Annex 75 Calculation Tool Documentation

Toivo Säwén, StruSoft AB, toivo.sawen@strusoft.com

Tool version 1.4.7, December 1, 2022

Contents

1 Introduction

The Annex 75 Calculation Tool (A75CT) was developed as part of the IEA EBC Annex 75 project entitled "Cost-effective Building Renovation at District Level Combining Energy Efficiency & Renewables" [IEA EBC, 2022]. The purpose of the tool is to conceptualise a calculation framework for optimising cost and environmental impact of building renovation measures and district energy supply systems.

The tool is developed by StruSoft AB with input from project participants of the Annex.

1.1 Delimitations

Currently, the A75CT allows the calculation of energy systems for heating combined with renovation measures intended to reduce the energy use.

1.2 Prerequisites

To use the A75CT, some data needs to be retrieved in advance, whether through calculations or through the collection of references:

- building energy needs for the entire district, regarding space heating
- building energy needs for the entire district, regarding the provision of domestic hot water
- domestic electricity consumption (lighting and appliances)
- calculation details regarding district systems and renewable energy sources (costs as a function of system size)

1.3 Output

The output of the tool is the key performance indicators specific annual primary energy use $[kWh/m^2, a]$, specific annualised cost $[€/m^2, a]$, and specific annualised carbon emissions $[kg\ CO_2eq/m^2, a]$ for any number of scenarios combining energy system options and renovation measures.

2 Interface

2.1 Workflow

When using the A75CT, a district assessment is called a "project", which includes data about the district, its related energy system and renovation options, and scenarios which combine these options. Once the user has created a project, the workflow for the user is divided into five steps:

1. Overview
2. Calculation data
3. Scenarios
4. Model

5. Results

The user can freely navigate between these steps to enter more data, add more options, and tweak the scenarios.

2.2 Creating a project

Once logged in, the user can create projects in the project list, which is accessed using the button in the top right corner of the interface. The project is created through using the "Add new project" button, and entering a unique project name. Alternatively, an existing project can be duplicated by clicking the cogwheel on the project card. This menu also allows changing the name of an existing project, deleting it, or exporting it in a spreadsheet format.
When entering data, the project is automatically saved as the user makes changes.

2.3 Overview panel

Provides an overview of the assessment.

Assessment info

Contains an overview of information about the ongoing assessment, for documentation purposes.

2.3.1 Location info

Contains information about the location of the assessment, which can be edited in the Calculation Data step.

2.4 Calculation data panel

On this panel, data about the district, building types, energy systems (including cost data and energy carriers), and renovation measures, are defined for use in the definition of scenarios.

2.4.1 District

Contains information on the district such as location, pipe length required for district heating, and availability of renewables.

2.4.2 Building types

Contains information about all the building types available in the project. In the Scenarios step, several buildings can be created which share a building type, that is, which have in common features such as geometry and thermal properties. If e.g. orientation or degree of insulation differs, a new building type should be defined.
Any number of building types can be added by using the "+" button. Also, building types can be removed or duplicated if desired.

2.4.3 Energy systems

Contains information about all the energy systems defined in the project. In the Scenarios step, an energy system needs to be selected for each building in the scenario. Multiple buildings can be connected to the same energy system.
Any number of energy systems can be added by using the "+" button. Also, energy systems can be removed or duplicated if desired.

Cost curves Cost curves (see Figure 2.1) which relate system size to investment, maintenance, and environmental cost need to be defined for each energy system option. For decentralised energy systems, only the costs for each individual substation needs to be defined. For centralised systems, both costs tied to the substation and to the central supply system need to be defined.

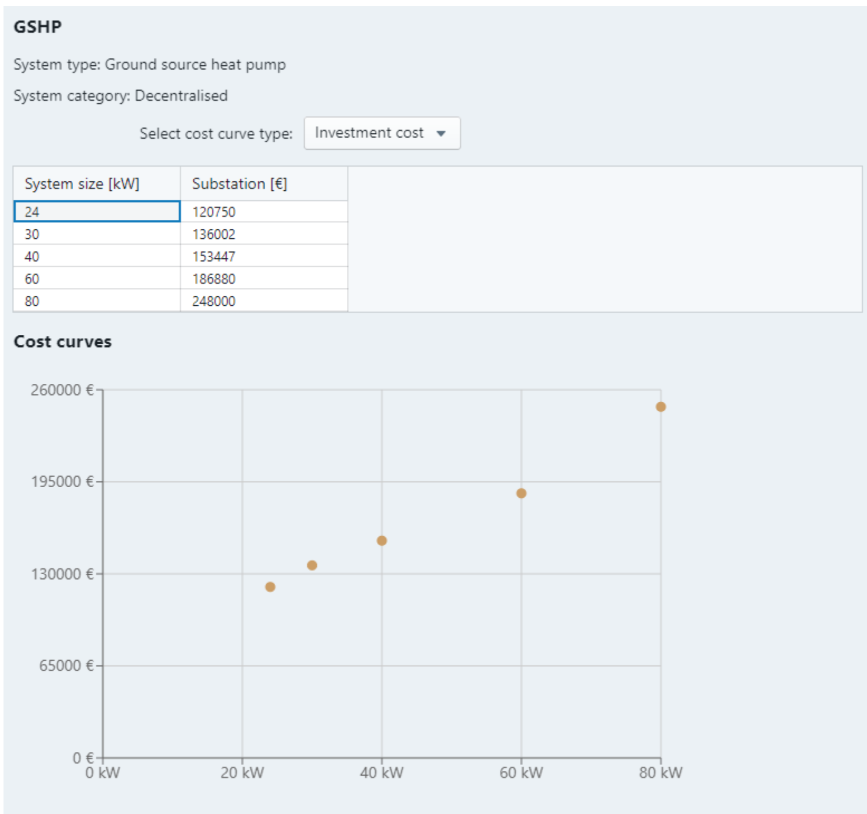

Figure 2.1: Example cost curve for a decentralised energy system.

Energy carrier Each energy system needs an associated energy carrier, which can be defined using the dropdown menu. Multiple energy systems can use the same energy carrier.
Any number of energy carriers can be added by using the "+" button. Also, energy carriers can be removed or duplicated if desired.

2.4.4 Building measures

Contains information about energy renovation measures available in the project. In the Scenarios step, combinations of renovation measures and energy systems can be investigated. Three categories of measures are available.
Any number of renovation measures for each group can be added by using the "+" button. Also, renovation measures can be removed or duplicated if desired.

Additional insulation Requires information about thermal conductivity, and cost and environmental footprint per thickness of insulation added to the existing building envelope.

Windows Requires information per square metre of window. In the scenarios it is assumed that the entirety of fenestration, as defined in the building type, is replaced.

HVAC system Requires information per unit, one per building. In the scenarios it is assumed that HVAC systems are replaced for every building of one type. Only one HVAC system can be defined for each building, i.e., combining heating, ventilation, and cooling.

2.5 Scenarios panel

On this panel, scenarios are defined from the previously defined calculation data. Any number of scenarios can be added using the (+) button. For each scenario, an energy system and renovation measures need to be defined for every building type, as well as number of buildings of each type. In the present version, heating need for each building type needs to be calculated using external software.

