Controlling the power of the ground by integration

D2.6
hybridGEOTABS sizing in feasibility studies and pre-design: tool and manual

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Summary

This report documents the design tool developed in the hybridGEOTABS project. The design tool assists the designer team in the assessment of the feasibility of applying hybridGEOTABS in their building project, and in the early stage hybridGEOTABS design. This tool, publicly available as a web-tool from www.hybridgeotabs.eu, allows a straightforward assessment of hybridGEOTABS projects, tailored to the needs of HVAC-designers, energy consultants and architects in the feasibility study and pre-design. In these early stages of the building and system design, the designers' interaction with the customer, the customer's mind set and the company's DNA play an important role in the decision process. Moreover, the design of the building geometry, structure and envelope is still very much in flux. Therefore, it is important that in the tool the key parameters can be easily varied so that the impact on cost, comfort, energy and sustainability quickly emerges and the feasibility of the hybridGEOTABS concept can be easily assessed.

As input, the design tool uses a basic building properties that are easily available in the early design, related to the building typology and location, and the main geometrical and building physical properties. As output, it provides the key performance data and indicators (related to energy, environmental, thermal comfort and cost performance) and sizing of the key components of the hybridGEOTABS concept and provides a comparison to some other HVAC and energy scenarios for the same building. The user of the tool does not need to go through time-consuming building energy calculations or simulations to assess the feasibility of the hybridGEOTABS concept. Instead, the tool relies on a database of about 140,000 pre-simulated and pre-engineered office, school, elderly home and multi-family buildings throughout the EU and experience-based cost correlations. The development of this building stock database, including studies of the EU building stock properties, the (optimization of the) dynamic behavior of hybridGEOTABS buildings and the control-integrated design, was the subject of the research in WP2 of the hybridGEOTABS project, and is documented in its deliverables D2.5 – D2.4 – D2.3 – D2.2 – D2.1.

This deliverable documents the functionalities of the design tool itself. It explains the concept of the design tool, its inputs and outputs, and the main calculation processes taking place in the background of the tool. The concept of the tool relies on the following conditions:

- The starting point is that we want to assess the feasible share of GEOTABS for a given building design. In other words, the tool does not intend to answer the question: "*to GEOTABS or not to GEOTABS?*", but to indicate how much of the heating and cooling demands for a particular building can be covered by GEOTABS, or thus: "*what is the amount of hybridity of the building?*".
- The basic functionalities of the tool have to be designed in such a way that it is easy to use for different parties who are involved into the design of a building (architect, design office, energy consultant, project developer…), and that by entering easily known input parameters an idea of hybridity and hybridGEOTABS performance is given.
- In feasibility study and pre-design as it is done nowadays, often no use is made of standards. The reason is that calculating according to these standards takes too much time at this very early stage in the design process of the project. Therefore, either benchmarking numbers are used, or numbers derived from previous projects or a calculation sheet in which the standards are incorporated. Therefore is important that this tool no longer requires calculations, and that there is information available on energy consumption, heating and cooling demand for the building concept. To do so, a database of pre-simulated building cases containing this information runs in the background of the tool. A high variety of building cases is required, so the tool can find a building case close to the users building project at hand. Furthermore, from previous hybridGEOTABS designs relations have been derived between early design parameters and parameters that are not known in the early design stage.
- Since the answering of the key question "*what is the amount of hybridity of the building?*" (as a starting point for estimating the sizing and performance of the hybridGEOTABS design for a certain building), requires a splitting between the share of GEOTABS and the share provided by a secondary system, and

given that the tool is interactive and easy to use, the load splitting and pre-engineering of the building case must happen via calculations in the background of the tool (not by the user).

- In a feasibility study various HVAC- and energy concepts are compared to one another for a given building project. This requires the estimation of key performance indicators in terms of energy, environment, cost (total cost of ownership) and comfort. Therefore, the tool needs to provide estimations of these parameters. Again, for assuring the easy use of the tool, these need to happen in the background of the tool.

The design tool consists of three main parts:

1. The first part contains the **input data** that is available in an early-design phase of the building. The user can select the building properties and its boundary conditions, and the tool searches for the most similar case in the database.
2. The second part is the output of the monthly **heating and cooling demand** as well as the **peak thermal powers** for the selected case from the database, for the primary GEOTABS and secondary heating and cooling system, and for different controllers.
3. The third part of the tool contains the **feasibility study**. Here the key performance indicators, in terms of comfort, energy, environment and financial costs, are provided for the hybridGEOTABS design with different controllers. Additional scenarios to which it can be compared are hybridGEOTABS designs with and without photovoltaics to provide electricity, a 'pure' GEOTABS design, and a non-GEOTABS design (based on fossil sources).

This deliverable documents the concept of the design tool, the three parts of the tool and the methodology used to estimate the total cost of ownership in the feasibility stage. The cost correlations used are documented in D2.7.

Table of Contents

Nomenclature

Acronyms

AB	As-built
AHU	Air Handling Unit
ASHP	Air Source Heat Pump
BMS	Building Management System
BTES	Borehole Thermal Energy Storage
COP	Coefficient of Performance
CO_2	Carbon Dioxide
DHW	Domestic Hot Water
EER	Energy Efficiency Ratio
FCU	Fan Coil Unit
GEOTABS	system combining TABS and geothermal energy using a heat pump
GRT	Geothermal Response Test
GSHP	Ground Source Heat Pump
GSHX	Ground Source Heat Exchanger
HP	Heat Pump
HVAC	Heating, Ventilation and Air Conditioning
KPI	Key Performance Indicator
MPC	Model Predictive Control
PCM	Phase-change materials
PV	Photovoltaic
RBC	Rule-based Control
RES	Renewable energy sources
R^2ES	Renewable and residual energy sources
RMOT	Running Mean Outdoor Temperature
SCOP	Seasonal Coefficient of Performance
SEER	Seasonal Energy Efficiency Ratio
SPF	Seasonal Performance Factor
TABS	Thermally Active Building System
VAV	Variable Air Volume

Symbols

T	Temperature (°C)
Q	Thermal Power (Capacity) (kW)
P	Electrical Power (kW)
$\dot{Q}$	Flow Rate (m^3/h)
W	Power (kW)

1. Concept of the design tool

1.1. A tool for early concept design and feasibility study of a hybridGEOTABS building: why?

In the early design phase, many decisions are made influencing the final cost of the project. According to Elkington [1], already 80% of the initial investment is decided in this early stage. Besides, as pointed out by Kovacic and Zoller [2] in the pre-design phase, the optimisation potential (change potential) is still very large. For this reason, it is important to have already in early design phase a trustworthy tool indicating whether it is interesting for a building concept to integrate the hybridGEOTABS concept (and/or assess how the building concept can be optimised towards the use of GEOTABS) and to what extend the TABS (thermally activated building system) can cover the heating and cooling loads (hybridity). Furthermore, the chosen concept will not only have an influence on the investment costs, but also on the future energy use (operational costs). Therefore, in the choice of a system concept, it would be too short-sighted to look only at the investment cost. It is important to take into account other factors such as energy use, the cost price during the lifetime of the building and the sustainability (cost to environment). Although performing this study in the beginning of the project will result in an additional cost (Figure 1), the cost of making of a well-informed decision is minimal compared to the turnover one makes from it.

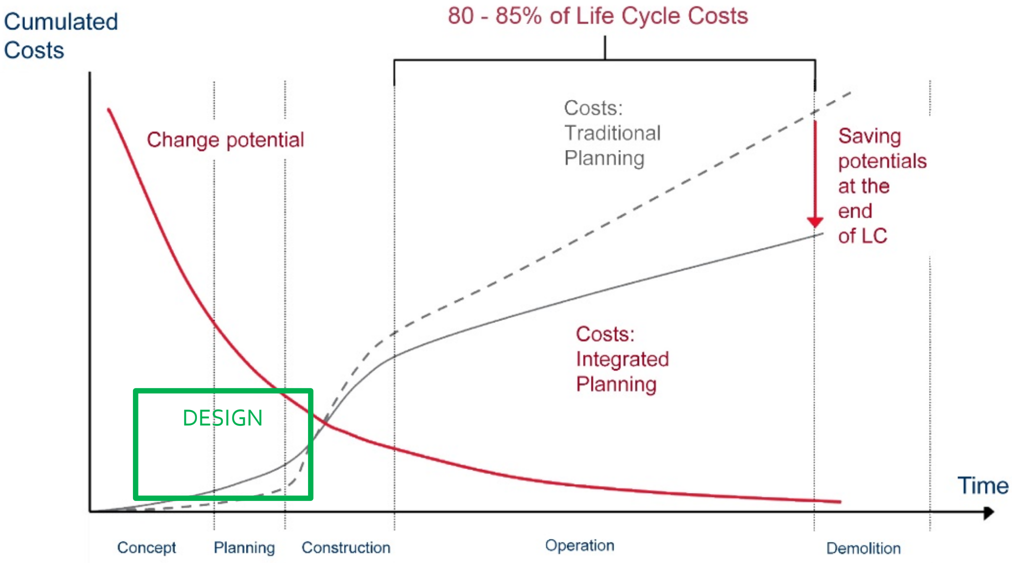


Figure 1-1: The cumulated cost and the change potential of the system concept during the different stages of a building [1].

However, to perform this study, a tool or guidelines are of no use if the result of the tool diverges too much from the result of the detailed design. In the Swiss Standard SN 506 511 , in the feasibility study a deviation of plus-minus 20% is allowed for estimating the cost. In the pre-design phase, it is even more strict, a deviation of plus-minus 10% on the final cost. It is therefore important to have a realistic estimate of the cost of a hybridGEOTABS building at this early stage. This means that it must also be possible to make an estimate of the share of "hybridity". In other words, it must also be possible to estimate the share of heating or cooling demand that can be provided by the GEOTABS system and the share that needs to be covered by a secondary system.

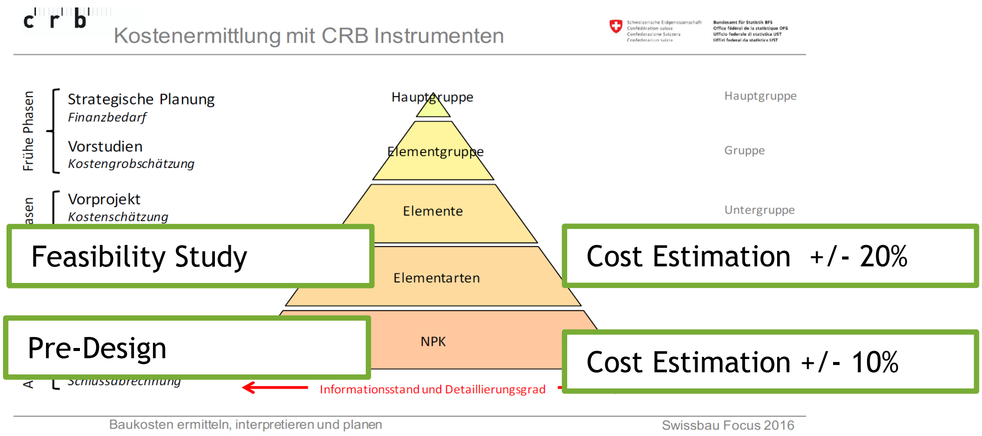


Figure 1-2: Design cost overview for each design phase

Two phases are mentioned in the graph: predesign and feasibility. During design those 2 phases have a different focus:

- ⇨ **At Feasibility stage = building level**: total heating and cooling demand for the building expressed a monetary value (cost) based on the sizing of the primary and secondary energy source and their yearly energy use. This information can be found in feasibility output from the tool.
- ⇨ **At Pre-design stage = A preliminary calculation for sizing the primary and secondary emission system at building level. The tool provides this information in the peak and demand page.**

1.2. The concept of the hybridGEOTABS design tool

The main idea is that ***every building deserves a share of GEOTABS***. Therefore, the concept of the tool relies on the following conditions:

- The starting point is to assess the feasible share of GEOTABS for a given building design. In other words, the tool does not intend to answer the question: "*to GEOTABS or not to GEOTABS?*", but to indicate how much of the heating and cooling demands for a particular building can be covered by GEOTABS, or thus: "*what is the amount of hybridity of the building?*". The term *hybridity* refers to a percentage expressing which share of the heating and cooling demand is covered by hybridGEOTABS and which part is covered by a secondary production system.
- The basic functionalities of the tool have to be designed in a way that it is easy to use for different parties who are involved into the design of a building (architect, design office, energy consultant, project developer…), and that by entering easily known input parameters an idea of hybridity and hybridGEOTABS performance is given.
- In feasibility study and pre-design as it is done nowadays, often no use is made of standards. The reason is that calculating according to these standards takes too much time at this very early stage in the design process of the project. Therefore, either benchmarking numbers are used, or numbers derived from previous projects or a calculation sheet in which the standards are incorporated. Therefore is important that this tool no longer requires calculations, and that there is information available on energy consumption, heating and cooling demand for the building concept. To do so, a database of pre-simulated building cases containing this information runs in the background of the tool. A high variety of building cases is required, so the tool can find a building case close to the users building project at hand. Furthermore, from previous hybridGEOTABS designs relations have been derived between early design parameters and parameters that are not known in the early design stage.
- Since the answering of the key question "*what is the amount of hybridity of the building?*" (as a starting point for estimating the sizing and performance of the hybridGEOTABS design for a certain building), requires a splitting between the share of GEOTABS and the share provided by a secondary system, and given that the tool is interactive and easy to use, the load splitting and pre-engineering of the building case must happen via calculations in the background of the tool (not by the user).
- In a feasibility study various HVAC- and energy concepts are compared to one another for a given building project. This requires the estimation of key performance indicators in terms of energy, environment, cost (total cost of ownership) and comfort. Therefore, the tool needs to provide estimations of these parameters. Again, for assuring the easy use of the tool, these need to happen in the background of the tool.

To do so, a tool is developed allowing to define for a specific building project the feasible hybridity. To do so, the tool consist of three steps: (1) define the building project, (2) receive the building thermal demands and the sizing of the hybridGEOTABS concept and (3) a processing of the results resulting in an early concept design and the feasibility of the hybridGEOTABS concept. These three main steps can also be found back in the tool:

1. The first part contains the **input data** that is available in an early-design phase of the building. The user can select the building properties and its boundary conditions, and the tool searches for the most similar case in the database.
1. The second part is the output of the monthly **heating and cooling demand** as well as the **peak thermal powers** for the selected case from the database, for the primary GEOTABS and secondary heating and cooling system, and for different controllers.
2. The third part of the tool contains the **feasibility study**. Here the key performance indicators, in terms of comfort, energy, environment and financial costs, are provided for the hybridGEOTABS design with different controllers. Additional scenarios to which it can be compared are hybridGEOTABS designs with and without photovoltaics to provide electricity, a 'pure' GEOTABS design, and a nonGEOTABS design (based on fossil sources).

1.3. The hybridGEOTABS system concept in the tool

The hybridGEOTABS system concept and modules are introduced in D6.1. In the design tool and study, it is assumed that the primary energy source, which is the ground-source heat pump (GSHP) will only feed the primary emission system, namely thermally active building systems (TABS). The secondary energy sources will only feed the secondary emission systems (Figure 3). The secondary emission system is a fast reacting system (e.g. air-based system, radiator) to compensate the peaks during a day that the TABS cannot compensate due to its thermal inertia. Furthermore, an air handling unit (ventilation system with mechanical supply and mechanical extraction) with heat recovery is assumed with a predefined recuperation efficiency of 84%. The sizing of the air-handling unit is a function of the building type and the conditioned floor area. Remark that other system configurations for the hybridGEOTABS system are possible, but are directly not included in this version of the tool. However, D6.5 provides example hydraulic schemes for some other system configurations.

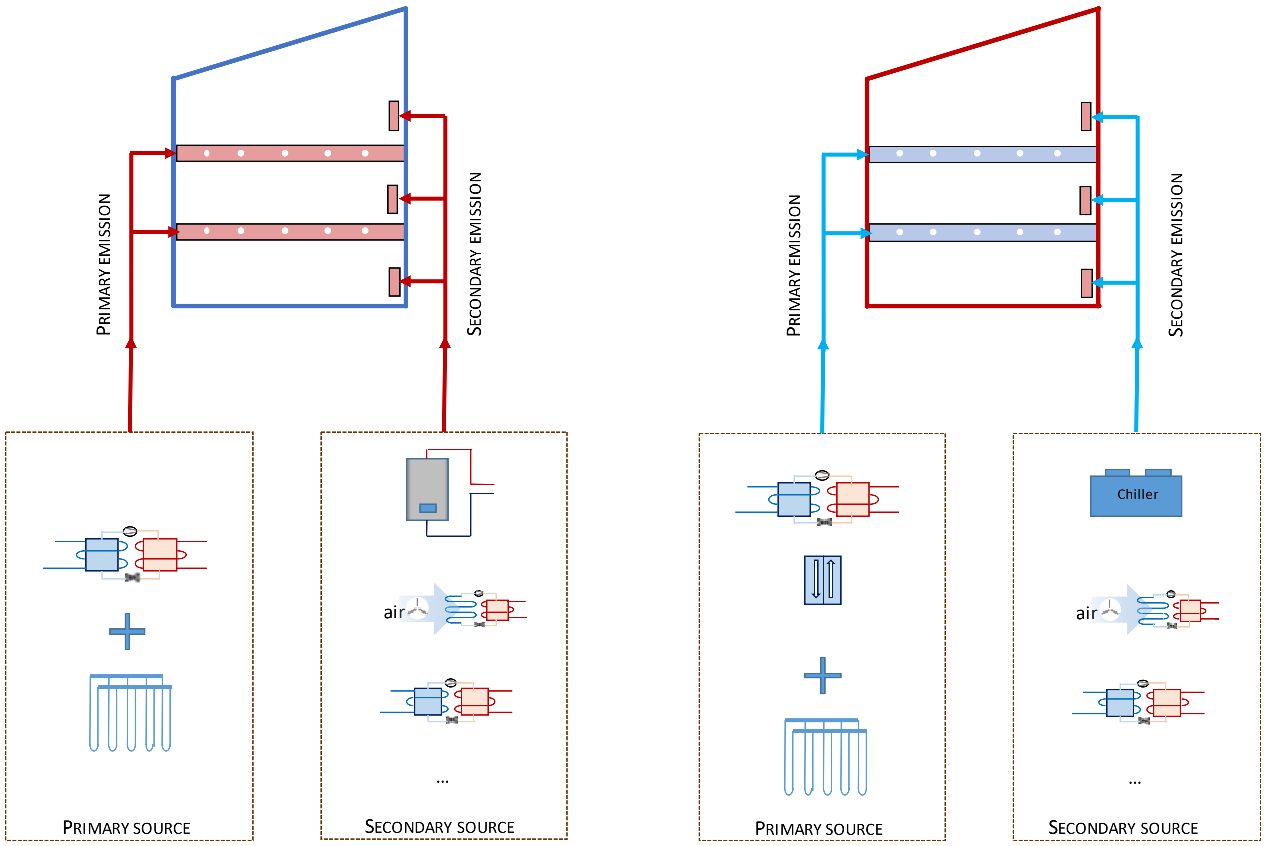


Figure 1-3: Schematic representation of the hybridGEOTABS system concept in heating (left) and cooling (right) as included in the tool

Furthermore, the design tool focuses on mid-size and large buildings from four building typologies (schools, offices, elderly homes and multi-family buildings), having a floor area larger than 1,000 m². The considered lay-outs of zones and functions for each typology are documented in D2.2. The TABS-design is fixed per typology: for offices and schools it is assumed that the TABS exchanges heat with the room via the ceiling, while for multi-family buildings and elderly homes two-sides TABS are provided, as depicted in Figure 4.

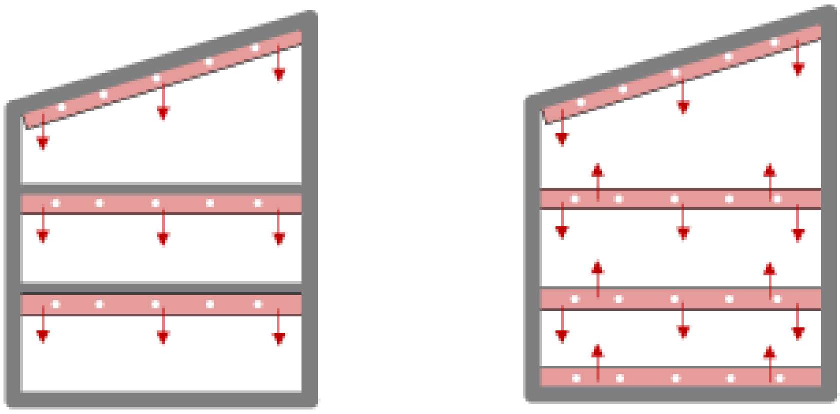


Figure 1-4: Schematic representation of (left) single-sided TABS (via ceiling) and (right) double-sided TABS

This choice influences the total TABS-area, which is 80% of the conditioned net floor area of the building for single-sided TABS, and 160% for double-side TABS, as well as the coefficients of heat transfer (see Table 1). Furthermore it is assumed that the TABS pipes (diameter 20 mm) are at a 10 cm depth in the concrete, and the distance between the pipes is 15 cm.

Table 1-1: Total heat transfer coefficients (radiation + convection) between TABS and zone

	Ceiling-Zone	Floor-Zone
Heating	6.0 W/m²K	9.5 W/m²K
Cooling	9.5 W/m²K	7.0 W/m²K

2. Description of the tool

The tool consist of three parts.

1. The first part, which is accessible to the user, is a **front end website**, available via the hybridGEOTABS website (http://www.hybridgeotabs.eu) (Figure 5).
2. The second part is a server side **processing tool** that analyses data, prepares the output and passes all results to the website.
3. The third part is a **SQL-server** (Figure 6). An active link is present between the processing application and the database.

