

Project no.: 637268
Project full title: Robust Internal Thermal Insulation of Historic Buildings
Project Acronym: RIBuild
Deliverable no.: D6.1

Title of the deliverable:	Web tool including feasibility study of possible input and output data
Contractual Date of Delivery to the EC	30.06.2020 (M66)
Actual Date of Delivery to the EC	01.07.2020 (M66)
Organisation name of lead contractor for this deliverable	DTU
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Work package contributing to the deliverable	WP6
Nature	R
Version	1.0
Total number of pages	36
Start date of project	01.01.2015
Duration of project	30.06.2020

Abstract:

This report describes the final version of the RIBuild Insulation Calculator tool for evaluating internal insulation of solid walls. In summary, the tool collects aggregates and presents the simulated data described in deliverable D6.5. Sorting- and filtering-functions helps the user to quickly find the right data and to get insight about the possibilities for internal insulation. In a test of the tool, the outcome was comparable with the outcomes of simulations with DELPHIN and WUFI, although the tool has many gaps, resulting in considerable deviations in a few points. The outputs are therefore useful but the user should therefore be aware of the shortcomings. Filling the gaps by supplementing with millions of simulations is not realistic instead the tool should be further developed by using a machine learning through using a meta-model.

Keyword list: Simulations, filter, user inputs, test, probabilistic.

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Abbreviations

API	Application Programming Interface
D	RIBuild Deliverable
DB	Database
HDD	Heating Degree Days
HDH	Heating Degree Hours
ICT	Insulation Calculator tool (WP6 web tool)
MongoDB	Mongo Database – most popular type of document-oriented NoSQL database
MySQL	Popular type of SQL database
NoSQL	Not Only Structured Query Language
PHP	General-purpose scripting language, well suited to web development
RDBMS	Relational database management system
SQL	Structured Query Language.
UI	User Interface
UX	User Experience

1 Executive Summary

A practical outcome of the RIBuild project is the Insulation Calculator Tool (ICT), described in this deliverable. The tool is accessible from the RIBuild website www.ribuild.eu and is intended to be the next step the user takes after having followed the guidelines on the website on how to determine whether a specific building is suitable for internal insulation. The ICT is planned to be used by a non-professional building owner who does not necessarily have any pre-existing knowledge about internal insulation but who is interested and able to investigate the building renovation options if the information available is not too technical.

The user can make nine different inputs in the tool, by typing information, and by using checkmarks and sliders. The basis for the ICT is a large number of precalculated simulations, performed in Delphin. The user input filters the simulations and the result is shown as different solutions with outcomes describing risk of mould and algae growth, minimum internal surface temperature, U-value and heat loss.

The simulations are sampled by the Sobol method, which is a probabilistic approach. Consequently, the results can be shown with uncertainties. If the user is especially interested, it is possible to see the result of each simulation that the total result is based on. This gives the more skilled an opportunity to understand why there might be considerable variations in the results.

The ICT contains 275.000 simulations, unfortunately, this is not enough; there are major gaps when the ICT is used. To avoid major gaps it is estimated that approximately 10 million simulations would be necessary. It is not realistic to perform that many simulations although the process is automated. Instead, the further development of the ICT should be based on applying a meta-model to the already performed simulations and through machine-learning fill in the gaps.

The ICT has been tested on cases known from RIBuild WP3. The output parameters from the ICT has been compared to deterministic simulations performed with WUFI and DELPHIN and with results from the case studies. Although there are gaps and some of the results differ considerably, the overall impression is that the ICT, in its current state, gives valuable information to the user, although the algae growth may be overestimated. The user must be aware of the shortcomings of the tool at its current state.

2 Introduction

In the RIBuild project, many aspects of internal insulation have been investigated. An important part of this has been to make sure that practitioners would benefit from the findings. One way of obtaining this is to develop a web tool that can be directly used by practitioners, when they want to predict the implications of adding internal insulation to a solid wall. This deliverable describes such a tool, here called Insulation Calculation Tool (ICT).

The basis for the tool can be found in most of the other deliverables from WP1, 2, 3 and 4. WP5 has not been used for this deliverable, as WP5 contains a stand-alone LCA tool. The most common constructions were found in WP1, issues on relevant materials, their properties and their importance were found in WP2. Data from WP3 has been used for testing the ICT (Section 5), and the probabilistic sampling method was described in WP4.

The main idea was to create a web tool where a building owner with only little knowledge on building physics by entering a few data on a specific building could get an idea of how a specific solid wall would perform after being internally insulated. Focus should not only be on energy savings but also on moisture related issues like mould and algae growth. The needed data should be easy to find and not require extra tests in the lab. The prerequisite would be that the user had checked the building according to the guidelines given at the website www.ribuild.eu and found it suitable for internal insulation. The ICT is just for preliminary assessment; it cannot replace professional assessment by experts, but give the owner an idea of whether it might be a good idea to proceed with plans of applying internal insulation.

The deliverable first describes how the ICT looks when the user first sees and uses it; main features are briefly described (Section 3). Hereafter the more technical descriptions of how the ICT was build follow (Section 4).

A test of the ICT is presented in Section 5, the outcome of the tool is compared to outcomes of deterministic simulations with WUFI and DELPHIN on projects described in WP3, therefore more precise simulations are also available on the same projects. Finally, the ICT is discussed and suggestions for improving the tool is given (Section 6).

3 User Interface and Experience (UI and UX)

3.1 The User

The Insulation Calculator (ICT) tool and website is designed for a non-professional building owner, who does not necessarily have any pre-existing knowledge about internal insulation but who is interested and able to investigate the building renovation options if the information available is not too technical. Both the website and the ICT are designed for this type of user, trying to guide the user through any complex topics. In the ICT, this is evident by the introduction text and the information text appearing upon 'hovering' over the many information icons illustrated by a question mark in light blue circle. In fact, all inputs and outputs have a short information text to help the user understand every input and output in the tool. The information texts are partially included in descriptions in section 3.3 and 3.4. The more professional user may also find interest in the information given by the tool, as information on each relevant simulation is accessible, which can help the experienced user to understand the variety of outcomes.

3.2 Design and layout

The Insulation Calculator tool (ICT) layout has search filters in a vertical menu on the left and the results summarized in horizontal grey 'cards' at the right with the option to click a button for additional information (Figure 1). The layout is inspired by the flight search engine momondo.com, having successfully used this layout for years.

The vertical menu on the left contains various input to filter out non-relevant results, decrease the variance and quickly find the simulated data for the given building currently investigated. Each grey card with a result corresponds to a specific insulation, e.g. 90 mm Phenolic Foam with a thermal conductivity of 0.02 W/(m K).

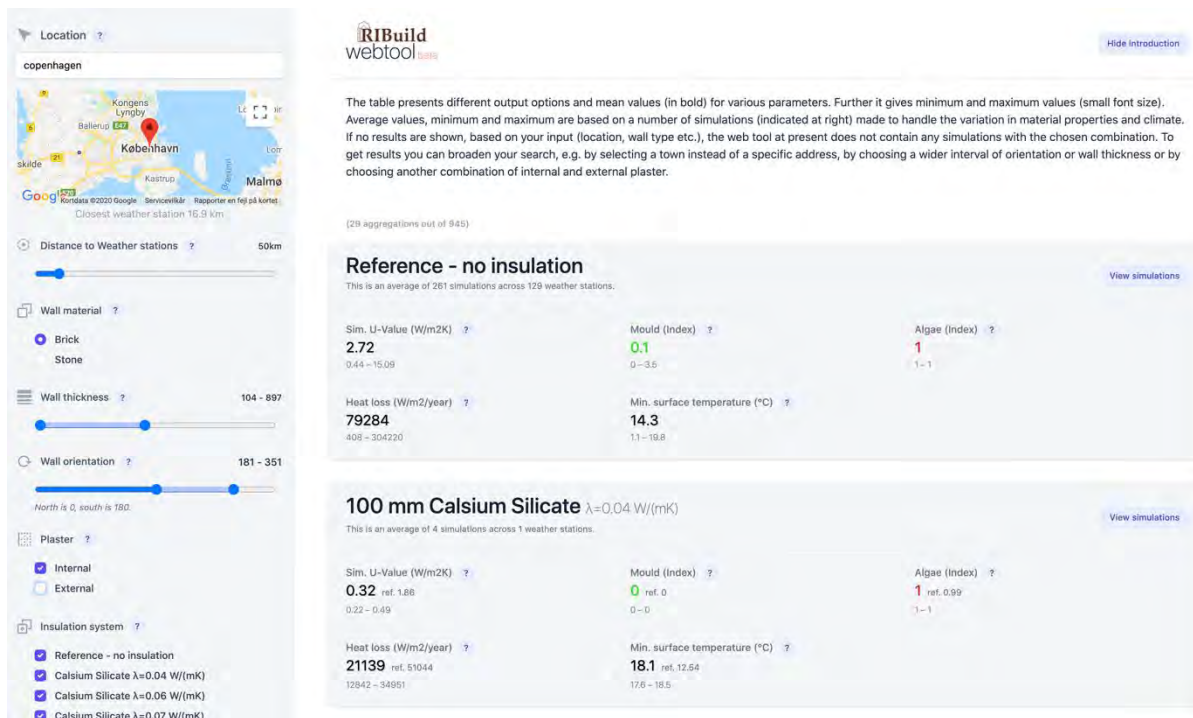


Figure 1: RIBuild Insulation calculation tool – screenshot June 2020

3.3 The Results – performance outputs

Each grey card contains five main results (performance outputs) expressed as averages of U-values, mould index, algae index, heat loss and minimum internal surface temperature. The averages are calculated from the simulations to match the type of insulation (thickness and material) and user inputs. Averages are used since most databases including MySQL has a build-in function to quickly find averages. In theory, the median number would be the best way to present the five main results, but medians are not possible to find quickly in the most common databases. It would have taken multiple seconds thereby decreasing the user experience. In comparison, searching using averages only takes about 200 milliseconds. A search is done every time the user changes any input.

On the top right of each card is a button named ‘View simulations’ which opens a table with all the individual simulations. Figure 2 shows a single card where the user has pressed the ‘view simulations’ button. Beside the five performance outputs, the table shows the name of the weather station, the wall width, wall orientation and the rain factor for each row. A row represents a single Delphin simulation. While a lot of information is presented, not all information is, e.g. the uncertainty parameters, the specific type of wall material, etc. described further in deliverable D6.5.

