LAB University of Applied Sciences

Applying WUFI Calculation Results to Finnish Mould Growth Model

LAB University of Applied Sciences
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Abstract

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Title of the thesis

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Abstract

Mould has always been one of the most destructive factors for building materials, especially for natural materials like timber and timber-based ones. Parameters of favorable environment for mould growth has long been known. However, in case of ever-changing conditions of outdoor and indoor climate of buildings determination of the values of temperature and relative humidity turns out to be rather complicated. Big data about climate during long-term period and material properties should be analyzed and calculated for predicting the risks.

This thesis is devoted to the study of calculating and assessing the risks of a mould growth process in building constructions. Calculations of temperature and relative humidity in the work were made in WUFI 2D software. The general approach of analysing the structures was made according to Finnish mould growth model.

The thesis was aimed to describe the way of calculating mould risks in building structures made of wood, but all the principal instructions given in this work can be applied to assess risks of mould in any building material.

Keywords

Mould, Moisture, CLT, WUFI 2D, Excel, Building envelope, Civil engineering

Contents

Appendices

List of terms

FMGM	Finnish mould growth model
CLT	Cross laminated timber
RH	Relative humidity
Isopleth	Function of relative humidity and temperature depending on time
LIM	Lowest isopleth for mould: lowest values of relative humidity and temperature when mould growing process is possible
txt	Format of text file
csv	Comma-separated values: format of text file with comma as a separating symbol

1 Introduction

While creating a project of buildings, choosing materials for building envelope and designing connections between elements, it is crucial to take into account not only bearing capacities of structures, appearance and thermal conductivity, but also assess and minimize risks of mould growth. Mould destroys materials, decreasing the bearing properties; causes human diseases; and spoils the visual pureness of surfaces.

Mould risk assessment entails difficulties with choosing and creating a mathematical model of structures; collecting, analyzing and bringing to calculations weather conditions of long time periods in exact region of construction site; modelling the temperature and moisture changes through the time; finding a numerical parameter for risk assessment.

This thesis is supposed to explain a method of mould growth assessment according to Finnish mould growth model created by Technical Research of Finland and Tampere University of Technology. This model is considered as one of the most comprehensive and state-of-the-art ones. It allows to determine risks of mould in all building materials. Nevertheless, it has not found a wide application in practical design because of a necessity of getting large amount of accurate data about structures temperature and moisture state.

The possible solution of mentioned issue is applying WUFI 2D software to hydrothermal analysis of structures. Due to its wide functionality and data library, flexibility in settings and capacity to precisely model objects, WUFI 2D tends to become the most suitable software for creating hydrothermal models of building structures and connections between them.

The main questions that arose the work were where enough data about material properties, exterior and indoor climate conditions can be gotten; how hydrothermal parameters of exact materials in construction can be calculated in WUFI 2D and how the results of these calculations can be applied to Finnish mould growth model?

All the structural designs used in the thesis work are a property of Alva-House Company based in Saint-Petersburg, Russia. These structures are used with the official permission of the author.

Calculations were made in WUFI 2D software (Version №4.3.3) on the rights of student license which was received from the Fraunhofer for writing this thesis work.

2 The physical explanation of a mould growth process

2.1 The mould concept in constructions

Organisms like fungi, bacteria, and other microorganisms are responsible for the fast decomposition of dead material, splitting it up into its components and thereby giving it a new access to a further life cycle. Therefore, microorganisms as fungi and bacteria are important components of our ecosystem. In buildings, however, favourable growing conditions for mould fungi can also occur and cause fungus infestation. Despite the quality of house building having improved over the last decades, especially by measures aiming at the reduction of heat losses due to transmission and ventilation, the number of reports on building damages caused by microorganisms, especially by mould fungi is still increasing (Sedlbauer Klaus, 2001). An example of progressive mould on timber rafters of private house is presented on Figure 1.

Figure 1. Example of mould growth in private house in Manchester, UK

Wooden rafters, timber beams in house basements, timber frame walls, massive timber constructions are inclined to be destroyed by mould growth.

2.1.1 Conditions when mould appears

Mould appears in case of combination of definite conditions: mould spores and food, temperature, moisture.

Mould spores are ranging from 3 to 40 microns in size and spread practically everywhere in the environment. It is hardly possible to control the mould spores and prevent building constructions from them.

Mould as an alive organism needs food for existence. Mould spores feed on carbon therefore lots of materials like timber and paper can serve as food. Consequently, the building material itself is a source for mould existence.

Temperature and moisture (or relative humidity) are the only parameters that change and can be predicted in case of mould protection of timber constructions. Most species of mould need a certain range of temperature and relative humidity for growth. The temperature values are between 0 and 50 degrees above zero (Tampere University, FMGM). The relative humidity is upper 80%. This range is similar to environment suitable for humans.

2.1.2 The necessity to prevent mould and access the risks of its appearance

Mould destroys building structures made from natural materials like timber causing leaks, thermal bridges, condensations and having negative effect on human health. That is why necessity to predict and prevent mould appearance in building structures is rather high.

To make a precise assessment of the risks it is needed to process big data about indoor and outdoor climate conditions depending on the time and season and accomplish lots of calculations based on this data. Nowadays, due to existing program software it is possible to manage with this issue.

2.2 Finnish mould growth model as an effective tool to access the risks of mould in constructions

2.2.1 General information about Finnish mould growth model

Finnish mould growth model is a calculation file for assessing mould growth on different building materials in changing conditions including temperature and moisture created by Technical Research Centre of Finland and Tampere University of Technology. This model is considered as the most complex tool for mould risk prediction due to its ability to take into account big number of parameters of materials and surrounding environment.

2.2.2 A mould index

The mould risk is described with a mould index M, which ranges between 0 and 6, and depicts the increasing amount of mould on the surface. The mould risk is calculated from hourly temperature and relative humidity values. The model also takes into account mould

decline when conditions are not favourable for mould growth (too cold or too dry). The mould index only describes the general growth of mould on materials and therefore says nothing about the mould types, so it can't be used to evaluate how hazardous the mould would be.

Special criteria was created for assessing a mould risk: a mould index M ranging between 0 (no mould growth) and 6 (the highest intensity of mould growth). Different values of mould index with descriptions is shown in Table 1 (Tampere University, FMGM).

Table 1. Mould Index

Mould index M	Found mould growth	Notes
0	No growth	Clean surface
1	Growth seen with a microscope	Growth is beginning in places
2	Clear growth seen with a microscope	Mould growth covers 10 % of area studied (microscope). Several mould colonies have formed
3	Growth seen with the naked eye Clear growth seen with a microscope	Growth covers less than 10 % of area studied (naked eye) Growth covers less than 50 % of area studied (microscope) New spores are starting to form
4	Clear growth seen with the naked eye Rich growth seen with a microscope	Growth covers more than 10 % of area studied (naked eye) Growth covers more than 50 % of area studied (microscope)
5	Rich growth seen with the naked eye	Growth covers more than 50 % of area studied (naked eye)
6	Very rich growth	Growth covers almost 100 % of area studied, dense mould growth

2.2.3 The initial data for calculations

Initial data for calculations according to Finnish mould growth model are hourly values of temperature and relative humidity. Material properties are taken into account via sensitivity classes and decline classes. These properties are estimated according to laboratory observations of mould growth on different materials (beginning phase, maximum amount of mould and mould decline).

Sensitivity classes respond for the resistance of materials to mould. Descriptions of sensitivity classes are shown in the Table 2 (Tampere University, FMGM).

Table 2. Mould sensitivity classes

Mould sensitivity class		Construction materials
MSC1	Very sensitive	Roughly sawn and dimensioned plank (pine, spruce and hardwood), planed pine, birch plywood, untreated porous wood fibre board, cardboard-surfaced gypsum board
MSC2	Sensitive	Planed pine, paper-based bituminized/treated products and films, wood-based glued boards, pine or spruce plywood, bituminized/treated porous fibre board
MSC3	Medium resistant	Mineral wools, plastic-based materials, autoclaved aerated concrete, expanded-clay lightweight concrete, carbonated old concrete, cement-based products, bricks, cement bonded fibreboard, fibreglass-surfaced gypsum board
MSC4	Resistant	Glass and metals, alcaline new concrete, products containing mould-preventive additives

Decline classes according to sensitivity classes are shown in Table 3 (Tampere University, FMGM).

Table 3. Decline classes

Mould sensitivity class	Mould decline class
MSC1	HTL2 Strong decline
MSC2	HTL3 Significant decline
MSC3	HTL4 Relatively low decline
MSC4	HTL4 Almost no decline

Favourable temperature and relative humidity conditions for mould growth depend on mould sensitivity and decline classes. Generally, temperature values range between 0 and 50 degrees above zero, relative humidity range between 80 and 100 %. The graph on Figure 2 (Tampere University, FMGM) shows these favorable zones of values. Mould growth stops when temperature or relative humidity move out of favorable values: temperature becomes too low or too high, relative humidity becomes too high.

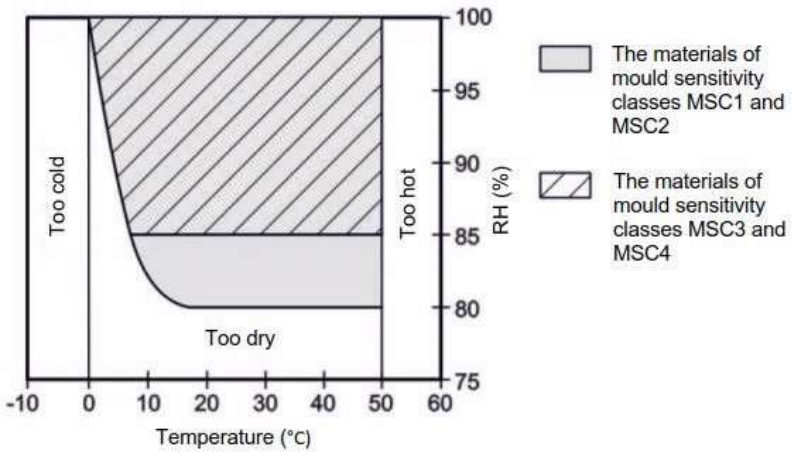

Figure 2. Favourable conditions for mould growth

As it is presented on the Figure 2, the favourable conditions for mould growth are inherent to the majority of climates on Earth. This fact demonstrates the importance of mould risk assessment for all the structures being designed from materials which are inclined to be a surface for mould appearance.

