Real demonstration results of BEM performance simulation using BIM-SPEED Toolset

Deliverable 4.2 – Energy Performance Report – Warmond demo

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BIM-SPEED
Harmonised Building Information Speedway for Energy-Efficient Renovation

This research project has received funding from the European Union's Programme H2020-NMBP-EEB-2018 under Grant Agreement no 820553.

ENERGY REPORT - WARMOND

Deliverable 4.2 – Energy Performance Report

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1. General information

1.1 Building description

The Warmond democase is a complex of 4 buildings located in Warmond (the Netherlands), at van den Woudestraat. For the generation of the BEM model, one of the buildings was selected (block A). Below the aerial photo of the site with an indicative view of the urban context.

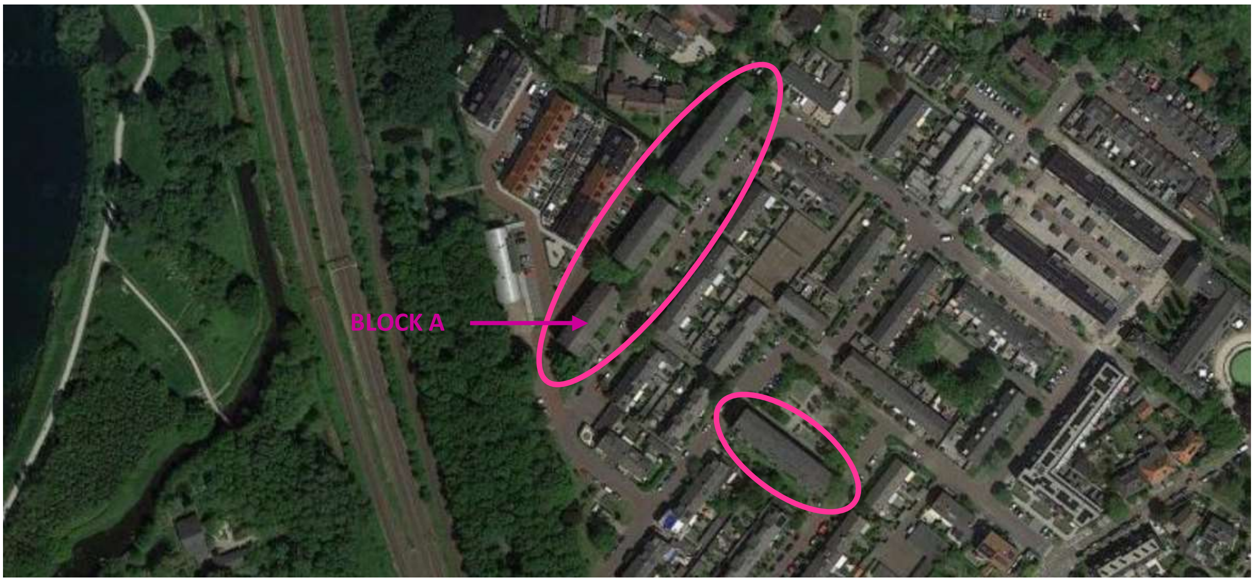


Figure 1: Aerial view of the urban context and building location

The building Block A was built in 1969 and consists of 12 dwellings, 2 staircases, a not-heated basement and a not-heated attic. The constructive characteristics of the building are consistent with the construction period and are characterized by not-insulated walls and brick mixed floors. Insulation in the cavity wall was added as part of the last renovation. Following photos shows the external view of the building.

Figure 2: External view of the building

Following a brief summary of the demo general data

Table 1: General information

General information	
Location	Warmond (The Netherlands)
Use category	Residential
Building type	Three-story building
Construction year	1969
Renovation year	n.d.
Number of floors	4 (including the basement)
Number of apartments/units	12 dwellings

1.2 GIS and environmental data

For the creation of the BEM for Warmond, the simulation engine from EnergyPlus was employed. Therefore, a weather data file in the EPW (weather data file saved in the standard EnergyPlus format) format was required. The EPW file selected for this project was from the station in Amsterdam, since it was the nearest location to Warmond. This EPW file was extracted from the Ladybug tool's epwmap available on their website.

Following a brief summary of the climate data.

Table 2: General environmental data

General environmental data	
Location	Warmond (The Netherlands)
Weather file	NLD_Amsterdam.062400_IEWC.epw
Altitude [m]	1
Latitude [degree]	52°11'39" N
Longitude [degree]	4°29'57'' E

As part of the BEM creation workflow using Grasshopper, the tool Ladybug imports the EnergyPlus Weather file (.EPW) into Grasshopper an enables multiple options for environmental analysis as well as the Building Energy Simulation. In Figure 3 the hourly data for Dry-bulb temperature along the year is shown.

