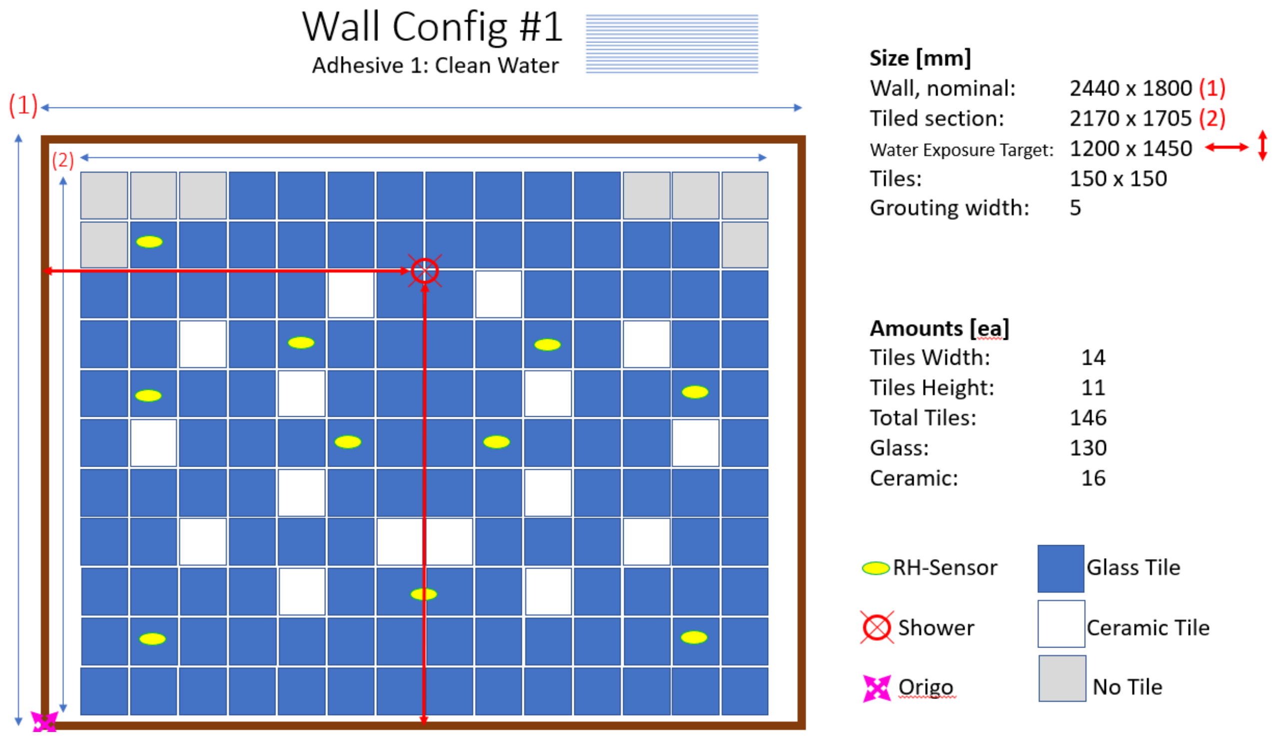
ID	Description	Verification
21.	Stop GoPro	
22.	Mount camera in fixed stand and take a picture of the total wall after markup.	Camera is mounted in same spot for each picture for comparison.
23.	Do a markup of the water exposed area on the wall using a **BLUE** sharpie, uniquely tagged with exposure time (e.g. 8m, 16m, 24m, 48m, 240m): - Measure the size of the moisture exposed area using a folding ruler or similar	Document moisture plot (x,y)
24.	Tilt the wall support feet so that the wall is hanging free. - Stabilize the wall from swaying 	Wall is hanging free and not swaying
25.	Start Catman logging setup for load cell and document the weight of the wall. - 2Hz measuring rate - Catman logger is running for 30s or stabilized @ +/- 0.0001 kN	Save file as Excel xml Document Average values in: "Water_Exposure.xlsx"
26.	Document the RH sensors using the InviSense scanner	Document values in: "Sensor_Location.xlsx"

ID	**Description**	**Verification**
27.	Repeat ID 10 through 26 for the remaining 8 min increments for the specific exposure period. Note: When finished with 3x8min or 24 min GoTo ID 28	
28.	Timelapse 1 image/ 2min using the GoPro between Morning exposure and Evening exposure.	GoPro is recording
29.	Repeat steps 1 through 28 for each Morning, Mid-day and Evening exposure.	
30.	End-of-Day/Next-Day actions: - Transfer media from all sources to PC - Charge batteries for Equipment - Document and sort files accordingly	

Appendix B

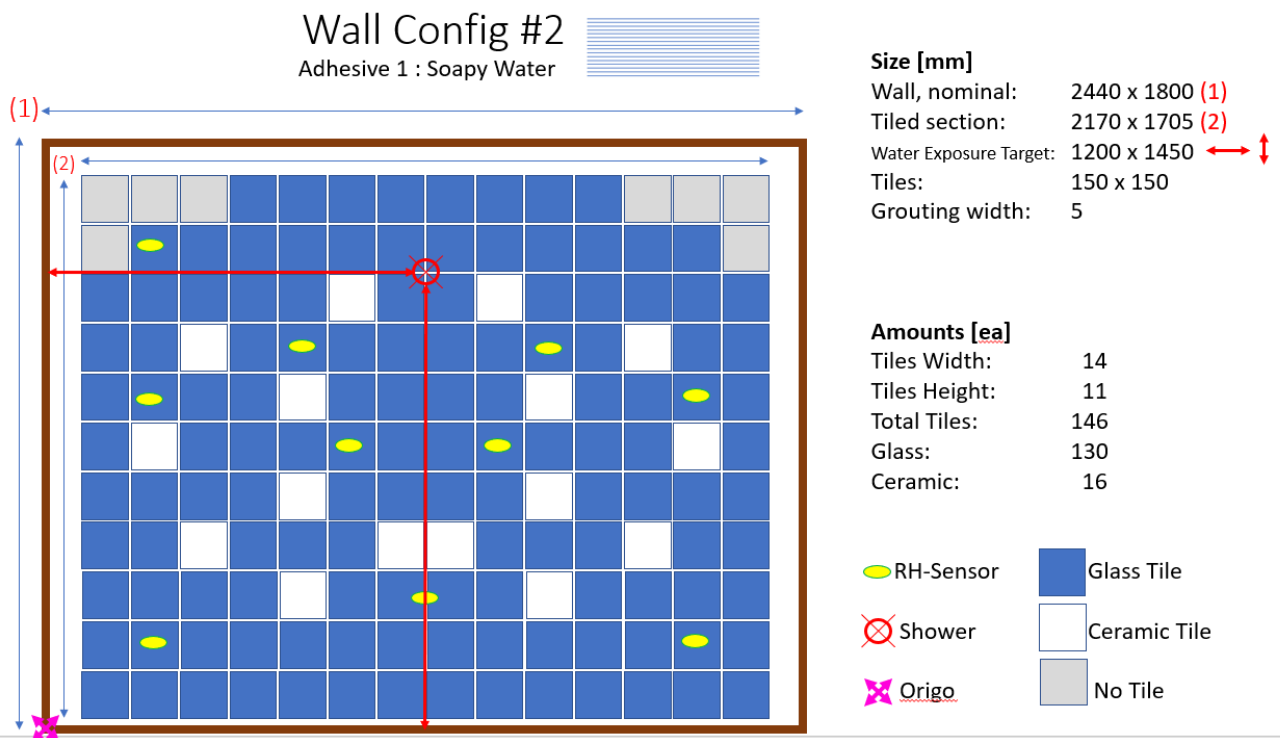
Excerpt from the EUT Design document are found below, describing all EUTs with their different layouts and configuration, along with the early-stage design overview.





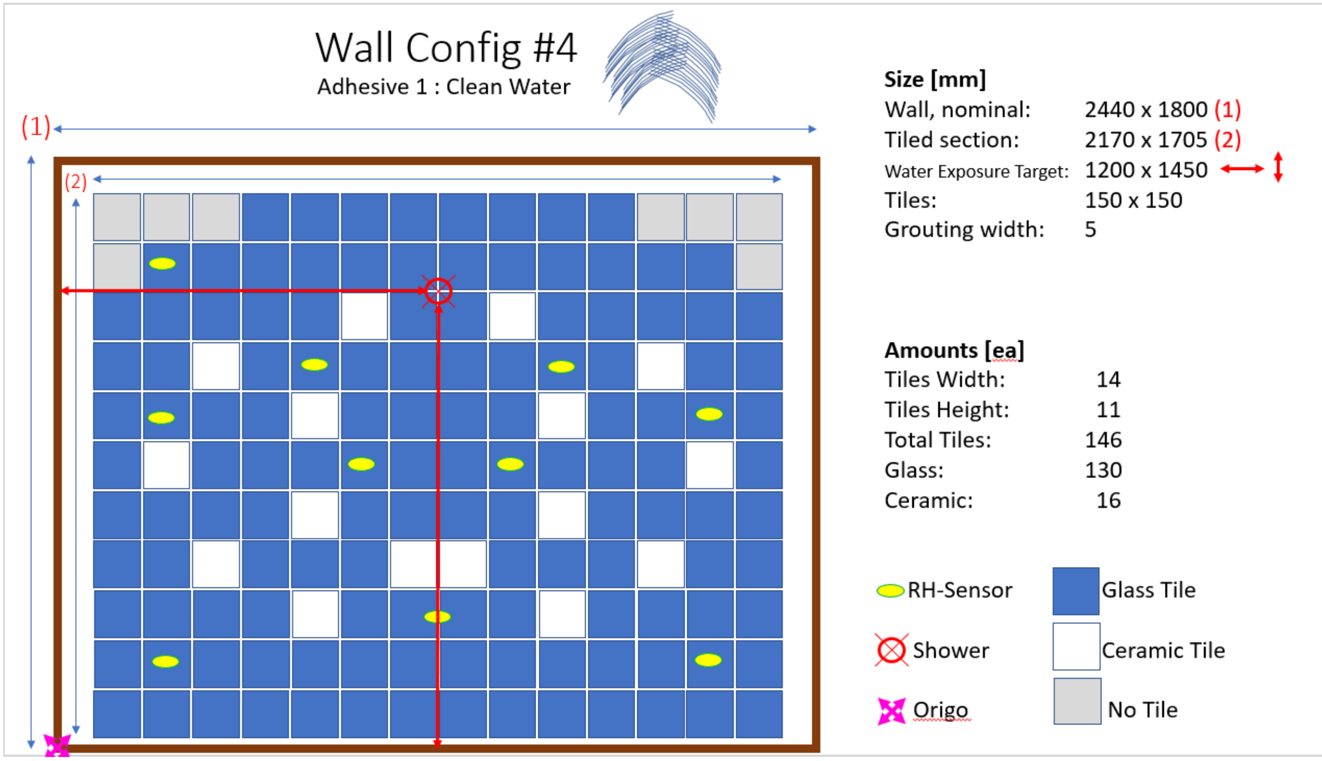
Size [mm]
Wall, nominal: 2440 x 1800 (1)
Tiled section: 2170 x 1705 (2)
Water Exposure Target: 1200 x 1450
Tiles: 150 x 150
Grouting width: 5

Amounts [ea]
Tiles Width: 14
Tiles Height: 11
Total Tiles: 146
Glass: 130
Ceramic: 16



Size [mm]
Wall, nominal: 2440 x 1800 (1)
Tiled section: 2170 x 1705 (2)
Water Exposure Target: 1200 x 1450
Tiles: 150 x 150
Grouting width: 5

Amounts [ea]
Tiles Width: 14
Tiles Height: 11
Total Tiles: 146
Glass: 130
Ceramic: 16

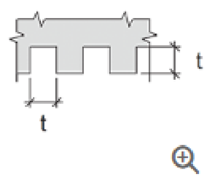
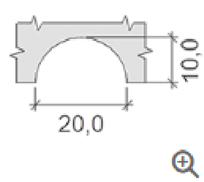

Wall Config #4
Adhesive 1 : Clean Water
(1)
(2)
Size [mm]
Wall, nominal: 2440 x 1800 (1)
Tiled section: 2170 x 1705 (2)
Water Exposure Target: 1200 x 1450
Tiles: 150 x 150
Grouting width: 5
Amounts [ea]
Tiles Width: 14
Tiles Height: 11
Total Tiles: 146
Glass: 130
Ceramic: 16
RH-Sensor
Glass Tile
Shower
Ceramic Tile
Origo
No Tile

Appendix C

A selection of tables and guidelines applicable for construction of the EUTs

<u>Trowel size dimensioning from Byggforsk 573.114 in Norwegian.</u>

Tabell 55
Omtrentlig limforbruk ut fra tannsparkeltype [951]

Flisformat	Type tannsparkel	Tannstørrelse, t mm	Limtykkelse mm	Omtrentlig forbruk[1)] kg/m²
Fliser og mosaikk med glatt bakside på slett underlag, anbefalt maks flisstørrelse 100 mm × 100 mm		4	2	1,5–2
Fliser med glatt bakside på litt ujevnt underlag, anbefalt maks flisstørrelse 200 mm × 200 mm		6	3	ca. 3
Fliser med rillet eller knastet bakside og fliser på jevnt underlag, anbefalt maks flisstørrelse 300 mm × 300 mm		8	4	4–4,5
Fliser på ujevnt underlag, anbefalt maks flisstørrelse 300 mm × 300 mm		10	5	6–7
Til storformatfliser brukes lim utlagt med stålsparkel med avrundet tanning.			5–6	7

1) Gjelder ikke lettlim

Tile adhesive properties from Byggforsk 573.114 in Norwegian [72].

Tabell 12
Karakteristiske materialegenskaper ved lim

Gruppe Limtype	C1 Standard sementbasert lim	C2 Sementbasert lim med forbedret vedheft	D Dispersjonslim (Pastalim)	R Herdeplastlim (Epoksy/polyuretan)
Heftfasthet til betong, N/mm^2 [1)]	≥ 0,5	≥ 1,0	≥ 1,0	≥ 2,0
Elastisitet	Liten	Middels (S1), eller høy (S2)	Høy	Varierende
Trykkfasthet	Høy	Høy	Lav−Middels	Høy
Fuktbestandighet	God	God	Varierende/dårlig	God
Kjemikaliebestandighet	Sårbar for sterke syrer	Sårbar for sterke syrer	Sårbar for alkalier	God
Merknader	Bør ikke brukes på underlag hvor større bevegelser kan opptre	«All-round»-lim. Høy andel plasttilsetning kan redusere vannbestandigheten noe.	Må ikke brukes på steder med stor vannpåkjenning	Vernetiltak påkrevd under utførelse

[1)] Vedheftverdiene danner grunnlag for produsentens klasseinndeling av limet. Verdiene er ikke et minimumskrav som skal etterprøves på byggeplass.

Grout classification from Byggforsk 573.114 in Norwegian [72].

Tabell 62
Klassebenevnelser for fugemasser i henhold til NS-EN 13888

Produkttype	Klassebenevnelse	Beskrivelse	Typiske bruksområder
Sement	CG1	Standard sementbasert masse	Standard fugemasse for vanlige formål
	CG2W	Forbedret sementbasert masse med høy vannopptaksmotstand (W)	Områder som krever liten fuktgjennomgang, som våtrom, svømmebasseng og områder som høytrykkspyles
	CG2A	Forbedret sementbasert masse med stor sitasjestyrke	Slitasjeutsatte områder som golv med mye trafikk og mye rengjøring
	CG2WA	Forbedret sementbasert masse med høy vannopptaksmotstand og høy slitasjestyrke	Vannpåkjente flater med høy slitasje
Herdeplast	RG	Standard herdeplastmasse	Kjemikaliepåkjente områder, spesielt slitasjeutsatte områder, flater med strenge krav til hygiene og renhold: svømmebasseng, fiskeforedlingsindustri, meierier

<u>Grout classification differences Mapei AS [73].</u>

Fundamental characteristics of Normal and Improved Cementitious Grouts

	Normal grouts CG1	Improved grouts CG2 A, CG2 W, CG2 WA
Resistance to abrasion	≤ 2000 mm^3	≤ 1000 mm^3
Flexural strength after 28 days	≥ 2.5 N/mm^3	≥ 2.5 N/mm^3
Flexural strength after freeze-thaw cycles	≥ 2.5 N/mm^3	≥ 2.5 N/mm^3
Compressive strength after 28 days	≥ 15 N/mm^2	≥ 15 N/mm^2
Compressive strength after freeze-thaw cycles	≥ 15 N/mm^2	≥ 15 N/mm^2
Shrinkage	≤ 3 mm/m	≤ 3 mm/m
Water absorption after 30 minutes	≤ 5 g	≤ 2 g
Water absorption after 240 minutes	≤ 10 g	≤ 5 g

Appendix D

RISIKOVURDERING

Verneombud Bjørn Ludvigsen og forsøksansvarlig Morten Brodahl har gjort en sikkerhetsvurdering den 3. Februar kl 10:00 av testoppsettet ifbm Masteroppgave Fukttransport i Flislim hos SINTEF Community i Børrestuveien, 0373 Oslo, lab U60.

Beskrivelse av testoppsett:

- En flislagt vegg på ca. 80kg henger i sjakkel fra taket med stativer og loggeutstyr rundt.
- Vann vil bli sprutet på veggen via tradisjonelt dusjhodet, og vann blir ledet til sluk.

Følgende punkter gjelder:

- Testområdet blir avsperret med sperrebånd.
- Ved bytte av vegg er det kjent arbeidsoperasjon for forsøksansvarlig.
    - Vernesko skal brukes.
- Ingen fare relatert til strøm, kjemikalier eller varme.

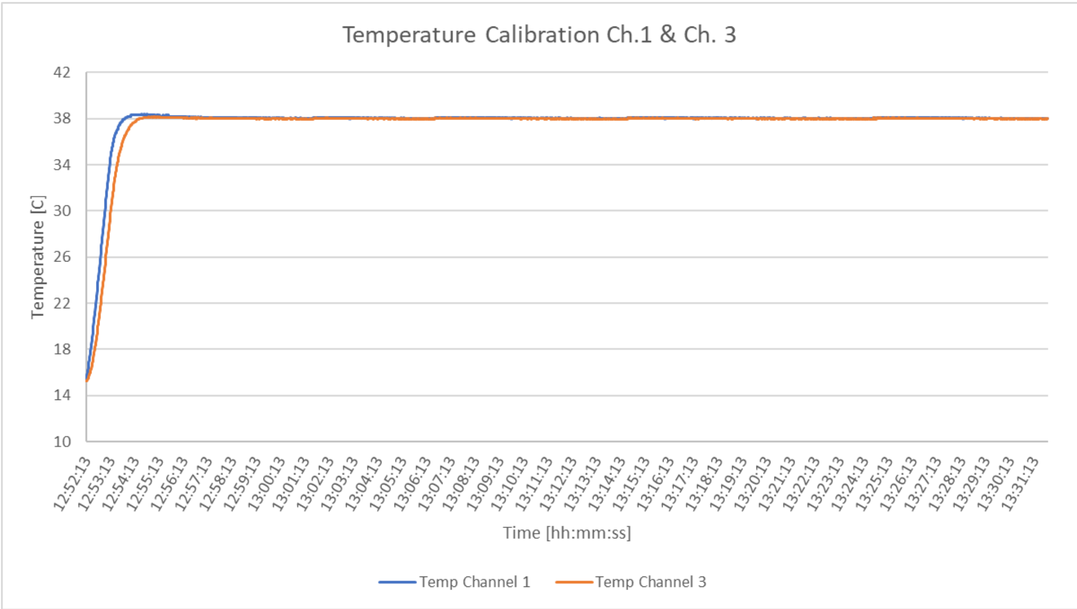
Sted: SINTEF Community

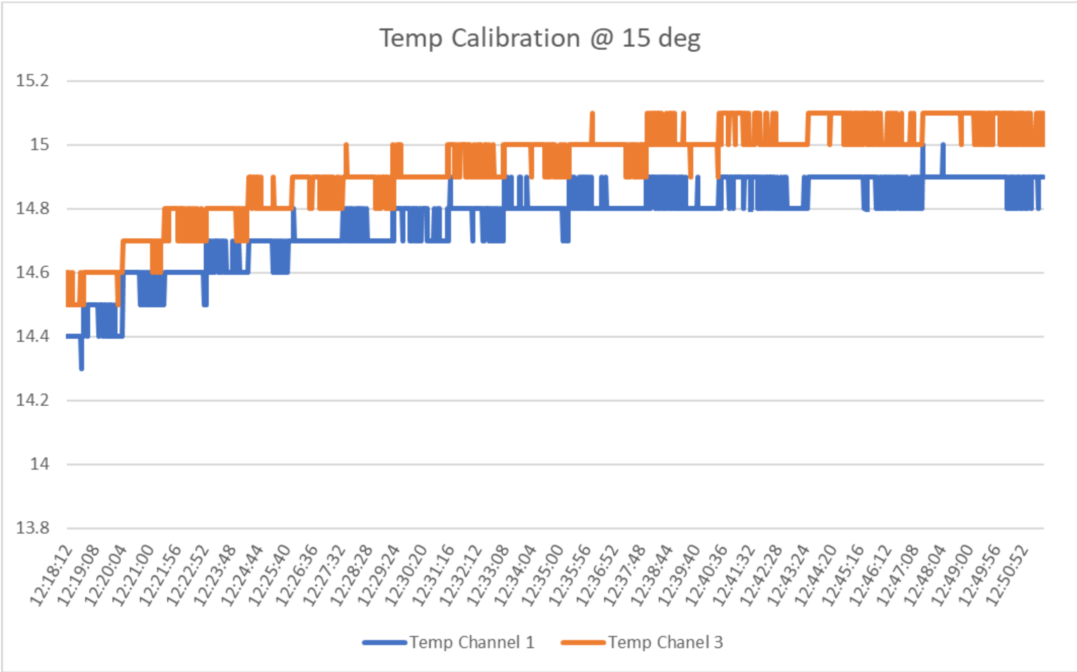
3/2-2023 3/2-23

Dato og sign. Bjørn Ludvigsen Dato og sign. Morten Brodahl

Appendix E

Temperature Graph during Calibration @ 38 °C and 15 °C – 30 Minutes.





Appendix F

Additional research experiment pictures can be found below.

Sorption Experiment

<u>Shower system</u>

<u>Tilework equipment</u>

Trial Tile Installation

Tile Installation

Grouting

Thermal camera

An attempt to use a thermal camera for something useful regarding moisture migration mapping. This was not followed up as it did not provide anything relevant.

