Assessing the project impact

Report on the European Building models and the benefits that can be achieved by the use of RES4BUILD systems

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Abbreviations

BPIE	Building Performance Institute Europe
BSO	Building Stock Observatory
BTES	Borehole Thermal Energy Storage
CO_2e	Carbon Dioxide equivalent
DEF	District Energy Feasibility
DHW	Domestic Hot Water
DOE	Department of Energy
EED	Energy Efficiency Directive
EPBD	Energy Performance of Buildings Directive
EPW	EnergyPlus Weather Format
EU	European Union
EUI	Energy Use Intensity
GHG	Greenhouse Gas
GWP	Global Warming Potential
HP	Heat Pump
IES	Integrated Energy Solution
ISEM	Integrated Single Electricity Market
MFRB	Multi Family Residential Building
NCSRD	National Center for Scientific Research Demokritos
NZEB	Nearly Zero Energy Buildings
PA	Acidification Potential
PEMT	Parametric Energy Modelling Tool
PM	Particulate matter / Respiratory inorganics midpoint
POCP	Photochemical Ozone Creation Potential

PV	Photovoltaic system
PVT	Photovoltaic system, combined with solar thermal energy collector
R&D	Research and development
RED	Renewable Energy Directive
RES4BUILD	Renewable Energy Systems for Buildings
RET	Renewable energy technologies
RIA	Research and Innovation Actions
SCOP	Seasonal Co-efficient of Performance
SEER	Seasonal energy efficiency ratio
SFH	Single Family Home
T	Task
TMY	Typical Meteorological Years
VITO	Vlaamse Instelling voor Technologisch Onderzoek - Flemish institute for technological research
WLCCA	Whole life cycle cost analysis
WP	Work Package

Executive summary

As part of the wider RES4BUILD framework, this report assesses the possible impacts in terms of operational greenhouse gas reduction of the Integrated Energy Solution (IES) proposed and tested within the RES4BUILD project. To do so, innovative simulation- and numerical tools are developed to calculate the prognosed emission reductions in switching from conventional solutions to the proposed IES.

Detailed research of the European Building Market, using existing statistical data, supports the selection of building typologies and locations for assessment: 4 typologies in 4 different climates. The research presents a clear outline of the stock, indicating a majority of area in the residential sector, a high density of property in the North & West regions and a major task for renovation of existing stock, of which 66% has an EPC-label lower than 'C'. Renovation and innovative solutions are required as the majority of building stock uses fossil fuels like gas or oil for the major share in energy use: space heating.

To indicate the possible impact, standard typologies are selected and modelled in an 'Individual Extensible Modelling' tool, based on EnergyPlus. Through this, a flexible approach is designed which is ready to cope with large varieties in geometries, user profiles, system details or climatic zones. This is necessary, as proven by the large diversity of energy densities per building type or country in the market study. The resulting hourly building demand profiles per typology/zone are validated with previous research and interpreted by the project team on current relevance. As accepted, they are the basis for prognosis of energy use by the Integrated Energy System.

Each typology is assessed and provided with optimal system sizes and control assumptions to best reflect the climate- and country specifics. The numerical calculation methodology is described in detail in other deliverables of the wider RES4BUILD research: D3.1 and D3.4.

The results of the selected typologies, climatic zones, building demand profiles and the IES are compared on their **environmental impact** in terms of CO_2e emissions saved from moving away from fossil fuels for thermal energy production. For comparison, it is assumed that residential buildings are renovated to a *cost optimal* level and non-residential buildings are renovated to NZEB level. The results are compared to 'conventional' alternatives for the current systems: a gas fired boiler + air source chiller or an air source heat pump.

In this scenario analysis, there is a full reduction in fossil fuel consumption as the RES4BUILD system is electricity based. However, the EU28 model only represents an estimated 86% of the building stock and therefore assuming fossil fuel use in all other buildings it is an 86% reduction in fossil-fuel consumption, higher than the initial analysis estimate of 77%.

As the initial analysis indicated, the environmental impact was expected to be at least 68% GWP saving in for CO_2e emissions, The results from detailed comparison analysis indicate implementation of the RES4BUILD system on the building typologies of SFH, MFRB, Commercial office, and Public-School across the EU would result in an estimated 75% reduction in GWP CO_2e emissions compared to a typical gas boiler and AC system. The GWP % CO2e savings will improve as the electricity grid continues to decarbonise. This is shown in table 1.

It is noted that this a high level 'best case' scenario with full implementation of the RES4BUILD system. In reality there is likely to be several barriers and market constraints to the RES4BUILD system that will limit implementation. This will be investigated further in T7.2.

Table 1 – EU Building Stock Thermal Energy & Emissions Impact Assessment Results Summary

EU Building Stock Thermal Energy & Emissions Impact Assessment			Baseline: gas boiler + AC Chiller		RES4BUILD		Impact
Location	**Typology**	**Est. EU Representative Building Floor Area**	**Gas use**	**Electricity use**	**Gas use**	**Electricity use**	**EN 15804 – GWP Saving**
		million m2	GWh/yr	GWh/yr	GWh/yr	GWh/yr	% CO_2-e Saved per annum
Athens, GRE - Warm Climate	SFH	3,253	88,786	59,766	0	35,593	74%
	MFRB	1,830	15,263	49,192	0	16,507	73%
	Commercial Office	521	2,528	16,706	0	8,767	53%
	Public - School	295	4,082	3,078	0	2,097	68%
Cork, IRL - Moderate-mixed Climate	SFH	1,884	122,506	1,545	0	26,261	75%
	MFRB	1,060	49,687	138	0	9,049	78%
	Commercial Office	324	7,778	1,227	0	4,023	48%
	Public - School	183	7,459	143	0	5,607	13%
Amsterdam, NL - Average Climate	SFH	5,088	275,329	38,977	0	61,314	77%
	MFRB	2,862	111,396	8,415	0	20,350	80%
	Commercial Office	858	20,950	11,603	0	10,779	63%
	Public - School	486	12,542	3,596	0	9,116	36%
Gdansk, PL - Cold Climate	SFH	3,610	305,154	14,117	0	68,526	75%
	MFRB	2,031	126,056	3,067	0	11,129	90%
	Commercial Office	590	18,620	7,749	0	10575.7	55%
	Public - School	334	11,605	2,361	0	9,350	23%
Total building stock	**EU28**	**25,211**	**1,179,741**	**221,677**	**0**	**309,046**	**75%**

1 Introduction and outline

Never has it been more important to decarbonise our energy systems. The ultimate driver is to reduce anthropogenic induced climate change by curtailing and eventually eliminating carbon dioxide, methane and all greenhouse gas (GHG) emissions to our planet's atmosphere. Recent geo-political events make it even more important to stop the burning of fossil fuels, and in the focus area of the built environment, to decarbonise power generation and heat. The RES4BUILD research project will culminate in April 2023 with the development of:

a. innovative hybrid solar energy collectors, PV and thermal, to generate both electricity and heat simultaneously,
b. testing of new technology magneto-caloric heat-pumps that have potential for high coefficients of performance (CoP),
c. development and testing of new multi-source heat pumps based on the vapour compression cycle with low-GWP refrigerants that select the heat source or sink according to the most favourable one to maximise the CoP, and
d. development and testing of intelligent control optimisation software that seeks to enable a building's energy systems (heat and power) to respond to the variable demand and supply conditions being placed on the electricity grid.

The electricity grid in Europe is changing rapidly to an Integrated Single Electricity Market (ISEM) that is achieving higher and higher levels of renewable energy and non-synchronous power generation from renewable energy technologies (in lieu of coal / oil / gas fired generation plant). The EU Member States are each at different stages of development of their own electricity network and for the next 5 to 10 years can be expected to have differing levels of CO_2 emissions intensity for each kWh of electricity delivered to the end user. However, in the not-too-distant future, the ISEM in Europe will have an electricity generation and delivery network that will be the lowest carbon intensity energy source available for heat generation. Hence the importance of assessing the potential for adopting Renewable Energy Systems for Buildings (RES4BUILD).

This report sets out to assess the possible impacts in terms of operational greenhouse gas reduction and environmental whole life cycle cost (WLCC) for optimisation of embodied carbon in the systems proposed for an Integrated Energy Solution (IES), as part of the RES4BUILD project.

These impacts can be achieved through innovative and integrated approaches as are being developed in the wider RES4BUILD framework as described in this introduction, which also guides towards underlying deliverables and upcoming work in the project.

1.1 RES4BUILD

Aligning with European aims to mitigate Climate Change impact and to provide 'Clean Energy for all Europeans (presented by the European Commission on 30 November 2016), the overall objective for the RES4BUILD project is to **decarbonise the energy consumption in buildings by developing integrated renewable-energy-based solutions that are tailored to the needs and requirements of the users and the installers and will be cost competitive by 2025.**

The project is expected to develop:

1. Advancement of renewable-energy-based technologies that can be integrated in buildings and deliver substantial reductions in fossil fuel dependence
2. Development of tools (hardware and software) for (co-)design, control and assessment of IES

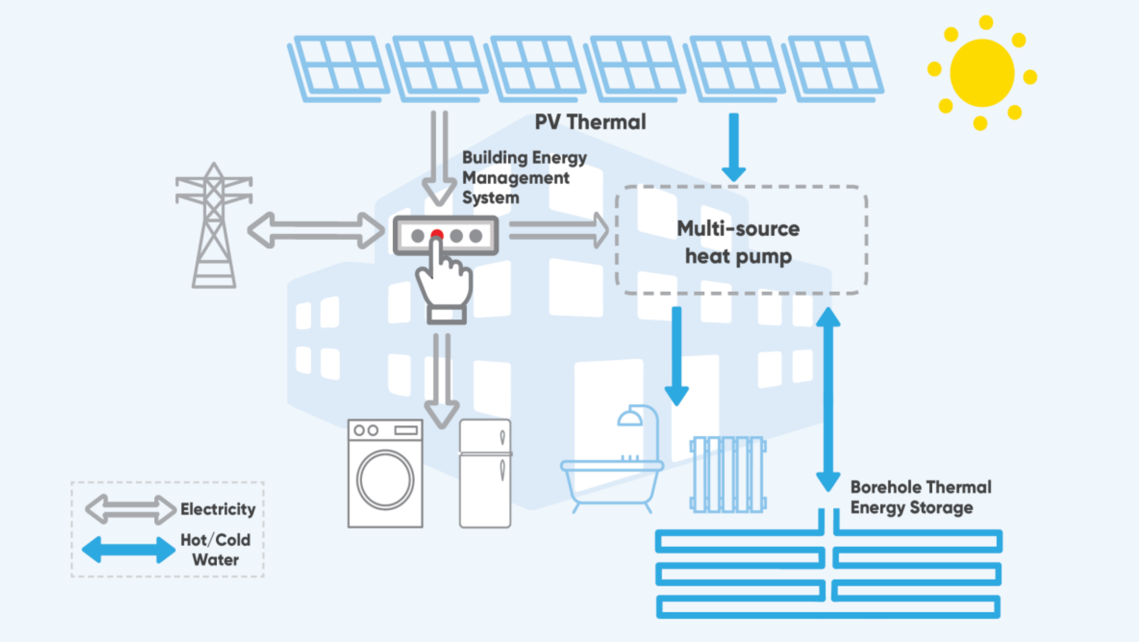

Figure 1: Graphic representation of the Integrated Energy Solutions in the RES4BUILD concept

This overall goal is split in the following partial objectives, of which the fifth is to this part of the study.

No.	Objective
1	Improve the performance and reduce the cost of the most innovative components of the RES4BUILD solutions.
2	Develop tools for simulation, sizing and control, making optimal use of the Integrated Energy System and the flexibility of consumption, while respecting the wishes of the end-users.
3	Develop tools for simulation, sizing and control, making optimal use of the Integrated Energy System and the flexibility of consumption, while respecting the wishes of the end-users.
4	Test various RES4BUILD solutions in different climates, validating the RES4BUILD solutions
5	Pave the way for bringing the developed solution to the market, ensuring wide adoption

The last objective is to be achieved through:

1 **Assessment of the project impact**
assessing the potential impact of the project through advanced building models

2 **Market analysis**
conducting a detailed regulatory and market analysis leading to business models for the optimal use of the system

3 **Business models**
Developing a roadmap that outlines the necessary R&D and other activities to be taken before the system can reach the market

These activities are grouped under 'Work package 7' (WP7). The scope of WP7 builds on that of preceding work packages and objectives, in which innovative technologies were developed, integrated, simulated, tested, reviewed through co-design processes, and assessed according to WLCCA, see the following diagram.

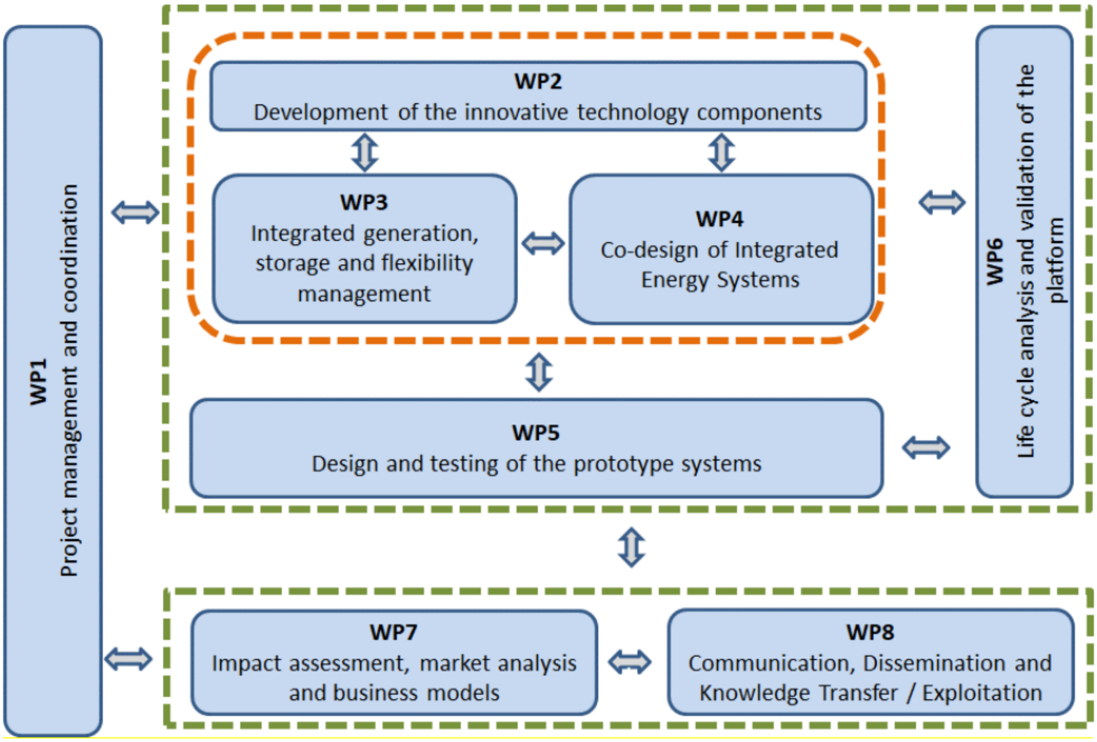

Figure 2: Relations between work packages.

An initial assessment of the project impact, the outcomes of the market analysis and the proposed business models was done as preparation for the project. The work in WP7 will contribute to validating and further detailing this initial assessment. This chapter gives a summary of the initial outcomes, which are to be used as reference for the research results.

1.2 WP7: Impact assessment, market analysis and business models

1.2.1 Assessment of the project impact

As part of the EU project H2020-LC-SC3-RES-4-2018, "Renewable energy system integrated at the building scale" there is a requirement to achieve certain impacts with the project approach. These relate to fossil fuels and value for money. Additional, environmentally and socially important impacts are being addressed.

No.	Impact
1	Reduction in use of fossil fuels for heating in buildings
2	Readiness for displacement of traditional heating solutions
3	Environmental impact
4	Social impact

Initial assessment of these impacts was done by high-level calculations for 4 EU-locations and 3 types of building use: 1. Multi-family, 2. Office, and 3. Public / Civic functions. These were chosen to be representative of most of the buildings in EU Member States that would benefit from full-scale IES systems.

In this assessment, the RES4BUILD technologies were simulated, based on rough estimations on performance. Assumptions were made for baseline use of fossil fuels and applicability of the technologies (eg. lowest limit of roofspace for PVT panels).

1.2.2 Reducing Dependence on Fossil Fuels

Overall, RES4BUILD solution eliminates the dependence on fossil fuels (at the building) for providing heating and cooling in buildings. There is an imperative for societal change to support the switch over to the adoption of proven, reliable renewable energy technologies through financial supports and regulatory drivers – the ‘carrot and stick’ approach.

Our analysis shows that the RES4BUILD solutions can make the necessary transition away from traditional solutions, with annual savings from rising costs of fossil fuels and diminishing market support services for traditional technologies reinforcing that move away from the status-quo.

The RES4BUILD project is focussed primarily on the displacement of fossil fuels for heating of the building. However, the project is also developing control algorithms that respond to external electricity grid signals that can help increase the uptake of ‘green’ electricity when renewable electricity generation peaks (from wind or solar) and conversely reduce demand by switching loads off when CO_2 grid intensity factor is high. This helps to increase the % of grid electricity that is supplied from renewable electricity generation as well as improving the resilience of a secure energy supply network.

1.2.3 Readiness for displacement of traditional heating solutions

To assess the readiness of the market in each member state to switch away from conventional fossil-fuel based heating systems to renewable energy systems, one has to consider the drivers will be different for new buildings and retrofit projects in existing buildings. As EU regulatory policy feeds through to the members states, we are seeing the forcible removal of fossil fuel based heating appliances from the market. So cost driven incentive for displacement of gas or oil-fired heating appliances in new-build projects is no longer in question. What is at stake is the timing of making the decision to install (as the primary heating source) an electrically driven heat-pump system coupled with solar thermal and / or solar photo-voltaic technologies to reduce and eventually eliminate the use of fossil fuels in heating of our existing buildings. This element of the project will be assessed in more detail in Task 7.2, the results of which will be reported on in deliverable Task 7.2 in October 2022.

Future changes in costs of systems, energy prices or value of money are not included in the initial assessment. Priority is given to energy efficiency measures: therefore, the RES4BUILD system is only applied in buildings where possible passive energy improvements have been implemented. To be clear on this point, the emissions reductions potential from renewable energy technologies is assessed based on a highly efficient ('cost-optimal') building that is well insulated against hot and cold weather. Savings in CO_2 emissions from energy efficiency improvement measures will often exceed those remaining to be offset by renewable energy technologies RET.

Financing solutions, such as technology support schemes (grant aid) or 'Pay-As-You-Save' loan schemes will be needed for widespread adoption. Finance interest rates and the economic climate in different countries will greatly affect the adoption and success of energy performance investment initiatives.

1.2.4 Environmental Impact

The positive environmental impact of the RES4BUILD solutions will be measured in terms of CO_2, NOX and SOX emissions reductions arising from use of fossil fuel heating systems at the building level. Furthermore, the embodied carbon content of the RETs being developed and the ability to recycle the materials within the specific equipment will be assessed as part of Work Package 6. Technology fact sheets are being developed for each of the components in the RETs considered by the RES4BUILD project.

For this report, estimated reductions in operational emissions of CO_2 are made using 2021 emission factors that are available for the grid supply of gas and electricity, considering the actual mix of grid electricity in each country (and its evolution over time).

1.2.5 Social Impact

The following social impacts are assumed to be achieved through application of the RES4BUILD system:

- **Comfort & wellbeing:** The project will lead to buildings, which provide higher comfort levels and wellbeing for their occupants. Buildings which are well heated and ventilated reduce negative health impacts caused by dampness, particularly amongst vulnerable groups such as children, the elderly and those with pre-existing illnesses[1].
- **Affordability:** The innovative control system of RES4BUILD will lead to more efficient operation and optimised interaction with the grid. All that will result in lower energy bill of the European consumers.
- **Jobs:** As the construction industry accounts for about 9% of Europe's GDP and 18 million jobs, the increased construction activities in the form of renovation will lead to job creation and increase economic growth in the EU.

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[1] https://ec.europa.eu/info/news/questions-answers-energy-performance-buildings-directive-2018-apr17_en?pk_campaign=ENERNewsletterMay2018

- **Human dimension:** In addition, by the co-design approach of WP4 the RES4BUILD approach targets the 'social element' or the 'human dimensions'[2] in the energy transition of the built environment.

While aligning the priorities and needs of all stakeholders and/or identifying compromises within the societal norms are complex challenges, a failure to adequately address these social needs will eventually slow down the energy transition.

1.3 Market analysis

The technology and solutions developed have the potential to be applied globally. This EU funded research project focusses on European member states and various building types within these markets. Initially eight member states are screened to assess the impact, targeting three types of buildings, which will be examined in detail under Task 7.2. The current report (Task 7.1) prepares for the examination, by addressing the building typologies for relevant climatic zones.

Table 2 : Initial scope of the EU market analysis

Markets / countries		Building types		Constructions types
Germany		Multi-family buildings		New developments
Greece				
Ireland		Office buildings		
Italy				
Netherlands				Renovations
Poland		Public buildings		
Spain				
Sweden				

Conclusions from the initial analysis are:

- **Substantial market sizes:** The size of the construction markets is substantial. The recent trends show an increase of construction, especially in residential markets to cover housing shortages.
- **Building activity:** The number of permits for new residential buildings indicate the possible impact of the RES4BUILD system: per year 878,000 permits for new buildings and an expected double amount for renovations. This means a total of 1.75 million residential buildings that need to be equipped with a new energy system in seven countries.
- **Growth:** The construction market is growing, with different rates in various countries. Growth rates vary between 0% (stable) to a high of 26%.
- **Competition:** Traditional solutions include natural gas or oil-fired boilers and grid electricity. The market for renewable energy technologies is growing (including energy efficiency, solar energy for hot water or electricity and heat-pump based solutions for heating and domestic hot water). Heat pumps tend to become the norm in new buildings in several countries. The RES4BUILD project aims to integrate these solutions together with innovative components.

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[2] Steg L, Perlaviciute G and van der Werff E (2015) Understanding the human dimensions of a sustainable energy transition. Front. Psychol. 6:805. doi: 10.3389/fpsyg.2015.00805 / https://www.frontiersin.org/articles/10.3389/fpsyg.2015.00805/full

- **Momentum:** The initial market analysis concludes that the high potential for reduction of fossil fuel use, readiness for displacement of traditional technologies, environmental and social impact can only be achieved through successful market implementation and growth in the technical qualifications of the service personnel required to install and maintain these systems. It is assumed that the RES4BUILD system will be market ready (and financially competitive) to meet the challenging deadlines set out by the European Union for banning the sale of fossil fuel burning appliances (2025). As there are millions of buildings per year built or refurbished in Europe, any delay of market introduction is a missed opportunity for impact. Business models shall aim to mitigate delays, e.g. through standardisation, scale-up of components etc.

1.4 Business models

The project aims to prepare business models for bringing the innovative RES4BUILD technologies to the markets. Therefore, stakeholders and an implementation plan are sketched during the initial analysis to increase the impact.

1.4.1 Stakeholders

The key stakeholders are defined, with their expected impact for their business.

Table 3: Impact for stakeholders (business models)

Stakeholder	Expected impact for their business (models)
Industry	The results related to the renewable-energy-based technologies will be used by the industry which is involved in manufacturing the relevant material and components and the industry that is involved in using the materials and components to develop the main equipment.
Integrators (installers, engineers, developers)	Companies that integrate the equipment into IES and installers will be partly users of these results. The different types of tools that will be developed will be used by various types of entities. First of all, engineering companies and architects will use the tools for designing IES to suit the requirements of specific buildings and the users. Developers of construction projects will be also among the users of the project results; the methodologies for engaging all stakeholders in a co-design process can be useful for them in order to come-up with a solution that makes sense both from financial and engineering point of view but is also addressing the wishes of the end-users
Planners, policy makers, other relevant public authorities	the planners, policy makers and other relevant public authorities can use the project results in order to assess the benefits of IES from an environmental, economic and social point of view.
End-users	The end-users will benefit from advanced control options and interfaces for the IES. Within the end-user category and depending on the situation in every building could be included the building owners, the occupants/tenants, the building users, or the facilities managers.
Other relevant stakeholders	Other stakeholders will benefit from the solutions: • Researchers and other academics who will use the project results for further research, education and training activities. • Electricity market players, such as: electricity supply companies, energy service companies, aggregators and the distribution system/network operators.

	• Producers of electricity using goods, such as smart appliances and electric cars • Bodies and authorities involved with standards and building codes

1.4.2 Implementation

To achieve these benefits, RES4BUILD includes a market assessment and the development of business models. The system design that will be proposed for each building type will need to be cost-effective in relation to market forces at play in each member state and will depend on a number of factors, such as:

- Energy market regulations,
- The specific needs of each building
- The expectations of end-users,
- Energy costs,
- Availability of RET, and
- The emissions reductions achieved by the innovative components.

1.4.3 Summary of scope in Work Package 7

The overarching aim for work package 7 is '**scaling'**, researching the innovative approaches to enable scaling up of IES solutions in Europe. In order to do so, the practical examples from Work package 4 and the technology development in Work Packages 2, 3, 5 and 6 feed into the **lessons learned** which can be used to distil innovations for scaling up IES solutions.

Below diagram shows the scaling of a technology solution, such as RES4BUILD's IES, along its learning curve through different phases.

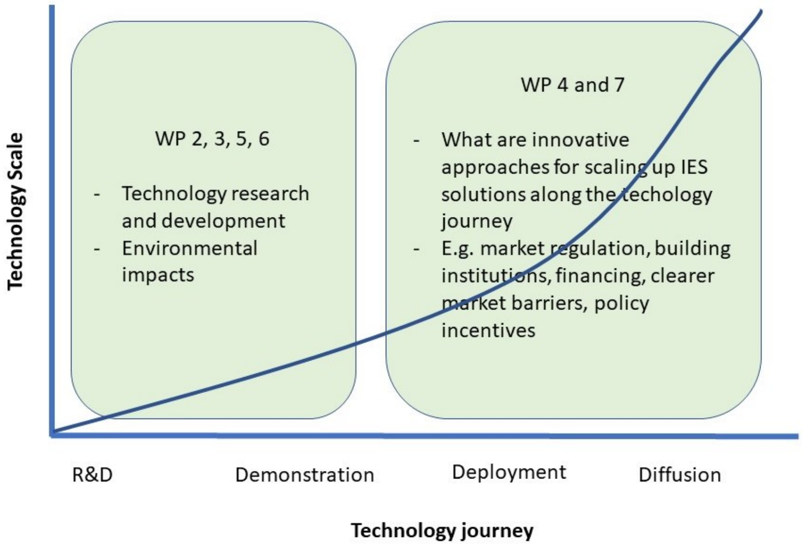


Figure 3: Representation of Technology Scale (by JIN).

Work package 7 plays a specific role in the deployment and moving towards diffusion, through the listed tasks:

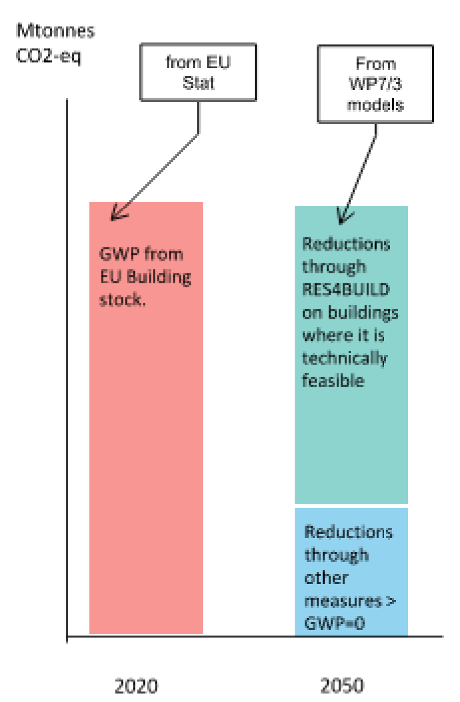
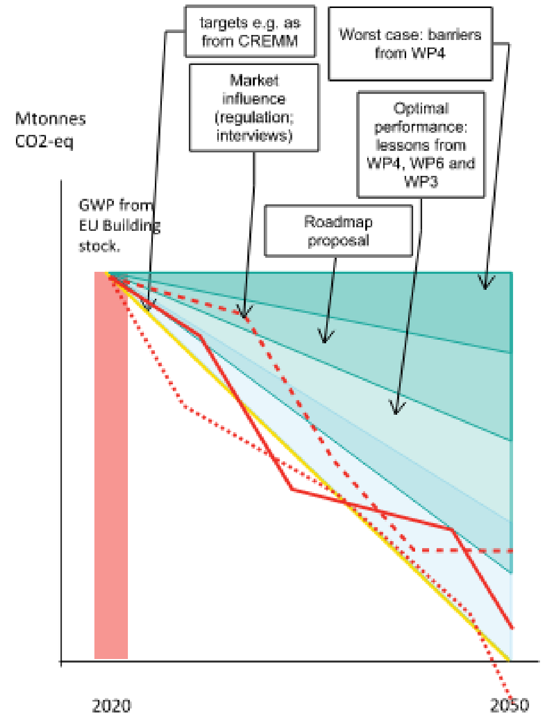
1. To assess the potential impact of the project through advanced building models (Task7.1)
2. To conduct a detailed regulatory and market analysis leading to business models for the optimal use of the system (Task 7.2)

3. To develop a roadmap that outlines the necessary R&D and other activities to be taken before the system can reach the market (Task 7.3)

Task 7.1 and Task 7.2 are related to each other, as they both investigate the potential impact of the project, with the difference that Task 7.1 focuses on the potential and Task 7.2 on the diverse scenario's which can occur in a changing regulatory and market environment. Both work packages Task 7.1 and Task 7.2 support in preparation the development of the roadmap in Task 7.3.

This is represented in the following table.

Table 4: Scope definition of Task 7.1 and Task 7.2

	
Task 7.1 Project impact Objective: to assess the potential impact of the project through advanced building models.	**Task 7.2 Market analysis** Objective: to conduct a detailed regulatory and market analysis leading to business models for the optimal use of the system.
Scope: • Review **current** energy use in building stock • Assess **current** building characteristics. • Setup simulation models to provide load profiles for simulations with WP3-tools. • Use outcomes of the simulations to assess total technical impact on the whole stock. Not taking into account time-related aspects, such as planned policies, market influence, climate change, etc.	Scope: • Review the quality of outcomes from T7.1 through a pilot test on a measured building with RES4BUILD technologies installed. • Review of policies & regulations affecting markets, including NZEB property improvements • Perform a market systems analysis to identify barriers and blockages in the specified countries (including end-users & local contacts of partners). • Investigation of financial models (stimulating / limiting), e.g. co-creation, circular, energy as a service. • Comparison to other technical developments (in competition), e.g. district heating, hydrogen. Using knowledge from the RHC Platform. • Considering climate change and geopolitical stability, affecting the predicted energy demand for heating or cooling, respectively the speed of transition. • Defining the relevant 'market share' for the RES4BUILD systems per country and per market segment.
Result: static potential of the project, defined in: • Potential fossil fuel reduction • Environmental impact • Recommendations for further analysis in Task 7.2	Result: scenario analysis for the impacts as defined in Task7.1. Leading to roadmap strategies for implementation of the system. Including system LCA, cost prognosis, environmental impact and social impact.
Climatic regions in assessment: Greece, Poland, Netherlands and Ireland.	Countries: Germany, Greece, Ireland, Italy, Netherlands, Poland, Spain and Sweden.

1.5 Report outline

A number of subtasks is defined for work package 7, in order to present the potential impact of the RES4BUILD system. These are outlined on the left-hand side of the table. The report outline, in which these items are addressed is given on the right-hand side.

Tasks 7.1	Outline
Building typologies, energy performance data and the design capacity of their heating/cooling systems will be collected for typical EU buildings; Existing data bases, such as Eurostat and BPIE, will be used for the initial data mining.	**Chapter 2: European Building Market Research** - Overview of databases and previous research - Building typologies: Data as required for modelling, such as U-values, setpoints, internal loads etc. - Locations: selected locations and showing representativity for EU wide CO2-eq estimation. - Overview of current energy performance, to use as baseline. Numbers for whole of Europe and explicit link to actual databases.
At least three typical building types and 4 locations in different climatic zones will be selected and the exercise will be carried out for each of them.	
Typical energy consumption profiles will be prepared for each of the building types in each of the climatic zones.	**Chapter 3: Advanced building energy modelling** - Methodology selection: comparison of various options; including lessons learned from other EU projects (e.g. Entranze) - Discussion on licensed tool modelling versus individual extensible modelling, resulting in the RES4BUILD energy modelling tool. **Chapter 4: Building Thermal Energy demand profiles** - Resulting profiles from modelling, on building thermal energy demand. **Chapter 5: RES4BUILD energy system** Results from modelling of the RES4BUILD Integrated Energy System, based on the building thermal energy demand.
The collected data will be processed using commercial software models such as the IESVE, bringing them to the format required for using them with the models of WP3	
The models will then be used together with the data on the building stocks to calculate the potential impact of the project on a national and European level, supplemented with LCA and LCE studies, in order to provide globally optimized solutions. This will validate whether the foreseen reduction of **fossil fuels** and **environmental impacts** are reached	**Chapter 6: RES4BUILD Impact assessment** - Assessment of potential **fossil fuel** savings and environmental impact on the building stock. - Target validation, reviewing the expected impacts compared to foreseen values. - Additional advice for further research on LCA and LCE studies in Task 7.2

2 European Building Market Research

2.1 EU databases and previous research

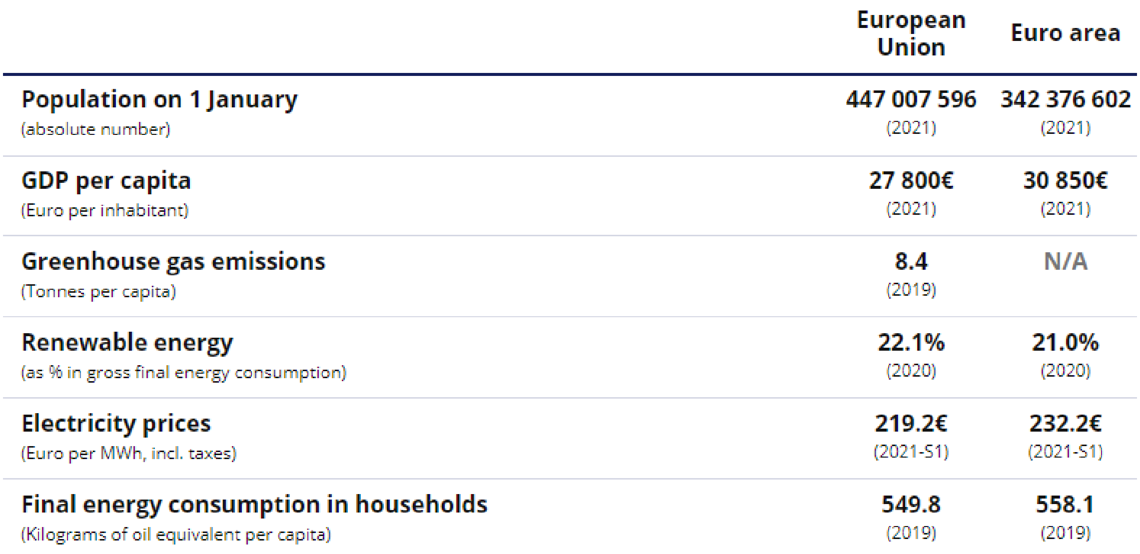
The RES4BUILD integrated renewable energy system is designed to be tailored to the needs and requirements of the users. These users are typically defined by the building typology which reflects their type of function and general form. Additionally, the energy performance of such building typologies affects the RES4BUILD system design, therefore the building typologies and energy performance data is collected for typical EU buildings.