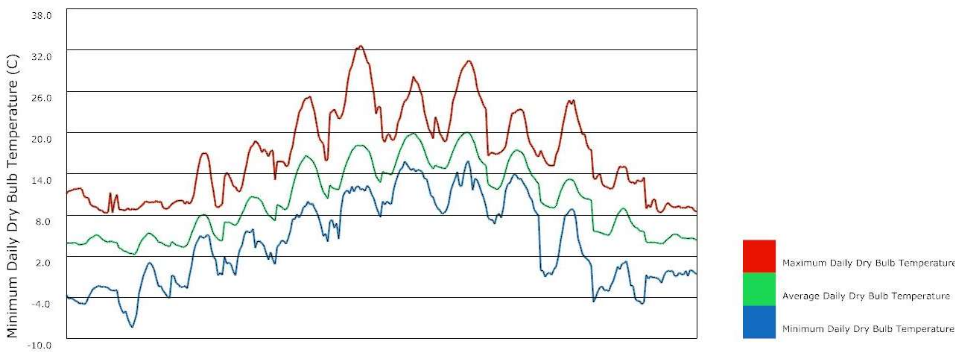


Figure 3: Hourly Data od Dry-bulb Temperature plot in °C

2. Energy modelling

2.1 Modelling workflow

For the specific demo case of Warmond it was proposed not to apply any BIM-to-BEM process, therefore the generation of the BEM model of the actual state has been independent from the available BIM, but it starts from scratch. The following figure summaries the workflow adopted.

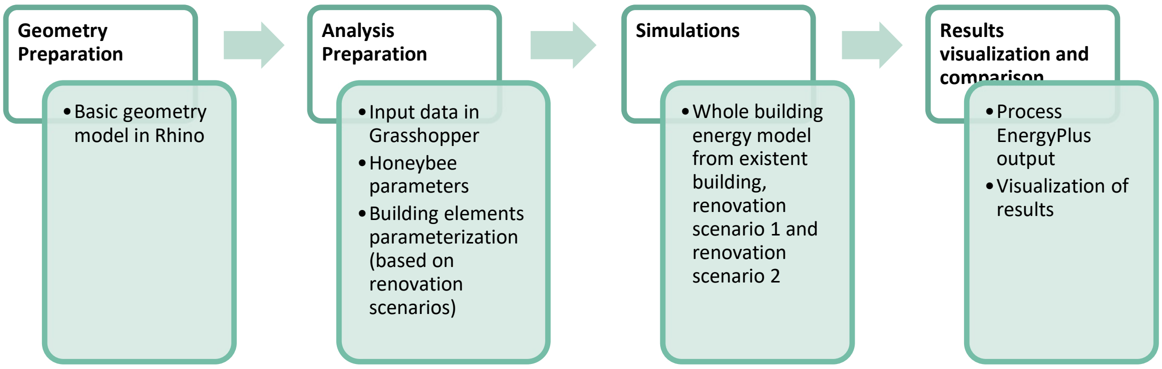


Figure 4: Warmond BEM creation workflow

The workflow consists of 4 main steps based on the combination of 3D modeling tool Rhinoceros/Grasshopper and simulation engine EnergyPlus to perform the energy simulation.

Geometry preparation

The first step in the workflow is the geometry preparation in Rhino 3D. In order to avoid inconsistencies by importing a gbXML file from the BIM model, the basic geometry was drawn from scratch in Rhino, simplifying the complexity of the existing BIM model, to later be linked into Grasshopper environment by setting each surface as a BREP ("Boundary Representation").

With the support of Grasshopper's Honeybee tool, which allowed parametrization of the building's characteristics, the planar geometry, as required for the EnergyPlus simulations, has been set and integrated into the IDF file.

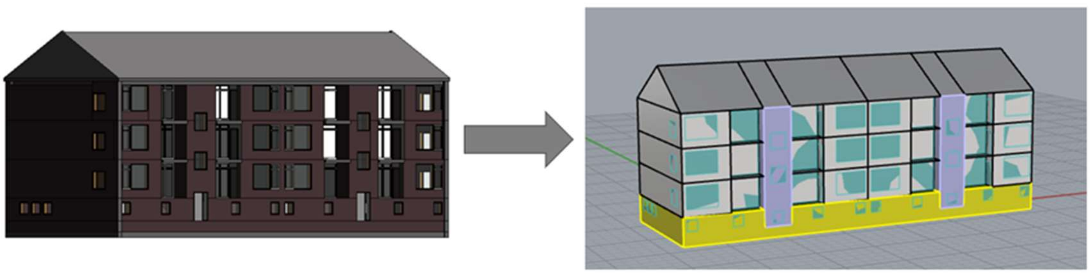


Figure 5: Geometry simplification

Analysis preparation

Once the building geometry was linked to the Grasshopper Environment, the volumes were intersected and transformed into volumes into the Honeybee Zone (thermal zones), the boundary conditions were set and fenestration surfaces (glazing) were added using the Honeybee component "assHBglz". After, all zones were defined, the building program is assigned and finally all HBZones are connected to the "runEnergySimulation" with the EPlus engine to create the IDF file and run simulation. The process of geometry preparation and the assignation of building program to the zones is shown in Figure 6.