2.5.1 Building types

Includes information on number of buildings of type, heating need per building, and additional documenting information.

2.5.2 Economy

Includes definition of calculation period, as well as assumed interest rate.

2.5.3 Energy system

Defines which energy system buildings of this type are connected to.

2.5.4 Building measures

Defines the renovation measures applied to this building type, including insulation thickness for each component of the envelope, as well as windows and HVAC system. It is assumed that each component is renovated to the same extent within each building type.

2.6 Model panel

On this panel, settings for the calculations can be changed, and the calculation can be activated if all prerequisites are met. If some field is missing, a warning will be displayed indicating what data needs to be entered.

2.7 Results panel

This panel presents the results of the assessment in graphical and tabulated format, and allows export to .pdf and .xlsx.

A Example project

This appendix provides an example, with figures, of how to perform an assessment using the A75CT. Figures are taken from the 1.4.7 version of the application.

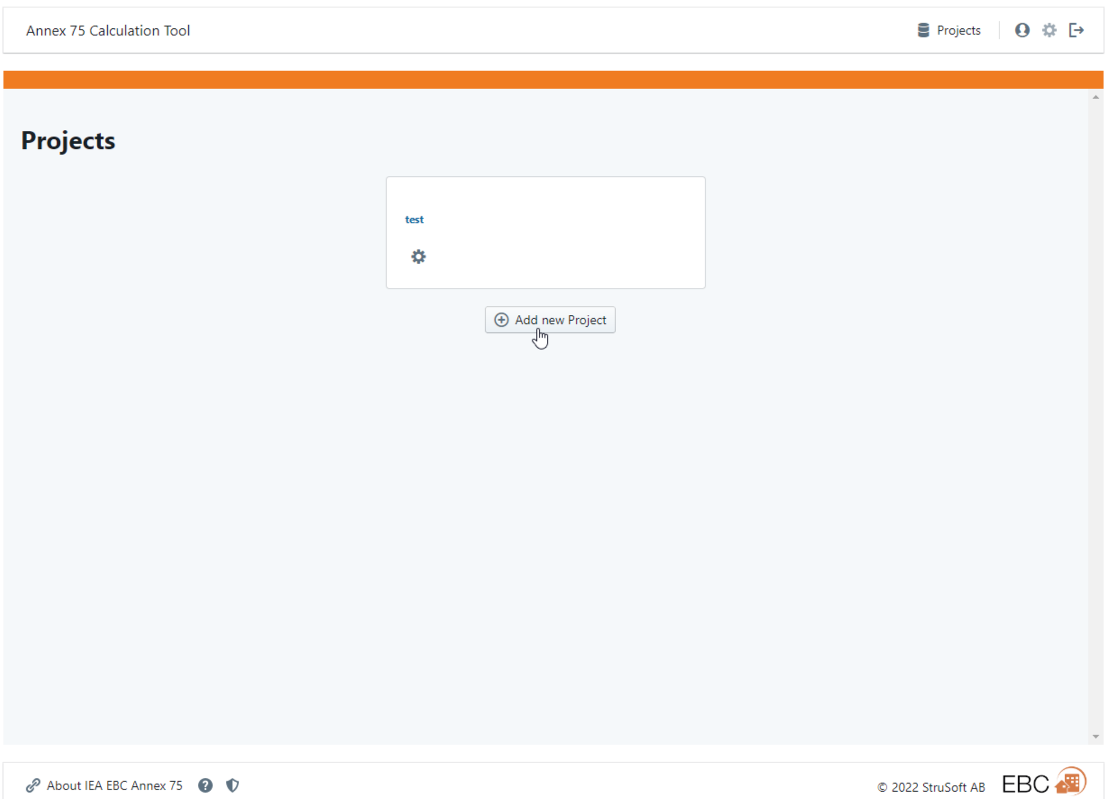

Figure A.1: In the project list, create a project using the button, or click the cogwheel of an existing project to duplicate it.

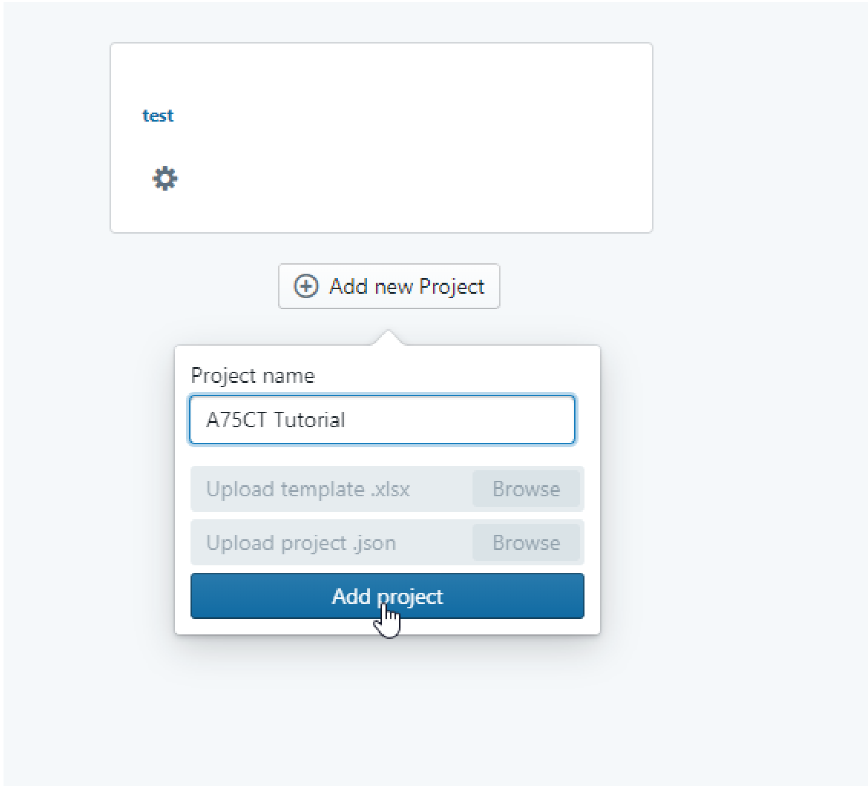

Figure A.2: Give the project a unique name and click "Add project" to add it to the database.

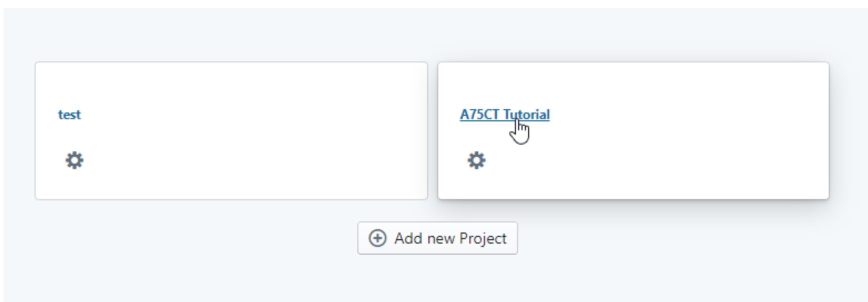

Figure A.3: Click the project name in the project list to enter the assessment workflow.