Finnish mould growth model is recognized as one of the most complex ones for evaluating the mold risks in the world. Properties of materials are taken into account according to the parameters of classes presented above. The influence of surface type, coating and the characteristics of contacting with other materials are also calculated and taken into account in sensitivity and decline classes.

The correctness and applicability of this system including the dividing of materials into classes is proved via laboratory experiments, data analysis and calculations made by Technical Research Centre of Finland and Tampere University of Technology. Besides the temperature, relative humidity and obvious parameters of materials like density there are many factors which affect the mould risk in structures:

- quantity of nutrition at the place of inspecting structure,
- amount of oxygen which can achieve the material,
- air speed,
- pH,
- dirt on the surface of material,
- susceptibility of each material to mould.

3 Calculating the initial data for Finnish mould growth model in WUFI 2D

3.1 The WUFI 2D software

3.1.1 General information about the software

For accomplishing the needed calculations to examine the risks of mould growth in constructions values of temperature and relative humidity of material should be found during the period of time which can describe a whole cycle of climate changes surrounding the structure. Furthermore, the material should be counted regarding the whole structure in case of multilayer constructions.

3.1.2 Advantages of the WUFI 2D

WUFI 2D is an appropriate software for this task due to following advantages:

- ability to model long-term heat and moisture states of structures via making step-by-step calculations with the set period (time step),
- working with structures in 2 dimensions, which allows to create models as similar to origin structures as possible, model connections between structures and get accurate results.

3.2 The calculation

3.2.1 The structures used for calculation

As initial data for calculations several structures with CLT were chosen. All the structures calculated in this work are designed by Alva-House Company and are used with the its official permission. CLT is one of the most modern and perspective timber materials which gives opportunity to construct timber buildings in the way as it has never been possible before: high-rise buildings, cantilever plates etc. During last decade CLT has become more widespread all over the world and the demand to study behavior of CLT through long-time term highly relevant. Due to its novelty CLT has less information base about mould growth comparing to other timber materials, therefore taking CLT as a main bearing material for this research allows to .

Two structures were selected:

- simple outer wall (Figure 4);

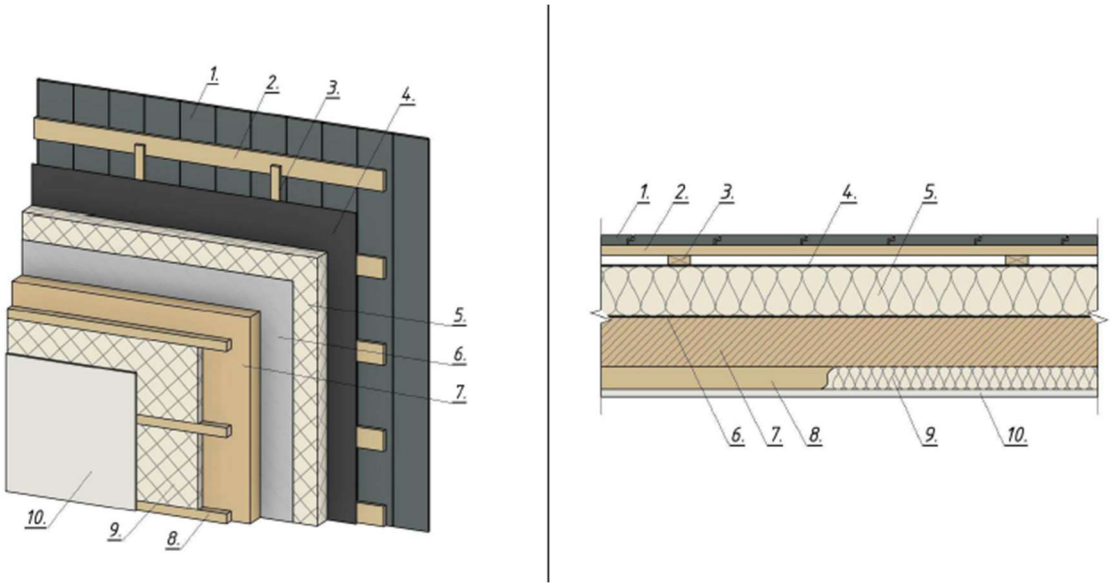

Figure 3. Structure 1 - outer wall with CLT: 1 – facade timber board (20 x 195 mm), 2 – timber frame (20 x 90 mm, spacing 400 mm), 3 – membrane, 4 – insulation (100 mm), 5 – membrane, 6 – CLT panel, 7 – timber frame (45 x 45 mm, spacing 400 mm), 8 – insulation (50 mm), 9 – gypsum board (15 mm).

- connection between frame wall, CLT balcony and CLT indoor slab (Figure 6).

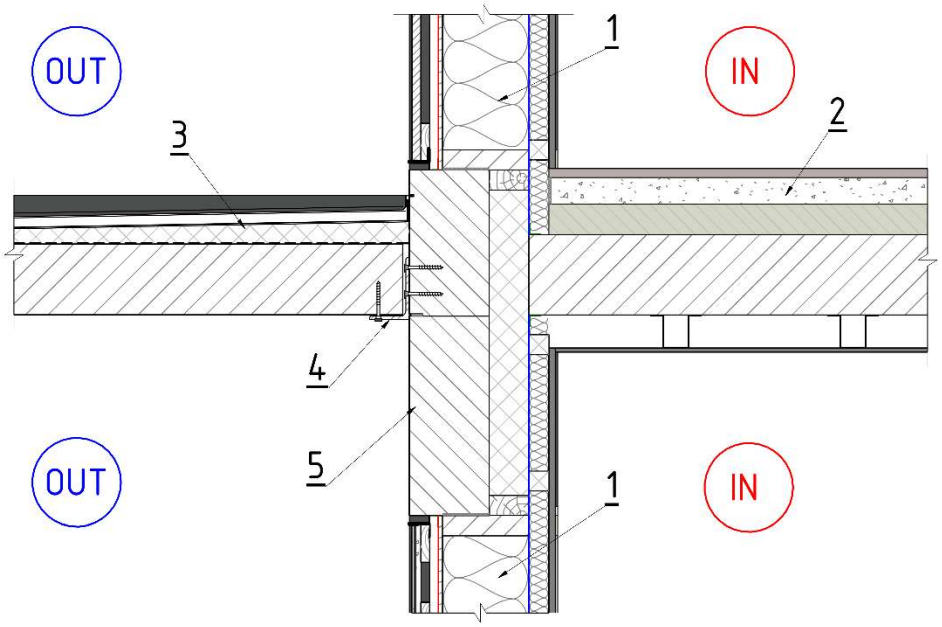

Figure 4. Structure 2 – connection between frame wall, CLT balcony and CLT indoor slab: 1 – frame wall, 2 – indoor overlap, 3 – outdoor overlap, 4 – steel connection detail, 5 – glulam beam.

The elements, connected in structure 2 are presented on figures 5-7.

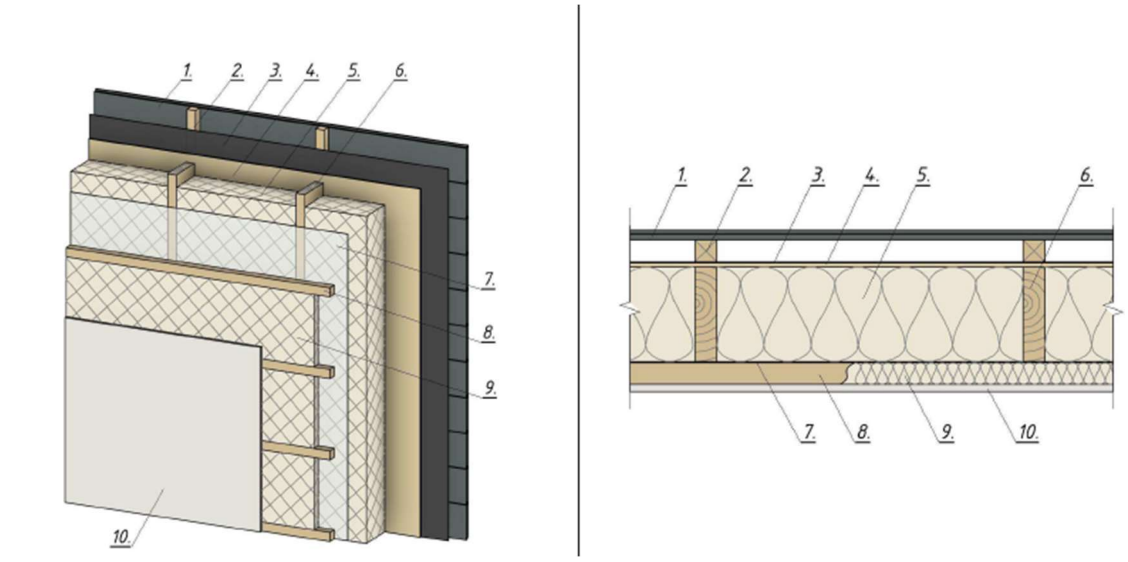

Figure 5. Frame wall: facade timber board (20 x 195 mm), 2 – timber frame (45 x 45 mm, spacing 400 mm), 3 – membrane, 4 – plywood (9 mm), 5 – insulation (200 mm), 6 – timber frame (45 x 195 mm), 7 – vapor barrier, 8 – timber frame (45 x 45 mm, spacing 400 mm), 9 – insulation (50 mm), 10 – gypsum board (15 mm).