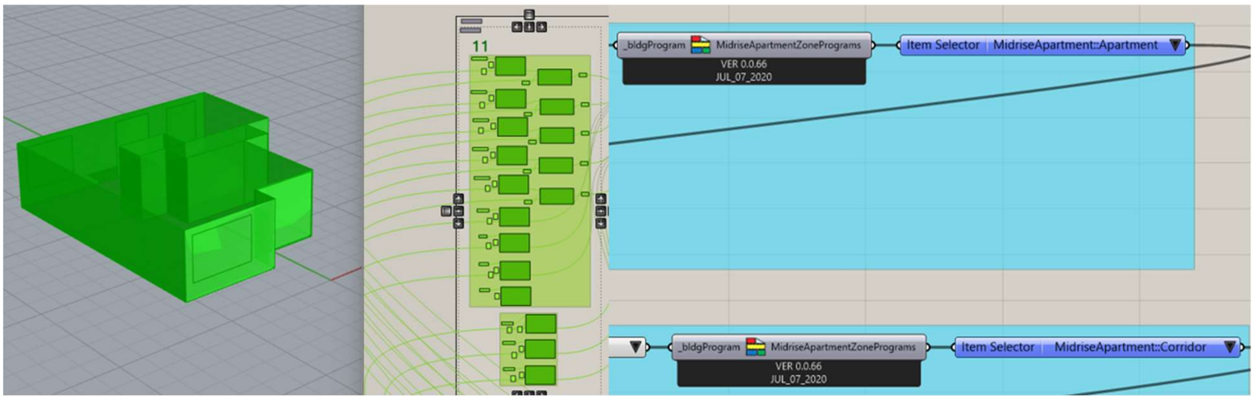


Figure 6: Input Data Preparation

To represent the thermal characteristics of the building components (for each of the scenarios: baseline and renovations) the constructions elements were connected to the BREPs in a way that they could be easily parameterized to create the BEM for each scenario.

In this way it was possible to assign the right parameters for each scenario in order to create the IDF files and run the simulations, being this more time efficient instead of building a singular model representative of each of the situations.

Simulation and results

After running the simulations with EnergyPlus, the output results were analyzed and visually presented.

2.2 Auditing procedures and data collection

As part of the BIM-SPEED project activities, different analyses have been done, such as a Laser Scanning and Deviation analysis, that analyzed the accuracy of the constructed mode helping the team to modify and improve the BIM according to the actual situation. An energy audit's information was also provided, from which it is also known that the buildings are still consuming natural gas and that the heating system is based on a central heating boiler.

As part of the initial activities of this project, it was required to collect the available information about the demo case in Warmond to know about the characteristics of the building and to identify the information needed for the creation of the BEM model.

To start, it was possible to explore the information available in the BIM-Speed platform and it was possible to be in contact with the housing company, who supported the process by providing specific information about the existing components in the building as well as the requirements for the same components for the renovation scenarios. In the following sections the general information about the demo case located in Warmond, the Netherlands is described.

2.3 Description of BEM's technical features

Warmond BEM (building Block A) consists of 12 dwellings, 2 staircases, a not-heated basement and a not-heated attic. Information about the building was collected from the available BIM model from the Housing Company.

2.3.1 Envelope components and materials

This paragraph summarises the construction systems implemented within the Warmond BEM to characterise the thermal behaviour of the building. According to the structural inventory, the external walls did not have insulation, but insulation in the cavity wall was added as part of the last renovation. Following table summarises the thermal characteristics of the construction elements.

Table 3: Building Components thermal characteristics

Construction	Layer	Material Name	Thickness {m}	Conductivity {W/m-K}	U-Factor {W/m2-K}
INTERIOR WALL	Outside Layer	G01a 19mm gypsum board	0,019	0,16	
INTERIOR WALL	Layer2	F04 Wall air space resistance			
INTERIOR WALL	Layer3	G01a 19mm gypsum board	0,019	0,16	
INTERIOR CEILING	Outside Layer	M11 100mm lightweight concrete	0,1016	0,53	
INTERIOR CEILING	Layer2	F05 Ceiling air space resistance			
INTERIOR CEILING	Layer3	F16 Acoustic tile	0,1016	0,53	
INTERIOR FLOOR	Outside Layer	F16 Acoustic tile	0,1016	0,53	
INTERIOR FLOOR	Layer2	F05 Ceiling air space resistance			
INTERIOR FLOOR	Layer3	M11 100mm lightweight concrete	0,1016	0,53	
EXTERNAL WALL	Outside Layer	M01 100MM BRICK	0,1016	0,53	
EXTERNAL WALL	Layer2	ROCKWOOL	0,06	0,037	
EXTERNAL WALL	Layer3	M01 100MM BRICK	0,1016	0,53	
BASEMENT CEILING	Outside Layer	M11 100mm lightweight concrete	0,1016	0,53	
BASEMENT CEILING	Layer 2	M11 100mm lightweight concrete	0,1016	0,53	
SLAB	Outside Layer	MAT-CC05 4 HW CONCRETE	0,1016	1,311	
ROOF	Outside Layer	ROOF MEMBRANE	0,0095	0,16	
ROOF	Layer2	EXISTINGROOFINSULATION	0,03	0,065	
ROOF	Layer3	METAL DECKING	0,0015	45,006	
STAIRS WALL	Outside Layer	M01 100MM BRICK	0,1016	0,53	
EXISTING GLAZING					2,8

2.3.2 HVAC systems

Each dwelling is equipped with a central heating boiler (CV-ketel), which is powered by gas and is used for heating, warm water and cooking. Since the exercise of creating a BEM for this demo case was based on analyzing the thermal performance of the building envelope components, an ideal air system with no air changes was set in the creation of the BEM.