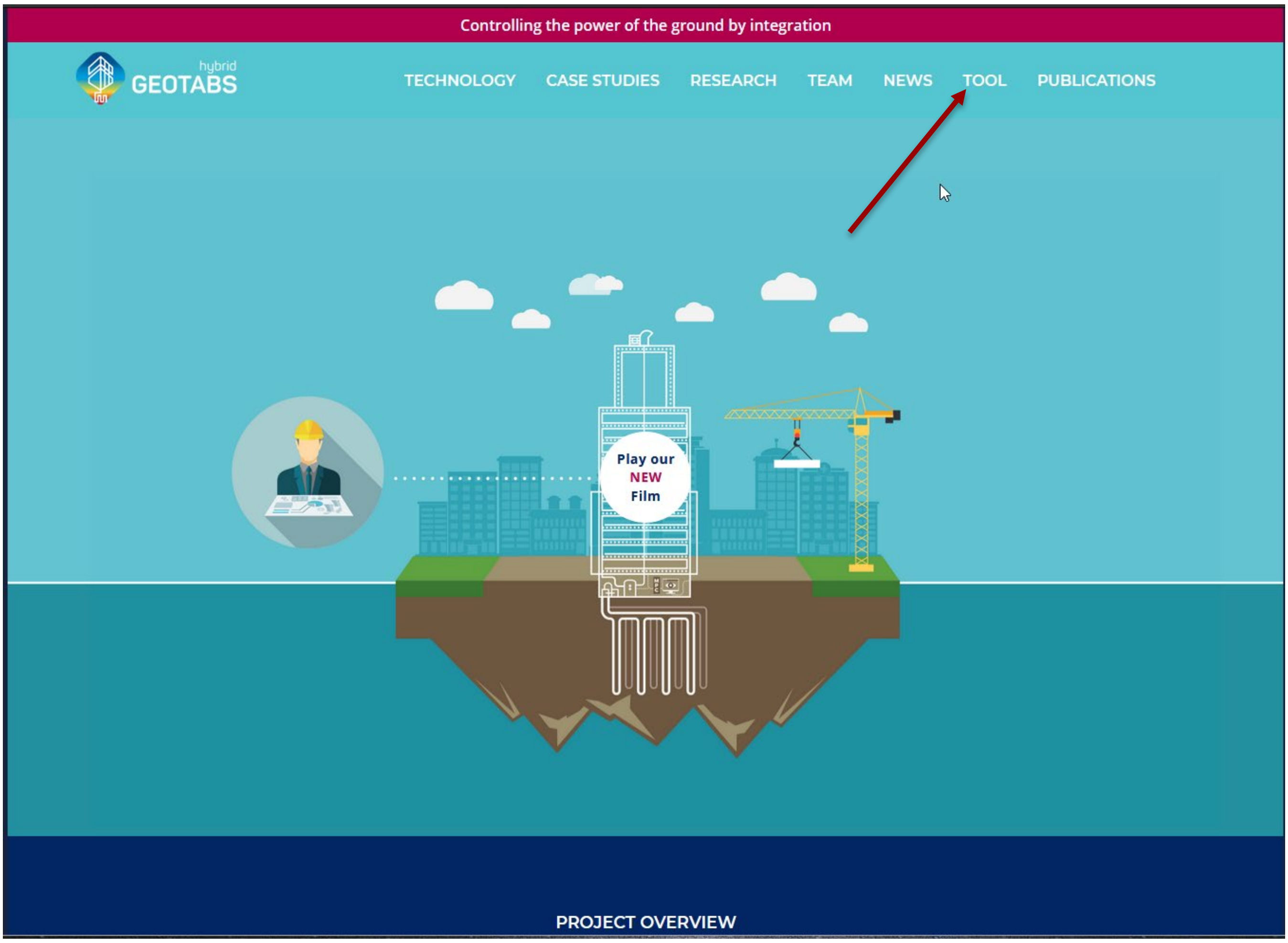


Figure 2-1: hybridGEOTABS website main screen

2.1. Tool structure

The user interface consists of three parts:

1. **Sheet 1 'DEFINE BUILDING'**: Define the characteristics of the particular building
2. **Sheet 2 'DEMANDS AND PEAK'**: The monthly demands and peaks for heating and cooling of the primary and the secondary system using 3 different control strategies; three typical weeks (heating period, cooling period, intermediate period) showing the course of the demands during one day, for the particular building.
3. **Sheet 3 'FEASIBILITY STUDY'**: Pre-design and feasibility study results of the particular building.

The database consists of:

1. **Database 'BUILDING GEOMETRY'**: Database containing building geometrical data describing the cases in the building stock (geometrical info and building physical or energy-related parameters of the building)
2. **Database 'DEMANDS'**: Database containing the heating and cooling demands of each building from the first database
3. **Database 'ECONOMIC VALUES'**: Database containing economic values to perform a feasibility study (inflation rate; cost electricity and natural gas; primary energy conversion factors; CO_2-emission factors)
4. **Database 'COST SYSTEM':** Database containing the costs of the system parts (borefield, heat pump …)

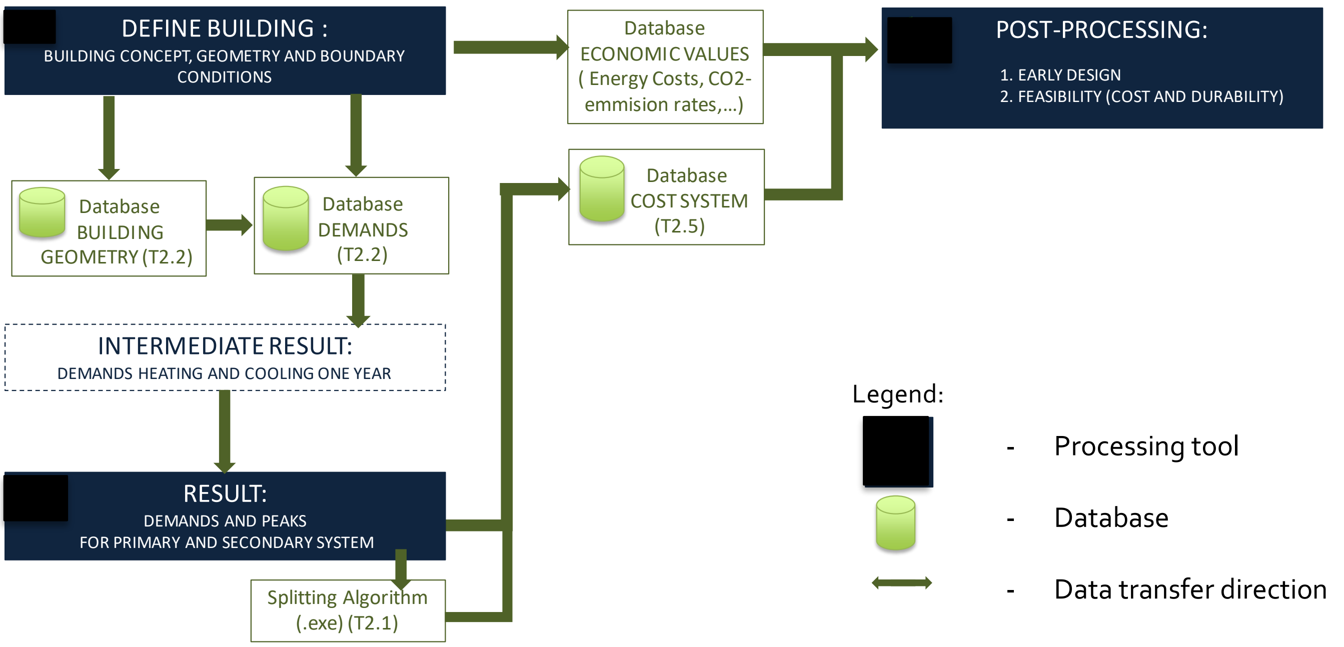


Figure 2-2: Schematic of the building-up of the tool

In sheet 1 of the tool, the user defines building by selecting the key building geometrical and energy-related properties. Then, the processing tool performs a 2 step fetching algorithm.
The first step is based on absolute parameters for which the user entered a discrete input on the website:

- Region/Location
- Building type
- Insulation level of the building
- Solar shading
- Thermal mass
- Internal heat gains
- Building orientation

The database query returns the building geometries that match the discrete inputs. A second algorithm then analyses the returned geometries by comparing the non-discrete input values:

- Conditioned floor area
- Building volume
- Glazing percentage
- Number of floors

Based on the non-discrete input values, the processing tool selects the closest pre-simulated case using a weighting function. For this case the processing tool then fetches the pre-simulated hourly heating and cooling needs and load splitting, that are displayed in the second sheet of the user interface.

2.2. Define building

Goal: Define all building and energy-related characteristics to be able to perform the pre-design and the feasibility of the particular building project.

The building database includes about 140,000 building cases of four building typologies. For each typology a range of building geometries (with floor area > 1,000 m²) were defined, and for each geometry a range of building physical or energy-related building properties were simulated. Table 2-1 shows the amount of cases per typology, according to the study in D2.2. Figure 10 provides an overview of the key building physical parameter and energy-related parameters that are available in the building stock database, according to the study in D2.2. The table in Annex 1 provides the values for each of these parameters, as well as the values for some other influential parameters (e.g. ventilation rates).

Table 2-1: Number of building cases and simulations in the database (source: D2.2 (Mahmoud et al.))

Typology	Number of geometrical Cases	Number of properties combinations	Total number of cases
Office buildings	278 (incl. range of glazing percentages)	144	40.032
Schools	116	144 * 3 glazing percentages	50.112
Elderly homes	20	72 * 3 glazing percentages	4.320
Multi-family residential	116	144 * 3 glazing percentages	50.112

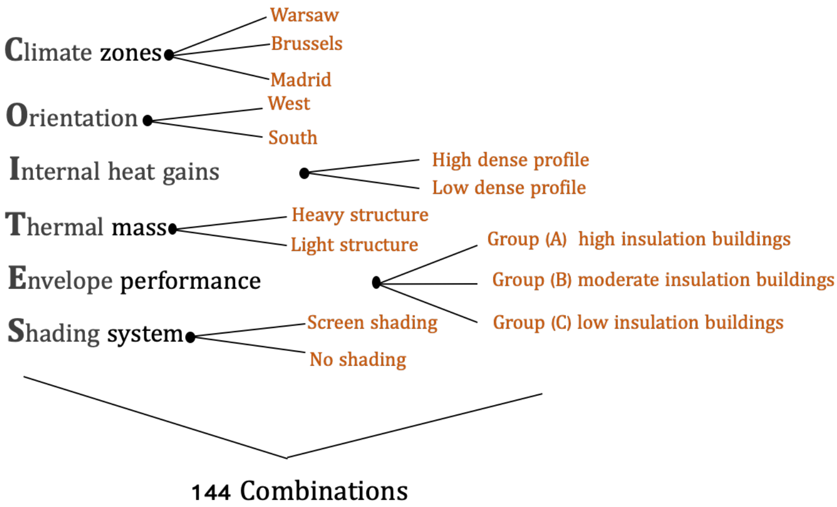


Figure 2-3: Combinations of building physical variations (source: D2.2 (Mahmoud et al.))

In the tool interface, these characteristics are divided into three categories, and are explained below more into detail.

- Category 1: General Input
- Category 2: Data containing information about the building geometry. Since in the early design stage no detailed information about the building is available, high-level input parameters are used.
- Category 3: Data containing information on the energetic characteristics of the building that has a significant impact on the thermal behaviour of the building.

<u>Category 1: General Input</u>

This data sets the region and the building type. This information is needed as this serves as boundary condition in the building simulation study. Furthermore, this data is used to retrieve the local parameters such as energy cost from the database. For the moment three regions can be specified. These are the regions from the weather files used in the building simulations: Brussels, Madrid and Warsaw. They represent the three major climatic regions found in the EU, as documented in D2.2 and D5.4. For the building type four options are possible: office, multi-family residential building, elderly care home and school.

Figure 2-4: ['DEFINE BUIDLING']: Set the region and the building type.

Figure 2-5: Map of Europe, showing the climate zones and the three selected cities (source: D2.2, Mahmoud et al.)

Category 2: Geometry

The building geometry is defined using three input values: the conditioned floor area, conditioned volume and glazing percentage. The glazing percentage is calculated as a percentage of the wall surfaces (excl. roofs and groundfloor surfaces).

For the selected geometry, two types of orientation can be chosen: long façade facing North/South or long façade facing East/West. Furthermore, it is assumed that each wall will contain the same window to wall ratio according to the specified glazing percentage.

Category 3: Energetic characteristics

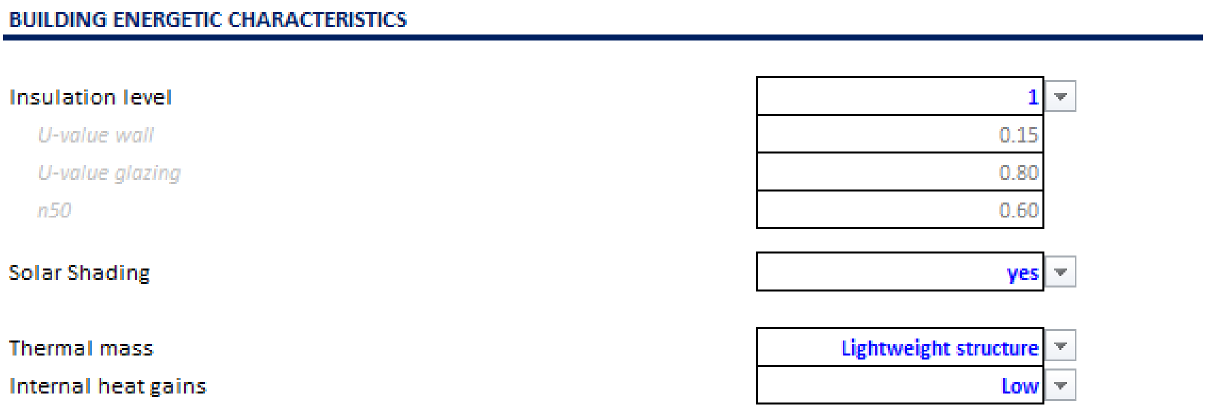


Figure 2-6: ['DEFINE BUIDLING']: Selection of the building energetic characteristics in the Tool.