Calibration and safety markings

Appendix G

Legend and color coding for the Gantt Chart

LEGEND	
	Main Period
	Main Period
	Main Period
	Main Period
	Main Period
	Research Activity
	Measurements
dd	Todays Date Highlight
	Holiday or Other Activity

Gantt chart for the whole experimental research period below

		November/December							December							December							December							December/Jan						
		Week 48							Week 49							Week 50							Week 51							Week 52						
		Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Course	**DESCRIPTION / DATE**	28	29	30	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	01
MABY5900 Master's Thesis	**Construction**																																			
	Base Wall	Sporadically prior to this																																		
	Complete Wall - RH-Sensor, Tile Adhesive, and Tiling																																			
	Complete Wall - Grouting																																			
	Experimental Work																																			
	Preliminary Discussion & Setup																																			
	Equipment Gathering and Setup																																			
	Prototyping																																			
	Equipment Training & Verification Setup																																			
	Verify the research setup																																			
	Main Experiment																																			
	EUT #1																																			
	Water Exposure																																			
	Artiificial Watering																																			
	Drying w/ Weekly RH-Measurement (orange)																																			
	EUT #2																																			
	Water Exposure																												Christmas Holiday								
	EUT #3 (CANCELLED)																																			
	EUT #4																																			
	Water Exposure																																			
	Drying w/Weekly RH- and Weight Measurement (Orange)																																			
	Supporting Experiment (Sorption)																																			
	Preliminary Study																																			
	Sorption Experiment Tile Adhesive																																			
	Sorption Experiment Tiles																																			
	OTHER																																			
	Result compiling																																			
	Post Analysis																																			
	Discussion & Conclusion																																			
	Prepare for Presentation - Nasjonalt Fuktseminar																																			

		January							January							January							January							January / February							February							February							February						
		Week 1							Week 2							Week 3							Week 4							Week 5							Week 6							Week 7							Week 8						
		Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Course	**DESCRIPTION / DATE**	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
MABY5900 Master's Thesis	**Construction**																																																								
	Base Wall																																																								
	Complete Wall - RH-Sensor, Tile Adhesive, and Tiling																																																								
	Complete Wall - Grouting																																																								
	Experimental Work																																																								
	Preliminary Discussion & Setup																																																								
	Equipment Gathering and Setup																																																								
	Prototyping																																																								
	Equipment Training & Verification Setup																																																								
	Verify the research setup																																																								
	Main Experiment																																																								
	EUT #1																																																								
	Water Exposure																																																								
	Artiificial Watering																																																								
	Drying w/ Weekly RH-Measurement (orange)																																																								
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	Drying w/Weekly RH- and Weight Measurement (Orange)																																																								
	Supporting Experiment (Sorption)																																																								
	Preliminary Study																																																								
	Sorption Experiment Tile Adhesive																																																								
	Sorption Experiment Tiles																																																								
	OTHER																																																								
	Result compiling																																																								
	Post Analysis																																																								
	Discussion & Conclusion																																																								
	Prepare for Presentation - Nasjonalt Fuktseminar																																																								

		February / March						March							March							March							March / April							April							April							April						
		Week 9						Week 10							Week 11							Week 12							Week 13							Week 14							Week 15							Week 16						
		Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Course	**DESCRIPTION / DATE**	28	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
MABY5900 Master's Thesis	**Construction**
	Base Wall
	Complete Wall - RH-Sensor, Tile Adhesive, and Tiling
	Complete Wall - Grouting
	Experimental Work
	Preliminary Discussion & Setup
	Equipment Gathering and Setup
	Prototyping
	Equipment Training & Verification Setup
	Verify the research setup
	Main Experiment
	EUT #1
	Water Exposure
	Artiificial Watering
	Drying w/ Weekly RH-Measurement (orange)
	EUT #2																																																			*Presenting at Nasjonalt Fuktseminar*				
	Water Exposure
	EUT #3 (CANCELLED)
	EUT #4
	Water Exposure
	Drying w/Weekly RH- and Weight Measurement (Orange)
	Supporting Experiment (Sorption)
	Preliminary Study
	Sorption Experiment Tile Adhesive
	Sorption Experiment Tiles
	OTHER
	Result compiling
	Post Analysis
	Discussion & Conclusion
	Prepare for Presentation - Nasjonalt Fuktseminar

		April / May							May							May							May							May						
		Week 17							Week 18							Week 19							Week 20							Week 21						
		Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Course	DESCRIPTION / DATE	24	25	26	27	28	29	30	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
MABY5900 Master's Thesis	**Construction**																																			
	Base Wall																																			
	Complete Wall - RH-Sensor, Tile Adhesive, and Tiling																																			
	Complete Wall - Grouting																																			
	Experimental Work																																			
	Preliminary Discussion & Setup																																			
	Equipment Gathering and Setup																																			
	Prototyping																																			
	Equipment Training & Verification Setup																																			
	Verify the research setup																																			
	Main Experiment																																			
	EUT #1																																			
	Water Exposure																																			
	Artiificial Watering																																			
	Drying w/ Weekly RH-Measurement (orange)																																			
	EUT #2																																			
	Water Exposure																																			
	EUT #3 (CANCELLED)																																			
	EUT #4																																			
	Water Exposure																																			
	Drying w/Weekly RH- and Weight Measurement (Orange)																																			
	Supporting Experiment (Sorption)																																			
	Preliminary Study																																			
	Sorption Experiment Tile Adhesive																																			
	Sorption Experiment Tiles																																			
	OTHER																																			
	Result compiling																																			
	Post Analysis																																			
	Discussion & Conclusion																																			
	Prepare for Presentation - Nasjonalt Fuktseminar																																			

Appendix H

Essential data sheets including tile adhesive, grout and construction materials are presented below.

ULTRALITE S1

One-component, high-performance, flexible, lightweight, cementitious adhesive with no vertical slip and long open time and extremely high yield. Easy to apply by trowel with excellent wetting properties, very low emission of volatile organic compounds for ceramic tiles, stone and thin porcelain tiles

CLASSIFICATION ACCORDING TO ISO 13007-1

Ultralite S1 is a C2TES1-class cementitious (C), improved (2), slip-resistant (T), extended open time (E), deformable (S1) adhesive.

WHERE TO USE

- Bonding all types and sizes of ceramic tiles (double-fired, single-fired, porcelain, klinker, terracotta, etc.) on uneven internal and external substrates, without having to even out the surface before fixing.
- Bonding all types of mosaic on internal and external surfaces even in swimming-pools.
- Bonding natural stone on internal and external surfaces (for stone which is stable and not sensitive to humidity).
- Bonding thin porcelain tiles on floors and walls, including external façades.

Some application examples

- Bonding ceramic tiles (double-fired, single-fired, porcelain, klinker, ceramic and glass mosaic, etc.), stone (if stable in damp environments) and thin porcelain tiles on conventional substrates, such as:
  – cementitious and anhydrite screeds (after preparation and applying a suitable primer);
  – heated screeds; – cementitious render or lime-mortar render;
  – gypsum-based plaster (after applying a suitable primer);
  – plasterboard, pre-fabricated panels, cement-fibre panels;
  – waterproofing membranes **Mapelastic Smart**, **Mapelastic Turbo**, **Mapelastic AquaDefense** and **Mapegum WPS**.
- Laying ceramic and natural stone on old floors (in ceramic, marble, etc.).
- Laying on marine plywood, wooden agglomerates and old, stable wooden floors.
- Laying ceramic and natural stone on balconies and terraces and paving slabs exposed to direct sunlight and thermal gradients.
- Laying on prefabricated concrete walls and concrete substrates.

TECHNICAL CHARACTERISTICS

Ultralite S1 is a grey or white powder made from cement, selected graded sand and a high amount of synthetic resin, with recycled silica micro-spheres which helps to make the mix lighter, according to a special formula developed in MAPEI's own Research & Development laboratories, as a contribution towards a sustainable building industry. The special technology used to manufacture **Ultralite S1** gives it a low density, a characteristic which offers two main advantages:
1) bags of **Ultralite S1** have the same volume but weigh less (13.5 kg) than bags of conventional cementitious adhesive (20 kg). This makes for easier handling and savings in transport costs;
2) higher yield: yield is approximately 60% higher compared with conventional MAPEI cementitious adhesives. Ultralite S1 mix has a low viscosity, which makes it easier and quicker to apply. Inspite of the above characteristics, the thixotropic nature of Ultralite S1 means there is no vertical slip when fixing on walls, even with large-sized tiles.
Its excellent back-buttering capability and thixotropic consistency make **Ultralite S1** particularly suitable for laying thin porcelain tiles. In fact, the application of **Ultralite S1** using the double-buttering technique on flat substrates ensures that there are absolutely no voids in the adhesive on the back of the tiles, thus avoiding the risk of fracture when subject to load. Its excellent non-slip properties also make it particularly easy and safe to fix tiles on vertical surfaces. When mixed with water, **Ultralite S1** forms a mortar with the following characteristics:

- excellent capacity of absorbing deformation in the substrate;
- excellent back-buttering property of the tiles;
- bonds perfectly to all materials normally used in the building industry;
- particularly long open and adjustment times, to make installation easier.

RECOMMENDATIONS

Do not use **Ultralite S1** in the following cases:
- on metal, rubber, PVC and linoleum;
- for slabs of marble and natural stone which are subject to efflorescence or staining;
- for natural agglomerate stone with high coefficients of moisture expansion.
- when the floored surface must be put quickly back into service.

Do not use **Ultralite S1** for installing thin porcelain tiles with reinforcement mesh larger than 5000 cm² (700 x 700 mm). Use an "S2" deformability class adhesive for this type of application such as **Ultralite S2**, **Kerabond Plus + Isolastic**, or **Keraquick S1 + Latex Plus.** When installing thin porcelain tiles on external facades and for further information on how to choose the correct adhesive, refer to the MAPEI technical manual "Selection Chart of Adhesives for Ceramic Tiles and Stone Material" available for download from our website www. mapei.com.au or alternatively contact the MAPEI Technical Services Department on freecall 1800 652 666 or email Technical-AU@ mapei.com.au. Do not add water to the mix once it starts to set.

APPLICATION PROCEDURE

Preparation of the substrate

All substrates must be mechanically strong, free of loose parts, grease, oil, paintwork, etc. and must be sufficiently dry. All cementitious substrates must be well cured and must not shrink after fixing the tiles. New concrete must be cured for at least 28 days and renders cured for at least 1 week for each centimetre of thickness. Screeds must be adequately cured and sufficiently dry (moisture content below 5%) prior to tiling. In order to fast track installations, it is recommended to use screeds made from special MAPEI binders such as **Mapecem**, or pre-blended mortars, such as **Topcem Pronto** and **Mapecem Pronto**. If the surface is too hot due to direct sunlight, cool it down with water. Gypsum substrates and anhydrite screeds must be perfectly dry, hard enough for the final intended use and free of dust and laitance. They must also be treated with **Primer G** or **Eco Prim T Plus**, while areas subject to high humidity must be primed with **Primer S**. Substrates on which thin porcelain is to be laid must be perfectly flat. Therefore, where necessary, even out the substrate before laying the floor with a self-levelling compound from the MAPEI range

Preparation of the mix

Blend **Ultralite S1** with clean water to obtain a smooth, lump-free mix. Let the mix stand for approximately 5 minutes, then blend again. Approximately 6.9-7.4 litres of water are required for each 13.5 kg bag of **Ultralite S1**. When blended as described above, the mix lasts for approximately 8 hours.

Spreading the mix

Apply **Ultralite S1** on the substrate using a notched trowel. Use a trowel with a notch size which guarantees complete buttering of the back of the tile. To guarantee a good bond, apply a thin layer of Ultralite S1 on the substrate using the smooth side of the trowel, and then immediately apply a further layer of **Ultralite S1** to the thickness required using a suitable trowel, according to the type and size of the tiles. When laying external flooring, for tile sizes larger than 900 cm2 (300 x 300 mm) and floors subject to heavy loads, spread the adhesive also on the back of the tile to ensure complete buttering. When laying thin porcelain floor tiles, we recommend that the adhesive is also spread (with the suitable notched trowel) on the backs of the tiles to guarantee there are no gaps to avoid the risk of fracture when in service.

Laying tiles

The tiles do not need to be wet before they are laid. However, if the back faces are particularly dusty, dip them into clean water. Ensure they are dry before fixing. When laying tiles, apply a firm pressure to guarantee good contact. The open time for **Ultralite S1** is at least 30 minutes in normal weather and humidity conditions. When conditions are not ideal (direct sunlight, dry wind, high temperatures, etc.), or if the substrate is particularly absorbent, this time may be reduced to only a few minutes. Therefore, check often to make sure a layer of skin does not form on the surface of the adhesive, and that it is still fresh. If a layer of skin forms, spread the adhesive again with the notched trowel. Do not wet the surface of the adhesive if a layer of skin forms. Water does not dissolve the skin, and impedes a good bond. Final adjustment of the tiles must be carried out within 45 minutes of laying. Tiles laid using **Ultralite S1** must be protected from water and rain for at least 24 hours, and from freezing weather and direct sunlight for at least 5 to 7 days.

Grouting and sealing

Tile joints may be grouted after 4 to 8 hours on walls and after 24 hours on floors. Use a MAPEI cementitious or epoxy grout, available in a wide variety of colours. Expansion joints must be sealed using a special MAPEI sealant.

SET TO LIGHT FOOT TRAFFIC

Floors may be walked on after approximately 24 hours.

READY-TO-USE

Surfaces are ready-to-use after approximately 14 days.

Cleaning

Tools and containers may be cleaned using water while **Ultralite S1** is still fresh. Clean the surfaces of the floor using a damp cloth before the adhesive sets.

PACKAGING

Ultralite S1 is available in 13.5 kg paper bags.

CONSUMPTION

0.8 kg/m² per mm of thickness, equal to 1.5-2.5 kg/m². A 13.5 kg bag covers 5.4 - 6.8 m2 using a 6 x 6 x 6 mm square-notched trowel or 3.6 - 4.5 m2 with a 6 x 10 x 6 mm notched trowel.

STORAGE

Ultralite S1 may be stored for up to 12 months in its original packaging in a dry place.


Spreading Ultralite S1 with a notched trowel on wall


Spreading adhesive on the back of the tile


Laying large-sized tiles on walls


Spreading the adhesive on floor with a 9 mm round-tooth notched trowel


Spreading the adhesive on the back of the tile


Installing thin porcelain tile on floor


Checking the complete back-buttering of thin porcelain tile

TECHNICAL DATA (typical values) Conforms to the following standards: – European EN 12004 (C2TE S1) – ISO 13007-1 (C2TE S1)	
PRODUCT IDENTITY	
Consistency	powder
Colour:	white or grey
Bulk density (kg/m³):	870
Dry solids content (%):	100
APPLICATION DATA (at +23°C - 50% R.H.)	
Mixing ratio:	100 parts of **Ultralite S1** with 51-54 parts of water by weigh
Consistency of mix:	creamy paste
Density of the mix (kg/m³):	1,200
pH of mix:	more than 12
Pot life of mix:	more than 8 hours
Application temperature range:	from +5°C to +40°C
Open time (according to EN 1346):	> 30 minutes
Adjustment time:	45 minutes
Grouting tile joints on walls:	after 4-8 hours
Grouting tile joints on floors:	after 24 hours
Set to light foot traffic:	24 hours
Ready-to-use:	14 days
FINAL PERFORMANCE	

MAPEI

Bond strength according to EN 1348 (N/mm²): – initial bond (after 28 days): – bond after application of heat source: – bond strength after immersion in water: – bond strength after freeze-thaw cycles:	 2 2 1.3 1.5
Resistance to alkalis:	excellent
Resistance to oils:	excellent (poor with vegetable oils)
Resistance to solvents:	excellent
In service temperature range:	from -30°C to +90°C
Deformability according to EN 12002:	S1 - deformable (> 2.5 mm, < 5 mm)

SAFETY INSTRUCTIONS FOR PREPARATION AND APPLICATION

Ultralite S1 contains cement that when in contact with sweat or other body fluids may cause an irritant alkaline reaction and allergic reactions to those predisposed. It can cause damage to eyes. It is recommended to use protective gloves and goggles and to take the usual precautions for handling chemicals. If the product comes in contact with the eyes or skin, wash immediately with plenty of water and seek medical attention.
For further and complete information about the safe use of our product, please refer to the latest version of our Safety Data Sheet available from our website at www.mapei.com.au.
PRODUCT FOR PROFESSIONAL USE.

WARNING

Although the technical details and recommendations contained in this product data sheet correspond to the best of our knowledge and experience, all the above information must, in every case, be taken as merely indicative and subject to confirmation after long-term practical application: for this reason, anyone who intends to use the product must ensure beforehand that it is suitable for the envisaged application: in every case, the user alone is fully responsible for any consequences deriving from the use of the product.
Please refer to the current version of the Technical Data Sheet, available from our website www.mapei.com.au

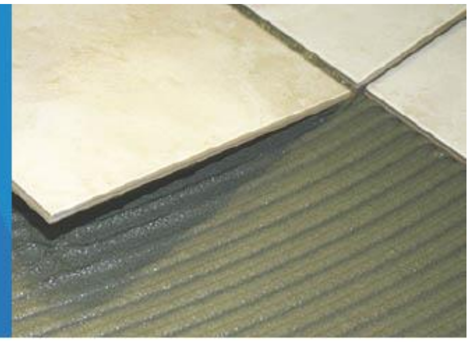
LEGAL NOTICE

The contents of this Technical Data Sheet ("TDS") may be copied into another project-related document, but the resulting document shall not supplement or replace requirements per the TDS in force at the time of the MAPEI product installation.
The most up-to-date TDS can be downloaded from our website www.mapei.com.au
ANY ALTERATION TO THE WORDING OR REQUIREMENTS CONTAINED OR DERIVED FROM THIS TDS EXCLUDES THE RESPONSIBILITY OF MAPEI.

71-05-2019(AUS)

MEGAFIX

High performance cementitious adhesive with no vertical slip and extended open time for ceramic tiles and stone material



CLASSIFICATION IN COMPLIANCE WITH EN 12004

Megafix is an improved (2) slip resistant (T) cementitious adhesive (C) with extended open time (E) as class C2TE.

Megafix is CE marked, as declared in ITT certificates **n° 25040476/Gi** (TUM) and **ITT n° 25080239/ Gi** (TUM) issued by the Technische Universität München laboratory (Germany) and in ITT certificates **n° 1220.12/10/R03 NPU**; **1220.14/10/R03 NPU**; **1220.11/10/R03 NPU** and **1220.13/10/R03 NPU** issued by the Istitute ITB Katowice (Poland).

AREA OF USE

Interior and exterior bonding of ceramic tiles porcelain, stone materials and mosaics of every type on floors, walls and ceilings. Also suitable for spot bonding of insulating materials such as expanded polystyrene, rock and glass wool, Eraclit® (wood-cement panels), sound-deadening / reduction panels, etc.

Some application examples:

- Bonding ceramic tiles (double fired, single fired, porcelain, clay tiles, clinker), stone materials and mosaics on the following substrates:
  - Cement or mortar wall renders
  - Interior aerated concrete block walls
  - Gypsum or anhydrite after having first applied **Primer G**
  - Gypsum board
  - Underfloor heating installations
  - Cement screeds, as long as they are sufficiently cured and dry
  - Interior painted walls, as long as the paint is firmly anchored
  - Waterproofed membranes in **Mapelastic** or **Mapegum WPS**

- Tile on tile of existing flooring.
- Bonding small sized tiles in swimming pools and basins.
- Bonding floors subject to heavy stress.

TECHNICAL CHARACTERISTICS

Megafix is a grey or white powder composed of cement and graded aggregates. It contains a high quantity of synthetic resins and special additives created according to a formula developed in MAPEI's research laboratories.

A mortar with the following features is obtained when mixed with water:

- Easily workable.
- Highly thixotropic; **Megafix** can be applied on a vertical surface without dripping or letting the tiles slip, even for heavy tiles. Tiles can be installed from the top towards the bottom without using spacer pegs.
- Perfect adherence to all materials normally used in building.
- Hardens without appreciable shrinkage.
- Extended open time.

MAPEI

RECOMMENDATIONS

Do not use Megafix:
· On concrete subject to strong shrinkage.
· On walls and floors subject to strong movement or vibration (wood, fibre-cement, etc.
· On metal surfaces.

APPLICATION PROCEDURE

Preparation of the substrate

The substrates must be flat, mechanically resistant, free of loose parts, grease, oils, paints, wax, etc. Damp substrates can slow down the setting of **Megafix**. Cement substrates should not be subject to shrinkage after the installation of the ceramic tiles, therefore, during spring and summer, renders must cure at least one week for each cm of thickness and cement screeds must have an overall cure time of at least 28 days, unless they are made with special binders for MAPEI screeds such as **VR-støp**, **Mapecem**, **Mapecem Pronto**, **Topcem** or **Topcem Pronto**.
Dampen with water to cool surfaces which have become heated from exposure to sunlight. Gypsum substrates and anhydrite screeds must be perfectly dry (max. residual moisture 0.5 %), sufficiently hard and free from dust. It is absolutely essential that they be treated with **Primer G** or **Eco Prim T**, while areas subject to extreme dampness must be primed with **Primer S**.

Preparation of the product

Mix **Megafix** with clean water until a smooth, lump-free paste is obtained. Leave to rest approximately 5 minutes and re-stir. Use 29 - 31 parts water for every 100 parts by weight of **Megafix**, which is equal to 7.25 - 7.75 litres of water for every 25 kg of powder. Mixed this way, **Megafix** has a pot life of approximately 8 hours.

Application of the product

Megafix is applied to the substrate using a notched trowel. Choose a trowel that allows for complete coverage of the tile backs. To achieve a good adhesion, spread an initial thin layer of **Megafix** on the substrate using the flat side of the trowel. Immediately after, apply the desired thickness of **Megafix** using a suitable notched trowel, depending on the type and size of the tiles (see "Coverage"). For external ceramic tile floors and walls, sizes greater than 900 cm², floors subject to heavy loads, when applying in swimming pools and basins filled with water, spread also the adhesive on the back of the tiles (back-buttering) in order to ensure a complete coverage.

Installing the tiles

There is no need to wet the tiles before installing them. Only with very dusty backs is it recommended to dip the tiles in clean water. Tiles should be installed under a firm pressure to ensure good coverage of the adhesive. In normal temperatures and humidity conditions, the open time of **Megafix** is approximately 30 minutes. Unfavourable weather conditions (strong sun, drying wind, high temperatures, etc.) or a highly absorbent substrate can reduce the open time, even to just a few minutes. It is therefore necessary that careful checks be made to ensure that a skin does not form on the surface of the spread adhesive, which should stay fresh. If not, re-freshen the adhesive by re-spreading with a notched trowel. It is not recommended to wet the adhesive with water once a skin has formed because, instead of dissolving the skin, the water will form an anti-adhesive film. If necessary, tiles should be adjusted within 60 minutes of installation. Tiling installed with **Megafix** must not be washed or exposed to rain for at least 24 hours and must be protected from frost and strong sun for at least 5 - 7 days.

Spot-bonding insulating materials

For spot-bonding sound-deadening or insulating panels, apply **Megafix** with a trowel or a float.

GROUTING AND SEALING

Wall joints can be grouted after 4 - 8 hours and floor joints can be grouted after 24 hours with the specific MAPEI cementitious or epoxy grouts, available in different colours.
Expansion joints must be sealed with the specific MAPEI sealants.

SET TO LIGHT FOOT TRAFFIC

Floors are set to light foot traffic after approx. 24 hours.

READY FOR USE

Surfaces are ready for use after approx. 14 days. Swimming pools and basins can be filled after 21 days.

CLEANING

Tools and containers should be cleaned with plenty of water while **Megafix** is still fresh. Surfaces should be cleaned with a damp cloth, before the adhesive dries.

CONSUMPTION

Bonding ceramic tiles:

· Mosaics and small sizes in general (trowel n. 4): 2 kg/m².
· Normal sizes (trowel n. 5): 2.5 - 3 kg/m².
· Large sizes, exterior floors (trowel n. 6): 5 kg/m².