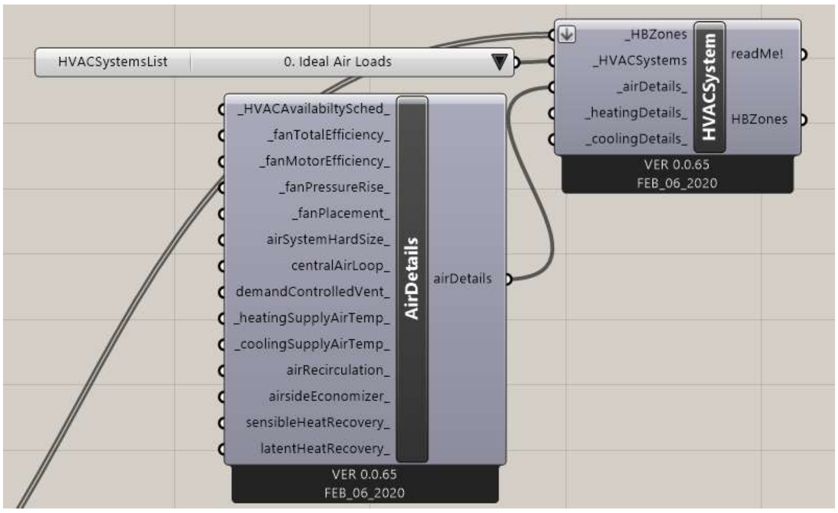


Figure 7: Representation of assignation of HVAC System type in Grasshopper

2.3.3 Occupancy, lighting and equipment schedules

With the support of Grasshopper's tool Honeybee, it was possible to assign a Zone Program to the different zones in the model. For the dwellings the Zone Program MidriseApartment::Apartment was assigned. In Figure 8 the load parameters for this program are presented.

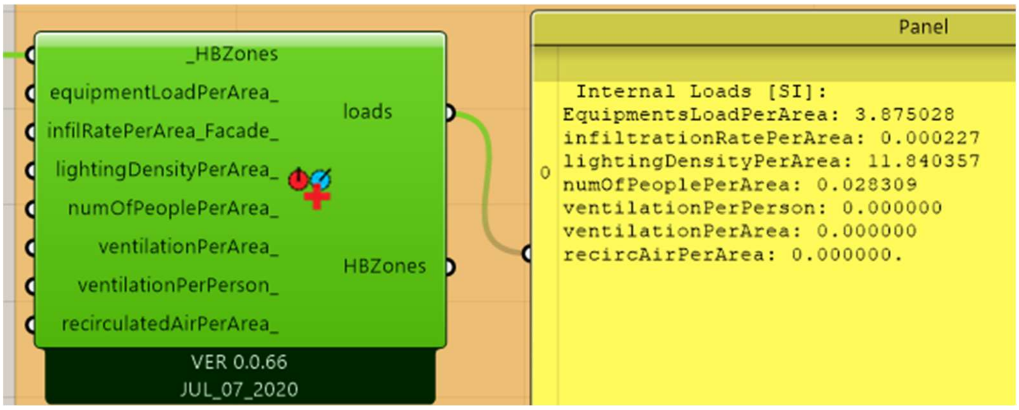


Figure 8: Zone Program "*MidriseApartment::Apartment loads*"

For the rest of the zones, the basement, attic and two staircases, the program MidriseApartment::Corridor was assigned. In Figure 9 the load parameters for this program are presented.

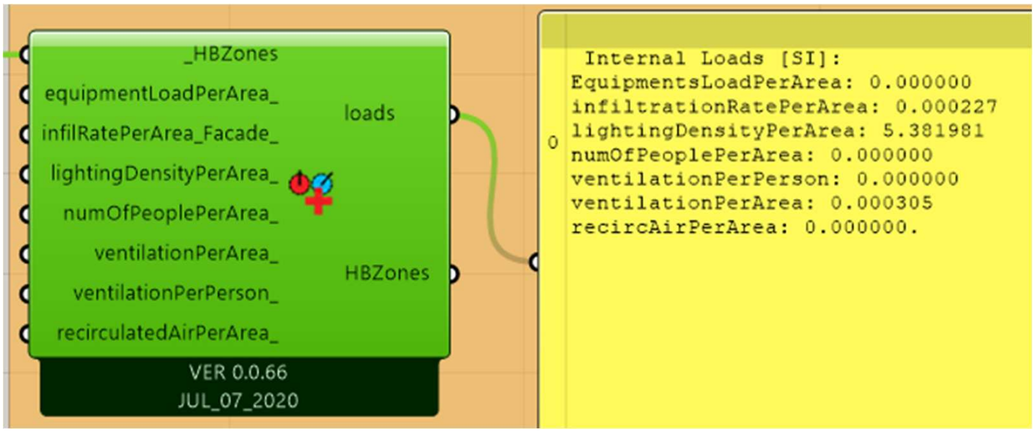


Figure 9: Zone Program "*MidriseApartment::Corridor loads*"

3. BEM calibration

3.1 Calibration methodology applied and results

The automated calibration procedure developed by UNIVMP in Task 3.4 has been applied to the Warmond BEM in order to check the reliability of the model and the related energy results. The energy consumption used to complete the procedure are documented in the following figure.