The **Insulation level** sets the U-values and airtightness of the whole building. Three levels can be chosen referring to a predefined combination for a U-value of the opaque parts (walls, roof and floor), a U-value of the windows and an infiltration rate [ach] of the building. The insulation levels and the predefined values are tabulated in Table 2.

Table 2-2: Predefined combination for a U-value of the opaque parts (walls, roof and floor), a U-value of the windows and an infiltration rate [ach] of the building.

	U-value opaque [W/m². K]	U-value window [W/m². K]	g-value glazing [-]	Airtightness [n50]
Level 1	0.15	0.80	0.40	0.6
Level 2	0.27	1.5	0.56	2.0
Level 3	0.50	2.5	0.60	5

The assumed type of solar shading consist of an external vertical screen on the windows with a shortwave transmittance of shortwave radiation equals to 0.24. the external screen controller is on when the direct solar irradiation on external windows reaches 150 W/m².

Furthermore, two types of thermal mass can be selected, corresponding to a heavy weight structure (e.g. a building with concrete floors, exterior and interior walls) or a lightweight building (with concrete structure and slabs and external walls, but lightweight internal walls and light-weight floor layers).

At least, it must be specified if the internal gains for the specified building type will be high or low. These internal gains include all types of internal gains for the particular building (i.e. occupancy, light and appliances) taking into account the dynamic use schedules of the various zones and functions as discussed in detail in D2.2. Table 3 provides a summary of the internal gains per building typology and an indication of the occupation density for the main function in these buildings.

Table 2-3: Internal heat gains (source: D2.2 (Mahmoud et al.))

	High occupancy	High internal gains	Low occupancy	Low internal gains
Office	1p / 10m² office	33.0 W/m²	1p / 20m² office	18.5 W/m²
School	1p / 2.5m² classroom	42.0 W/m²	1p / 3.5m² classroom	33.0
Elderly home	1p / 24m² bedroom	10.7 W/m²	NA	NA
Multi-family	3p/apartment	28.6 W/m²	1p / apartment	7.5 W/m²

A complete overview of these and other parameters is provided in Annex 1.

Once the building parameters have been defined, the most similar building is selected from the database. They are displayed in the sheet 'Database building stock results' on the tool (Figure 2-7)

Database building stock results

Your results are now generated, and have been organised over 3 sections.

OF_G0256P092

Conditioned floor area	1026 **m²**
Building volume	4528 **m³**
Glazing percentage	21.32
compactness	2.43
loss area	1862 **m²**
roof area	342 **m²**
floor level height	4.08 **m**
number of floor levels	3

Figure 2-7 Web-tool: building stock results

2.3. Results Building Demands, Energy use and Peaks

Goal:	Show the total heating and cooling demand for the selected building Show the peak demand for heating and for cooling Show the energy use for the primary and the secondary system corresponding to the baseload algorithm Show the ideal sizing for the primary and the secondary system corresponding to the baseload algorithm Let the user play with the sizing of the primary and the secondary system

Building heating and cooling demand

For the selected building, that was defined using the inputs from the first sheet, the resulting hourly total heating and cooling demand are retrieved from the database 'DEMANDS'. This total heating and cooling demand is the ideal heating and cooling demand without taking into account an energy source or an emission system and is therefore considered as the **building demand** (D2.2). The hourly demands are further processed resulting in total, peak and monthly data. These demands serve as the starting point to calculate the **the production systems energy use.** The thermal energy needed to meet the building demand is split in two shares: one delivered by the primary system (GEOTABS) and one delivered by a secondary classic heating and cooling system.

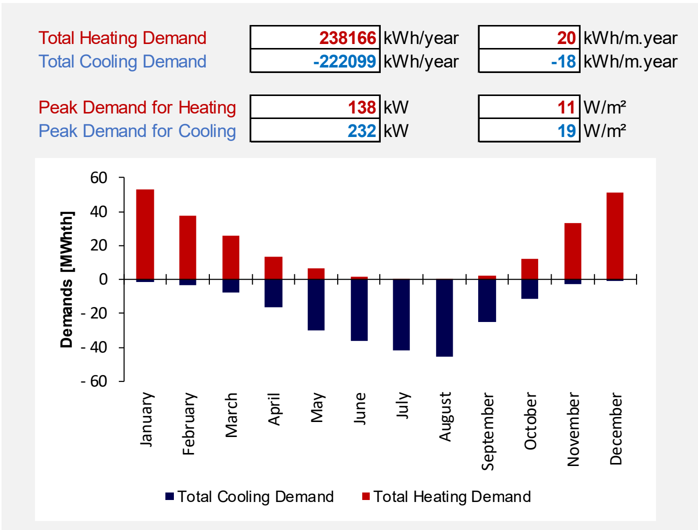


Figure 2-8: [SHEET 'DEMAND and PEAK']: monthly total heating and cooling demands

Furthermore, in the sheet the heating and cooling demand of three representative weeks is visualized (Figure 2-9). This heating and cooling demand is the demand of one zone that is representative for the user-defined building typology. The user has the possibility to change the number of the week. The default values for the number of the weeks are:

- Week heating season: week 5 (from 05/02 till 12/02)
- Week intermediate season: week 15 (from 16/04 till 23/04)
- Week cooling season: week 25 (from 25/06 till 02/07)

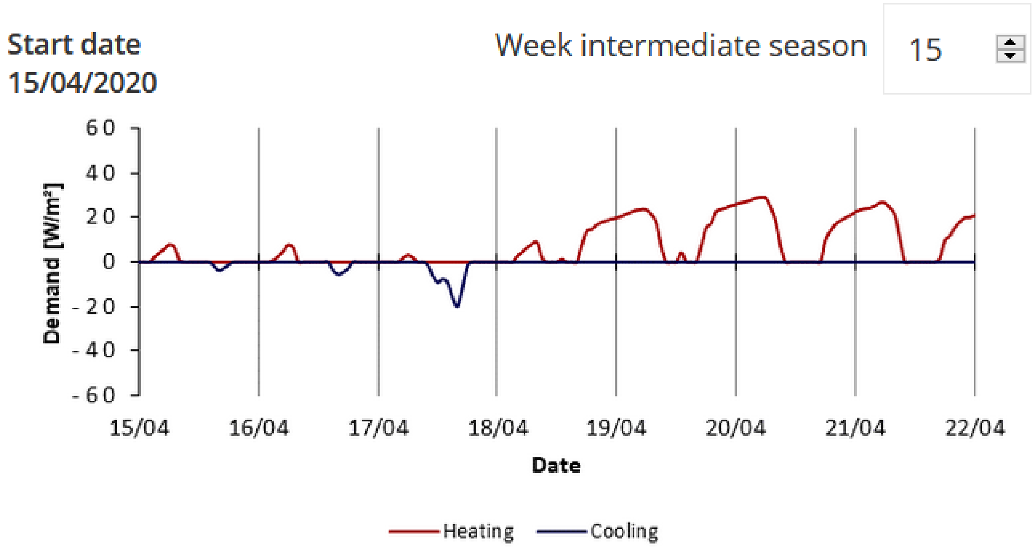


Figure 2-9 Example weekly demands

The figures allows to quickly define the hybridity of the emission system. In case the curve is flat (small amplitude), tabs will be sufficient to acclimatize the building without a daily air temperature amplitude that is too large related to thermal comfort. In case the curve shows high amplitudes, for example high peaks related to high internal loads, TABS could not compensate for the quick increase or decrease in air temperature. A secondary system will therefore be needed to maintain comfort.

Energy use

The energy use needed to meet the building heating and cooling demand is split over a primary production system and two secondary production systems. The used method to obtain the split is performed by a load splitting algorithm as introduced in D2.5 (and D2.1). The split is done in two ways (Figure 14).

- **Split - option 1:** The first suggested split is the split determined by the baseload algorithm. For all buildings in the database, the total heating and cooling demand is thus divided into the energy use provided by the primary system and by the secondary system (Figure 7). This theoretical suggested split is the most optimal solution from energetic point of view, assuming an optimal controller.
- **Split - option 2:** The second shown split is a split that is calculated in real time in the tool itself. Namely, in addition to the proposed baseload split (split – option 1), the user has the opportunity to assess the impact of the baseload split on, for example, cost, sustainability (CO_2), borefield balance… Because it is not possible, at least not in a quick and easy way, for the user to do the sizing for the heat pump himself, the so-called equalizer is used. The user inputs. The monthly average core temperatures of the TABS, are reprocessed. When core temperatures are modified, the hourly loads for primary and secondary system are recalculated.

Monthly set points

This equalizer like function makes it possible to specify a core temperature for the TABS (supply temperature of water). The idea is that this way the user can define roughly how much the TABS heat or cool to the zone. For example, if the set temperature of the zone is 22°C and the core temperature of the TABS is also set to 22°C, the TABS will do very little. If, on the other hand, the defined core temperature of the tabs is set to 25°C, the TABS heat up and will emit this heat through radiation and convection to the zone.

	Core Temperature of Tabs
jan	32
feb	32
mrt	30
apr	26
mei	23
jun	20
jul	18
aug	18
sep	20
okt	23
nov	26
dec	30

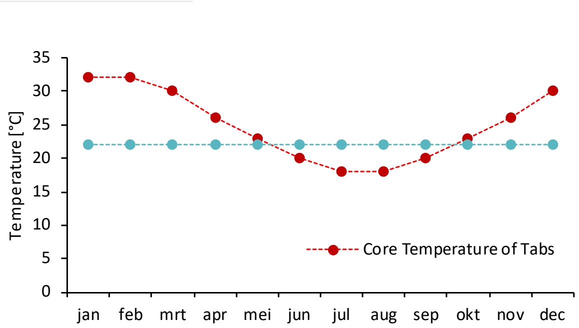


Figure 2-10: Equalizer: the user can specify a core temperature [°C] for the TABS.

The user-defined core temperatures serve as input for the baseload algorithm. Using these temperatures, a split is calculated using the total hourly heating and cooling demand of the whole building available in the database.