Fortunately, there has been extensive research on building typologies and energy performance for Europe which we have utilised to produce the RES4BUILD blueprint of the EU building stock. Existing data bases, such as Eurostat, EU Building Stock Observatory and BPIE, were used for the initial data mining, with additional relevant research projects such as ENTRANZE, EPISCOPE - TABULA and STRATEGO reviewed to develop learnings further.

The RES4BUILD selected building typologies and energy performance data are presented in detail later in this report, with a summary of existing research, lessons learned and utilised databases provided below.

Eurostat is the statistical office of the European Union. Its mission is to provide high quality statistics for Europe. It provided news, data and publications across a range of topics not just energy or building related.

The expansive collection of data makes focused review of building and energy related topics more difficult than other databases. However the high-level European data on population, greenhouse gas emissions and renewable energy percentages may be useful.



	European Union	Euro area
Population on 1 January (absolute number)	**447 007 596** (2021)	**342 376 602** (2021)
GDP per capita (Euro per inhabitant)	**27 800€** (2021)	**30 850€** (2021)
Greenhouse gas emissions (Tonnes per capita)	**8.4** (2019)	**N/A**
Renewable energy (as % in gross final energy consumption)	**22.1%** (2020)	**21.0%** (2020)
Electricity prices (Euro per MWh, incl. taxes)	**219.2€** (2021-S1)	**232.2€** (2021-S1)
Final energy consumption in households (Kilograms of oil equivalent per capita)	**549.8** (2019)	**558.1** (2019)

Figure 4 - Eurostat EU Database Example

The EU Building Stock Observatory (BSO) was established in 2016 as part of the Clean energy for all Europeans package and aims to provide a better understanding of the energy performance of the building sector through reliable, consistent and comparable data. It contains a data mapper and factsheets for monitoring the energy performance of buildings across Europe, both developed from the BSO database feed from over 250 indicators organised according to 10 themes including building stock characteristics, energy consumption and building renovation.

The BSO has proved one of the most applicable databases with its data and associated graphs, particularly around the breakdown of the European building stock, referenced throughout this section. While much of its data is based on 2013 data which is nearly a decade old at this stage, more recent reliable data is difficult to source.

It is on the other hand more up to date on future on European building energy policies, and of interest - renovation requirements. There have been several building renovation legislations put in place in Europe, the 2010 Energy Performance of Buildings Directive (EPBD, 2010/31/EU) introduced the requirement of implementing energy efficiency measures in connection to major renovations to encourage more ambitious renovation and requested cost-optimal energy performance requirements for existing and new builds. The EPBD encourages the elimination of market barriers to deep renovation and recommends economic supports to stimulate residential and non-residential building renovation.

The 2012 Energy Efficiency Directive (EED, 2012/27/EU) encourages renovations through the requirement to establish strategies for the renovation of their national building stocks (to be submitted every three years and to target renovation of 3 % of the building stock annually[3].

The EPISCOPE-TABULA project, funded by the Intelligent Energy Europe Programme, developed residential building typologies for residential building stock segments in 17 European countries. It defines building stock segments based on the following parameters:

- Country,
- Building use,
- Construction period
- Building size
- Building Envelope Performance Specs

This is useful for projects requiring an indept review of existing building stock thermal envelope and specific residential housing archetypes. This does not particularly fit the scope of the RES4BUILD project requirements, although it did provide an accepted reference for residential building sizes.

The EU-funded Hotmaps project is an online open-source tool aimed to support public authorities and other strategic planners on local and national levels, promote sustainable heating and cooling in line with EU policies.

The interactive tool main function is to enable the identification of the location of current heating and cooling demand as well as supply on a map of the EU28. More applicable to RES4BUILD, Hotmaps as one of its outputs, provides a publicly available building stock data on EU28 countries covering both the residential and non-residential segments.

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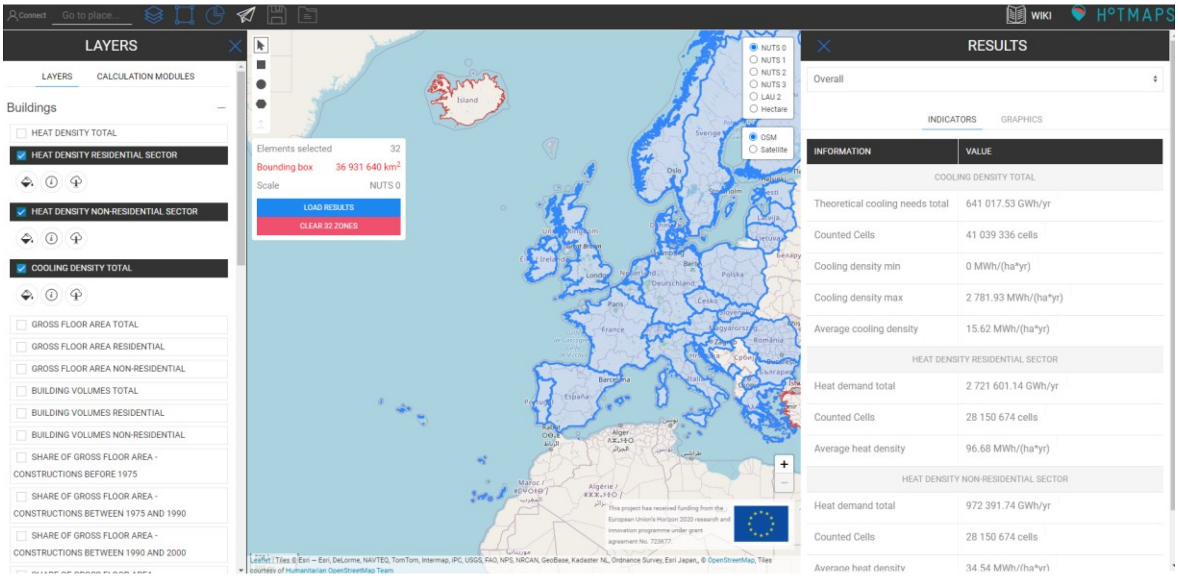
[3] https://ec.europa.eu/energy/eu-buildings-factsheets_en



Buildings

☐ HEAT DENSITY TOTAL
☑ HEAT DENSITY RESIDENTIAL SECTOR
☑ HEAT DENSITY NON-RESIDENTIAL SECTOR
☑ COOLING DENSITY TOTAL
☐ GROSS FLOOR AREA TOTAL
☐ GROSS FLOOR AREA RESIDENTIAL
☐ GROSS FLOOR AREA NON-RESIDENTIAL
☐ BUILDING VOLUMES TOTAL
☐ BUILDING VOLUMES RESIDENTIAL
☐ BUILDING VOLUMES NON-RESIDENTIAL
☐ SHARE OF GROSS FLOOR AREA - CONSTRUCTIONS BEFORE 1975
☐ SHARE OF GROSS FLOOR AREA - CONSTRUCTIONS BETWEEN 1975 AND 1990
☐ SHARE OF GROSS FLOOR AREA - CONSTRUCTIONS BETWEEN 1990 AND 2000

Elements selected: 32
Bounding box: 36 931 640 km²
Scale: NUTS 0

LOAD RESULTS
CLEAR 32 ZONES

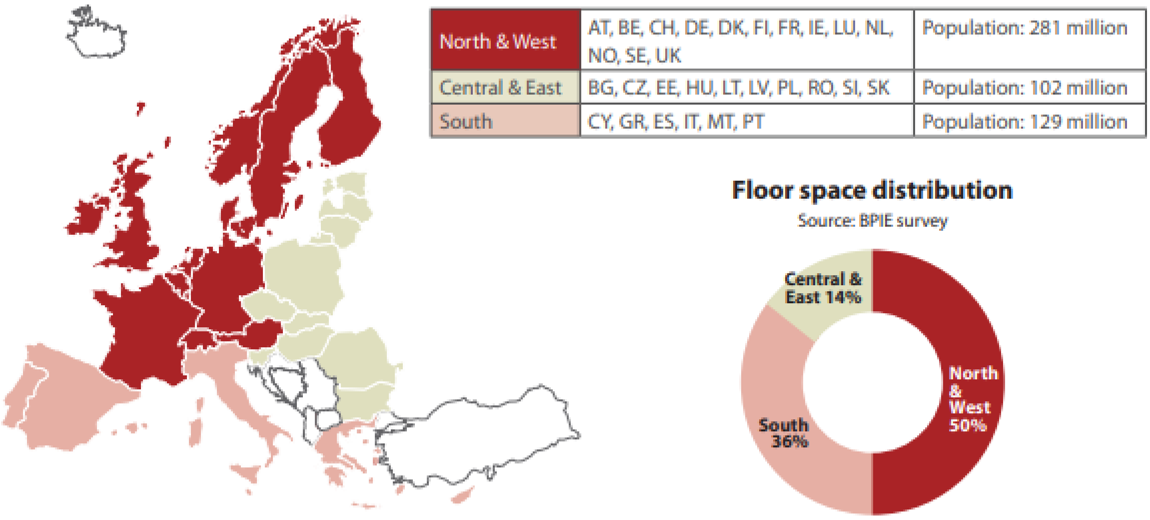
Overall

INFORMATION	VALUE
COOLING DENSITY TOTAL	
Theoretical cooling needs total	641 017.53 GWh/yr
Counted Cells	41 039 336 cells
Cooling density min	0 MWh/(ha*yr)
Cooling density max	2 781.93 MWh/(ha*yr)
Average cooling density	15.62 MWh/(ha*yr)
HEAT DENSITY RESIDENTIAL SECTOR	
Heat demand total	2 721 601.14 GWh/yr
Counted Cells	28 150 674 cells
Average heat density	96.68 MWh/(ha*yr)
HEAT DENSITY NON-RESIDENTIAL SECTOR	
Heat demand total	972 391.74 GWh/yr
Counted Cells	28 150 674 cells
Average heat density	34.54 MWh/(ha*yr)

Figure 5 - Europe Hotmaps platform

A more detailed breakdown of the EU28 building stock is provided in Europe's Buildings Under the Microscope - A country-by-country review of the energy performance of buildings. The report from 2011 estimates there is 26 billion m^2 of useful floor space in the EU28, approximately the land area of Belgium, split between 75% Residential and 25% Non-residential, with further classification of both provided also as described in section 2.2 Building Typologies.

The building floor area is also grouped geographically, with South, Central & East, and North & West regions identified in this study. Half of the total estimated floor space is located in the North & West region of Europe while the remaining 36% and 14% are contained in the South and Central & East regions, respectively. This relatively aligns with the RES4BUILD locations grouping except for the inclusion of Scandinavia with the western region countries, the RES4BUILD logic explained in section 2.3 Locations.

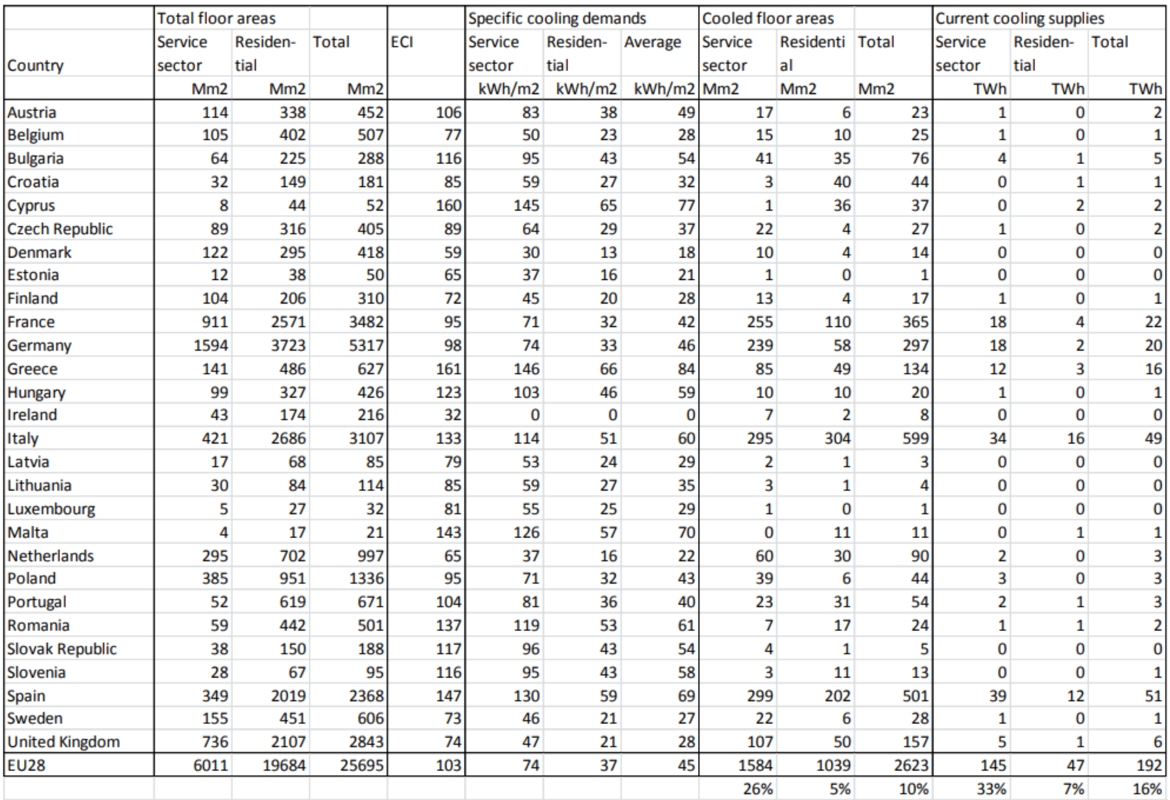


North & West	AT, BE, CH, DE, DK, FI, FR, IE, LU, NL, NO, SE, UK	Population: 281 million
Central & East	BG, CZ, EE, HU, LT, LV, PL, RO, SI, SK	Population: 102 million
South	CY, GR, ES, IT, MT, PT	Population: 129 million

Figure 6 - Example breakdown of EU Building Stock by Region

According to the above report the annual growth rates in the EU residential sector are around 1% but no figure is provided for non-residential buildings. However, it is recorded in “Energy transition of the EU building stock; Unleashing the 4th Industrial Revolution in Europe” (Yamina SAHEB from OpenExp) that the non-residential new construction market share in Europe 2015 is approximately equal to the residential market (22% residential versus 21% non-residential). However, this value is given as an EU average, it is expected that EU residential and non-residential sector annual growth rates will vary across Europe, for example in Ireland residential growth is predicted at approx. 1.5% annually whereas in Netherlands growth has been lower at around 0.5%[4]. The report also notes the renovation market share of residential buildings (37%) is almost twice as much as non-residential (20%) in 2015.

The Stratego: Quantifying the Heating and Cooling Demand in Europe report co-funded by the Intelligent Energy Europe Programme unsurprisingly focuses on the energy performance of EU buildings, specifically on the cooling demand which is an additional useful reference for the RES4BUILD project. It provides estimations of the total floor areas and specific cooling demand (kWh/m2) for residential and service (non-residential) buildings in EU28 countries.



	Total floor areas				Specific cooling demands			Cooled floor areas			Current cooling supplies		
Country	Service sector	Residen-tial	Total	ECI	Service sector	Residen-tial	Average	Service sector	Residential	Total	Service sector	Residen-tial	Total
	Mm2	Mm2	Mm2		kWh/m2	kWh/m2	kWh/m2	Mm2	Mm2	Mm2	TWh	TWh	TWh
Austria	114	338	452	106	83	38	49	17	6	23	1	0	2
Belgium	105	402	507	77	50	23	28	15	10	25	1	0	1
Bulgaria	64	225	288	116	95	43	54	41	35	76	4	1	5
Croatia	32	149	181	85	59	27	32	3	40	44	0	1	1
Cyprus	8	44	52	160	145	65	77	1	36	37	0	2	2
Czech Republic	89	316	405	89	64	29	37	22	4	27	1	0	2
Denmark	122	295	418	59	30	13	18	10	4	14	0	0	0
Estonia	12	38	50	65	37	16	21	1	0	1	0	0	0
Finland	104	206	310	72	45	20	28	13	4	17	1	0	1
France	911	2571	3482	95	71	32	42	255	110	365	18	4	22
Germany	1594	3723	5317	98	74	33	46	239	58	297	18	2	20
Greece	141	486	627	161	146	66	84	85	49	134	12	3	16
Hungary	99	327	426	123	103	46	59	10	10	20	1	0	1
Ireland	43	174	216	32	0	0	0	7	2	8	0	0	0
Italy	421	2686	3107	133	114	51	60	295	304	599	34	16	49
Latvia	17	68	85	79	53	24	29	2	1	3	0	0	0
Lithuania	30	84	114	85	59	27	35	3	1	4	0	0	0
Luxembourg	5	27	32	81	55	25	29	1	0	1	0	0	0
Malta	4	17	21	143	126	57	70	0	11	11	0	1	1
Netherlands	295	702	997	65	37	16	22	60	30	90	2	0	3
Poland	385	951	1336	95	71	32	43	39	6	44	3	0	3
Portugal	52	619	671	104	81	36	40	23	31	54	2	1	3
Romania	59	442	501	137	119	53	61	7	17	24	1	1	2
Slovak Republic	38	150	188	117	96	43	54	4	1	5	0	0	0
Slovenia	28	67	95	116	95	43	58	3	11	13	0	0	1
Spain	349	2019	2368	147	130	59	69	299	202	501	39	12	51
Sweden	155	451	606	73	46	21	27	22	6	28	1	0	1
United Kingdom	736	2107	2843	74	47	21	28	107	50	157	5	1	6
EU28	6011	19684	25695	103	74	37	45	1584	1039	2623	145	47	192
								26%	5%	10%	33%	7%	16%

Figure 7 - Stratego Building Floor Area, Heating and Cooling Estimates

The ENTRANZE research project has the objective to actively support policy making by providing the required data, analysis and guidelines to achieve a fast and strong penetration of nZEB and renewable heating and cooling within the existing national building stocks, and hence overlaps strongly with the RES4BUILD project. The research database includes interactive graphs on EU building stock floor areas, heating and cooling systems (residential), and energy use.

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[4] nl_2020_ltrs_en.pdf

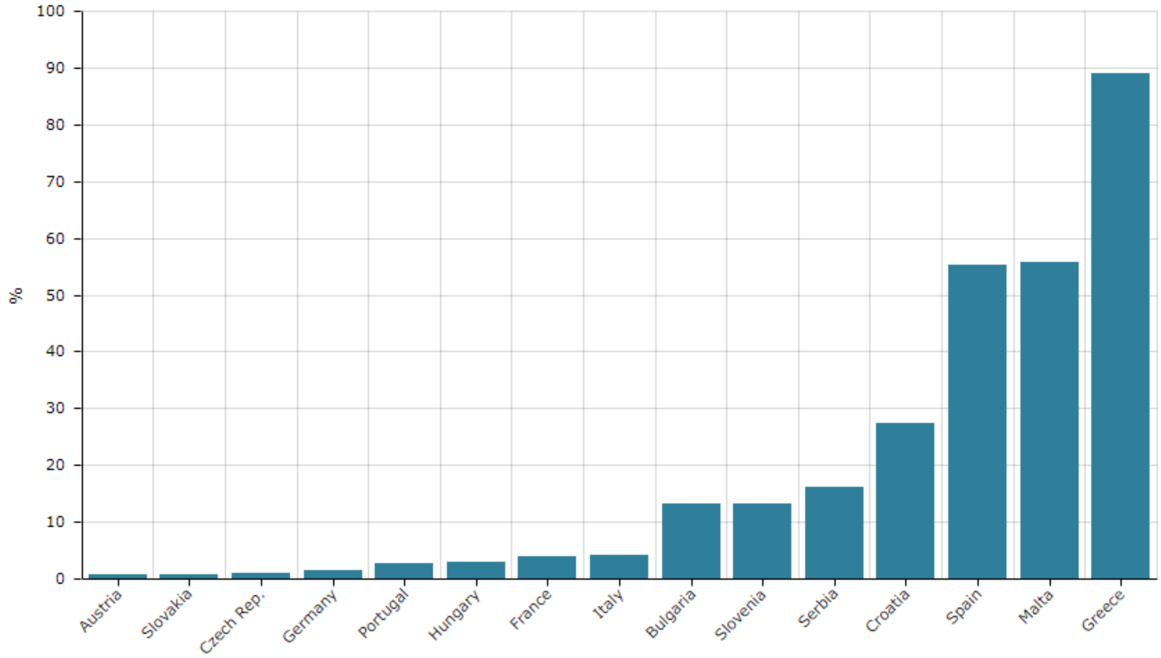
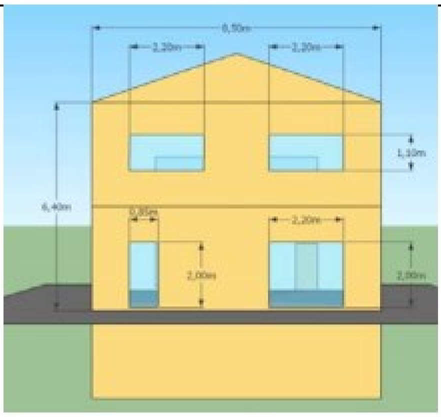
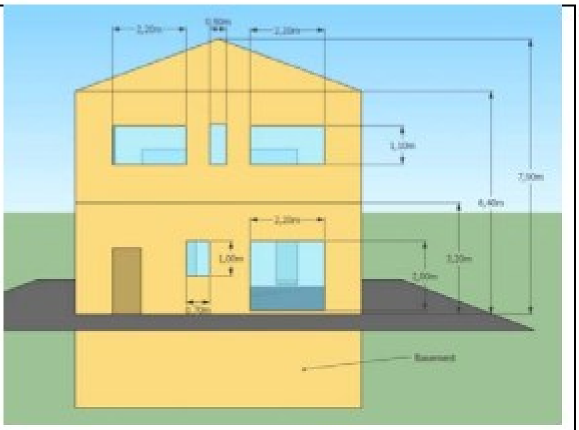


Figure 8 - Dwellings with Air Conditioning from ENTRANZE database

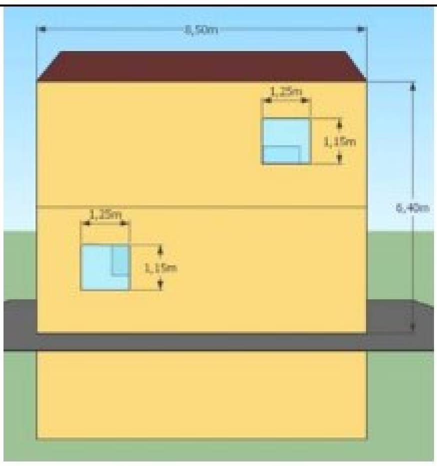
The ENTRANZE research report - Heating and cooling energy demand and loads for building types in different countries of the EU details the results and methodology used to produce heating and cooling loads for European representative buildings. Using EnergyPlus energy modelling software, 4 different building typologies (single family house, apartment block, office and school) in 10 relevant European cities are modelled to produce annual heating and cooling profiles. An example of the single-family home building typology geometry, thermal demand profile for Seville, Spain and a table of the EU selected cities energy demand results from ENTRANZE is below.



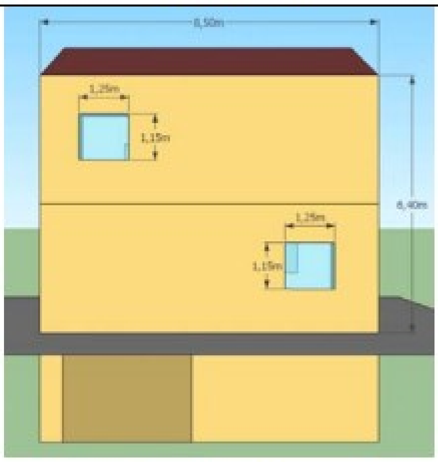
North façade



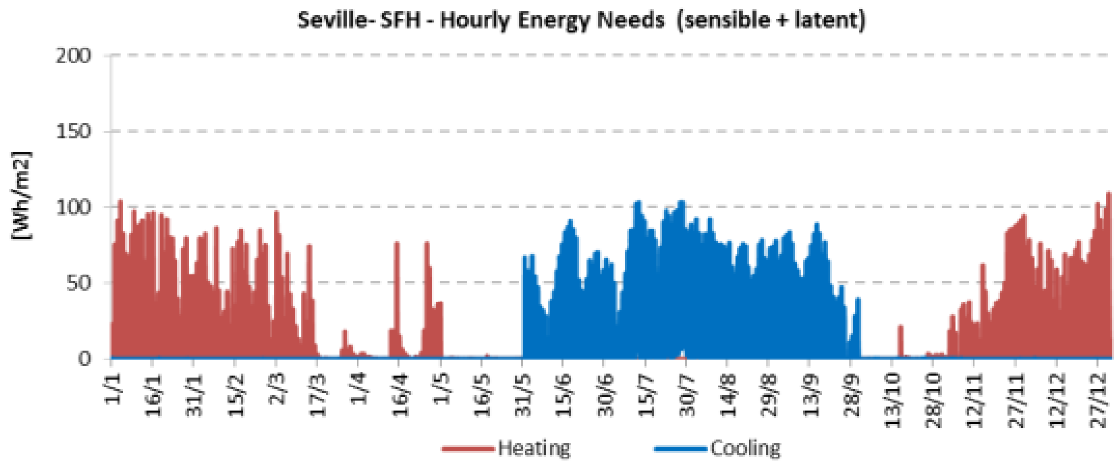
South façade

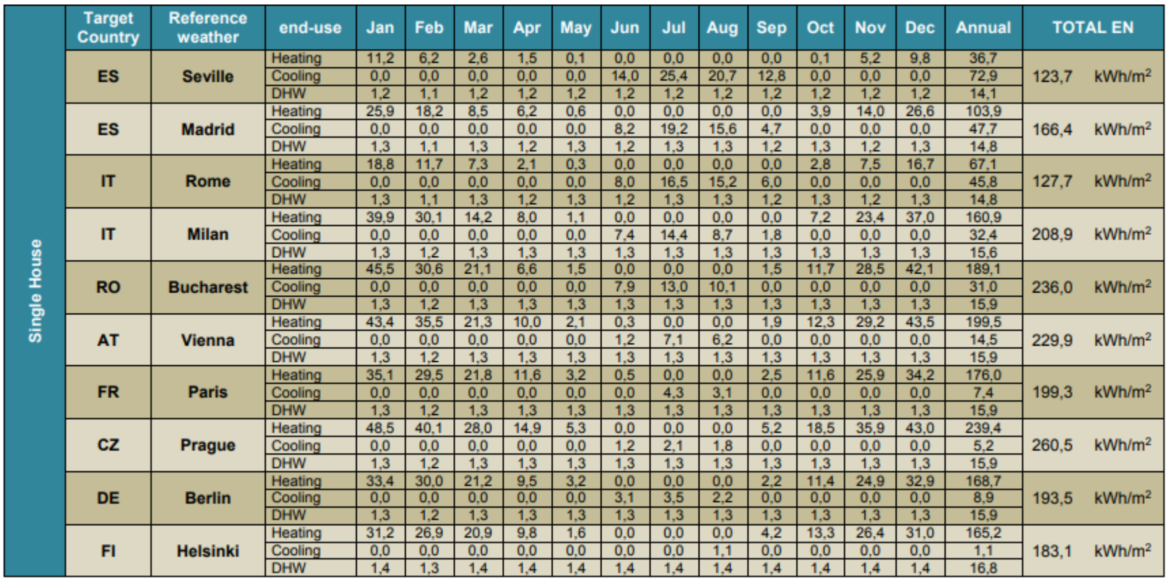


East façade



West façade





	Target Country	Reference weather	end-use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	TOTAL EN
Single House	ES	Seville	Heating	11,2	6,2	2,6	1,5	0,1	0,0	0,0	0,0	0,0	0,1	5,2	9,8	36,7	123,7 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	14,0	25,4	20,7	12,8	0,0	0,0	0,0	72,9	
			DHW	1,2	1,1	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	14,1	
	ES	Madrid	Heating	25,9	18,2	8,5	6,2	0,6	0,0	0,0	0,0	0,0	3,9	14,0	26,6	103,9	166,4 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	8,2	19,2	15,6	4,7	0,0	0,0	0,0	47,7	
			DHW	1,3	1,1	1,3	1,2	1,3	1,2	1,3	1,3	1,2	1,3	1,2	1,3	14,8	
	IT	Rome	Heating	18,8	11,7	7,3	2,1	0,3	0,0	0,0	0,0	0,0	2,8	7,5	16,7	67,1	127,7 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	8,0	16,5	15,2	6,0	0,0	0,0	0,0	45,8	
			DHW	1,3	1,1	1,3	1,2	1,3	1,2	1,3	1,3	1,2	1,3	1,2	1,3	14,8	
	IT	Milan	Heating	39,9	30,1	14,2	8,0	1,1	0,0	0,0	0,0	0,0	7,2	23,4	37,0	160,9	208,9 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	7,4	14,4	8,7	1,8	0,0	0,0	0,0	32,4	
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,6	
	RO	Bucharest	Heating	45,5	30,6	21,1	6,6	1,5	0,0	0,0	0,0	1,5	11,7	28,5	42,1	189,1	236,0 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	7,9	13,0	10,1	0,0	0,0	0,0	0,0	31,0	
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,9	
	AT	Vienna	Heating	43,4	35,5	21,3	10,0	2,1	0,3	0,0	0,0	1,9	12,3	29,2	43,5	199,5	229,9 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	1,2	7,1	6,2	0,0	0,0	0,0	0,0	14,5	
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,9	
	FR	Paris	Heating	35,1	29,5	21,8	11,6	3,2	0,5	0,0	0,0	2,5	11,6	25,9	34,2	176,0	199,3 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	0,0	4,3	3,1	0,0	0,0	0,0	0,0	7,4	
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,9	
	CZ	Prague	Heating	48,5	40,1	28,0	14,9	5,3	0,0	0,0	0,0	5,2	18,5	35,9	43,0	239,4	260,5 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	1,2	2,1	1,8	0,0	0,0	0,0	0,0	5,2	
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,9	
	DE	Berlin	Heating	33,4	30,0	21,2	9,5	3,2	0,0	0,0	0,0	2,2	11,4	24,9	32,9	168,7	193,5 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	3,1	3,5	2,2	0,0	0,0	0,0	0,0	8,9	
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,9	
	FI	Helsinki	Heating	31,2	26,9	20,9	9,8	1,6	0,0	0,0	0,0	4,2	13,3	26,4	31,0	165,2	183,1 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,1	0,0	0,0	0,0	0,0	1,1	
			DHW	1,4	1,3	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	16,8	

Figure 9 - ENTRANZE Summary of simulated energy needs for heating, cooling and DHW for the single house base cases.

The ENTRANZE reference building typology models are based on data collected in the research project are representative of existing buildings in Europe and hence are particularly applicable resource to the RES4BUILD project. The research thermal profiles and demand results provide validated reference values for RES4BUILD energy modelling also.

Unlike several other European research projects (EPISCOPE - TABULA, Entranze), RES4BUILD did not require data on the existing building stock condition and thermal performance as it is assumed that all modelled building stock will achieve the country specific renovation target thermal performance, which is detailed later in this report.

2.2 Building typologies

As previously stated, there is 26 billion m^2 of useful floor space in the EU28 over several building typologies which reflect their type of function and general form, and occupants' activities (if applicable). Building typologies can be categorised most simply as 'Residential' and 'Non-residential' with data on EU distribution of both available from the BSO database.

The EU building stock is quite varied across all member countries, although most of the floor area is made up by residential buildings. The share varies considerably, from around 60% in Slovakia, Netherlands and Austria to more than 85% in the southern countries of Cyprus, Malta and Italy. The EU average is the majority residential with 3 of every 4 buildings (75%) residential in Europe.