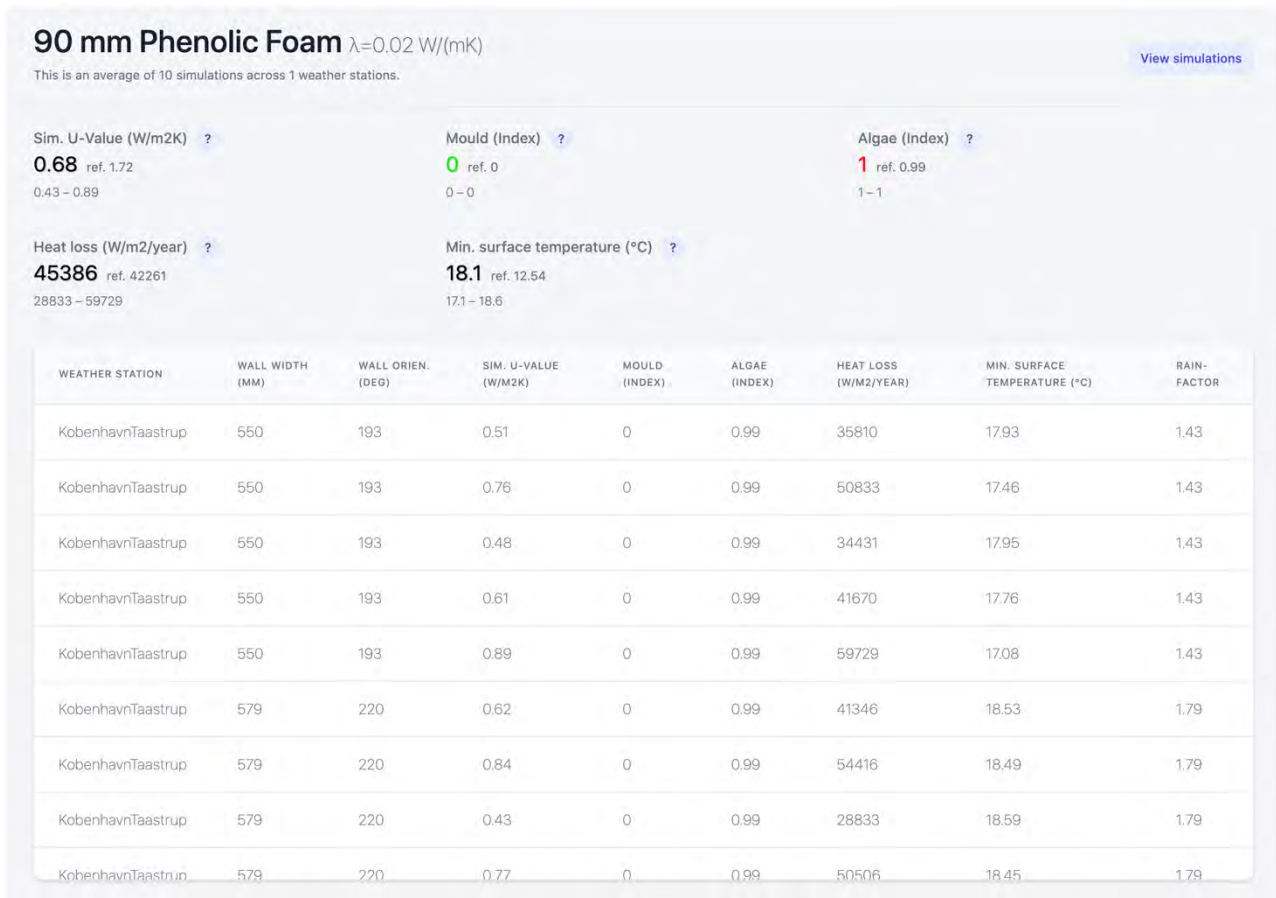


Figure 2: A single card where the user has pressed the 'view simulations' button

3.3.1 Simulated U-value (W/(m²K))

Requirement for the simulated thermal resistance (W/(m² K)) or simulated U-value of the wall is usually specified in building regulations and based on climatic zones. A low U-value corresponds to a low heat loss. Note, that the U-values are simulated concurrently with the hygrothermal simulations and not calculated after the simulation ended, like some of the other performance output.

3.3.2 Mould (index)

A number on a scale from 0 (no mould) to 6 (extensive mould growth) indicating the risk for mould growth between the existing wall and the internal insulation. This is based on a complex interaction between environmental factors (relative humidity and temperature) and duration, material properties and the characteristics of mould fungi present, using the VTT model (Ojanen *et al.*, 2010; Ojanen *et al.*, 2011). Colour coding using green (low index), yellow (medium) and red (high) classifies the different solutions presented. The number given is the maximum value within a five-year simulation period. The low index (green) correspond to 1 and below while the problematic (red) correspond to 4 and above. Numbers between 1 and 4 are coloured by a linear gradient going from green to red, through orange in between. It can be discussed whether the chosen mould prediction model is correct for internal insulation, as the model is based on mould growth at surfaces surrounded by air, which is likely to contain dust i.e. organic matter. Here the model is used at an interface where there is no new

supply of organic material and the pH value is high, at least in the beginning, due to the cement containing glue mortar. As high pH value inhibits the mould growth, the model may overestimate the risk of mould growth (Jensen et al., 2020). To counter this the sensitivity class of the intersection has been set to “resistant” i.e. less sensitive than “moderate sensitive” which is often used for these materials.

3.3.3 Heat Loss (W/m²/Year)

Heat loss through the external wall per m² per year after being insulated. The lower the number, the higher the reduction compared to the situation before applying internal insulation. Heat loss is expressed for a homogenous part of the wall with no thermal bridges etc. Heat loss depends on the outdoor climate, i.e. a location in a cold climate corresponds to a high heat loss compared to a location in a warmer climate.

3.3.4 Algae (index)

A number on a scale from 0 (no algae) to 1 (full coverage) indicating the share of the exterior surface covered by algae. This is based on a complex interaction between environmental factors (relative humidity and temperature) and duration, and surface properties (porosity, roughness), based on Avrami's law improved into a modified model (Graziani, Quagliarini & D'Orazio, 2016a, 2016b; Graziani & Quagliarini, 2018). Colour coding using green (low index), yellow (medium) and red (high) classifies the different solutions presented. The number given is the maximum value within a five-year simulation period. The low index (green) is all indices below 0.1 and problematic (red) is indices above or equal to 0.5. Numbers between 0.1 and 0.5 are coloured by a linear gradient going from green to red, through orange in between. The general impression is that the algae prediction model may be overestimating the risk of algae growth, as most simulations end up with an Algae index close to 1.

3.3.5 Minimum Surface Temperature (°C)

Minimum temperature (°C) of the interior surface of the walls achieved within a five-year simulation period. The lower the temperature, the higher the risk of mould growth or condensation. The critical surface temperature depends on the location of the building and the indoor climate. The simulations are based on indoor climate EN 15026 class A and B (EN 15026, 2007). In both cases, indoor temperature goes from 20°C at 10°C outdoor to 25°C at 20°C outdoor. No change below 10°C outdoor or above 20°C outdoor. Class A: Relative humidity goes from 35 % at -10°C outdoor to 65 % at 20°C outdoor. Class B: From 40 % to 70 %. No change below -10°C and above 20°C.

3.4 User Input

All user inputs are located in a vertical menu on the left side. Nine different inputs enable the user to quickly find the simulations best suited for the investigated building renovation project. The results shown are automatically updated when the user changes any of the nine inputs. The nine inputs are:

- 1) building location
- 2) maximum searched distance to the nearest weather station
- 3) wall material

- 4) wall thickness
- 5) wall orientation
- 6) internal and external plaster
- 7) insulation system
- 8) insulation thickness
- 9) priority of output

In practice, the first eight inputs functions as filters, to hide any simulation not within the given input search criteria. The ninth input ‘priority’ functions as a multi-criteria sorting mechanism, to change the order of the ‘cards’ containing different insulation systems. The input is described further in Section 3.4.1 – 3.4.6.

3.4.1 Location and distance to weather station

The location is chosen by searching the address or city name where the investigated building is located. After searching the geographical location, it is presented on the map below the search field. The map also shows all the weather stations. The ICT location is used to find the closest weather station and hereby the simulations with the correct weather and indoor climate using (EN 15026, 2007), described further in deliverable D6.5. All weather stations are selected by default. The map feature is powered by Google maps JavaScript API (Google Javascript API, 2020).

The location input is coupled with a number slider, a second input returning the distance as a radius from the found location (latitude, longitude). All weather stations within this distance given by the number slider are included in the data set. The average result shown in the grey cards on the right may come from several locations depending on the location settings. The number of weather stations found is indicated under the heading in each grey card along with the number of simulations used for averages, e.g., *“This is an average of 20 simulations across 2 weather stations.”* The names of the weather stations used are listed in a table found by clicking the ‘view simulations’ button in the top right of each card. As default, 50 km is selected, but it does not have an effect if no location is selected at first.

3.4.2 Wall material

The user can select between two wall materials used for the building facades (external walls). The first one is brick (masonry) and the second is natural stone (sandstone, limestone, granite, etc.). The output can be based on one or more of the bricks or natural stones involved in the simulations. The different types of stones and the sampling scheme is described further in deliverable D6.5. The three main reasons to simplify the wall materials is:

- 1) The impact of the wall materials was lower than original expected as described in (RIBuild Deliverable D2.1, 2018).
- 2) The detailed investigation and tests needed to identify specific material for the user – ‘the interested but non-professional building owner’.
- 3) The high amount of simulations needed to cover all wall materials as individual materials instead of sampling from a collection of general materials. Brick is selected as default material.

3.4.3 Wall thickness and orientation

Thickness of the existing external wall ranging between 100 and 900 mm. On a number-slider, the user can narrow the interval between minimum and maximum thickness to be considered. If the thickness of the wall is not well defined, a wide interval is recommended. The range shown by numbers are the minimum and maximum wall thickness simulated and found in the database. Based on the other inputs, the minimum and maximum wall thickness available may change. By default, the full range is selected.

The wall orientation refers to the ‘facing’ orientation of the external wall. North is 0 and south is 180 degrees. Similar to the wall thickness, orientation also uses a number-slider with two handles, to specify the orientation in an interval. As default, the entire 360-degree spectrum is selected.