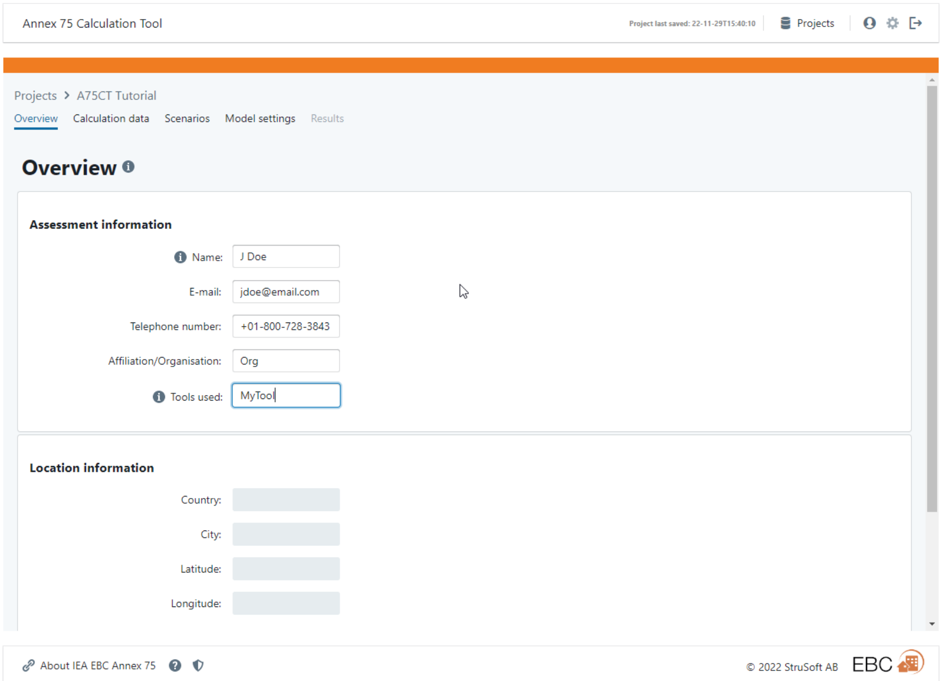

Figure A.4: The workflow has five steps. In the first one, "Overview", enter information about the project for future reference.

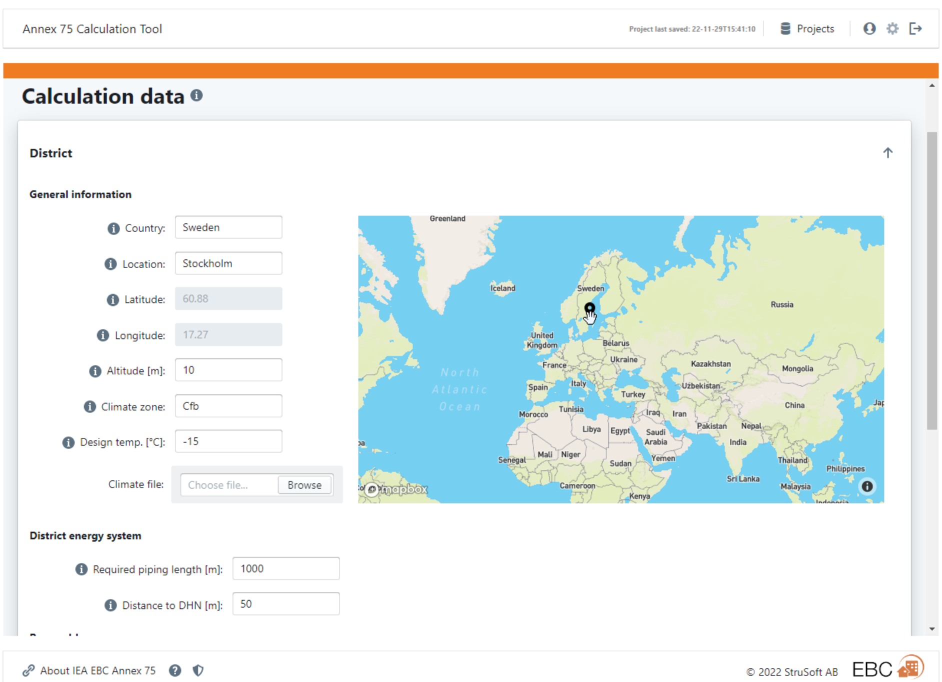

Figure A.5: In the workflow at the top, the next step is "Calculation data". In this panel, general information about the district can be added.

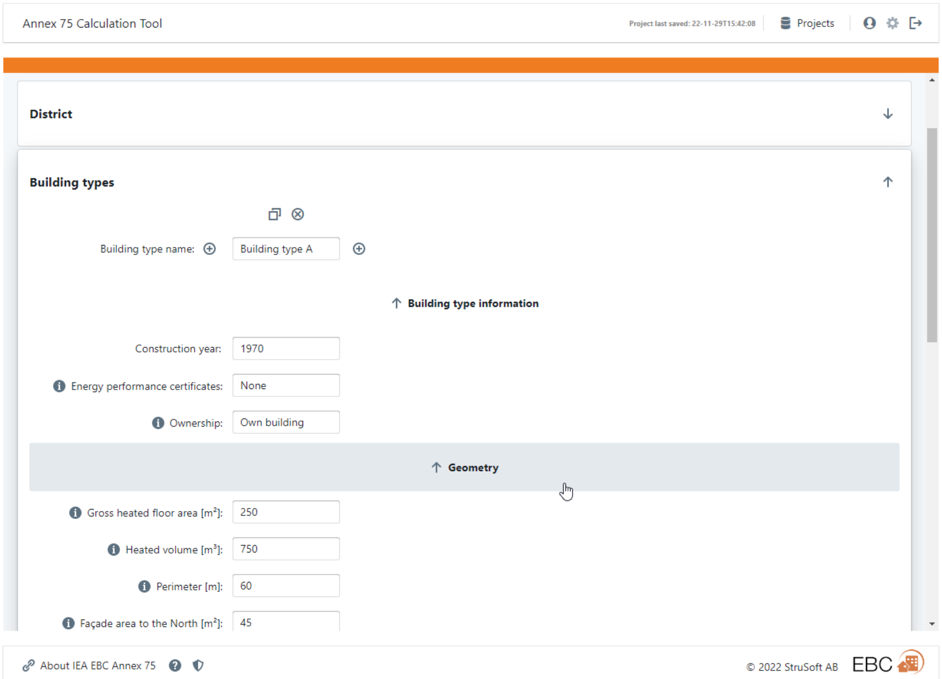

Figure A.6: A district is composed of buildings of different types. Expand the "Building types" menu to add multiple building types, and include information about the building geometry...