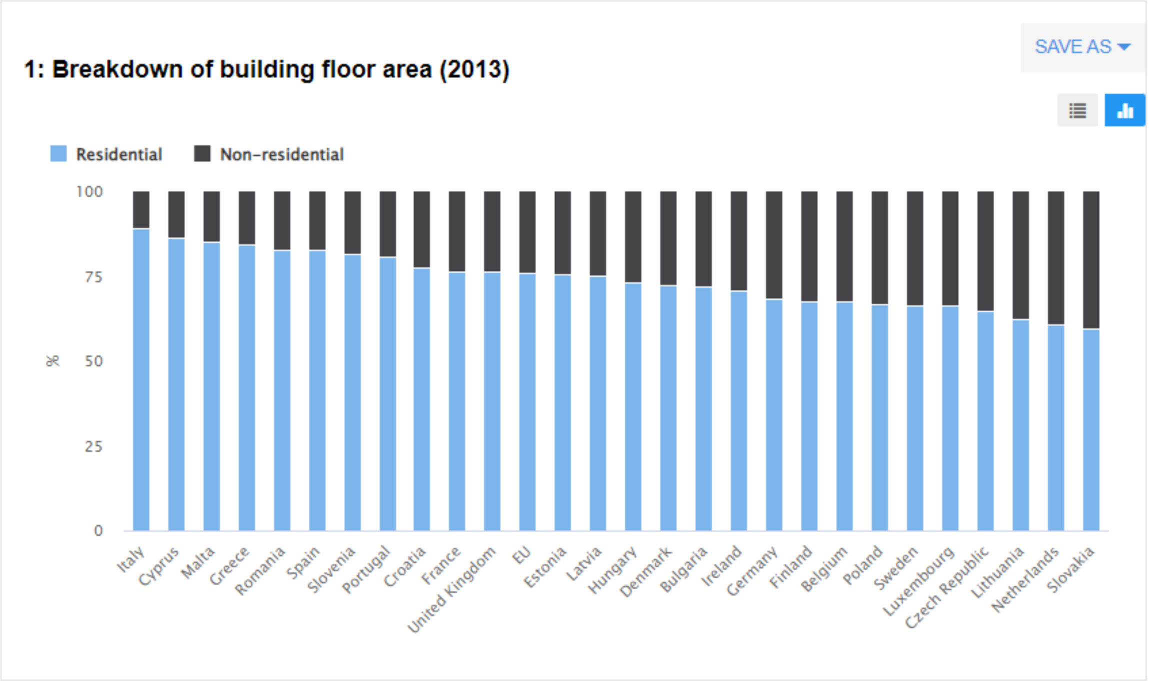


Figure 10 - EU Breakdown of Building Floor Area (2013)

Focusing on the larger residential category, it can be sub-categorized into single family home (SFH) and multi-family residential building (MFRB) or apartment building. This residential building typology differs significantly across the EU. In the United Kingdom (pre-Brexit data) and Ireland, SFHs are the dominant type (above 80%), while in contrast Spain and Estonia, MFRBs are dominant representing more than 70% of all dwellings. The EU average provided does vary depending on sources and countries included (for example it excludes the UK post Brexit increases in share of MFRBs in Europe) and ranges from almost an equal share of both types of residential, with approx. 49% MFRBs and 51% SFHs, to 64% SFHs and 36% MFRB according to BPIE survey (2011). In either case, to get a representative case of the residential buildings in Europe it is concluded that a MFRB typology model and SFH typology model, and their corresponding energy demand profiles are required for practical RES4BUILD results.

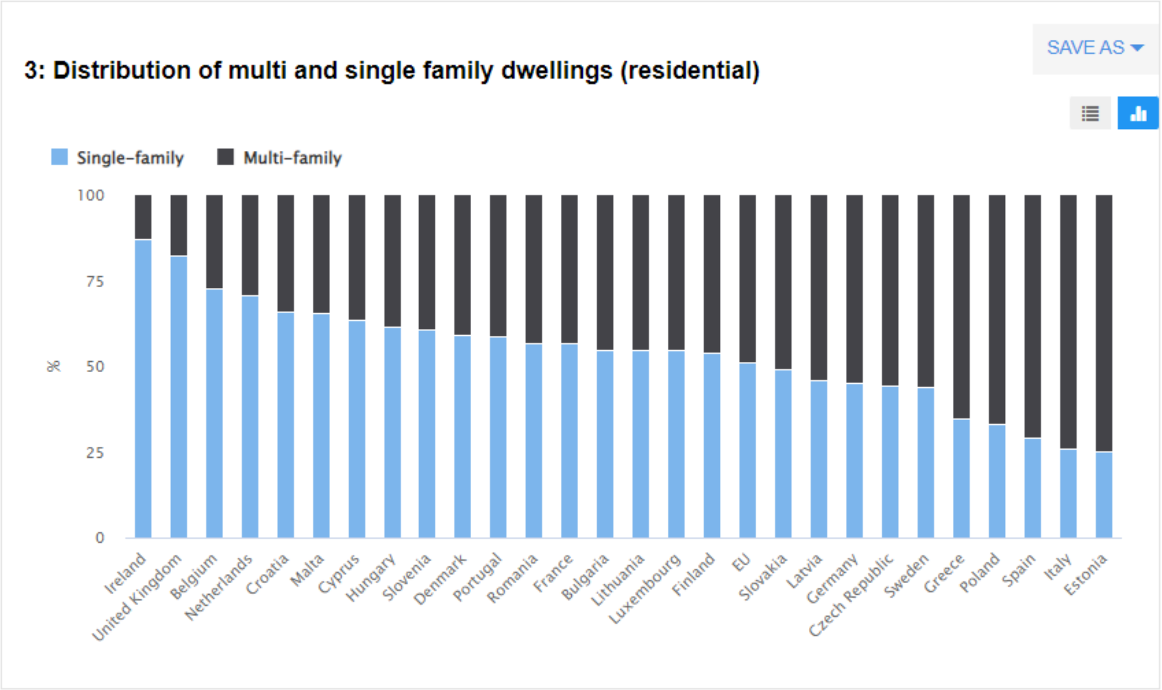


Figure 11 - Distribution of EU Multi and Single-Family Homes

The non-residential or services category account for 25% of the total stock in Europe and comprise a much more diverse category compared to residential. It can be sub-divided into multiple sectors covering a range of economic activities from commercial office, retail, educational, health and sport to name some of the major sectors. On average, three quarters of the service floor area is covered by offices (30% - 23% private and 7% public), retail & wholesale (28%) and educational (17%).

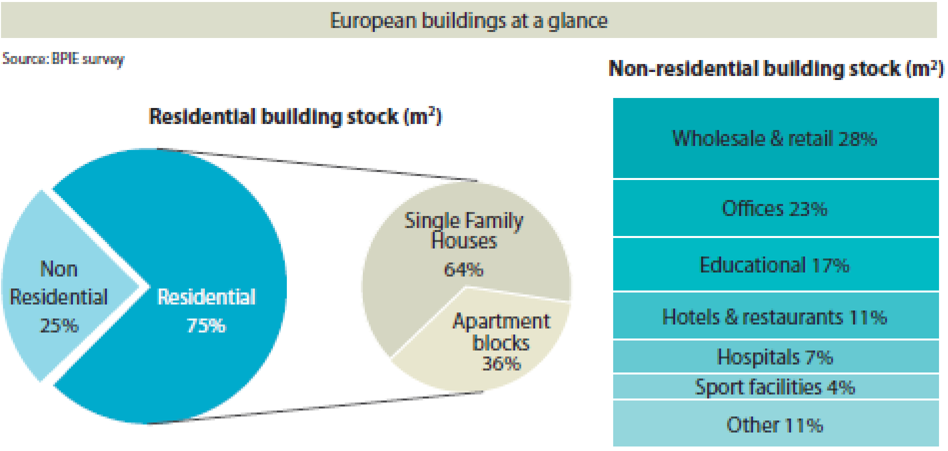


Figure 12- EU Buildings Overview - BPIE

The retail and wholesale buildings comprise a large portion of the non-residential stock however, they can be difficult to model in terms of energy demand profiles. This is due to variations in usage pattern (e.g. warehouse versus local shop), energy intensity (e.g. commercial refrigeration versus to storage rooms in retail), and construction techniques, just some of the factors adding to the complexity of the sector. Therefore, the retail and wholesale building typologies are not selected for inclusion in the RES4BUILD typology selection. However, the major sector of commercial offices and educational buildings (schools) are selected for the RES4BUILD project thermal profile modelling to be representative of a selection of the non-residential building stock across Europe.

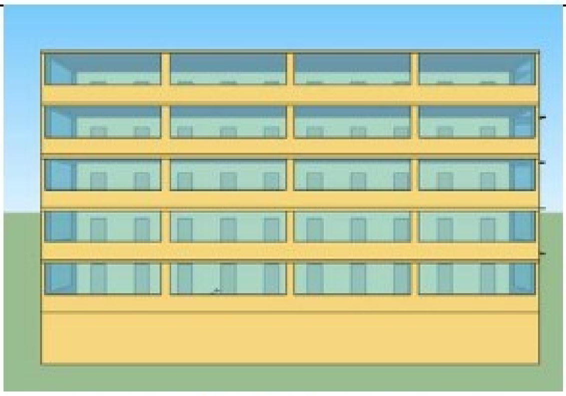
The required 3 building typologies selected (expanded to 4 to include SFH & MFRB to represent the majority of residential sector) for the RES4BUILD project are;

1. Multi-family Residential Building (MFRB)
2. Single Family Home (SFH) Building
3. Commercial Office Building
4. Public School Building

This aligns with the original RES4BUILD research submission assessment target typologies of multi-family residential, commercial office and ‘other public buildings’ such as school or education buildings. This also aligns with ENTRANZE building models allowing RES4BUILD to build upon and cross-reference previous research.

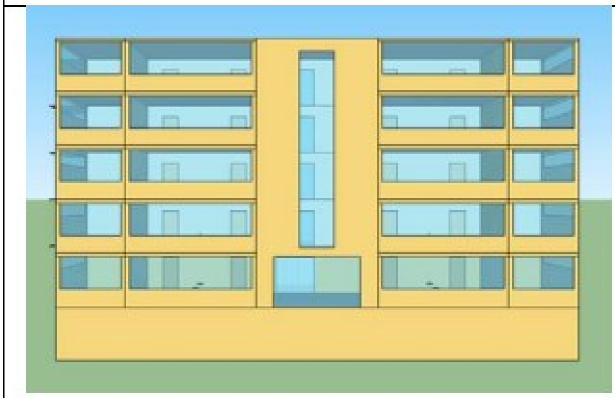
The 4 selected building typologies were modelled using selected representative geometry and fixed design characteristics as set out in the ENTRANZE research report, which conducted extensive investigation into existing building stock characteristics to produce a representative form. A European representative building geometry, design characteristics and climate is vital to the validity of the produced building thermal profiles, as indicated in the 3.1 Building model methodology section of this report.

An example of the Commercial Office typology building geometry and fixed design characteristics used in this research as per the ENTRANZE project is provided below.

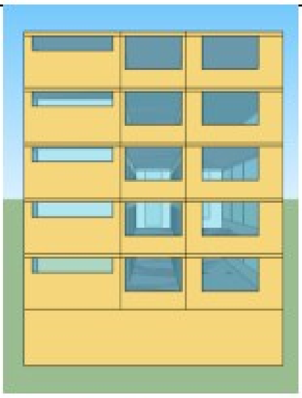


South façade

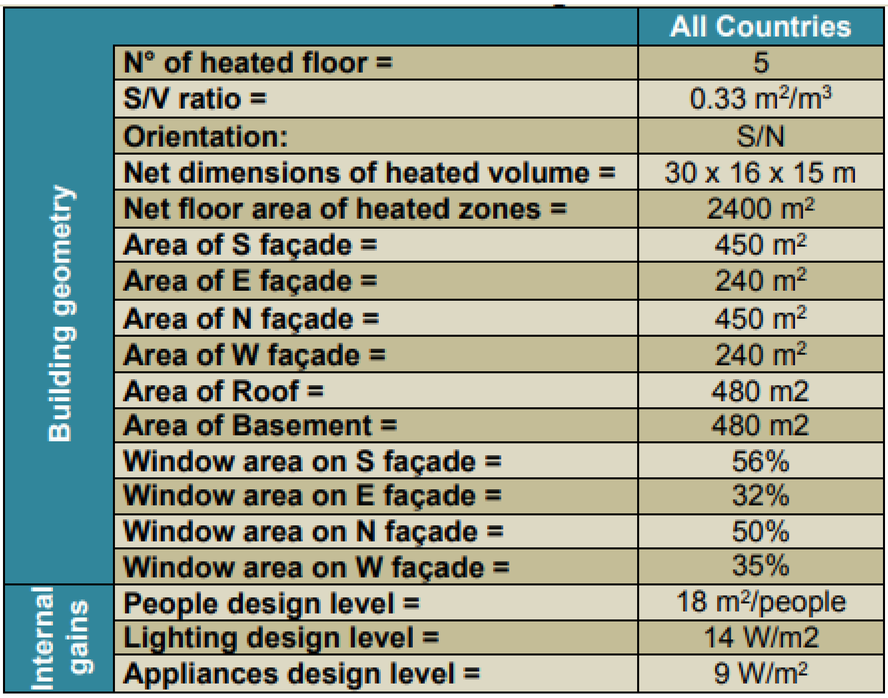
East façade



North façade



West façade



		All Countries
Building geometry	N° of heated floor =	5
	S/V ratio =	0.33 m²/m³
	Orientation:	S/N
	Net dimensions of heated volume =	30 x 16 x 15 m
	Net floor area of heated zones =	2400 m²
	Area of S façade =	450 m²
	Area of E façade =	240 m²
	Area of N façade =	450 m²
	Area of W façade =	240 m²
	Area of Roof =	480 m2
	Area of Basement =	480 m2
	Window area on S façade =	56%
	Window area on E façade =	32%
	Window area on N façade =	50%
	Window area on W façade =	35%
Internal gains	People design level =	18 m²/people
	Lighting design level =	14 W/m2
	Appliances design level =	9 W/m²

Figure 13 - ENTRANZE Building Model Geometry & Inputs

The full details for all 4 building typologies used in the RES4BUILD project are located in Appendix A of this report.

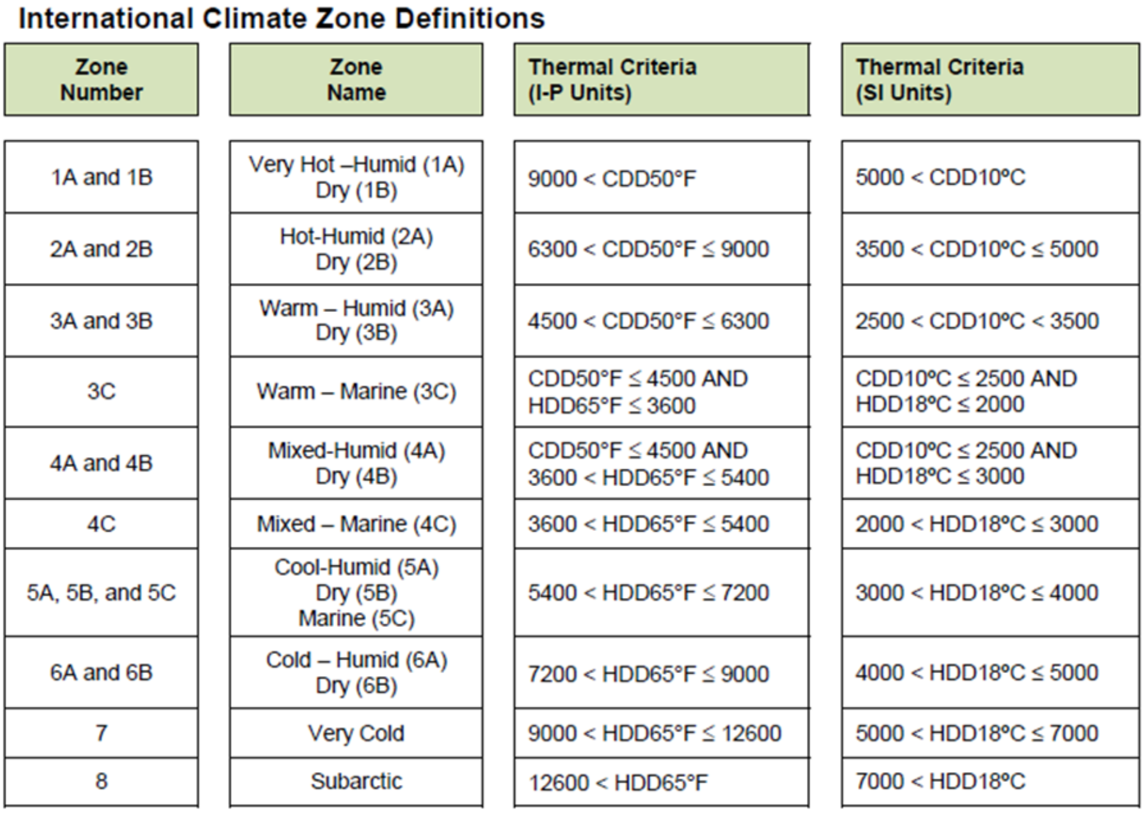
In contrast to the ENTRANZE research project and typology models, the RES4BUILD approach does not use existing building stock fabric thermal properties (U-values) but those of major refurbishment properties in line with EU requirements. The values used and rationale behind these are provided in Energy Performance Data section of this report.

The climates chosen for the energy modelling of these typologies are detailed in the 'Locations' section below.

2.3 Locations

The production of typical energy consumption profiles for the 4 building typologies should be conducted across 4 locations in different climatic zones as set out in the Task 7.1 description of work.

There are several sources and variations of global and European climatic zones. The "Map of Climate Areas in Europe" (EUCA15000) divides Europe into 35 different climate areas, this is aggregated to a more manageable 6 general climates in this report by Schneider et al.,(2013). The American based ASHRAE has developed 17 climate zones to represent global climates based on their thermal criteria as summarised in the table below.



International Climate Zone Definitions

Zone Number	Zone Name	Thermal Criteria (I-P Units)	Thermal Criteria (SI Units)
1A and 1B	Very Hot –Humid (1A) Dry (1B)	9000 < CDD50°F	5000 < CDD10ºC
2A and 2B	Hot-Humid (2A) Dry (2B)	6300 < CDD50°F ≤ 9000	3500 < CDD10ºC ≤ 5000
3A and 3B	Warm – Humid (3A) Dry (3B)	4500 < CDD50°F ≤ 6300	2500 < CDD10ºC < 3500
3C	Warm – Marine (3C)	CDD50°F ≤ 4500 AND HDD65°F ≤ 3600	CDD10ºC ≤ 2500 AND HDD18ºC ≤ 2000
4A and 4B	Mixed-Humid (4A) Dry (4B)	CDD50°F ≤ 4500 AND 3600 < HDD65°F ≤ 5400	CDD10ºC ≤ 2500 AND HDD18ºC ≤ 3000
4C	Mixed – Marine (4C)	3600 < HDD65°F ≤ 5400	2000 < HDD18ºC ≤ 3000
5A, 5B, and 5C	Cool-Humid (5A) Dry (5B) Marine (5C)	5400 < HDD65°F ≤ 7200	3000 < HDD18ºC ≤ 4000
6A and 6B	Cold – Humid (6A) Dry (6B)	7200 < HDD65°F ≤ 9000	4000 < HDD18ºC ≤ 5000
7	Very Cold	9000 < HDD65°F ≤ 12600	5000 < HDD18ºC ≤ 7000
8	Subarctic	12600 < HDD65°F	7000 < HDD18ºC

Figure 14 – ASHRAE International Climate Zone Definitions

However, due to the pivotal importance of the heat pump in the RES4BUILD project the European climatic zones as set out in EN14825 and shown in figure 16 below as a map of Europe. The standard EN14825 describes calculation methods to determine the averaged performance during the heating season, the SCOP – the Seasonal Performance factor, particularly for energy labels.

Figure 15 - European Climatic Zones as Set Out in EN14825[5]

Climate zones is one important aspect of the energy labels for heat pumps and the heating mode. Information on the energy label directly refers to a specific climate zone and the figures are calculated based on their local conditions. The European Reference for climate conditions divides Europe geographically into three zones: colder (blue), average (green) and warmer (orange) climate conditions as shown in the map in figure 16 above. A similar map is shown on the energy label of individual product.

The representative locations for each of these climates selected for the RES4BUILD study are:

1. Gdansk, Poland – Colder (blue)
2. Amsterdam, Netherlands – Average (green)
3. Athens, Greece – Warmer (orange)

The pitfall of this European climatic zoning is that it is based on heat pump heating operation mode climate conditions and does not consider cooling. As a result, the generally cooler maritime climate of Ireland is categorised with the warm climate of Greece as both countries experience relatively warm outdoor air temperatures for air-source heat pump heating operation.

To account for this, the fourth location selected is Cork, in Ireland, to represent the cooler, maritime European climate particularly in terms of peak heating and cooling requirement.

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[5] Nordsyn Study on Air-To-Air Heat Pumps in Humid Nordic Climate

Therefore, the 4 locations in different climatic zones selected for RES4BUILD Task 7.1 include;

1. Gdansk, Poland – Cold
2. Amsterdam, Netherlands - Average
3. Athens, Greece – Warm
4. Cork, Ireland – Moderate-mixed

This aligns with the initial RES4BUILD application assessment which took Athens, Munich and Stockholm as representative of the European market and climatic conditions. However this is extended to 4 climatic conditions in the full RES4BUILD research project to provide better representation of the more moderate maritime climates.

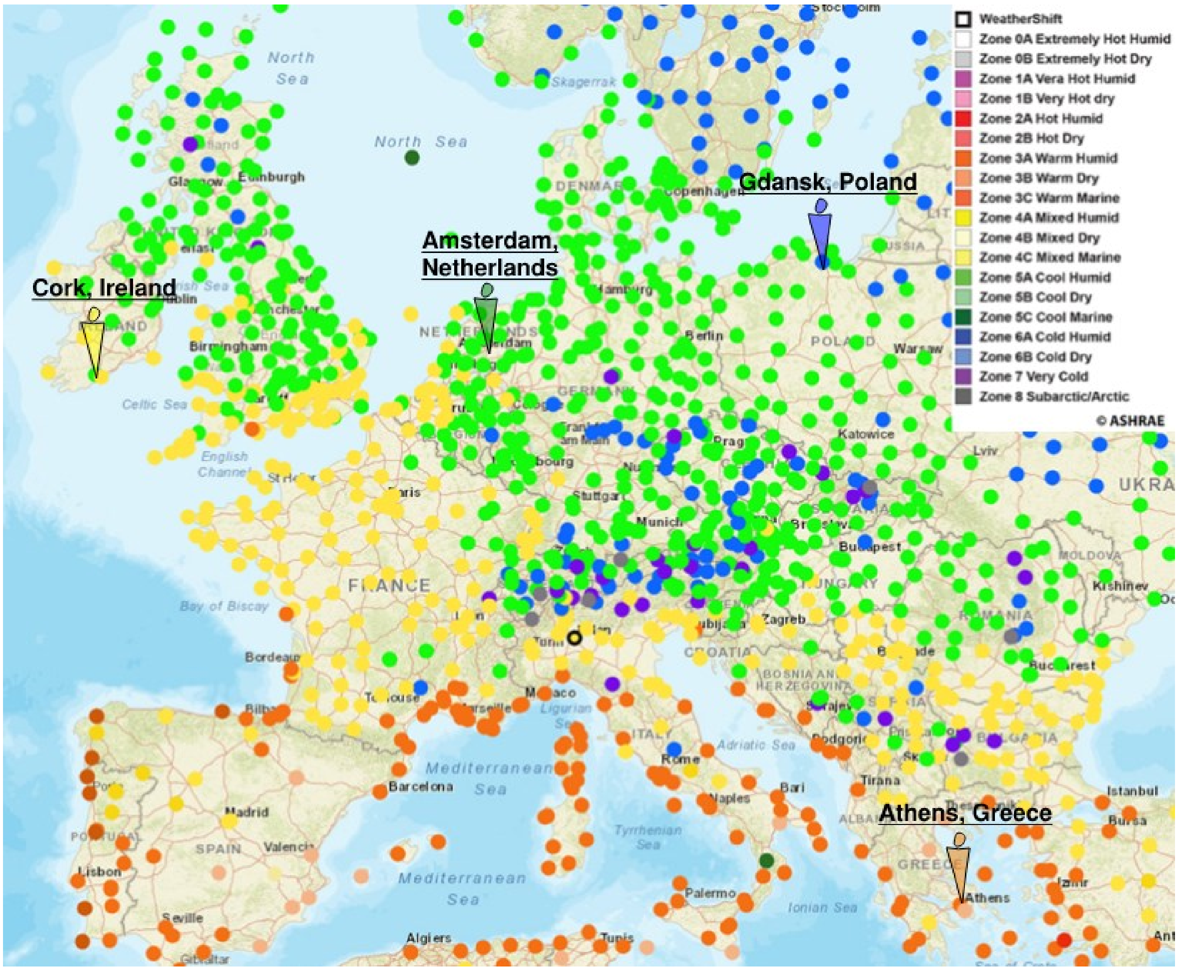

Figure 16 RES4BUILD Locations & Climates Maps[6]

The locations of Amsterdam, Netherlands and Gdansk, Poland were selected as they intersect with research work on co-design of integrated energy systems in WP4, and cover the 'average' – cool climate, and the 'cold' climate respectively. Athens, Greece represents the 'warm' climate and is a RES4BUILD system test location for WP5. Cork, Ireland was added to represent the more moderate 'mixed' climate of Europe and is also the location of the Arup office involved in this research.

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[6] https://americasgis.arup.com/climatetool/

Using the above EU climatic zones and the Hotmaps project map the estimated EU representative building floor area for each building typology in each climatic zone (represented by location) is calculated and summarised in table X below.

Table 5 - Hotmaps based EU Building Stock Floor Areas

Location	Hotmaps Floor Area	Typology	Est. EU Representative Building Floor Area
	Million m2		Million m2
Athens, GRE - Warm Climate	**Residential**	SFH	3,253.44
	5,083.50	MFRB	1,830.06
	Non - Residential	Commercial Office	521.25
	1,737.50	Public - School	295.38
Cork, IRL - Moderate-mixed Climate	**Residential**	SFH	1,883.84
	2,943.50	MFRB	1,059.66
	Non - Residential	Commercial Office	323.67
	1,078.90	Public - School	183.41
Amsterdam, NL - Average Climate	**Residential**	SFH	5,088.32
	7,950.50	MFRB	2,862.18
	Non - Residential	Commercial Office	857.55
	2,858.50	Public - School	485.95
Gdansk, PL - Cold Climate	**Residential**	SFH	3,610.43
	5,641.30	MFRB	2,030.87
	Non - Residential	Commercial Office	590.16
	1,967.20	Public - School	334.42
Total building stock	**29,260.90**	**EU28**	**25,210.59**

The total Hotmaps project map EU building floor area is approx. 29.26 billion m2 which is aligned with earlier estimates, of which the RES4BUILD representative typology and climate models cover 25.2

billion m2 or 86% of the total EU building stock recorded. This could be increased further by including a Wholesale & Retail, Food service, and medical care non-residential building energy models.

2.4 Energy performance data

Across Europe building energy performance data is available generally due to the Energy Performance of Buildings Directive (EPBD) - a legislative framework that promote policies that will help achieve a highly energy efficient and decarbonised building stock by 2050.
The EPBD together with the relevant provisions of the Energy Efficiency Directive (EED) and the Renewable Energy Directive (RED), are the main elements of EU legislation impacting the building sector. First adopted in 2010 and revised in 2018, the EPBD aims to improve the energy performance of the European building stock by introducing measures and obligations for both new and existing buildings, to ensure buildings consume the least energy possible and to decarbonise the remaining energy that they consume. For example, EU countries must establish long-term renovation strategies, aiming at decarbonising the national building stocks by 2050.

Energy Performance Certificates (EPCs) play a key role in the context of the EPBD and measuring building energy performance. It measures the energy efficiency of a property on a scale of A-G, with A the most energy efficient building and G the least.

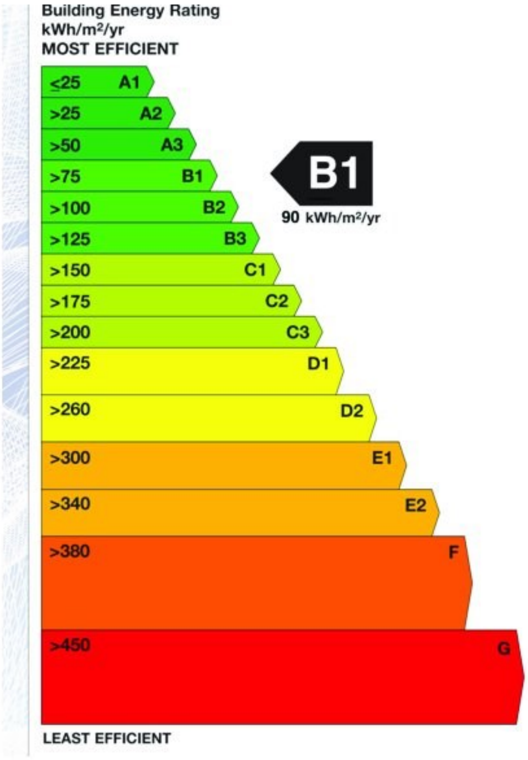


Figure 17 - Example EPC

All EU member states have introduced EPCs, with varying quality, reliability and market acceptance and many EU member states have set up a register of EPCs to record national building stock energy performance. It is understood that EPC data is not a truly accurate representation of building energy consumption as the standard process to produce EPCs includes several assumptions on occupancy profiles and regulated energy users. However, national EPC data was at the time of writing the only source of reliable information on the energy performance of the European building stock. EPC data based on the corresponding kWh/m2/yr energy consumption value for each label can be used to extrapolate approximate building energy consumption for profile comparison if the EPC distribution of EU building stock is known.

A BPIE study analysing data for 16 EU countries covering 2/3rd of the European building floor area found that over 90% of the building stock has an EPC C or lower and therefore requires renovation to achieve cost optimal energy standards.

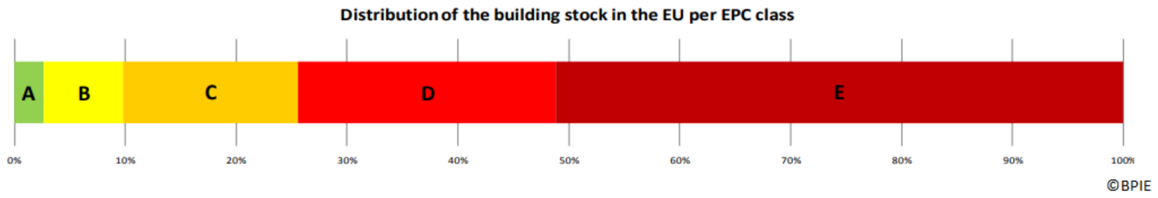


Figure 18 – Distribution of EU building stock in the EU per EPC class

A breakdown of the countries included in the BPIE study indicates select countries have higher levels of energy efficient buildings such as France (20%) and Denmark (15%), while some countries such as Spain (0%) and Bulgaria (2%) have minimally energy efficient buildings.

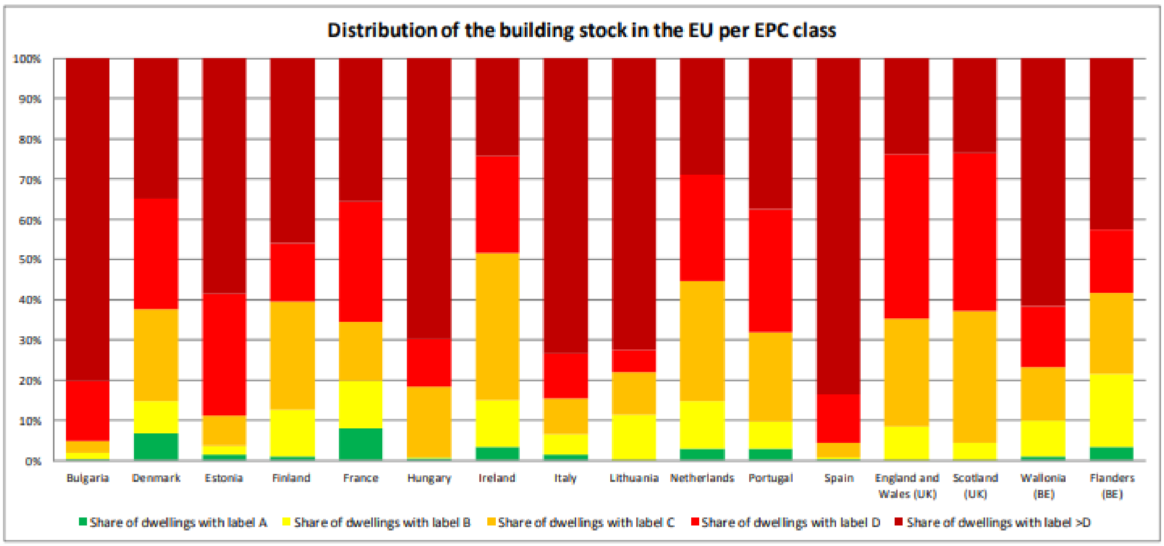


Figure 19 - Distribution of EU building stock in the EU per EPC class per country

An alternative approach is to utilise top-down building specific energy use intensity (kWh/m2/yr) values based on country, or region, specific total building energy consumption and floor area data. At the EU level, the average annual specific consumption per m^2 for residential type of buildings was around 180 kWh/m^2 in 2013. It differs among countries: from 47 kWh/m² in Malta and 70 kWh/m² for Portugal and Cyprus, to 300 kWh/m² in Romania and 290 kWh/m² in Latvia and Estonia which is significantly higher than the EU average. However, even for countries with a similar climate, significant discrepancies exist (e.g. 210 kWh/m² in Sweden, 18% lower than Finland). Such differences are partly explained by climatic conditions, building thermal properties and means of heating adopted.