3.4.4 Plasters

Two checkmarks are used for inputs to select whether the existing wall includes 10-20 mm protective or decorative layer (plaster or mortar) internally or externally. The simulated plaster thickness can be any number between 10 and 20 millimetres. As default, the wall includes plaster both internally and externally.

3.4.5 Insulation system and thickness

Including no insulation system, eight system can be selected on eight checkmarks by ticking each checkmark on/off. The systems include Calcium Silicate with three different thermal conductivities, Mineral Wool, PUR foam with CaSi channels, Phenolic Foam and Polyurethane Foam. If selected, the reference wall with no insulation is always shown as the first ‘card’ on the page. By default, all insulation systems are ticked on.

Similar to wall thickness the insulation system is selected on a numbers-slider with two handles making it possible to select an interval instead of a number within the range of 10 - 150 mm. By default, the full range from 10 to 150 mm is selected.

By ticking on/off insulation systems or changing the range of the thickness, the grey cards with solutions outside the selection are hidden. The other inputs add and remove rows in the table in each of the grey cards. Changing the insulation system does not change the averages or does not minimize the uncertainty; it simply hides or show solutions to make it easier to find the most relevant insulation system.

3.4.6 Priority

The user has the option to prioritize the insulation systems solutions based on the output parameters – mould, heat loss, u-value, algae and min. int. surface temperature. The prioritization is done by changing the numbers-slider corresponding to the output parameter wished to prioritize. Moving the sliders affect the prioritization and hereby the order in which solutions are presented. “Low” (left slider position) and “high” (right slider position) represent the priority (importance) of a parameter, not the size. As default, all output parameters are given the same priority (medium). The priority is found by a weighted normalized decision matrix, based on the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method (Yoon & Hwang, 1981).

4 Technical implementation

4.1 Code - Git repository

The technical implementation of the ICT is described on a high conceptual level. To ensure a deeper level is available for future research all code is publicly available from the RIBuild WP6 GitHub repository (RIBuild WP6 Github repository, 2020).

Direct link to the ICT GitHub repository: <https://github.com/ribuild/webtool>

4.2 Technologies used – an overview

To develop and run the ICT, a handful of technologies are used, as described in section 4.2.1 - 4.2.4.

4.2.1 Digital Ocean

Websites are hosted on servers, the RIBuild ICT is hosted on a server, a cloud service provided by Digital Ocean – one of the largest webhosting companies in the world. Websites on Digital Ocean are hosted in droplets. A droplet is a simple scalable virtual machine. The droplet runs the Docker containers described in Section 4.2.2. The droplet needed to run the RIBuild ICT smoothly is a ‘Standard / 2GB / 1 vCPU’ droplet costing 10 USD per month. Depending on the website traffic and the desired speed, the droplet can be decreased or increased at any time. Digital Ocean is commercial product, not associated with any of the RIBuild partners, making it easy to provide the username and password for the partner to take over and maintain the ICT. For more information visit Digital Oceans website: <https://www.digitalocean.com/>

4.2.2 Docker

Docker is a Package Software into Standardized Units for Development, Shipment and Deployment. The standardized unites are called ‘containers’ to reference the comparable real-life shipping-containers. From Docker’s website: *“A container is a standard unit of software that packages up code and all its dependencies, so the application runs quickly and reliably from one computing environment to another. A Docker container image is a lightweight, standalone, executable package of software that includes everything needed to run an application: code, runtime, system tools, system libraries and settings.”* (Docker containers, 2020) Using Docker for the RIBuild projects helps ensuring quick development and makes it easy to move and run the ICT from any server in the future after the project ends, helping to ensure the ICT future. Further details about Docker can be found on the website: <https://www.docker.com/>

4.2.3 PHP

The RIBuild ICT is mainly written in the coding language PHP. *“PHP is a popular general-purpose scripting language that is especially suited to web development. Fast, flexible and pragmatic, PHP powers everything from your blog to the most popular websites in the world.”* (PHP Website, 2020). PHP is widely used on the web and has a tested and proven track record. For further information visit PHPs official website: <http://php.net>

4.2.4 MySQL

MySQL is used to store and access the simulated data. MySQL is an open source RDBMS¹. Data is accessed by Structured Query Language (SQL). While the final ICT data is stored in MySQL, the simulation procedure used MongoDB, a NoSQL database described further in deliverable D6.5 and briefly in Section 4.3 about data imports. For more detail visit MySQLs official website: <https://www.mysql.com/>

4.3 Database imports changes

The simulation tool handles and organizes data in the NoSQL database, MongoDB (MongoDB Website, 2020), which is described further in deliverable D6.5. The ICT utilizes the more traditional relational database, MySQL (MySQL Website 2020). MySQL is widely used and known for web development. Relational databases require a much more rigid data structure enforced by a database schema. Using MySQL, the widely known query language SQL (Structured Query Language) is used instead of MongoDB queries, searching for simulations. Before the data transfer from multiple simulation database tables, the data is collected and aggregated to a single normalized MongoDB table, simplifying the transfer. Figure 3 illustrates the data transfer process from simulation input to ICT simplified, and “Appendix A – MongoDB JSON Document example” show an example of a document containing data for a single simulation in the normalized MongoDB database.

Section 4.3.1 – 4.3.15 describe the data in the normalized MongoDB table and MySQL and the changes resulting in minor differences. The data to and from the simulation procedure in MongoDB is described in detail in deliverable D6.5.

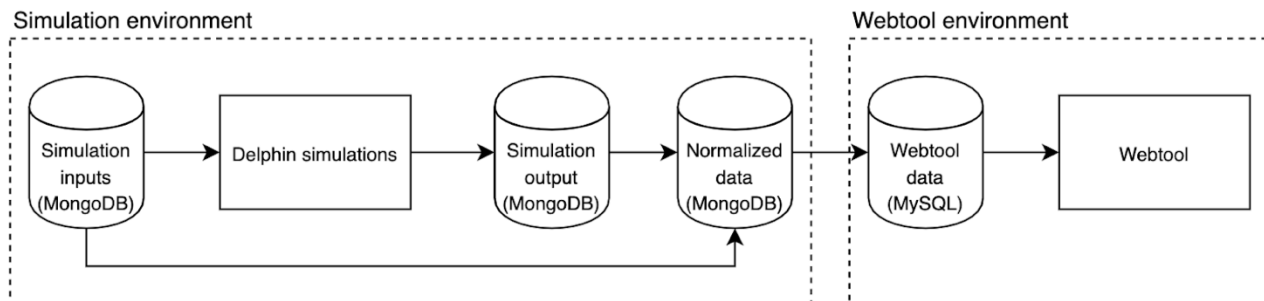


Figure 3: The data transfer process from simulation input to ICT simplified

4.3.1 Latitude and longitude

Stored in MongoDB as a GeoJSON Point; see example in Appendix A – MongoDB JSON Document example. All latitudes and longitudes represent locations of weather stations and originate from the Climate for Culture weather data file (Erhardt & Antretter, 2011). The latitude and longitude are not changed but are stored in individual fields named ‘latitude’ and ‘longitude’ in MySQL.

¹ Relational database management system

4.3.2 Wall Orientation

Named 'orientation' in MongoDB and MySQL. Orientation is simulated as a uniform number from 0 to 360 but rounded to an integer in MongoDB before importing to MySQL. A North-facing wall is 0 and a South-facing wall is 180.

4.3.3 Wall width

Named 'wall_width' in MongoDB and MySQL. The Wall width is simulated as a uniform number from 0.1 to 0.9 - unit in meters. The numbers and units were changed to millimetres while moving the data from MongoDB to MySQL. This was done to get a whole number and improve the user experience.

4.3.4 Wall material

Named 'wall_material' in MongoDB and MySQL. In the ICT, the selected wall material can either be 'natural stone' or 'brick'. This is a simplification of the 33 variations of natural stones and 52 variations of bricks simulated. All bricks and natural stones placed in one of the groups. The simplification happens in the normalized MongoDB table and is described further in deliverable D6.5.

4.3.5 Internal and External plasters

Internal and external plaster is named 'int_plaster' and 'ext_plaster' in MongoDB and MySQL. Both plasters are simplified in the normalized MongoDB database. Both are boolean values, True/False, meaning with or without plaster. Plasters are simulated with a uniform varying thickness from 10 to 20 mm (True) or with no plaster 0 mm (False). The plaster materials change too, but this is not part of the ICT and like wall material changes, plaster thickness functions as an uncertainty parameter - see Deliverable D6.5 for more information about uncertainty parameters.

4.3.6 City

Named 'city' in MongoDB and MySQL. The cities are the name of the city where the weather stations are located. Similar to longitude and latitude this originates from the climate for culture weather data files (Erhardt & Antretter, 2011). The data is not changed between MongoDB and MySQL.

4.3.7 Heat loss

Named 'heat_loss' in MongoDB and MySQL. The heat loss is aggregated and represents the average heat loss for a single year for the entire simulation period. The aggregation is important since the simulation periods can vary in length. The aggregation is done for the normalized MongoDB database and is described further in deliverable D6.5. The data is not changed between MongoDB and MySQL.

4.3.8 Mould index

Named 'mould' in MongoDB and MySQL. The mould value is the highest mould index found in the entire simulation period using the VVT-model further described in deliverable D6.5. The data is not changed between MongoDB and MySQL.

4.3.9 Thermal transmittance (U-value)

Named 'u_value' in MongoDB and MySQL. The thermal transmittance is the simulated u-value from Delphin. It is a simulated and *not* calculated value, meaning the U-value may change based on the moisture content of the wall, meaning the same wall-insulation configuration may have different U-values for different locations, orientations, etc. The unit for Thermal transmittance is $W/(m^2 K)$.

4.3.10 Algae

Named 'algae' in MongoDB and MySQL. The value is the highest algae index found in the entire simulation period using the algae growth model developed in WP2. The developed algae output criteria do not work with some wall materials resulting in a "-1" value in the normalized MongoDB database. All -1 values are changes to None in MySQL, becoming empty values in the user interface and not affecting the average value or misleading the user.

4.3.11 Insulation System

Named 'insulation_system' in MongoDB and MySQL. Most of the insulation systems names have changed. This was done to remove any association to specific commercial products. Table 1 shows the old and new names. Repeating names are dealt with by adding the thermal conductivity to the names in the search and user interface, creating new unique names.