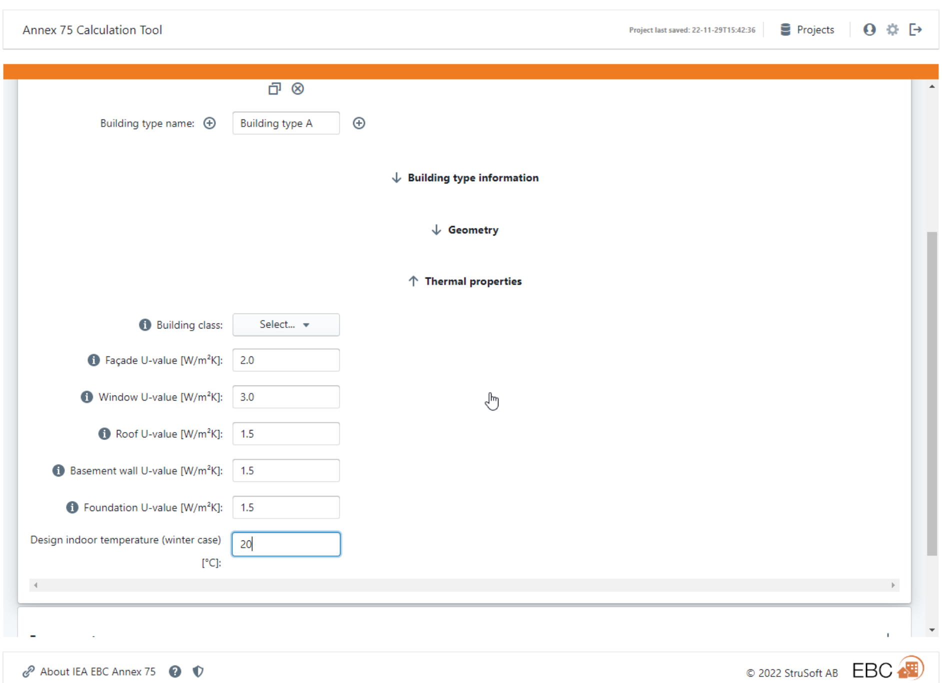

Figure A.7: ...and thermal properties.

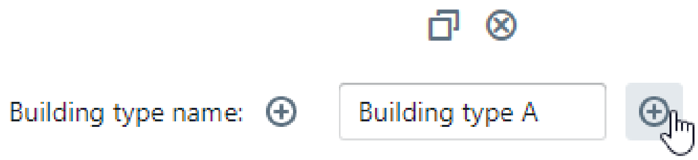

Figure A.8: One building type is a set of buildings which share some property such as orientation, geometry, and thermal properties. If such parameters differ, a new building type should be added. The plus button can be used to add more building types. The "X" button can be used to remove an unused building type.

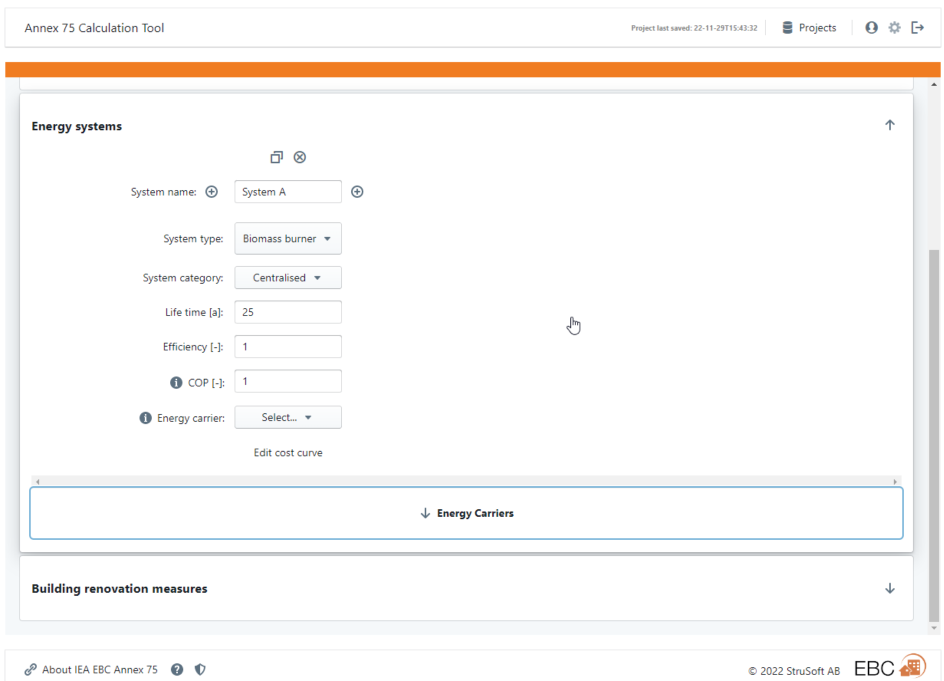

Figure A.9: The next step is to add all the potential energy system options.

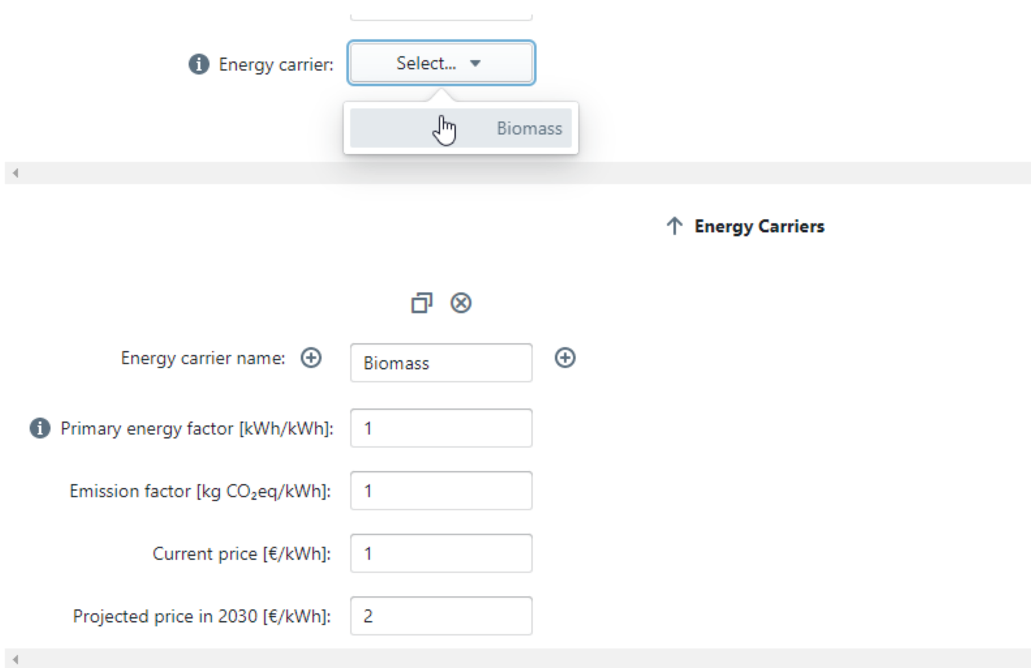

Figure A.10: An energy carrier must be defined for the energy system, this is done at the dropdown menu at the bottom of the ”Energy system” menu.