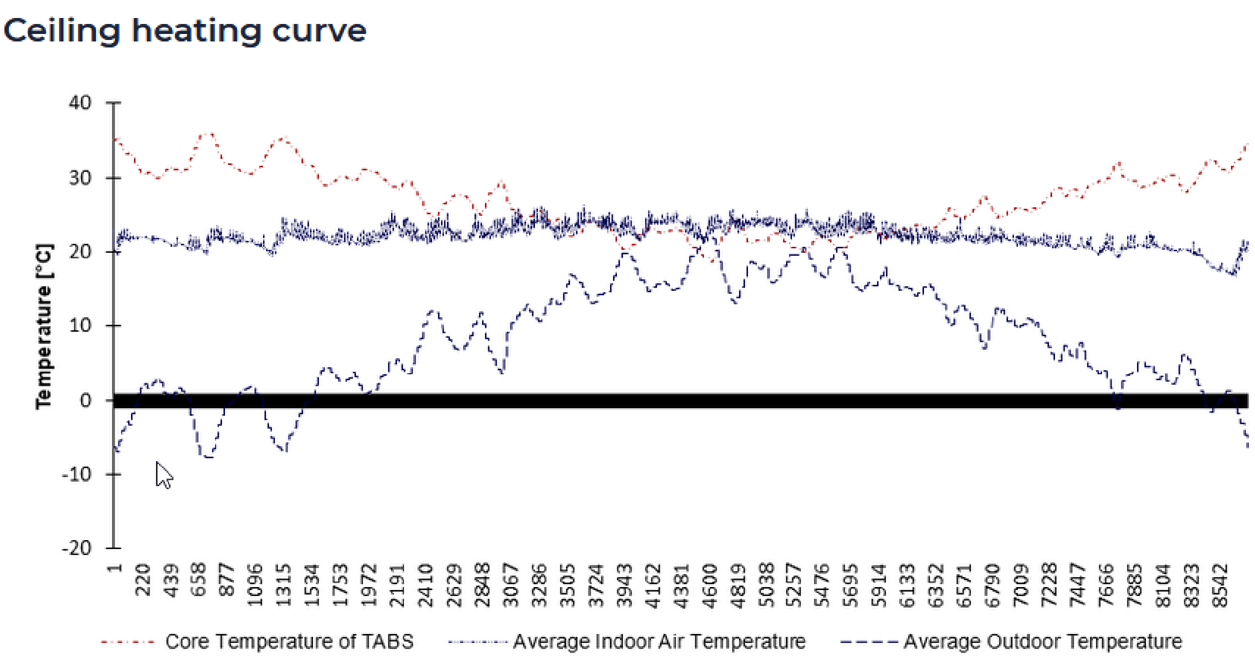


Figure 2-11: [SHEET 'DEMAND and PEAK']: *Monthly set point resulting temperature overview*

Monthly energy use

Three monthly demands are shown corresponding to heating and cooling demands as shown in Figure 14: (1) annual heating and cooling demand, (2) annual heating and cooling demand for the primary and secondary system following the optimal solution following baseload splitting algorithm, and (3) annual heating and cooling demand for the primary and secondary system following the optimal solution following the own provided inputs (equalizer).

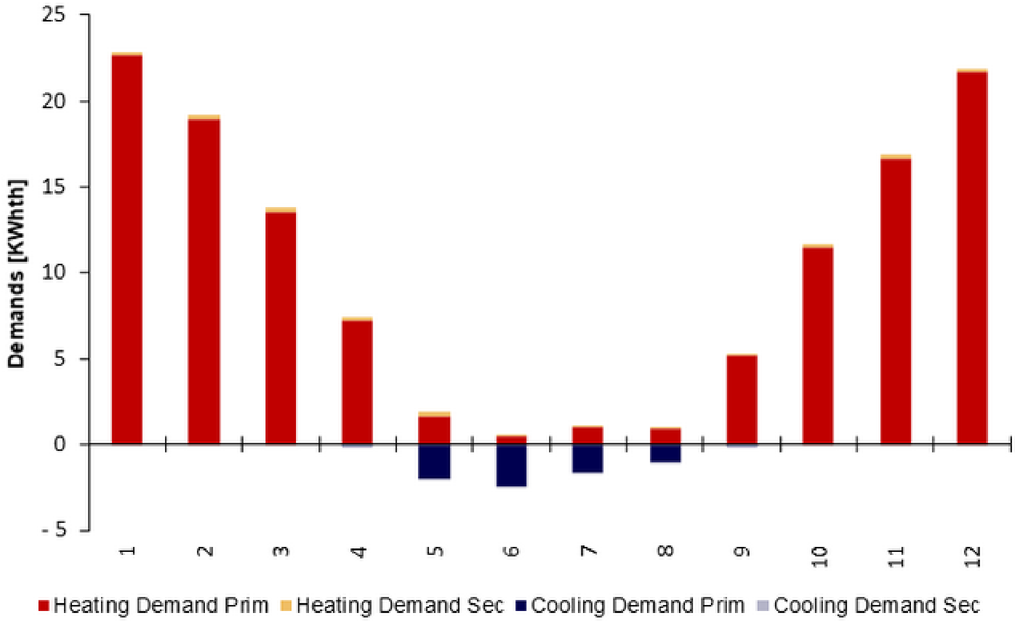


Figure 2-12: Mothnly energy for primary and secondary sustems with baseload splitting using an MPC

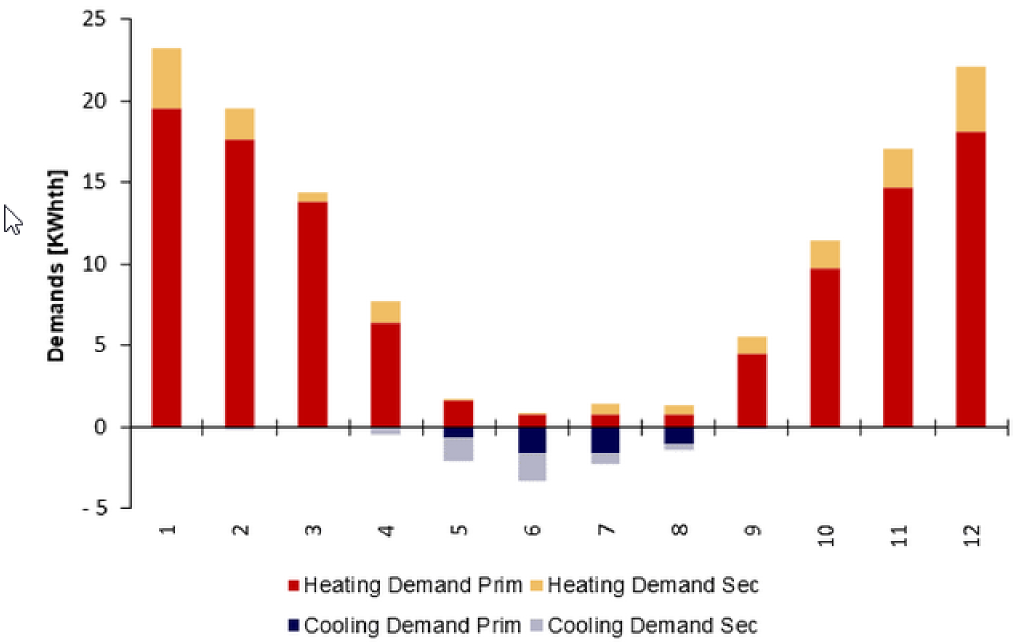


Figure 2-13 Monthly energy for primary and secondary systems with baseload splitting using an optimized RBC

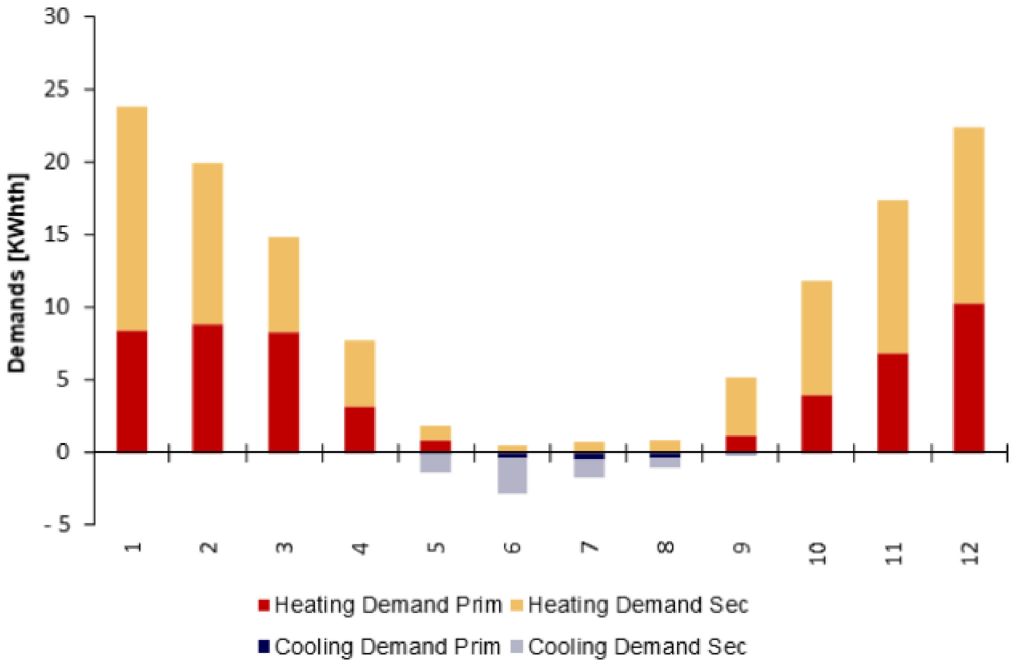


Figure 2-14 Monthly energy for primary and secondary systems with baseload splitting using the monthly set points

<u>Borefield Balance related to the balance</u>
The tool shows in 2 graphs the monthly demands for heating and cooling towards the borefield.

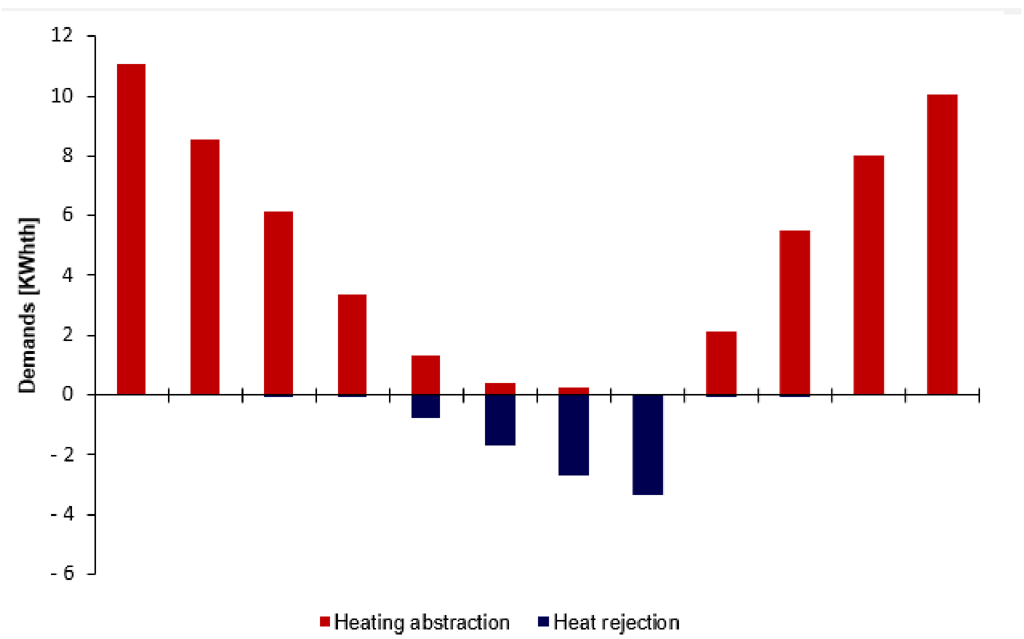


Figure 2-15 Heat extracted and injected into the borefield using baseload splitting based on an mpc

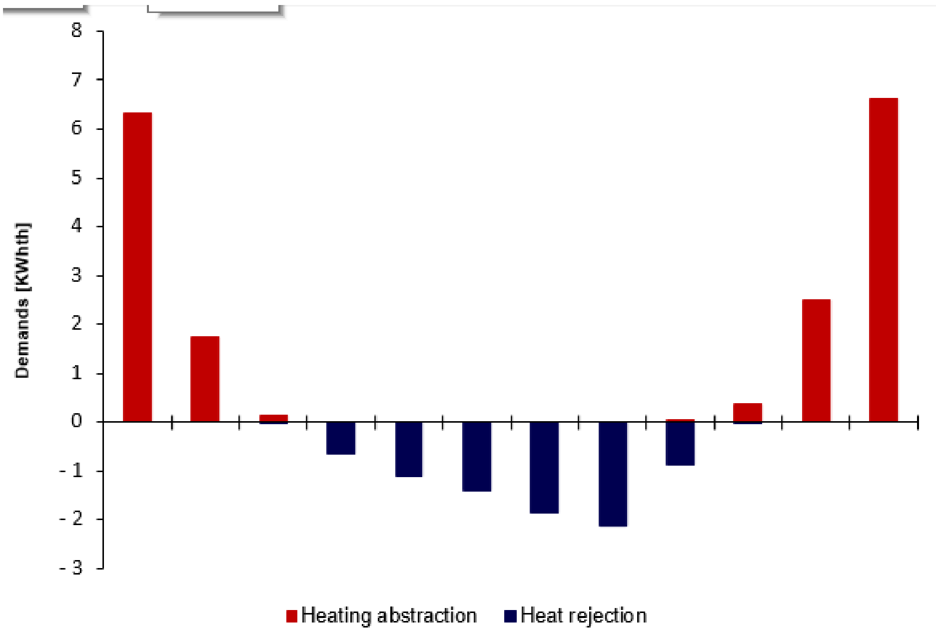


Figure 2-16 Heat extracted and injected into the borefield using baseload splitting based on monthly set points

Nominal power for heating and cooling

To calculate the investment costs for a system, it is necessary to know the nominal capacities. A way to define the peak demand for the heating system is to calculate this value as suggested by the European standard EN 12831. This steady state method only takes into account heat losses (through transmission, ventilation and infiltration) and no heat gains (internal gains and solar gains). Furthermore, an additional capacity is considered to compensate heating-up after a period of setback or closure. The data from the database, on the other hand, results from a dynamic simulation that takes into account the internal heat gains and solar gains and inertia from the building.