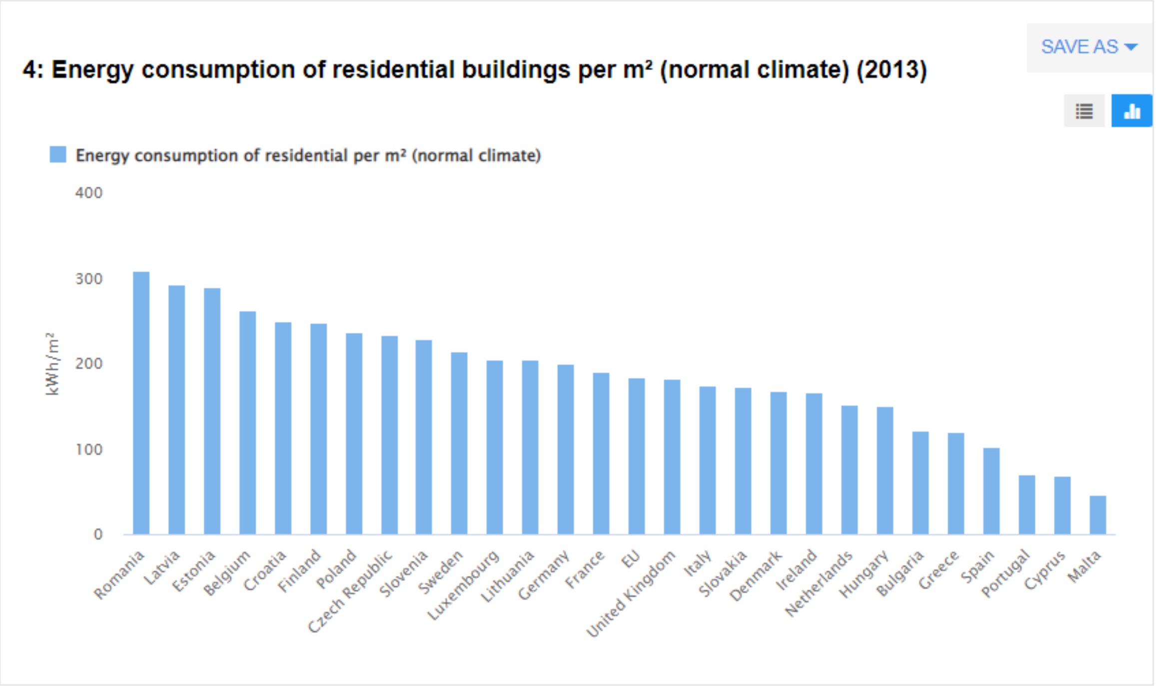


Figure 20 - Energy consumption of Residential Buildings per m2 (2013)

Non-residential buildings are on average 40% more energy intensive than residential buildings (250 kWh/m^2 compared to 180 kWh/m^2) and energy consumption per m^2 is highly varied. Italy, Malta and Estonia use by far the largest amount of energy per m^2 (more than 1.5 times higher than the EU average). For the other countries, energy consumption per m^2 is much more homogeneous: most countries use between 200 and 300 kWh per m^2.

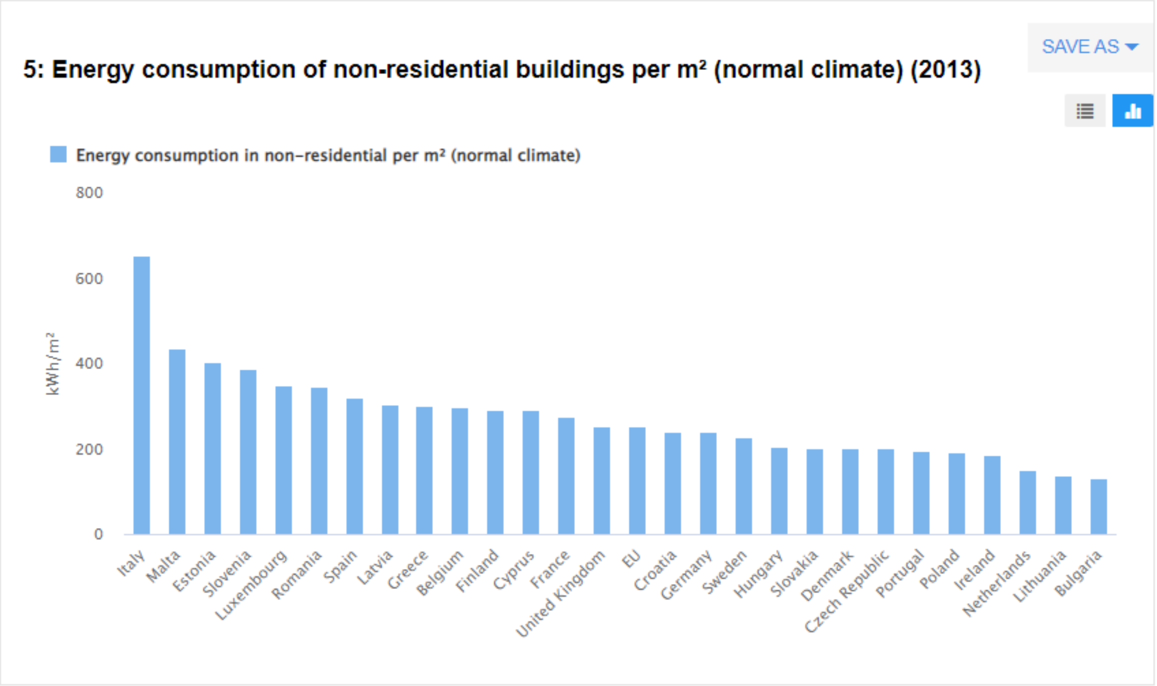


Figure 21 - Energy consumption of Non-Residential Buildings per m2 (2013)

This building energy consumption is divided between several final end uses. Space heating is the most important end-use in the residential sector (68%). In most countries, the share of space heating represents 60-80% of the total energy consumption. In Malta, Cyprus and Portugal, the share of space heating is below 30% and just below 50% in Spain and Romania. Water heating ranks second with a quite considerable share (13%). Electrical appliances are becoming more important and represent 12% of the final energy consumption of residential buildings at the EU level. Cooking represents 5% of the total energy consumption and lighting just 2%. In contrast in non-residential buildings by HVAC (75%), lighting and other services are the dominant energy consumers but is more difficult to specify across the heterogenous sector.

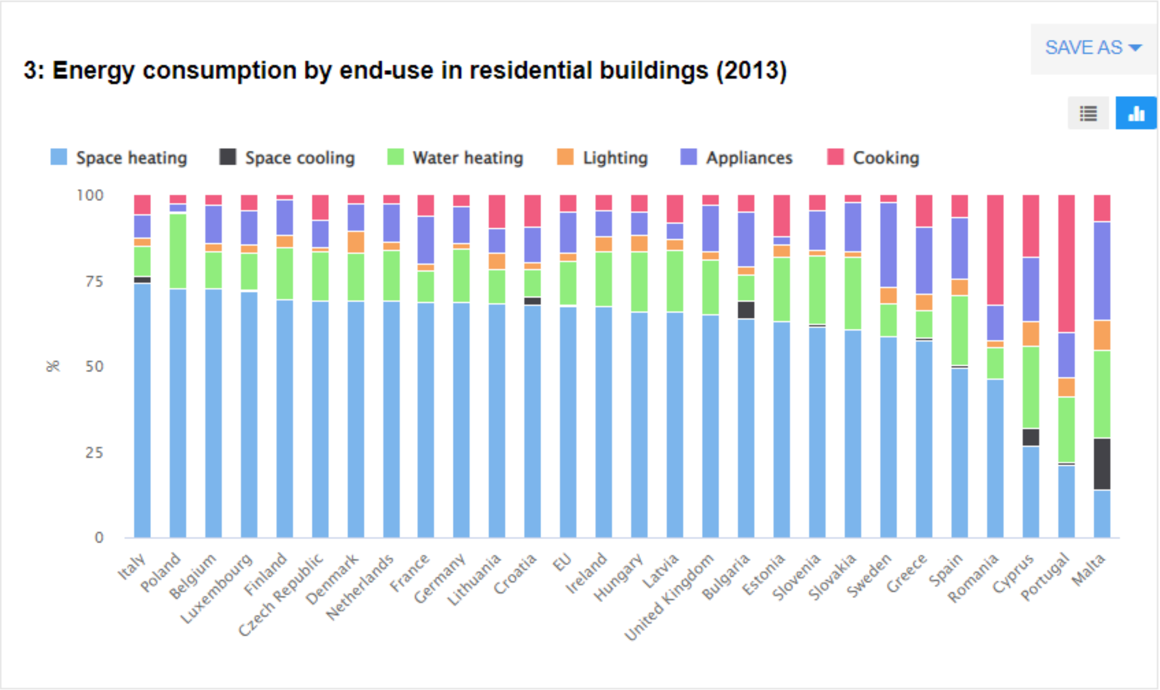


Figure 22 - Energy Consumption by End-use in Residential Buildings (2013)

Heating and cooling energy demand data for European buildings is provided in the Stratego: Quantifying the Heating and Cooling Demand in Europe study.

Heating values are particularly climate specific and vary significantly across the EU countries. The national average specific heat demand values range from approximately 10 to 50 GJ per-capita, with a EU28 national average at ~28 GJ per-capita. Per capita values can be converted to floor area specific values using population and building floor area data. Cooling data is provided in the kWh/m^2 metric and compared to two other recent studies to give a wide range of reference cooling specific demand values for EU28.

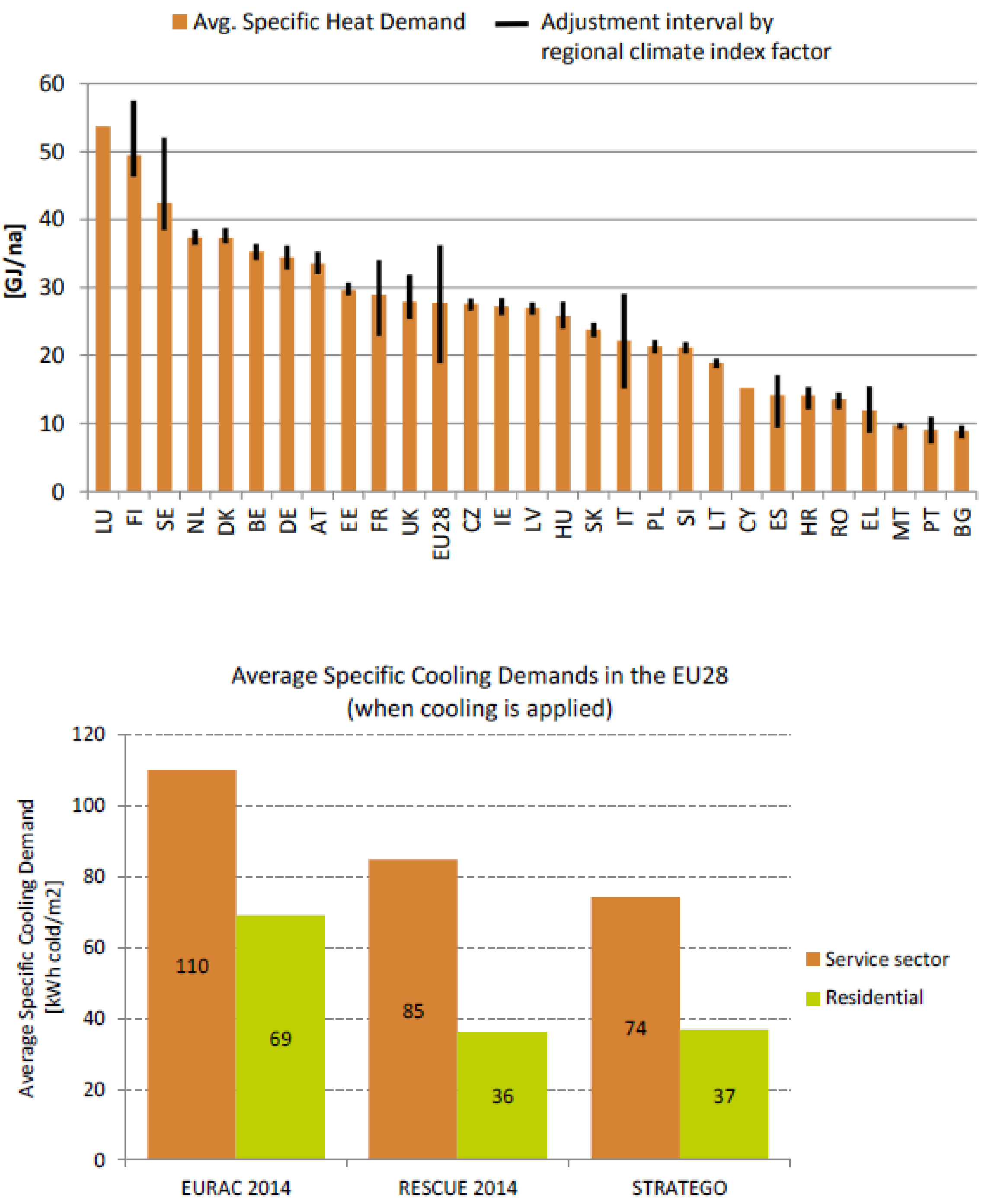
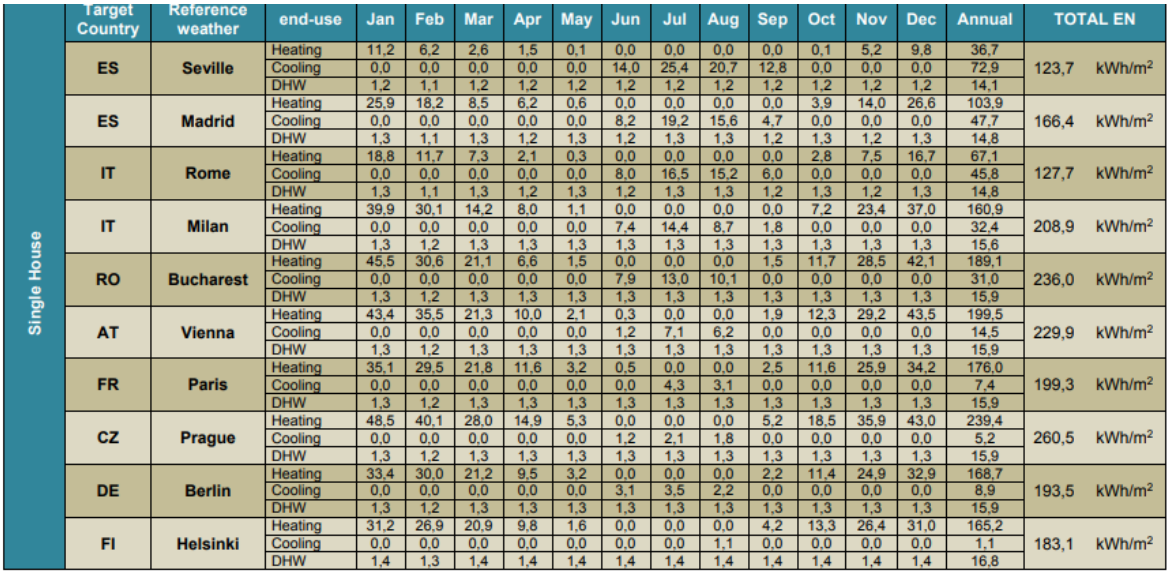


Figure 23 - Stratego: Quantifying the Heating and Cooling Demand in Europe

More specific reference heating and cooling demand data across 10 representative 10 EU cities for the selected RES4BUILD typologies is provided in the ENTRANZE report. The tables display a summary of simulated energy needs for heating, cooling and DHW for all 4 typologies, an example of which is shown below and all 4 provided in Appendix B of this report.

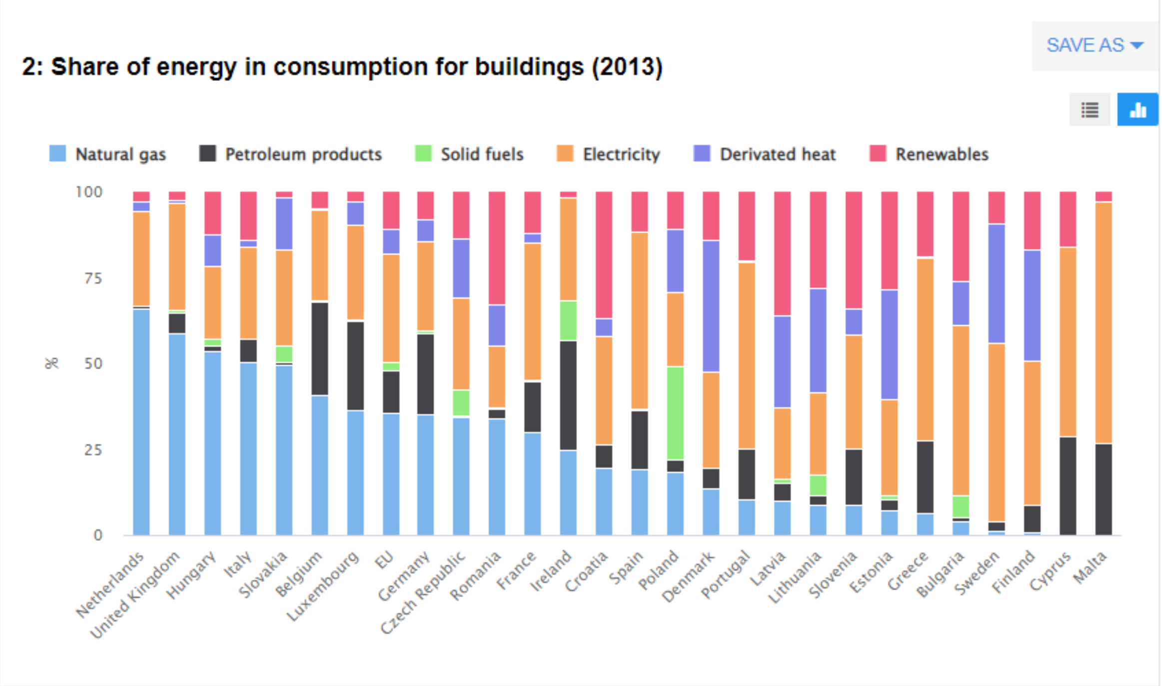


	Target Country	Reference weather	end-use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	TOTAL EN	
Single House	ES	Seville	Heating	11,2	6,2	2,6	1,5	0,1	0,0	0,0	0,0	0,0	0,1	5,2	9,8	36,7	123,7	kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	14,0	25,4	20,7	12,8	0,0	0,0	0,0	72,9		
			DHW	1,2	1,1	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	14,1		
	ES	Madrid	Heating	25,9	18,2	8,5	6,2	0,6	0,0	0,0	0,0	0,0	3,9	14,0	26,6	103,9	166,4	kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	8,2	19,2	15,6	4,7	0,0	0,0	0,0	47,7		
			DHW	1,3	1,1	1,3	1,2	1,3	1,2	1,3	1,3	1,2	1,3	1,2	1,3	14,8		
	IT	Rome	Heating	18,8	11,7	7,3	2,1	0,3	0,0	0,0	0,0	0,0	2,8	7,5	16,7	67,1	127,7	kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	8,0	16,5	15,2	6,0	0,0	0,0	0,0	45,8		
			DHW	1,3	1,1	1,3	1,2	1,3	1,2	1,3	1,3	1,2	1,3	1,2	1,3	14,8		
	IT	Milan	Heating	39,9	30,1	14,2	8,0	1,1	0,0	0,0	0,0	0,0	7,2	23,4	37,0	160,9	208,9	kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	7,4	14,4	8,7	1,8	0,0	0,0	0,0	32,4		
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,6		
	RO	Bucharest	Heating	45,5	30,6	21,1	6,6	1,5	0,0	0,0	0,0	1,5	11,7	28,5	42,1	189,1	236,0	kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	7,9	13,0	10,1	0,0	0,0	0,0	0,0	31,0		
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,9		
	AT	Vienna	Heating	43,4	35,5	21,3	10,0	2,1	0,3	0,0	0,0	1,9	12,3	29,2	43,5	199,5	229,9	kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	1,2	7,1	6,2	0,0	0,0	0,0	0,0	14,5		
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,9		
	FR	Paris	Heating	35,1	29,5	21,8	11,6	3,2	0,5	0,0	0,0	2,5	11,6	25,9	34,2	176,0	199,3	kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	0,0	4,3	3,1	0,0	0,0	0,0	0,0	7,4		
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,9		
	CZ	Prague	Heating	48,5	40,1	28,0	14,9	5,3	0,0	0,0	0,0	5,2	18,5	35,9	43,0	239,4	260,5	kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	1,2	2,1	1,8	0,0	0,0	0,0	0,0	5,2		
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,9		
	DE	Berlin	Heating	33,4	30,0	21,2	9,5	3,2	0,0	0,0	0,0	2,2	11,4	24,9	32,9	168,7	193,5	kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	3,1	3,5	2,2	0,0	0,0	0,0	0,0	8,9		
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,9		
	FI	Helsinki	Heating	31,2	26,9	20,9	9,8	1,6	0,0	0,0	0,0	4,2	13,3	26,4	31,0	165,2	183,1	kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,1	0,0	0,0	0,0	0,0	1,1		
			DHW	1,4	1,3	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	16,8		

Figure 24 – ENTRANZE Simulated Energy Needs for Heating, Cooling and DHW

The energy used in buildings, particularly for heating and cooling is also mainly from non-renewable sources, an issue the RES4BUILD project is attempting to rectify.

Gas energy consumption represents the highest share of energy use in buildings (residential and non-residential) on the EU level (36%) and it represents the largest consumption in several countries: at least 50% in Italy and Hungary, and above 60% of building energy consumption in the Netherlands. The second important energy use is electricity, 32% at EU level and up to 70% in Malta. Renewables and oil stand at 10%-12% of energy used for buildings at EU level and represents a third of the energy consumption in Ireland.



2: Share of energy in consumption for buildings (2013)

Figure 25 – Share of Energy Consumption for EU Buildings

The consumption of these energy sources in buildings produces emissions that has an environmental impact. The emissions considered in the RES4BUILD study include Global warming potential (GWP) in kg CO2 eq., Ozone Depletion Potential (ODP) in kg R11 eq., and 03 EN15804+A1 Acidification potential (AP) in kg SO2 eq. The EN15804 emissions factors for each of these environmental impact categories in the 4 RES4BUILD EU locations is provided in the table below along with a calculated representative EU average value for the main fuel types of grid electricity and gas heating.

Quantities	01 EN15804+A1 GWP [kg CO2 eq.]	02 EN15804+A1 ODP [kg R11 eq.]	03 EN15804+A1 AP [kg SO2 eq.]
GR: Electricity grid mix	0.732190666	1.62317E-14	0.00210057
NL: Electricity grid mix	0.498478041	9.2141E-15	0.000369148
PL: Electricity grid mix	0.923779427	2.58699E-15	0.001838629
IE: Electricity grid mix	0.527699314	2.80001E-15	0.000467917
Representative EU Average	0.670536862	7.7082E-15	0.001194066

Quantities	01 EN15804+A1 GWP [kg CO2 eq.]	02 EN15804+A1 ODP [kg R11 eq.]	03 EN15804+A1 AP [kg SO2 eq.]
GR: Gas condensing boiler	0.255898525	1.46784E-16	0.000107964
NL: Gas condensing boiler	0.222502197	1.24537E-16	4.0927E-05
PL: Gas condensing boiler	0.241751894	5.30461E-17	8.8698E-05
IE: Gas condensing boiler	0.244936277	4.95212E-17	7.98977E-05
Representative EU Average	0.241272223	9.3472E-17	7.93717E-05

The focus of the T7.1 deliverable is on the GWP in kg CO2 eq. of building energy consumption with ODP and AP discussed in greater detail in WP6. The representative EU average value for gas heating GWP of 0.2413 kg CO2 eq. is in line with known EU-28 average values with minimal deviation between the EU countries.

The representative EU average value for grid electricity of 0.6705 kg CO2 eq. is significantly higher than known EU-28 average values due to the high variability of electricity grid emissions factors across countries. This variability is displayed graphically in Figure 27 below.

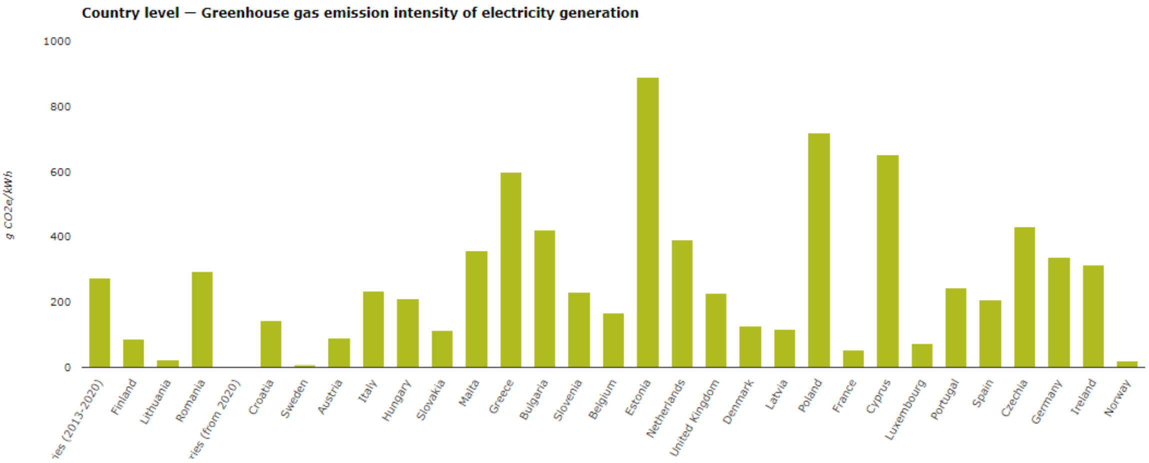


Figure 26 - EU Countries Grid Electricity GHG emissions[7]

The emissions factor values can range from 8 gCO2e/kWh in Sweden to 891 gCO2e/kWh in Estonia in 2019. At a European level the average electricity grid emissions factor is 287 gCO2e/kWh in 2018 and this is the value used for representative EU grid CO2e emissions factor in the RES4BUILD impact analysis, as in line with WP6. However, note that this average electricity grid emissions factor is predicted to fall to between 75 – 97 gCO2e/kWh by 2030 and be carbon neutral by 2050 with the increased introduction of renewable energy generation sources.

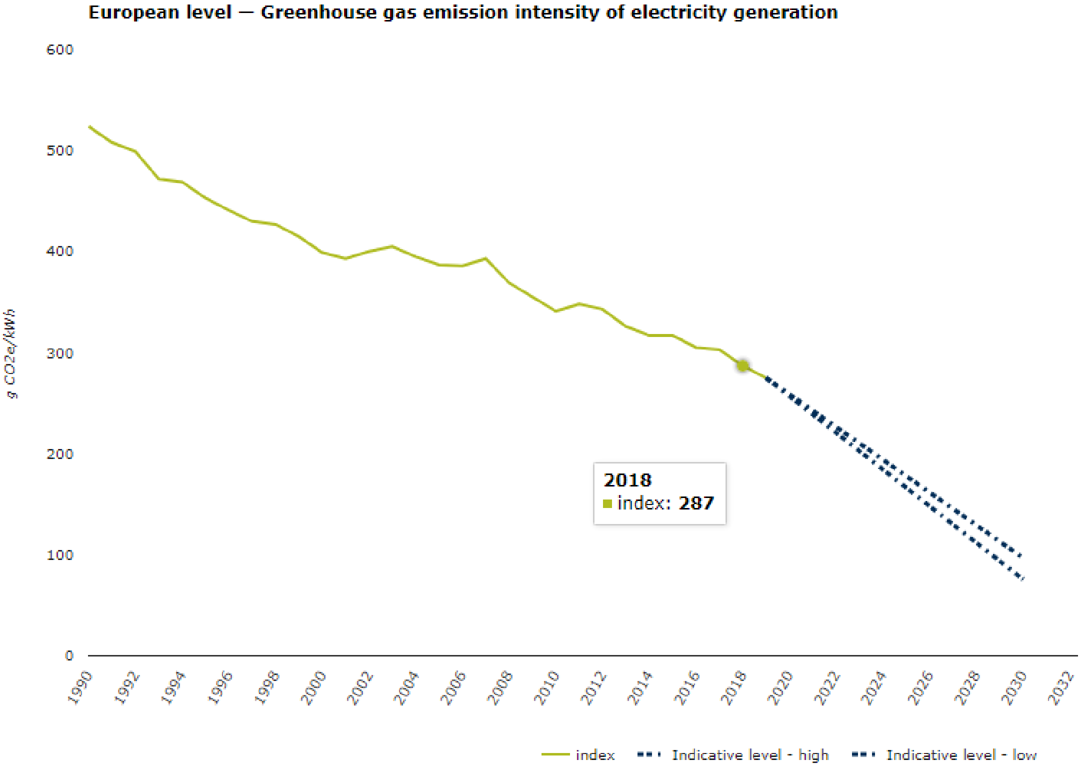


Figure 27- EU Countries Grid Electricity GHG emissions [9]

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[7] https://www.eea.europa.eu/data-and-maps/indicators/overview-of-the-electricity-production-3/assessment

The majority of the above energy performance data is based on the European existing building stock however, for RES4BUILD as it is assumed that all modelled building stock will achieve renovation standard thermal performance specification.

Crucially for RES4BUILD, the Energy Performance of Buildings Directive (EPBD) also requires that EU countries set cost-optimal minimum energy performance requirements for new buildings, for existing buildings undergoing major renovation, and for the replacement or retrofit of building elements like heating and cooling systems, roofs and walls.

Additionally, as of 2021, all new buildings must be nearly zero-energy buildings (NZEB) and since 2019, all new public buildings should be NZEB. These NZEB new buildings have relatively low energy (heating and cooling) demand and will be able to select smaller capacity heat pumps from the RES4BUILD pallet of RETs. But the level of change in energy related CO_2 emissions for these high performance NZEBs is small compared to that achieved with renovated existing buildings which when upgraded to cost-optimal standard do not achieve as low an NZEB standard as a new-build structure.

The cost optimal building thermal performance specification for renovations used in the RES4BUILD energy models is based on the following country specific cost optimal renovation reports:

- Aecom, Report on the Development of Cost Optimal Calculations and Gap Analysis for Buildings in Ireland under Directive 2010/31/EU on the Energy Performance of Buildings (RECAST), Section 1- Residential Buildings, Final report revised 07/4/2020.
- Aecom, Report on the Development of Cost Optimal Calculations and Gap Analysis for Buildings in Ireland under Directive 2010/31/EU on the Energy Performance of Buildings (RECAST), Section 2- Non-Residential Buildings, Final report revised 07/4/2020.
- CRES, Concerted Action: EPBD implementation in Greece, Status in December 2016
- CRES, Concerted Action: EPBD implementation in Poland, Status in December 2016
- CRES, Concerted Action: EPBD implementation in the Netherlands, Status in December 2016
- Technical Chamber of Greece, Technical Directive, TOTEE 20701-1/2017 ,Detailed national standards of parameters for the calculation of the energy yield of buildings and the issue of the energy performance certificate according to the revision of K.EN.A.K. (2017), September 2017.

The values are summarised in the energy model input reference sheets in Appendix C at the end of this report.

No research study identified the future energy demand of renovated building in Europe to national standards, and the energy consumption of the low carbon energy system required to meet this demand and European targets.

3 Advanced Building Energy Modelling

3.1 Building Energy modelling methodology

RES4BUILD will develop renewable-energy-based solutions for decarbonising the energy used in buildings. The approach of the project is flexible, so that the solutions are applicable to a wide variety of buildings, new or renovated, tailored to their size, their building typology, and the climatic zones of their location. The RES4BUILD project task 7.1 includes an assessment of the project impact on an EU representative sample of this variety of buildings.

As part of this assessment at least three typical building types and four locations in different climatic zones are selected and typical energy demand profiles prepared for each. These energy demand profiles will form the energy consumption basis of WP3 energy models and hence are to be delivered in the required 8,760 data point format providing hourly building heating and cooling energy demand profiles. Domestic Hot Water (DHW) and electrical demand profiles are produced separately based on typical representative profiles as required.

Project partners NCSRD and VITO (shown in Figure 5) have utilised the Arup produced building energy demand profiles to model the RES4BUILD system operation and energy consumption profiles using optimised control algorithms as set out in the WP3 deliverable reports (D3.1 and D3.4). These results are summarised in this report. As part of WP6, USTUTT conducted a Life Cycle Assessment (LCA) and produced factsheets indicating Life Cycle Economics (LCE) of the RES4BUILD system. Their work included the system final energy demand output in the operational phase analysis as explained in the WP6 deliverable report, the results of which are summarised in this report.