Table 1: Name changes for insulation systems going from simulations (MongoDB) to ICT (MySQL).

MongoDB (Simulation database)	MySQL (ICT)
NoInsulation	None
MineralFoamMultopor	Calcium Silicate
ClimateBoard	Calcium Silicate
CalciumSilicateBoard	Calcium Silicate
PolyurethaneFoam	Polyurethane Foam
MineralWool32	Mineral Wool
PhenolicFoam	Phenolic Foam
CasiPlus	Calcium Silicate
PhenolicFoam	Phelnolic Foam
CasiPlus	Calcium Silicate
iQ-Therm	PUR foam with CaSi channels

4.3.12 Insulation thickness

Named 'insulation_thickness' in MongoDB and MySQL. The insulation thickness is simulated as a uniform number from 0.01 to 0.09 - unit in meters. The numbers and units are changed to millimetres while moving the data from MongoDB to MySQL. This was done to get a whole number and improve the user experience. For the reference with no insulation, the empty field is set to 'None' and not shown in the user interface.

4.3.13 Minimum internal surface temperature

Named 'min_surface_temp' in MongoDB and MySQL. The minimum internal surface temperature is the lowest temperature in Celsius registered in the entire simulation period. While using the lowest 0,1-fractile was discussed and preferred, the lowest temperature was chosen since it is much easier to communicate and understand by the end-user.

4.3.14 Thermal conductivity - lambda value

Named 'lambda_value' in MongoDB and MySQL. The value of the thermal conductivity for the internal insulation system originates from the Delphin material file. While the thermal conductivity is important to know for the user, it is also used to differentiate between similar insulation material names after the name changes done to remove association to specific commercial products. For the reference with no insulation, the empty field is set to 'None' and not shown in the user interface. The unit for Thermal conductivity is W/(m K).

4.3.15 Rain factor

Named 'rain' in MongoDB and MySQL. The rain factor is a uniform uncertainty between 0 and 2. The rain factor is not used for searches or as a result, but it is important to communicate in the detailed table due to the high impact on the results, creating possible confusion for the end-user. For example, if all other simulation inputs are identical but the simulated results are different due to differences in the, otherwise not visible, rain factor. The rain factor is further described in deliverable D6.5.

4.4 Docker container setup and data transfer

The ICT is hosted on Digital Ocean using Docker containers briefly described in section 4.2.2. Three Docker containers is used to run ICT. The first container named 'mysql' is dedicated to run the MySQL database, specific version 8. The second container is named 'app' and runs the php webserver using a custom image developed by Mathias Larsen running php 7.4 (Larsen, 2020). The third container named 'traefik' is a reverse proxy to isolate the webserver from the internet. The 'traefik' container is only used when a domain is assigned to the website to ensure the webserver is not exposed. After doing a git pull command from the git repository, one command is needed to start the website.

```
Compose up -d
```

The process to transfer data from MongoDB to MySQL and making minor changes, described in the previous sections, is a semi-automated process and can be done with a few commands. The commands are written inside the app container.

Going into the app container	<code>docker-compose -f production.yml exec app bash</code>
Downloads from the MongoDB normalized table file (located on DTU server) to csv on server	<code>art import:simulation export.csv</code>
Reads csv file and insert new and changed data	<code>art import:sim export.csv</code>

4.5 Data query

The ICT sorts and presents data based on the ‘user inputs’ - search query. Most of the ‘heavy lifting’ is done by a number of php-functions making the SQL query. Ignoring the technical aspect of the search, the following simplified pseudo code/example should clarify the procedure behind the search query and hereby the entire ICT.

Find all simulations where...	
The locations of simulations (weather station) are within the chosen distance from the chosen location ... (not showing data outside the selected distance)	Latitude
	Longitude
	Distance to weather station
AND The selected wall material is equal to the simulated wall material... (not showing unselected data)	Wall material
AND the chosen wall orientation range is within the simulated wall orientation... (not showing data outside this range)	Wall orientation
AND The selected internal/external plaster configuration (2x true/false) matches the simulation plaster configuration... (not showing data not matching the selected configuration)	Plasters (Internal and External)
GROUP the simulations by the unique combinations of insulation systems and insulation thicknesses...	
selected by the user (not showing unselected data)	Insulation System
	Insulation Thickness

After the procedure above, multiple groups with simulations are available to visualize in ICT. All groups are individual presented in a ‘grey card’. Across the simulations in a group, an average of each output parameter is found. Technically, the averages are also done by the database while making the search query. A secondary query is done when clicking ‘view simulations’ to see the table with individual simulations but the basic principle behind both queries are the same as shown above. The only difference is that the first query also finds the average values and thereby only need to handle the average values outside the database increasing the performance.

5 Test of RIBuild Insulation Calculation Tool

This test is based on six cases from RIBuild Deliverable 3.2. The included cases were chosen to have different internal insulation systems, different locations and orientations, with and without external render, besides both brick and stone walls. As the current ICT does not hold insulation materials of EPS, XPS, AAC, aerogel, PIR, and VIP these cases were neglected.

The present test is performed for four output parameters; U-value, annual heat loss through 1 m², Mould Index and minimum internal temperature. The case studies include in-situ measurements to some extent, also hygrothermal simulations in both WUFI 6 and DELPHIN 5.9.5 have been carried out to support the testing process. Post-processing tools have also been implemented, including WUFI Mould Index VTT (Zirkelbach *et al.*, 2007) and the VTT Mould Model included in DELPHIN (Nicolai and Grunewald, 2006).

5.1 Case studies

The test is based on six case studies from the RIBuild project, presented in deliverable D3.2, Appendix I. The cases included are; Haderslev (DK), Meinungsgade (DK), Kildevældsgade (DK), Rectorate Palace (IT), Old Farm Building (NW and SW) (CH), and Dankepi (LV). Table 2 presents the case studies briefly, including the location, orientation, and information on the existing walls and insulation systems applied. For the case of the Old Farm Building, two orientations have been included.

Table 2: Overview of case studies

	Location	Orientation	Existing wall	Insulation material
Haderslev	Haderslev, Denmark	S	Brick, 350 mm	PUR with CaSi channels, 80 mm
Meinungsgade	Copenhagen, Denmark	SW	Brick, 350 mm	Phenolic foam, 60 mm
Kildevældsgade	Copenhagen, Denmark	N	Brick, 350 mm + external render	Phenolic foam, 20 mm
Rectorate Palace	Ancona, Italy	NW	Brick, 500-900 mm	Calcium Silicate, 130 mm
Old farm building	Brütteln, Switzerland	NW + SW	Brick, 500 mm + external render	Mineral wool, 170 mm
Dankepi	Juanjlgava, Latvia	-	Stone, 450-600 mm	Mineral wool, 150 mm

5.2 RIBuild Insulation Calculation Tool

As RIBuild ICT is based on previously performed simulations involving a probabilistic approach, ICT models do not necessarily match the case studies directly. RIBuild ICT models are presented in Table 3 together with the actual cases, in order to demonstrate the differences.

Table 3: Overview of cases and RIBuild ICT models

Location	Actual case	RIBuild ICT
Number of simulations	-	6
Location	Haderslev, Denmark	List, Germany (address + 80 km)
Orientation [°]	180 (S)	80 (E)
Wall thickness [mm]	350	619
Insulation thickness [mm]	80	80
Insulation λ [W/(m K)]	0.031	0.040
Number of simulations	-	30
Location	Copenhagen, Denmark	Taastrup, Denmark + Lund, Sweden (address + 80 km)
Orientation [°]	225 (SW)	54, 87, 193 (NE, E, S)
Wall thickness [mm]	350	397, 519, 550
Insulation thickness [mm]	60	65
Insulation λ [W/(m K)]	0.020	0.020
Number of simulations	-	5
Location	Copenhagen, Denmark	Lund, Sweden (address + 80 km)
Orientation [°]	0 (N)	87 (E)
Wall thickness [mm]	350	519
Insulation thickness [mm]	25	20
Insulation λ [W/(m K)]	0.020	0.020
Number of simulations	-	2
Location	Ancona, Italy	Cervia, Italy (address + 120 km)
Orientation [°]	315 (NW)	11 (N/NNE)
Wall thickness [mm]	500-900	238
Insulation thickness [mm]	130	80
Insulation λ [W/(m K)]	0.053	0.060
Number of simulations	-	5
Location	Brütteln, Switzerland	Payerne, Switzerland (address + 80 km)
Orientation [°]	315 (NW) and 225 (SW)	41 (NE)
Wall thickness [mm]	500	241
Insulation thickness [mm]	170	120
Insulation λ [W/(m K)]	0.035	0.030
Number of simulations	-	5
Location	Juanjlgava, Latvia	Liepaya, Latvia (address + 250 km)
Orientation [°]	Unknown	66 (NE)
Wall thickness [mm]	450-600	660
Insulation thickness [mm]	150	120
Insulation λ [W/(m K)]	0.035	0.030

5.3 Hygrothermal simulation models

Hygrothermal simulations were constructed as simple 1D models in both WUFI and DELPHIN to simulate results. RIBuild ICT is based on predicted climate, wherefore this would present discrepancies in results. Nevertheless, all simulations have been performed for five years, with local climate from climate databases incorporated in the respective programs, and can be related to ICTs results. All the simulation models involved, had three output locations; exterior surface, interface between existing wall and internal insulation, and interior surface. In each output location from the WUFI and DELPHIN models, temperature, relative humidity, and moisture content have been generated on an hourly basis.

Table 4 presents the vital input for the hygrothermal models in the two simulation programs, including the physical construction and materials from the respective databases, indoor and outdoor climate conditions, and initial conditions.