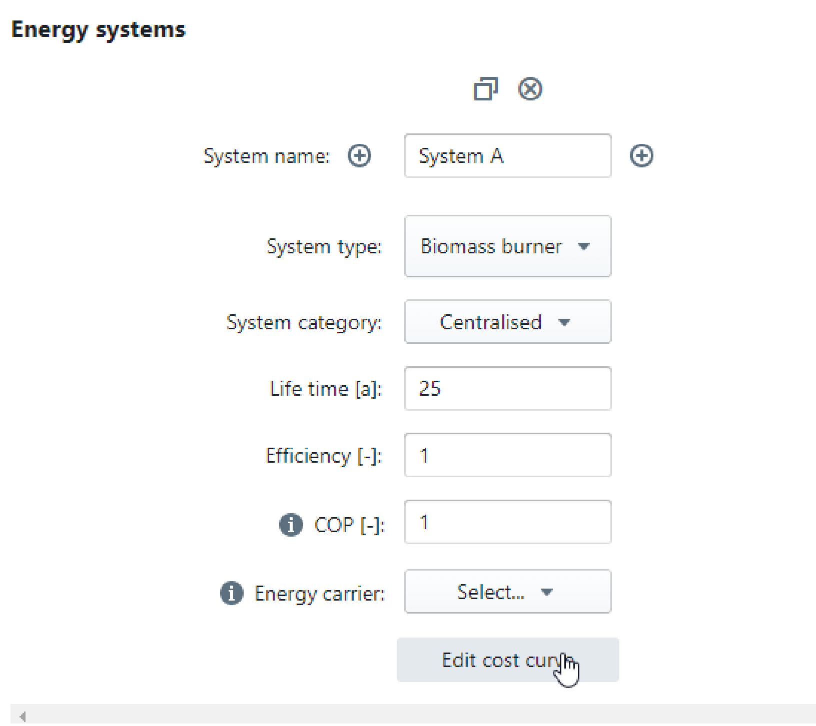

Figure A.11: The cost of the energy system as a function of system size is defined using the ”Edit cost curve” button.

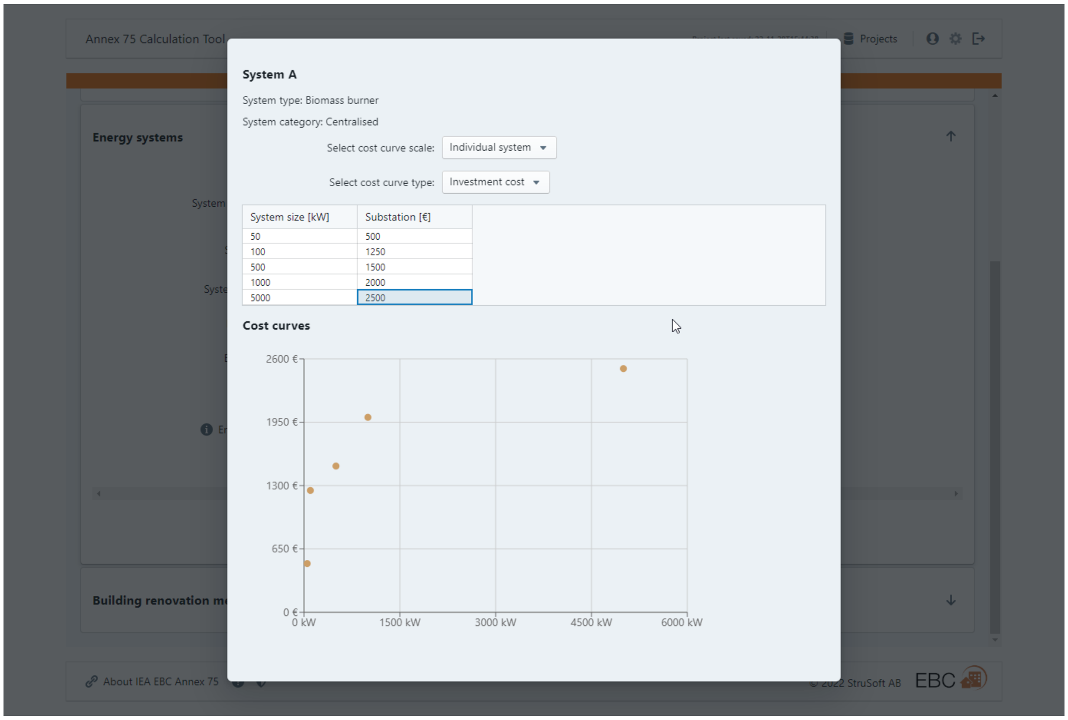

Figure A.12: A cost curve needs to be defined for each component (scale) of the system. Investment cost, maintenance cost, and embodied carbon can be entered.

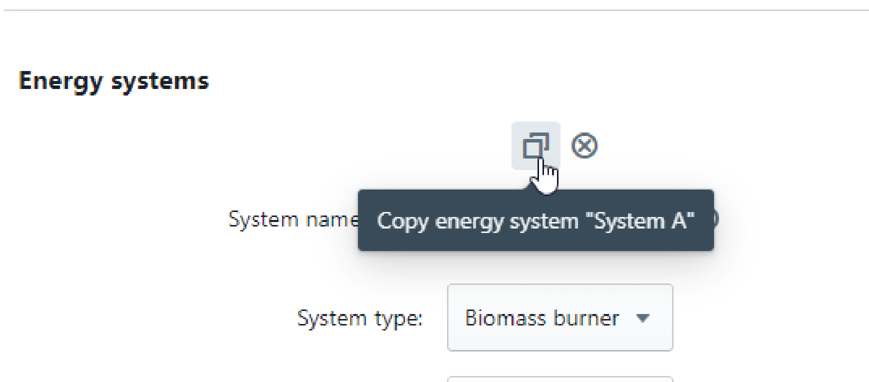

Figure A.13: Energy systems can be copied using the "duplicate" button, or added with the plus button.

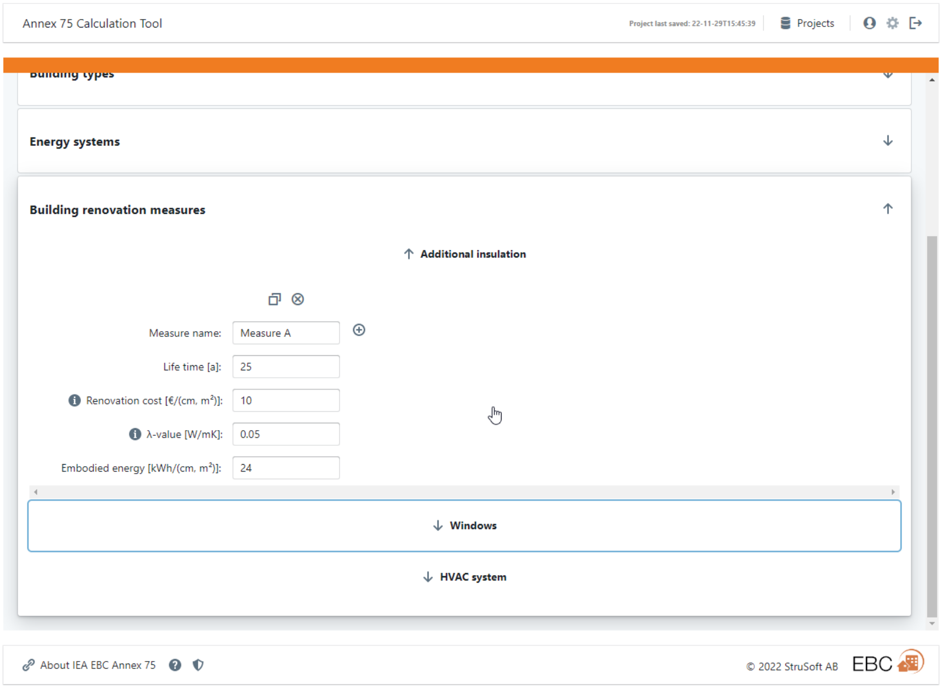

Figure A.14: Next, renovation measures should be defined. Insulation measures are defined per centimetre of added insulation to the original building.