Table 4: Real energy consumption for space heating and DHW production

Uw historisch verbruik

Van Duvenvoordestraat 32, 2361JT WARMOND

Datum	Stroomverbruik	Gasverbruik
Maart 2022	214 kWh	114 m³
Februari 2022	180 kWh	136 m³
Januari 2022	225 kWh	167 m³
December 2021	274 kWh	176 m³
November 2021	220 kWh	140 m³
Oktober 2021	204 kWh	98 m³

To simplify and speed up the process, the calibration has been focused on a single apartment (Flat n. 32) following 2 main steps:

1. Sensitivity analysis: carried out to identify the most important parameters and discard uninfluential ones from the calibration process;

2. Calibration Phase: carried out in terms of energy consumption to find the CoP value that provides the best fit for the energy consumption for space heating obtained from bills.

The following figure shows how the calibrated BEM reaches a higher match with the real building.

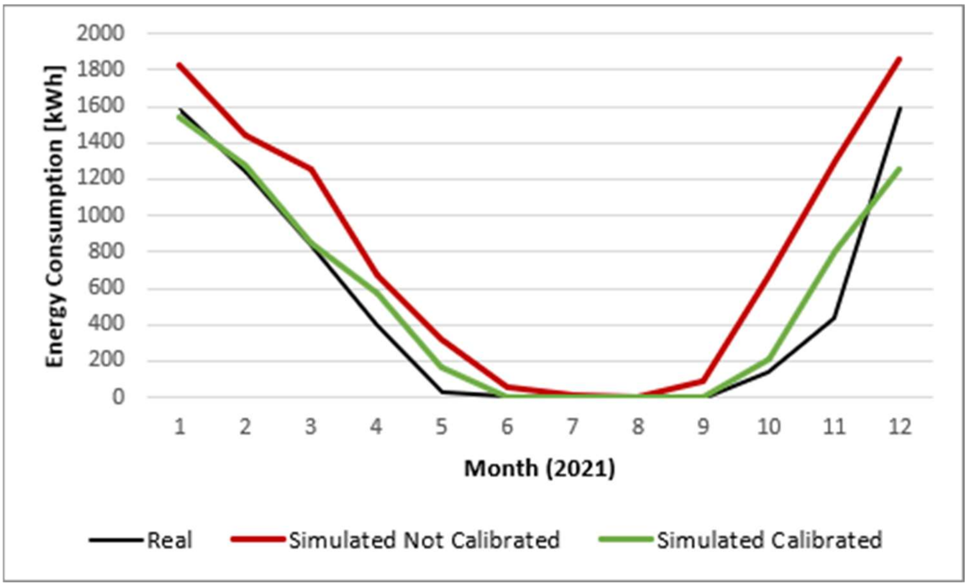


Figure 10: Energy consumption (real – simulated not calibrated – simulated calibrated)

Following table provides the calibration results. The CVRMSE, which indicates the overall error of the model, passes from 70% to 28%. Unfortunately, this error is still higher than the thresholds that are used by Standards to consider a model calibrated (15%).

Table 5: Calibration results

CV(RMSE)	Original BEM	Phase 1 Calibration
CV(RMSE)	70%	28%

To improve the reliability of the model, it could be useful to use the monitored data (heating season between 2021 and 2022) to understand when people activate the space heating system (hours of the day and holiday periods). As the purpose of the model is to evaluate the reliability of the renovation scenarios, without any changes in the operating usages, the calibrated model form phase 1 has been adopted as the reference BEM model for the actual state and has been then used to develop the interventions.

4. Building energy performance simulation results

4.1 General considerations

In this section the simulation results for the baseline scenario is presented and analyzed. Since no HVAC system was selected in the creation of the BEM, the results from the simulations reflect the **energy demand for heating** considering an Ideal Load. Taking into account that no HVAC system is either proposed in neither of the renovation scenarios, the existing HVAC system (old central heating boiler) was considered in order to calculate the energy consumption and therefore the resulting heating demand was divided by a COP value of about 0.6.

Table 6: Existing Building Simulation Results

Apt	Area [m2]	HVAC Zone Eq & Other Sensible Air Heating [kWh]	Heating Demand [kWh/m2]	With COP [kWh/m2]
APT11	86.65	3441.73	39.72	65.94
APT12	75.3	1797.31	23.87	39.62
APT13	86.65	2127.95	24.56	40.77
APT14	75.3	3268.31	43.40	72.05
APT21	86.65	2962.38	34.19	56.75
APT22	75.3	1337.96	17.77	29.50
APT23	86.65	1611.38	18.60	30.87
APT24	75.3	2833.76	37.63	62.47
APT31	86.65	5182.45	59.81	99.28
APT32	75.3	3212.91	42.67	70.83
APT33	86.65	3615.92	41.73	69.27
APT34	75.3	4801.73	63.77	105.85
Total	**971.7**	**36193.79**	**37.31**	**61.93**

4.2 Energy KPIs

The following Energy KPI has been calculated according to D4.1 descriptions.

BS.TED: Total Energy Demand

The table below summarises the results obtained from the calculation of the heating energy demand of each occupied zone, as well as the total energy demand of the building.

Table 7: BS.TED Total Energy Demand

BS.TED: Total Energy Demand	
$Q_{TOTAL\ BUILDING}$ [kWh/m²year]	**37.31**

BS.TEC: Total Energy Consumption

Total Energy Consumption has been calculated starting from the heating demand and considering a COP value of about 0.6.