Table 4: Overview of hygrothermal simulation inputs for WUFI and DELPHIN

	WUFI-model	DELPHIN-model
Haderslev (DK)		
Construction	350 mm Solid Brick Masonry 10 mm Cement Lime Plaster 7 mm Remmers IQ Fix 80 mm Remmers IQ Therm 10 mm Remmers IQ top	350 mm Historical Brick (Cluster 4) 10 mm Lime Cement Mortar 80 mm IQ-Therm 10 mm IQ-top
Outdoor climate	Lund, Sweden	Bremerhaven, Germany
Indoor climate	EN15025/WTA 6-2, Medium moisture loads + 5% (design)	20°C / 50% RF
Initial conditions	20°C / 80% RF	12°C / 80% RF
Meinungsgade (DK)		
Construction	350 mm Solid Brick Masonry 10 mm Cement Lime Plaster 60 mm Phenolic foam 12.5 mm gypsum board	350 mm Historical Brick (Cluster 4) 10 mm Lime Cement Mortar 60 mm Kingspan_Phenolic foam Vapour barrier: sd = 1000 m 12.5 mm Gypsum Board
Outdoor climate	Lund, Sweden	Bremerhaven, Germany
Indoor climate	EN15025/WTA 6-2, Medium moisture loads + 5% (design)	20°C / 50% RF
Initial conditions	20°C / 80% RF	12°C / 80% RF
Kildevældsgade (DK)		
Construction	External render of 4 layers as prescribed by WUFI 350 mm Solid Brick Masonry 10 mm Cement Lime Plaster 60 mm Phenolic foam 12.5 mm gypsum board	10 mm Lime Cement Mortar 350 mm Historical Brick (Cluster 4) 10 mm Lime Cement Mortar 25 mm Kingspan_Phenolic foam Vapour barrier: sd = 1000 m 12.5 mm Gypsum Board
Outdoor climate	Lund, Sweden	Bremerhaven, Germany
Indoor climate	EN15025/WTA 6-2, Medium moisture loads + 5% (design)	20°C / 50% RF

Initial conditions	20°C / 80% RF	12°C / 80% RF
Rectorate Palace (IT)		
Construction	700 mm Solid Brick Masonry 10 mm Cement Lime Plaster 130 mm CaSi-Board (Washington) 12.5 mm gypsum board	700 mm Historical Brick (Cluster 4) 10 mm Lime Cement Mortar 130 mm Calsitherm Climate Board WF 12.5 mm Mineral Interior Plaster
Outdoor climate	Modena, Italy	Ancona, Italy
Indoor climate	EN15025/WTA 6-2, Medium moisture loads + 5% (design)	20°C / 50% RF
Initial conditions	20°C / 80% RF	12°C / 80% RF
Old Farm Building (CH)		
Construction	External render of 4 layers as prescribed by WUFI 500 mm Solid Brick Masonry 10 mm Cement Lime Plaster 120 mm mineral wool, Vario Xtra Vapour Barrier 50 mm mineral wool 12.5 mm gypsum board	10 mm Lime Plaster (historical) 500 mm Historical Brick (Cluster 4) 10 mm Lime Cement Mortar 130 mm Mineral Wool 032 Vapour barrier: sd = 12 m 40 mm Mineral Wool 032 12.5 mm gypsum board
Outdoor climate	Zürich, Switzerland	Stötten, Germany
Indoor climate	EN15025/WTA 6-2, Medium moisture loads + 5% (design)	20°C / 50% RF
Initial conditions	20°C / 80% RF	12°C / 80% RF
Dankepi (LV)		
Construction	525 mm Krensheimer Shelley Limestone 20 mm Cement Lime Plaster 100 mm mineral wool Vario Xtra Vapour Barrier 50 mm mineral wool 12.5 mm gypsum board	525 mm Sandstone Krenzheimer 20 mm Lime Cement Mortar 100 mm Mineral Wool 032 Vapour barrier: sd = 12 m 50 mm Mineral Wool 032 20 mm gypsum board
Outdoor climate	Warsaw, Poland	Potsdam, Germany
Indoor climate	EN15025/WTA 6-2, Medium moisture loads + 5% (design)	20°C / 50% RF
Initial conditions	20°C / 80% RF	12°C / 80% RF

5.4 Post-processing

The output from simulation programs (temperature, relative humidity and moisture content at external surface, interface between internal insulation and existing wall, and internal surface) have been processed for comparison purpose to RIBuild ICT outputs. Integrated post-processing tools in both WUFI and DELPHIN were used for determination of Mould Index. The prerequisites for both tools are listed below.

WUFI Mould Index VTT (Zirkelbach et al., 2007)

- Occupant exposition class: Inside constructions/exterior surfaces without direct contact to interior air
- Other materials: Cement based materials
- Sensitivity Class: Resistant
- Material Class: Relatively low decline
- Type of Surface: Cleaned

DELPHIN VTT Mould Model (Nicolai and Grunewald, 2006)

- Material: medium resistant (concrete, mineral wool)
- Surface: resistant
- Decline: relatively low decline

5.4.1 U-value

WUFI generates U-value automatically based on construction setup with thicknesses and materials. The U-value generated for DELPHIN constructions was calculated based on thicknesses and thermal conductivities of materials, given in the programs material database. The U-values given in RIBuild Deliverable D3.2, 2019) are also presented for comparison. Figure 4 presents the generated and given U-values from ICT, hygrothermal simulations and D3.2.

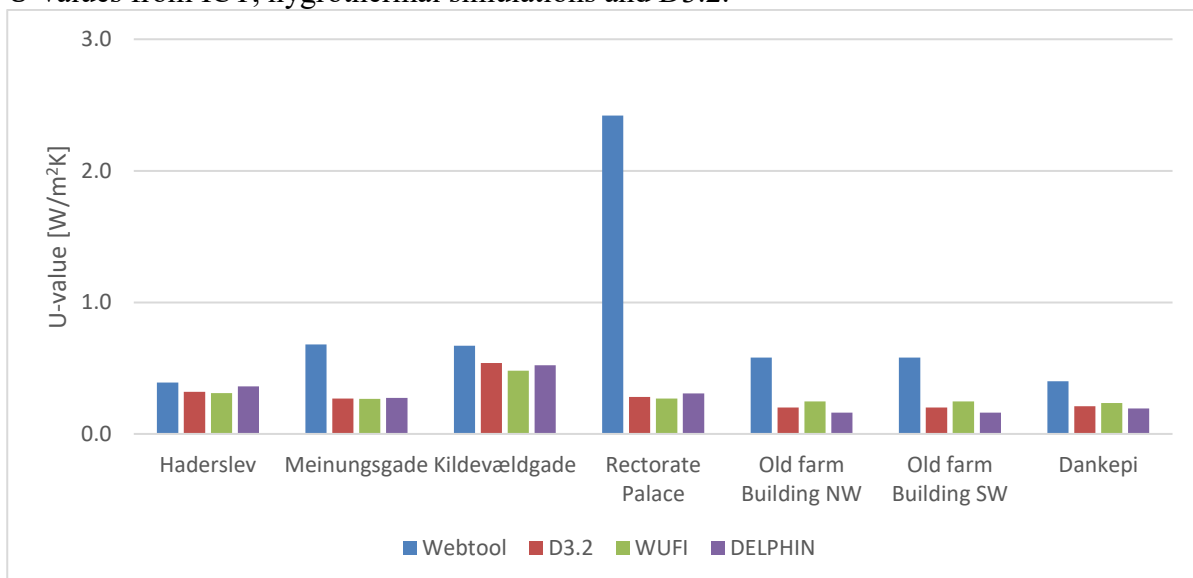


Figure 4: U-values generated by RIBuild ICT, given in the deliverable D3.2, and from simulation tools WUFI and DELPHIN

As seen in Figure 4, the U-values appear to be within the same ranges for all cases with the exception of Rectorate Palace. In all the cases, ICT is seen to generate higher U-values when compared to simulation models and values from deliverable D3.2. This can be explained by the ICT using a probabilistic approach, involving different types of brick and wall thicknesses, opposed to the WUFI and DELPHIN models created for this test. Rectorate Palace stands out, as the ICT generated U-value is significantly higher compared to the other values. As seen in Table 3, ICT has calculated this case with a wall thickness of only 238 mm, when the case is 500-900 mm. Furthermore, the insulation thickness provided by RIBuild ICT was only 80 mm compared to the 130 mm in the actual case.

5.4.2 Heat loss

The heat loss is generated based on the given U-values and Heating Degree Hours (HDH) given in WP5 Sustainability WebTool (Walther, 2019). The HDH are given in Table 5. They were transformed to Heating Degree Days (HDD) and multiplied with the U-value, to generate the heat loss through 1m² of internally insulated wall.

Table 5: Heating Degree Hours (HDH) given for the different cases

Case	Location for HDH	HDH [Kh]
Haderslev	Silkeborg (Denmark6), Denmark	1,751,011
Meinungsgade	KobenhavnTaastrup, Denmark	1,699,033
Kildevældsgade	KobenhavnTaastrup, Denmark	1,699,033
Rectorate Palace	AnconaFalconara, Italy	502,144
Old Farm Building	Payerne, Switzerland	1,353,746
Dankepi	Riga, Latvia	2,231,133

The annual heat loss through 1 m² of internally insulated wall, is presented in Figure 5. RIBuild deliverable D3.2 does not report heat loss. Values representing D3.2 (RIBuild deliverable D3.2, 2019) were generated from the reported U-values, and HDH expressed in Table 5.