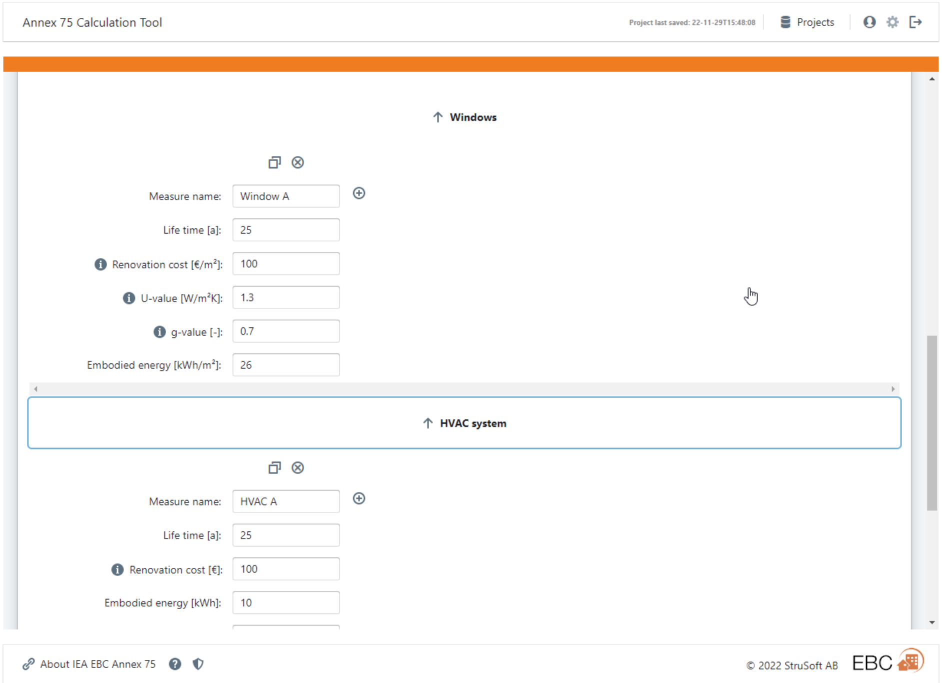

Figure A.15: Renovation measures for windows and HVAC system also need to be similarly defined (per square metre, and per unit, respectively).

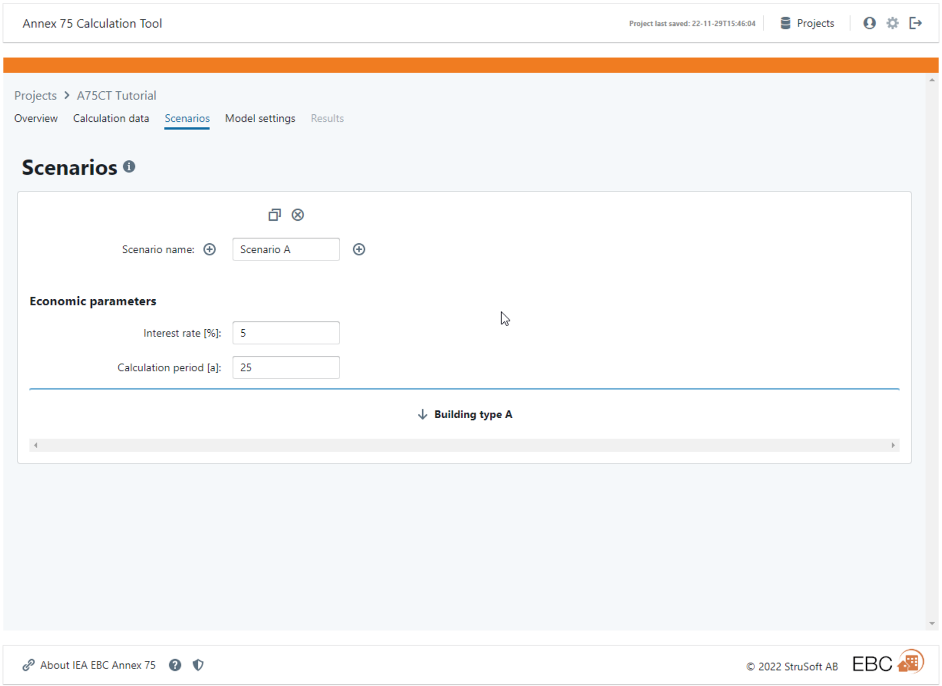

Figure A.16: The building types, energy systems, and renovation measures are combined in the "Scenarios" tab of the workflow. A scenario firstly includes information about the assessment period.

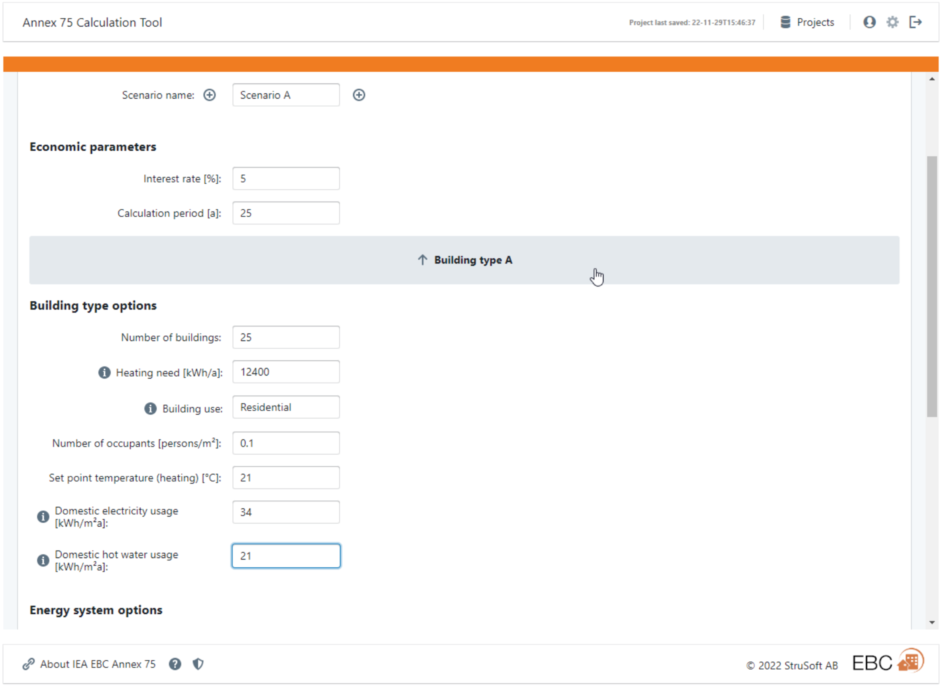

Figure A.17: Secondly, the number of buildings of each building type, as well as data per building such as energy need, should be entered.