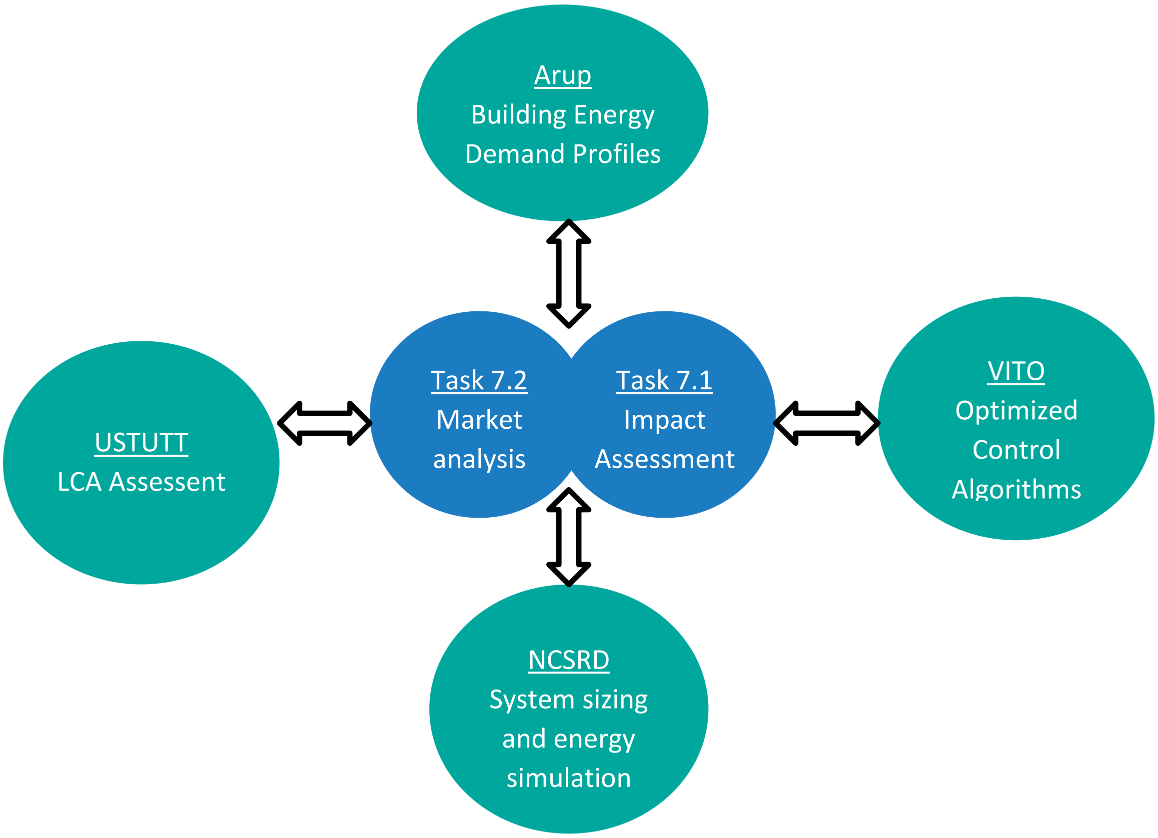


Figure 28 - Partners collaborating in WP7

There are two main proposed methods for the production of the typical energy demand profiles in the required format:

1. Closed System - Licensed Tool Energy Modelling
2. Open System – Individual Extensible Energy Modelling

Both systems use the validated EnergyPlus energy modelling engine. EnergyPlus is one of the most widely used and recognized programs for energy analysis and thermal load simulation. It is based on a description of the building's geometry, thermal performance, operational profile and climate. EnergyPlus is able to calculate the heating and cooling loads dynamically and produce the required hourly profiles.

A comparison of the two methodologies shown in Table 5 below displays a clear advantage of the adjustable open system with European focused inputs; however, this customised, extensible modelling approach will require extensive review and validation to ensure models are correct unlike the closed system approach which utilises fixed, validated models.

Table 6 - RES4BUILD Energy Model Systems Comparison

Method	**Closed System**	**Open System**
Software	DEF Tool	Rhino-Grasshopper
Engine	Energy Plus	Energy Plus
Weather Files	American	European
Geometry	DOE Reference Models	ENTRANZE Models
U-values	ASHRAE (Fixed)	Local (Adjustable)
Setpoints	ASHRAE (Fixed)	CIBSE (Adjustable)
Loads	Fixed	Adjustable
Schedules	Fixed	Adjustable

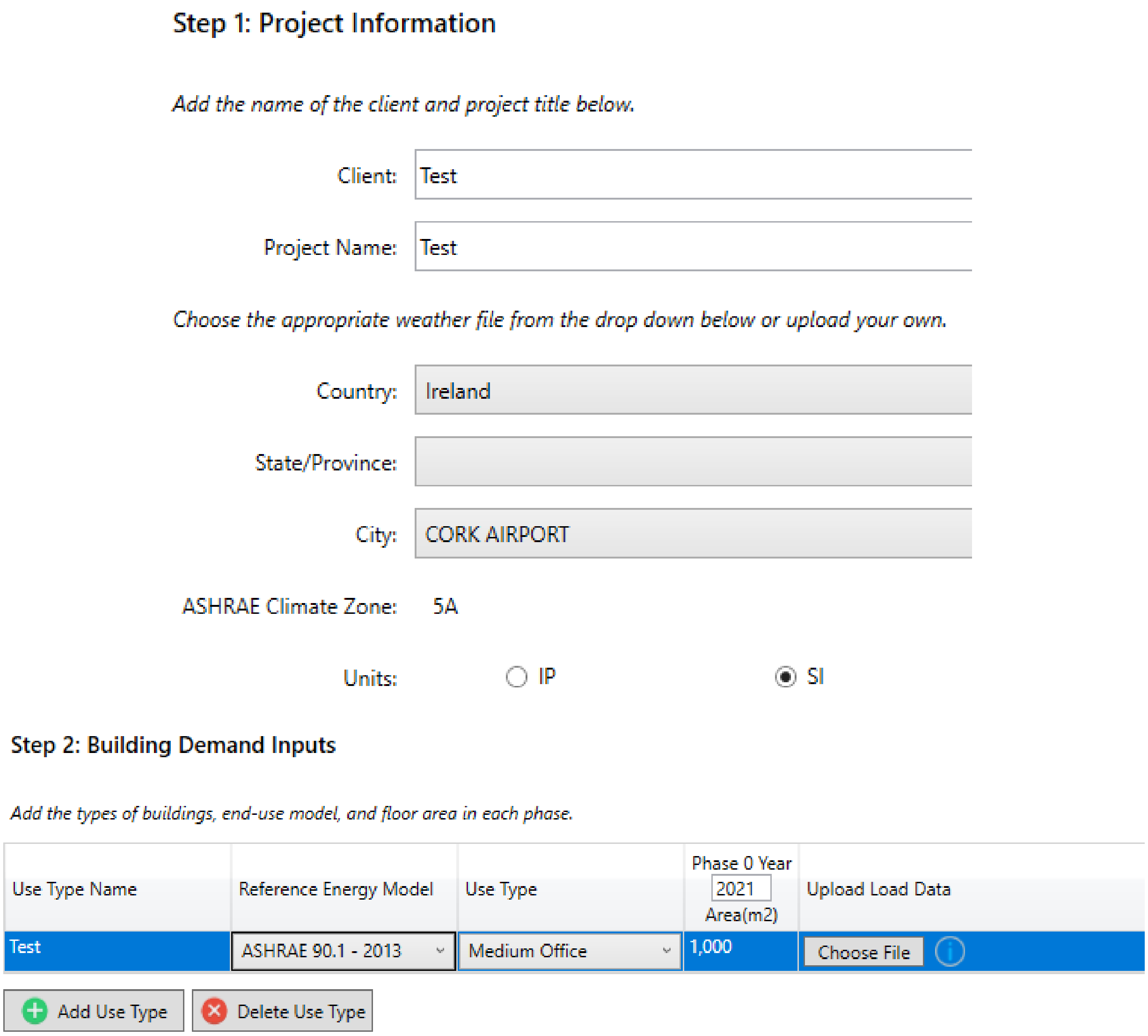
The respective methodologies are outlined in detail below.

3.2 Closed System - Licensed Tool modelling

The proposed closed system energy modelling methodology utilises a combination of the open-source U.S. Department of Energy Commercial Reference Building Models of the National Building Stock and an Arup licensed software District Energy Feasibility (DEF) tool to produce the typical energy demand profiles.

This method has the advantage of replicability, scalability and ability to produce validated energy demand profiles in the required 8,760 data point format based in available inputs.

The District Energy Feasibility, or DEF, tool estimates the heating, cooling and electric load for buildings using user input information on the Project Location, Building Area, and Building Use Type (e.g. commercial, residential, etc.). This enables energy demand profiles to be tailored to their size, type and building location climate as shown in Figure 30 below.



Step 1: Project Information

Add the name of the client and project title below.

Client: Test

Project Name: Test

Choose the appropriate weather file from the drop down below or upload your own.

Country: Ireland

State/Province:

City: CORK AIRPORT

ASHRAE Climate Zone: 5A

Units: ○ IP ● SI

Step 2: Building Demand Inputs

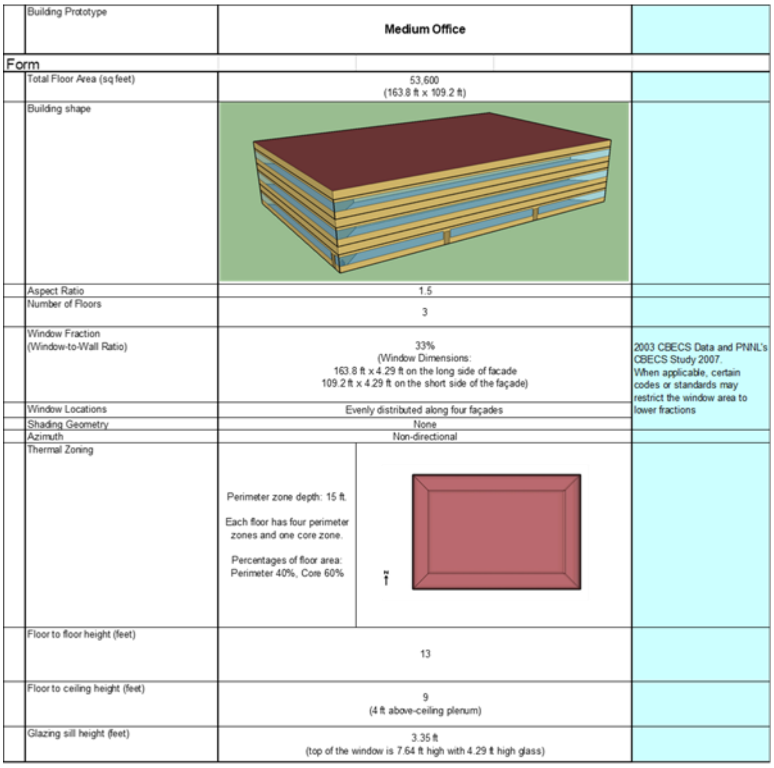
Add the types of buildings, end-use model, and floor area in each phase.

Use Type Name	Reference Energy Model	Use Type	Phase 0 Year 2021 Area(m2)	Upload Load Data
Test	ASHRAE 90.1 - 2013	Medium Office	1,000	Choose File

Figure 29 - DEF Tool Input

Energy demand profiles produced are based on reference building models stored in the DEF database. These reference building models are openly available from, and validated by, the US Department of Energy (DOE). A detailed example of a building reference model description is shown below in Figure 31.

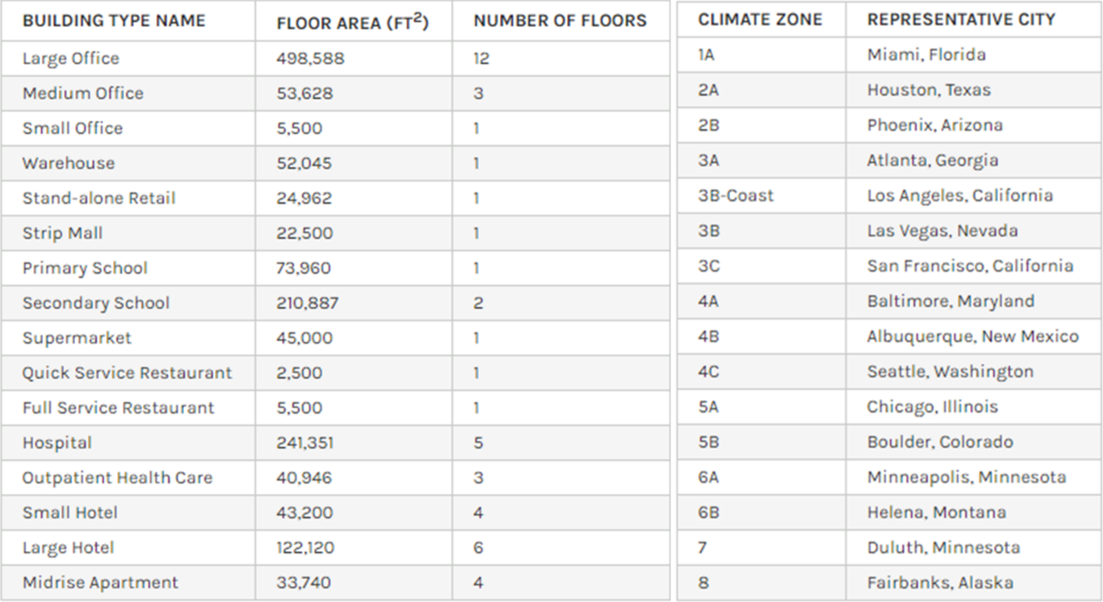
The DEF tool combines the user inputs above with the US Department of Energy (DOE) Commercial Reference Building Models in the tools database to calculate project energy loads, and energy use for specified systems if required.



Building Prototype	Medium Office	
Form		
Total Floor Area (sq feet)	53,600 (163.8 ft x 109.2 ft)	
Building shape		
Aspect Ratio	1.5	
Number of Floors	3	
Window Fraction (Window-to-Wall Ratio)	33% (Window Dimensions: 163.8 ft x 4.29 ft on the long side of facade 109.2 ft x 4.29 ft on the short side of the façade)	2003 CBECS Data and PNNL's CBECS Study 2007. When applicable, certain codes or standards may restrict the window area to lower fractions
Window Locations	Evenly distributed along four façades	
Shading Geometry	None	
Azimuth	Non-directional	
Thermal Zoning	Perimeter zone depth: 15 ft. Each floor has four perimeter zones and one core zone. Percentages of floor area: Perimeter 40%, Core 60%	
Floor to floor height (feet)	13	
Floor to ceiling height (feet)	9 (4 ft above-ceiling plenum)	
Glazing sill height (feet)	3.35 ft (top of the window is 7.64 ft high with 4.29 ft high glass)	

Figure 30 - DOE Commercial Office Reference Building Model

The U.S. Department of Energy (DOE), in conjunction with three of its national laboratories, developed commercial reference buildings, formerly known as commercial building benchmark models. There are 16 building types (shown in Figure 32 below) that represent approximately 70% of the commercial buildings in the U.S. and all global climate zones, according to the report published by the National Renewable Energy Laboratory titled U.S. Department of Energy Commercial Reference Building Models of the National Building Stock. These models provide a consistent baseline of comparison and improve the value of computer energy simulations using software such as EnergyPlus and Arup's internal District Energy Feasibility (DEF) tool.



BUILDING TYPE NAME	FLOOR AREA (FT^2)	NUMBER OF FLOORS
Large Office	498,588	12
Medium Office	53,628	3
Small Office	5,500	1
Warehouse	52,045	1
Stand-alone Retail	24,962	1
Strip Mall	22,500	1
Primary School	73,960	1
Secondary School	210,887	2
Supermarket	45,000	1
Quick Service Restaurant	2,500	1
Full Service Restaurant	5,500	1
Hospital	241,351	5
Outpatient Health Care	40,946	3
Small Hotel	43,200	4
Large Hotel	122,120	6
Midrise Apartment	33,740	4

CLIMATE ZONE	REPRESENTATIVE CITY
1A	Miami, Florida
2A	Houston, Texas
2B	Phoenix, Arizona
3A	Atlanta, Georgia
3B-Coast	Los Angeles, California
3B	Las Vegas, Nevada
3C	San Francisco, California
4A	Baltimore, Maryland
4B	Albuquerque, New Mexico
4C	Seattle, Washington
5A	Chicago, Illinois
5B	Boulder, Colorado
6A	Minneapolis, Minnesota
6B	Helena, Montana
7	Duluth, Minnesota
8	Fairbanks, Alaska

Figure 31 – ASHARE Building Typology Models

These 16 American based ASHRAE climate zones are mapped and translated to European city climates within the DEF tool based on available weather station data and heating and cooling degree day data. This aligned locations well based on average temperatures however it was noted during the modelling exercise that peak temperatures varied substantially between European cities and their representative American counterparts which could affect the modelled energy profiles.

Therefore, despite the energy models and results being independently verified (in the US) there are notable differences to the EU market. Figure 33 below shows graphically the heating and cooling demand profiles produced for the Cork Commercial Office energy model. Instinctively it was noted the cooling demand profile and cooling peak were larger than expected for the given climate.

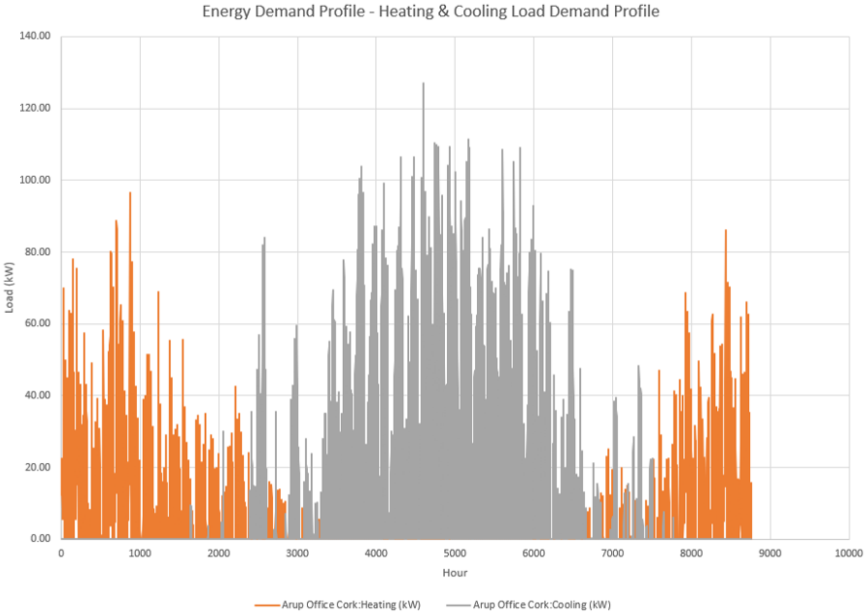


Figure 32 - DEF Tool Thermal Profile Output

Therefore, it was decided to confirm if the modelled energy demand profiles were generally representative of actual building stock energy demand. To do this the closed system licensed tool model results for a selected building were compared to actual building energy data available -the Arup Cork Office was chosen due to availability of data. The Arup Cork office actual data was extracted from its internal data analytics platform which monitors building systems metering and operational data.

Actual hourly energy consumption data was available for building electricity usage including lighting, appliances and small power but not electrical air conditioning energy demand (which is included in heating and cooling energy demand) that, assuming no losses in building distribution, represents the building hourly electrical energy demand.

Building actual heating and cooling energy consumption hourly data was not available. Total office heating and cooling energy demand was calculated based on AHU gas heating system specifications, and electrical air conditioning heating energy consumption figures and system performance coefficients (SCOP = 3).

Actual total annual building energy demand for the Arup Cork office was then compared to the total DEF tool modelled building energy demand for same with the result given below in Table 6.

Table 7 – Closed Tool Validation

Results Comparative Analysis	**Heating**	**Cooling**	**Elec**	**Total**
	kWh/yr	**kWh/yr**	**kWh/yr**	**kWh/yr**
DEF Tool	49,176	106,236	134,352	289,764
Building Data	64,621	59,561	144,006	268,187
Deviation	-23.9%	78.4%	-6.7%	8.0%

It is found that the DEF tool model under-estimated the Arup office heating demand by 24% and over-estimated the cooling energy demand by 78%. This deviation in results may be due to several causes including differences in underlying assumptions in heating and cooling setpoints and differences in the actual Irish climate in that year versus the 5A climate weather file used in the proposed energy modelling methodology.

Hence, the need for a more flexible, extensible energy modelling method was identified based on the research partners feedback, which could produce similar thermal profile output but utilising more representative European climates, internal parameters, envelope properties, and building typology data.

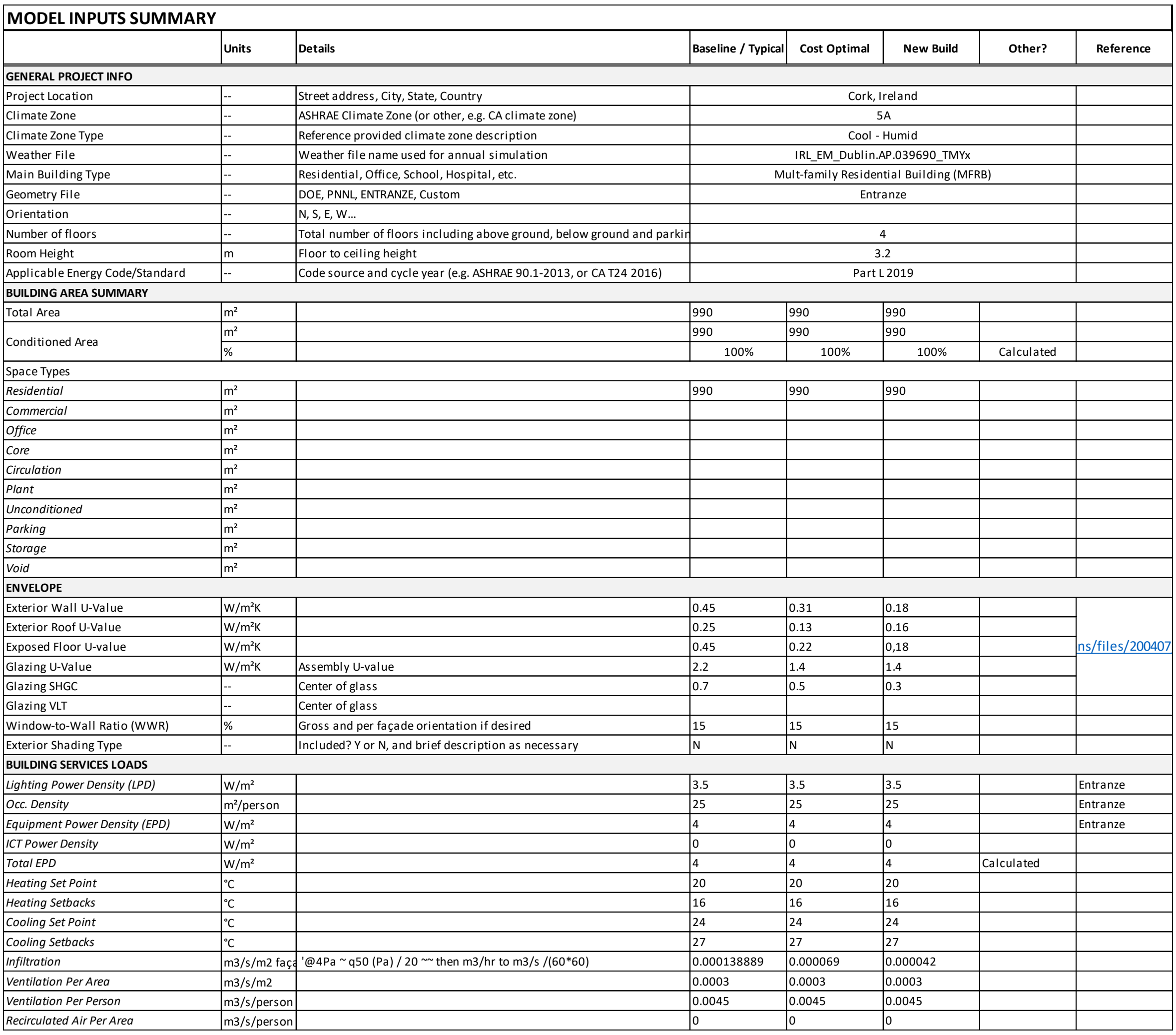
3.3 Open System – Individual Extensible modelling

The proposed open system energy modelling methodology utilises a combination of the widely available Rhino and Grasshopper software tools, operating with several open-source ‘plug-ins’ such as Honeybee, Open Studio and IronBug. Using these software packages a RES4BUILD energy modelling script or tool was developed to produce the required building energy demand profiles.

The advantage of this method is the flexibility, accessibility, and the customisation of the energy modelling process which still produces the energy demand profiles in the required 8,760 data point format. However, this does require additional time and data input associated with the inherent software scripting and results validation.

The RES4BUILD energy modelling script was developed based on an existing Arup Parametric Energy Modelling Tool (PEMT) and customised to produce the energy demand profiles in the required 8,760 data point format from the RES4BUILD specific building typology, climate and building performance inputs.

A summary of the inputs for each building energy model is provided in Appendix C of this report and follow the format as shown in Figure 34 below, an example of the Cork Multifamily Residential Building (MFRB) model input summary sheet.



MODEL INPUTS SUMMARY	Units	Details	Baseline / Typical	Cost Optimal	New Build	Other?	Reference
GENERAL PROJECT INFO							
Project Location	--	Street address, City, State, Country	Cork, Ireland				
Climate Zone	--	ASHRAE Climate Zone (or other, e.g. CA climate zone)	5A				
Climate Zone Type	--	Reference provided climate zone description	Cool - Humid				
Weather File	--	Weather file name used for annual simulation	IRL_EM_Dublin.AP.039690_TMYx				
Main Building Type	--	Residential, Office, School, Hospital, etc.	Mult-family Residential Building (MFRB)				
Geometry File	--	DOE, PNNL, ENTRANZE, Custom	Entranze				
Orientation	--	N, S, E, W...					
Number of floors	--	Total number of floors including above ground, below ground and parkin	4				
Room Height	m	Floor to ceiling height	3.2				
Applicable Energy Code/Standard	--	Code source and cycle year (e.g. ASHRAE 90.1-2013, or CA T24 2016)	Part L 2019				
BUILDING AREA SUMMARY							
Total Area	m^2		990	990	990		
Conditioned Area	m^2		990	990	990		
	%		100%	100%	100%	Calculated	
Space Types							
Residential	m^2		990	990	990		
Commercial	m^2						
Office	m^2						
Core	m^2						
Circulation	m^2						
Plant	m^2						
Unconditioned	m^2						
Parking	m^2						
Storage	m^2						
Void	m^2						
ENVELOPE							
Exterior Wall U-Value	W/m^2K		0.45	0.31	0.18		ns/files/200407
Exterior Roof U-Value	W/m^2K		0.25	0.13	0.16		
Exposed Floor U-value	W/m^2K		0.45	0.22	0,18		
Glazing U-Value	W/m^2K	Assembly U-value	2.2	1.4	1.4		
Glazing SHGC	--	Center of glass	0.7	0.5	0.3		
Glazing VLT	--	Center of glass					
Window-to-Wall Ratio (WWR)	%	Gross and per façade orientation if desired	15	15	15		
Exterior Shading Type	--	Included? Y or N, and brief description as necessary	N	N	N		
BUILDING SERVICES LOADS							
Lighting Power Density (LPD)	W/m^2		3.5	3.5	3.5		Entranze
Occ. Density	m^2/person		25	25	25		Entranze
Equipment Power Density (EPD)	W/m^2		4	4	4		Entranze
ICT Power Density	W/m^2		0	0	0		
Total EPD	W/m^2		4	4	4	Calculated	
Heating Set Point	°C		20	20	20		
Heating Setbacks	°C		16	16	16		
Cooling Set Point	°C		24	24	24		
Cooling Setbacks	°C		27	27	27		
Infiltration	m3/s/m2 faça	'@4Pa ~ q50 (Pa) / 20 ~~ then m3/hr to m3/s /(60*60)	0.000138889	0.000069	0.000042		
Ventilation Per Area	m3/s/m2		0.0003	0.0003	0.0003		
Ventilation Per Person	m3/s/person		0.0045	0.0045	0.0045		
Recirculated Air Per Area	m3/s/person		0	0	0		

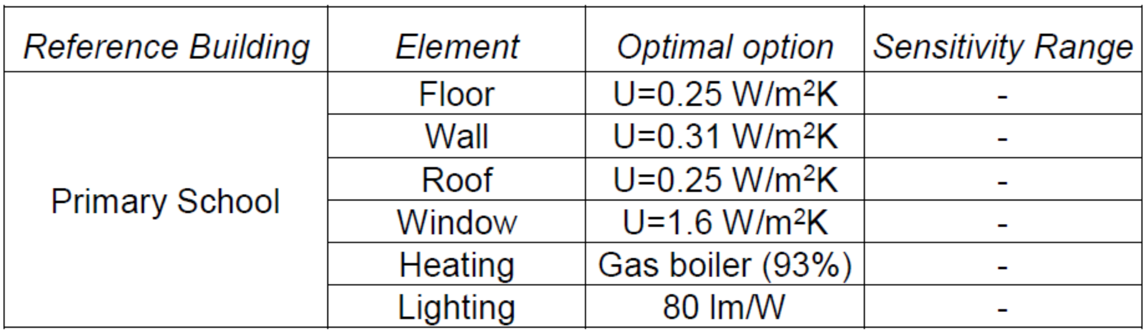
Figure 33 - Cork Multifamily Residential Building (MFRB) Model Input Summary Sheet

These inputs have been drawn from a number of sources as detailed above in section 2 - European Building Market Research.

Heating and cooling setpoints were extracted from the CIBSE Guide A Environmental Design Guide for each typology, and then shared with the research project partners and team for specific climate and comfort levels adaption.

The key inputs of the building fabric thermal performance to cost-optimal renovation level were sourced from country specific regulations. The cost optimal renovation level was selected as it will represent the largest share of EU building stock with over 90% requiring some form of energy renovation to achieve national requirements.

An example from the Irish Cost Optimal Report 2019 from the Department of Housing, Planning and Local Government shows the 'Economic Optimal Energy Performance Level' specifications for a school which was input into the RES4BUILD School energy model.



Reference Building	Element	Optimal option	Sensitivity Range
Primary School	Floor	U=0.25 W/m²K	-
	Wall	U=0.31 W/m²K	-
	Roof	U=0.25 W/m²K	-
	Window	U=1.6 W/m²K	-
	Heating	Gas boiler (93%)	-
	Lighting	80 lm/W	-

Figure 34 – Ireland Economic Optimal Energy Performance Level specifications for School Building

The respective building fabric thermal performance specification was applied to each representative geometry sourced from the ENTRANZE European research project as simplified models that represent the typical European building of that typology. Activity metrics such as occupancy, lighting and equipment load densities are also sourced from ENTRANZE project as representative values.

The RES4BUILD typologies of the single-family home, MFRB, commercial office building and public school buildings were input as geometries created in the Rhino software. This Rhino geometry was connected to the Grasshopper energy modelling script through ‘Brep’ components by building area function classification. The MFRB example below in Figure 36 shows the typology geometry in Rhino and the corresponding connected Apartments, Circulation and Attic zones to represent the different functional areas within the building.

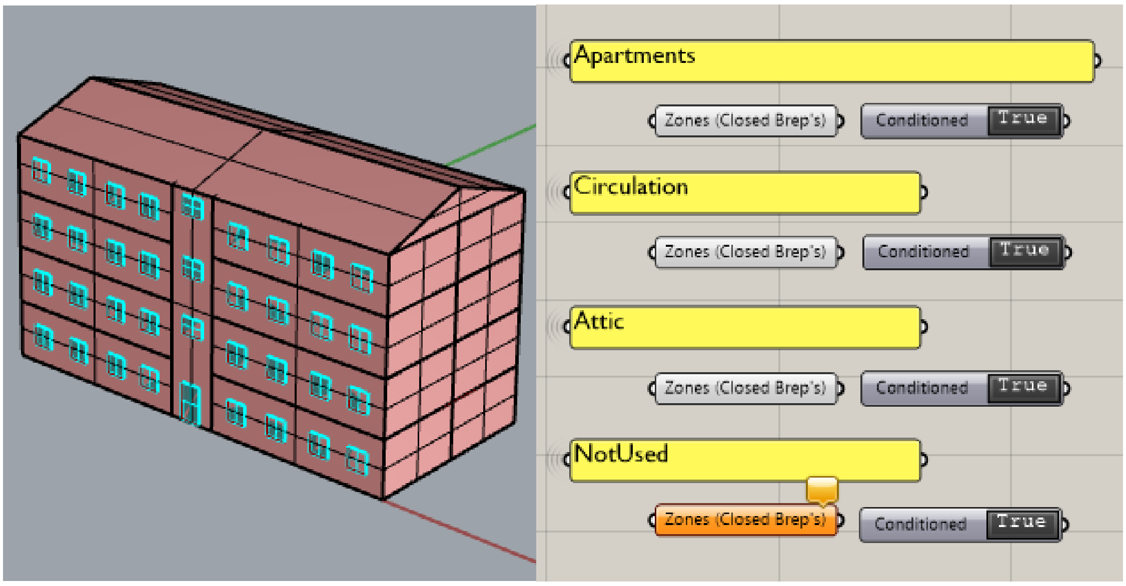
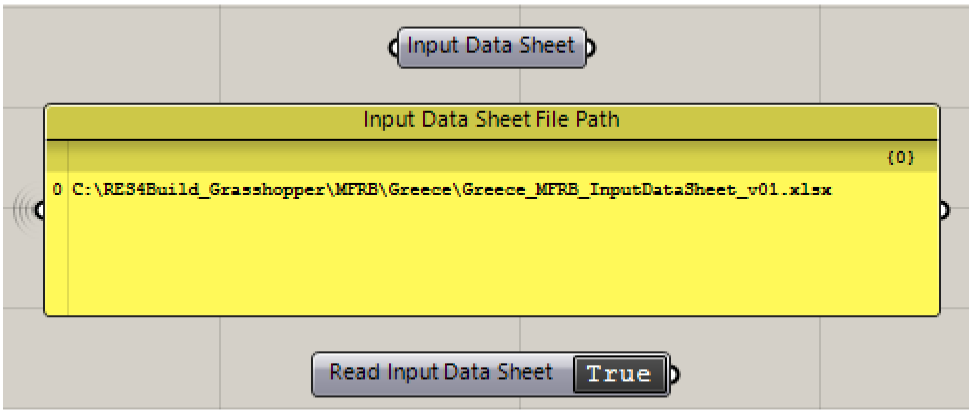


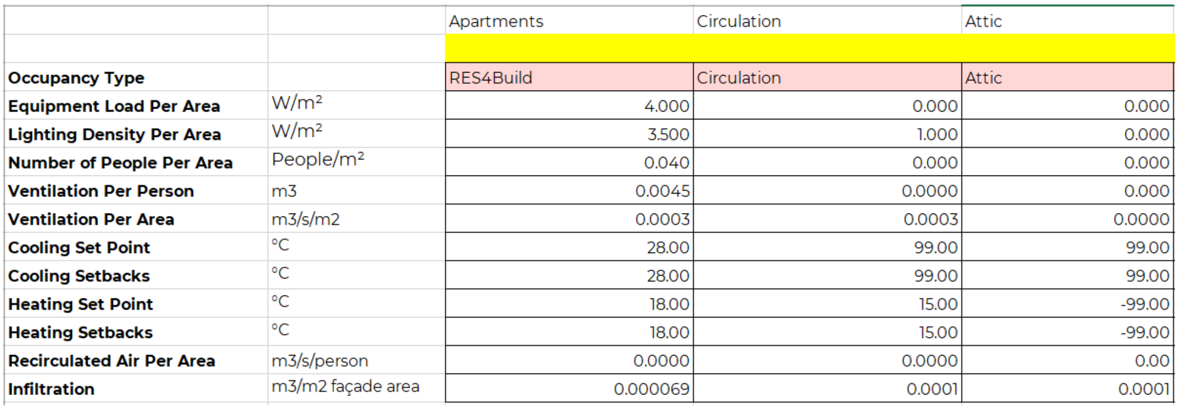
Figure 35 – MFRB Model Rhino Geomtry & Corresponding Energy Zones

The building typology is further represented by the activity of the building which is input into the building energy model using the Input Data Sheet function in Grasshopper (as shown in Figure 37). The activity characteristics covered in this data input sheet include internal loads, occupancy, heating and cooling setpoints, ventilation rates and infiltration as shown in Figure 38.