Spot-bonding insulating material:

· Foam, etc. approx. 0.5 - 0.8 kg/m².
· Gypsum board panels, cellular concrete: approx. 1.5 kg/m².

PACKAGING

Megafix white and grey are available in 20 kg bags and in 4 x 5 kg alupack.

STORAGE

Megafix can be stored 12 months in a normal environment in original packaging.
The product complies with the conditions of Annex XVII to Regulation (EC) N° 1907/2006 (REACH), item 47.

SAFETY INSTRUCTIONS FOR PREPARATION AND INSTALLATION

Instructions for the safe use of our products can be found on the latest version of the SDS available from our website **www.mapei.no**

PRODUCT FOR PROFESSIONAL USE.

TECHNICAL DATA (typical values)

According to these norms: - European EN 12004, such as C2TE - ISO 13007-1, such as C2TE - American ANSI A 118.4-1999

PRODUCT IDENTITY	
Appearance:	powder
Colour:	white or grey
Bulk density (kg/m³):	1.300
Dry solids content (%):	100
EMICODE:	EC1 R Plus - very low emission

APPLICATION DATA (at +23°C and 50 % R.H.)	
Mixing ratio:	100 parts **Megafix** with 29 - 31 parts water by weight
Consistency of mix:	pasty
Density of the mix (kg/m³):	1.500
pH of mix:	13
Pot life:	over 8 hours
Application temperature range:	from +5°C to +40°C
Open time (acc. EN 1346):	> 30 minutter
Adjustability time:	approx. 60 minutes
Ready for grouting on walls:	after 4 - 8 hours
Ready for grouting on floors:	after 24 hours
Set to light foot traffic:	24 hours
Ready for use:	14 days

MAPEI

FINAL PERFORMANCES	
Bonding strength according to EN 1348 (N/mm²):	
– initial bonding after 28 days:	1.8
– bonding after heat exposure:	1.7
– bonding after immersion in water:	1.2
– bonding after freeze/thaw cycles:	1.4
Resistance to alkali:	excellent
Resistance to oils:	excellent (poor to vegetable oils)
Resistance to solvents:	excellent
Temperature when in use:	from -30°C to +90°C

WARNING

Although the technical details and recommendations contained in this product data sheet correspond to the best of our knowledge and experience, all the above - information must, in every case, be taken as merely indicative and subject to confirmation after long-term practical application: for this reason, anyone who intends to use the product must ensure beforehand that it is suitable for the envisaged application: in every case, the user alone is fully responsible for any consequences deriving from the use of the product.

Please refer to the current version of the technical data sheet, available from our web site www.mapei.no

LEGAL NOTICE

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ANY ALTERATIONS TO THE WORDING OR REQUIREMENTS CONTAINED IN OR DERIVED FROM THIS TDS SHALL VOID ALL RELATED MAPEI WARRANTIES.

10213-06-2019-gb

MEGARAPID 2K PLUS

Highly derformable, high performance, fast setting and hydration two-component cementitious adhesive with extended open time and no vertical slip, for ceramic tiles and stone material

CLASSIFICATION ACCORDING TO EN 12004

Megarapid 2K Plus is a highly deformable (S2), improved (2), fast-setting (F) cementitious (C) adhesive, slip-resistant (T) and with extended open time (E), classified as C2FTE S2.
*Conformity of **Megarapid 2K Plus** is declared in **TT** certificate **No. 25070277/Gi (TUM)** and **No. 25080024/Gi (TUM)** issued by the Technische Universität München laboratory (Germany).*

WHERE TO USE

Bonding to internal and external walls and floors of all types and sizes of ceramic tiles (single-fired, double-fired, porcelain, clinker, terracotta, etc.), natural stone (marble, granite, etc.) and artificial materials which are slightly sensitive to humidity (class B MAPEI dimensional stability standard) which require the use of a fast-drying adhesive.

Some application examples:

- Laying ceramic and stone floor coverings which are subject to intense traffic.
- Quick repair operations where the floor needs to be put into service immediately (public buildings, motorway service areas, supermarkets, airports, pedestrian areas), even during hot weather. Compared with other fast-setting adhesives, the longer pot-life of **Megarapid 2K Plus** makes it more easy to apply even during hot weather.
- Laying tiles on deformable substrates: marine plywood, wooden agglomerates (if sufficiently stable to water), old wooden floors, etc.
- Quick laying or repair of tiled finishes in places such as swimming pools, refrigeration units, industrial plants (breweries, wine cellars, dairies etc.).
- Laying even large-sized ceramic and stone tiles on façades, balconies, terraces, and sun-roofs and patios which are subject to direct sunlight and thermal gradients.
- Laying tiles in areas subject to high mechanical stresses and vibration (railway underpasses, underground railway platforms, etc.).
- Laying tiles on concrete substrates and pre-cast walls.
- Laying large-format tiles on heated screeds or on top of existing floor coverings in ceramic, terrazzo, marble, etc.
- Laying tiles on surfaces waterproofed with **Mapelastic** or **Mapegum WPS**.
- Laying stone material which is sensitive to stains (white Carrara, etc.)

TECHNICAL CHARACTERISTICS

Megarapid 2K Plus is a two-component adhesive available in grey or white consisting of a special binder and selected silica sand (comp. A) and a synthetic latex rubber (comp. B).

When the two components are mixed together, a mortar with the following characteristics is obtained:

- Low viscosity, therefore easy to apply.

- Highly thixotropic: **Megarapid 2K Plus** may be applied on vertical surfaces without sagging, and even large-sized, heavy tiles do not slip. Tiles may be laid starting from the top of the surface without using spacers.
- The pot-life of the mix is particularly long compared with other fast-setting adhesives, making the laying operation easier even during the summer at high temperatures.
- Good capacity for accomodating deformation of the substrate and tiles (chipboard, marine plywood, concrete, etc.).
- Perfect bonding to all materials normally used in building.
- Thicknesses of up to 10 mm set without shrinkage and without a reduction in thickness, until a considerably high mechanical strength is reached.

Megarapid 2K Plus has high bonding strength after only 2 - 3 hours and, therefore, floor and wall coverings may be put into service very quickly.

RECOMMENDATIONS

Do not use **Megarapid 2K Plus**:

- On metallic, rubber, PVC or linoleum surfaces.
- With marble or artificial materials which are subject to high levels of moisture movement (green marble, some types of slate and sandstone in the class C MAPEI dimensional stability standard). In this case, use **Keralastic, Keralastic T** or **Kerapoxy**.

Do not add water or component B to the mixture that has begun to set.

APPLICATION PROCEDURE

Preparing the substrate

The substrates must be flat, stable, mechanically strong, sufficiently dry and free from loose or crumbly parts, grease, oil, paint, and wax, etc. Damp substrates may slow down the setting of **Megarapid 2K Plus.**
Cementitious substrates must not be subject to shrinkage after laying the tiles and therefore, during good weather, the substrates must be cured for at least 1 week per centimetre of thickness. Cementitious screeds must be cured for at least 28 days, unless they are made using a MAPEI special binder for screeds such as **Mapecem**, **Mapecem Pronto, Topcem** or **Topcem Pronto**.
Dampen with water to cool down surfaces which are too hot due to exposure to direct sunlight. Gypsum substrates and anhydrite screeds must be perfectly dry (max. residual moisture 0.5 %), sufficiently hard and free of dust. They must be treated with **Primer G** or **Primer FR**, while areas subject to high humidity must be treated with **Primer S**. In general, refer to the relative MAPEI technical documentation regarding substrate preparation before repairing cracks in substrates, consolidating rapid-drying screeds and levelling installation surfaces.

Preparing of the mix

Mix 20 kg of component A (cementitious powder) with 5 kg of component B (synthetic latex rubber). It is best to use a low-speed mechanical mixer to obtain a smooth, homogenous paste by pouring the powder (component A) into the latex (component B). The pot life is approximately 60 - 75 minutes at +20°C, but higher temperatures may reduce this time considerably. Compared to other fast-setting adhesives, however, the longer open time of **Megarapid 2K Plus** means that it is easier to lay tiles even during hot weather.

Applying the mix

Apply **Megarapid 2K Plus** on the substrate with a notched trowel. Use a trowel which guarantees that the adhesive is spread well on the back of the tile.
To achieve a good bond, first spread a thin layer of **Megarapid 2K Plus** on the substrate using the smooth side of the trowel, and then immediately apply another layer to the thickness required with a notched trowel according to the type and size of the tile. For pieces of mosaic up to 5 x 5 cm, use a MAPEI No. 4 or 5 trowel (consumption 2.5 - 3 kg/m²).
For normal ceramic coverings, a MAPEI No. 5 trowel with a rhomboid notch is recommended (consumption 3.5 - 4 kg/m²).
For uneven floors or surfaces or tiles with a ribbed back, a MAPEI No. 6 trowel with a rhomboid notch is recommended (consumption 5 - 6 kg/m²).
For very uneven surfaces or with large tiles and tiles with large ribs on the back, a MAPEI No. 10 trowel with a square notch is recommended (consumption 8 kg/m²).
For laying ceramic or natural stone on floors externally, tiles with a dovetail or knobbled back, tiles larger than 900 cm², floor coverings to be polished on site or subject to heavy loads or for swimming pools and water basins, spread the adhesive also on the back of the tile to guarantee full contact.

Laying the tiles

It is not necessary to wet the tiles before laying them. Only when the backs are very dusty it is advisable to dip the tiles in clean water. The tiles must be laid by pressing them down firmly to ensure a good contact with the adhesive. Under normal climatic conditions, the open time of **Megarapid 2K Plus** is approximately 30 minutes.
Under unfavourable weather conditions (strong, direct sunlight, wind, high temperature and low R.H.), or if the substrate is very absorbent, the open time may be reduced to only a few minutes. Wetting the substrate before applying the adhesive helps to increase the open time. Check constantly to make sure that the adhesive does not form a surface skin and that it is still fresh. If a surface skin forms, re-spread the adhesive with a notched trowel. Do not wet the adhesive if a surface skin forms. Instead of dissolving the skin, a nonadhesive skin will form. Surfaces tiled with **Megarapid 2K Plus** must not be washed down or exposed to rain for at least 3 - 4 hours and must be protected from strong, direct sunlight for at least 12 hours.

GROUTING AND SEALING

The joints between the tiles may be grouted after 3 hours with a suitable MAPEI cementitious or epoxy grout, which is available in a variety of colours. Expansion joints must be sealed with a suitable MAPEI sealant.

POLISHING

The surfaces may be polished after 24 hours.

SET TO LIGHT FOOT TRAFFIC

Floors are set to light foot traffic after 3 - 4 hours.

READY FOR USE

The surfaces are ready for use after approximately 24 hours. Basins and swimming pools can be filled after 3 days.

CLEANING

Tools may be cleaned with clean water before the adhesive sets. Once set, cleaning becomes very difficult, but the use of a solvent such as white spirits or a similar product usually helps.

CONSUMPTION

- Mosaics and small-sized tiles (trowel No. 4): 2.5 - 3 kg/m²
- Normal-sized tiles (trowel No. 5): 3.5 - 4 kg/m²
- Large tiles and external floors (trowel No. 6): 5 - 6 kg/m²
- Uneven back faces and substrates, natural stone (trowel No. 10): 8 kg/m² or more

PACKAGING

Megarapid 2K Plus is available in grey colour.
Megarapid 2K Plus: 25 kg kit, comprising:
- Component A: 20 kg bag
- Component B: 5 kg drum

STORAGE

Megarapid 2K Plus component A may be stored for up to 12 months in its original packaging in a dry place.
Megarapid 2K Plus component B may be stored for up to 24 months. Protect from frost.

SAFETY INSTRUCTIONS FOR PREPARATION AND INSTALLATION

Instructions for the safe use of our products can be found on the latest version of the SDS available from our website **www.mapei.no**

PRODUCT FOR PROFESSIONAL USE.

TECHNICAL DATA (typical values)

In compliance with the norms: EN 12004, such as C2FTES2 – ISO 13007-1 such as C2FTES2

PRODUCT IDENTITY COMPONENT A	
Consistency:	grey or white powder
Bulk density:	1.250 kg/m³
Dry solids content:	100 %

MAPEI

PRODUCT IDENTITY COMPONENT B	
Consistency:	liquid
Colour:	white
Density:	1.035 g/cm³
pH:	7.5
Dry solids content:	31 %

APPLICATION DATA (at +23°C and 50 % R.H.)	
Mixing ratio:	component A: 20 kg + component B: 5 kg
Consistency of mix:	thick paste
Density of mix:	1.650 kg/m³
pH of mix:	approx. 11
Application temperature range:	from +5°C to +30°C
Pot life:	60 - 75 minutes
Open time (according to EN 1346):	≥ 30 minutes
Setting time:	120 - 150 minutes
Time to grouting:	after 3 hours
Set to light foot traffic:	after 3 hours
Ready for use:	after 24 hours (3 days for swimming pools and basins)

FINAL PERFORMANCES	
Bonding strength according to EN 1348: **- initial (after 28 days):** **- after heat ageing:** **- after immersion in water:** **- after freeze/thaw cycles:**	 2.5 N/mm² 2.5 N/mm² 1.5 N/mm² 1.8 N/mm²
Flexural strength - after 28 days:	6.0 - 7.0 N/mm²
Compressive strength - after 28 days	17.0 - 18.0 N/mm²
Resistance to acids:	poor
Resistance to alkalis:	excellent
Resistance to oil:	excellent
Resistance to solvents:	excellent
Service temperature range:	from -30°C to +90°C
Deformability according to EN 12002:	S2 - highly deformable

WARNING

Although the technical details and recommendations contained in this product data sheet correspond to the best of our knowledge and experience, all the above - information must, in every case, be taken as merely indicative and subject to confirmation after long-term practical application: for this reason, anyone who intends to use the product must ensure beforehand that it is suitable for the envisaged application: in every case, the user alone is fully responsible for any consequences deriving from the use of the product.

Please refer to the current version of the technical data sheet, available from our web site www.mapei.no

LEGAL NOTICE

The contents of this Technical Data Sheet ("TDS") may be copied into another project-related document, but the resulting document shall not supplement or replace requirements per the TDS in effect at the time of the MAPEI produc installation. For the most up-to-date TDS and warranty information, please visit our website at www.mapei.no

ANY ALTERATIONS TO THE WORDING OR REQUIREMENTS CONTAINED IN OR DERIVED FROM THIS TDS SHALL VOID ALL RELATED MAPEI WARRANTIES.

10204-1-2023-gb

MAPEI

CLASSIFICATION ACCORDING TO EN 12004

Ultrabond Eco PU 2K is an R2T class reactive (R) improved (2) slip-resistant (T) adhesive.

*Conformity of **Ultrabond Eco PU 2K** is declared in **TT** certificates **n° 15/10709-1380** and **n° 15/10709-1380-S** issued by LGAI Technological Center S.A. of Bellaterra - Barcelona (Spain).*

WHERE TO USE

Bonding ceramic tiles, stone tiles and mosaics on all types of internal and external wall and floor substrates normally used in the building industry such as screeds, render, concrete, cement-fibre panels, gypsum, plaster-board, pre-fabricated gypsum panels, etc. and on particularly difficult substrates such as metal, PVC, polyester, etc.

Some application examples

- Bonding all types of ceramic tile, stone tile and mosaic in showers and on sheet steel used to make prefabricated bathrooms.
- Bonding of ceramic tiles, natural stone or mosaic on on floors in elevators.
- Bonding ceramic and mosaic on wooden work surfaces and kitchen tops.
- Bonding ceramic tiles, stone tiles and mosaics on external balconies and terraces, accessible flat roofs and domed roofs.
- Bonding recomposed and natural stone, including materials subjected to large movements and dimensional variations in contact with water (class C according to MAPEI internal standards, such as Green Alpine).
- Bonding ceramic and stone tiles on substrates subjected to high vibrations and deformation.

TECHNICAL CHARACTERISTICS

Ultrabond Eco PU 2K is a two-component, solvent and water-free, elastic, waterproof adhesive with very low emission level of volatile organic compounds (EMICODE EC1 Plus) made up of a polyurethane base (component A) and a special catalyser (component B).

When the two components are mixed together they form a paste with the following characteristics:

- good workability;
- excellent durability and resistance to ageing;
- perfect adhesion to all types of substrate normally used in the building industry;
- hardens by chemical reaction without shrinking to form a tough, strong bond;
- high elasticity;
- may be applied on vertical surfaces without slumping and without allowing tiles to slip, including large, heavy tiles;
- suitable for users allergic to epoxy and epoxy-polyurethane products.

The slip-resistance of the product complies with EN 12004 standards.

RECOMMENDATIONS

- Do not use on damp surfaces or if there is a risk of capillary-action rising damp.

Ultrabond Eco PU 2K

TECHNICAL DATA (typical values)		
Compliant to the standard:	– Euronorm EN 12004 (R2T) – ISO 13007-1 (R2T)	
PRODUCT IDENTITY		
	component A	**component B**
Consistency:	thixotropic paste	liquid
Colour:	grey/white	dark
Density (g/cm³):	1.6	1.2
Dry solids content (%):	100	100
Brookfield viscosity (mPa·s):	6,000,000 (rotor F - 1 rpm)	150 (rotor 1 - 100 rpm)
EMICODE:	EC1 Plus - very low emission	
APPLICATION DATA (at +23 °C and 50% R.H.)		
Mixing ratio in weight:	88/12	
Consistency of mix:	thixotropic	paste
Density of mix (g/cm³):	1.5	
Brookfield viscosity (mPa·s):	2,500,000 (rotor F - 1 rpm)	
Pot life of mix:	30 - 40 minutes	
Application temperature:	+5 °C and +30 °C	
Open time (EN 1346):	20 minutes	
Adjustment time:	70 minutes	
Setting time: **– start:** **– finish:**	 4,5 hours 7 hours	
Set to foot traffic:	12 hours	
Ready for service:	7 days	
FINAL PERFORMANCE		
Adhesion according to EN 12003 (N/mm²): **– initial adhesion:** **– adhesion after immersion in water:** **– adhesion after thermal shock:**	 > 2 > 2 > 2	
Resistance to ageing:	high	
Resistance to solvents and oil:	good	
Resistance to acids and alkalis:	good	
Resistance to temperatures:	-40 °C to +100 °C	
Deformability:	good	
CERTIFICATES AND CLASSIFICATION		
Ris. IMO 61 (67) FTCP - Ann. 1, part 2 and 5:	low flames spread characteristics	

- The kits are pre-dosed to prevent mixing errors. Do not use partial quantities of the product and do not guess the amounts to be mixed: hardening will be affected if the two components are not mixed together correctly.
- The components must be mixed together at a temperature of between +5°C and +30 °C.
- Contact MAPEI Technical Services before using the product for surfaces permanently immersed in water.
- Do not use **Ultrabond Eco PU 2K** to bond transparent glass.

APPLICATION PROCEDURE

Substrate preparation

Substrates must be well cured, strong, free of loose portions, grease, oil, paint, wax etc. and sufficiently dry.
Cementitious substrates must not shrink after bonding tiles. In good weather, therefore, render must be cured for at least one week per cm of thickness and cementitious screeds must be cured for at least 28 days, unless they are made using a special MAPEI ready-mixed screed binder such as **Mapecem**, **Mapecem Pronto**, **Topcem** or **Topcem Pronto**.
Metallic substrates must be sandblasted to remove all traces of rust.
For gypsum and anhydrite we recommend consolidating the surface by applying a coat of **Primer EP** or **Primer MF**.

Preparation of the mix

Ultrabond Eco PU 2K is supplied in two pre-dosed tubs:
- component A: grey or white colour, 88 parts in weight;
- component B: dark colour, 12 parts in weight.

The mixing ratio between the resin (component A) and catalyser (component B) must be strictly adhered to; any variation may affect the hardening process of the product.
Pour the catalyser (component B) into the container of component A and blend together with a mixer at low-speed to form a smooth, even grey or white paste.
A low speed electric mixer is preferable for this operation so that the paste is perfectly blended without overheating, which would reduce its workability time. Apply the adhesive within 30-40 minutes of mixing.

Spreading the mix

Apply an even layer of **Ultrabond Eco PU 2K** on the substrate with a notched spreader. Use a spreader that allows at least 65-70% of the back of the tiles to be wetted (see "Consumption" section).
When bonding tiles on external surfaces make sure the back of the tiles is completely wetted.
When the adhesive is used to both waterproof the surface and bond tiles, such as when bonding tiles on wooden kitchen tops, apply an even layer of **Ultrabond Eco PU 2K** around 1 mm thick with a smooth spreader to waterproof the surface, then apply a second layer of **Ultrabond Eco PU 2K** with a notched spreader when the first layer has hardened (within 24 hours).

Bonding tiles

Tiles must always be dry when they are bonded.
Press the tiles down well to ensure they are in contact with the adhesive and that the back of the tiles are wetted. If the layer of wet **Ultrabond Eco PU 2K** also acts as a waterproofing layer, make sure the ribs on the back of the tiles do not penetrate completely through the adhesive.
When using **Ultrabond Eco PU 2K** to bond tiles on deformable substrates, tiles larger than 5x5 cm must be positioned so they have large gaps between them.
In normal conditions (temperature and humidity level) the open time of **Ultrabond Eco PU 2K** is approximately 20 minutes.
Final adjustment of the tiles must be carried out within 70 minutes of bonding.
The setting time of the adhesive depends on the surrounding temperature (see following table).
Setting time of **Ultrabond Eco PU 2K** according to surrounding temperature:

Temperature in °C	30	25	20	15	10
Time in hours	2	4	5	7	10

GROUTING AND SEALING

Grout the gaps between the tiles after 12 hours using a suitable cementitious or epoxy MAPEI grouting mortar, available in a wide range of colours.
Seal expansion joints using a suitable MAPEI sealant.

SET TO FOOT TRAFFIC

Floors set to foot traffic after 12 hours.

READY FOR USE

Surfaces are ready for use after 7 days.

Cleaning

Ultrabond Eco PU 2K is easy to remove from tools, buckets and clothing before it hardens with alcohol.
Once hardened **Ultrabond Eco PU 2K** must be removed mechanically or with **Pulicol 2000**.

CONSUMPTION

Bonding ceramic and stone:
- mosaics and small tiles (No. 4 spreader): 2.5 kg/m²;
- normal size tiles (N° 5 spreader): 3.5 kg/m²;
- large tiles, marble and stone (double-buttering technique): 5 kg/m².

PACKAGING

Ultrabond Eco PU 2K is supplied in twin metal tubs comprising:
- 10 kg kits (8.8 kg component A + 1.2 kg component B).
- 5 kg total weight (4.4 kg component A + 0.6 kg component B).

Ultrabond Eco PU 2K

STORAGE

Ultrabond Eco PU 2K remains stable for at least 12 months if the tubs are sealed. Component B (catalyser) must be stored in a warm area to prevent it crystallising at cold temperatures (minimum +10 °C). If the catalyser crystallises it must be warmed up before use.

SAFETY INSTRUCTIONS FOR PREPARATION AND APPLICATION

For further information about the safe use of our product, please refer to the latest version of our Material Safety Data Sheet, to be found on our website, www.mapei.no

PRODUCT FOR PROFESSIONAL USE.