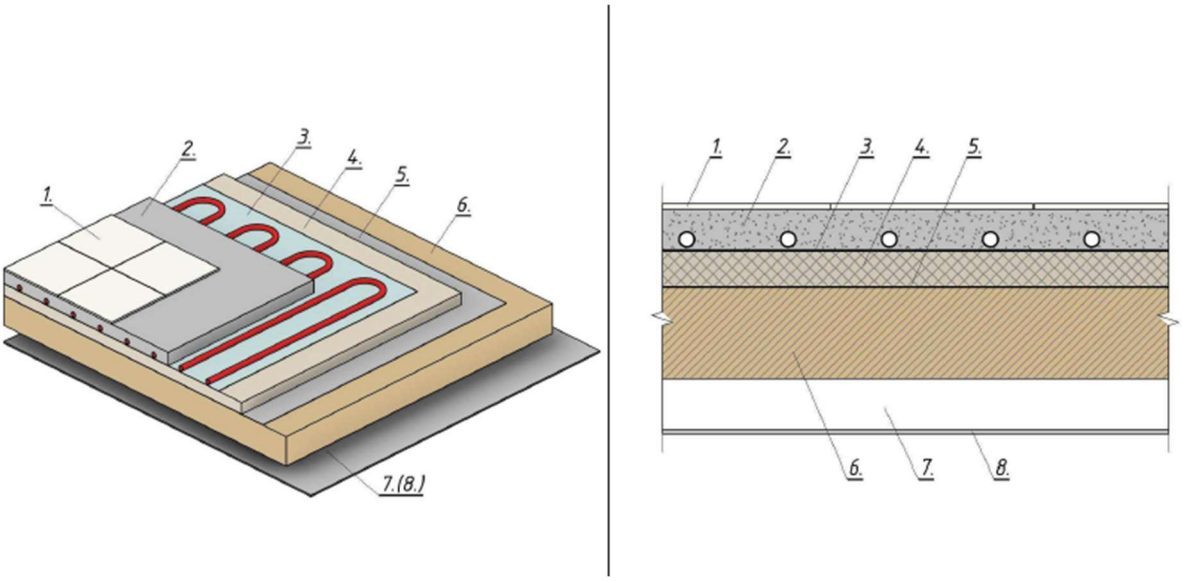

Figure 6. Indoor overlap: 1 – porcelain tile (20 mm), 2 – cement-sand screed (80 mm), 3 – plastic film, 4 – wood-fiberboard (50 мм), 5 – membrane, 6 – CLT plate (180 mm), 7 – suspended ceiling (75 mm), 8 – gypsum board (9 mm).

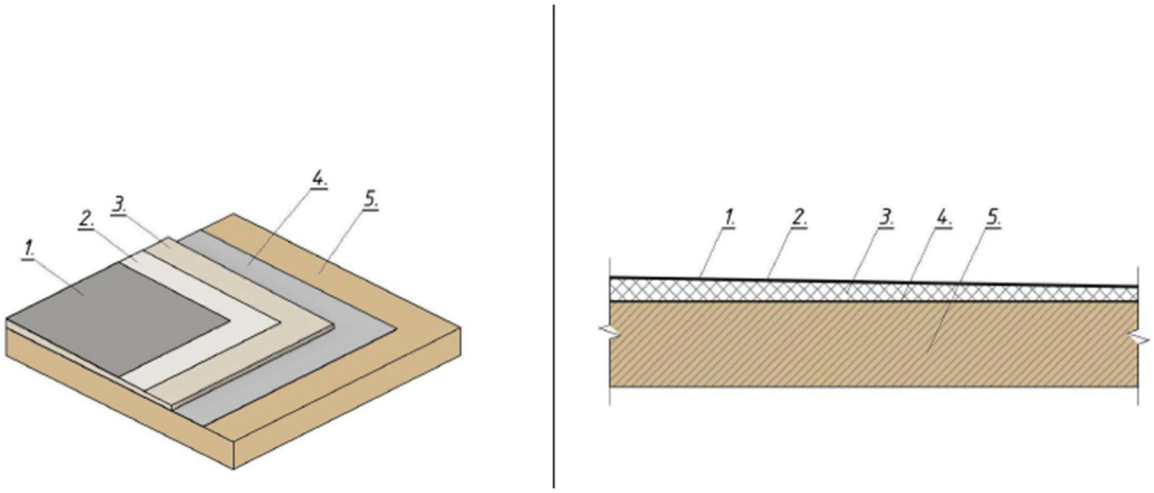

Figure 7. Outdoor overlap: 1 – roof PVC membrane, 2 – geotextile, 3 – PIR slope-forming plates 4 – membrane, 5 – CLT plate (160 mm).

Both structures were drawn in WUFI 2D graphic mode with actual sizes (Figure 8-9).

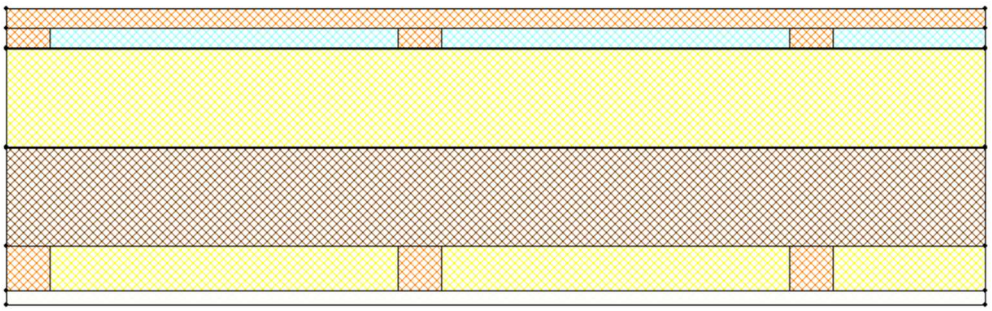

Figure 8. Structure 1 – WUFI 2D Geometry

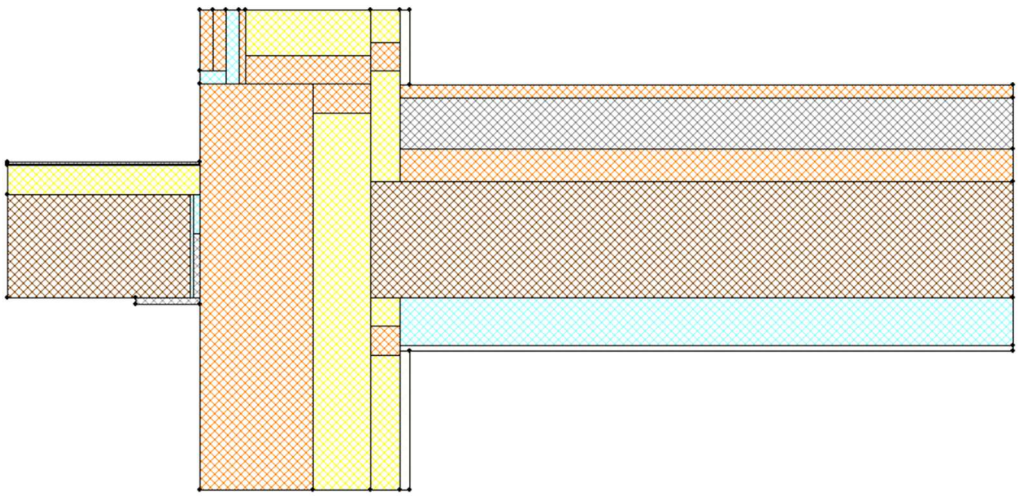

Figure 9. Structure 2 – WUFI 2D Geometry

3.2.2 Material properties

Material properties were chosen from the WUFI library according to the suitable materials. The list of materials is shown on the Figure11.

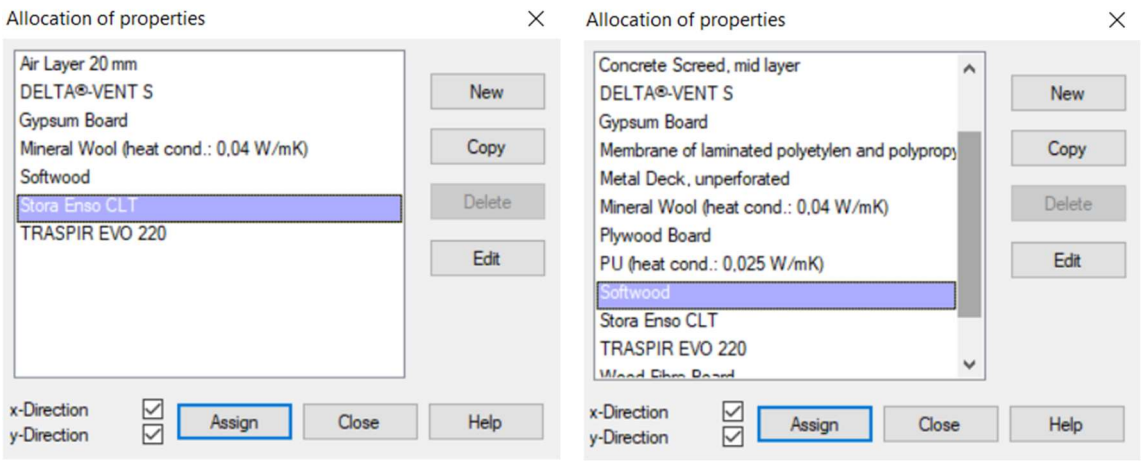

Figure 10. Materials used

3.2.3 Climate conditions

In WUFI 2D climate conditions are set to borders of structures. The borders from cutting sides are calculated as adiabatic (no heat and moisture movement). Outdoor and indoor climate parameters are assigned according to the orientation of the structure (Figure 11-12)

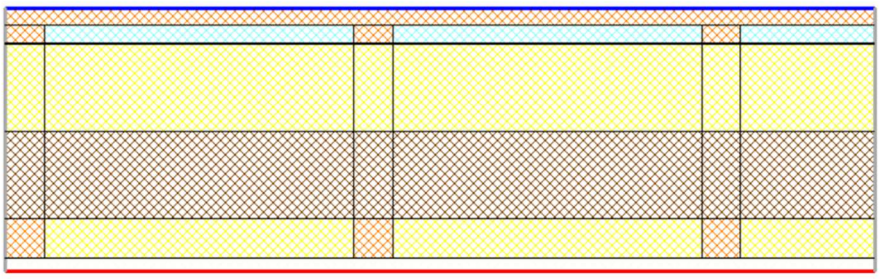

Figure 11. Surface conditions (Structure 1): blue line – outdoor surface, red line – indoor surface

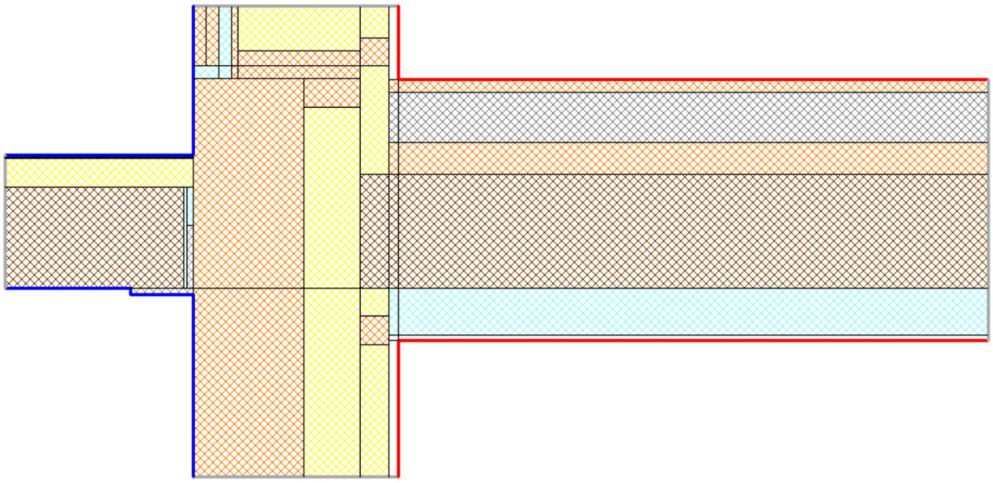

Figure 12. Surface conditions (Structure 2): blue line – outdoor surface, red line – indoor surface

The edges that were cut are assigned as adiabatic borders. Therefore, no temperature or humidity movement is allowed in these directions.