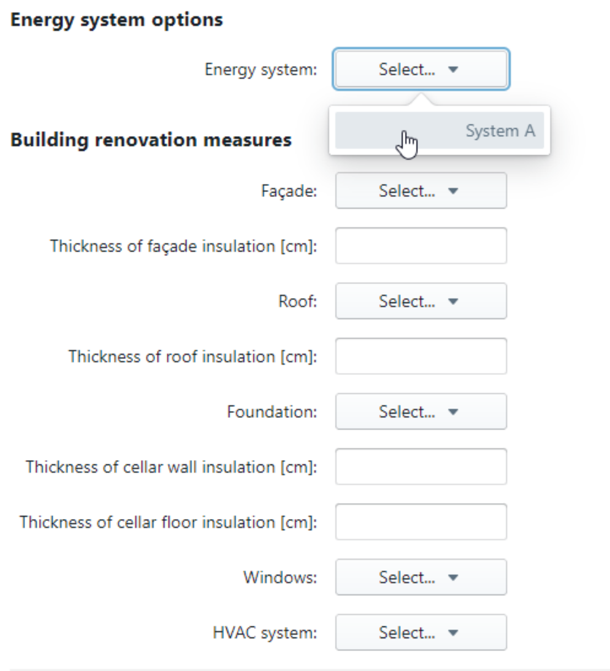

Figure A.18: An energy system serving the building is added...

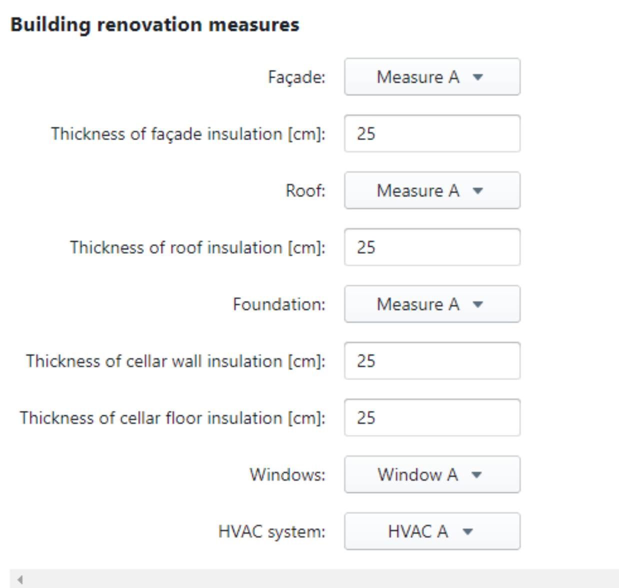

Figure A.19: ...and renovation measures for the various building components are selected.

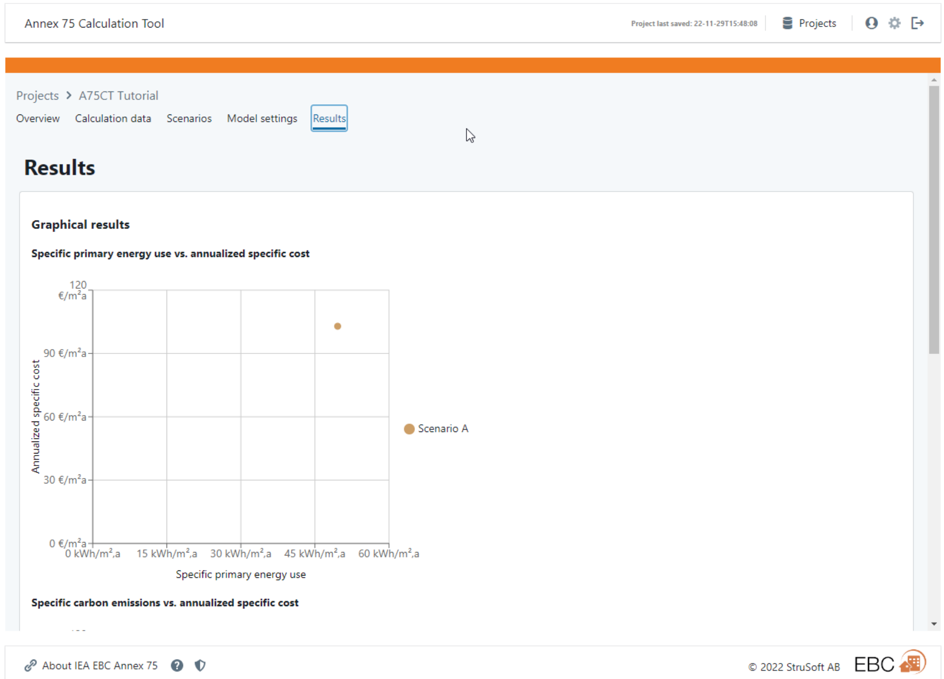

Figure A.20: Finally, the results are presented graphically and in tabular form in the ”Results” tab of the workflow.

B Calculation model

This appendix documents the calculation model

B.1 Energy system size and cost calculations

In each scenario, the goal to calculate the size of the global system by in turn calculating the power needed to heat each building.
For each scenario S:

For each building type B:

E := energy system used in B in scenario S.
Q := heating need $[Wh/a]$ per building of B in scenario S.
HLC := heat loss coefficient $[W/K]$ of B, calculated according to Equation (1).

$$HLC = \sum_c U_c A_c + \sum_w U_w A_w + q_v + q_\Psi, \tag{1}$$

where U_c is the U-value $[W/m^2K]$ of each component c (roofs, exterior walls, floor, basement wall,), calculated according to Equation (2), and A_c is the total area of that component, whereas U_w and A_w is the U-value $[W/m^2K]$ and total area $[m^2]$ of windows, respectively, and q_v and q_Ψ are the heat losses due to ventilation and thermal bridges, respectively.

$$U_c = 1/R_c, \tag{2}$$

where R_c is the thermal resistance of component c, calculated according to Equation (3).

$$R_c = 1/U_{c,original} + t_{c,insulation}/\lambda_{c,insulation}, \tag{3}$$

where $U_{c,original}$ is the U-value of the original construction, and $t_{c,insulation}$ and $\lambda_{c,insulation}$ are the thickness and thermal conductivity of the additional insulation, respectively.

In Equation (1), the ventilation losses q_v are calculated according to Equation (4).

$$q_v = c_{air} * n * V, \tag{4}$$

where the heat storage capacity of the air c_{air} $[Wh/m^3K]$ is calculated according to Equation (5), n is the air change rate $[1/h]$ of the defined HVAC system, and V is the volume of the building $[m^3]$.

$$c_{air} = 1220 - 0.14 * a, \tag{5}$$

where a is the altitude above sea level $[m]$.
In Equation (1), the thermal bridge losses q_Ψ are calculated according to Equation (6).

$$q_\Psi = \sum_{tb} q_{tb}, \tag{6}$$

where tb are all the linear thermal bridges defined in the model, outlined in Equations (6a-6e). Ψ values are defined in Table 1, as collected from the BIM Energy database [StruSoft AB, 2022].

Table 1: Ψ values for linear thermal bridges.