WARNING

Although the technical details and recommendations contained in this product data sheet correspond to the best of our knowledge and experience, all the above information must, in every case, be taken as merely indicative and subject to confirmation after long-term practical application; for this reason, anyone who intends to use the the product must ensure beforehand that it is suitable for the envisaged application. In every case, the user alone is fully responsible for any consequences deriving from the use of the product.

Please refer to the current version of the Technical Data Sheet, available from our website www.mapei.no

LEGAL NOTICE

The contents of this Technical Data Sheet ("TDS") may be copied into another project-related document, but the resulting document shall not supplement or replace requirements per the TDS in force at the time of the MAPEI product installation.
The most up-to-date TDS can be downloaded from our website www.mapei.no
ANY ALTERATION TO THE WORDING OR REQUIREMENTS CONTAINED OR DERIVED FROM THIS TDS EXCLUDES THE RESPONSIBILITY OF MAPEI.

This symbol is a conformity mark which prove that the product is suitable for marine equipment in compliance with **the Marine Equipment Directive (MED) 96/98/EC** and subsequent amendments. For the products with this marking, MAPEI is also allowed to affix the U.S Coast Guard approval number **as allowed by the "Agreement between the European Community and the United States of America on mutual recognition of certificates of conformity for marine equipment" signed February 27th, 2004.**

GEV-EMICODE EC 1 PLUS very low emission

This symbol is used to identify Mapei products which give off a low level of volatile organic compounds (VOC) as certified by GEV (Gemeinschaft Emissionskontrollierte Verlegewerkstoffe, Klebstoffe und Bauprodukte e.V.), an international organisation for controlling the level of emissions from products used for floors.

All relevant references for the product are available upon request and from www.mapei.no

2719-5-2021 (GB-NO)

MAPEI
BUILDING THE FUTURE

KLASSIFISERT I SAMSVAR MED EN 13888
Megafug G forbedret, sementbasert fugemasse som spesifisert for klasse CG2WA.

BRUKSOMRÅDE
Innendørs og utendørs fuging av gulv og vegger belagt med keramisk flis (enkelt brent, dobbelt brent, klinker, porcelenatoflis etc.), terrakotta og steinmaterialer (naturstein, marmor, granitt og andre steinsorter).

Eksempler på bruk
- Fuging av fasader, balkonger, terrasser og svømmebasseng.
- Fuging av gulv som skal ha et rustikk uttrykk (terrakotta, glassert porselen, antikk marmor, klinkerfliser og enkeltbrent flis).
- Fuging av keramiske fliser på gulv og vegger innendørs.
- Fuging av keramisk flis i industrigulv, der det ikke stilles krav om kjemikaliebestandighet for fugemassen (garasjer, lager, osv.).

TEKNISKE OPPLYSNINGER
Megafug G er sammensatt av sement, velgradert sand, syntetiske polymerer, utvalgte tilsetningsstoffer og pigmenter.

Følgende egenskaper oppnås når produktet blandes med rett mengde vann og påføres på riktig måte:

- god trykkfasthet, bøyestrekkfasthet og god motstand mot fryse/tine sykler, noe som medfører god bestandighet;
- god slitestyrke;
- lavt svinn og derfor ingen opprissing eller oppsprekking;
- god bestandighet mot syrer med pH > 3;
- lavt kostnad - kvalitet forhold.

Megafug G kan blandes med et spesielt syntetisk polymerprodukt, **Fugolastic**, for å oppnå tilstrekkelige forbedringer på viktige egenskaper under tøffe belastninger (fuging av fasader, svømmebasseng, bad og gulv med tyngre belastninger).
For mer informasjon henvises til teknisk datablad for **Fugolastic**.

ANBEFALINGER
- Bland aldri **Megafug G** med sement eller andre produkter. Tilsett aldri vann til en blanding som har begynt å binde av.
- Bruk aldri saltvann eller skittent vann til blanding av **Megafug G**.
- Bruk produktet ved temperaturer mellom +5ºC og +35ºC.

Megafug G

- Mål opp vannmengden nøyaktig. Overforbruk av vann kan medføre at man får en hvitaktig utfelling i overflaten (saltutslag). Hvis det brukes ulike vannmengder i forskjellige blandinger, vil dette medføre fargeforskjeller. Utfellinger i overflaten skyldes dannelsen av kalsiumkarbonat og kan også forårskes av overskudd på fuktighet i limet, ikke gjennomherdet fugemasse, ikke uttørket underlag eller underlag som ikke er beskyttet med diffusjonssperre.
- Etter fuging skal det ikke strøs tørt **Megafug G** pulver over flaten, da dette kan skape fargeskjolder.
- Når det stilles krav til bestandighet mot syrer eller i områder med strenge hygienekrav, skal det brukes spesielle produkter for dette (f.eks. **Kerapoxy**).
- Bruk ikke **Megafug G** til fuging av ekspansjonsfuger eller fuger med bevegelse. Bruk en egnet elastisk fugemasse fra MAPEI.
- Noen keramiske fliser og naturstein har røffe overflater med mikroriss og en porøsitet som medfører at vasking er vanskelig. Gjør en test på vaskbarhet og om nødvendig beskytt flisens overflate før fuging – sørg for at slik beskyttelse ikke kommer ned i fugene.

RETNINGSLINJER FOR BRUK

Klargjøring av fugene

Vent med fuging til limmørtelen er gjennomherdet. Herdetid for limmørtel framgår av produktdatablad for det aktuelle produkt. Fugene skal være rene, fri for støv og minst 2/3 av tykkelsen på flisen skal kunne fuges med **Megafug G**. Overskytende lim eller mørtel bør fjernes før det herder. Dersom det arbeides med porøse keramiske fliser i varmt vær og når det er vind, sørg for at fugene blir forfuktet med rent vann.

Blanding

Hell riktig vannmengde (18-20 vekt-%) eller **Fugolastic** (hvis det er krav om det) i en ren beholder og tilsett **Megafug G** pulver under omrøring. Ved fuging av gulv kan massen blandes tynnere ved å tilsette inntil 24 vekt-% vann.Det anbefales at blanding skjer med en langsomtgående blandemaskin/drill med visp for å unngå at det dannes mye luft i massen.Bland til massen har jevn konsitens. La massen stå å trekke i 2-3 minutter – rør deretter opp massen. Massen er nå klar for bruk.

Bruk massen innen 2 timer etter blanding.

Fuging

Fyll fugene godt med **Megafug G**. Bruk et egnet MAPEI brett eller en gumminal. Sørg for at fugene blir godt kompaktert og uten ujevnheter. Fjern overflødig **Megafug G** fra overflaten ved å bevege brettet/gumminalen diagonalt over fugene mens massen ennå er fersk.

Sluttbearbeiding

Vask bort overskytende **Megafug G** fra overflaten med en fuktig hard svamp (f.eks. en MAPEI svamp) straks fugemassen mister sin plastisitet og blir jevn i fargen, vanligvis etter 10-20 minutter. Arbeid alltid diagonalt på fugeretningen. Vask av svampen med jevne mellomrom og bruk to bøtter vann; en for å vaske av overskytende fugemasse fra svampen og den andre med rent vann for å skylle svampen. Dette kan også utføres maskinelt eller med et svampbrett. For å fjerne herdet fugemasse fra fliser kan man bruke en fuktig Scotch-Brite® svamp eller maskinelt utstyr med en grovfibret skive. Hvis det vaskes for tidlig (mens fugemassen fortsatt er plastisk) kan fugene bli delvis tømt for fugemasse og det kan bli store fargeforskjeller. På den annen side dersom fugemassen herder på overflaten må det brukes mekanisk utstyr for å fjerne overskytende masse – dette kan skade flisenes overflate. Når **Megafug G** påføres ved ekstremt høye temperaturer eller dersom det er sterk vind, anbefales det å etterfukte fugene i flere timer. Tilførsel av fuktighet til **Megafug G** i herdefasen vil alltid bidra til bedre sluttegenskaper. Sluttrengjøring for å fjerne et mulig pulverslør av **Megafug G** fra overflaten kan utføres med en tørr ren klut. Hvis overflaten etter sluttrengjøringen fortsatt er tilsølt med **Megafug G** på grunn av dårlig utført arbeid, kan det brukes et syrebasert rensemiddel (f.eks. **Megarens**), men ikke før fugemassen har herdet i 10 døgn – følg instruksjonene nøye. Bruk **Megarens** bare på fliser som er syrebestandige og aldri på fliser av marmor eller kalkstein.

GANGBAR

Gulv kan belastes med lett gangtrafikk etter ca. 24 timer.

FULLT BELASTBAR

Gulv er klare for tyngre belastninger etter 7 døgn. Basseng kan fylles opp etter 7 døgn.

Rengjøring

Redskaper og blandekar kan vaskes med vann før **Megafug G** herder.

FORBRUK

Forbruket av **Megafug G** varierer avhengig av fugebredden og flisenes dimensjoner. Noen forbrukseksempler i kg/m² er vist i tabellen.

EMBALLASJE

20 kg sekker, esker à 8x2 kg Alupack, avhengig av farge.

FARGER

Megafug G leveres i 9 farger som angitt i MAPEIs fargekart. Se fargeprøver.

LAGRING

Megafug G kan lagres i 12 måneder på et tørt sted i originalemballasje. 24 måneder for Alupack.

Produktet er i samsvar med kravene i Annex XVII av regulativet (EC) No 1907/2006 (REACH), punkt 47.

TEKNISKE DATA (typiske verdier) I samsvar med:	– European EN 13888 as CG2WA
PRODUKT IDENTITET	
Type:	grovt pulver
Farge:	9 farger fra MAPEIs fargeutvalg
Romtetthet (kg/m³):	1300-1500
Tørrstoffinnhold (%):	100
BRUKSEGENSKAPER (ved +23°C og 50% R.H.)	
Blandingsforhold:	100 deler **Megafug G** med 18-20 vektdeler vann
Konsistens:	tynn pasta
Blandingstetthet (kg/m³):	2000
Blandingens pH:	ca. 13
Pot life:	ca. 2 timer
Brukstemperatur:	fra +5°C til +35°C
Fuging etter flis setting: – vegg med normalt herdende lim 4-8 timer: – vegg med hurtigherdende lim 1-2 timer: – vegg med tykt mørtelunderlag 2-3 dager: – gulv med normalt herdende lim 24 timer: – gulv med hurtigherdene lim 3-4 timer: – gulv med tykt mørtelunderlag:	 4-8 timer 1-2 timer 2-3 døgn 24 timer 3-4 timer 7-10 døgn
Tid før sluttbehandling kan starte:	10-20 minutter
Gangbar:	24 timer
Gjennomherding:	7 døgn
PRODUKT EGENSKAPER	
Bøyestrekkfasthet etter 28 dager (EN 12808-3): Trykkfasthet etter 28 dager (EN 12808-3): Bøyestrekkfasthet etter fryse/tine syklus (EN 12808-3): Trykkfasthet etter fryse/tine syklus (EN 12808-3): Slitasjemotstand (EN 12808-2): Svinn (EN 12808-4): Vannopptak etter 30' (EN 12808-5): Vannopptak etter 4 timer (EN 12808-5):	I samsvar med den Europeiske normen EN 13888 som CG2WA
FUktbestandighet:	utmerket
Aldringsbestandighet:	utmerket
Bestandighet overfor løsemidler, oljer og alkalier:	utmerket
Syrebestandighet:	god dersom pH > 3
Temperaturbestandighet:	fra –30°C til +80°C

Megafug G

FORBRUKSTABELL ETTER FLIS-STØRRELSE OG FUGEBREDDE ((kg/m²)

Flis-størrelse (mm)	Fugebredde (mm)			
	3	5	8	10
75 x 150 x 6	1,0			
100 x 100 x 6	1,0			
100 x 100 x 10	1,6			
100 x 200 x 6	0,8			
100 x 200 x 10	1,2	2,0	2,4	
150 x 150 x 6	0,7			
200 x 200 x 8	0,7			
120 x 240 x 12	1,2	2,0	2,4	
250 x 250 x 12	0,8	1,3	1,6	
250 x 250 x 20	1,3	2,1	2,6	3,9
250 x 330 x 8	0,5	0,8	0,9	
300 x 300 x 8	0,5	0,7	0,9	
300 x 300 x 10	0,6	0,9	1,1	
300 x 300 x 20	1,1	1,7	2,2	3,2
300 x 600 x 10	0,4	0,7	0,8	
330 x 330 x 10	0,5	0,8	1,0	
400 x 400 x 10	0,4	0,7	0,8	
450 x 450 x 12	0,5	0,7	0,9	
500 x 500 x 12	0,4	0,6	0,8	
600 x 600 x 12	0,4	0,5	0,7	

FORBRUKSBEREGNING:

$$\frac{(A + B)}{(A \times B)} \times C \times D \times 1{,}6 = \frac{kg}{m^2}$$

A = flisens lengde (i mm) **C** = flisens tykkelse (i mm)
B = flisens bredde (i mm) **D** = fugens bredde (i mm)

SIKKERHETSINSTRUKSJONER FOR BLANDING OG PÅFØRING

Megafug G Megafug G inneholder sement som i kontakt med svette eller andre kroppsvæsker forårsaker en irriterende alkalisk og allergisk reaksjon hos de som er følsomme for slike produkter.
Produktet kan forårsake øyeskade.

Vi anbefaler å bruke vernehansker og vernebriller, samt ta vanlige forhåndsregler ved bruk av kjemikalier.
Hvis produktet kommer i kontakt med øyene eller hud, skyll umiddelbart med store mengder vann og søk legehjelp.
For mer utfyllende informasjon vedrørende sikker håndtering av våre produkter, vennligst se vår siste utgave av sikkerhetsdatablad for produktene.

PRODUKT FOR PROFESSJONELT BRUK.

MERK

De tekniske anbefalinger og detaljer som fremkommer i denne produktbeskrivelse representerer vår nåværende kunnskap og erfaring om produktet. All ovenstående informasjon må likevel bli betraktet som retningsgivende og gjenstand for vurdering. Enhver som benytter produktet må på forhånd forsikre seg om at produktet er egnet for tilsiktet anvendelse. Brukeren står selv ansvarlig dersom produktet blir benyttet til andre formål enn anbefalt, eller ved feilaktig utførelse.

Vennligst referer til siste oppdaterte versjon av teknisk datablad som finnes tilgjengelig på vår webside www.mapei.no

Dette symbolet brukes til å identifisere MAPEI-produkter med lave utslipp av flyktige organiske forbindelser som er sertifisert av GEV (Gemeinschaft Emissionskontrollierte Verlegewerkstoffe, Klebstoffe und Bauprodukte e.V), en internasjonal organisasjon som overvåker utslipp fra gulvprodukter.

Vår forpliktelse til miljøet
MAPEI`s produkter bidrar til at arkitekter og entreprenører kan utvikle LEED sertifiserte prosjekter, i samsvar med U.S Green Building Council.

Alle referanser for produktet er tilgjengelige på forespørsel og på vår hjemmeside www.mapei.no

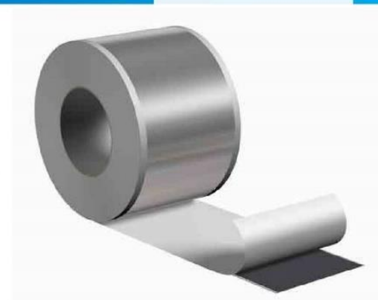
2815-5-2015 (N)

MAPEI
BUILDING THE FUTURE

Litex Skjøtebånd Selvklebende

Datablad 006
22.05.2013

Side 1 av 2



Selvklebende butyl forseglingsbånd beskyttet med aluminiumsfilm.

Produktbeskrivelse
Litex Skjøtebånd Selvklebende er et damptett, selvklebende bånd av butylgummiblanding forsterket med polyester/aluminium.
Litex Skjøtebånd Selvklebende kan lime til de fleste glatte overflater. Aluminium/polyesterfilmen gjør båndet aldringsbestandig og motstandsdyktig mot oksidering forårsaket av atmosfæriske og kjemiske faktorer.

Produktspesifikasjoner
- Vanntett
- Gode limegenskaper ved lave temperaturer
- Stabil etter applikasjon i temperaturområdet - 40 °C / + 100 °C.
- Ingen oljemigrering
- Kan overmales
- Motstandsdyktig mot
- aldring, rift og UV stråler
- Ingen løsemidler
- Damptett

Bruksområder
Forsegling av skjøter, gjennomføringer og overganger på Litex Membranplater.

Underlag
Litex Membranplater. Vil også lime og forsegle materialer som glass, stål, pleksiglass, polykarbonat, treverk, aluminium, PVC og andre vanlige byggematerialer.
Overflaten skal være tørr, ren, glatt og støvfri. På sementbaserte overflater eller andre overflater med kappelærvandring av vann skal det ikke benyttes Litex Skjøtebånd Selvklebende.

Påføring
Rull ut skjøtebåndet i ønsket lengde og skjær til. Fjern silikonfilmen som dekker limsiden og press båndet ned med for eksempel en gummirulle. Båndet må jobbes godt med og rulles over både i horisontal og vertikal retning. Til dette benyttes Litex Rillet Rulle.
Dersom det er mye støv i rommet, kan det gi problemer med heft. En klut fuktet med ufortynnet primer kan da strykes over skjøten før montering av skjøtebåndet.
Primeren har en tørketid på 10-15 minutter før montering av Litex Skjøtebånd Selvklebende.

Etterbehandling
Flislegging og fuging.
Det er ingen spesielle krav til flislimet eller fugemasser som benyttes sammen med Litex Våtromsystem.

Lagring
Kvaliteten og karakteristikkene til materialet forblir uendret over lang tid. Produktet er best dersom det benyttes innen 12 måneder fra produksjonsdato. Produktet må lagres korrekt på et kaldt og tørt sted. Optimalt mellom + 5 °C til + 30 °C.
Litex Skjøtebånd Selvklebende tåler kulde.

Dimensjoner og forpakninger:
Lengde 10 meter
Bredde: 10 cm
Tykkelse: 0,8 mm
Rullene er individuelt pakket i krympeplast i esker à 12 ruller.

Merknader
Det er ingen risiko knyttet til Litex Skjøtebånd Selvklebende ved normal bruk.
Holdes utilgjengelig for barn.

Dokumenter
HMS-datablad
FDV-dokument

Litex AS
Postboks 1073, 3204 Sandefjord
Telefon 33 48 99 70

TB Board

Datablad 001
11.09.2013

Lett byggeplate som underlag for flis.

Side 1 av 2

Produktbeskrivelse
TB Board er en lett byggeplate av XPS (ekstrudert polystyren) belagt på begge sider med armering og en tynn sement.

TB Board leveres i følgende dimensjoner:
1220 mm x 600 mm (lengde x bredde) Tykkelse: **6 mm.**

2440 mm x 600 mm (lengde x bredde)
Tykkelser: 12 mm, 20 mm, 30 mm og 50 mm

Areal pr plate: 0,732 m^2 (6mm)
Areal pr plate: 1,464 m^2 (12, 20, 30, 50 mm)

Produktspesifikasjon
Base: Plate i ekstrudert polystyren (XPS). Produsert uten bruk av CFC/HFC-gasser. Kjernematerialet produseres ikke av resirkulert råvare/plastmateriale og CO_2

Brannklasse: Kjernematerialet av XPS er klassifisert i klasse E iht. test ifølge GB/T10801.2-2002. Egenskaper ved brannpåvirkning for TB Board uten tildekning er ikke bestemt; Klasse F iht. NS-EN 13501-1. Med tildekning av keramiske fliser tilfredsstiller overflaten brannteknisk klasse In1 iht. NS3919

Bruksområder
TB Board er ideell som underlag for flis på vegg og gulv utenfor våtrom.

TB Board kan benyttes som underlag for flis på vegg i våtrom. Ved slik bruk må krav til våtsoner og damptetthet ivaretas.

I tillegg kan platen benyttes til innbygginger, bygge konstruksjoner og baderomsinnredning.

Underlag
TB Board kan monteres på tre, metall- og trestenderverk, spon, gips, finer, mur, klinkerpuss, betong, støp og gulvavrettning. Underlaget bør være tørt. Ved montering på gulv må underlaget være stabilt.

Montering på vegg
Minimum TB Board 12 mm kan monteres på stenderverk med senteravstand på 30 cm.
Minimum TB Board 20 mm kan monteres på stenderverk med stenderavstand på 60 cm.
På fast underlag kan alle tykkelser (fra 6mm – 50 mm) av TB Board benyttes.
Platene skal festes i plateskjøtene med skruer og monteringsskiver. Det bør beregnes minst 5 mm klaring mot tak og tilstøtende vegg.

Skruelengder:
På heldekkende underlag:
Platetykkelse +underlag + ca 5 mm
På stenderverk: Platetykkelse + ca 25 mm.

Skrueavstand i skjøter på TB Board 12 mm, 20 mm og 30 mm er hhv 25 cm, 30 cm og 40 cm. Ved montering på stenderverk C/C 30 cm eller fast underlag bør 2-4 skruer med monteringsskive plasseres langs midten av platen. Ellers plasseres minst ett festepunkt for hvert horisontale spikerslag.

På montering på stålstendere benyttes nålespisskruer som er 5-10 mm lenger enn platetykkelsen. Skru med 25-30 cm avstand samt midt på platen på topp og bunnsvill.

Montering på mur og betong:
Alle tykkelser av TB Board kan benyttes på pusset eller upusset mur og betong.12 mm hellimes med flislim som trekkes ut med en tannsparkel eller strenger med Litex Monteringslim i avstand på ca 30 cm. Tykkere plater punktlimes med flislim eller Litex Monteringslim i 6-8 punkter pr kvm jevnt fordelt utover platen. All løs puss, maling, støv og tapet må fjernes før limingen av platene, og underlagets sugeevne skal kontrolleres.
Dersom det er tvil om flislimets heft til underlaget skal platene festes til veggen med 6-8 bolter pr kvm.

Montering på gulv
Alle tykkelser av TB Board kan monteres på gulv av betong eller et undergulv av bygningsplater med stivhet og konstruksjonsdetaljer iht. Byggforkseriens Byggedetaljer 522.861 og 541. 805. Platene festes med skrue og monteringsskive tilhørende våtromsystemet.

Utenfor våtrom kan platene flislegges direkte.

Ved bruk på gulv i våtrom må det monteres overliggende damptett membran.

Dampsperre:
TB Board tilfredsstiller ikke grenseverdien til vanndampmotstand i yttervegger og til vegger mot rom uten eller med begrenset oppvarming. (SD ≥ 10) F,eks. soverom må regnes som rom med begrenset oppvarming pga temperaturforskjell mellom bad og soverom.

Datablad 001
11.09.2013

TB Board

TB Board må derfor påføres et sjikt med membran på varm side for å tilfredsstille kravet til dampmotstand på Sd ≥ 10 m. For eksempel en påstrykningsmembran med dokumentert vanndampmotstand.

Eventuell plastfolie bak platene fjernes.

TB Board skal alltid flislegges eller dekkes med puss i tykkelse og mengde som tilfredsstiller krav til hardhet og brannhemming. Vannabsorpsjonstallet til flisene skal maksimalt være 20 % for vegg, 10 % for gulv og 6 % ved bruk av lavtbyggende gulvvarmesystem.

Etterbehandling
Flislegging og fuging.

Det er ingen spesielle krav til flislimet eller fugemasser som benyttes sammen med TB Board. På gulv bør platene overdekkes av støpemasse som tåler vann.