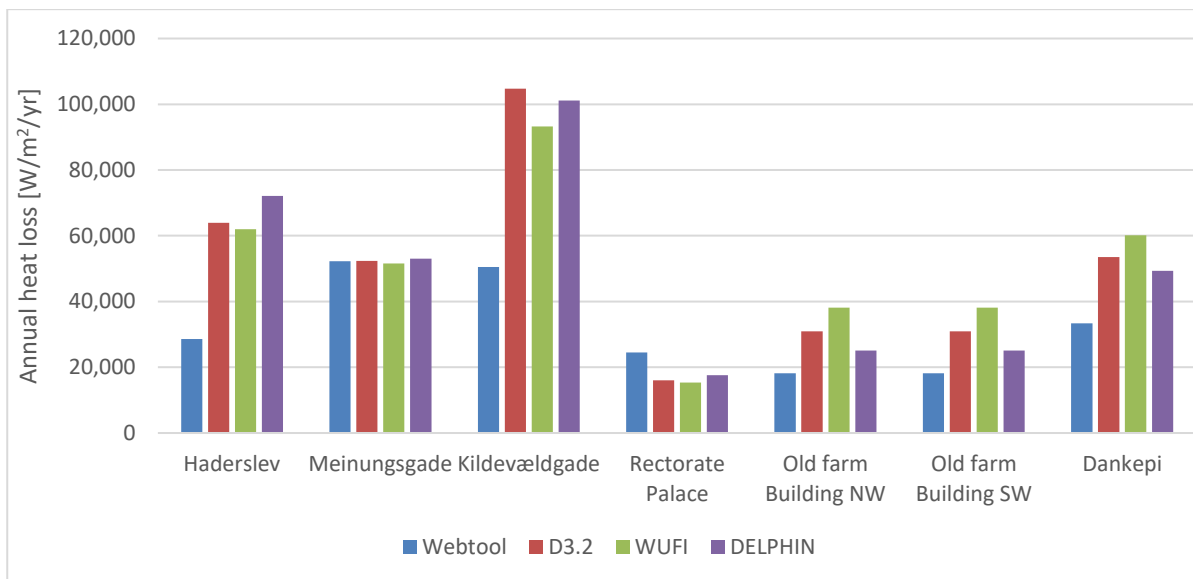


Figure 5: Heat loss through 1 m² of internally insulated wall

As seen in Figure 5, heat losses generated by the various methods appear to comply relatively well in two cases, namely Meinungsgade and Rectorate Palace. In the remaining five cases, ICT appears to underestimate the heat loss when compared to the other methods. This is most pronounced in Kildevældsgade and Haderslev, where RIBuild ICT generates significantly lower heat loss when compared to the other methods. The results are curious, as RIBuild ICT had a tendency of overestimating the U-value, and thus the heat loss would be assumed higher. However, the discrepancies may occur due to different locations used for HDH; for the manual processing, HDH

has been chosen for the physically nearest location, while the RIBuild ICT may interpolate between the locations included for climate determination.

5.4.3 Minimum temperature on internal surface

Application of internal insulation increases the internal surface temperature, and can therefore help reduce nuisances related to cold external walls. This parameter was not given in RIBuild Deliverable D3.2.

As seen in Figure 6, the temperature of the internal surface in all the cases, is within 2,5°C – all in the range of 17-19,5°C. The results largely agree, and the small discrepancies can be partially caused by the fact that ICT gives the temperature 0,5 mm from the surface, whereas the temperatures given by WUFI and DELPHIN were on the surface. However, this would probably not explain the differences using the web tool, WUFI or DELPHIN for Meinungsgade, Kildevældsgade and Rectorate Palace. In the Swiss and Latvian cases (Old Farm Building and Dankepi), the internal surface temperature are more or less the same for the three methods.

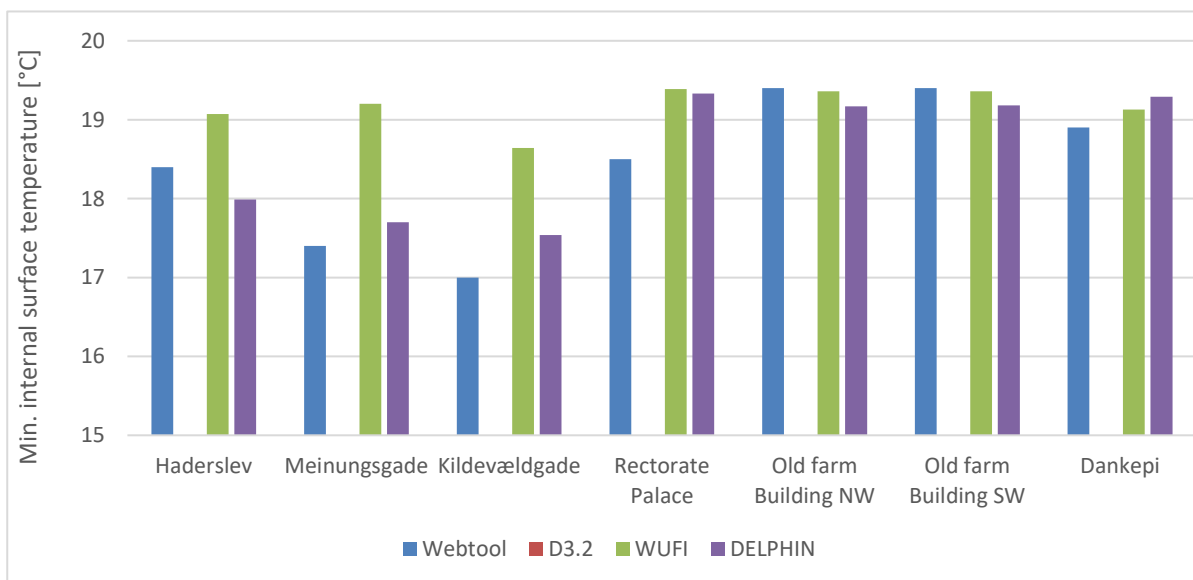


Figure 6: Minimum temperature on the internal surface, given by RIBuild ICT, and simulations in WUFI and DELPHIN

WUFI and DELPHIN results differ significantly in the three Danish cases; Haderslev, Meinungsgade and Kildevældsgade. The four remaining cases show good coherence between all three methods. RIBuild ICT shows largest deviations from WUFI and DELPHIN simulations in cases: Meinungsgade, Kildevældsgade and Rectorate Palace. These three cases all deviate in ICT when compared to reality, with regard to especially orientation and wall thickness, however all the ICT models deviate from reality on these parameters.

Figure 7 shows the average internal surface temperatures from the RIBuild ICT, WUFI and DELPHIN respectively, as well as the standard deviation for each case.

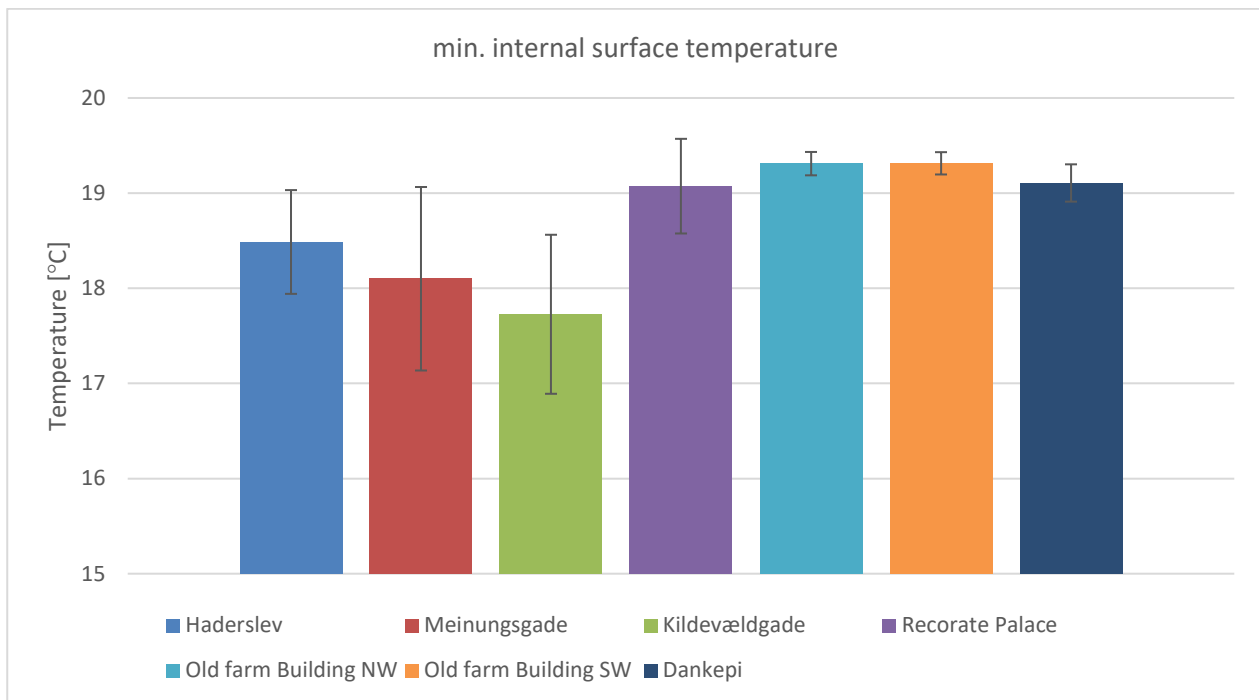


Figure 7: Average values for minimum internal surface temperature as well as standard deviations

The results show reasonable values with regard to internal surface temperatures. In the cases of Old Farm Building (NW and SW) and Dankepi, the smallest standard deviation is found ($< 0,2^{\circ}\text{C}$). The highest deviations are found in cases from Denmark; Meinungsgade and Kildevældsgade ($> 0,8^{\circ}\text{C}$). Haderslev and Rectorate Palace are in between with standard deviations around $0,5^{\circ}\text{C}$.

5.4.4 Mould Index

The Mould Index is generated for the interface between internal insulation and the existing wall, as this is an area of risk, due to possible condensation. Figure 8 presents the mould indexes. (RIBuild Deliverable D3.2, 2019) does not give exact values for Mould Index in all cases, however statements in D3.2 of “safe with regard to mould”, or “below LIM II curve”, will be presented as zero. In some cases, the value for Mould Index has been presented in other RIBuild dissemination, and is presented in the graph. The Old Farm Building has *not* been evaluated with regard to Mould Index within RIBuild dissemination.