When comparing the peak demands found by a dynamic simulation with those found by the normative calculation, two things can be noticed:

- The peak demand and therefore also the maximum power that comes from the dynamic calculation is much lower than that from the normative calculation.
- The peak demand for the primary heating system and the secondary heating system will not be a split of the total peak demand (resulting from the splitting algorithm). The peak demand for the primary system will be used at another time than the peak capacity of the secondary system (for example, when the secondary system is at rest).

The question now is what peak power should be used as design value for the primary and the secondary system. The following procedure is used in the tool.

Peak demand for heating and cooling

All peak demands that are based on dynamic simulation are lower than heat loss and cooling load according to standard.

Peak demands for heating and cooling are the respectively maximum and minimum for each time series. The different baseload splitting algorithms result in different peak demands for both primary and secondary system. For the moment the tool visualizes these peaks for the MPC and the monthly set point control strategies. Based on both strategies, it also gives an insight on the borefield balance for the selected case. An unbalance of 60% is still considered as acceptable. Based on the difference between the energy consumption the amount of hybridity is also displayed.

	baseload splitting (predictive control)		Rule based control using monthly setpoints	
borefield unbalance	565%		120%	
	Energy use [kWh/year]	Thermal Power [kW]	Energy use [kWh/year]	Thermal Power [kW]
Heating: Primary system	71.063,15	30,80	22.111,57	17,19
Heating: Secondary system	1.430,26	8,79	54.660,02	26,88
Cooling: Primary system	-8.551,84	-12,37	-8.058,43	-12,06
Passive cooling by heat exchanger	-8.551,84	-12,37	-8.058,43	-12,06
Active cooling by heat pump	0,00	0,00	0,00	0,00
Cooling: Secondary system	-220,59	-6,59	-3.572,98	-19,36
Hybridity: Sum Energy use sec/Sum Energy use pri+sec	2%		66%	

Figure 2-17 Energy consumption and power peak according to mpc and montly setpoints.

2.4. Feasibility

Goal: Compare different energy concept scenarios
Make an informed decision with estimated GHG emissions, Primary Energy Use and total cost of ownership

<u>Input and assumptions</u>

Given the demands and peaks for the primary and secondary system, a total cost of ownership (TCO) calculation is performed in order to compare the hybridGEOTABS design with other scenarios for the selected case. The TCO-calculation compares different scenarios while taking into account all relevant costs during the lifetime of the building heating and cooling for production and emission systems. Hence, as described in the introduction, it is too short-sighted to look only at the investment cost and not at the operational costs and sustainability of a system concept.

The calculation of the total cost of ownership is based on the EN 15459:2017 [3]. The calculated global cost following this standard allows comparing the energy need of the alternative solutions in order to verify economic feasibility of the options and quantifying the economic performance of a building as a whole... [4]. Hereby, it is to be noted that the TCO only focusses on the HVAC system of the building. This means that for a system, cost, (primary) energy use and CO_2 emission is calculated. Cost and CO_2-emissions related to raw materials, construction of the building, maintaining the building... are not included.

To calculate the total costs of the different hybridGEOTABS scenarios, it is mandatory to define the system that serves as primary and secondary energy source. Concerning the primary energy source, it is assumed that this source consists of a borefield combined with:

- In heating mode: a heat pump
- In cooling mode: a heat exchanger (passive cooling mode)

The primary energy source will feed the TABS.

The secondary energy source and secondary emission

- For heating: Condensing gas boiler
- For cooling: Chiller

The secondary emission consists of 2 pipe fan coil units and radiators.

<u>Feasibility study</u>

Scenario's

The five main considered scenarios in the tool are:

- **0**: Non GEOTABS based on heat loss and cooling load stationary calculation. Production and emission are based on elements from secondary system (gas condensing boiler and chiller).
- **1:** Non GEOTABS (fossil) building: in this scenario, heating and cooling is produced only by the secondary production system. The heating and cooling is emitted to the building by the secondary fast reacting emission system. The dimensioning is based on the dynamic simulation baseload calculation.
- **2:** HybridGEOTABS baseload splitting (predictive control): heating and cooling demands as well as sizing are coming directly out of the database. They derived by the baseload splitting optimisation using a predictive control (mpc).
- **3:** HybridGEOTABS optimised rbc: The baseload is split using an optimised rule based controller.
- **4:** 100% GEOTABS: no secondary energy production system and emission types are used.

Besides these four main scenarios, a variation on the two HybridGEOTABS scenarios are calculated.
- (Scenario 2b: hybridGEOTABS scenario 2 + including photovoltaic panels)
- (Scenario 3b: hybridGEOTABS scenario3 + including photovoltaic panels)

The number of photovoltaic panels is based on the maximum number determined by:
- the number of panels that can be placed on the roof
- The number of panels needed to cover electricity needs for production of heating and cooling without injecting electricity back in the grid. The number does not take into account other electrical needs in the building.

For all these scenarios, the heating and cooling demand is turned into a net energy demand. This is done by taking into account the COP, EER or efficiency of the production system (4).

Table 2-4: COP,EER or efficiency of the production system.

Component	COP/EER/Efficiency
Chiller (Air-Water)	2.8
Condensing Gas Boiler	0.98
Heat Pump: Air-Air	3.5
Heat Pump: Air-Water	3
Heat Pump: Ground-Water	5
Pellet Burner	0.9
Primary system: passive cooling (HEX)	22

Furthermore, for each system, the energy source (gas, electricity, pellets…) is defined, allowing to calculate the CO2-emmision. To do so, conversion factors, as stored in the database '*Economic Values*', are used as default values.

Calculation method

To determine the total cost, the Net Present Value (NPV) is calculated. This dynamic variable represents the amount of actualised (or discounted) cash flows considering all cost during over a period of 30 years. Two types of cost are calculated: a so-called micro-economic cost and a macro-economic cost. (A detailed description of the calculation methodology performed in the background is described in Chapter 3)
- **Micro-economic cost:** Total financial cost including the investment costs, replacement costs, annual costs (energy and maintenance) during a defined lifetime.
- **Macro-economic cost:** Total financial cost and environmental costs (e.g. by expressing the primary energy and/or GHG-emissions in a monetary cost).

To be able to calculate the Net Present Value (NPV), at the one hand values for costs of the system components and energy prices are necessary. Default values are stored in the database '*Cost system*'. On the other hand, economic parameters like inflation rates and conversion factors for the CO2-emission are needed. These are stored in the database containing the economic parameters: '*Economic Values*'. The derived heating and cooling demand for the primary and secondary system

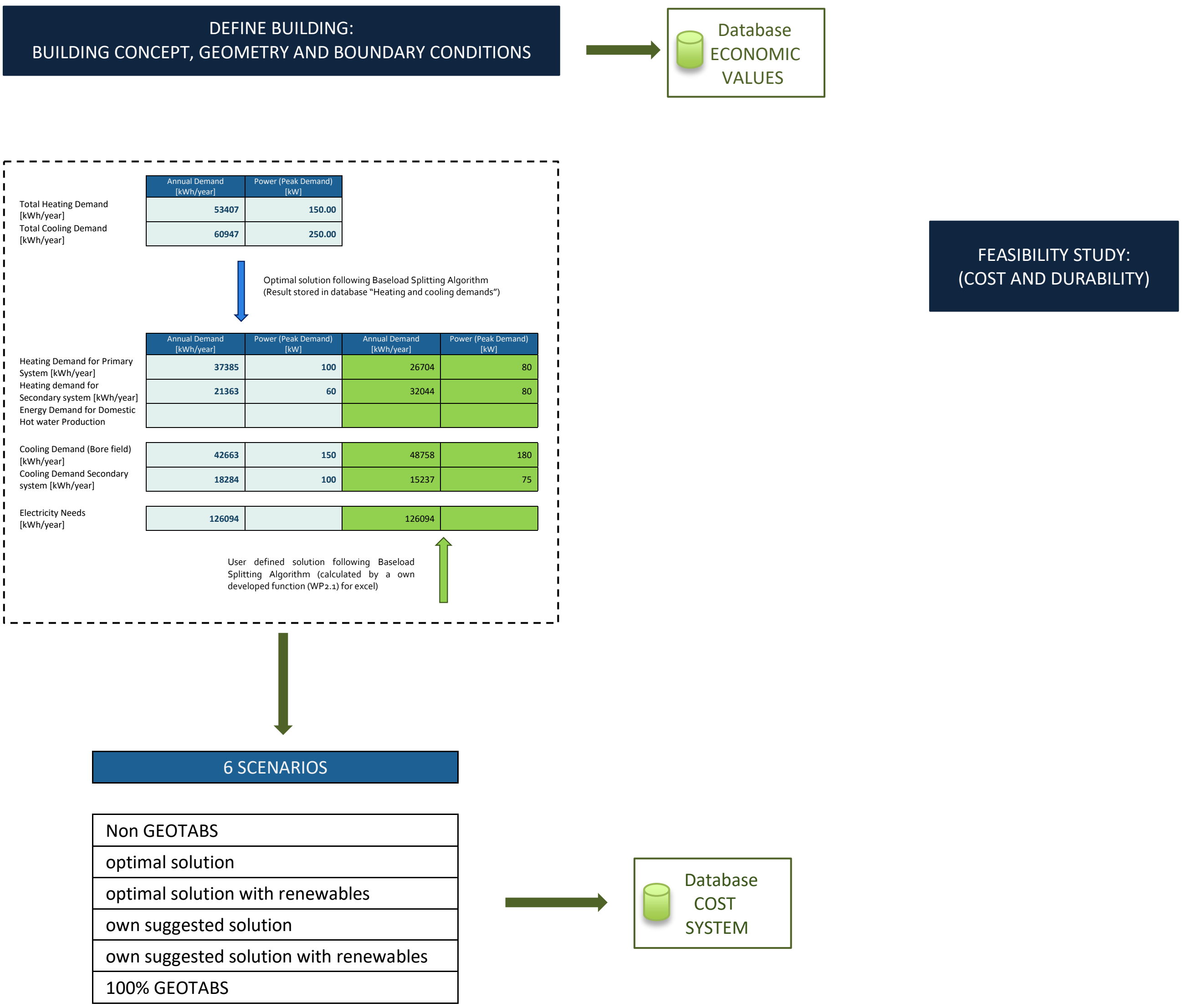


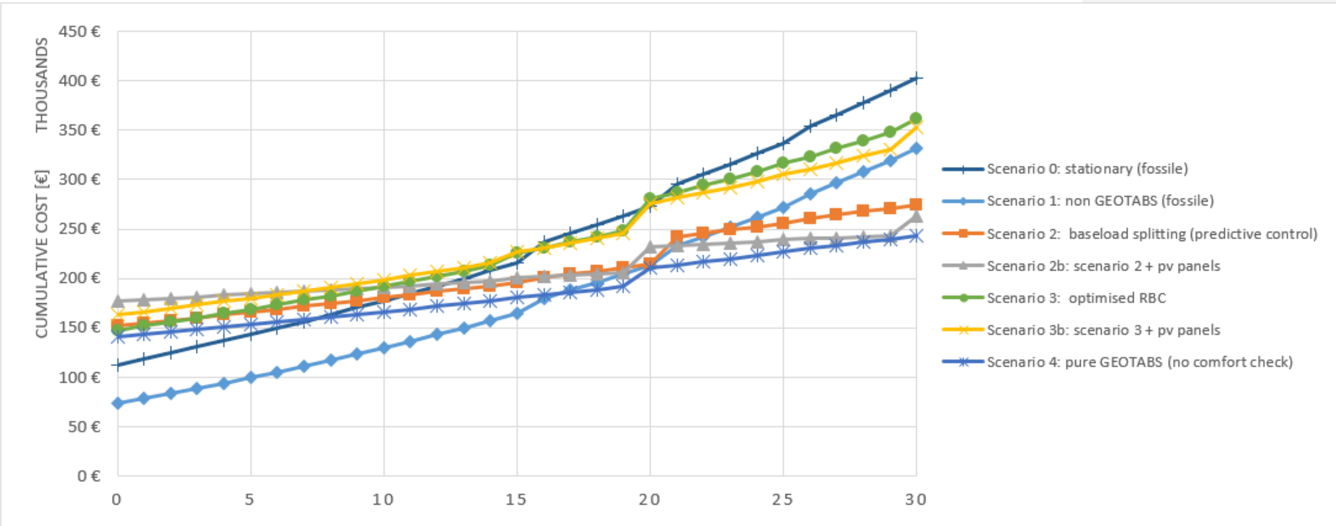
Figure 2-18: Schematic of the building-up of the tool and