0 C:\RES4Build_Grasshopper\MFRB\Greece\Greece_MFRB_InputDataSheet_v01.xlsx

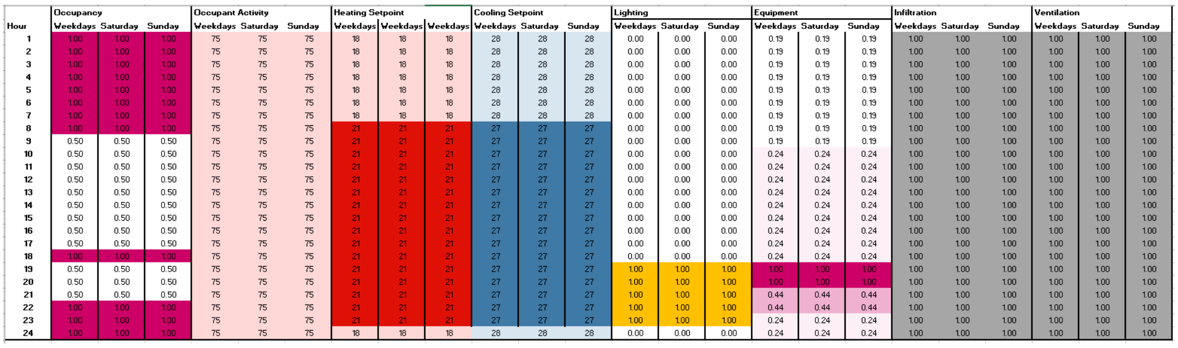
Figure 36 Grasshopper Input Data Sheet Function



		Apartments	Circulation	Attic
Occupancy Type		RES4Build	Circulation	Attic
Equipment Load Per Area	W/m²	4.000	0.000	0.000
Lighting Density Per Area	W/m²	3.500	1.000	0.000
Number of People Per Area	People/m²	0.040	0.000	0.000
Ventilation Per Person	m3	0.0045	0.0000	0.000
Ventilation Per Area	m3/s/m2	0.0003	0.0003	0.0000
Cooling Set Point	°C	28.00	99.00	99.00
Cooling Setbacks	°C	28.00	99.00	99.00
Heating Set Point	°C	18.00	15.00	-99.00
Heating Setbacks	°C	18.00	15.00	-99.00
Recirculated Air Per Area	m3/s/person	0.0000	0.0000	0.00
Infiltration	m3/m2 façade area	0.000069	0.0001	0.0001

Figure 37 – Example Grasshopper model Input Data Sheet Extract

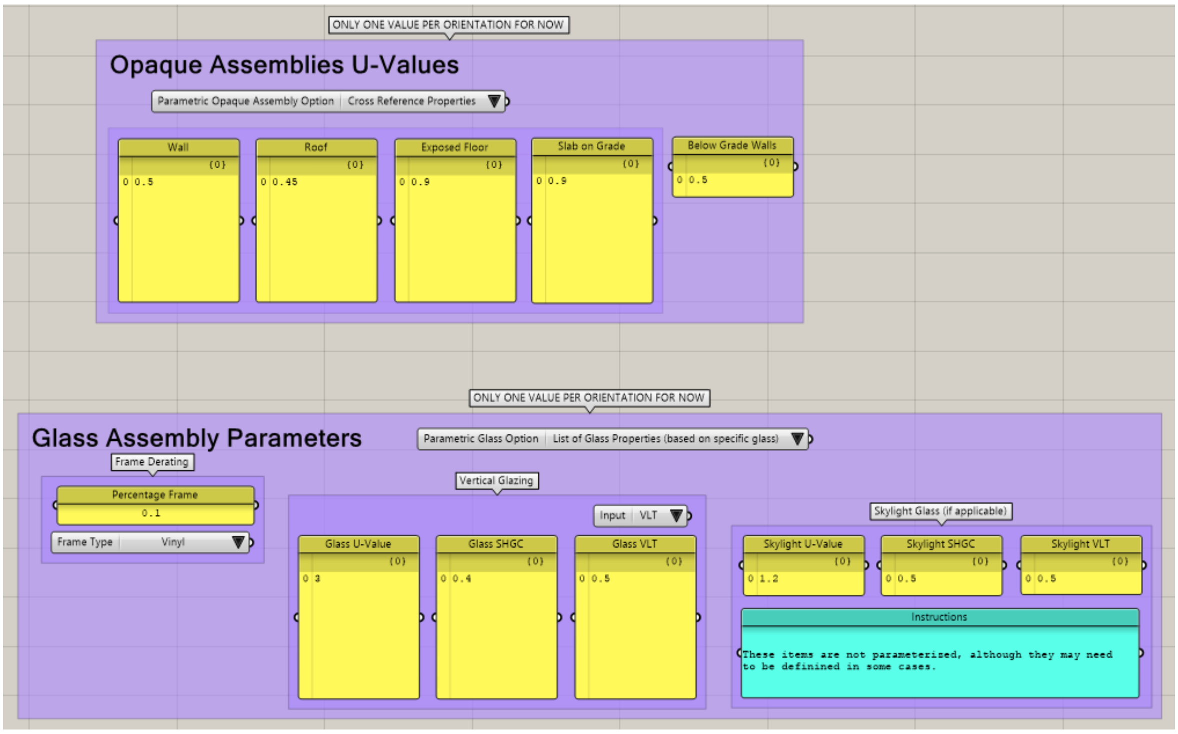
The representative schedule of these activities is also included in the input data sheet, and example is shown in Figure 39 below.



	Occupancy			Occupant Activity			Heating Setpoint			Cooling Setpoint			Lighting			Equipment			Infiltration			Ventilation		
Hour	Weekdays	Saturday	Sunday	Weekdays	Saturday	Sunday	Weekdays	Weekdays	Weekdays	Weekdays	Saturday	Sunday	Weekdays	Saturday	Sunday	Weekdays	Saturday	Sunday	Weekdays	Saturday	Sunday	Weekdays	Saturday	Sunday
1	1.00	1.00	1.00	75	75	75	18	18	18	28	28	28	0.00	0.00	0.00	0.19	0.19	0.19	1.00	1.00	1.00	1.00	1.00	1.00
2	1.00	1.00	1.00	75	75	75	18	18	18	28	28	28	0.00	0.00	0.00	0.19	0.19	0.19	1.00	1.00	1.00	1.00	1.00	1.00
3	1.00	1.00	1.00	75	75	75	18	18	18	28	28	28	0.00	0.00	0.00	0.19	0.19	0.19	1.00	1.00	1.00	1.00	1.00	1.00
4	1.00	1.00	1.00	75	75	75	18	18	18	28	28	28	0.00	0.00	0.00	0.19	0.19	0.19	1.00	1.00	1.00	1.00	1.00	1.00
5	1.00	1.00	1.00	75	75	75	18	18	18	28	28	28	0.00	0.00	0.00	0.19	0.19	0.19	1.00	1.00	1.00	1.00	1.00	1.00
6	1.00	1.00	1.00	75	75	75	18	18	18	28	28	28	0.00	0.00	0.00	0.19	0.19	0.19	1.00	1.00	1.00	1.00	1.00	1.00
7	1.00	1.00	1.00	75	75	75	18	18	18	28	28	28	0.00	0.00	0.00	0.19	0.19	0.19	1.00	1.00	1.00	1.00	1.00	1.00
8	1.00	1.00	1.00	75	75	75	21	21	21	27	27	27	0.00	0.00	0.00	0.19	0.19	0.19	1.00	1.00	1.00	1.00	1.00	1.00
9	0.50	0.50	0.50	75	75	75	21	21	21	27	27	27	0.00	0.00	0.00	0.19	0.19	0.19	1.00	1.00	1.00	1.00	1.00	1.00
10	0.50	0.50	0.50	75	75	75	21	21	21	27	27	27	0.00	0.00	0.00	0.24	0.24	0.24	1.00	1.00	1.00	1.00	1.00	1.00
11	0.50	0.50	0.50	75	75	75	21	21	21	27	27	27	0.00	0.00	0.00	0.24	0.24	0.24	1.00	1.00	1.00	1.00	1.00	1.00
12	0.50	0.50	0.50	75	75	75	21	21	21	27	27	27	0.00	0.00	0.00	0.24	0.24	0.24	1.00	1.00	1.00	1.00	1.00	1.00
13	0.50	0.50	0.50	75	75	75	21	21	21	27	27	27	0.00	0.00	0.00	0.24	0.24	0.24	1.00	1.00	1.00	1.00	1.00	1.00
14	0.50	0.50	0.50	75	75	75	21	21	21	27	27	27	0.00	0.00	0.00	0.24	0.24	0.24	1.00	1.00	1.00	1.00	1.00	1.00
15	0.50	0.50	0.50	75	75	75	21	21	21	27	27	27	0.00	0.00	0.00	0.24	0.24	0.24	1.00	1.00	1.00	1.00	1.00	1.00
16	0.50	0.50	0.50	75	75	75	21	21	21	27	27	27	0.00	0.00	0.00	0.24	0.24	0.24	1.00	1.00	1.00	1.00	1.00	1.00
17	0.50	0.50	0.50	75	75	75	21	21	21	27	27	27	0.00	0.00	0.00	0.24	0.24	0.24	1.00	1.00	1.00	1.00	1.00	1.00
18	1.00	1.00	1.00	75	75	75	21	21	21	27	27	27	0.00	0.00	0.00	0.24	0.24	0.24	1.00	1.00	1.00	1.00	1.00	1.00
19	0.50	0.50	0.50	75	75	75	21	21	21	27	27	27	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
20	0.50	0.50	0.50	75	75	75	21	21	21	27	27	27	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
21	0.50	0.50	0.50	75	75	75	21	21	21	27	27	27	1.00	1.00	1.00	0.44	0.44	0.44	1.00	1.00	1.00	1.00	1.00	1.00
22	1.00	1.00	1.00	75	75	75	21	21	21	27	27	27	1.00	1.00	1.00	0.44	0.44	0.44	1.00	1.00	1.00	1.00	1.00	1.00
23	1.00	1.00	1.00	75	75	75	21	21	21	27	27	27	1.00	1.00	1.00	0.24	0.24	0.24	1.00	1.00	1.00	1.00	1.00	1.00
24	1.00	1.00	1.00	75	75	75	18	18	18	28	28	28	0.00	0.00	0.00	0.24	0.24	0.24	1.00	1.00	1.00	1.00	1.00	1.00

Figure 38 – Example Energy Model Schedule Input

Building thermal envelope specifications are input directly using the Grasshopper component as shown below in Figure 40. Thermal envelope U-values and window G-values input are based on the country specific cost-optimal façade values identified by the representative countries as part of the EPBD as discussed earlier. Details of the thermal envelope specifications including U-values and window G-values for each energy model are provided in the model input summary sheets in Appendix C.

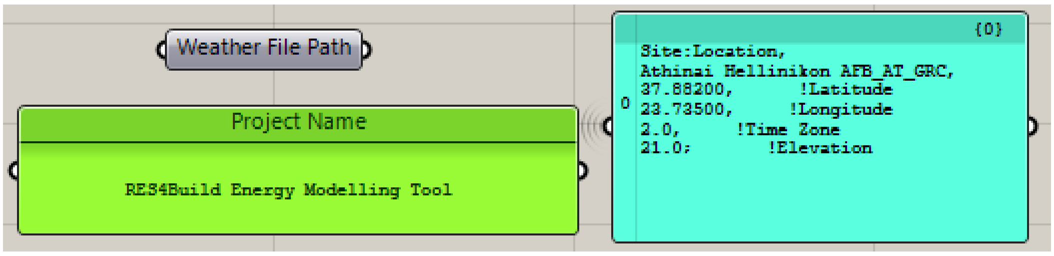


Wall {0} 0 0.5
Roof {0} 0 0.45
Exposed Floor {0} 0 0.9
Slab on Grade {0} 0 0.9
Below Grade Walls {0} 0 0.5
Percentage Frame 0.1
Frame Type Vinyl
Input VLT
Glass U-Value {0} 0 3
Glass SHGC {0} 0 0.4
Glass VLT {0} 0 0.5
Skylight U-Value {0} 0 1.2
Skylight SHGC {0} 0 0.5
Skylight VLT {0} 0 0.5

```
These items are not parameterised, although they may need
to be definined in some cases.
```

Figure 39 - Open System Model Thermal Performance Input

The climatic conditions of the European representative locations of Athens, Amsterdam, Cork, and Gdansk are input into the energy model using the weather file path component in Grasshopper as shown in Figure 41. The location weather files input are Typical Meteorological Years (TMY) published by a variety of organisations that represent the typical climate of the location over the most recently available years of 2004 to 2018. The weather files are EPW (EnergyPlus Weather Format) for streamlined use in the EnergyPlus energy modelling engine being used. Location weather files were sourced from Climate.OneBuilding.Org.



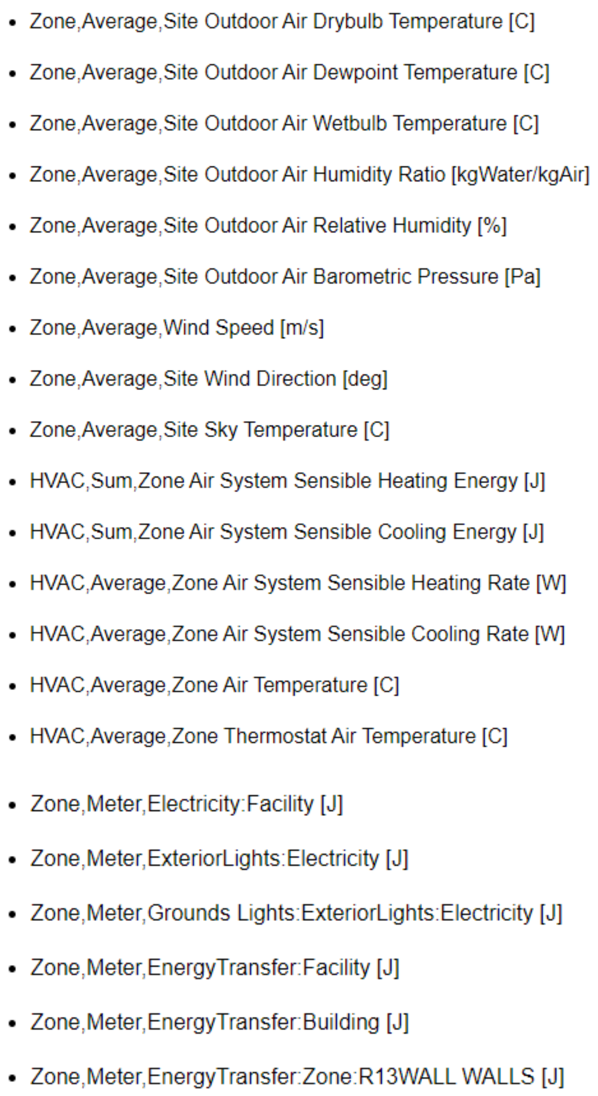
```
RES4Build Energy Modelling Tool
```

```
{0}
Site:Location,
Athinai Hellinikon AFB_AT_GRC,
37.88200,        !Latitude
23.73500,       !Longitude
2.0,      !Time Zone
21.0;        !Elevation
```

Figure 40 - Open System Weather File Path Location

These above inputs are processed in the RES4BUILD developed Grasshopper script and return the given output(s) – in this case building zones heating and cooling energy demand values in CSV format.

Building Energy models utilise the EnergyPlus engine and therefore outputs are not limited to heating and cooling energy demand values as used in RES4BUILD. All outputs included in the EnergyPlus programme are available in the RES4BUILD energy model tool, an example selection of which are shown in the table below.

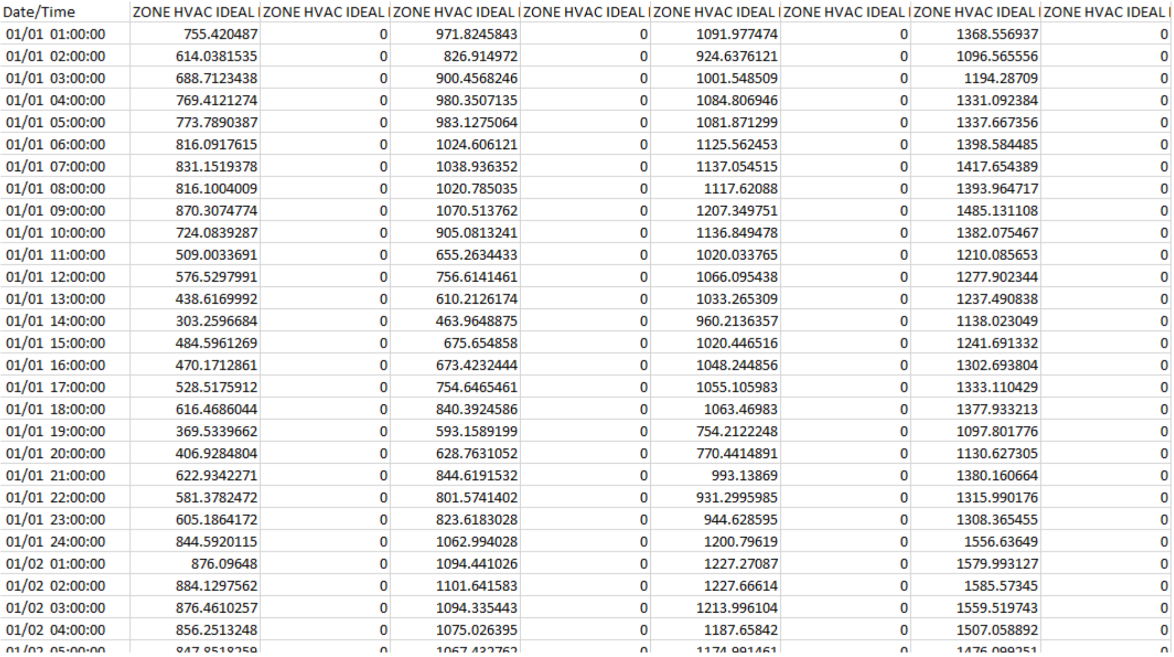


- Zone,Average,Site Outdoor Air Drybulb Temperature [C]
- Zone,Average,Site Outdoor Air Dewpoint Temperature [C]
- Zone,Average,Site Outdoor Air Wetbulb Temperature [C]
- Zone,Average,Site Outdoor Air Humidity Ratio [kgWater/kgAir]
- Zone,Average,Site Outdoor Air Relative Humidity [%]
- Zone,Average,Site Outdoor Air Barometric Pressure [Pa]
- Zone,Average,Wind Speed [m/s]
- Zone,Average,Site Wind Direction [deg]
- Zone,Average,Site Sky Temperature [C]
- HVAC,Sum,Zone Air System Sensible Heating Energy [J]
- HVAC,Sum,Zone Air System Sensible Cooling Energy [J]
- HVAC,Average,Zone Air System Sensible Heating Rate [W]
- HVAC,Average,Zone Air System Sensible Cooling Rate [W]
- HVAC,Average,Zone Air Temperature [C]
- HVAC,Average,Zone Thermostat Air Temperature [C]

- Zone,Meter,Electricity:Facility [J]
- Zone,Meter,ExteriorLights:Electricity [J]
- Zone,Meter,Grounds Lights:ExteriorLights:Electricity [J]
- Zone,Meter,EnergyTransfer:Facility [J]
- Zone,Meter,EnergyTransfer:Building [J]
- Zone,Meter,EnergyTransfer:Zone:R13WALL WALLS [J]

Figure 41 - EnergyPlus Programme Outputs Selection Schedule

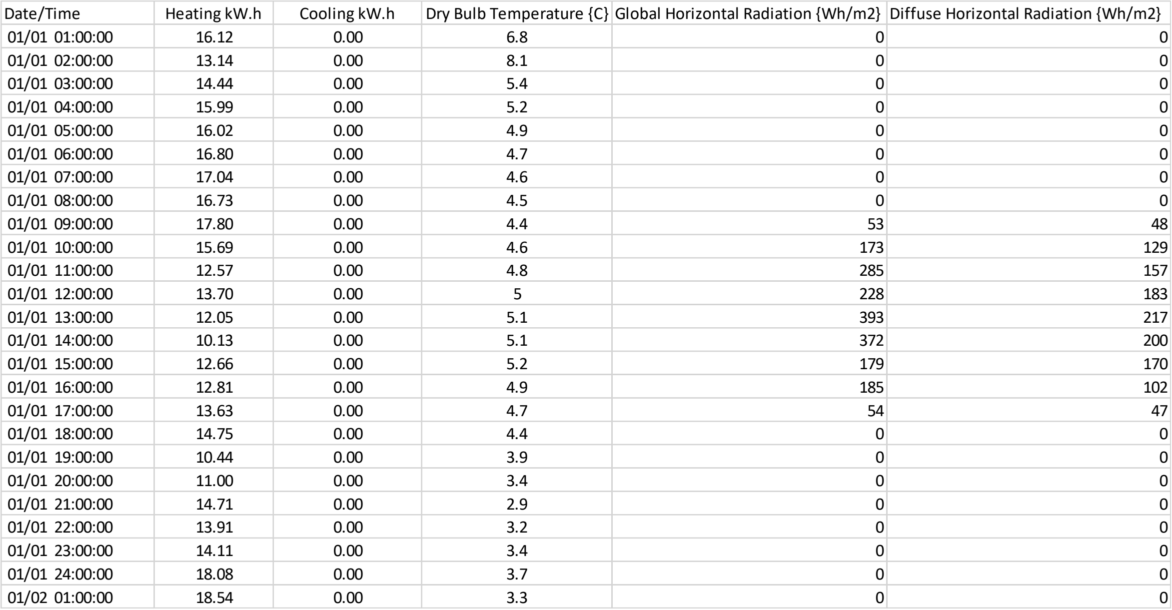
An abbreviated example of the RES4BUILD energy model output is shown in Figure 43 below.



Date/Time	ZONE HVAC IDEAL	ZONE HVAC IDEAL	ZONE HVAC IDEAL	ZONE HVAC IDEAL	ZONE HVAC IDEAL	ZONE HVAC IDEAL	ZONE HVAC IDEAL	ZONE HVAC IDEAL
01/01 01:00:00	755.420487	0	971.8245843	0	1091.977474	0	1368.556937	0
01/01 02:00:00	614.0381535	0	826.914972	0	924.6376121	0	1096.565556	0
01/01 03:00:00	688.7123438	0	900.4568246	0	1001.548509	0	1194.28709	0
01/01 04:00:00	769.4121274	0	980.3507135	0	1084.806946	0	1331.092384	0
01/01 05:00:00	773.7890387	0	983.1275064	0	1081.871299	0	1337.667356	0
01/01 06:00:00	816.0917615	0	1024.606121	0	1125.562453	0	1398.584485	0
01/01 07:00:00	831.1519378	0	1038.936352	0	1137.054515	0	1417.654389	0
01/01 08:00:00	816.1004009	0	1020.785035	0	1117.62088	0	1393.964717	0
01/01 09:00:00	870.3074774	0	1070.513762	0	1207.349751	0	1485.131108	0
01/01 10:00:00	724.0839287	0	905.0813241	0	1136.849478	0	1382.075467	0
01/01 11:00:00	509.0033691	0	655.2634433	0	1020.033765	0	1210.085653	0
01/01 12:00:00	576.5297991	0	756.6141461	0	1066.095438	0	1277.902344	0
01/01 13:00:00	438.6169992	0	610.2126174	0	1033.265309	0	1237.490838	0
01/01 14:00:00	303.2596684	0	463.9648875	0	960.2136357	0	1138.023049	0
01/01 15:00:00	484.5961269	0	675.654858	0	1020.446516	0	1241.691332	0
01/01 16:00:00	470.1712861	0	673.4232444	0	1048.244856	0	1302.693804	0
01/01 17:00:00	528.5175912	0	754.6465461	0	1055.105983	0	1333.110429	0
01/01 18:00:00	616.4686044	0	840.3924586	0	1063.46983	0	1377.933213	0
01/01 19:00:00	369.5339662	0	593.1589199	0	754.2122248	0	1097.801776	0
01/01 20:00:00	406.9284804	0	628.7631052	0	770.4414891	0	1130.627305	0
01/01 21:00:00	622.9342271	0	844.6191532	0	993.13869	0	1380.160664	0
01/01 22:00:00	581.3782472	0	801.5741402	0	931.2995985	0	1315.990176	0
01/01 23:00:00	605.1864172	0	823.6183028	0	944.628595	0	1308.365455	0
01/01 24:00:00	844.5920115	0	1062.994028	0	1200.79619	0	1556.63649	0
01/02 01:00:00	876.09648	0	1094.441026	0	1227.27087	0	1579.993127	0
01/02 02:00:00	884.1297562	0	1101.641583	0	1227.66614	0	1585.57345	0
01/02 03:00:00	876.4610257	0	1094.335443	0	1213.996104	0	1559.519743	0
01/02 04:00:00	856.2513248	0	1075.026395	0	1187.65842	0	1507.058892	0
01/02 05:00:00	847.8518259	0	1067.432762	0	1174.991461	0	1476.099251	0

Figure 42 - RES4BUILD Energy Model Output Extract

These CSV outputs are then post-processed in Excel to produce the required building heating and cooling demand profiles in the 8,760 data point format required for WP3 as shown in Figure 44 below. A graphical display of these thermal energy demand profiles is provided in the Building Thermal Energy Demand Profiles section of this report. The energy model location dry bulb temperature (°C), and Global and Diffuse Horizontal Radiation (Wh/m2) were also included as required inputs for the RES4BUILD system simulation in WP3.



Date/Time	Heating kW.h	Cooling kW.h	Dry Bulb Temperature {C}	Global Horizontal Radiation {Wh/m2}	Diffuse Horizontal Radiation {Wh/m2}
01/01 01:00:00	16.12	0.00	6.8	0	0
01/01 02:00:00	13.14	0.00	8.1	0	0
01/01 03:00:00	14.44	0.00	5.4	0	0
01/01 04:00:00	15.99	0.00	5.2	0	0
01/01 05:00:00	16.02	0.00	4.9	0	0
01/01 06:00:00	16.80	0.00	4.7	0	0
01/01 07:00:00	17.04	0.00	4.6	0	0
01/01 08:00:00	16.73	0.00	4.5	0	0
01/01 09:00:00	17.80	0.00	4.4	53	48
01/01 10:00:00	15.69	0.00	4.6	173	129
01/01 11:00:00	12.57	0.00	4.8	285	157
01/01 12:00:00	13.70	0.00	5	228	183
01/01 13:00:00	12.05	0.00	5.1	393	217
01/01 14:00:00	10.13	0.00	5.1	372	200
01/01 15:00:00	12.66	0.00	5.2	179	170
01/01 16:00:00	12.81	0.00	4.9	185	102
01/01 17:00:00	13.63	0.00	4.7	54	47
01/01 18:00:00	14.75	0.00	4.4	0	0
01/01 19:00:00	10.44	0.00	3.9	0	0
01/01 20:00:00	11.00	0.00	3.4	0	0
01/01 21:00:00	14.71	0.00	2.9	0	0
01/01 22:00:00	13.91	0.00	3.2	0	0
01/01 23:00:00	14.11	0.00	3.4	0	0
01/01 24:00:00	18.08	0.00	3.7	0	0
01/02 01:00:00	18.54	0.00	3.3	0	0

Figure 43 - RES4BUILD Energy Model Output Extract post processing CSV

An example building thermal energy demand profile for the Cork Commercial Office energy model is provided in Figure 45 below. The cooling profile is significantly lower in comparison to the previous Closed System methodology, with peak cooling values and cooling season duration more representative of a typical typology profile.

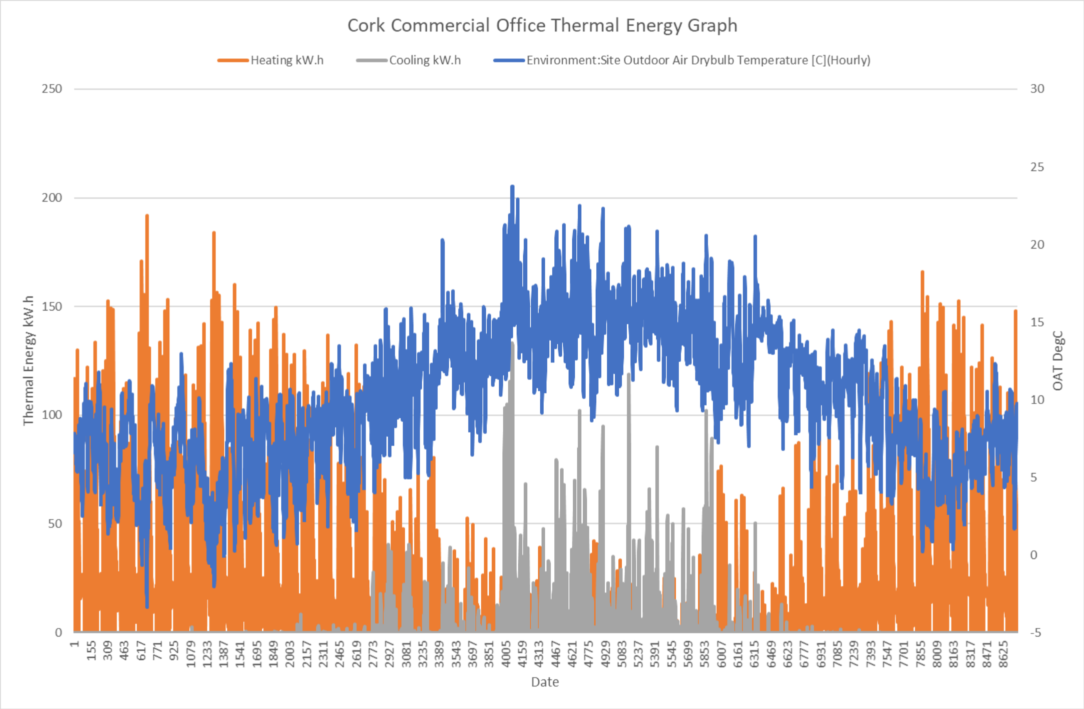


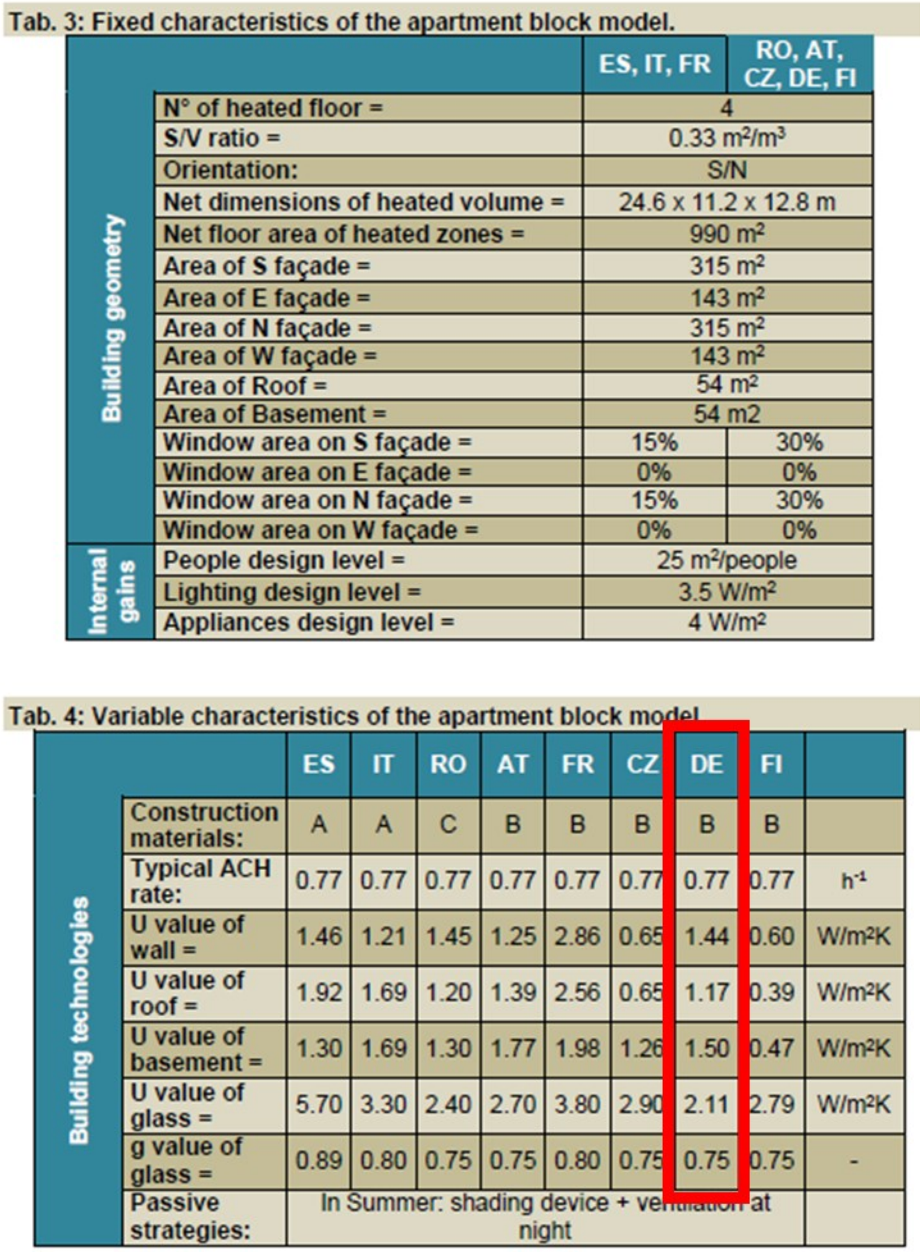
Figure 44 - Example Building Thermal Energy Demand Profile for the Cork Commercial Office

Despite, appearing more in line with expected results, the energy modelling methodology still required validation against a known output as detailed below.