Outdoor climate should be assigned according to actual construction place. Lappeenranta, Finland was chosen in current study. The WUFI Map does not include Lappeenranta and thereby the outdoor climate was assigned according to imported open data [000] to WUFI. The data included hourly values of temperature and relative humidity for 2021 year. Exterior climate in graphic view is presented on Figure 13.

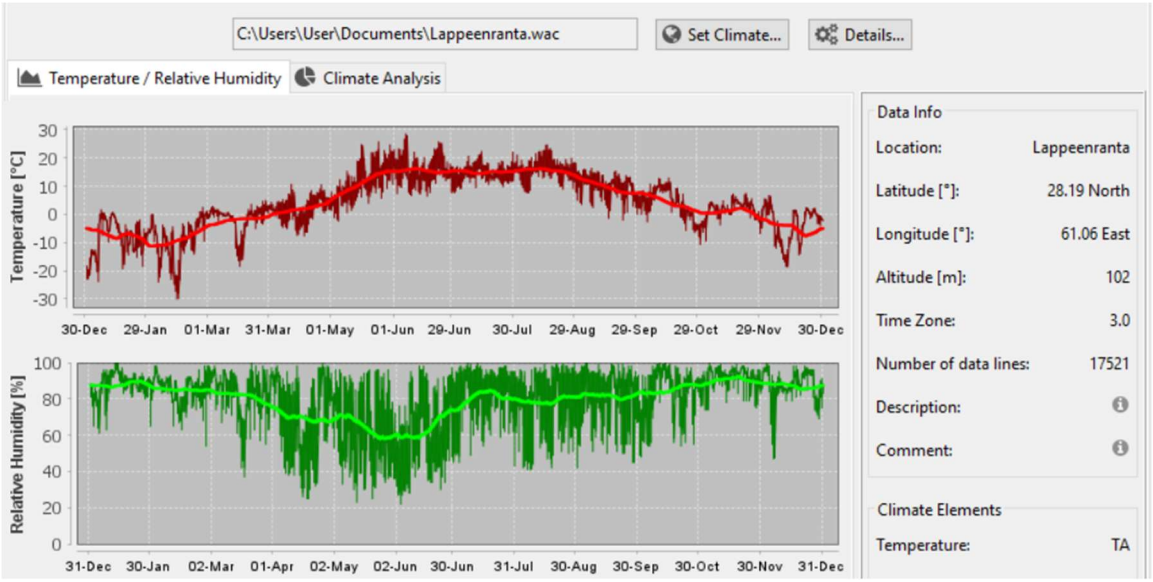

Figure 13. Exterior surface

Indoor climate is assigned via sine curves with mean value of temperature: 21 degrees above zero and mean value of relative humidity 80% (Figure 14).

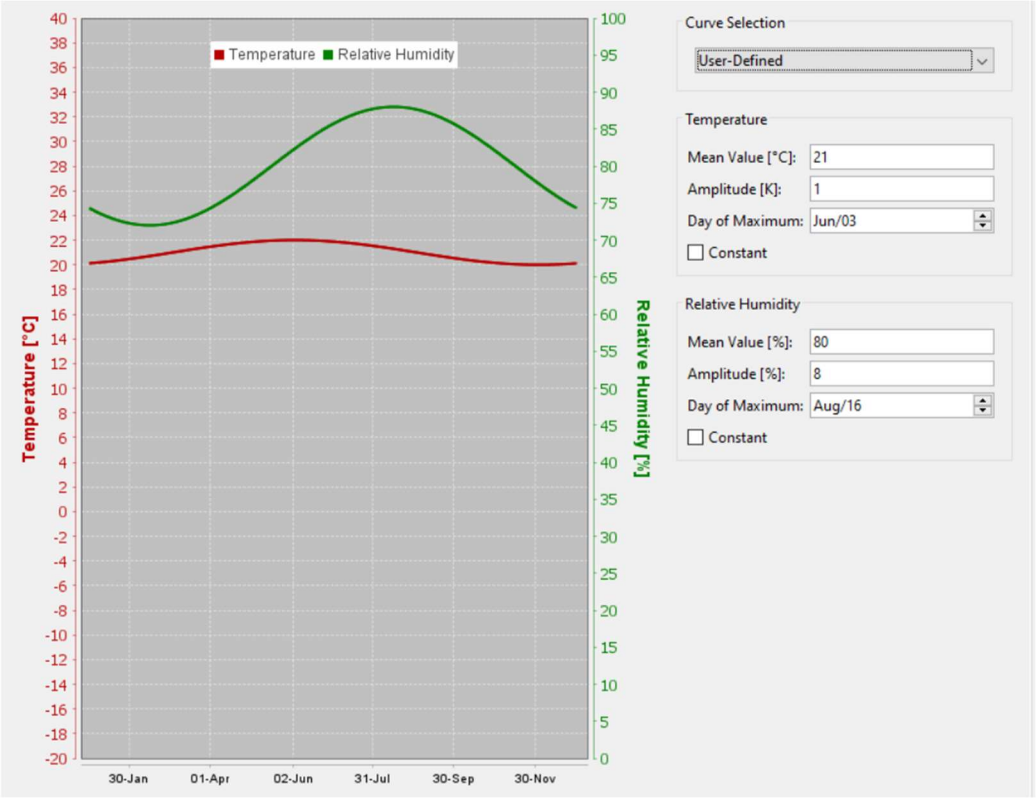

Figure 14. Indoor surface

3.3 Results analysis

3.3.1 WUFI Results

The parameters of calculation were set up according to number of imported time steps – 8760 steps. The results are assessed in graph mode in WUFI.

The temperature and relative humidity graphs for CLT in structure 1 and isopleths for the indoor CLT slab, outdoor CLT slab and a part of frame in Structure 2 are presented in Appendix 1. Isopleths show the RH and Temperature values at the same graph during the time. An example of calculated isopleth is shown on Figure 15.

WUFI 2D allows to assess the area of construction. For the final evaluation of mould risks the most preferable points for mould growth were chosen: with higher humidity levels. The exact points are stated in description for Figures in Appendix 1.

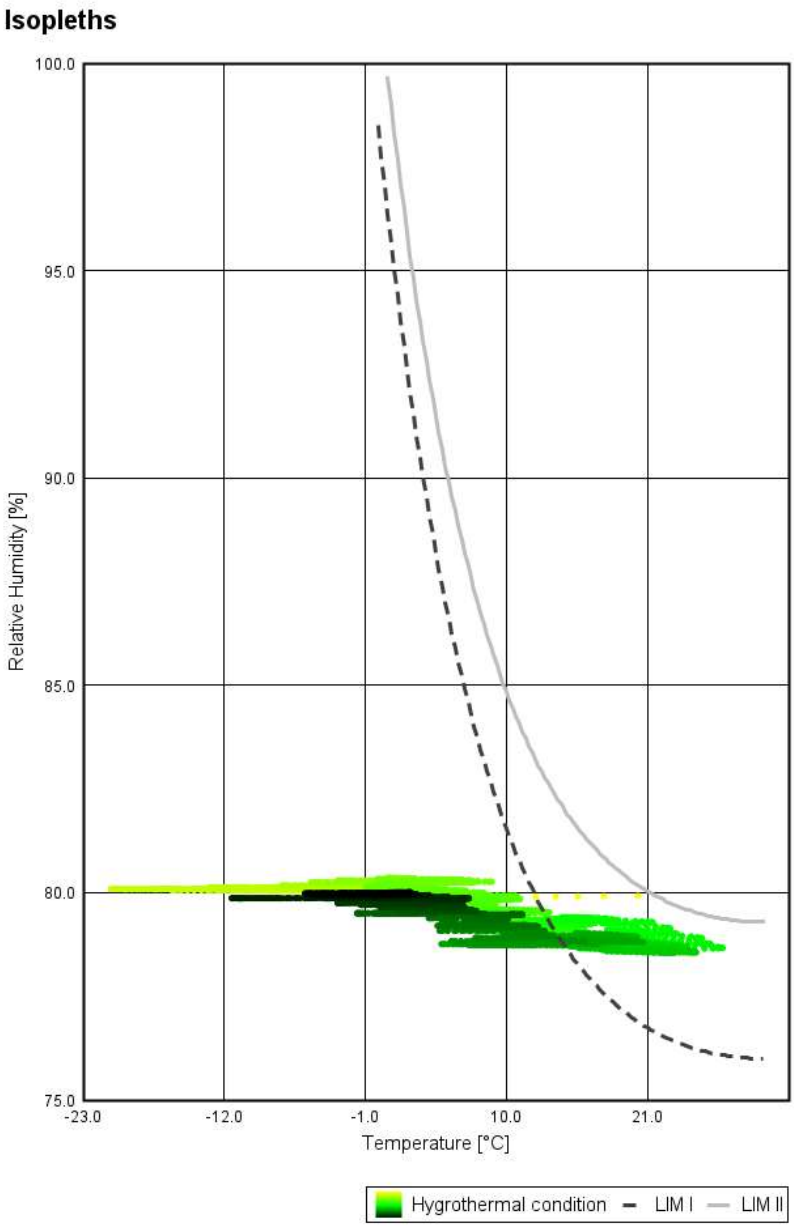

Figure 15. Example of isopleth (the indoor CLT slab)

LIM on graph is the Lowest Isopleth for Mould which shows the border between zone of relative humidity and temperature where mould can growth and where there is no mould activity. Therefore, under the LIM there is no risk of mould growth. LIM I and II are values for different substrate categories. Timber materials belong to group II.

All final graphs show that there is no risk of mould growth in CLT in both modelled structures. However, there are values of suitable for mould growth conditions in isopleth for timber frame elements of Structure 2. To assess the risk of mould growth according to Finnish Mould Growth Model results should be exported from WUFI to Excel file of FMGM. Instructions for correct export are presented in Appendix 2.