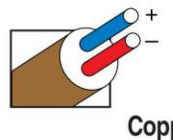
Lagring
TB Board bør lagres på tørt, plant underlag og beskyttes mot direkte sollys og regn.

Merknader
TB Board må ikke utsettes for løsemidler da det vil etse og skade platen.

Platene vil ikke avgi partikler, gassing eller stråling som gir negativ påvirkning på innemiljøet eller som har helsemessig betydning.

Dimensjon	Innhold pr. pakke			Innhold pr. pall					NOBB-nr.	NRF-nr.
	stk.	kg/pk. snitt	m^2	stk.	pk.	kg/pall snitt	Dimensjon l x b x h	m^3		
6 x 600 x 1220 mm	10	22,7	7,320	160	16	363,2	1240 x 1220 x 645 mm	0,976	45121466	6211684
12 x 600 x 2440 mm	5	23,3	7,320	80	16	372,8	2460 x 1220 x 620 mm	1,861	45121474	6211685
20 x 600 x 2440 mm	4	23,6	5,856	48	12	283,2	2460 x 1220 x 650 mm	1,951	45121493	6211686
30 x 600 x 2440 mm	4	25,2	5,856	48	12	302,4	2460 x 1220 x 860 mm	2,581	45121504	6211687
50 x 600 x 2440 mm	3	21,3	4,392	24	8	170,4	2460 x 1220 x 720 mm	2,161	45121512	6211688

Revised Thermocouple Reference Tables

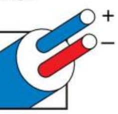


Thermocouple Grade

TYPE T

Reference Tables
N.I.S.T.
Monograph 175
Revised to
ITS-90

Copper vs. Copper-Nickel



Extension Grade

MAXIMUM TEMPERATURE RANGE
Thermocouple Grade
– 328 to 662°F
– 200 to 350°C
Extension Grade
– 76 to 212°F
– 60 to 100°C
LIMITS OF ERROR
(whichever is greater)
Standard: 1.0°C or 0.75% Above 0°C
1.0°C or 1.5% Below 0°C
Special: 0.5°C or 0.4%
COMMENTS, BARE WIRE ENVIRONMENT:
Mild Oxidizing, Reducing Vacuum or Insert; Good Where Moisture Is Present; Low Temperature and Cryogenic Applications
TEMPERATURE IN DEGREES °F
REFERENCE JUNCTION AT 32°F

Thermoelectric Voltage in Millivolts

°F	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	°F
-450							-6.258	-6.257	-6.256	-6.255	-6.254	-450
-440	-6.254	-6.253	-6.252	-6.251	-6.250	-6.248	-6.247	-6.245	-6.243	-6.242	-6.240	-440
-430	-6.240	-6.238	-6.236	-6.234	-6.232	-6.230	-6.227	-6.225	-6.222	-6.220	-6.217	-430
-420	-6.217	-6.215	-6.212	-6.209	-6.206	-6.203	-6.200	-6.197	-6.194	-6.191	-6.187	-420
-410	-6.187	-6.184	-6.180	-6.177	-6.173	-6.170	-6.166	-6.162	-6.158	-6.154	-6.150	-410
-400	-6.150	-6.146	-6.141	-6.137	-6.133	-6.128	-6.124	-6.119	-6.115	-6.110	-6.105	-400
-390	-6.105	-6.100	-6.095	-6.090	-6.085	-6.080	-6.075	-6.069	-6.064	-6.059	-6.053	-390
-380	-6.053	-6.047	-6.042	-6.036	-6.030	-6.025	-6.019	-6.013	-6.007	-6.001	-5.994	-380
-370	-5.994	-5.988	-5.982	-5.976	-5.969	-5.963	-5.956	-5.950	-5.943	-5.937	-5.930	-370
-360	-5.930	-5.923	-5.916	-5.909	-5.902	-5.896	-5.888	-5.881	-5.874	-5.867	-5.860	-360
-350	-5.860	-5.853	-5.845	-5.838	-5.830	-5.823	-5.815	-5.808	-5.800	-5.792	-5.785	-350
-340	-5.785	-5.777	-5.769	-5.761	-5.753	-5.745	-5.737	-5.729	-5.721	-5.713	-5.705	-340
-330	-5.705	-5.697	-5.688	-5.680	-5.672	-5.663	-5.655	-5.646	-5.638	-5.629	-5.620	-330
-320	-5.620	-5.612	-5.603	-5.594	-5.585	-5.577	-5.568	-5.559	-5.550	-5.541	-5.532	-320
-310	-5.532	-5.523	-5.513	-5.504	-5.495	-5.486	-5.476	-5.467	-5.458	-5.448	-5.439	-310
-300	-5.439	-5.429	-5.420	-5.410	-5.400	-5.391	-5.381	-5.371	-5.361	-5.351	-5.341	-300
-290	-5.341	-5.332	-5.322	-5.312	-5.301	-5.291	-5.281	-5.271	-5.261	-5.250	-5.240	-290
-280	-5.240	-5.230	-5.219	-5.209	-5.198	-5.188	-5.177	-5.167	-5.156	-5.145	-5.135	-280
-270	-5.135	-5.124	-5.113	-5.102	-5.091	-5.081	-5.070	-5.059	-5.048	-5.036	-5.025	-270
-260	-5.025	-5.014	-5.003	-4.992	-4.980	-4.969	-4.958	-4.946	-4.935	-4.923	-4.912	-260
-250	-4.912	-4.900	-4.889	-4.877	-4.865	-4.854	-4.842	-4.830	-4.818	-4.806	-4.794	-250
-240	-4.794	-4.783	-4.771	-4.759	-4.746	-4.734	-4.722	-4.710	-4.698	-4.685	-4.673	-240
-230	-4.673	-4.661	-4.648	-4.636	-4.624	-4.611	-4.599	-4.586	-4.573	-4.561	-4.548	-230
-220	-4.548	-4.535	-4.523	-4.510	-4.497	-4.484	-4.471	-4.458	-4.445	-4.432	-4.419	-220
-210	-4.419	-4.406	-4.393	-4.380	-4.366	-4.353	-4.340	-4.326	-4.313	-4.300	-4.286	-210
-200	-4.286	-4.273	-4.259	-4.246	-4.232	-4.218	-4.205	-4.191	-4.177	-4.163	-4.149	-200
-190	-4.149	-4.136	-4.122	-4.108	-4.094	-4.080	-4.066	-4.052	-4.037	-4.023	-4.009	-190
-180	-4.009	-3.995	-3.980	-3.966	-3.952	-3.937	-3.923	-3.908	-3.894	-3.879	-3.865	-180
-170	-3.865	-3.850	-3.836	-3.821	-3.806	-3.791	-3.777	-3.762	-3.747	-3.732	-3.717	-170
-160	-3.717	-3.702	-3.687	-3.672	-3.657	-3.642	-3.626	-3.611	-3.596	-3.581	-3.565	-160
-150	-3.565	-3.550	-3.535	-3.519	-3.504	-3.488	-3.473	-3.457	-3.441	-3.426	-3.410	-150
-140	-3.410	-3.394	-3.379	-3.363	-3.347	-3.331	-3.315	-3.299	-3.283	-3.267	-3.251	-140
-130	-3.251	-3.235	-3.219	-3.203	-3.187	-3.171	-3.154	-3.138	-3.122	-3.105	-3.089	-130
-120	-3.089	-3.072	-3.056	-3.040	-3.023	-3.006	-2.990	-2.973	-2.956	-2.940	-2.923	-120
-110	-2.923	-2.906	-2.889	-2.873	-2.856	-2.839	-2.822	-2.805	-2.788	-2.771	-2.754	-110
-100	-2.754	-2.737	-2.719	-2.702	-2.685	-2.668	-2.651	-2.633	-2.616	-2.598	-2.581	-100
-90	-2.581	-2.564	-2.546	-2.529	-2.511	-2.493	-2.476	-2.458	-2.440	-2.423	-2.405	-90
-80	-2.405	-2.387	-2.369	-2.351	-2.334	-2.316	-2.298	-2.280	-2.262	-2.244	-2.225	-80
-70	-2.225	-2.207	-2.189	-2.171	-2.153	-2.134	-2.116	-2.098	-2.079	-2.061	-2.043	-70
-60	-2.043	-2.024	-2.006	-1.987	-1.969	-1.950	-1.931	-1.913	-1.894	-1.875	-1.857	-60
-50	-1.857	-1.838	-1.819	-1.800	-1.781	-1.762	-1.743	-1.724	-1.705	-1.686	-1.667	-50
-40	-1.667	-1.648	-1.629	-1.610	-1.591	-1.572	-1.552	-1.533	-1.514	-1.494	-1.475	-40
-30	-1.475	-1.456	-1.436	-1.417	-1.397	-1.378	-1.358	-1.338	-1.319	-1.299	-1.279	-30
-20	-1.279	-1.260	-1.240	-1.220	-1.200	-1.181	-1.161	-1.141	-1.121	-1.101	-1.081	-20
-10	-1.081	-1.061	-1.041	-1.021	-1.001	-0.980	-0.960	-0.940	-0.920	-0.900	-0.879	-10
0	-0.879	-0.859	-0.839	-0.818	-0.798	-0.777	-0.757	-0.736	-0.716	-0.695	-0.675	0

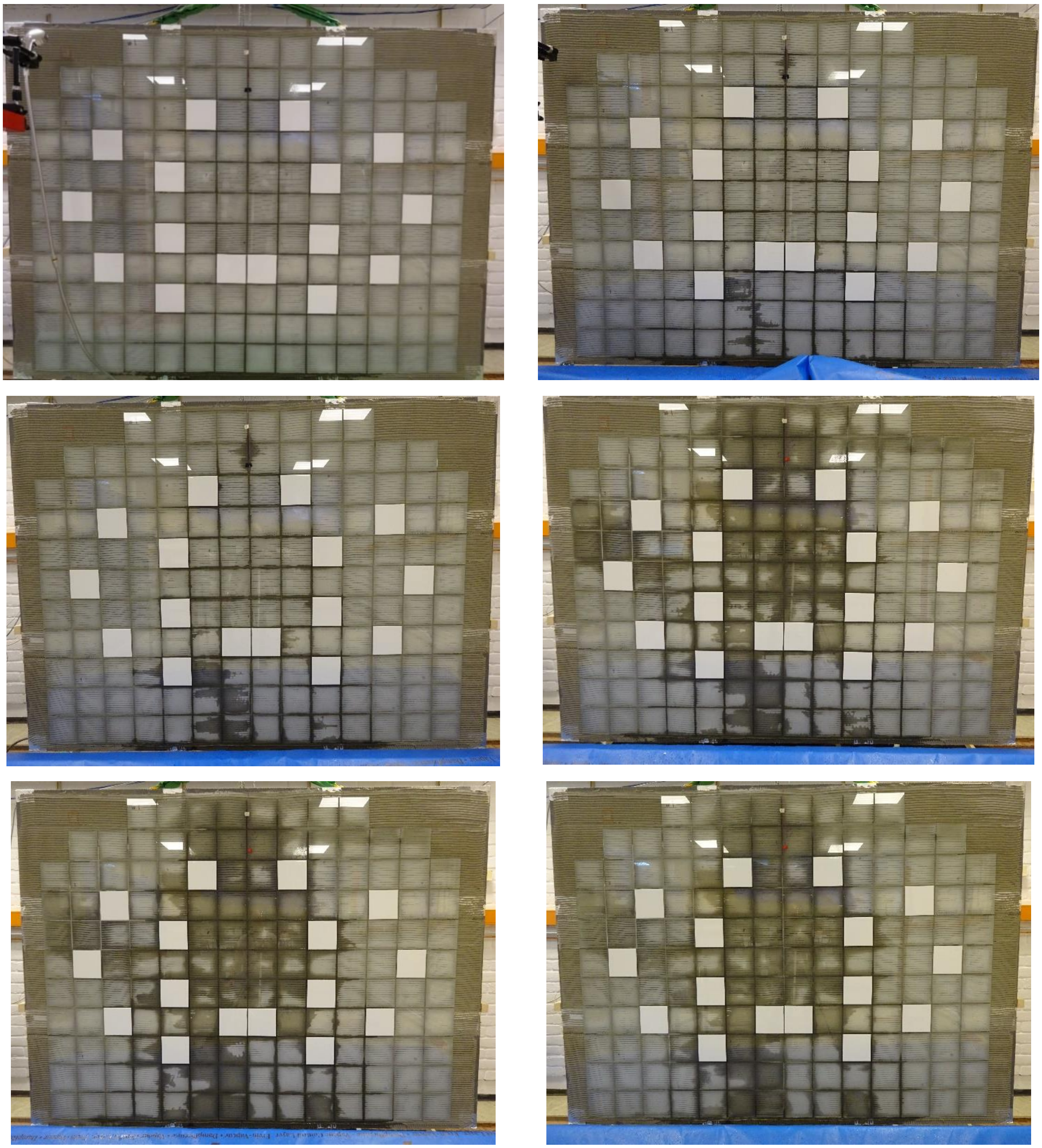
°F	0	1	2	3	4	5	6	7	8	9	10	°F
0	-0.675	-0.654	-0.633	-0.613	-0.592	-0.571	-0.550	-0.530	-0.509	-0.488	-0.467	0
10	-0.467	-0.446	-0.425	-0.404	-0.383	-0.362	-0.341	-0.320	-0.299	-0.278	-0.256	10
20	-0.256	-0.235	-0.214	-0.193	-0.171	-0.150	-0.129	-0.107	-0.086	-0.064	-0.043	20
30	-0.043	-0.022	0.000	0.022	0.043	0.065	0.086	0.108	0.130	0.151	0.173	30
40	0.173	0.195	0.216	0.238	0.260	0.282	0.303	0.325	0.347	0.369	0.391	40
50	0.391	0.413	0.435	0.457	0.479	0.501	0.523	0.545	0.567	0.589	0.611	50
60	0.611	0.634	0.656	0.678	0.700	0.723	0.745	0.767	0.790	0.812	0.834	60
70	0.834	0.857	0.879	0.902	0.924	0.947	0.969	0.992	1.015	1.037	1.060	70
80	1.060	1.083	1.105	1.128	1.151	1.174	1.196	1.219	1.242	1.265	1.288	80
90	1.288	1.311	1.334	1.357	1.380	1.403	1.426	1.449	1.472	1.496	1.519	90
100	1.519	1.542	1.565	1.588	1.612	1.635	1.658	1.682	1.705	1.729	1.752	100
110	1.752	1.776	1.799	1.823	1.846	1.870	1.893	1.917	1.941	1.964	1.988	110
120	1.988	2.012	2.036	2.060	2.083	2.107	2.131	2.155	2.179	2.203	2.227	120
130	2.227	2.251	2.275	2.299	2.323	2.347	2.371	2.395	2.420	2.444	2.468	130
140	2.468	2.492	2.517	2.541	2.565	2.590	2.614	2.639	2.663	2.687	2.712	140

°F	0	1	2	3	4	5	6	7	8	9	10	°F
150	2.712	2.737	2.761	2.786	2.810	2.835	2.860	2.884	2.909	2.934	2.958	150
160	2.958	2.983	3.008	3.033	3.058	3.082	3.107	3.132	3.157	3.182	3.207	160
170	3.207	3.232	3.257	3.282	3.307	3.333	3.358	3.383	3.408	3.433	3.459	170
180	3.459	3.484	3.509	3.534	3.560	3.585	3.610	3.636	3.661	3.687	3.712	180
190	3.712	3.738	3.763	3.789	3.814	3.840	3.866	3.891	3.917	3.943	3.968	190
200	3.968	3.994	4.020	4.046	4.071	4.097	4.123	4.149	4.175	4.201	4.227	200
210	4.227	4.253	4.279	4.305	4.331	4.357	4.383	4.409	4.435	4.461	4.487	210
220	4.487	4.513	4.540	4.566	4.592	4.618	4.645	4.671	4.697	4.724	4.750	220
230	4.750	4.776	4.803	4.829	4.856	4.882	4.909	4.935	4.962	4.988	5.015	230
240	5.015	5.042	5.068	5.095	5.122	5.148	5.175	5.202	5.228	5.255	5.282	240
250	5.282	5.309	5.336	5.363	5.389	5.416	5.443	5.470	5.497	5.524	5.551	250
260	5.551	5.578	5.605	5.632	5.660	5.687	5.714	5.741	5.768	5.795	5.823	260
270	5.823	5.850	5.877	5.904	5.932	5.959	5.986	6.014	6.041	6.068	6.096	270
280	6.096	6.123	6.151	6.178	6.206	6.233	6.261	6.288	6.316	6.343	6.371	280
290	6.371	6.399	6.426	6.454	6.482	6.510	6.537	6.565	6.593	6.621	6.648	290
300	6.648	6.676	6.704	6.732	6.760	6.788	6.816	6.844	6.872	6.900	6.928	300
310	6.928	6.956	6.984	7.012	7.040	7.068	7.096	7.124	7.152	7.181	7.209	310
320	7.209	7.237	7.265	7.294	7.322	7.350	7.378	7.407	7.435	7.463	7.492	320
330	7.492	7.520	7.549	7.577	7.606	7.634	7.663	7.691	7.720	7.748	7.777	330
340	7.777	7.805	7.834	7.863	7.891	7.920	7.949	7.977	8.006	8.035	8.064	340
350	8.064	8.092	8.121	8.150	8.179	8.208	8.237	8.266	8.294	8.323	8.352	350
360	8.352	8.381	8.410	8.439	8.468	8.497	8.526	8.555	8.585	8.614	8.643	360
370	8.643	8.672	8.701	8.730	8.759	8.789	8.818	8.847	8.876	8.906	8.935	370
380	8.935	8.964	8.994	9.023	9.052	9.082	9.111	9.141	9.170	9.200	9.229	380
390	9.229	9.259	9.288	9.318	9.347	9.377	9.406	9.436	9.466	9.495	9.525	390
400	9.525	9.555	9.584	9.614	9.644	9.673	9.703	9.733	9.763	9.793	9.822	400
410	9.822	9.852	9.882	9.912	9.942	9.972	10.002	10.032	10.062	10.092	10.122	410
420	10.122	10.152	10.182	10.212	10.242	10.272	10.302	10.332	10.362	10.392	10.423	420
430	10.423	10.453	10.483	10.513	10.543	10.574	10.604	10.634	10.664	10.695	10.725	430
440	10.725	10.755	10.786	10.816	10.847	10.877	10.907	10.938	10.968	10.999	11.029	440
450	11.029	11.060	11.090	11.121	11.151	11.182	11.213	11.243	11.274	11.304	11.335	450
460	11.335	11.366	11.396	11.427	11.458	11.489	11.519	11.550	11.581	11.612	11.643	460
470	11.643	11.673	11.704	11.735	11.766	11.797	11.828	11.859	11.890	11.920	11.951	470
480	11.951	11.982	12.013	12.044	12.075	12.106	12.138	12.169	12.200	12.231	12.262	480
490	12.262	12.293	12.324	12.355	12.386	12.418	12.449	12.480	12.511	12.543	12.574	490
500	12.574	12.605	12.636	12.668	12.699	12.730	12.762	12.793	12.824	12.856	12.887	500
510	12.887	12.919	12.950	12.982	13.013	13.045	13.076	13.108	13.139	13.171	13.202	510
520	13.202	13.234	13.265	13.297	13.328	13.360	13.392	13.423	13.455	13.487	13.518	520
530	13.518	13.550	13.582	13.614	13.645	13.677	13.709	13.741	13.772	13.804	13.836	530
540	13.836	13.868	13.900	13.932	13.964	13.995	14.027	14.059	14.091	14.123	14.155	540
550	14.155	14.187	14.219	14.251	14.283	14.315	14.347	14.379	14.411	14.444	14.476	550
560	14.476	14.508	14.540	14.572	14.604	14.636	14.669	14.701	14.733	14.765	14.797	560
570	14.797	14.830	14.862	14.894	14.926	14.959	14.991	15.023	15.056	15.088	15.121	570
580	15.121	15.153	15.185	15.218	15.250	15.283	15.315	15.347	15.380	15.412	15.445	580
590	15.445	15.477	15.510	15.543	15.575	15.608	15.640	15.673	15.705	15.738	15.771	590
600	15.771	15.803	15.836	15.869	15.901	15.934	15.967	15.999	16.032	16.065	16.098	600
610	16.098	16.130	16.163	16.196	16.229	16.262	16.295	16.327	16.360	16.393	16.426	610
620	16.426	16.459	16.492	16.525	16.558	16.591	16.624	16.657	16.690	16.723	16.756	620
630	16.756	16.789	16.822	16.855	16.888	16.921	16.954	16.987	17.020	17.053	17.086	630
640	17.086	17.120	17.153	17.186	17.219	17.252	17.286	17.319	17.352	17.385	17.418	640
650	17.418	17.452	17.485	17.518	17.552	17.585	17.618	17.652	17.685	17.718	17.752	650
660	17.752	17.785	17.819	17.852	17.886	17.919	17.952	17.986	18.019	18.053	18.086	660
670	18.086	18.120	18.153	18.187	18.221	18.254	18.288	18.321	18.355	18.389	18.422	670
680	18.422	18.456	18.490	18.523	18.557	18.591	18.624	18.658	18.692	18.725	18.759	680
690	18.759	18.793	18.827	18.861	18.894	18.928	18.962	18.996	19.030	19.064	19.097	690
700	19.097	19.131	19.165	19.199	19.233	19.267	19.301	19.335	19.369	19.403	19.437	700
710	19.437	19.471	19.505	19.539	19.573	19.607	19.641	19.675	19.709	19.743	19.777	710
720	19.777	19.811	19.845	19.879	19.913	19.947	19.982	20.016	20.050	20.084	20.118	720
730	20.118	20.152	20.187	20.221	20.255	20.289	20.323	20.358	20.392	20.426	20.460	730
740	20.460	20.495	20.529	20.563	20.597	20.632	20.666	20.700	20.735	20.769	20.803	740
750	20.803	20.838	20.872									750

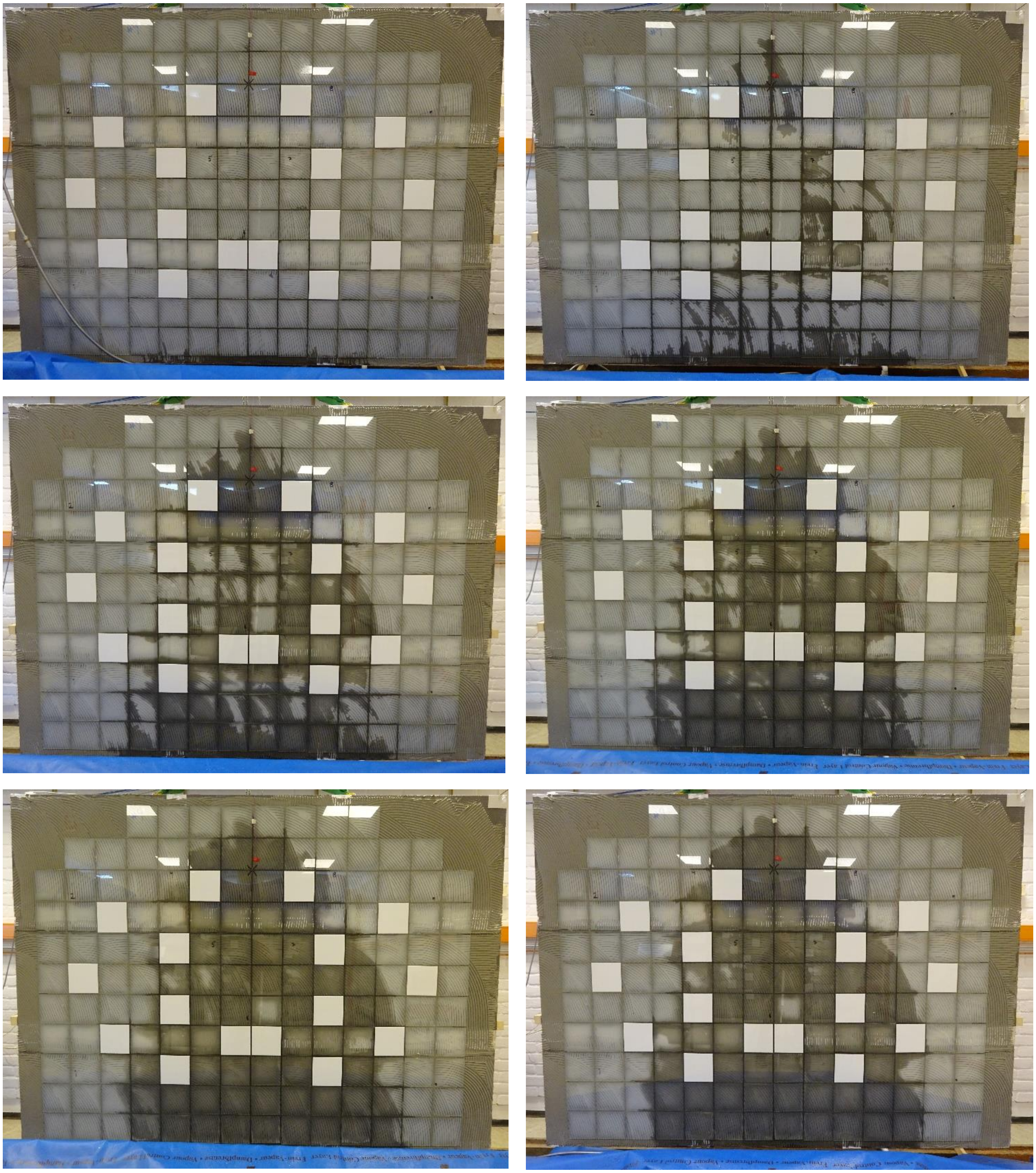
Z-223

Appendix I

Moisture migration 0 min to 664 min in Wall #1 – Read left to right, top to bottom.