It was decided to validate the proposed methodology and to confirm if the modelled thermal energy demand profiles were generally in line with other accepted thermal energy demand profiles and representative of actual building stock energy demand.

To do this the Open System – Individual Extensible modelling methodology used the known and widely accepted ENTRANZE heating and cooling energy demand research input data and output results for comparison.

Taking the MFRB (referred to as Apartment Block in the ENTRANZE report) building typology geometry – which is identical in RES4BUILD and ENTRANZE research - in the Berlin climate, and the available input data as summarised in the table below, this is input into the Open System tool in Grasshopper to compare the output results to the ENTRANZE results. The details of the typology from the relevant ENTRANZE report as shown in Figure 46 below.



Tab. 3: Fixed characteristics of the apartment block model.

		ES, IT, FR	RO, AT, CZ, DE, FI
Building geometry	N° of heated floor =	4	
	S/V ratio =	0.33 m²/m³	
	Orientation:	S/N	
	Net dimensions of heated volume =	24.6 x 11.2 x 12.8 m	
	Net floor area of heated zones =	990 m²	
	Area of S façade =	315 m²	
	Area of E façade =	143 m²	
	Area of N façade =	315 m²	
	Area of W façade =	143 m²	
	Area of Roof =	54 m²	
	Area of Basement =	54 m2	
	Window area on S façade =	15%	30%
	Window area on E façade =	0%	0%
	Window area on N façade =	15%	30%
	Window area on W façade =	0%	0%
Internal gains	People design level =	25 m²/people	
	Lighting design level =	3.5 W/m²	
	Appliances design level =	4 W/m²	

Tab. 4: Variable characteristics of the apartment block model

		ES	IT	RO	AT	FR	CZ	DE	FI	
Building technologies	Construction materials:	A	A	C	B	B	B	B	B	
	Typical ACH rate:	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	h⁻¹
	U value of wall =	1.46	1.21	1.45	1.25	2.86	0.65	1.44	0.60	W/m²K
	U value of roof =	1.92	1.69	1.20	1.39	2.56	0.65	1.17	0.39	W/m²K
	U value of basement =	1.30	1.69	1.30	1.77	1.98	1.26	1.50	0.47	W/m²K
	U value of glass =	5.70	3.30	2.40	2.70	3.80	2.90	2.11	2.79	W/m²K
	g value of glass =	0.89	0.80	0.75	0.75	0.80	0.75	0.75	0.75	-
	Passive strategies:	In Summer: shading device + ventilation at night								

Figure 45 -Validation Model ENTRANZE Inputs

A graphical comparison of the (first) RES4BUILD energy model and (second) ENTRANZE Berlin MFRB heating and cooling demand profile is provided below in Figure 47 and 48.

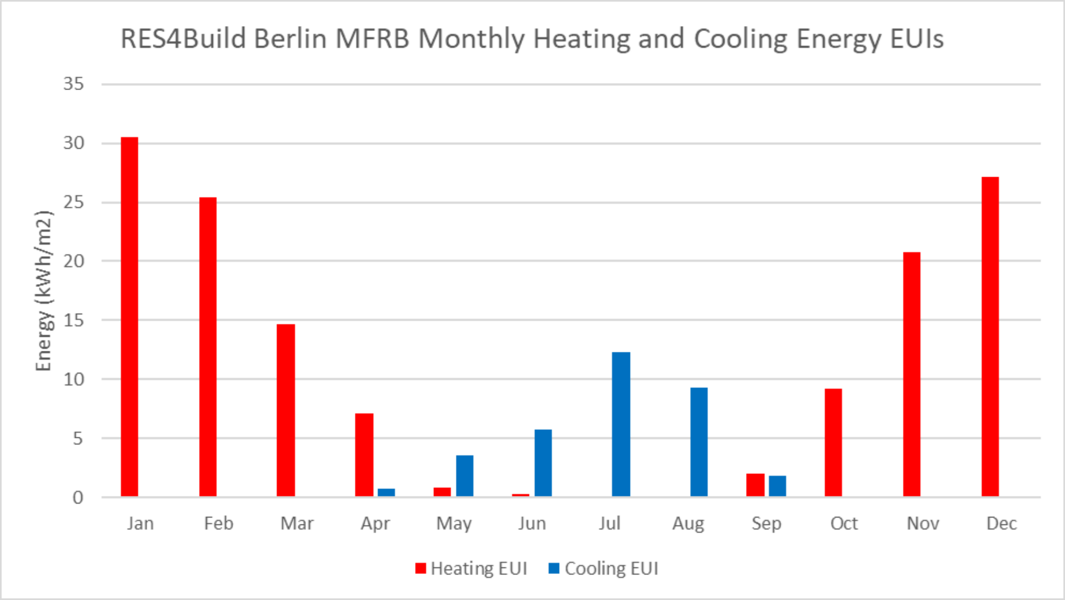


Figure 46 – RES4BUILD Berlin MFRB Monthly Demand Profile

2.2.9 Berlin (DE)

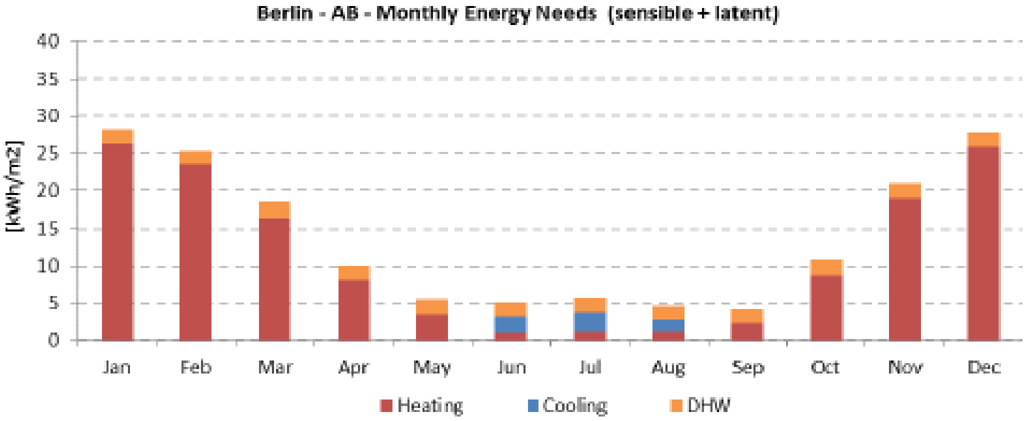


Figure 47: Monthly energy needs for heating, cooling and DHW of the apartment block located in Berlin.

Figure 47 – ENTRANZE Berlin MFRB Monthly Demand Profile

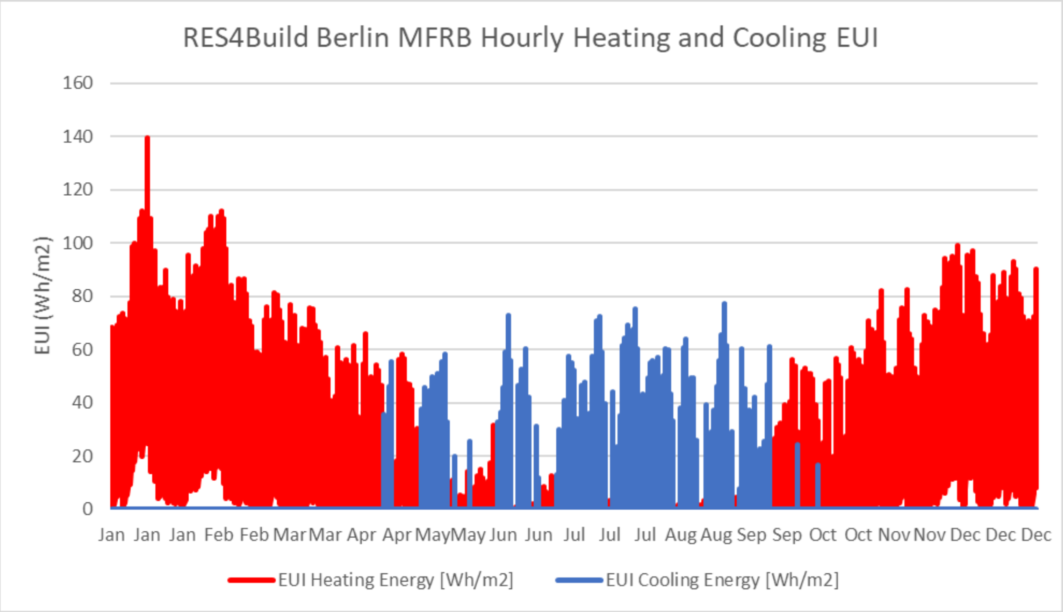


Figure 48 – RES4BUILD Berlin MFRB Hourly Demand Profile

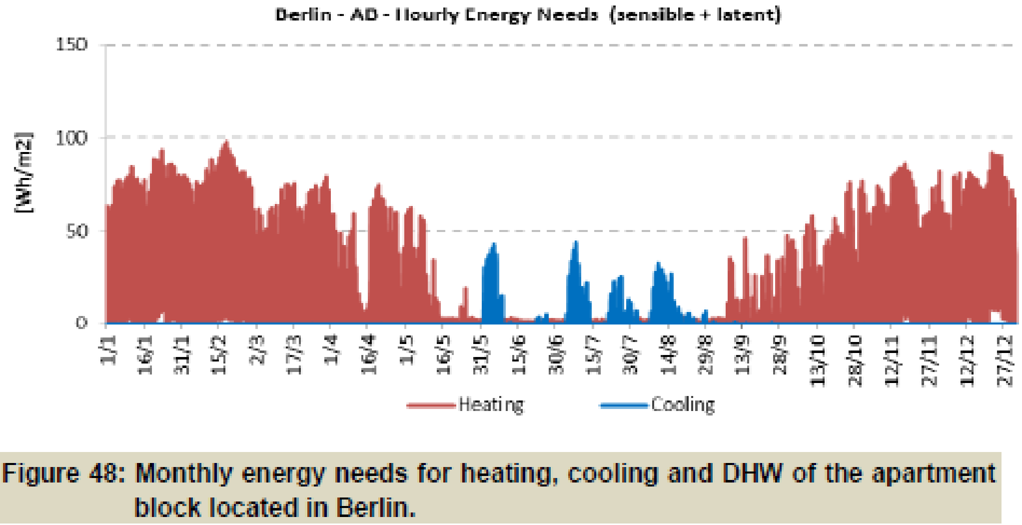


Figure 48: Monthly energy needs for heating, cooling and DHW of the apartment block located in Berlin.

Figure 49 – ENTRANZE Berlin MFRB Hourly Demand Profile

Initially, it can be seen that there are some differences between the two energy model profiles. The RES4BUILD Berlin energy model has a larger cooling peak demand of 78 Wh/m^2 and longer cooling season compared to the ENTRANZE model (48 Wh/m^2). This results in a significantly greater monthly cooling energy demand for the RES4BUILD energy model. Additionally, while the heating season is similar, the peak heating demand is larger in the RES4BUILD model (140 Wh/m^2) compared to the ENTRANZE model (100 Wh/m^2).

This deviation in results can be partly explained by the weather file or climate used in both models. The RES4BUILD energy model uses the most recent TMY 2004-2018 weather file which included the warmest years recorded in recent history (increasing cooling demand) and greater temperature extremes (increasing peak loads). The ENTRANZE model weather file uses older climate data with less extreme air temperatures and cooler summers.

Additionally, the RES4BUILD energy model uses fixed heating and cooling set points of 21 °C and 24 °C respectively, with simplified fixed temperature and set back control - unoccupied setback temperatures of 16 °C and 27 °C respectively. This results in heating and cooling energy demand recorded with any small variance in room temperature, with no allowances for temperature dead-bands (a temperature range in which neither heating nor cooling is required) or adaptive comfort in shoulder seasons. The ENTRANZE building energy model heating and cooling setpoints 21 °C and 26 °C respectively, and the control strategy was not immediately clear from the report.

This learning on the importance of temperature setpoints and control was brought forward into the RES4BUILD building thermal energy demand models as flexibility with heating and cooling setpoints to represent 'dead-bands' was included to be more representative of actual building operation.

Despite these model differences, on average over the year there is not a significant difference between the RES4BUILD and ENTRANZE models heating energy demand with less than 1% deviation as shown in Table 7 below. There is a significant difference in cooling demand modelled (81%), however based on the increasing global temperatures and weather extremes as shown in recent weather data increased cooling demand is expected. Building electricity demand was not modelled in this test case as was not modelled in the ENTRANZE report.

Table 8 - Open System Validation Comparison Table – ENTRANZE

Results Comparative Analysis	**Heating**	**Cooling**	**Elec**	**Total**
	kWh/m2/yr	**kWh/m2/yr**	**kWh/m2/yr**	**kWh/m2/yr**
RES4BUILD	138.1	33.6	NA	171.7
ENTRANZE	136.8	6.4	NA	143.2
Deviation	*1%*	*81%*	*NA*	*17%*

Based on this test case, it is accepted that the energy modelling tool is validated and that the output thermal energy demand profiles are presentative of the EU building stock. A final check to compare the updated RES4BUILD Cork commercial office energy model versus the Arup office actual building data reconfirmed the conclusion of a validated energy modelling tool for representative thermal energy demand profiles, with a relatively small difference in estimated heating and cooling energy demand, accounted by the difference in building geometry and operation, as summarised in Table 8 below.

Table 9 -- Open System Validation Comparison Table – Arup Office, Cork

Results Comparative Analysis	**Heating**	**Cooling**	**Elec**	**Total**
	kWh/m2/yr	**kWh/m2/yr**	**kWh/m2/yr**	**kWh/m2/yr**
RES4BUILD	54.8	9.8	NA	64.6
Arup Office Data	39.8	6.4	NA	60.6
Deviation	*27%*	*35%*	*NA*	*6%*

As a validated energy modelling methodology with EU representative building energy profile outputs, the flexible Open System, with editable inputs to meet changing European landscapes and markets, is the chosen energy modelling methodology for the RES4BUILD Thermal Energy Demand Profiles.

4 Building Thermal Energy Demand Profiles

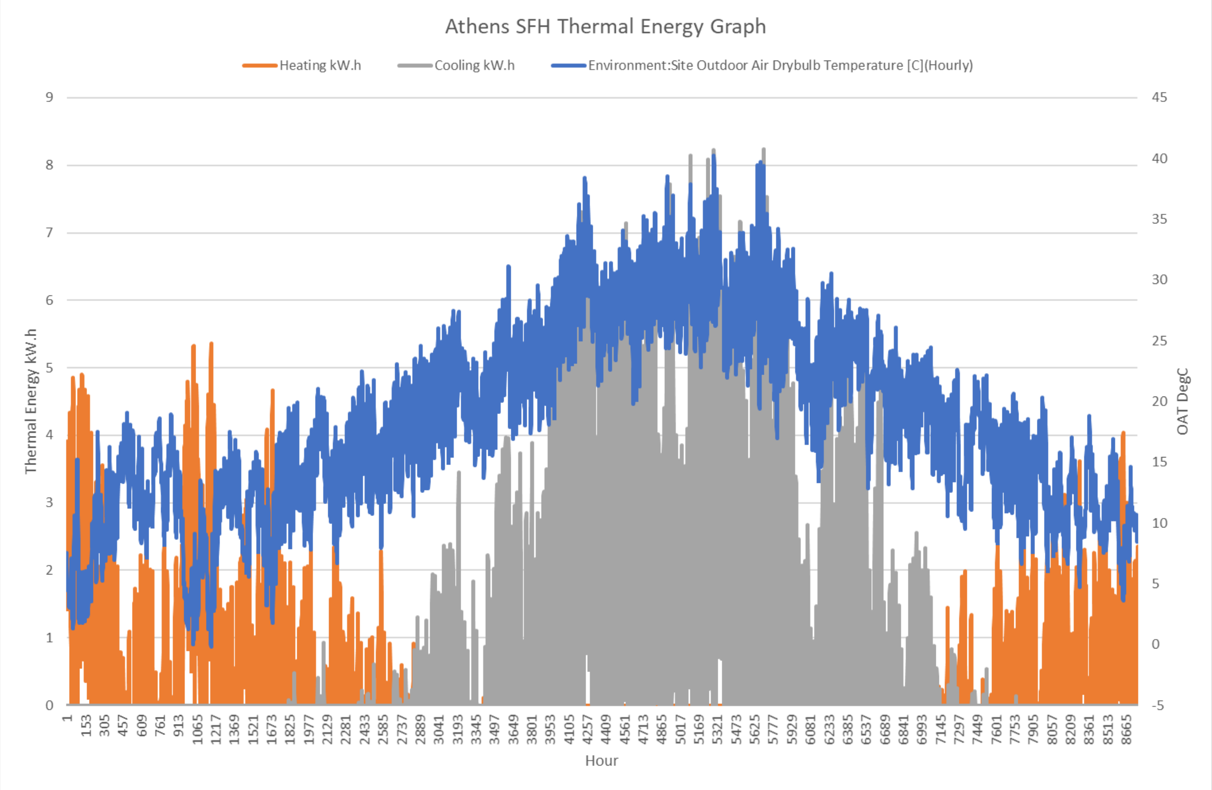
As detailed above, the building thermal energy demand profiles for 4 building typologies in 4 climates across Europe were produced using the RES4BUILD open system methodology – Rhino-Grasshopper based energy modelling script with EnergyPlus engine and model inputs as summarised in Appendix C.

The resulting building thermal energy demand profiles produced are shown graphically in the following paragraphs as an annual heating energy (red) and cooling (grey) demand profile in Wh per m2 floor area, and outside air temperature (blue) in DegC overlay for climate perspective.

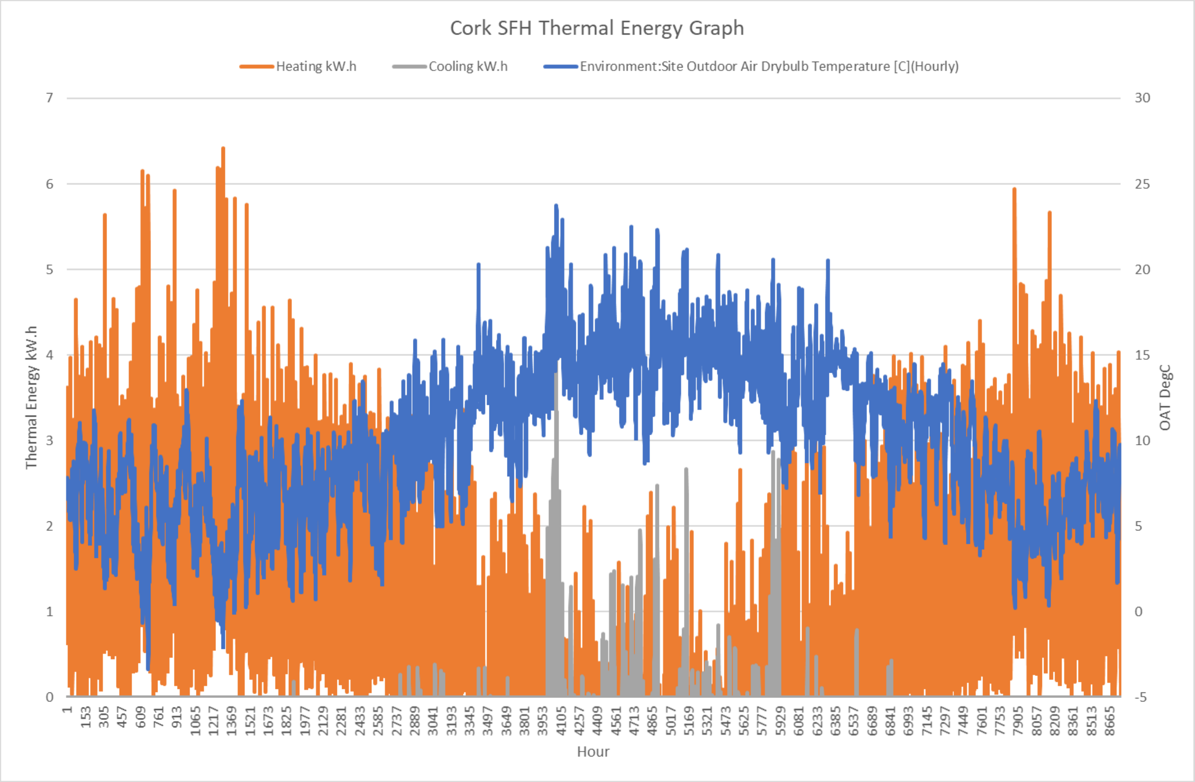
These thermal energy demand profiles are utilised in WP3 numerical tools to produce RES4BUILD energy system operation profiles, as summarised in in Section 5.