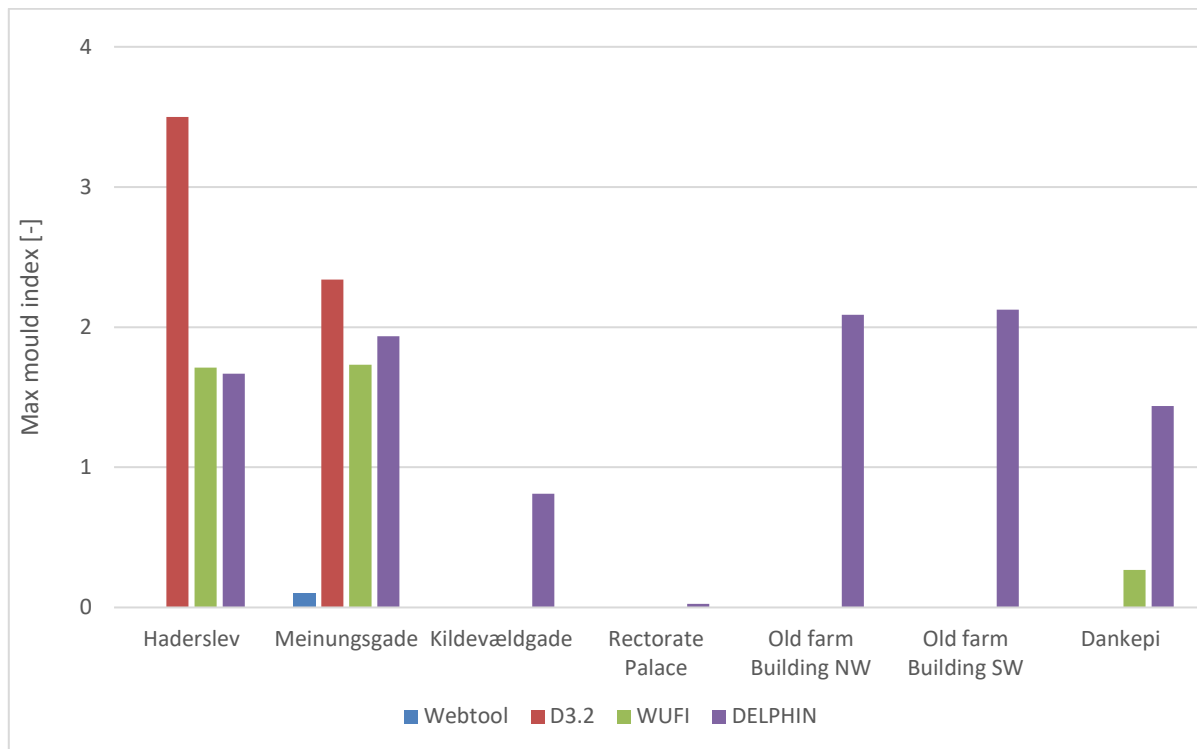


Figure 8: Mould index generated by RIBuild ICT, and with WUFI and DELPHIN post processing tools respectively, as well as values given in RIBuild dissemination

In Figure 8, a large variation is seen in the generated mould indexes. RIBuild ICT generates a Mould Index of 0 in all the cases, with the exception of Meinungsgade, that exhibits a very low mould Index of 0,1 by ICT. For Kildevældsgade and Rectorate Palace, all the calculation methods yield Mould Index below 1. In these cases, RIBuild ICT, D3.2 information and WUFI all yielded Mould Indexes of 0, while DELPHIN did show slight risk of mould growth.

In Haderslev, D3.2 generated a very high Mould Index, but in-situ measurements also showed above 90% relative humidity in the interface for duration of measurements, and a high Mould Index was expected. The WUFI/DELPHIN-simulations of Haderslev used general climate data from the databases, and gave very similar results to each other. RIBuild ICT does not indicate risk of Mould Growth. In Meinungsgade the Mould Index by D3.2, WUFI and DELPHIN are very similar, around 2, while ICT yields a low value of 0,1. With regard to the Old Farm Building, DELPHIN yielded risk of mould growth with a mould index of 2 in both orientations, while neither WUFI nor ICT showed risk of mould growth. In the case of Dankepi, ICT as well as the in-situ measurements did not indicate risk of mould, whilst WUFI (<1) and DELPHIN (<2) exhibits somewhat risk of mould growth.

Discrepancies found in results with regard to Mould growth is largely due to the variety in input parameters in the different programs, including the climate files. When studying the ICT results against Mould Index generated by in-situ measurements, they match in the cases of Kildevældsgade, Rectorate Palace, and Dankepi. In the cases of Haderslev and Meinungsgade however, RIBuild ICT appears to underestimate the risk of mould growth, when compared to the other calculation methods.

6 Discussion of Insulation Calculation Tool

6.1 Number of simulations – data gaps in tool

The final tool contains about 275,000 simulations. While 275,000 simulations sound of a lot, it is not near enough to cover the possible variations created by changing input parameters used in the simulations. The results of having too few simulations, in relation to the number of possible inputs for a simulation, is seen as a missing solution in ICT. Not having enough simulations or having too many inputs is bound in multiple oversights during the project.

The probabilistic methodology used for simulations in ICT is developed by the Building Physics Department of KU Leuven, based on the quasi-Monte Carlo methodology Sobol (Van Gelder *et al.*, 2014), (RIBuild Deliverable D4.1, 2017). The use of the methodology for simulations behind the ICT tool is described in deliverable D6.5. Summarized, the probabilistic simulation methodology in RIBuild repeatedly runs DELPHIN simulations, while changing input values between simulations to determine the probability distribution of the simulated output values. By design, this probabilistic simulation approach should run until a convergence level is reached – the convergence level being an error estimation. The first oversight is the developed error estimation looking at all simulation data globally. For the current implementation of the ICT, the error estimation should have looked at data locally in clusters for the individual locations. The number of simulations found by the error estimation gave a false sense of security opening up for adding more changing input values for the simulations or vice versa not removing enough inputs. A tool based on the globally based error estimation could be possible, but it would require a multi-criteria meta-model looking at the entire data space, e.g. a neural network. The distribution of simulations, because of the probabilistic simulation approach, makes the dataset very suitable to build a meta-model using a neural network. This possibility is discussed further in section 6.5.

Over a period of multiple months about 300,000 simulations were done with the external wall material not changing, although it should have changed between the 33 types of natural stones and 52 types of bricks included in the data input. This error created many duplicates, however not visible in the database or within the comprehensive testing system. It was only visible by manually downloading and comparing multiple simulated DELPHIN files. This oversight removed about 300,000 simulation from the final number of simulations. In the beginning of the simulation period, many technical problems may have resulted in an estimated added loss of about 200,000 simulations.

To keep adding simulation is not a viable option for the current implementation of ICT without a meta-model. It is currently estimated that about 10 million simulation is needed to give an acceptable user experience filling many simulation gaps - not good but acceptable. Building a meta-model (Section 6.5.1) using 275,000 simulations is probable the best option to improve ICT and make the tool good with no gaps.

6.2 User Interface and technical implementation

The data gaps in ICT as a result of the low number of simulations (Section 6.1), is the main issue in ICT. Before this issue is fixed, further development on ICT is futile. ICT still has a few minor other issues related to the user interface and the technical implementation.

The current implementation of ICT is mainly developed for larger screens, such as large tablets, laptops and desktop computers. Smaller screens such as smartphones will only show the message: *“The RIBuild Insulation Calculation Tool is not optimized for small screen devices, we hope you’ll open the tool on a device with a larger screen. We apologize for the inconvenience.”* This could be changed by creating a version of the tool specific for small screen devices. The expectation is that most users of the website and web tool will do so from larger screen devices, for that reason a version for small screen devices has not been prioritized within the short development period of ICT.

ICT updates the search results ‘live’, in about 200 milliseconds. Each time a user makes a change to an input, a number-slider, a checkmark, etc. the query is sent to the database. For the current technical implementation, this can sometimes result in a bad user experience if the user changes another input within the 200 milliseconds it takes to make a database query. In case an input change is made before the query is done, the changes under a query might be changed back.

An example: A user tick-on a checkmark, and while the database starts a query for 200 milliseconds, the user tick-on another checkmark. When the database query ends, the second checkmark is ticked off again by the current technical implementation. This ensures that user inputs and results match, but it may give a bad user experience for a few quick users. To fix this issue, an asynchronous implementation of the query and inputs could be implemented. The current implementation to fix some of this problem is to set a delay on a few inputs, such as the map. The map inputs wait 500 milliseconds after the latest typed input, and first then sends an API request to Google Maps to return a latitude and longitude based on the text-based address given by the user.

The layout, including user-inputs and the presentation of the results could be improved a lot. While ICT is both simple and easy to use, improvements are called for. The current ‘simple’ implementation of user-inputs, such as the number-sliders and checkmarks should be changed for more visual and descriptive inputs. E.g. the number-slider for orientation could be a circular compass-like slider showing the selected range, with named orientations. The checkmarks for the insulation systems could be a graphical interface showing the insulation system with a short description or maybe even a video.

The presentation of the results could also be improved. Currently, the results are shown by numbers. Ideally, small dynamic visualization of mould growing on a wall or a dynamics plots could illustratively show the result. The information texts could also be accompanied by individual videos describing each input and output. Many such refinements could be made, but until the data related problem is fixed (Section 6.1), the tool is found to have an acceptable performance.

6.3 Feasibility

Overall, ICT appears to be a helpful tool, for a fast analysis of a given construction. The RIBuild ICT is based on a probabilistic approach, and the validity is therefore dependent on the number of simulations that have been run previously. RIBuild ICT generates probabilistic results within the given ranges of input, and can therefore include uncertainties on e.g. material parameters and climate.

WUFI and DELPHIN operate deterministic, why they do not address the uncertainties to the same extent. Further, parameters such as orientation, wall thickness and in some cases insulation thickness vary significantly in RIBuild ICT compared to the actual cases, which influences the results. With more simulations, ICT will only improve. Furthermore, the climate data implemented in ICT is forecasted weather 2020-2050 for various locations. The in-situ measurements were performed during standard years, and simulations performed with climate data integrated in WUFI and DELPHIN respectively. This is also expected to have an impact on results achieved.

The U-values given by RIBuild ICT as it is now, are largely in the same order or magnitude, however ICT does seem to overestimate the U-value in most cases. This is likely linked to the fact that wall and insulation thicknesses do not match exactly. For Rectorate Palace, ICT largely overestimates the U-value, but in the ICT model, the wall was half as thick as reality, and the insulation was 50 mm thinner than in the actual case. With regard to heat losses, there is generally good compliance. Overall, RIBuild ICT appears to underestimate the heat loss slightly, when compared to other methods. This does not apply to Meinungsgade, which has overall good coherence, and Rectorate Palace, which also exhibits good coherence, but in this case heat loss according to ICT is slightly higher when compared to other values. The minimum internal surface temperatures are similar in most cases, and all the cases exhibit internal surface temperatures of around 17-19°C. The largest deviations were found in two Danish cases; Meinungsgade and Kildevældsgade.