Moisture migration 0 min to 2 920 min in Wall #4 - Read left to right, top to bottom.



Ambient Conditions

AMBIENT CONDITIONS WALL #1					
Exposure Day	Date	Temperature Pre [° C]	Temperature Post [° C]	RH Pre [%]	RH Post [%]
1	06-02-23	22.8	22.8	11	19
2	07-02-23	22.8	22.8	16	21
3	08-02-23	22.6	22.8	18	22
4	09-02-23	22.2	21.9	23	30
5	10-02-23	22.1	22.0	17	22
6	15-02-23	22.8	22.8	13	25
7	16-02-23	22.5	22.7	21	25
8	17-02-23	22.5	22.8	25	30
9	18-02-23	22.5	22.5	10	21
10	20-02-23	22.6	22.6	8	27
Average		22.5	22.6	16.2	24.2

AMBIENT CONDITIONS WALL #4					
Exposure Day	Date	Temperature Pre [° C]	Temperature Post [° C]	RH Pre [%]	RH Post [%]
1	20-02-23	22.7	22.8	16	24
2	21-02-23	22.4	22.9	10	19
3	22-02-23	22.6	22.9	11	24
4	23-02-23	22.6	22.8	14	25
5	25-02-23	22.4	22.1	10	26
6	28-02-23	22.4	22.6	10	19
7	01-03-23	22.4	22.4	13	25
8	02-03-23	22.6	22.5	10	15
9	03-03-23	22.2	22.5	10	28
10	04-03-23	22.4	22.5	10	13
11	06-03-23	22.9	22.5	12	20
12	09-03-23	23.1	22.9	10	10
13	13-03-23	22.4	22.4	10	24
14	14-03-23	22.3	22.4	11	24
15	15-03-23	22.8	22.5	10	14
16	16-03-23	22.8	22.5	11	13
17	17-03-23	22.6	22.5	10	22
Average		22.6	22.6	11.1	20.3

Wall #1 Exposure Details - Days 1 - 10

Date		06-Feb	07-Feb	08-Feb	09-Feb	10-Feb	15-Feb	16-Feb	17-Feb	18-Feb	20-Feb
Wall 1		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
MORNING 0800											
Start	Time	08:50	08:30	10:30	08:20	09:00	08:50	09:05	08:55	16:50	08:30
Ambient Temp [C]		22.8	22.5	22.5	21.8	21.8	22.5	22.4	22.4	22.3	22.5
Ambient RH [%]		11	16	18	23	17	13	21	25	10	8
Temp Calibration [C]		37	38	37	37	38	37	38	38	38	37
Flow Rate [l/min]		10.938	9.739	10.475	8.591	10.378	10.116	9.930	9.250	8.464	7.918
Weight_Pre [kg]		73.381	73.661	73.699	73.914	73.922	74.848	74.92025	75.01802	74.92939	74.9108
Cycle 1	Duration	8	8	8	8	8	8	8	8	8	8
Cycle 2	Duration	8	8	8	8	8	8	8	8	8	8
Cycle 3	Duration	8	8	8	8	8	8	8	8	8	8
Temp_Avg_During		35.753	37.245	37.367	37.049	37.130	37.943	37.073	35.12446	37.3542	37.3398
Weight_Post [kg]		73.558	73.776	73.841	74.047	74.057	74.971	75.04894	75.13978	75.06133	75.00247
Weight_Delta [kg]		0.177	0.116	0.141	0.133	0.135	0.123	0.129	0.122	0.132	0.092
Ambient Temp [C]		22.8	22.8	22.6	22.2	22.1	22.8	22.5	22.5	22.5	22.6
Ambient RH [%]		17	21	24	31	25	28	27	32	21	27
Stop	Time	10:45	09:20	11:20	09:15	09:45	09:50	09:50	09:55	17:40	09:30
Mid-Day 1 1000											
Start	Time		12:00	12:15	11:00	11:15	10:30	11:00	10:45		
Ambient Temp [C]			22.6	22.7	22.3	21.9	22.8	22.5	22.5		
Ambient RH [%]			17	19	26	16	16	25	27		
Temp Calibration [C]			38	37	38	38	38	37	37		
Flow Rate [l/min]			N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Weight_Pre [kg]			73.541	73.824	74.014	74.015	74.941	75.01802	75.11541		
Cycle 1	Duration		8	8	8	8	8	8	8		
Cycle 2	Duration		8	8	8	8	8	8	8		
Cycle 3	Duration		8	8	8	8	8	8	8		
Temp_Avg_During			37.484	37.110	37.032	37.568	35.015	36.863	37.45543		
Weight_Post [kg]			73.715	73.924	74.081	74.089	75.023	75.096	75.19528		
Weight_Delta [kg]			0.174	0.100	0.067	0.074	0.081	0.078	0.080		
Ambient Temp [C]			22.7	22.7	22.4	22.1	22.8	22.6	22.7		
Ambient RH [%]			20	24	30	22	25	26	31		
Stop	Time		13:00	13:00	11:50	12:05	11:30	11:45	11:38		
Mid-Day 2 1200											
Start	Time	14:15	15:00	14:00	14:05	13:25	12:00	12:40	12:30		
Ambient Temp [C]		22.8	22.6	22.8	21.8	22.1	22.7	22.5	22.6		
Ambient RH [%]		15	17	21	20	17	18	22	24		
Temp Calibration [C]		37	38	37	38	37	38	38	37		
Flow Rate [l/min]		8.630	10.359	8.9052	N/A	N/A	N/A	N/A	N/A		
Weight_Pre [kg]		73.49215	73.731	73.890	74.0375	74.06064	74.988	75.05895	75.16774		
Cycle 1	Duration	8	8	8	8	8	8	8	8		
Cycle 2	Duration	8	8	8	8	8	8	8	8		
Cycle 3	Duration	8	8	8	8	0	8	8	8		
Temp_Avg_During		38.018	37.343	38.088	34.87318	38.04662	34.548	36.657	36.84707		
Weight_Post [kg]		73.65729	73.815	73.975	74.11939	74.10342	75.007	75.09081	75.20756		
Weight_Delta [kg]		0.165	0.083	0.084	0.082	0.043	0.019	0.032	0.040		
Ambient Temp [C]		22.8	22.8	22.8	21.9	22	22.8	22.5	22.7		
Ambient RH [%]		19	21	22	30	22	19	27	28		
Stop	Time	15:30	15:45	15:30	15:00	14:30	13:30	13:45	13:30		
EVENING 1400											
Start	Time						14:30	14:30	14:50		
Ambient Temp [C]							22.7	22.6	22.8		
Ambient RH [%]							15	23	27		
Temp Calibration [C]							38	37	38		
Flow Rate [l/min]							10.634	9.272	9.671		
Weight_Pre [kg]							74.978	75.07458	75.19576		
Cycle 1	Duration						8	8	8		
Cycle 2	Duration						8	8	8		
Cycle 3	Duration						8	8	8		
Temp_Avg_During							37.668	35.649	37.05769		
Weight_Post [kg]							75.060	75.13346	75.25786		
Weight_Delta [kg]							0.082	0.059	0.062		
Ambient Temp [C]							22.8	22.7	22.8		
Ambient RH [%]							25	25	30		
Stop	Time						15:35	15:30	15:30		

Wall #1 Total Exposure Details - Days 1 - 10

Wall 1	06-Feb	07-Feb	08-Feb	09-Feb	10-Feb	15-Feb	16-Feb	17-Feb	18-Feb	20-Feb
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
SubTotal M	24	24	24	24	24	24	24	24	24	24
Sub Total MD1	0	24	24	24	24	24	24	24	0	0
Sub Total MD2	24	24	24	24	16	24	24	24	0	0
SubTotal E	0	0	0	0	0	24	24	24	0	0
Total	48	72	72	72	64	96	96	96	24	24
Total Accumulative	48	120	192	264	328	424	520	616	640	664
Grand Total	**664**									
Total in h	11.07		Number of Showers		**83**					

Wall #4 Exposure Details - Days 1 - 4

Date		20-Feb	21-Feb	22-Feb	23-Feb
Wall 4		Day 1	Day 2	Day 3	Day 4
MORNING 0800					
Start	Time	11:00	08:25	08:55	08:35
Ambient Temp [C]		22.7	22.4	22.6	22.6
Ambient RH [%]		16	10	11	14
Temp Calibration [C]		37	38	38	38
Flow Rate [l/min]		7.918	N/A	N/A	N/A
Weight_Pre [kg]		74.301	74.550	74.851	75.118
Cycle 1	Duration	8	8	8	8
Cycle 2	Duration	8	8	8	8
Cycle 3	Duration	8	8	8	8
Temp_Avg_During		40.010	36.452	38.205	38.204
Weight_Post [kg]		74.523	74.820	75.054	75.287
Weight_Delta [kg]		0.222	0.270	0.203	0.169
Ambient Temp [C]		22.8	22.5	22.8	22.8
Ambient RH [%]		27	20	24	25
Stop	Time	12:00	09:30	09:50	09:25
Mid-Day 1 1000					
Start	Time	12:40	10:15	11:45	11:30
Ambient Temp [C]		22.6	22.5	22.8	22.8
Ambient RH [%]		15	10	10	19
Temp Calibration [C]		38	38	37	37
Flow Rate [l/min]		N/A	N/A	N/A	N/A
Weight_Pre [kg]		74.494	74.775	75.000	75.232
Cycle 1	Duration	8	8	8	8
Cycle 2	Duration	8	8	8	8
Cycle 3	Duration	8	8	8	8
Temp_Avg_During		34.172	36.410	37.384	36.369
Weight_Post [kg]		74.621	74.886	75.133	75.301
Weight_Delta [kg]		0.126	0.111	0.133	0.069
Ambient Temp [C]		22.8	22.7	22.8	22.8
Ambient RH [%]		26	19	25	30
Stop	Time	13:20	11:10	12:30	12:05
Mid-Day 2 1200					
Start	Time	14:40	11:55	13:00	13:10
Ambient Temp [C]		22.7	22.7	22.7	22.7
Ambient RH [%]		14	10	11	14
Temp Calibration [C]		37	38	38	37
Flow Rate [l/min]		N/A	N/A	N/A	N/A
Weight_Pre [kg]		74.57816	74.843	75.109	75.30135
Cycle 1	Duration	8	8	8	8
Cycle 2	Duration	8	8	8	8
Cycle 3	Duration	8	8	8	8
Temp_Avg_During		36.264	37.352	35.739	36.162
Weight_Post [kg]		74.57816	74.895	75.200	75.39958
Weight_Delta [kg]		0.000	0.052	0.091	0.098
Ambient Temp [C]			22.7	22.8	22.7
Ambient RH [%]			11	20	22
Stop	Time	N/A	12:55	13:50	14:00
EVENING 1400					
Start	Time	N/A	14:20	14:45	14:45
Ambient Temp [C]			22.7	22.7	22.7
Ambient RH [%]			10	11	14
Temp Calibration [C]			37	37	38
Flow Rate [l/min]		N/A	9.832	9.708	9.752
Weight_Pre [kg]		74.578	74.886	75.152	75.352
Cycle 1	Duration	8	8	8	8
Cycle 2	Duration	8	8	8	8
Cycle 3	Duration	8	8	8	8
Temp_Avg_During		37.843	38.435	40.499	36.558
Weight_Post [kg]		74.792	75.029	75.243	75.435
Weight_Delta [kg]		0.213	0.143	0.091	0.084
Ambient Temp [C]		22.8	22.9	22.9	22.8
Ambient RH [%]		24	19	24	25
Stop	Time	15:55	15:10	15:30	15:40

Wall #4 Exposure Detail - Days 5 - 17

Date		25-Feb	28-Feb	01-Mar	02-Mar	03-Mar	04-Mar	06-Mar	09-Mar	13-Mar	14-Mar	15-Mar	16-Mar	17-Mar
Wall 4		Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14	Day 15	Day 16	Day 17
MORNING 0800														
Start	Time	10:45	12:40	09:35	10:00	15:25	10:45	08:45	07:50	09:40	11:50	10:00	09:15	12:30
Ambient Temp [C]		22.4	22.4	22.4	22.6	22.2	22.4	22.9	23.1	22.4	22.3	22.8	22.8	22.6
Ambient RH [%]		10	10	13	10	10	10	12	10	10	11	10	11	10
Temp Calibration [C]		38	38	37	37	38	38	37	38	38	37	38	38	37
Flow Rate [l/min]		8.718	9.512	9.654	9.752	10.204	9.328	10.426	9.392	8.77	9.666	9.978	10.046	9.338
Weight_Pre [kg]		75.170	75.086	75.26621	75.40581	75.47748	75.48684	75.52424	75.49297	75.44308	75.5871	75.5778	75.55101	75.64446
Cycle 1	Duration	96	120	220	285	93	300	300	135	120	240	240	240	147
Cycle 2	Duration													
Cycle 3	Duration													
Temp_Avg_During		35.169	33.052	35.072	28.795	35.932	33.889	28.473	5.592	30.237	25.633	24.737	27.397	17.030
Weight_Post [kg]		75.416	75.411	75.5836	75.63024	75.70212	75.76553	75.80899	75.75056	75.75012	75.78993	75.7914023	75.75366	75.83283
Weight_Delta [kg]		0.247	0.324	0.317	0.224	0.225	0.279	0.285	0.258	0.307	0.203	0.214	0.203	0.188
Ambient Temp [C]		22.1	22.6	22.4	22.5	22.5	22.5	22.5	22.9	22.4	22.4	22.5	22.5	22.5
Ambient RH [%]		26	19	25	15	28	13	20	10	24	24	14	13	22
Stop	Time	13:00	14:45	15:40	14:00	17:20	16:15	14:45	10:30	12:00	16:00	14:20	13:50	15:10

Wall #4 Total Exposure Details - Days 1 - 17

Wall 4	20-Feb	21-Feb	22-Feb	23-Feb	25-Feb	28-Feb	01-Mar	02-Mar	03-Mar	04-Mar	06-Mar	09-Mar	13-Mar	14-Mar	15-Mar	16-Mar	17-Mar
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14	Day 15	Day 16	Day 17
SubTotal M	24	24	24	24	96	120	220	285	93	300	300	135	120	240	240	240	147
Sub Total MD1	24	24	24	24													
Sub Total MD2	24	24	24	24													
SubTotal E	24	24	24	24													
Total	96	96	96	96	96	120	220	285	93	300	300	135	120	240	240	240	147
Total Accumulative	96	192	288	384	480	600	820	1105	1198	1498	1798	1933	2053	2293	2533	2773	2920
Grand Total	2920																
Total in h	48.67		Number of Showers		365												

Wall #4 Number of Wet Tiles in Specific Rows 1 – 11 Throughout Day 1 - 17

WALL 4	Day ID	1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	Minutes	8	96	192	288	384	480	600	820	1105	1198	1498	1798	1933	2053	2293	2533	2773	2920
	Date	20-Feb	20-Feb	21-Feb	22-Feb	23-Feb	25-Feb	28-Feb	01-Mar	02-Mar	03-Mar	04-Mar	06-Mar	09-Mar	13-Mar	14-Mar	15-Mar	16-Mar	17-Mar
Tile Layer	EXPOSURE TIMESTAMP 0	24	96	192	288	384	480	600	820	1105	1198	1498	1798	1933	2053	2293	2533	2773	2920
ROW 1	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.5	0.6	0.6
ROW 2	0.0	0.1	0.2	0.8	1.2	1.7	1.9	2.3	2.6	2.7	2.9	3.2	3.1	3.3	3.4	3.4	3.5	3.5	3.5
ROW 3	0.0	0.1	0.1	0.5	3.8	4.1	4.2	4.3	4.4	4.5	4.8	4.8	4.7	4.7	4.7	4.7	4.8	4.9	5.0
ROW 4	0.0	0.1	0.1	0.5	2.8	4.1	4.2	4.3	4.3	4.4	4.4	4.7	4.7	4.7	4.7	4.8	4.8	4.8	5.0
ROW 5	0.0	0.1	0.2	0.9	2.0	4.0	4.2	4.5	5.1	5.8	6.9	6.9	7.0	7.0	6.9	7.0	7.0	7.2	7.2
ROW 6	0.0	0.1	0.4	1.0	2.1	2.8	4.0	4.3	4.8	6.0	6.8	6.8	6.8	6.8	6.8	6.9	7.1	7.5	7.6
ROW 7	0.0	0.2	0.3	2.0	3.7	5.1	5.5	5.8	6.2	6.4	7.0	7.1	7.4	7.4	7.2	7.2	7.2	7.2	7.3
ROW 8	0.0	0.1	2.0	4.0	4.5	5.1	5.2	5.4	5.8	6.0	6.6	7.0	7.5	7.5	7.8	8.3	8.7	8.9	9.5
ROW 9	0.0	0.1	0.3	1.0	4.5	4.9	5.5	6.1	6.8	7.5	7.9	8.1	8.2	8.2	8.2	8.2	8.3	8.4	8.5
ROW 10	0.0	0.1	0.1	2.0	3.0	4.9	6.0	6.5	7.8	8.0	8.5	8.5	9.1	8.7	8.7	8.9	9.0	9.0	9.0
ROW 11	0.0	0.3	1.0	3.0	5.3	6.3	7.3	7.5	8.4	8.6	8.8	8.9	8.8	8.8	8.6	9.0	9.0	9.1	9.1
	Total	1.4	4.8	15.8	33.1	43.2	48.2	51.2	56.5	60.2	64.9	66.3	67.6	67.4	67.3	68.8	69.9	71.1	72.3

Wall #4 Drying Period

Date		31-Mar	07-Apr	13-Apr	21-Apr	28-Apr
Wall 4		Day 14	Day 21	Day 27	Day 36	Day 42
MORNING 0800						
Start	Time	12:00	12:00	12:00	12:00	12:00
Ambient Temp [C]		22.5	22.4	22.6	22.8	22.8
Ambient RH [%]		15	13	29	18	10
Temp Calibration [C]		N/A	N/A	N/A	N/A	N/A
Flow Rate [l/min]		N/A	N/A	N/A	N/A	N/A
Weight [kg]		75.16974	74.91938	74.96377	74.745	74.669

Wall #1 Relative Humidity Measurements Source Data (Yellow is Water Exposure [min] – Green is Drying [days])

				Day 1								Day 2					
				Morning				Evening				Morning		Mid-Day		Evening	
Sensor ID	x	y	Wall Config ID	Pre	8m	8m	8m	Pre	8m	8m	8m	Pre	24m	Pre	24m	Pre	24m
Shower	1200	1600	1	0	8	16	24	24	32	40	48	48	72	72	96	96	120
S1-1	300	400	1	33	33	33	34	35	35	35	35	34	37	35	37	35	38
S1-2	300	1300	1	28	31	32	31	30	31	31	31	31	31	33	33	33	34
S1-3	300	1650	1	21	21	21	21	21	21	21	21	21	27	21	28	32	31
S1-4	800	1400	1	71	71	71	70	71	71	71	72	68	71	70	68	70	71
S1-5	1000	1050	1	47	47	47	47	48	48	48	49	52	52	52	52	53	54
S1-6	1200	700	1	21	41	53	62	78	90	89	97	94	101	100	105	104	110
S1-7	1400	1050	1	35	37	37	38	42	44	44	44	52	55	57	57	58	59
S1-8	1600	1400	1	64	62	64	64	61	61	64	62	59	61	61	60	61	63
S1-9	2100	1300	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S1-10	2100	400	1	41	42	41	42	42	42	43	44	41	41	42	44	44	44

	Day 3						Day 4						Day 5					
	Morning		Mid-Day		Evening		Morning		Mid-Day		Evening		Morning		Mid-Day		Evening	
Sensor ID	Pre	24m	Pre	24m	Pre	24m	Pre	24m	Pre	24m	Pre	24m	Pre	24m	Pre	24m	Pre	16m
Shower	120	144	144	168	168	192	192	216	216	240	240	264	264	288	288	312	312	328
S1-1	37	38	37	38	38	41	40	40	40	42	40	42	33	33	33	35	37	35
S1-2	31	31	34	35	36	37	36	36	36	37	36	35	29	29	29	30	29	30
S1-3	26	26	21	28	30	35	28	33	28	32	21	30	21	21	21	21	21	21
S1-4	71	71	69	68	69	70	68	70	71	70	69	69	68	69	70	69	68	69
S1-5	58	58	58	59	59	60	61	61	64	64	64	63	65	66	66	65	65	64
S1-6	104	110	106	111	108	116	114	122	118	123	123	128	122	132	130	128	126	134
S1-7	61	62	64	63	64	65	66	70	68	69	71	69	70	71	68	71	70	70
S1-8	64	61	62	60	60	61	61	61	61	60	62	59	60	59	61	61	61	61
S1-9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S1-10	44	45	45	45	45	45	43	46	45	46	45	46	41	40	41	40	41	40