Table 8: BS.TEC Total Energy Consumption

BS.TEC: Total Energy Consumption	
EP_{TOT}[kWh/m²]	**61.93**

5. Building renovation scenarios

To perform and assess multiple energy simulations for building renovation scenarios, the MTB Optimisation tool has been applied.

Figure 11: Graphical view of the Simulation model

5.1 Renovation scenarios proposed

For the Warmond democase, the following building renovation elements have been assessed according to Task 7.1 premises.

- External walls insulation
- Windows replacement (incl. shading system)
- Roof insulation
- HVAC replacement
- PV system installation

5.2 Optimisation set-up: planning variants considered

The following table summarizes the optimization setting applied to the Warmond BEM model. For each type of intervention, different solutions were examined, making the characteristic parameters vary between a certain range of values.

Table 9: Optimisation setting – Intervention, ranges of variation and number of options

Type of intervention	Optimisation settings and ranges of variation	Number of options
External walls insulation	Insulation Types: (1) Stone wool (λ 0,035 W/mK); (2) Mineral wool (λ 0,032 W/mK); (3) Wood derivates wood wool (λ from 0,038 W/mK)	3
	Thickness options: 1 cm – 30 cm in 10 regular steps (1, 4, 7, 11, 14, 17, 20, 23, 27, 30 cm)	10

Roof insulation	Insulation Types: (1) Stone wool (λ 0,035 W/mK); (2) Mineral wool (λ 0,032 W/mK); (3) PUR foam (λ 0,026 W/mK)	3
	Thickness options: 1 cm – 32 cm in 10 regular steps (1, 4, 7, 11, 14, 18, 21, 25, 29, 32 cm)	10
Windows replacement	U-values from 1,3 to 0,62 kWh/m²K (steps: 1,3; 1,1; 1,0; 0,9; 0,7,0,62) no change in windows dimensions	6
Shading system	(1) Interior blind with low reflectivity slats; (2) Exterior shade roll medium translucent; (3) Exterior blinds w. low/med/high reflectivity and 30° - 135° angle	19
Photovoltaic	Photovoltaic type: (1) No photovoltaic (2) Photovoltaic polycrystalline, efficiency 0.15 (3) Photovoltaic polycrystalline, efficiency 0.17 (4) Photovoltaic polycrystalline, efficiency 0.19 (5) Photovoltaic polycrystalline, efficiency 0.21	4 (+1)
	Photovoltaic covered surface that is oriented South: (1) 40% (2) 50% (3) 75% (4) 100%	4
	Battery types (each with 5 capacity steps): (1) No battery (2) Lithium iron phosphate batteries (with 10 capacity steps)	10 (+1)
HVAC	Heat distribution: (1) Hot water underfloor heating (2) Hot water ceiling (3) Hot water radiator	3
	Heat supply: (1) Condensation boiler (2) District heating (3) Ground source heat pump (4) Combined heat and power	4
	Total number of theoretical combinations	**217.922.400**

5.3 Ranges of optimal solutions

Following the specific optimization set-up of the project, the theoretical number of possible renovation scenarios to be assessed is nearly 218 million. Out of these, 4.000 scenarios have been automatically simulated and assessed, controlled by an evolutionary optimization algorithm. This process took a computation time of approx. 27hrs (26hrs 50min on a server cluster with 288 cores and 470 GB RAM involving server costs of approx. 145€).

Figure 10 shows the Pareto-graph of simulates renovation scenarios, sorted by construction costs and energy demand. The solution space includes renovation scenarios with resulting end energy demands up to 56 kWh/(m² year) and construction costs between EUR 420.000 and EUR 1.100.000. The points within the red circle represent a range of optimal solutions for reducing energy demand while the solutions highlighted in green represents the optimal solutions to reduce construction costs.