Derived Results

Using the NPV, two other indicators are derived in the tool. The first indicator is the payback period, defined as the time necessary for the return-on-investment of the initial investment costs. The second indicator is the amount of savings in relation to the additional investment cost. In the tool, the results of this analyses are represented in a table and in visualised in a graph (Figure 16).

Micro Economic:

SCENARIOS	Hybridity (NPPrim Energy/Npinstalled)	Investment Cost	Total Cost	Total savings	Payback
		M133	AU136		
Scenario 0: stationary (fossile)		€ 112.747,40	€ 374.929,55		
Scenario 1: non GEOTABS (fossile)		€ 73.407,86	€ 313.361,25		
Scenario 2: baseload splitting (predictive control)		€ 151.977,67	€ 262.712,08	-€ 50.649,17	
Scenario 2b: scenario 2 + pv panels		€ 177.177,67	€ 171.193,87	-€ 142.167,38	
Scenario 3: optimised RBC		€ 148.013,23	€ 278.836,84	-€ 34.524,40	
Scenario 3b: scenario 3 + pv panels		€ 163.413,23	€ 266.824,66	-€ 46.536,59	
Scenario 4: pure GEOTABS (no comfort check)		€ 141.285,33	€ 159.965,35	-€ 153.395,89	



CASE	CO_2 Emissions [Ton]	CO_2 Reduction	Total Cost	Total Cost CO_2	Total Cost Including CO_2	Total savings	Payback
	AQ166		AQ175	AQ170			
Scenario 0: stationary (fossile)	478		289.140 €	11.128 €	300.268 €	-	
Scenario 1: non GEOTABS (fossile)	478		230.896 €	11.128 €	242.023 €	-	
Scenario 2: baseload splitting (predictive control)	155	67%	226.618 €	3.620 €	230.237 €	-11.786 €	
Scenario 2b: scenario 2 + pv panels	-162	134%	219.286 €	-3.780 €	215.505 €	-26.518 €	
Scenario 3: optimised RBC	337	29%	276.228 €	7.857 €	284.085 €	42.061 €	
Scenario 3b: scenario 3 + pv panels	337	29%	275.433 €	7.857 €	283.290 €	41.267 €	
Scenario 4: pure GEOTABS (no comfort check)	149	69%	204.538 €	3.460 €	207.999 €	-34.025 €	

Macro economic:

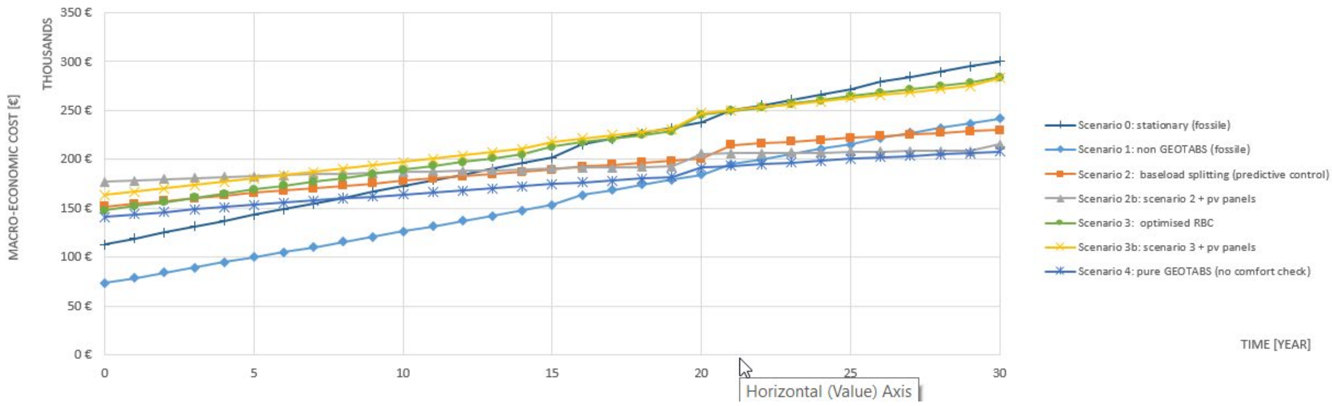


Figure 2-19: - FEASIBILITY STUDY: calculated micro-and macro-economic cost.

3. Feasibility study: methodology

3.1. Total cost of ownership (TCO) and the net present value (NPV) method

The feasibility study for a certain case is evaluated by calculating the (TCO) for the different scenarios. The used method used for determining a TCO is the life cycle cost approach (LCC). In literature, different LCC-methodologies can be found, like Net Present Value, Net Savings, Savings-to-Investment Ratio, Internal Rate of Return, and Payback Period [5]. Each method has its purpose, advantages and disadvantages. Schade [6] compares the different methods, and concludes from a thorough literature review that the most used approach for LCC in construction industry is the net present value (NPV) method. This is also the method suggested by ISO 15686-5:2008 [7] and by Annex III to Directive 2010/31/EU [8].

The processing tool uses the methodology to calculate these costs is drawn from the methodology provided by European Commission through the Directive 2010/31/EU and described in the Delegated Regulation (EU) No 244/2012 of 16 January 2012 [9].

3.2. Calculation of the Global Cost

To calculate the global cost of an energy efficient system, it is also necessary to take into account one's objectives and expectations as regards to the investment to be made [10, 11]. When the objective is to compare the financial benefit from an investment point of view, only the micro-economic costs need to be considered.

When the objective goes beyond the financial point of view and also takes into account actions that prove to be beneficial to society (and sometimes a less attractive investment), the **macro-economic** cost is used [11]. Therefore the calculation of the macro-economic cost, takes into consideration the greenhouse gas emission costs. This cost can be defined as the monetary value of environmental damage caused by CO2 emissions related to the energy consumption in a building. The equations to calculate the micro-economic and macro-economic costs are described in the paragraph below.

Micro-Economic Cost

When determining the global cost of a system, the relevant prices to be taken into account are the prices paid by the customer. Ideally the subsidies available for the measures are to be included into the calculation, but Member States of the EU can choose to leave subsidies aside [9]. The option to include subsidies is for the moment not included in the tool.

$$TCO_{micro} = \mathrm{I}_0 + \sum_{\mathrm{j}} \left[\sum_{\mathrm{t}=1}^{\tau} \left(C_{A,t}(j) \times R_D(t) \right) - C_{R,t}(j) \right]$$

With:

I_0	Initial investment cost [€]
$\mathrm{C_a}$,i	Annual costs during year i. (operational cost, maintenance costs) and replacement cost
$\mathrm{R_{D,i}}$	Real Discount factor
C_R	Residual value of component j in case the lifetime of the component is
j	component (primary energy system, secondary energy system,…)
τ	calculation period
t	time [year]

The annual costs during a year consist of operational cost and maintenance costs. In case the life span of a system is less than the calculation period, the system has to be replaced. In that case, also a replacement cost is taken into account for the particular year. The annual cost during a year C_a,I is then calculated as following:

$$C_{A,t}(j) = \sum_{t} C_E \times (1 + r_E)^t + \sum_{t} C_M \times (1 + r_M)^t + \sum_{t} C_{RI} \times (1 + r_{RI})^t$$

With:

C_E	Operational cost [€]
r_E	Evolution of the energy cost above inflation
C_M	Maintenance cost [€]
r_M	Evolution of the maintenance cost above inflation
C_{RI}	Replacement or reinvestment cost where applicable [€]
r_{RI}	Evolution of the product costs above inflation

Macro-Economic Cost

- When determining the macro-economic cost, the financial costs are taken into account, as described under micro-economic costs. However, the relevant prices to be taken into account are the prices excluding all applicable taxes, VAT, charges and subsidies.

In addition, the cost of greenhouse gas emissions is included. The cost becomes:

$$TCO_{macro} = I_0 + \sum_{j} \left[\sum_{t=1}^{\tau} \left(C_{A,t}(j) \times R_D(t) \right) + \boldsymbol{C_{c,t}(j)} - C_{R,t}(j) \right]$$

Costs

It should be noted that the global cost methodology as prescribed in the Regulation, and followed in this tool, does not include costs other than energy (e.g. water costs) as it follows the scope of Directive 2010/31/EU. The global cost concept is not fully in line with a complete life cycle assessment (LCA) that would take into account all environmental impacts throughout the lifecycle including so-called grey energy. Further, only energy cost that are different between the scenarios are taken into account, consequently cost for backup-units, lightning, domestic hot water, electricity use for appliances are not considered in the NPV-method.

Investment Costs (I_0)

The Regulation states that cost data must be market-based (e.g. obtained by market analysis) and coherent in regard to location, moment of investment, running costs, energy costs and if applicable disposal costs. This means that cost data need to be gathered from (1) evaluation of recent projects; (2) analysis of standard offers; (3) use of existing cost databases, that has been derived from market-based data gathering.

In this tool, the investment cost was derived by analysing cost tenders of 95 project from Boydens engineering office (D2.7). Other European partners in the project revised this derived cost functions and adjustments were made in order to obtain a general cost .

Table 3-1: Cost functions used to derive the investment cost.

Component	Cost Function [€]
Primary source	
Vertical Ground Source Heat Exchanger	$35x + 36397$ $x \in [0\ \text{m}, \infty\ \text{m}]$

Ground source Heat Pump(1) (2)	$161.0x + 16389.94$ $x \in [kW, \infty]$
Plate Heat Exchanger for passive cooling (ground source)	$29.9x + 1304.1$ $x \in [kW, \infty]$
Secondary Source	
Condensing Gas Boiler	$97.0x + 6797.7$ $x \in [kW, \infty]$
Chiller (Air-Water)	$340.8x + 625.2$ $x \in [kW, \infty]$
Ventilation System	
AHU	$3.0x + 23186$ $x \in [0\ m^2, \infty\ m^2]$
Additional cost (grilles, ducts, extraction)	$66.4x$ $x \in [0\ m^2, \infty\ m^2]$
Primary Emission	
TABS	$33.9x$ $x \in [0\ m^2, \infty\ m^2]$
Secondary Emission	
Secondary emission system for heating	
Secondary emission system for cooling	

Operational costs (C_E)

Electricity (based on Eurostat[1]): Electricity prices for industrial consumers are defined as follows: Average national price in Euro per kWh without taxes applicable for the first semester of each year for medium size industrial consumers (Consumption Band Ic with annual consumption between 500 and 2000 MWh).