	Day 6								Day 7							
	Morning		Mid-D1		Mid-D2		Evening		Morning		Mid-D1		Mid-D2		Evening	
Sensor ID	Pre	24m	Pre	24m	Pre	24m	Pre	24m	Pre	24m	Pre	24m	Pre	24m	Pre	24m
Shower	328	352	352	376	376	400	400	424	424	448	448	472	472	496	496	520
S1-1	43	44	45	44	45	46	46	46	42	44	45	46	44	48	46	47
S1-2	123	126	126	129	123	128	119	126	116	123	120	120	118	118	117	119
S1-3	21	31	28	33	31	31	29	32	27	34	32	35	35	35	33	37
S1-4	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
S1-5	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
S1-6	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
S1-7	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
S1-8	70	69	66	67	67	69	70	70	73	73	74	75	74	75	75	75
S1-9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S1-10	45	44	45	45	45	47	45	49	46	48	47	49	48	48	49	49

	Day 8								Day 9		Day 10	
	Morning		Mid-D1		Mid-D2		Evening		Morning		Morning	
Sensor ID	Pre	24m	Pre	24m	Pre	24m	Pre	24m	Pre	24m	Pre	24m
Shower	520	544	544	568	568	592	592	616	616	640	640	664
S1-1	43	44	45	46	47	49	47	47	38	38	37	36
S1-2	113	113	112	111	113	114	113	112	106	102	94	95
S1-3	29	34	33	36	34	36	34	36	21	21	21	28
S1-4	140	140	140	140	140	140	140	140	140	140	140	140
S1-5	140	140	140	140	140	140	140	140	140	140	140	140
S1-6	140	140	140	140	140	140	140	140	140	140	140	140
S1-7	140	140	140	140	140	140	140	140	140	140	140	140
S1-8	78	78	77	79	78	78	76	80	82	82	82	82
S1-9	0	0	0	0	0	0	0	0	0	0	0	0
S1-10	48	49	48	49	49	50	49	51	45	44	42	42

				Day 1	21-Feb	22-Feb	23-Feb	24-Feb	25-Feb	26-Feb	28-Feb	01-Mar	02-Mar	03-Mar	04-Mar	06-Mar	09-Mar	10-Mar	11-Mar	12-Mar	13-Mar	14-Mar	15-Mar	16-Mar	17-Mar	24-Mar	31-Mar	07-Apr	13-Apr	21-Apr	28-Apr
				Morning	08:45	09:15	08:45	08:45	10:45	08:45	08:45	08:45	08:45	08:45	08:45	08:45	08:45	08:45	08:45	08:45	08:45	08:45	08:45	08:45	08:45	12:00	12:00	12:00	12:00	12:00	12:00
Sensor ID	x	y	Wall Config ID	Pre	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
Shower	1200	1600	1	0	1	2	3	4	5	6	8	9	10	11	12	14	17	18	19	20	21	22	23	24	25	32	39	46	53	60	67
S1-1	300	400	1	33	35	35	37	35	31	32	31	35	32	31	27	23	21	21	21	21	27	29	21	21	32	40	26	33	40	36	33
S1-2	300	1300	1	28	89	82	78	77	71	62	62	61	59	51	55	52	45	43	41	41	40	42	40	41	42	47	36	38	45	40	38
S1-3	300	1650	1	21	21	21	21	21	21	21	21	25	21	21	21	21	21	21	21	21	21	21	21	21	32	24	21	21	31	23	21
S1-4	800	1400	1	71	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	138	123	105	95	93	93	87
S1-5	1000	1050	1	47	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	138	131	125	104	87	76	73	70	67
S1-6	1200	700	1	21	140	140	140	140	140	140	140	140	139	138	137	129	121	116	114	113	112	110	108	107	104	101	98	90	87	80	77
S1-7	1400	1050	1	35	140	140	140	140	140	140	140	140	140	140	140	140	140	138	131	124	120	117	113	110	105	88	75	64	62	59	57
S1-8	1600	1400	1	64	81	81	81	80	80	73	74	75	71	72	69	68	62	63	61	51	50	57	57	56	55	57	51	46	50	50	48
S1-9	2100	1300	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S1-10	2100	400	1	41	41	40	42	41	38	38	38	40	37	35	35	32	29	27	24	27	29	34	28	28	34	41	29	34	41	38	34

Wall #4 Relative Humidity Measurement Source (Yellow is Water Exposure [min] – Green is Drying [days])

				Day 1						Day 2							
				Morning		Mid-Day 1		Mid-Day 2		Morning		Mid-Day 1		Mid-Day 2		Evening	
				Pre	24m	Pre	24m	Pre	24m	Pre	24m	Pre	24m	Pre	24m	Pre	24m
DUSJ	1200	1600	4	0	24	24	48	48	96	96	120	120	144	144	168	168	192
S4-1	300	400	4	38	39	42	40	42	42	40	40	40	42	42	41	39	41
S4-2	300	1300	4	28	28	29	28	31	32	28	29	28	29	29	31	31	31
S4-3	300	1650	4	28	31	32	34	30	35	21	27	21	29	21	22	21	29
S4-4	800	1400	4	33	32	34	33	34	32	31	33	35	33	35	33	34	35
S4-5	1000	1050	4	40	40	40	42	42	43	52	52	53	52	53	54	55	57
S4-6	1200	700	4	27	82	83	111	108	132	132	140	140	140	140	140	140	140
S4-7	1400	1050	4	31	34	32	35	34	39	53	84	99	132	138	140	140	140
S4-8	1600	1400	4	29	30	30	31	31	32	32	32	33	31	33	33	34	33
S4-9	2100	1300	4	29	28	28	30	29	28	28	28	29	26	28	27	28	28
S4-10	2100	400	4	33	35	37	37	36	38	31	32	35	35	35	35	33	34

				Day 3								Day 4							
				Morning		Mid-Day 1		Mid-Day 2		Evening		Morning		Mid-Day 1		Mid-Day 2		Evening	
				Pre	24m	Pre	24m	Pre	24m	Pre	24m	Pre	24m	Pre	24m	Pre	24m	Pre	24m
DUSJ	1200	1600	4	192	216	216	240	240	264	264	288	288	312	312	336	336	360	360	384
S4-1	300	400	4	37	40	40	38	40	43	42	42	42	40	42	41	42	40	44	43
S4-2	300	1300	4	28	30	30	30	31	30	33	32	31	32	32	33	33	33	35	34
S4-3	300	1650	4	21	31	25	32	30	33	28	33	26	32	28	35	29	35	31	35
S4-4	800	1400	4	34	35	34	34	35	34	34	35	36	35	37	34	35	36	36	36
S4-5	1000	1050	4	62	65	64	66	64	66	66	73	79	80	82	82	83	89	92	99
S4-6	1200	700	4	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
S4-7	1400	1050	4	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
S4-8	1600	1400	4	32	31	33	33	32	32	33	33	35	33	36	35	36	36	39	39
S4-9	2100	1300	4	26	25	28	28	27	28	28	30	28	31	31	31	31	31	31	31
S4-10	2100	400	4	31	32	36	35	38	35	36	35	35	38	38	40	39	40	41	43

				Day 5		Day 6		Day 7		Day 8		Day 9		Day 10		Day 11		Day 12		Day 13		Day 14		Day 15		Day 16		Day 17	
				Morning		Morning		Morning		Morning		Morning		Morning		Morning		Morning		Morning		Morning		Morning		Morning		Morning	
				Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
DUSJ	1200	1600	4	384	480	480	600	600	820	820	1105	1105	1198	1198	1498	1498	1798	1798	1933	1933	2053	2053	2293	2293	2533	2533	2773	2773	2935
S4-1	300	400	4	37	38	38	41	37	45	39	40	35	38	34	43	33	35	30	31	30	31	31	35	33	34	31	34	35	37
S4-2	300	1300	4	26	29	27	24	27	35	28	31	25	31	21	31	21	26	21	21	21	24	21	26	21	24	21	27	28	30
S4-3	300	1650	4	21	28	21	35	21	40	21	31	21	39	21	35	21	27	21	21	21	31	21	30	21	28	21	21	24	32
S4-4	800	1400	4	36	35	37	37	38	40	40	41	42	45	48	78	90	91	84	84	77	80	79	78	79	79	76	77	76	77
S4-5	1000	1050	4	108	125	130	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
S4-6	1200	700	4	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
S4-7	1400	1050	4	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
S4-8	1600	1400	4	34	34	38	35	41	47	49	49	45	56	67	79	87	90	90	91	90	93	95	100	101	102	107	106	109	109
S4-9	2100	1300	4	31	31	24	30	28	31	28	29	21	26	28	27	21	21	21	21	21	21	21	21	21	21	21	21	24	25
S4-10	2100	400	4	28	28	21	38	21	44	29	35	28	37	21	39	21	34	24	28	21	31	27	31	24	34	21	36	36	38

				24-Mar	31-Mar	07-Apr	13-Apr	21-Apr	28-Apr
				12:00	12:00	12:00	12:00	12:00	12:00
				Dry	Dry	Dry	Dry	Dry	Dry
DUSJ	1200	1600	4	7	14	21	27	35	42
S4-1	300	400	4	41	31	34	42	40	37
S4-2	300	1300	4	36	21	29	38	31	24
S4-3	300	1650	4	34	21	27	37	31	21
S4-4	800	1400	4	80	66	59	60	53	48
S4-5	1000	1050	4	140	140	140	140	140	140
S4-6	1200	700	4	140	140	140	137	131	117
S4-7	1400	1050	4	140	140	140	140	140	122
S4-8	1600	1400	4	122	115	90	84	73	66
S4-9	2100	1300	4	34	21	26	35	30	21
S4-10	2100	400	4	40	26	32	42	33	31

Appendix J

<u>Statistical Software (NCSS 2023)</u>

NCSS has several incredibly elaborate user manuals, and provide a set of quick start guides training videos as well. From studying the SW-guidelines and technical support, several parameter evaluations has been presented as key contributors to be able to evaluate the analysis validity [79-81]. According to the NCSS 2023 guides, there are several evaluations to be made to validate the results presented in the automatically generated reports made by the SW. In addition, a recommendation of an iterative analysis approach is provided.

The analysis have been run using one dependent variable, combined with up to 7 independent variables. SW documentation recommend removing one variable at a time, then rerunning the analysis repeatedly for as many iterations necessary, ending with the 2 or 3 variables having the highest effect on the dependent variable. When the analysis is completed, the NCSS SW provide the user with an in-depth report to be inspected. Evaluation into which independent variables to discard, or to evaluate the total validity of the analysis is based on the following points:

- Coefficient of determination (R^2) identifies certainty of the analysis from 0.0 to 1.0 with 1.0 being the highest certainty.
- Probability Level (P-value): significance between all parameters.
    - Small P-values indicate significant predictors, even 0.000 could be a valid number. However, the risk for the statistical 'null hypothesis', indicating that no relationship is present between different data sets, is present. Recommendations to verify P-values being at $\alpha > 0.05$.
    - Evaluate the rejection due to 'null hypothesis' H0 at $\alpha = 0.05$
- Evaluate Shapiro-Wilk as this has to do with the null hypothesis with P-values should be above $\alpha = 0.2$
- Any Variance Inflation Factor above 15 should be removed.

An example of a report from NCSS is found at the end of Appendix J, where the above evaluation points are highlighted.

After running several analyses with the accumulative- and incremental dependent variables listed above, most of the analyses ended with one or more of the evaluation factors above being outside what is recommended. Unfortunately, all analyses had a general impression of being too uncertain, and the validity was questionable. However, two analysis results are highlighted having the highest relevance for the results, identified as 1. and 2:

1. *<u>Accumulated 'Weight Post'</u>*

This analysis showed promising results with both the total amount of water in liters the wall was exposed to and the total accumulated exposure time. The probability levels were 0.08 and 0.09, no issues regarding 'null hypothesis' regarding 0.05 or Shapiro-Wilk. However, the Coefficient of determination (R^2) showed a marginal 0.69, and the deciding analysis disregarding factor was the Variance Inflation Factor which should be below 15, showed values above 9 000. This value indicates an abnormality and suspicion goes towards the two parameters being derived from the same source, being the flow rate parameter, hence the two parameters are interpreted close to similar by the SW. The previously evaluated variables in previous iteration of the same analysis also had issues related to the evaluation parameters, concluding with an analysis which was deemed non-pertinent.

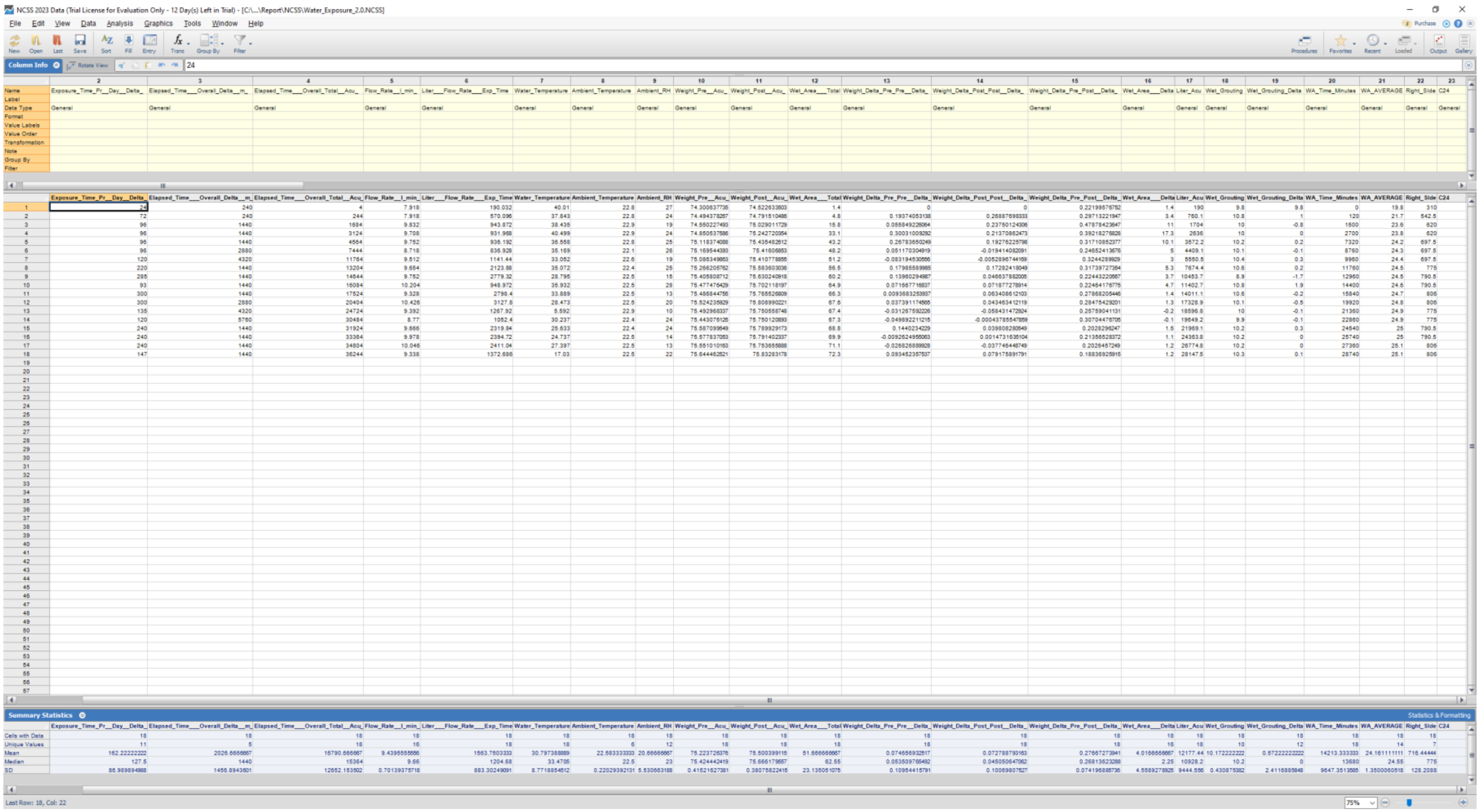
2. *<u>Incremental 'Weight Delta Pre-Post'</u>*

This analysis showed promising results with both water temperature and ambient temperature being variables having the highest impact on the incremental weight in the wall. 5 iterations were run in total, disregarding both the exposed water amount in liters and the incremental wet area in the tiles in early iterations. Both variables were deemed highly not pertinent by the SW, with several of the SW-evaluation criteria listed above being far into the discard category. Attempts were made to add the wet area and the incremental moisture development in the wall as independent variables as well. These variables, together with either the amount of exposed water on the wall, or the flow rate itself, being the author's expectation for the most prominent cause for moisture migration and weight increase in the wall.

The probability levels for both temperature variables were 0.02 in the final analysis iteration, which means the 'null hypothesis' regarding 0.05 might be a concern. However, the Shapiro-Wilk had no issue and the Coefficient of determination (R^2) showed 0.78, and the Variance Inflation Factor showed values around 1. The R^2 might be reason for concern, but it is far from critical. On paper, this analysis seemed plausible, however due to the author's expectations towards a different reason, led to further inspection of the dataset.

No further analysis was done to the Ambient Temperature in analysis above, as this had a max delta temperature of 0.8 °C, between 22.1 °C and 22.9 °C throughout the whole experiment and were deemed not applicable in regard to having an impact in this context.

Complete Dataset Excerpt from NCSS 2023 SW



Row	Exposure_Time_Pr__Day__Delta_	Elapsed_Time___Overall_Delta__m_	Elapsed_Time___Overall_Total__Acu_	Flow_Rate__l_min_	Liter___Flow_Rate___Exp_Time	Water_Temperature	Ambient_Temperature	Ambient_RH
1	24	240	4	7.918	190.032	40.01	22.8	27
2	72	240	244	7.918	570.096	37.843	22.8	24
3	96	1440	1684	9.832	943.872	38.435	22.9	19
4	96	1440	3124	9.708	931.968	40.499	22.9	24
5	96	1440	4564	9.752	936.192	36.558	22.8	25
6	96	2880	7444	8.718	836.928	35.169	22.1	26
7	120	4320	11764	9.512	1141.44	33.052	22.6	19
8	220	1440	13204	9.654	2123.88	35.072	22.4	25
9	285	1440	14644	9.752	2779.32	28.795	22.5	15
10	93	1440	16084	10.204	948.972	35.932	22.5	28
11	300	1440	17524	9.328	2798.4	33.889	22.5	13
12	300	2880	20404	10.426	3127.8	28.473	22.5	20
13	135	4320	24724	9.392	1267.92	5.592	22.9	10
14	120	5760	30484	8.77	1052.4	30.237	22.4	24
15	240	1440	31924	9.666	2319.84	25.633	22.4	24
16	240	1440	33364	9.978	2394.72	24.737	22.5	14
17	240	1440	34804	10.046	2411.04	27.397	22.5	13
18	147	1440	36244	9.338	1372.686	17.03	22.5	22

Row	Weight_Pre__Acu_	Weight_Post__Acu_	Wet_Area___Total	Weight_Delta_Pre_Pre__Delta_	Weight_Delta_Post_Post__Delta_	Weight_Delta_Pre_Post__Delta_
1	74.300637736	74.522633503	1.4	0	0	0.22199576752
2	74.494378267	74.791510486	4.8	0.19374053138	0.26887698333	0.29713221947
3	74.550227493	75.029011729	15.8	0.055849226064	0.23750124306	0.47878423647
4	74.850537586	75.242720354	33.1	0.30031009292	0.21370862473	0.39218276828
5	75.118374088	75.435482612	43.2	0.26783650249	0.19276225796	0.31710852377
6	75.169544393	75.41606853	48.2	0.051170304919	-0.019414082091	0.24652413676
7	75.086349863	75.410778856	51.2	-0.083194530566	-0.0052896744169	0.3244289929
8	75.266205762	75.583603036	56.5	0.17985589985	0.17282418049	0.31739727354
9	75.405808712	75.630240918	60.2	0.13960294987	0.046637882006	0.22443220667
10	75.477476429	75.702118197	64.9	0.071667716837	0.071877278914	0.22464176775
11	75.486844756	75.765526809	66.3	0.0093683253937	0.063408612103	0.27868205446
12	75.524235829	75.808990221	67.6	0.037391174566	0.043463412119	0.28475429201
13	75.492968337	75.750558748	67.4	-0.031267592226	-0.058431472924	0.25759041131
14	75.443076126	75.750120893	67.3	-0.049892211216	-0.00043785547859	0.30704476706
15	75.587099649	75.789929173	68.8	0.1440234229	0.039808280549	0.2028296247
16	75.577837053	75.791402337	69.9	-0.0092624956063	0.0014731635104	0.21356528372
17	75.551010163	75.753655888	71.1	-0.026826889928	-0.037746448749	0.2026457249
18	75.644462521	75.83283178	72.3	0.093452357537	0.079175891791	0.18836925915

Row	Wet_Area___Delta	Liter_Acu	Wet_Grouting	Wet_Grouting_Delta	WA_Time_Minutes	WA_AVERAGE	Right_Side	C24
1	1.4	190	9.8	9.8	0	19.8	310	
2	3.4	760.1	10.8	1	120	21.7	542.5	
3	11	1704	10	-0.8	1500	23.6	620	
4	17.3	2636	10	0	2700	23.8	620	
5	10.1	3572.2	10.2	0.2	7320	24.2	697.5	
6	5	4409.1	10.1	-0.1	8760	24.3	697.5	
7	3	5550.5	10.4	0.3	9960	24.4	697.5	
8	5.3	7674.4	10.6	0.2	11760	24.5	775	
9	3.7	10453.7	8.9	-1.7	12960	24.5	790.5	
10	4.7	11402.7	10.8	1.9	14400	24.6	790.5	
11	1.4	14011.1	10.6	-0.2	15840	24.7	806	
12	1.3	17328.9	10.1	-0.5	19920	24.8	806	
13	-0.2	18596.8	10	-0.1	21360	24.9	775	
14	-0.1	19649.2	9.9	-0.1	22860	24.9	775	
15	1.5	21969.1	10.2	0.3	24540	25	790.5	
16	1.1	24363.8	10.2	0	25740	25	790.5	
17	1.2	26774.8	10.2	0	27360	25.1	806	
18	1.2	28147.5	10.3	0.1	28740	25.1	806	

Summary Statistics

Statistic	Exposure_Time_Pr__Day__Delta_	Elapsed_Time___Overall_Delta__m_	Elapsed_Time___Overall_Total__Acu_	Flow_Rate__l_min_	Liter___Flow_Rate___Exp_Time	Water_Temperature	Ambient_Temperature	Ambient_RH
Cells with Data	18	18	18	18	18	18	18	18
Unique Values	11	5	18	16	18	18	6	12
Mean	162.22222222	2026.6666667	16790.666667	9.4395555556	1563.7503333	30.797388889	22.583333333	20.666666667
Median	127.5	1440	15364	9.66	1204.68	33.4705	22.5	23
SD	86.989894988	1456.8943601	12662.153502	0.70139375718	883.30249091	8.7718854512	0.22029392131	5.530663188

Statistic	Weight_Pre__Acu_	Weight_Post__Acu_	Wet_Area___Total	Weight_Delta_Pre_Pre__Delta_	Weight_Delta_Post_Post__Delta_	Weight_Delta_Pre_Post__Delta_
Cells with Data	18	18	18	18	18	18
Unique Values	18	18	18	18	18	18
Mean	75.223726376	75.500399116	51.666666667	0.074656932517	0.072788793163	0.27667273941
Median	75.424442419	75.666179657	62.55	0.053509765492	0.045050647062	0.26813623288
SD	0.41521627381	0.38075822415	23.135051075	0.10954415791	0.10069807527	0.074196886736

Statistic	Wet_Area___Delta	Liter_Acu	Wet_Grouting	Wet_Grouting_Delta	WA_Time_Minutes	WA_AVERAGE	Right_Side	C24
Cells with Data	18	18	18	18	18	18	18	
Unique Values	16	18	10	12	18	14	7	
Mean	4.0166666667	12177.44	10.172222222	0.57222222222	14213.333333	24.161111111	716.44444	
Median	2.25	10928.2	10.2	0	13680	24.55	775	
SD	4.5589278925	9444.556	0.430875382	2.4116886848	9647.3513585	1.3500060518	128.2088	

NCSS 2023 SW Report Printout

Printout of a report from the NCSS 2023 SW below. Evaluation points as specified in 5.5.3.1 is highlighted in yellow text:

NCSS 2023, v23.0.1 03-May-23 09:00:07 1

This report is for evaluation purposes only.
There are 30 days remaining in your free trial (Expires on 30-May-23).