4 Calculating and evaluating the mould index according to Finnish mould growth model in Excel

4.1 Calculation in Excel file

The results from WUFI 2D were exported to Finnish mould growth model excel file according to the instruction presented in Appendix 2.

The only parameters which should be assigned in the FMGM file are:

- Temperature and Relative humidity during the time
- Sensitivity classes according to the materials: for the CLT slabs there were assigned class 2 (sensitive), for the framing – class 1 (very sensitive)
- Decline class according to the material: for the CLT slabs there were assigned decline factor 0,25 (relatively low decline), for the framing – decline factor 0,5 (significant decline)

4.2 Final results

Finally, after calculating in FMGM file mould index should be assessed. The result graphs are shown on Figures 16-19. As it was mentioned earlier, CLT in all cases do not have risk of mould growth.

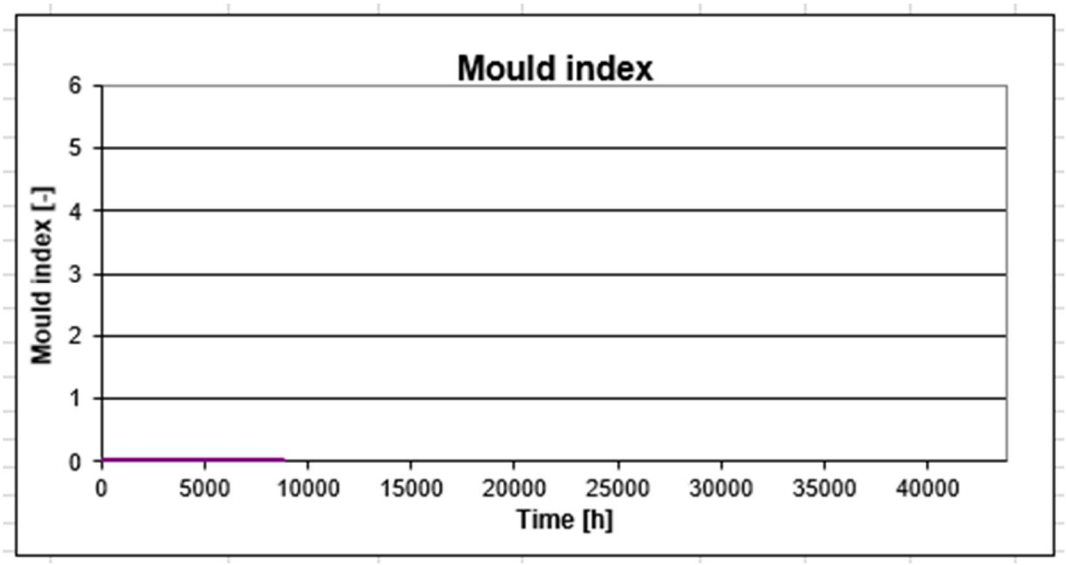

Figure 16. Structure 1 - CLT

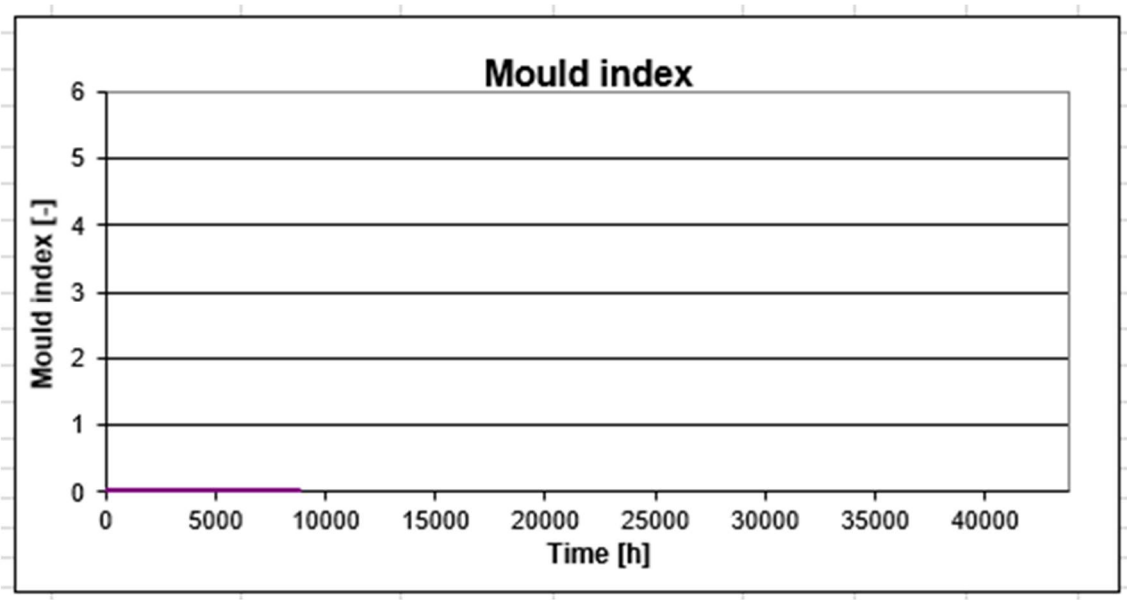

Figure 17. Structure 2 – indoor CLT slab

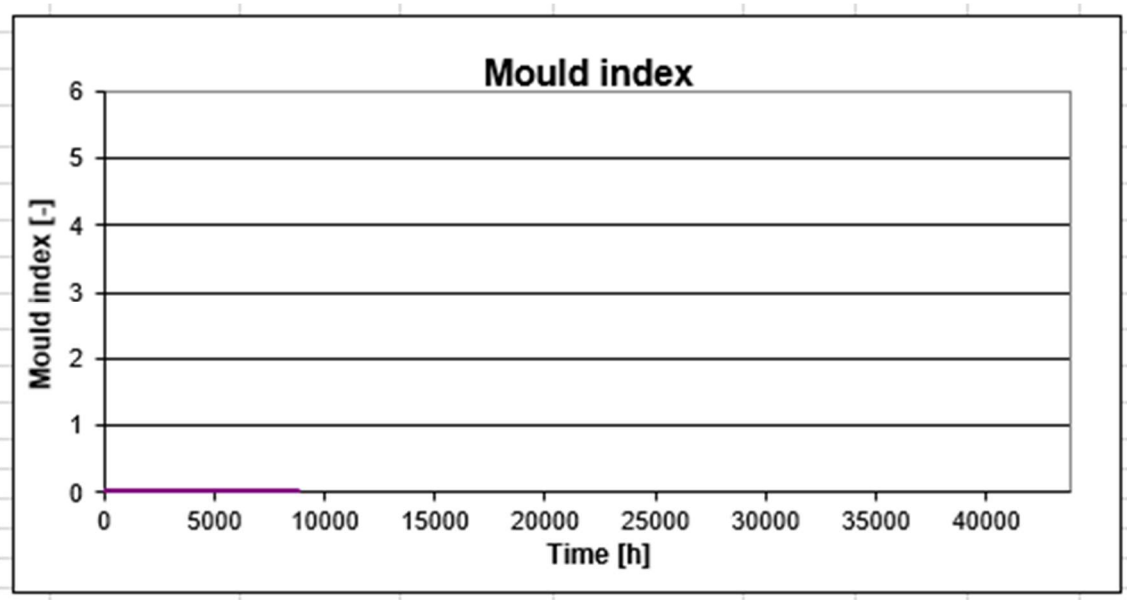

Figure 18. Structure 2 – outdoor CLT slab

Figure 19 shows the value of mould index in timber frame but still this value is less than 1 which means that the surface of material stays clean and no growth of mould is seen with a microscope.

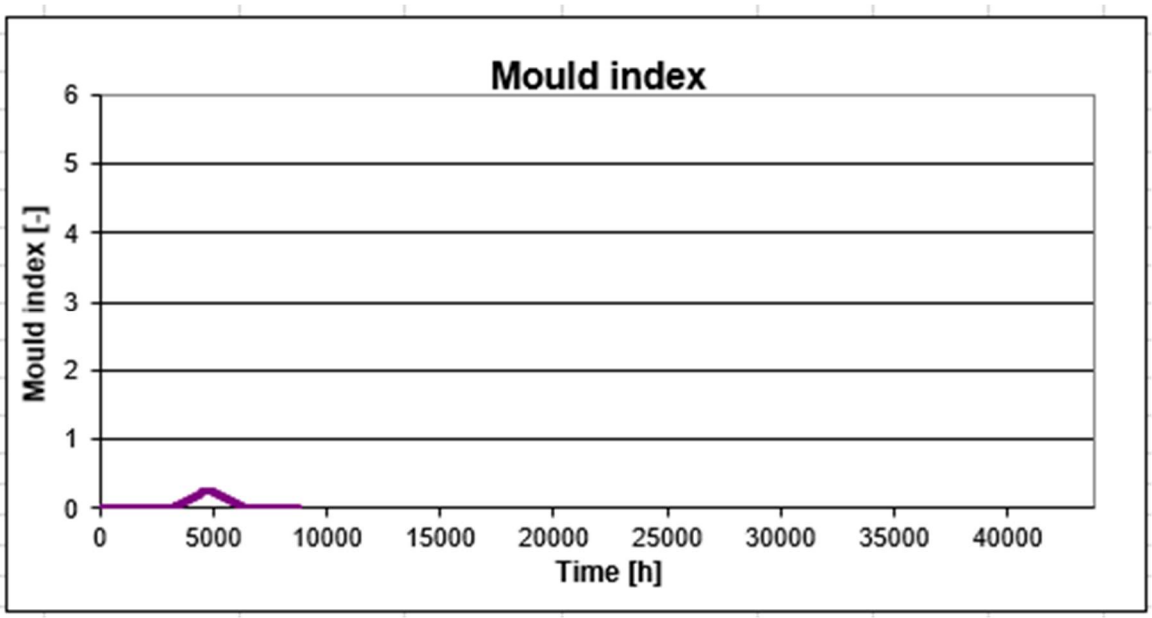

Figure 19. Structure 2 – timber framing

Assessing the risks of mould growth via the presented model do not allow to define an exact amount of mould which can appear on the surface of inspected material under the environment conditions through the time. As it is seen on the Figures 16, 17, 18, 19, the only parameter which shows the mould risk is changing value of mould index during the time.

However, due to the complexity of the Finnish mould growth model described in this thesis work, its ability to take into account all the main parameters of materials which affect the mould risk, the ruslts can be considered as an accurate explanation of mould risk.