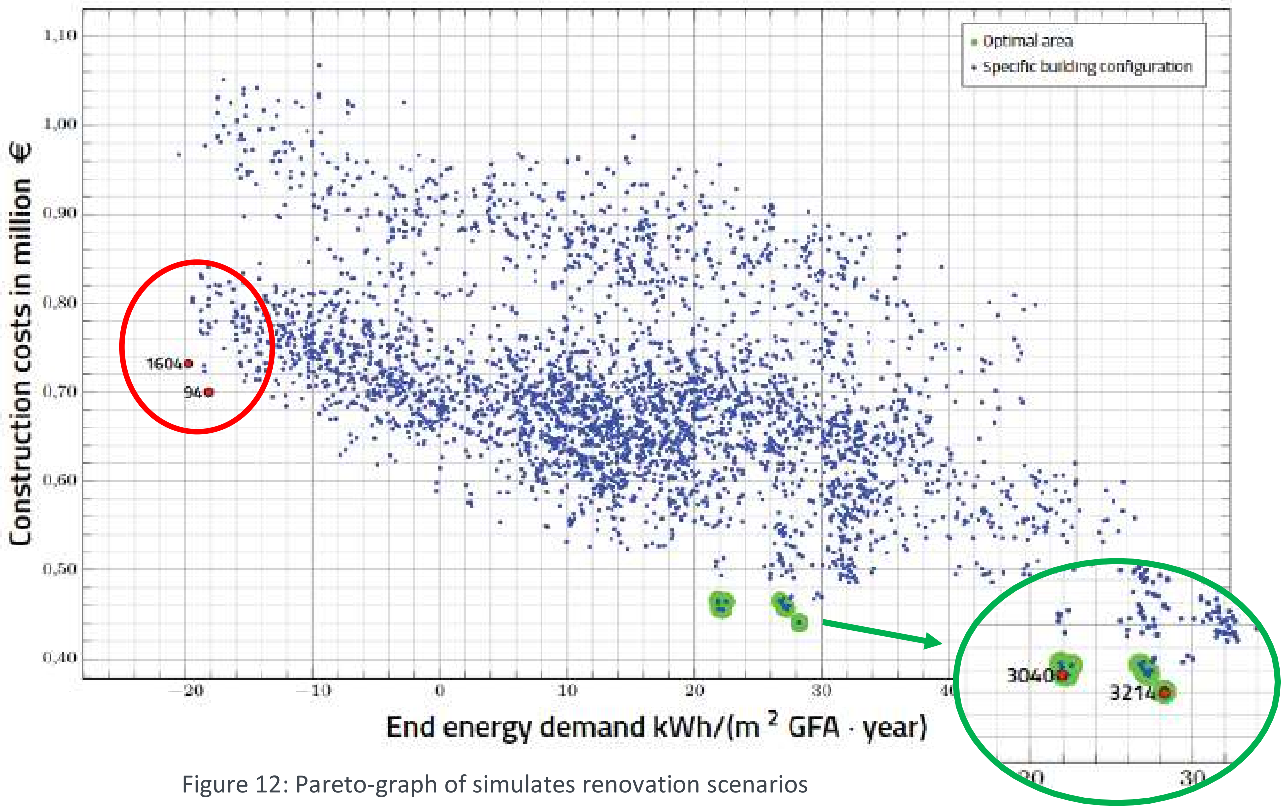


Figure 12: Pareto-graph of simulates renovation scenarios

Out of this solution space, 4 renovation scenarios have been identified as among optimal solutions:

- Energy-optimal: Two solutions with best results in end energy demand, while still having a good costs and comfort performance (ID 1604 & ID 0094)
- Cost-optimal: Two solutions with best results in cost performance, while still having a good energy and comfort performance (ID 3040 & ID 3214)

Those two Energy-optimal renovation alternatives are being described in the following.

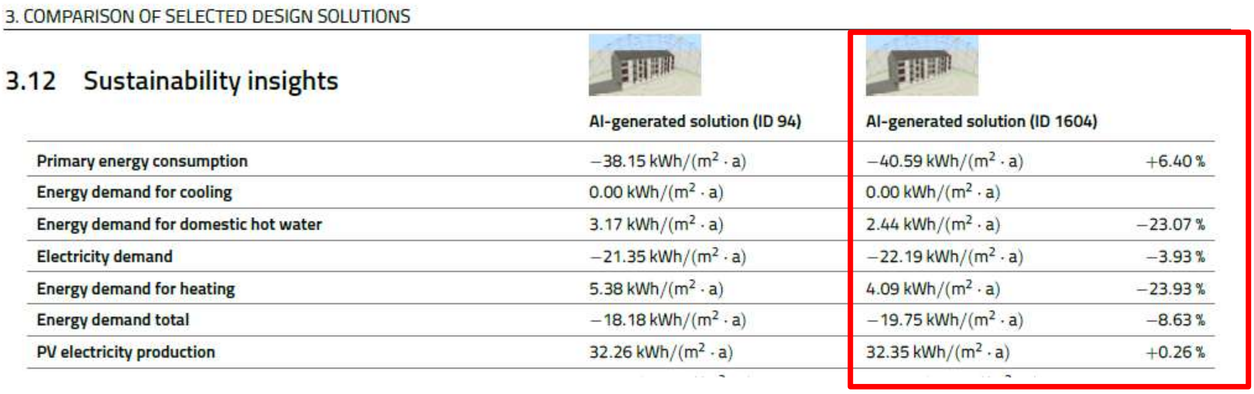
5.4 Scenario 1: description and results

Scenario 1 (ID 1604) has been identified as an energy-optimal renovation scenario. In comparison with all simulated renovation scenarios, this scenario has a very good end energy demand, while still having a medium cost (approx. EUR 740.000) and comfort performance. Its configuration and its simulation results are described in the following tables.