Multiple Regression Report

Dataset C:\Users\morte\Documents\SKOLE\MASTER\Skole\Master\MABY5900 - Master Thesis\Report\NCSS\Analysis_01.NCSS
Dependent Weight_Post

Run Summary

Item	Value	Rows	Value
Dependent Variable (Y)	Weight_Post	Rows Processed	18
Number of Independent Variables (X)	3	Rows Used in Estimation	18
Weight Variable	None	Rows with X's Missing	0
R^2	0.8713	Rows with Y Missing	0
Adjusted R^2	0.8437		
Coefficient of Variation	0.0020		
Mean Square Error (MSE)	0.02265598		
Square Root of MSE	0.150519		
Average |Percent Error|	0.132		
Completion Status	Normal Completion		

Descriptive Statistics

Variable	Count	Mean	Standard Deviation	Minimum	Maximum
Flow_Rate__l_min_	18	9.439555	0.7013938	7.918	10.426
Water_Temperature	18	30.79745	8.771774	5.592476	40.4988
Ambient_Temperature	18	22.58333	0.2202939	22.1	22.9
Weight_Post	18	75.5004	0.3807582	74.52264	75.83283

Regression Coefficient T-Tests

Independent Variable	Regression Coefficient b(i)	Standard Error Sb(i)	Standardized Coefficient	T-Test of H0: β(i) = 0 T-Statistic	P-Value	Reject H0 at α = 0.05?
Intercept	91.02232	3.840534	0.0000	23.700	0.0000	Yes
Flow_Rate__l_min_	0.2794388	0.05346695	0.5148	5.226	0.0001	Yes
Water_Temperature	-0.02073087	0.004263582	-0.4776	-4.862	0.0003	Yes
Ambient_Temperature	-0.7758484	0.1666638	-0.4489	-4.655	0.0004	Yes

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This report is for evaluation purposes only.
There are 30 days remaining in your free trial (Expires on 30-May-23).

Multiple Regression Report

Dataset C:\Users\morte\Documents\SKOLE\MASTER\Skole\Master\MABY5900 - Master Thesis\Report\NCSS\Analysis_01.NCSS
Dependent Weight_Post

Regression Coefficient Confidence Intervals

Independent Variable	Regression Coefficient b(i)	Standard Error Sb(i)	95% Confidence Limits of β(i) Lower	Upper
Intercept	91.02232	3.840534	82.78519	99.25945
Flow_Rate__l_min_	0.2794388	0.05346695	0.1647636	0.394114
Water_Temperature	-0.02073087	0.004263582	-0.02987535	-0.0115864
Ambient_Temperature	-0.7758484	0.1666638	-1.133307	-0.4183902

Note: The T-Value used to calculate the confidence limits was 2.145.

Residual Normality Tests

Test Name	Test of H0: Residuals Normally Distributed Test Statistic Value	P-Value	Reject H0 at α = 0.2?
Shapiro-Wilk	0.909	0.0816	Yes
Anderson-Darling	0.680	0.0760	Yes
D'Agostino Skewness	1.652	0.0985	Yes
D'Agostino Kurtosis	0.843	0.3994	No
D'Agostino Omnibus	3.441	0.1790	Yes

R^2 Report

Independent Variable (IV)	Total R^2 for this IV and IV's Above	Increase in R^2 if this IV Included with IV's Above	Decrease in R^2 if this IV was Removed	R^2 if this IV was Fit Alone	Partial R^2 if Adjusted for All Other IV's
Flow_Rate__l_min_	0.4357	0.4357	0.2511	0.4357	0.6611
Water_Temperature	0.6721	0.2364	0.2173	0.3790	0.6281
Ambient_Temperature	0.8713	0.1992	0.1992	0.2800	0.6075

NCSS 2023, v23.0.1 03-May-23 09:00:07 3

This report is for evaluation purposes only.
There are 30 days remaining in your free trial (Expires on 30-May-23).

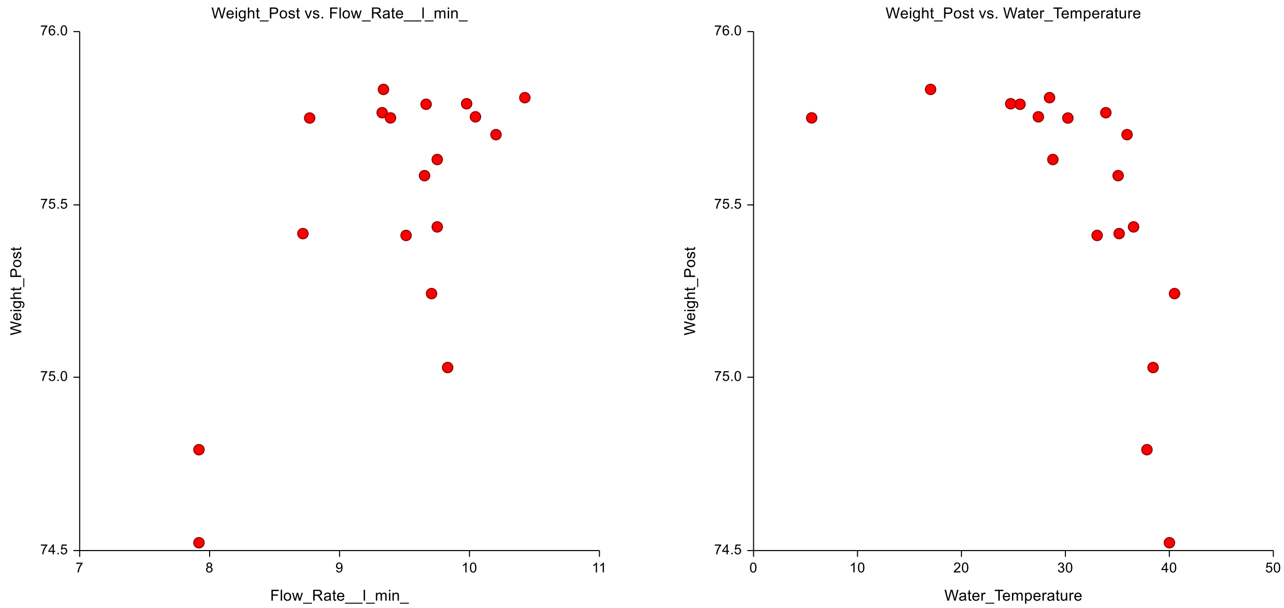
Multiple Regression Report

Dataset C:\Users\morte\Documents\SKOLE\MASTER\Skole\Master\MABY5900 - Master Thesis\Report\NCSS\Analysis_01.NCSS
Dependent Weight_Post

Multicollinearity Report

Independent Variable (IV)	Variance Inflation Factor	R^2 Versus Other IV's	Tolerance	Diagonal of X'X Inverse
Flow_Rate__l_min_	1.0553	0.0524	0.9476	0.1261793
Water_Temperature	1.0495	0.0472	0.9528	0.0008023548
Ambient_Temperature	1.0115	0.0113	0.9887	1.226025

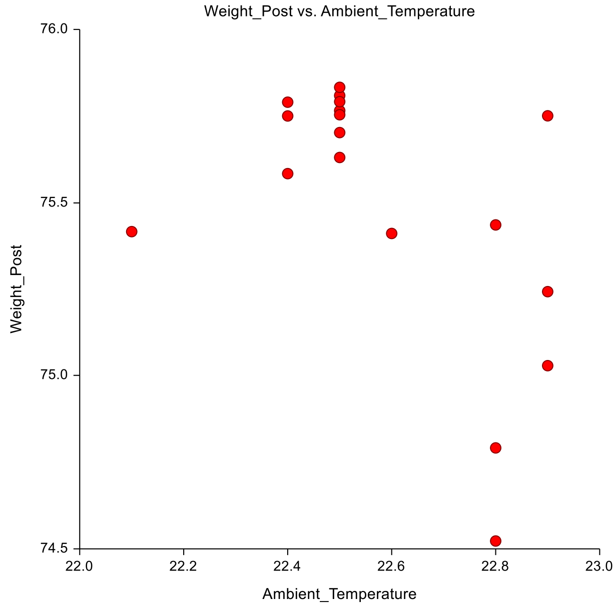
Y vs X Plots



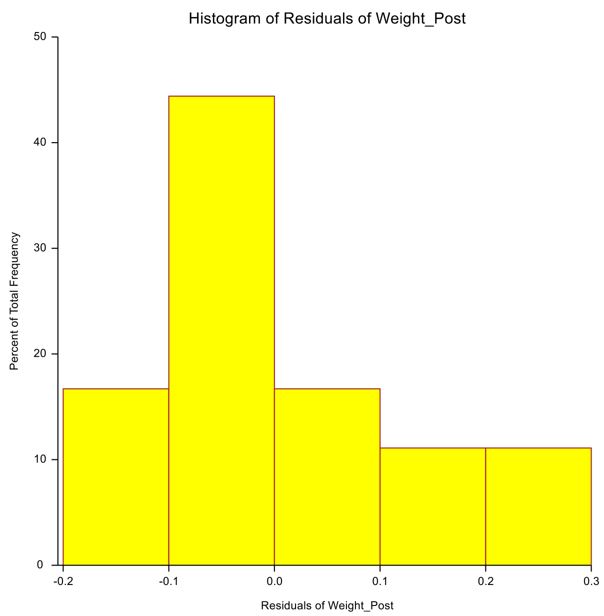
Multiple Regression Report

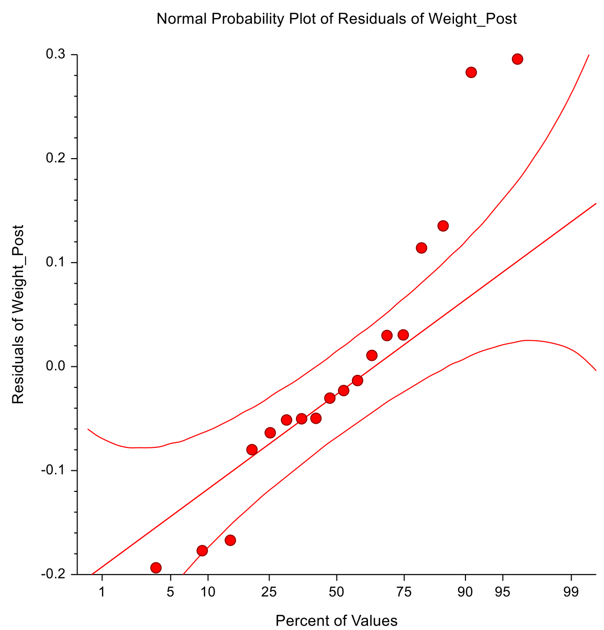
Dataset C:\Users\morte\Documents\SKOLE\MASTER\Skole\Master\MABY5900 - Master Thesis\Report\NCSS\Analysis_01.NCSS
Dependent Weight_Post

Y vs X Plots (Continued)



Residual Distribution Plots

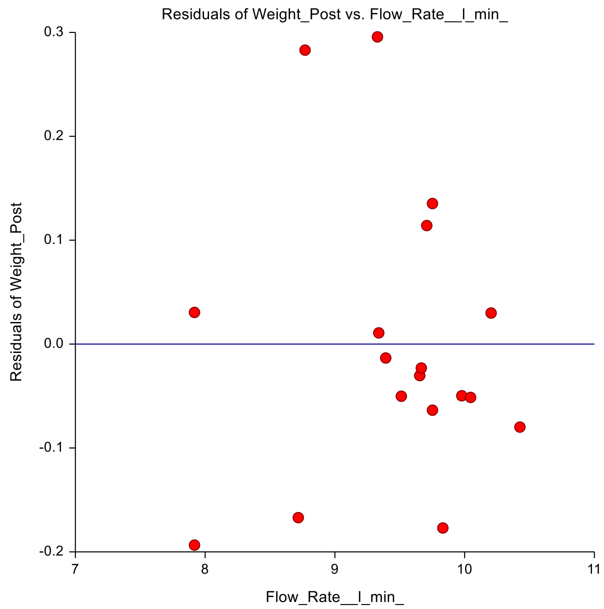


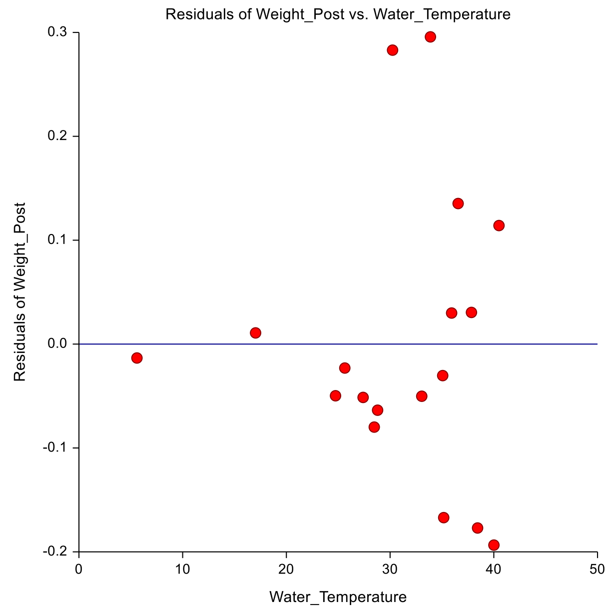


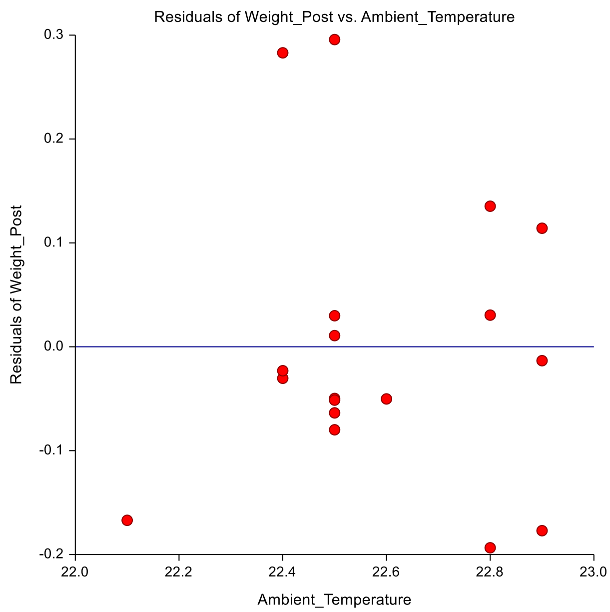
Multiple Regression Report

Dataset C:\Users\morte\Documents\SKOLE\MASTER\Skole\Master\MABY5900 - Master Thesis\Report\NCSS\Analysis_01.NCSS
Dependent Weight_Post

Residuals vs X Plots







This report is for evaluation purposes only.
There are 30 days remaining in your free trial (Expires on 30-May-23).

Multiple Regression Report

Dataset C:\Users\morte\Documents\SKOLE\MASTER\Skole\Master\MABY5900 - Master Thesis\Report\NCSS\Analysis_01.NCSS
Dependent Weight_Post

Procedure Input Settings

Autosaved Settings File
C:\Users\morte\Documents\NCSS 2023\Procedure Settings\Autosave\Multiple Regression - Autosaved 2023_5_3-9_0_8.t157

Variables, Model Tab

-- Variables --

Y:	Weight_Post
Numeric X's:	Flow_Rate__l_min_, Water_Temperature, Ambient_Temperature
Categorical X's:	<Empty>
Weights:	<Empty>

-- Regression Model --

Terms:	1-Way
Remove Intercept	Unchecked

Reports Tab

-- Select Reports ---

·· Summaries ···

Run Summary	Checked
Descriptive Statistics	Checked
Correlation Matrix	Unchecked

·· Regression Coefficients ···

Coefficient T-Tests	Checked
Coefficient C.I.'s	Checked
Estimated Equation	Unchecked

·· ANOVA ···

ANOVA Summary	Unchecked
ANOVA Detail	Unchecked

·· Assumptions ···

Residual Normality Tests	Checked
Serial Corr. (Durbin-Watson)	Unchecked
PRESS Statistics	Unchecked

·· X Diagnostics ···

R^2	Checked
Variable Omission	Unchecked
Sum of Squares	Unchecked
Sequential Models	Unchecked
Multicollinearity	Checked

Multiple Regression Report

Dataset	C:\Users\morte\Documents\SKOLE\MASTER\Skole\Master\MABY5900 - Master Thesis\Report\NCSS\Analysis_01.NCSS
Dependent	Weight_Post

Procedure Input Settings (Continued)

Reports Tab (Continued)

·· Eigenvalues and Eigenvectors ···

Eigenvalues (Centered)	Unchecked
Eigenvectors (Centered)	Unchecked
Eigenvalues (Uncentered)	Unchecked
Eigenvectors (Uncentered)	Unchecked

·· Row-by-Row Lists ···

Show:	All Rows
Predicted Values for Means	Unchecked
Predicted Values for Individuals	Unchecked
Residuals	Unchecked

Regression Diagnostics	Unchecked
DFBETAS	Unchecked

-- Alphas, Confidence Level, and Power ---

Tests Alpha:	0.05
Assumptions Alpha:	0.2
Confidence Level:	95
Compute Power	Unchecked

-- Resampling ---

Calculate Bootstrap Confidence Intervals for Regression Estimates and Predicted Values	Unchecked

Report Options Tab

-- Labels ---

Stagger label and output if label length is ≥	40

-- Report Formatting ---

Precision:	Single

·· Decimal Places ···

Regression Coefficients:	All
Standard Error of b's:	All
Test Statistics and Weights:	3
P-Values and Power:	4
Alphas and Confidence Levels:	All
Means:	All
Standard Deviations:	All
R^2, Correlations, Standardized Coef's:	4
Mean Squares, Sum of Squares:	All
X's, Y's, Residuals, etc.:	All
Standard Error of Y:	All
Eigenvalues:	4
Eigenvectors:	4
Diagonal of X'X Inverse:	All

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Multiple Regression Report

Dataset C:\Users\morte\Documents\SKOLE\MASTER\Skole\Master\MABY5900 - Master Thesis\Report\NCSS\Analysis_01.NCSS
Dependent Weight_Post

Procedure Input Settings (Continued)

Plots Tab

-- Select Plots ---

·· Y vs X Plots ···

Y vs X Plots	Checked

·· Residual Distribution Plots ··

Histogram	Checked
Probability Plot	Checked

·· Residual Analysis Plots ··

Residuals vs X	Checked
Residuals vs Yhat	Unchecked
RStudent vs X	Unchecked
RStudent vs Hat	Unchecked
Partial Residuals vs X	Unchecked
Sequence Plot	Unchecked
Serial Correlation Plot	Unchecked

Storage Tab

-- Select Items to Store with the Dataset --

·· Row-by-Row Items ··

Predicted Y	Unchecked
Residuals	Unchecked
Standard Error of the Predicted Mean	Unchecked
Lower Confidence Limit of the Predicted Mean	Unchecked
Upper Confidence Limit of the Predicted Mean	Unchecked
Standard Error of a Predicted Individual	Unchecked
Lower Confidence Limit of a Predicted Individual	Unchecked
Upper Confidence Limit of a Predicted Individual	Unchecked
Rstudent	Unchecked
Hat Diagonals	Unchecked
CovRatio	Unchecked
Dffits	Unchecked
MSE(i)	Unchecked
Cook's D	Unchecked
DFBETAS	Unchecked

·· Matrices ··

X'X Inverse Matrix	Unchecked
VC(Betas) Matrix	Unchecked
Expanded X Matrix	Unchecked

Multiple Regression Report

Dataset	C:\Users\morte\Documents\SKOLE\MASTER\Skole\Master\MABY5900 - Master Thesis\Report\ NCSS\Analysis_01.NCSS
Dependent	Weight_Post

Procedure Input Settings (Continued)

Storage Tab (Continued)

·· Storage Options ······························

Storage Location:	In empty column(s) after the last column with data
Skip one or more columns before item storage	Unchecked
Rename the storage column(s) using the item name(s)	Checked
Add a Note about each stored item in the Column Info table	Checked
Overlay storage data when the Group By System is active	Unchecked

Appendix K

As the report from the grout experiment performed by SINTEF in 2000, has limited access, all content not provided in the main part of this master's thesis is paraphrased below [9]:

Key measuring points during the experiment was as follows:

- Time until visible moisture is seen in the grout from the rear.
- Total size of visibly moist area in the tiles observed from the rear.
- Length of visibly moist grout observed from the rear.

The single component cementitious tile adhesive, called Mira 3130 superfix was used for all five wall configurations, while three different grout were used. One single component cementitious grout, one polymer added grout and one epoxy-based grout:

Type 1: Fug FB 25. Single component cementitious grout from Höganäs.

Type 2: Mira Supercolour 115. Quick curing, polymer added grout.

Type 3: Epoxy grout from Höganäs.

The tiles were not adhered using full adhesive coverage, instead the tiles were mounted with approx. 50% coverage, with the tile adhesive centered on the tile.

The flow rate was set to 0.1 l / s = 6 l / min using a commercially available shower head. The water temperature was set to 20 °C. The shower head was aimed at the wall with a distance of 200 mm, with the shower head slightly angled downwards. The water cone on the tiled wall was close to fully circular, measuring 170mm in diameter. Each water exposure lasted for 60 minutes.

The overall results and conclusion of the experiment provided the following:

- Type 1 – 5mm width:
  - 9 seconds: First visible moisture in grout.
  - 1 minute: Visible moisture in 9 tiles.

    - 3 minutes: Continuous moisture in grout covering all 738 cm.
    - 15 minutes: All tiles are visibly moist.
    - Total moist area in tiles: 1000 cm^2
- Type 2 – 5mm width:
    - 7 minutes: First visible moisture in grout.
    - 25 minutes: First visible moisture in tiles.
    - 60 minutes:
        - Moisture in grout, total length of 385 cm.
        - Total moist area in tiles: 45 cm^2
- Type 3 – 5mm width:
    - 60 minutes: No visible moisture in grout or tiles

From the experiment it can be concluded that the single component cementitious grout from Höganäs had a rather high moisture penetration. Furthermore, the epoxy grout had no moisture penetration after 60 minutes of water exposure.