Besides the fact that inspected materials in this work have zero mould index, do not have risk of mould growth and have no values of the area covered by mould, FMGM is able to give values of the area size relatively to the whole area of surface which will be covered by mould in case of mould index values ranging between 2 to 6. These area sizes allow to assess the problem about mould, predict extent of pollution appeared by mould and reduce risks at the design stage.

5 Summary

Modern software tools allow to solve lots of problems connected with building design: architectural design in 3D modelling programs, structural design in calculation programs. Hydrothermal design is also one of the tasks which can be made using modern software tools.

Nowadays, the amount of researches, articles, modelling principles is sufficient for accomplishing calculations, analyzing the hydrothermal state of constructions and assessing the risks of mould growth. The only problem that still exists is integration data from one program to others: lack of clear instructions and engineering exchange of experience slows down the usage of existing tools. This thesis shows the way of integration data from WUFI into Finnish mould growth model file.

The main question that arose throughout the work was how hydrothermal parameters of exact materials in construction can be calculated in WUFI 2D and how the results of these calculations can be applied to Finnish mould growth model. This thesis work gives the instructions about sources of information necessary for calculations, explains main calculation steps and gives instructions about interaction between WUFI 2D and Finnish Mould Growth Model. All instructions are presented in text, appendices and also are presented in presentation format for LAB University of Applied Sciences.

The presentation can be used as a manual for calculations in WUFI 2D and result assessment in FMGM. Presentation is designed for being a property of LAB University of Applied Sciences and can be used as a learning material.

Calculated examples showed positive results of hydrothermal state of structures with CLT. The value of Mould Index is 0 for all modelled structures which means that the surfaces of materials will be clean at given climate parameters and risk of mould will be avoided. This fact confirms the correctness of designed solutions for building envelope and gives opportunity to use such kind of structures in similar weather conditions.

Generally, the experience of applying results of WUFI calculations to FMGM covered in this work can be used in everyday design practice due to its simplicity and assurance of evaluation. Finnish Mould Growth Model is an open data source therefore it can be downloaded from the webpage of Tampere University being easily accessible. Moreover, this kind of assessing the risks allows to take into account the majority of material properties, climate parameters of indoor and outdoor environment.

One of possible ways for developing and improving calculations of mould risk is integration of FMGM directly to WUFI software for finding the mould index straight to the program without using additional Excel files. This solution will lead to simplification of big data assessment and make calculations more efficient.

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Appendix 1. Temperature, Relative Humidity and Isopleths

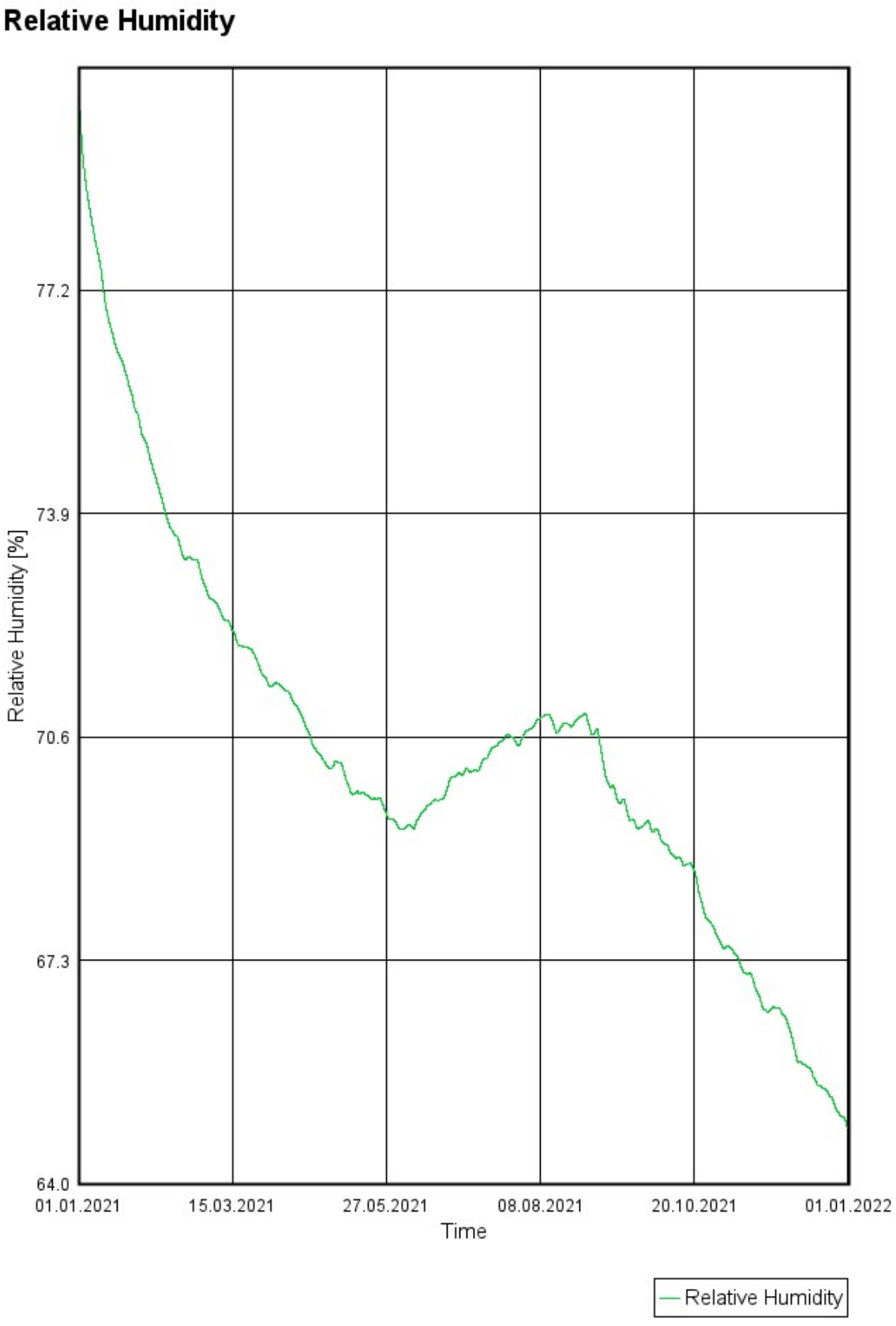


Figure 20. Structure 1 – outer surface of CLT slab (relative humidity)

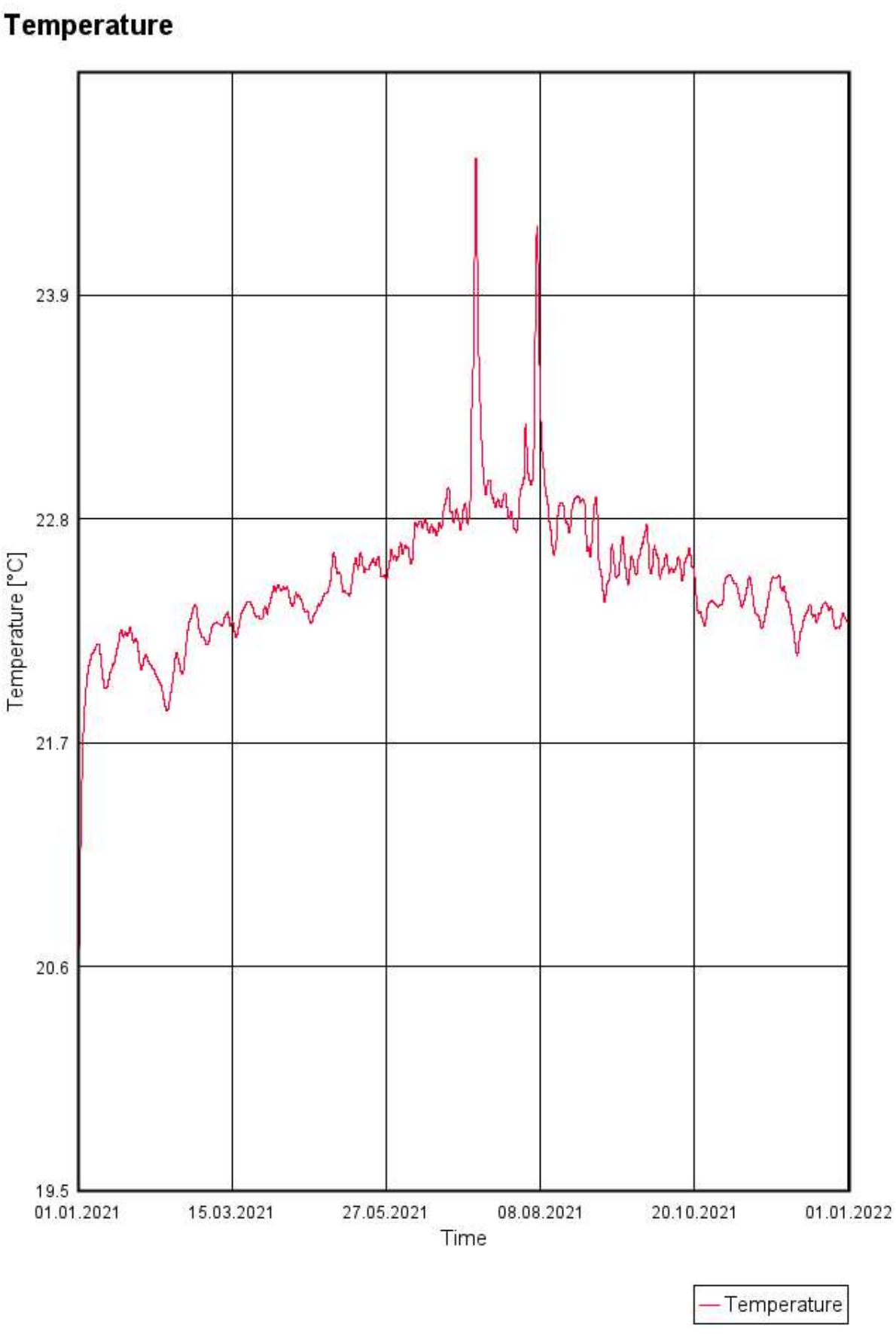


Figure 21. Structure 1 – outer surface of CLT slab (temperature)