Table 10: Renovation setup for the energy-optimal scenario 1 (ID 1604)

Type of intervention	Optimisation settings and ranges of variation	

External walls insulation	Insulation material: Mineral wool Total thickness of external wall U-Value	0,18 m 0,40 m 0,17 W/m²K
Roof insulation	Insulation material: PUR foam Total thickness U-Value	0,26 m 0,63 m 0,09 W/m²K
Windows replacement	Glazing type: Triple glazing, Low-E PVC frame no change in windows dimensions	Ug = 0,7
Shading system	Exterior blind low reflectivity slats 90°	
HVAC	Heat distribution: Hot water ceiling Heat supply: Ground Source Heat Pump Cooling: None	
Electricity Generation	Solar Thermal size Solar Collector type Roof area covered by PV Battery type PV orientation option (respect to south) PV tilt options (respect to horizontal)	21.11 m² Flat solar collector 158.33 m² Lithium, 32 kWh -45° 30°


3. COMPARISON OF SELECTED DESIGN SOLUTIONS

3.12 Sustainability insights

	AI-generated solution (ID 94)	AI-generated solution (ID 1604)	
Primary energy consumption	−38.15 kWh/(m² · a)	−40.59 kWh/(m² · a)	+6.40 %
Energy demand for cooling	0.00 kWh/(m² · a)	0.00 kWh/(m² · a)	
Energy demand for domestic hot water	3.17 kWh/(m² · a)	2.44 kWh/(m² · a)	−23.07 %
Electricity demand	−21.35 kWh/(m² · a)	−22.19 kWh/(m² · a)	−3.93 %
Energy demand for heating	5.38 kWh/(m² · a)	4.09 kWh/(m² · a)	−23.93 %
Energy demand total	−18.18 kWh/(m² · a)	−19.75 kWh/(m² · a)	−8.63 %
PV electricity production	32.26 kWh/(m² · a)	32.35 kWh/(m² · a)	+0.26 %

Figure 13: Screenshot from the optimisation report with energy related KPIs

The following KPIs have been calculated:

BS.TED: Total Energy Demand

Table 11: BS.TED Total Energy Demand

BS.TED: Total Energy Demand	
Q_{TOT} [kWh/m²year]	-19.75

BS.TEC: Total Energy Consumption (and sub KPIs; Energy consumption for heating, cooling, lighting, DHW)

Table 12: BS.TEC Total Energy Consumption

BS.TEC: Total Energy Consumption	
EP_{TOT}[kWh/m²]	**-40.59**

BS.TES: Total Energy savings

Table 13: BS.TES Total Energy Savings

BS.TES: Total Energy Savings			
	Baseline	Scenario 01	SAVING
EP_{TOT}[kWh/m²]	61.93	-40.59	21.34

5.5 Scenarios 2: description and results

Scenario 2 (ID 1726) has been identified as an energy-optimal renovation scenario. In comparison with all simulated renovation scenarios, this scenario has a very good end energy demand, while still having a good costs and comfort performance (**Error! Reference source not found.**). Its configuration and its simulation results are described in the following tables.

Table 14: Renovation setup for the energy-optimal scenario 1 (ID 94)

Type of intervention	Optimisation settings and ranges of variation	
External walls insulation	Insulation material: Stone wool Total thickness of external wall U-Value	0,21 m 0,43 m 0,16 W/m²K
Roof insulation	Insulation material: Mineral wool Total thickness U-Value	0,29 m 0,66 m 0,10 W/m²K
Windows replacement	Glazing type: Triple glazing, Low-E PVC frame no change in windows dimensions	Ug = 0,7
Shading system	Exterior blind high reflectivity slats 135°	
HVAC	Heat distribution: Hot water radiator Heat supply: Ground Source Heat Pump Cooling: None	
Electricity Generation	Solar Thermal size Solar Collector type Roof area covered by PV Battery type PV orientation option (respect to south) PV tilt options (respect to horizontal)	42.22 m² Flat solar collector 158.33 m² Lithium, 32 kWh -45° 30°


3. COMPARISON OF SELECTED DESIGN SOLUTIONS

3.12 Sustainability insights

	AI-generated solution (ID 94)	AI-generated solution (ID 1604)	
Primary energy consumption	−38.15 kWh/(m² · a)	−40.59 kWh/(m² · a)	+6.40 %
Energy demand for cooling	0.00 kWh/(m² · a)	0.00 kWh/(m² · a)	
Energy demand for domestic hot water	3.17 kWh/(m² · a)	2.44 kWh/(m² · a)	−23.07 %
Electricity demand	−21.35 kWh/(m² · a)	−22.19 kWh/(m² · a)	−3.93 %
Energy demand for heating	5.38 kWh/(m² · a)	4.09 kWh/(m² · a)	−23.93 %
Energy demand total	−18.18 kWh/(m² · a)	−19.75 kWh/(m² · a)	−8.63 %
PV electricity production	32.26 kWh/(m² · a)	32.35 kWh/(m² · a)	+0.26 %

Figure 14: Details from optimisation report with energy related KPIs (Scenario 2)

The following KPIs have been calculated:

BS.TED: Total Energy Demand

Table 15: BS.TED Total Energy Demand

BS.TED: Total Energy Demand	
Q_{TOT} [kWh/m^{2}year]	-18.18

BS.TEC: Total Energy Consumption (and sub KPIs; Energy consumption for heating, cooling, lighting, DHW)

Table 16: BS.TEC Total Energy Consumption

BS.TEC: Total Energy Consumption	
EP_{TOT}[kWh/m^2]	**-38.15**

BS.TES: Total Energy savings

Table 17: BS.TES Total Energy Savings

BS.TES: Total Energy Savings			
	Baseline	Scenario 02	SAVING
EP_{TOT}[kWh/m^2]	**61.93**	**-38.15**	**23.78**

6. Time reduction evaluation

The time reduction evaluation for the BIM-to-BEM process is not relevant from the Warmond democase as the BEM was created with a traditional process using directly BEM software and not starting from a BIM model.