Symbol	Component	Value
$\Psi_{ext,ext}$	Exterior wall - exterior wall	0.2
$\Psi_{ext,int}$	Exterior wall - interior floor	0.2
Ψ_{win}	Windows	0.04
$\Psi_{ext,roof}$	Exterior wall - roof	0.14
$\Psi_{ext,fnd}$	Exterior wall - foundation	0.26

$$q_{ext,ext} = \Psi_{ext,ext} * h_{storey} * n_{storeys} * 4, \tag{6a}$$

where $q_{ext,ext}$ is the thermal bridge $[W/K]$ where two exterior walls meet, h_{storey} is the height of each storey $[m]$ of building type B, and $n_{storeys}$ is the number of storeys of building type B. This assumes that the building is rectangular.

$$q_{ext,int} = \Psi_{ext,int} * p_{storey} * (n_{storeys} - 1), \tag{6b}$$

where $q_{ext,int}$ is the thermal bridge $[W/K]$ where an exterior wall meets an interior floor, p_{storey} is the perimeter of each storey $[m]$ of building type B, and $n_{storeys}$ is the number of storeys of building type B. This assumes that all storeys have the same perimeter.

$$q_{win} = \Psi_{win} * \sqrt{A_w} * 4, \tag{6c}$$

where q_{win} is the thermal bridge $[W/K]$ surrounding each window, and A_w is the total area $[m^2]$ of windows of the building. This assumes all windows are square shaped.

$$q_{ext,roof} = \Psi_{ext,roof} * p_{storey}, \tag{6d}$$

where $q_{ext,roof}$ is the thermal bridge $[W/K]$ where an exterior wall meets the roof, and p_{storey} is the perimeter $[m]$ of building type B.

$$q_{ext,fnd} = \Psi_{ext,fnd} * p_{storey}, \tag{6e}$$

where $q_{ext,roof}$ is the thermal bridge $[W/K]$ where an exterior wall meets the foundation, and p_{storey} is the perimeter $[m]$ of building type B.

Using the heat loss coefficient of each building, we can now calculate the power output needed to ensure an acceptable indoor climate when the outdoor temperature reaches the design temperature.

S_d is the size $[kW]$ of the subsystem of E dedicated to each building, calculated according to Equation (7).

$$S_d = \Delta T * HLC/\eta_{system} * 1000, \tag{7}$$

where ΔT is the difference between the design outdoor temperature and the setpoint heating temperature, and η_{system} is the efficiency $[-]$ of the subsystem.

$S_c :=$ size of the central system, calculated according to Equation (8).

$$S_c = \sum_d S_d * n_{buildings,d}, \tag{8}$$

where d are all the subsystems connected to the central system, and n_d are the number of buildings with such a subsystem.
Costs $C_{investment}$, $C_{maintenance}$, and $C_{embodied}$ are calculated through linear interpolation from the respective cost curves and system sizes.
The primary energy use PEU $[kWh]$ of E is calculated according to Equation (9).

$$PEU = f_{PE} * Q_{tot}/(\eta_{system} * COP_{system}), \tag{9}$$

where f_{PE} is the primary energy factor of the energy carrier $[-]$, Q_{tot} is the total heating need for all building supplied by this energy system, and η_{system} and COP_{system} are the efficiency and coefficient of performance of the energy system $[-]$.

Emissions, EM are calculated similarly, replacing f_{PE} with f_{em}, the emission factor of the energy carrier $[-]$.
Costs for primary energy, C_{PE} are calculated according to Equation (10).

$$C_{PE} = PEU * C_e * l, \tag{10}$$

where C_e is the projected price of energy in 2030 [€], and l is the projected lifetime of the energy system.

B.2 Building measure calculations

For each scenario S:

For each building type B:

$C_{M,c}$:= cost of renovation measure applied to component c of building type B in scenario S, calculated according to Equation (11a) for facades, roofs, foundations, according to Equation (11b) for windows, and according to Equation (11c) for HVAC system.

$$C_{M,c} = A_c * t_{ins} * C_{ins} * n_{buildings}, \tag{11a}$$

where A_c is the area $[m^2]$ of the component, t_{ins} is the thickness of additional insulation $[m]$, C_{ins} is the cost $[€/m3]$ of the insulation material, and $n_{buildings}$ is the number of buildings of type B.

$$C_{M,w} = A_w * C_w * n_{buildings}, \tag{11b}$$

where A_w is the area $[m^2]$ of replaced windows, and C_w is the cost $[€/m2]$ of window replacement.

$$C_{M,HVAC} = C_{HVAC} * n_{buildings}, \tag{11c}$$

where C_{HVAC} is the cost [€] of HVAC system replacement.

Embodied energy $EE_{M,c}$ for each component is calculated similary, replacing cost [€] by embodied energy EE_c $[kgCO_2eq]$.

B.3 Summation

For each scenario S:

$C_{E,annualised,specific,investment}$:= annualised specific cost of investment for energy systems in scenario S, calculated according to Equation (12)

$$C_{E,annualised,specific,investment} = \sum_E C_{E,investment} * l_E / A_{total,buildings}, \tag{12}$$

where $C_{E,investment}$ is the investment costs [€] for all energy systems E in scenario S, l_E is the lifetime of energy system E, and $A_{total,buildings}$ is the total floor area of buildings in scenario S.

$C_{E,specific,maintenance}$:= specific cost of maintenance for energy systems in scenario S, calculated according to Equation (13)

$$C_{E,specific,maintenance} = \sum_E C_{E,maintenance} / A_{total,buildings}, \text{ (13)}$$

where $C_{E,maintenance}$ is the maintenance costs [€$/a$] for all energy systems E in scenario S, and $A_{total,buildings}$ is the total floor area of buildings in scenario S.

Specific energy costs, $C_{specific,energy}$, specific primary energy use, $PEU_{specific}$, specific embodied energy, $EE_{E,specific}$ and specific emissions, $EM_{specific}$, are calculated similarly using the energy cost C_{PE}, primary energy use PEU, embodied energy, EE_E and emissions EM, respectively, of each energy system. $C_{annualised,specific,renovation}$:= Annualised specific costs for renovation measures are also calculated similarly, according to Equation (14)

$$C_{annualised,specific,renovation} = \sum_M \sum_c C_{M,c} * l_{M,c} / A_{total,buildings}, \tag{14}$$

where $\sum_c C_{M,c}$ is the sum of costs of each component c for measure M, $l_{M,c}$ is lifetime of the measure, and $A_{total,buildings}$ is the total floor area of buildings in scenario S.
Specific embodied energy is calculated similarly.
This allows summation of costs, embodied energy, and primary energy use, according to Equations (15a-c).

$$C_{total,annualised,specific} = C_{E,annualised,specific,investment} \\ + C_{E,specific,maintenance} + C_{specific,energy} + C_{annualised,specific,renovation}, \tag{15a}$$

$$EE_{total,specific} = EE_{E,annualised,specific} + EE_{M,annualised,specific}, \tag{15b}$$

$$PEU_{total,specific} = \sum_E PEU / A_{total,buildings}. \tag{15c}$$

References

IEA EBC. Annex 75, 2022. URL `https://annex75.iea-ebc.org/`.

StruSoft AB. BIM Energy, 2022. URL `http://www.bimenergy.com/`.