Isopleths

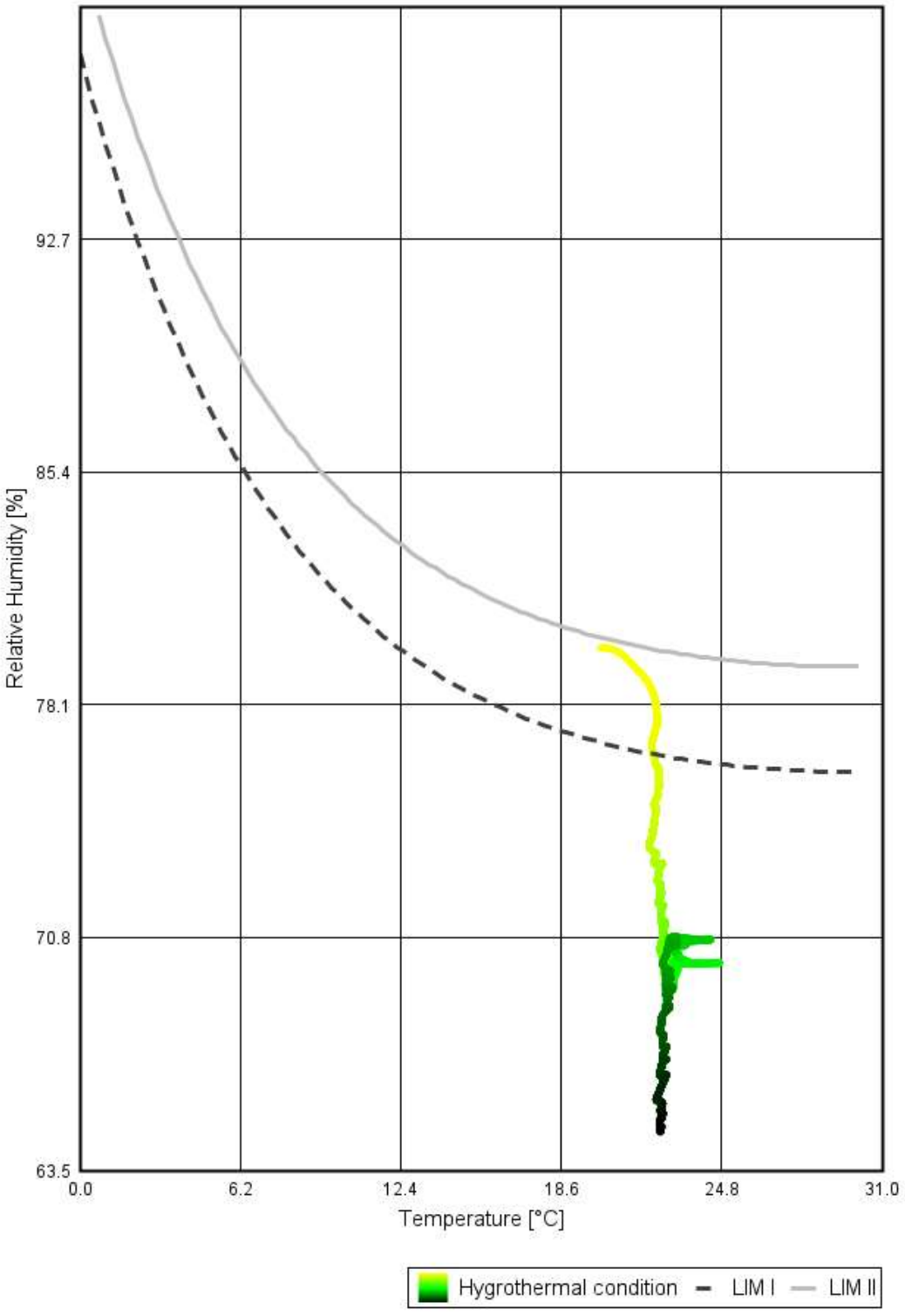


Figure 22. Structure 2 - outer surface of inner CLT slab

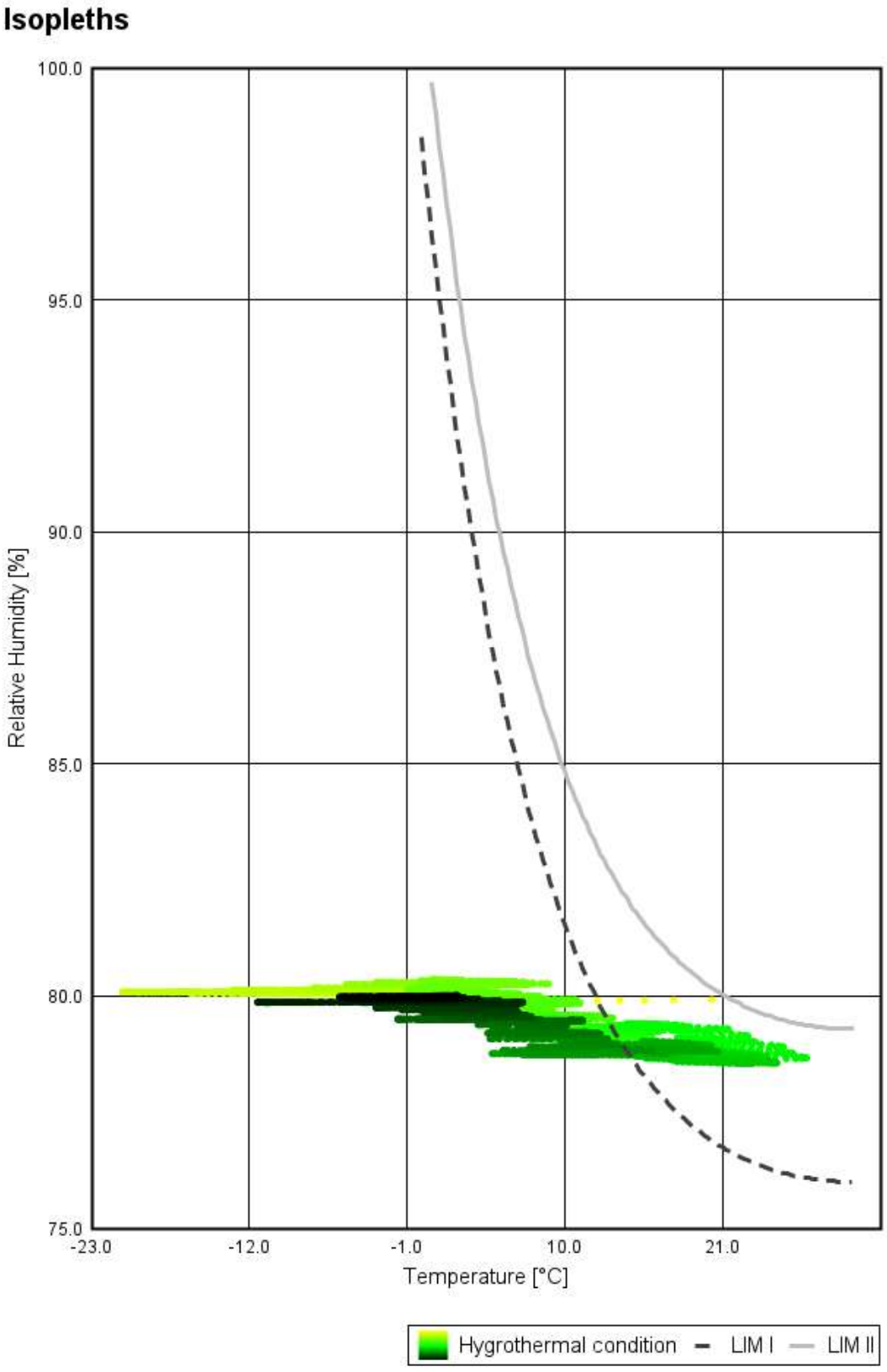


Figure 23. Structure 2 - outer surface of outer CLT slab

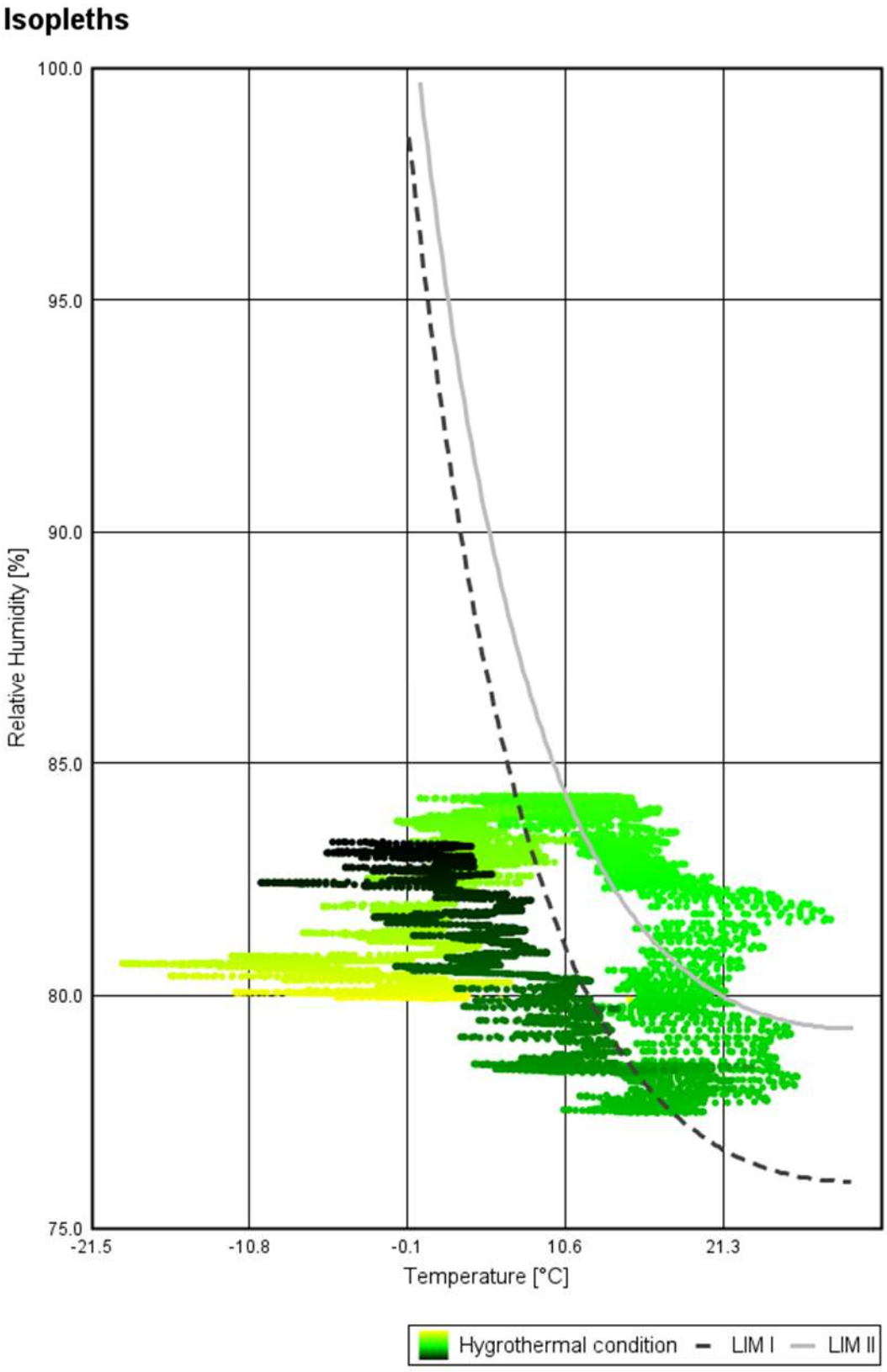


Figure 24. Structure 2 – outer surface of timber frame in the border between timber and insulation

Appendix 2. Instruction for exporting the results from WUFI 2D and importing it to Finnish mould growth model file

In order to use the results from WUFI 2D in Excel file for calculating the mould index it is needed to export the data from the results page in WUFI Graph as a .txt file.