The Mould Index yielded significant discrepancy between ICT, and measurements and simulations. In cases where the risk of mould growth was low, determined by in-situ measurements, ICT also generated low mould index (Kildevældsgade, Rectorate Palace, Dankepi). However, in cases with presented imminent risk of mould growth (Haderslev, Meinungsgade), ICT presents little to no risk. In fact, ICT at no point generated Mould Index higher than 0.1 (Meinungsgade). The settings in various post-processing tools can influence these results. It is a general problem, not only in the ICT, that the mould prediction models may not correspond to what is seen in reality, as mentioned in Deliverable D6.5 (2020). Apparently, the used models do not take into account, that the pH behind insulation applied with a cement containing glue mortar, inhibits mould growth. That is why the sensitivity class in the intersection between wall and insulation was chosen to be “resistant” instead of “moderate sensitive”, that ICT seems to underestimate the mould growth may therefore not be true in reality.

To summarize, discrepancies are largely accounted for by missing simulations in RIBuild ICT. At the moment, one cannot expect to have models at the exact orientation or wall thickness, however the closest options are present, and as shown in this test, the tool can still yield useful results. If the number of simulations behind the program were increased, the tool would be improved. However, as this would require many more simulations, it is not realistic to fill in all the gaps in this way.

6.4 ICT disclaimer

Due to the problems mentioned in the previous sections, the following disclaimer is shown before entering the site. Before a user can visit the ICT, they need to press a button and hereby accepting the content of the disclaimer.

- 1) The present version of the RIBuild web tool is a beta version, not fully developed. It is based on numerous pre-calculated simulations of the hygrothermal conditions (temperature, relative humidity, etc.) in internally insulated solid walls made of brick masonry or natural stone, situated at different locations in the RIBuild countries (Belgium, Denmark, Germany, Italy, Latvia, Sweden and Switzerland). The simulations are based on the simulation tool DELPHIN and uses a probabilistic approach to represent the variation in e.g. material properties and outdoor climate, thereby indicating the risk of applying a certain solution.
- 2) Based on User input (location, orientation, wall type and thickness) the web tool selects possible solutions among the precalculated ones. The table presents different output options and average values (in bold) for various parameters. Further, it gives minimum and maximum values (small font size). Average values, minimum and maximum are based on a number of simulations (indicated at right).

At present, the web tool covers not all locations and orientations, wall designs, insulation systems, etc. Therefore, depending on the User input, it might happen, that no solutions are suggested. To get results you can broaden your search, e.g. by selecting the town instead of the specific address, by choosing a wider interval of orientation or wall thickness or by choosing another combination of internal and external plaster.

Further, the web tool covers not all failure modes, as research within RIBuild concluded that not in all cases, models representing a specific failure mode (e.g. frost) were sufficiently reliable. This has to be taken into consideration when using the web tool. In its present state it cannot be used as a stand-alone tool when deciding what solution to choose when insulating a historic building internally.

- 3) For any contractual and legal claims, RIBuild's liability shall be limited to wrongful intent and gross negligence. No claim of liability will be accepted if the use of the web tool violates any third-party industrial property rights or copyrights or any use that causes damage to third parties, unless the rights of third parties are known, or unknown as a result of gross negligence or if they are fraudulently concealed. At the effective date hereof, RIBuild knows no such rights. RIBuild shall inform the User immediately if any conflicting third-party rights become known to RIBuild, and provide the User with any information necessary for the defense against such claims and support him insofar as no conflicting interests of RIBuild exist.
- 4) RIBuild is an EU-funded 5½-year project ending on 30 June 2020. The project consortium ceases to exist as an entity after this date, and the members of the consortium, single or united, cannot be held liable for any claims after the completion of the project.

6.5 Further development

6.5.1 Meta-models

A meta-model built with a machine learning algorithm, such as a neural network, would probably give the quickest and best return of investment for any future development. Currently ICT has 275.000 simulations results, simulated by a probabilistic simulation approach, ideally distributed for

building a meta-model - a 'hyper-dimensional data fit' between input and output parameters. In practice, a meta-model could be developed for the five individual outputs. If such models could be developed with a large degree of certainty, no database query would be needed, since the results would come directly from the meta-model – a hyper-dimensional data fit between the user-inputs.

Unfortunately, it was not possible to investigate the feasibility for a meta-model using the final 275.000 simulation dataset within the RIBuild project. RIBuild highly recommends that the 275.000 simulation dataset is investigated further using a data scientific approach. Please note, while meta-models are worth investigating, they will never become better than the data used. Future research into the performance criteria (RIBuild deliverable D2.2, 2019) must be done too. The 275.000 simulations dataset gives good opportunities to test and demonstrate future performance-criteria models using data science.

6.5.2 Averages, medians and uncertainties

ICT uses averages and not median which would be the more descriptive option. The reason for not using median is related to the performance. Like almost any other SQL database MySQL does not have median build-in as a query function, making it necessary to query all data related to the simulations and then calculate a median, increasing the query time. The database MariaDB has a built-in median function. MariaDB was not tested during the RIBuild project but could be an option for future development, if no meta-models are developed.

Using meta-models, a database would be needed. Everything would be contained within the model itself. While ICT returns an average value found from multiple simulations and a corresponding min-max range giving an indication of the uncertainty. The meta-model will give a single deterministic value found in the models multidimensional data-fit. Alone this is not enough. In all types of data-fit, a 'statistical error' or the 'disturbance', meaning the amount an observation differs from the expected value, can be calculated. Then the user would not only get the deterministic value found in the meta-model, he would also get a corresponding 'statistical error' otherwise known as the 'inherent uncertainty'.

6.5.3 Visualisation possibilities

ICT is built to help the user to quickly find the simulations best suited for the investigated building renovation project. Other variations of the tool and different data visualizations could be developed as well to present the data in different ways giving new insights. One other method to present and visualize all the data at once could be using a plot called 'parallel coordinates' shown in Figure 9. A parallel coordinate present the value of every input and output on a corresponding vertical line. A simulation is shown by a continuous line through the input and output values found on the vertical lines. A parallel coordinates plot is great to see multidimensional connections and trends.

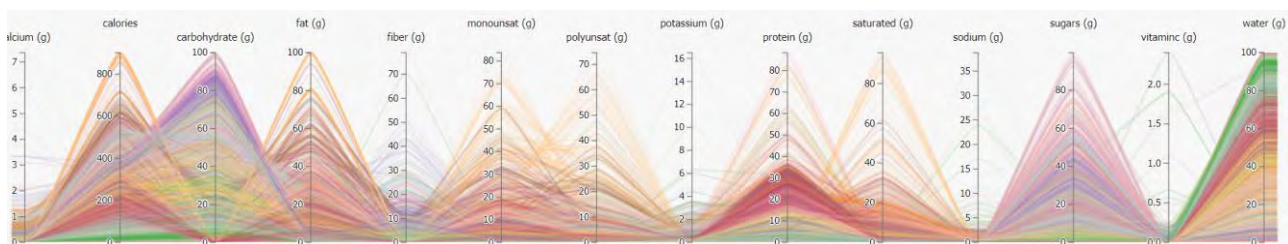


Figure 9 - Parallel coordinates plot example from <http://bl.ocks.org/syntagmatic/raw/3150059/>

Weather data and the indoor climate are derived from the location, meaning the chosen location must have a high influence on the final result. By eliminating the location as input and presenting the results using a 'false colour map' of Europe could give new insights into the influence of the weather, indoor climate. To compare locations, identical simulation must be simulated at each location with only the data derived from the location being changed. Currently, this is not done using the probabilistic simulation methodology. Having a meta-model could fill in the gaps, enabling this type of visualization. To illustrate all five outputs, five corresponding maps would be needed.

Experimenting with the 275,000 simulations dataset using data science and different forms of data visualization techniques, could likely give new insights or create new open questions into internal insulations and the performance criteria. Unfortunately, the dataset was created in the final period of RIBuild. That is why RIBuild has not used the dataset to its full potential and are only able to pass data to future research projects.

7 Conclusion

One of the outcomes of RIBuild is a website (www.ribuild.eu) that will help both non-professionals and professionals to decide if a given building is suitable for interior insulation. If the building is suitable, the aim is that the user can move on to a web-based tool, the so-called Insulation calculation tool (ICT), the subject of this deliverable. After the user has entered maximum nine different parameters, the ICT lists possible solutions (based on seven possible insulation systems and the performed simulations), and what the consequences are. The user can choose to focus on specific main outputs i.e. predictions of mould and algae growth, minimal interior surface temperature, U-value and heat loss. The interested user can also look at the different simulations in detail to understand what may be causing high uncertainties.

The calculations are based on a probabilistic approach, based on the Sobol method, which reduces the needed number of simulations. However, at the moment the ICT is based on 275,000 simulations, and there are many gaps, i.e. when using the ICT, the user will experience that very few simulations seem to correspond well with the actual building. Having more simulations would improve the ICT, however this would require millions of simulations, and is not realistic. Instead, the ICT could be improved by having a meta-model to fill in the gaps.

Despite the many gaps, a test of the tool showed that in many cases the outcome was not too far from what has been obtained by traditional deterministic simulations with DELPHIN or WUFI or by comparison to results obtained from case buildings in RIBuild Deliverable D3.2. However, algae growth tend to always reach 0.99 or 1, while mould growth seem to be underestimated compared to other models. The latter can be explained by the chosen sensitivity class in the intersection insulation material/existing wall; it was set to “resistant” instead of “moderate sensitive”, which would normally be used for these materials. This was done to counter the tendency of existing mould growth prediction models to overestimate in this area. In general, there is a need for better models for mould growth behind interior insulation.

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Appendix A – MongoDB JSON Document example

Example below shows a single JSON Document from the Normalized collection in MongoDB.

```
{
  "_id" : ObjectId("5ecbd67529a08e29981bbcce"),
  "delphin" : {
    "_cls" : "Delphin",
    "_ref" : DBRef("delphin", ObjectId("5e9e1af581953a0001ae376d"))
  },
  "loc" : {
    "type" : "Point",
    "coordinates" : [
      56.50972222,
      21.01333333
    ]
  },
  "orientation" : NumberInt(66),
  "wall_width" : 0.659375,
  "wall_material" : "natural_stones",
  "ext_plaster" : false,
  "int_plaster" : true,
  "city" : "Liepaya",
  "heat_loss" : 192917.44500080158,
  "mould" : 0.0,
  "u_value" : 2.2555243302407164,
  "algae" : 0.9848533850895324,
  "insulation_system" : "CasiPlus",
  "insulation_thickness" : NumberInt(30),
  "min_surface_temp" : 22.5526,
  "lambda_value" : 0.0611,
  "rain" : 1.3046875
}
```