Gas (based on Eurostat): Gas prices for industrial consumers

Maintenance Costs (C_M)

The maintenance cost is a percentage of the investment cost. Percentage following EN 15459

Replacement Costs (C_{RI})

The lifespan following EN 15459

Table 3-2: Lifespan in years and maintenance cost in % for the different components

Component	Life span in years	annual maintenance cost in % of the initial investment	Source
Floor heating	50	2	EN 15459
Borefield	100	0	
Chiller (Air-Water)	15	4	EN 15459: Air cooler
TABS (	50	2	EN 15459:
Condensing Gas Boiler	10	2	EN 15459
Control system - central	20	4	EN 15459
Fan Coil Unit	15	4	EN 15459
Heat Pump: Air-Air	10	4	
Heat Pump: Air-Water	15	4	
Heat Pump: Ground-Water	20	4	
Pellet Burner	20	1.5	EN15459-2017:

[1] European Commission. "Eurostat." [Online]. Available on: http://ec.europa.eu/eurostat/data/database. (Accessed: 02 07 2019)

Photovoltaic panel	30	0.5	EN15459-2017:
Primary system: passive cooling (HEX)	30	2	
Radiators	35	1.5	EN 15459: Radiators, water

Residual value

In case a (replaced) component has a longer lifetime than the calculation period, a residual value has to be calculated for the remaining time. A straight-line deprecation is assumed to calculate the residual value. This value has to be discounted to the beginning of the calculation period.

Economic parameters (collected in database Economic Values)

Calculation Period

To compare the different scenarios a fixed calculation period has been determined of 30 years.

Evolution of the energy costs above inflation

The tool uses a fixed number to calculate in increase of the energy costs above inflation. A default value for gas and electricity is used from the Commission Energy 2030: "Trends 2030".

Different options are possible to determine the evolution of the energy costs above inflation:

1. Check evolution real prices (e.g. Eurostat)
    a. Local
    b. Risk for Over/underestimation because looked at past and mostly for a short term (accurate enough to predict future evolution?)
2. Use numbers from Commission Energy 2030: "Trends 2030". They specify three options "
    a. Advantage: same method for whole EU
    b. Swiss is not in it
    c. Newest findings: After 2020 electricity prices stabilize and even decrease
3. Use economic data presented in legislative documents or directives

Default Economic values for Calculation	Uccle	Swiss	Madrid	Warsaw	...
Inflation rate [r]	0,015		0,012	0,012	
Discount rate micro-economic calculation	0,030		0,030	0,030	
Discount rate macro-economic calculation	0,050		0,050	0,050	
Sources Price increase (without inflation) [Re] -> mid scenario					
gas	0,059	0,059	0,059	0,059	
Electricity	0,035	0,035	0,035	0,035	
Heating Oil	0,033	0,033	0,033	0,033	
Pellets	0,033	0,033	0,033	0,033	
water	0,030	0,030	0,030	0,030	

Figure 3-1 Inflation rates used in processing tool

Inflation Rate

Inflation is a phenomenon that results in decrease in of money and increase in the nominal value of expenses. This rate of increase or decrease is the inflation rate (r_{inf}). As shown in Figure 23, this value varies from year to year. A study of the inflation forecast would take us too far for this project. Therefore, the tool uses a constant value that can be defined for the entire calculation period.

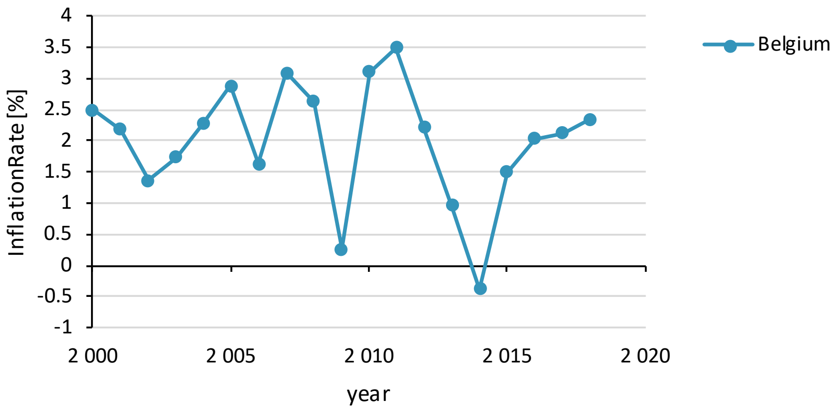


Figure 3-2: Inflation rate[2]

(Real) Discount Rate and Discount Factor

The discount rate (r_{nom}) is a value used to compare the value of money at different times and thus to calculate the net present value (NPV). The factor determines the weight placed on future costs in relation to immediate investments. The parameter is rather a subjective parameter and will be dependent among others on the building type (commercial, public, residential). According to the Delegated Regulation No 244/2012 [9], the discount rate is expressed in real terms (see Real Discount Rate). Hence, in a TCO-calculation two methods are possible to take into account the inflation rate (r_{inf}) and discount rate. Either, all cash flows are expressed in real terms, and therefore the discount rate, either all cash flows are expressed in nominal terms, and then the nominal discount rate is used. In this tool, the real discount rate is used, in which the inflation rate is combined with the nominal discount rate. It is calculates as following:

$$r = \frac{1 - r_{nom}}{1 - r_{inf}}$$

The discount factor $R_{D,i}$, used to discount the costs is:

$$\mathrm{R_{D,i}} = \left(\frac{1}{1 + \frac{r}{100}}\right)^{t}$$

A distinction is made between the discount rate used in a micro-economic and thus for financial objective and the discount rate used in a macro-economic calculation. As the micro-economic calculation objects at the financial benefit, and this is personal for a firm or investor, the financial discount rate is a concept to characterise the private investment. It should represent the opportunity cost of what else the firm or investor could accomplish with those same funds [12].
For the macro-economic calculation, the directive No 244/2012 [9] suggest that one value (of at least two) for the real discount rate is 3%. Therefore, this value is in the tool specified as default value.

Durability parameters

CO2

CO_2 emission is calculated based on the total final energy use per energy source

[2] source: http://nl.inflation.eu/inflatiecijfers/belgie/historische-inflatie/cpi-inflatie-belgie.aspx

$$CO_2 = Q_{energy,\,source} \times F_{CO_2}$$

The factor F_{CO_2} is defined in the database 'economic values'.

In macro-economic calculation, the CO2 emission is included as an environmental cost. This is done by converting the CO2-emmision into a cost representing the monetary value of damage to the environment caused by CO2 emissions relating to the energy use in buildings. The carbon price will increase in future as tabulated in Table 7.

Table 3-3: Carbon price evolution for the base scenario (reference)[3].

Up till:	2020	2025	2030	2035	2040	2045	2050
Carbon price [€/ton]	16.5	20	36	50	52	51	50

Primary Energy Use

Primary energy conversion factors are defined at national level

Source	BRUSSELS	Uccle	Swiss	Madrid	Warsaw
Natural gas	0,202	0,202		0,211	0,211
Electricity	0,395	0,333		0,149	0,149
Electricity from PV-panels	NULL	-0,709		0,000	0,000
Heating Oil	0,267	0,263		0,263	0,263
Biogas	0,197	0,202		0,000	0,000
Biomass	0,360	0,202		0,017	0,017
Wood	0,403	0,000		0,000	0,000
Pellets	0,360	0,000		0,016	0,016
District heating_WKK	NULL	0,126		0,000	0,000
District heating_noWKK	NULL	0,263		0,000	0,000

Figure 3-3Overview national conversion factors primary energy use to Co² (kgCO²/KWh)

[3] European Commission, 2011, Impact assessment. A Roadmap for moving to a competitive low carbon economy in 2050 https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=SEC:2011:0288:FIN:EN:PDF

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List of Tables

List of Figures

Annex 1: Building parameters

A summary of the parameters used in the modelling and simulation of the four typologies. Those parameters are varied across the building geometries that are found in the EU building stock.

	Parameters		*Office building*	*School building*	*Elderly home*	*Multi-family*
Window to wall ratio	*Lower value*		Non-discrete values	20%	20%	20%
	Average value			40%	35%	35%
	Upper value			60%	50%	50%
Orientation (large facade)	*Lower value*		South	South	South	South
	Upper value		West	West	West	West
Shading System	*Lower value*		No-Shading	No-Shading	No-Shading	No-Shading
	Upper value		External screen is on at 150 (W/m^2)	External screen is on at 150 (W/m^2)	External screen is on at 150 (W/m^2)	External screen is on at 150 (W/m^2)
Envelope performance	*lower value*	Envelope U-value	0.5 (w/m^2.k)	0.5 (w/m^2.k)	0.5 (w/m^2.k)	0.5 (w/m^2.k)
		Window U-value	2.5(w/m^2.k)	2.5(w/m^2.k)	2.5(w/m^2.k)	2.5(w/m^2.k)
		Glass g-value	0.6	0.6	0.6	0.6
		air-tightness n50	5.0 (h^{-1})	5.0 (h^{-1})	5.0 (h^{-1})	5.0 (h^{-1})
	Average value	Envelope U-value	0.27 (w/m^2.k)	0.27 (w/m^2.k)	0.27 (w/m^2.k)	0.27 (w/m^2.k)
		Window U-value	1.5 (w/m^2.k)	1.5 (w/m^2.k)	1.5 (w/m^2.k)	1.5 (w/m^2.k)
		Glass g-value	0.56	0.56	0.56	0.56
		air-tightness n50	2.0 (h^{-1})	2.0 (h^{-1})	2.0 (h^{-1})	2.0 (h^{-1})
	Upper value	Envelope U-value	0.15 (w/m^2.k)	0.15 (w/m^2.k)	0.15 (w/m^2.k)	0.15 (w/m^2.k)
		Window U-value	0.8 (w/m^2.k)	0.8 (w/m^2.k)	0.8 (w/m^2.k)	0.8 (w/m^2.k)
		Glass g-value	0.4	0.4	0.4	0.4
		air-tightness n50	0.6 (h^{-1})	0.6 (h^{-1})	0.6 (h^{-1})	0.6 (h-1)
Building mass	Lower value		390 (kg/m^2)	391 (kg/m^2)	392 (kg/m^2)	207 (kg/m^2)
	Upper value		630 (kg/m^2)	630 (kg/m^2)	630 (kg/m^2)	661 (kg/m^2)
Internal heat gains			**Office zone**	**Classroom zone**	**Elderly room zone**	**Apartments zone**
	Lower value	Density	1Person/20m^2	1Student/3.5m^2	___	1 person / dwelling
		Occupancy	5.0 (W/m^2)	21.0 (W/m^2)	0	1.2 (W/m^2)
		Lighting	8.0 (W/m^2)	8.0 (W/m^2)	0	1.5 (W/m^2)
		Appliances	5.5 (W/m^2)	4.0 (W/m^2)	0	4.8 (W/m^2)
		Total	18.5 (W/m^2)	33.0 (W/m^2)	0	7.5 (W/m^2)
	Upper value	*Density*	1Person/10m^2	1Student/2.5m^2	1Elderly/24m^2	3 people / dwelling
		Occupancy	10.0 (W/m^2)	30.0 (W/m^2)	3.0 (W/m^2)	3.6 (W/m^2)
		Lighting	8.0 (W/m^2)	8.0 (W/m^2)	3.75 (W/m^2)	2.0 (W/m^2)

		Appliances	15.0 (W/m²)	4.0 (W/m²)	4.0 (W/m²)	23.0 (W/m²)
		Total	33.0 (W/m²)	42.0 (W/m²)	10.7 (W/m²)	28.6 (W/m²)
Ventilation flow rate	*Constant*		36 (m³/h)	36 (m³/h)	50 (m³/h)	1 (m³/m²/h) dwellings 0.2 (m³/m²/h) staricases
Operative temperature	*Constant*		24 (°C)	23 (°C)	24 (°C)	23 (°C)