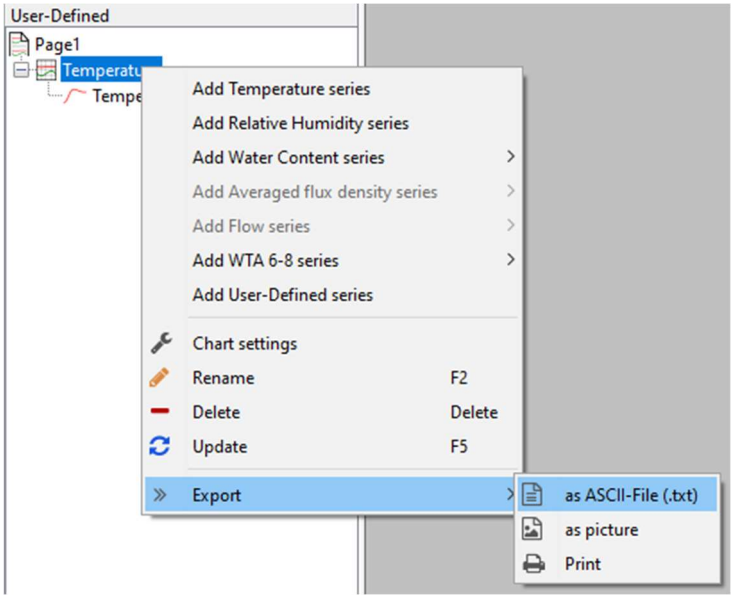
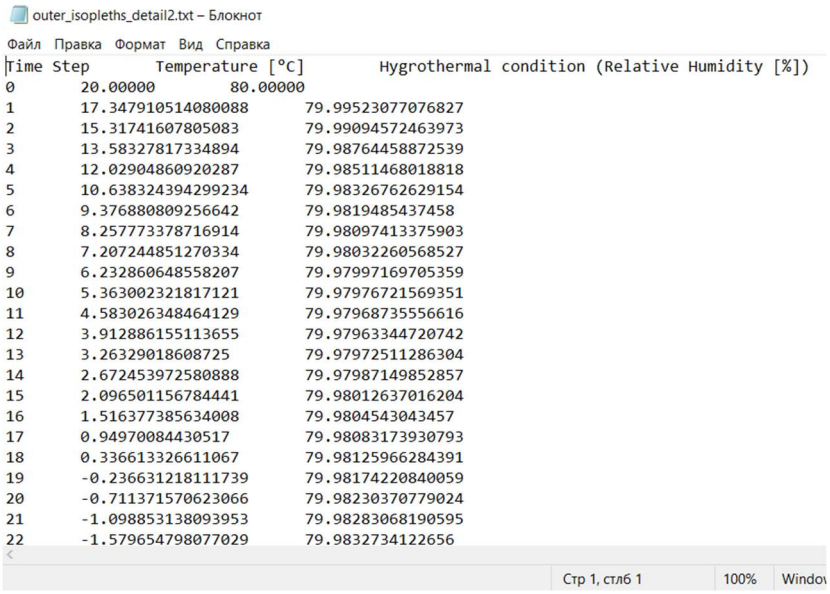


Figure 25. Export .txt file

It is crucial to check the dividing symbols in numbers. They should be the same as used in Excel program. Default symbol in results file is dot, but default symbol to divide the integer part in Excel is comma. To change the symbol in the whole .txt file the combination of keys “CTRL+H” can be used. Degrees



outer_isopleths_detail2.txt – Блокнот

Файл Правка Формат Вид Справка

Time Step	Temperature [°C]	Hygrothermal condition (Relative Humidity [%])
0	20.00000	80.00000
1	17.347910514080088	79.99523077076827
2	15.31741607805083	79.99094572463973
3	13.58327817334894	79.98764458872539
4	12.02904860920287	79.98511468018818
5	10.638324394299234	79.98326762629154
6	9.376880809256642	79.9819485437458
7	8.257773378716914	79.98097413375903
8	7.207244851270334	79.98032260568527
9	6.232860648558207	79.97997169705359
10	5.363002321817121	79.97976721569351
11	4.583026348464129	79.97968735556616
12	3.912886155113655	79.97963344720742
13	3.26329018608725	79.97972511286304
14	2.672453972580888	79.97987149852857
15	2.096501156784441	79.98012637016204
16	1.516377385634008	79.9804543043457
17	0.94970084430517	79.98083173930793
18	0.336613326611067	79.98125966284391
19	-0.236631218111739	79.98174220840059
20	-0.711371570623066	79.98230370779024
21	-1.098853138093953	79.98283068190595
22	-1.579654798077029	79.9832734122656

Стр 1, стлб 1 100% Windo

Figure 26. Initial exported .txt file

Firstly, to import data from txt file to Finnish mould growth model file it is highly recommended to use one more excel file to keep only the results and check the correct format. In order to export the data create a new Excel file and press: Data/From Text/CSV.

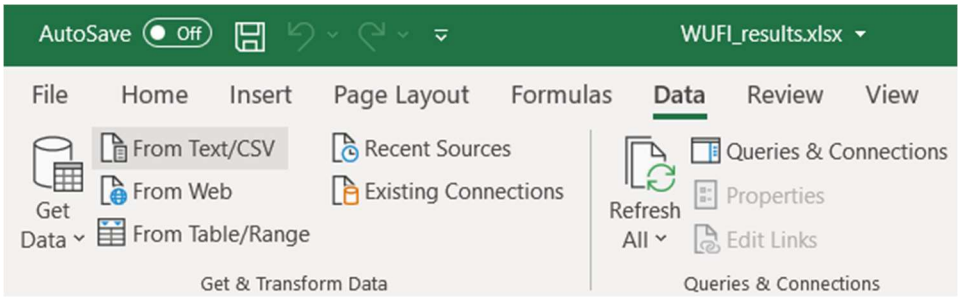


Figure 27. Export from Text/CSV

Check the appearing window with the preview of the table. If needed, change the parameters of delimiter, data type or transform data using the button underneath. Then import can be made by the button Load.

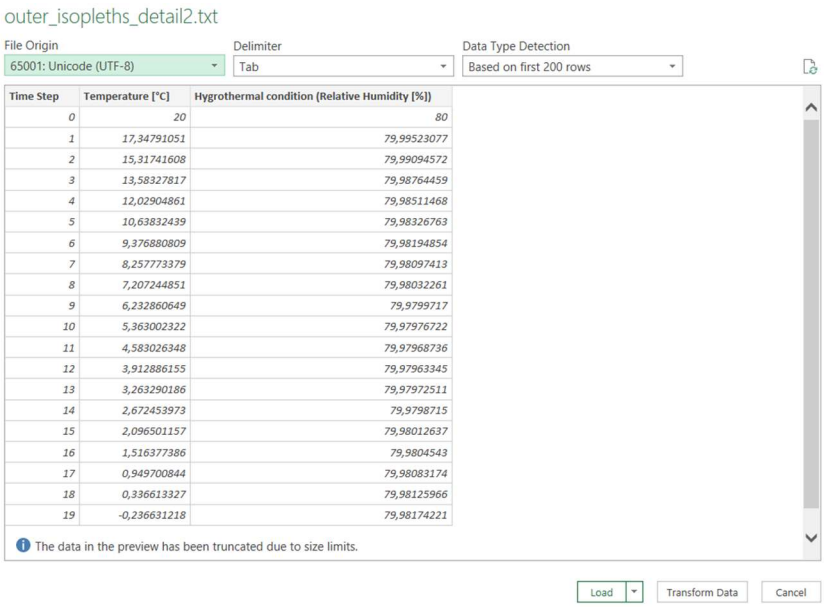


Figure 28. Preview of the table

The resulting table should include the separate columns with temperature and relative humidity. A comma should be used as a dividing symbol.

	A	B	C
1	Time Step	Temperature [°C]	Hygrothermal condition (Relative Humidity [%])
2	0	20	80
3	1	17,34791051	79,99523077
4	2	15,31741608	79,99094572
5	3	13,58327817	79,98764459
6	4	12,02904861	79,98511468
7	5	10,63832439	79,98326763

Figure 29. Table with the imported results

Secondly, all data from the temperature and relative humidity columns should be copied using the combination CTRL+C and pasted to the FMGM Excel file using the combination CTRL+V.

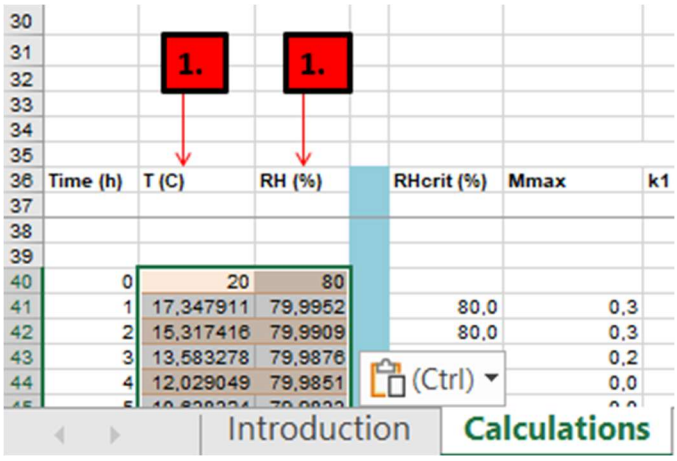


Figure 30. Importing the data to FMGM Excel file