4.1 Single Family Home (SFH)

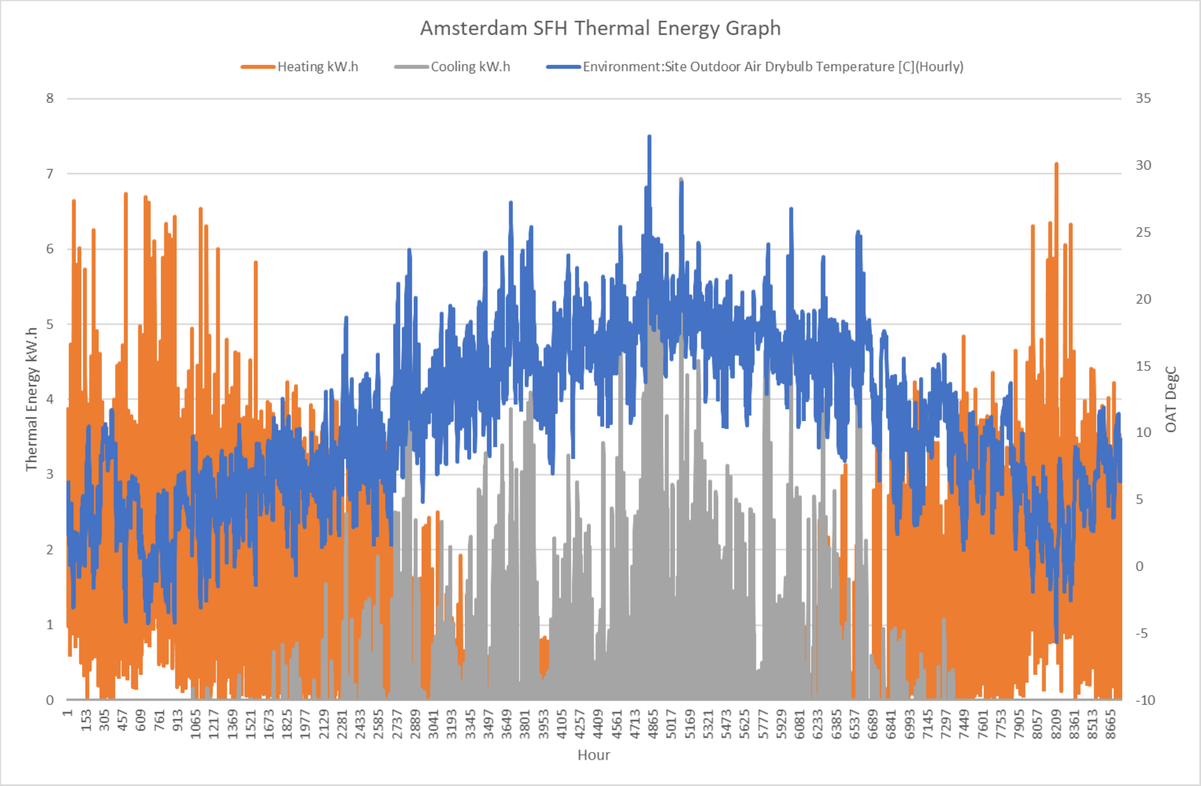
4.1.1 Athens, Greece



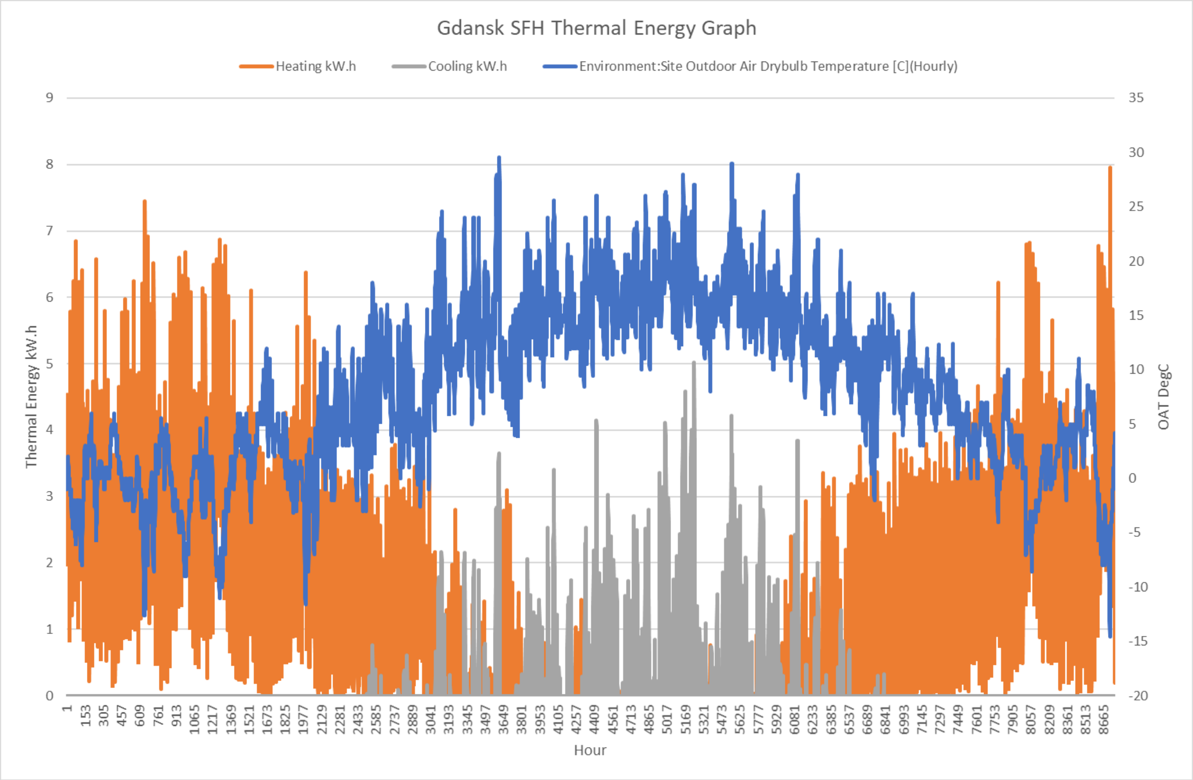
4.1.2 Cork, Ireland



4.1.3 Amsterdam, Netherlands

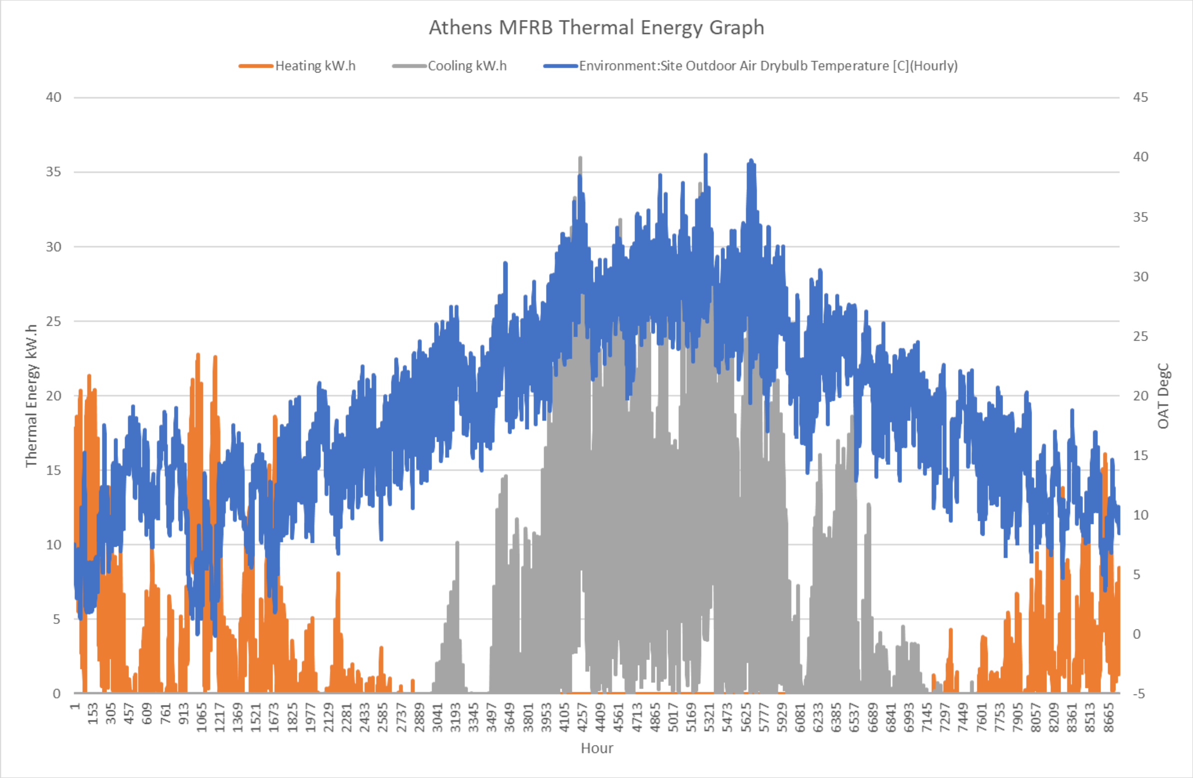


4.1.4 Gdansk, Poland

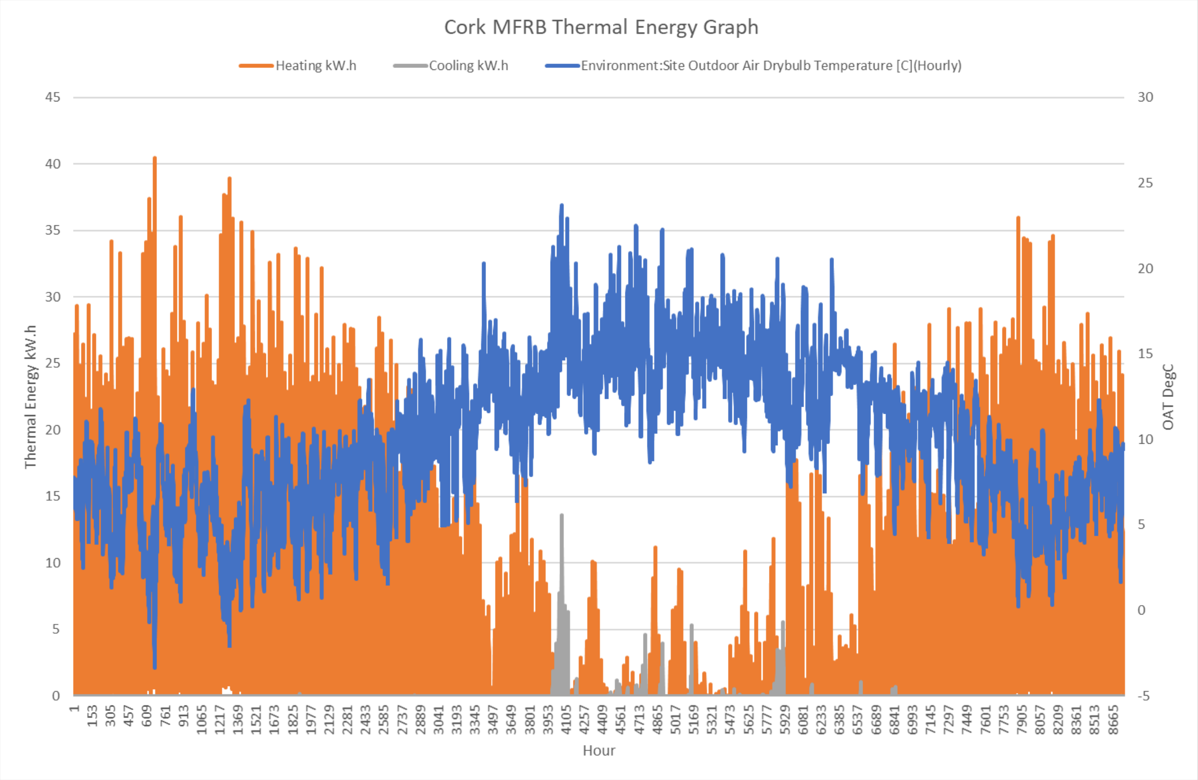


4.2 Multi-Family Residential Building (MFRB)

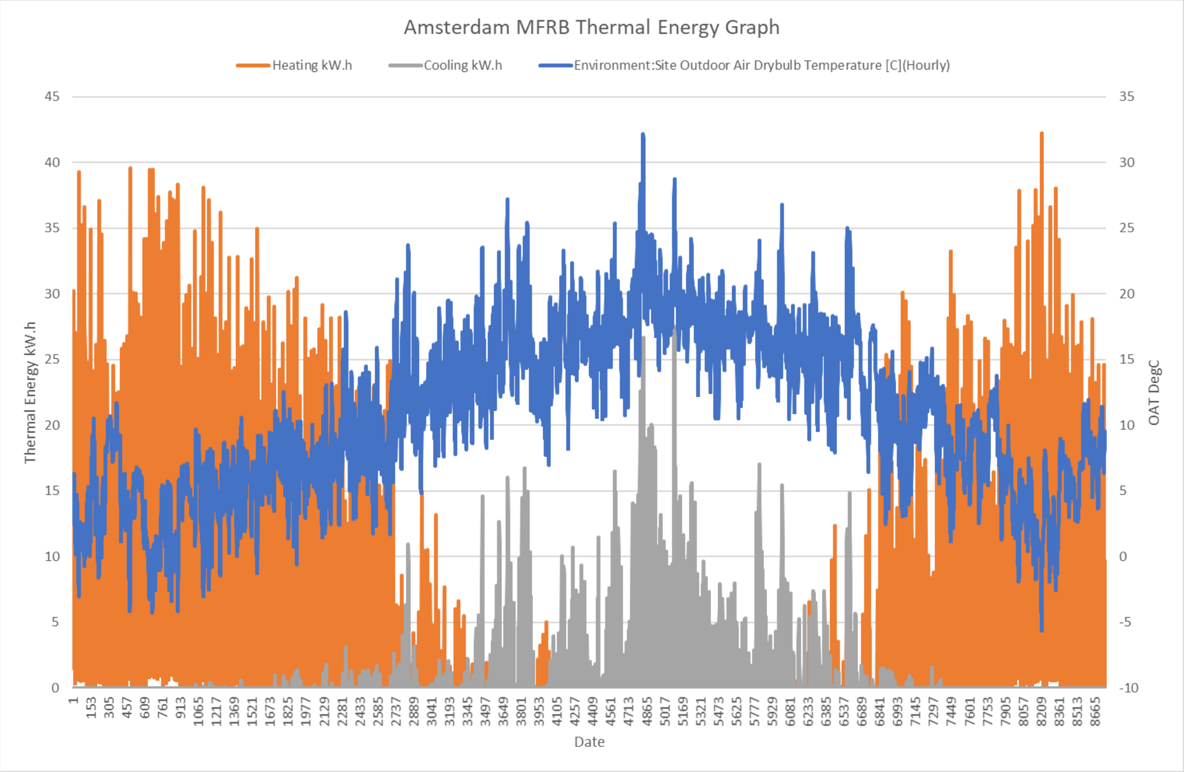
4.2.1 Athens, Greece



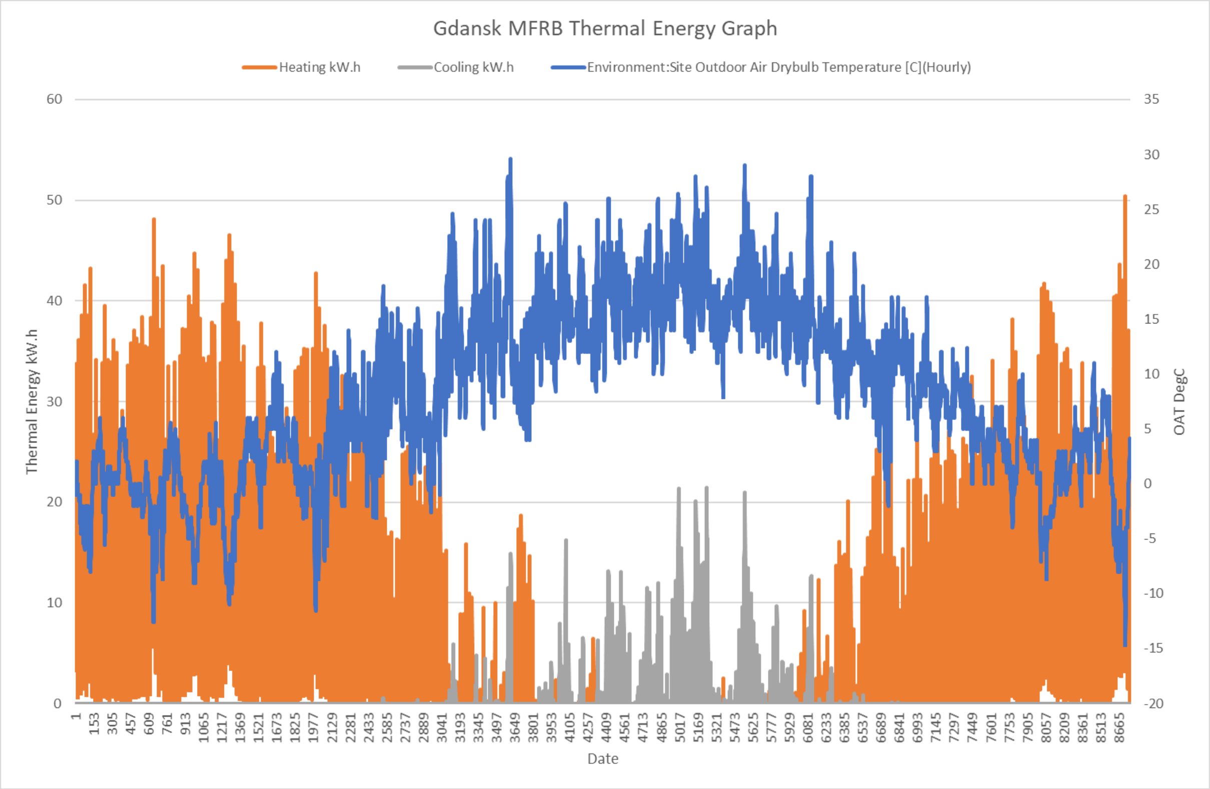
4.2.2 Cork, Ireland



4.2.3 Amsterdam, Netherlands

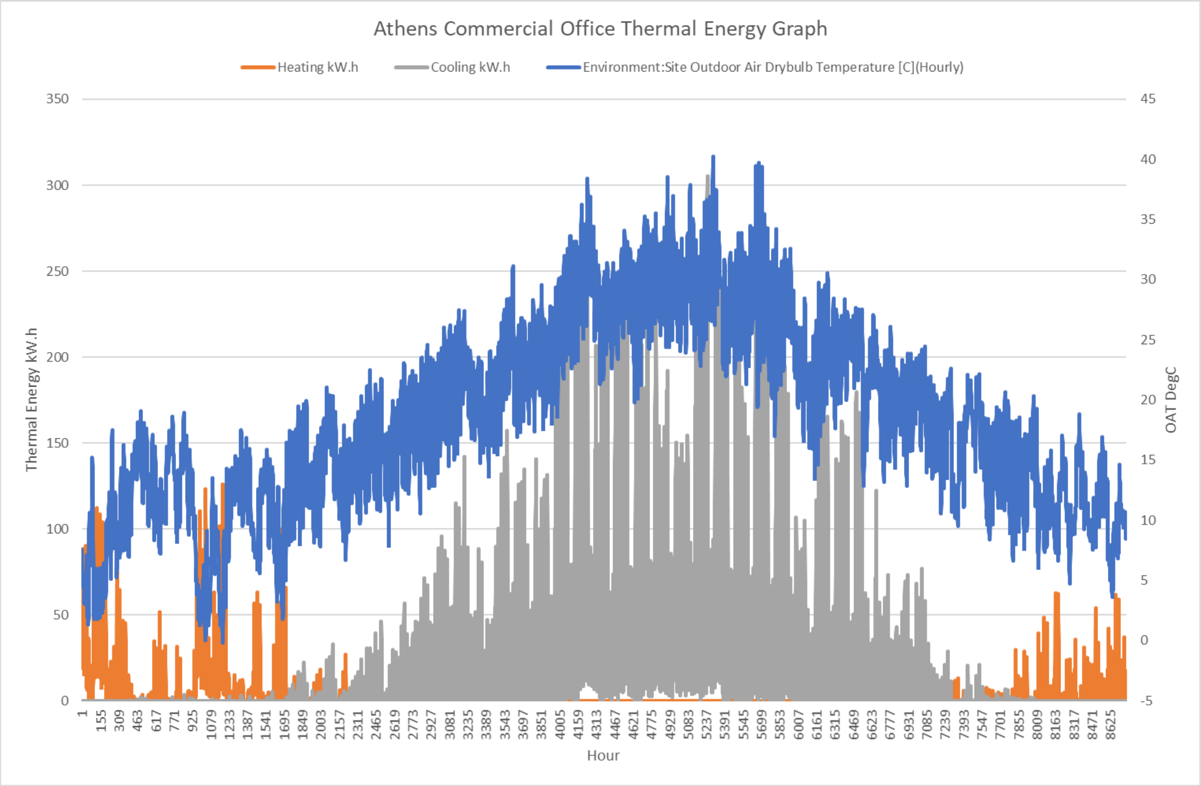


4.2.4 Gdansk, Poland

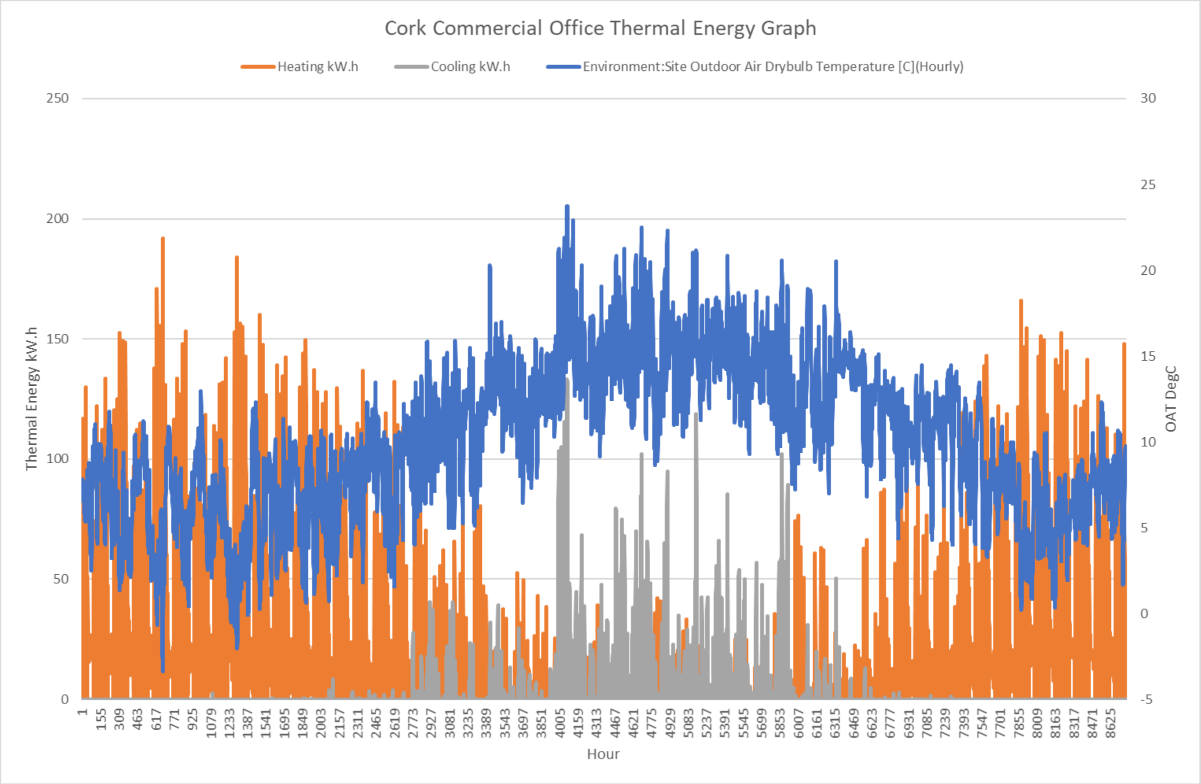


4.3 Commercial Office Building

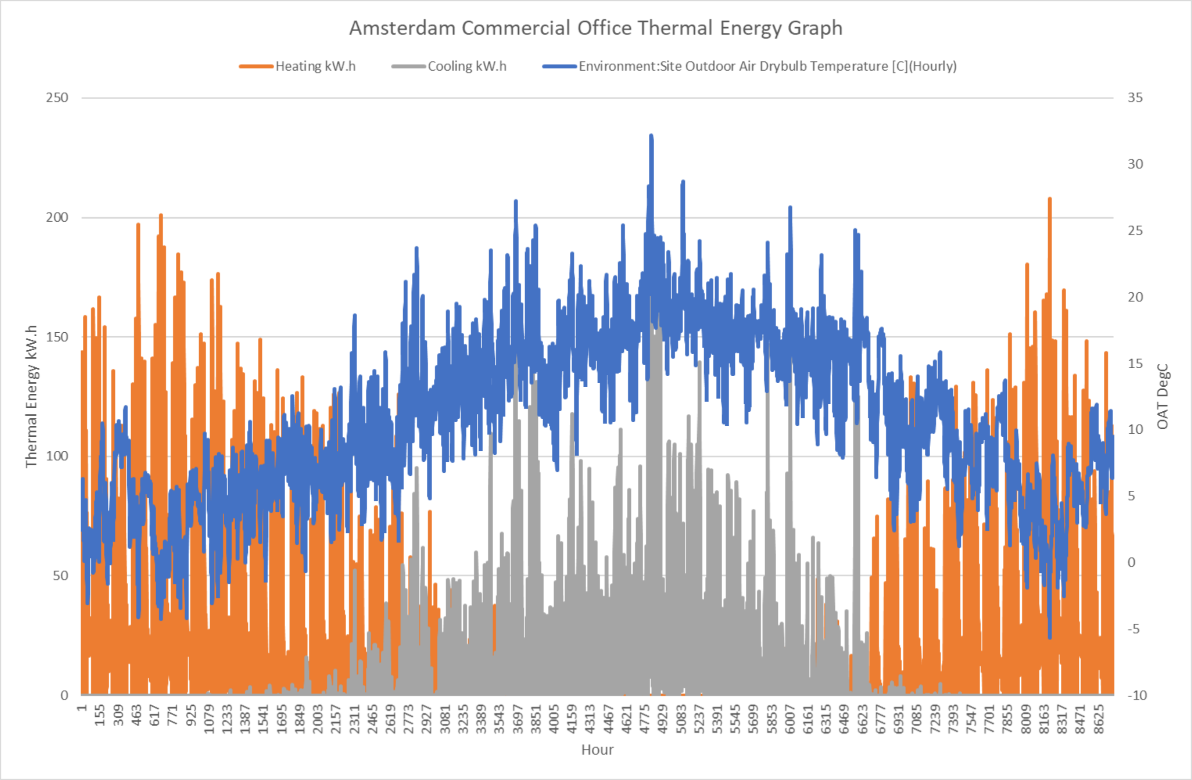
4.3.1 Athens, Greece



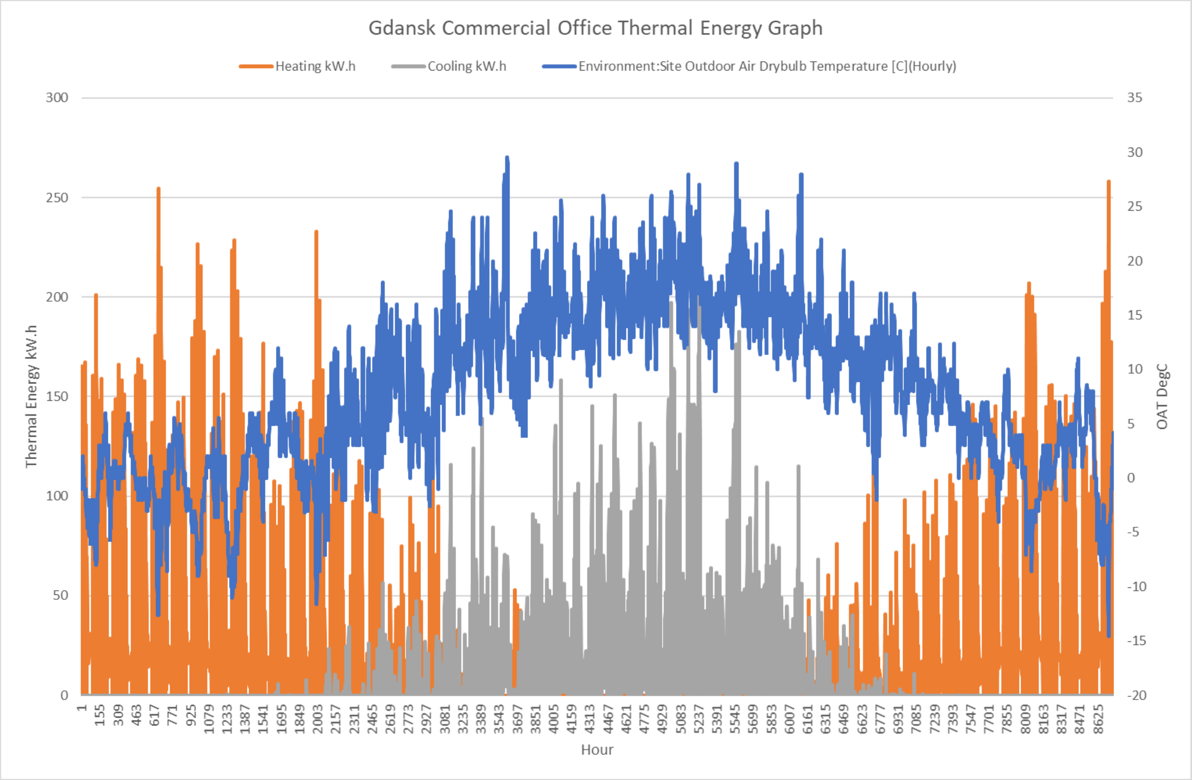
4.3.2 Cork, Ireland



4.3.3 Amsterdam, Netherlands

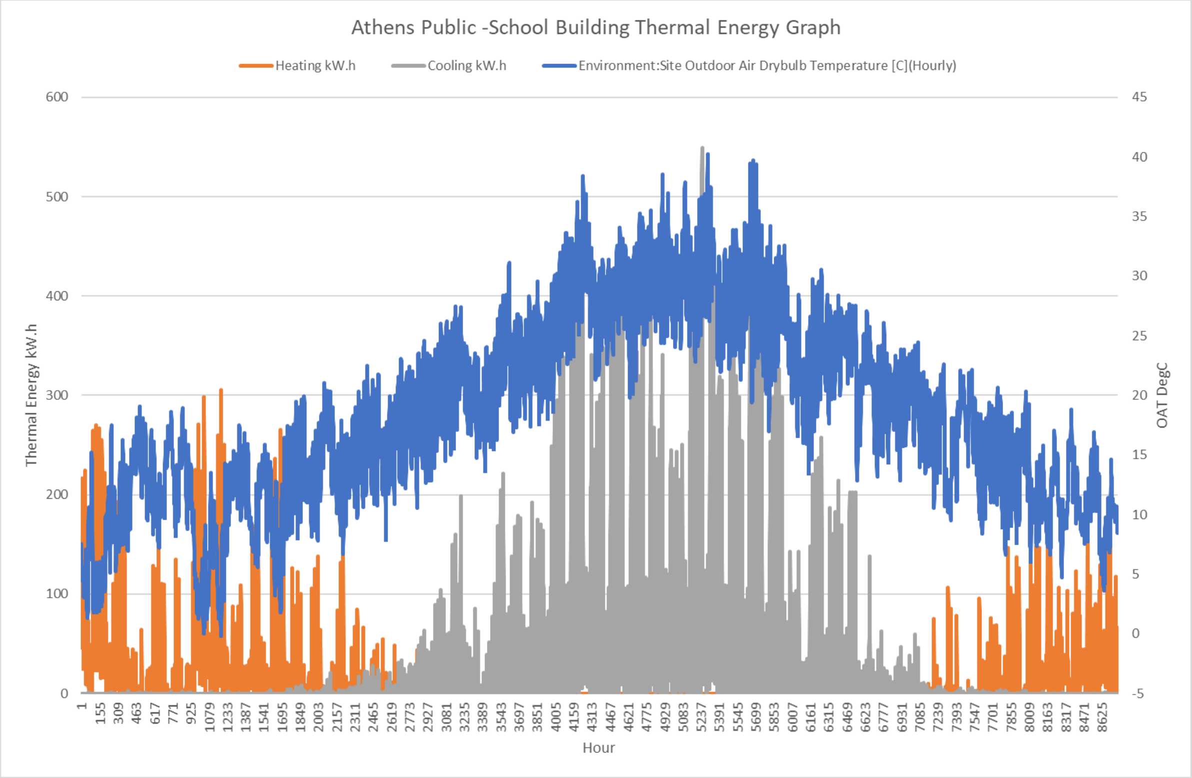


4.3.4 Gdansk, Poland

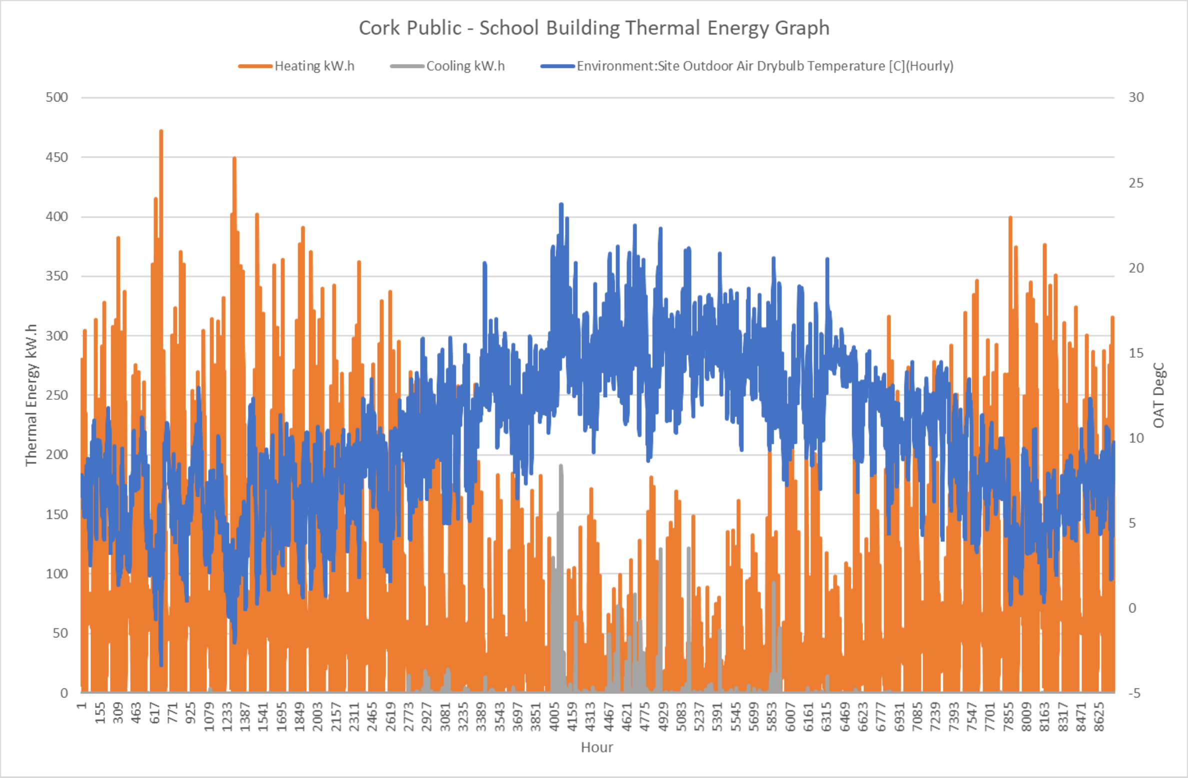


4.4 Public School Building

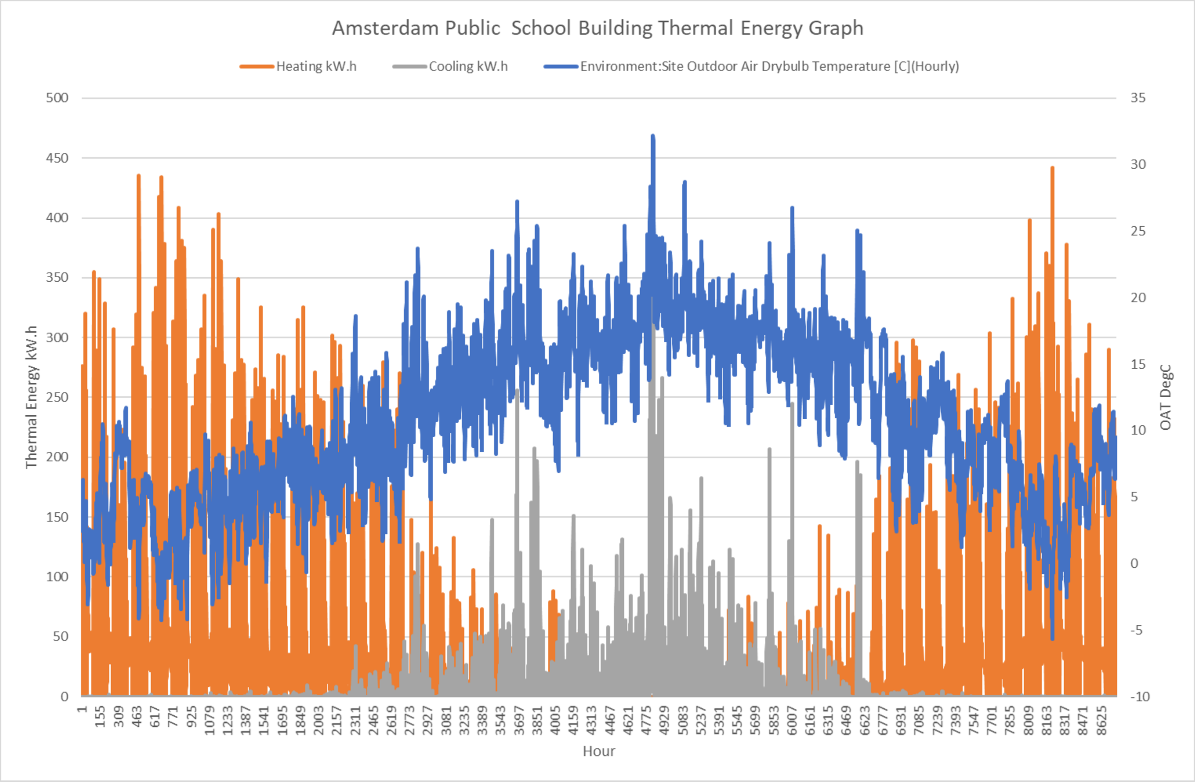
4.4.1 Athens, Greece



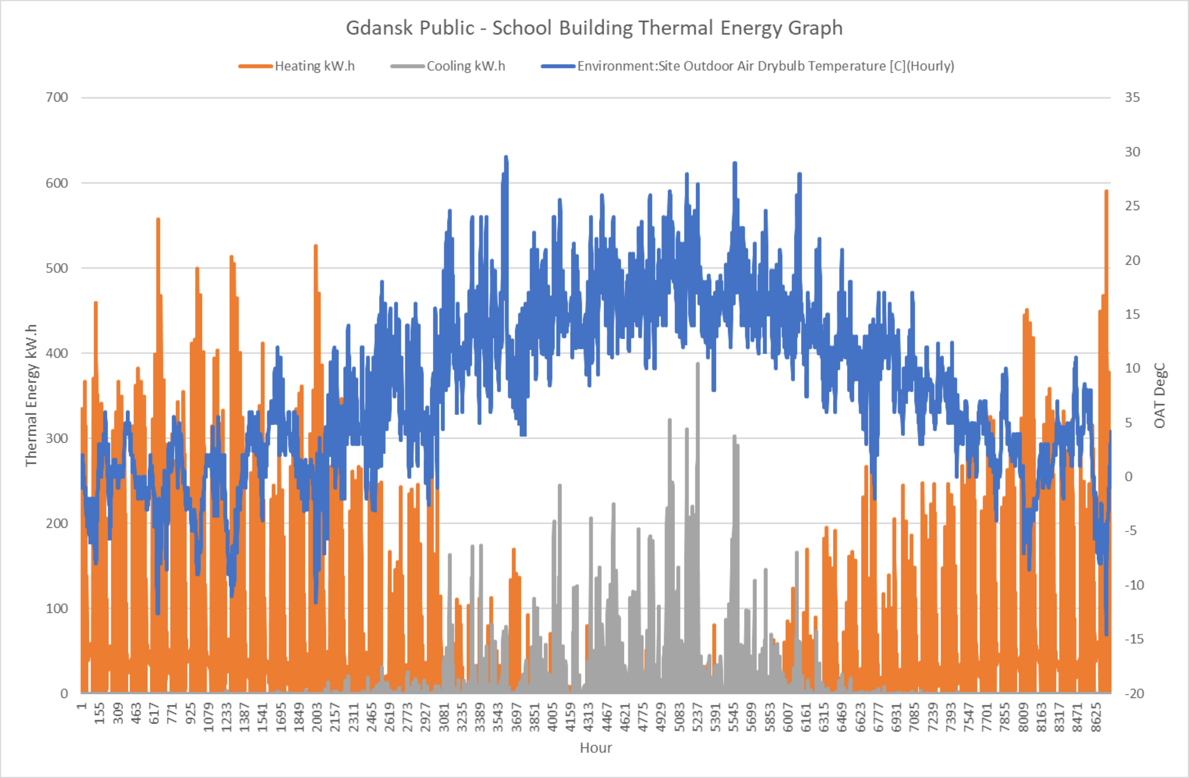
4.4.2 Cork, Ireland



4.4.3 Amsterdam, Netherlands



4.4.4 Gdansk, Poland



4.5 Summary

Summary table of annual total of the thermal energy profile results provided above;

Typology	Location	Annual Heating Demand (kWh/yr)	Annual Cooling Demand (kWh/yr)	Heating EUI (kWh/m2/yr)	Cooling EUI (kWh/m2/yr)
SFH (140m2 GIA)	Athens, Greece	3629.91	6685.16	25.92	47.75
	Cork, Ireland	8,649.09	298.78	61.78	2.13
	Amsterdam, Netherlands	7,196.19	2,789.32	51.40	19.92
	Gdansk, Poland	11240.98	1423.45	80.29	10.17
MFRB (990m2 GIA)	Athens, Greece	12,869.03	26,827.87	13	27.1
	Cork, Ireland	43,659.80	329.7	44.1	0.33
	Amsterdam, Netherlands	36,241.63	7,574.65	36.61	7.65

	Gdansk, Poland	57,788.79	3,891.82	58.37	3.93
Commercial Office (2400m2 GIA)	Athens, Greece	26,525.37	199,965.37	11.05	83.32
	Cork, Ireland	131,508.51	23,627.11	54.8	9.84
	Amsterdam, Netherlands	133,679.66	84,440.68	55.7	35.18
	Gdansk, Poland	172,656.87	81,943.75	71.94	34.14
Public – School (3500m2 GIA)	Athens, Greece	97,033.41	244,595.95	27.72	69.88
	Cork, Ireland	473,265.80	7,066.89	135.22	2.02
	Amsterdam, Netherlands	300,417.63	67,345.07	85.83	19.24
	Gdansk, Poland	403,805.20	64,266.28	115.37	18.36

5 RES4BUILD Energy System

The RES4BUILD system concept is developed in a flexible way to allow the integration of the main system components such as the multi-source heat pump and the PVT collectors, as well as standard components, such as solar thermal collectors or PVs. This results in a variety of possible layouts that can be fine-tuned according to the building typology and heating/cooling needs (highly depending on the geographical location).

5.1 System layouts

For the needs of the current report with the aim to identify the potential impact of the solution when applied in the following building types:

- Single-family home (SFH)
- Multi-Family Residential Building (MFRB)
- Commercial office building
- Public school building

To take into account the climatological conditions, all of these buildings are simulated on four different locations:

- Athens (GR)
- Cork (IE)
- Amsterdam (NL)
- Gdansk (PL)

The same system layout has been considered in all cases with few modifications. The main features of this layout and its main components are described as follows:

- **PVT collectors** further improved during the RES4BUILD project. The circulated solar fluid is directed either to the DHW tank for direct use of hot water (in residential buildings) or to the solar buffer tank for supplying with low-temperature heat (below 25 °C) the heat pump (in all buildings) or to the space heating buffer tank to support the heating production (in non-residential buildings). Solar Thermal heat can also be rejected to atmosphere through a dedicated element. The total collector surface depends on the available rooftop area and the building typology, in order to limit the heat rejected during the summer months, when the demand is low (in residential buildings) or none (in office and public buildings).
- A **multi-source heat pump** supplied with heat either from the ambient or the solar buffer tank or the ground (from a BTES field). The refrigerant of the heat pump is the HFO blend R454C with a GWP below 150. The heat pump operates either for heating or cooling depending on the needs to charge the water tanks. The performance of the heat pump is considered to be equal to the one developed and tested during the project, while its capacity is scaled with an appropriate factor to match the needs of large buildings[8].
- A **BTES field** composed of several boreholes at a depth of 80 m with their number selected according to the necessary heating or cooling capacity and to restrict the ground temperature variation during a year below ±2 °C. In locations with low ground temperatures, all locations other than Athens, the BTES is directly coupled with the space cooling tank, bypassing the heat pump,

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[8] The heating capacity of the prototype heat pump is up to 15 kW.

for rejecting heat to the ground, and thus enabling the passive (or "free") cooling. This takes place for a ground temperature below 12 °C.

- A number of water tanks with each one having a different function as follows:

    1. **DHW tank** is used only in residential buildings, charged by either the PVT collectors or the heat pump. The selected tapping profile corresponds to the "M" profile according to the EN16147:2017 standard for water-heaters, hot water storage appliances and water heating systems[9], adjusted to take into consideration the demand variation during the seasons[10].
    2. **Space buffer tank** that stores heat during winter and charged only by the heat pump in residential buildings, and by the heat pump and the collectors in non-residential ones. Therefore, the same tank functions as a space heating tank during winter (maximum charging temperature of 45 °C) and space cooling tank during summer (minimum charging temperature of 7 °C).
    3. **Solar buffer tank** that stores the low-temperature heat of the collectors, considered in all building typologies. In non-residential buildings during summer, the tank is kept charged at 25 °C, and any excess heat from the collectors is rejected to the ambient with the use of an fan to avoid the overheating of the collectors.

Some typical (simplified) layouts that correspond to heating and cooling modes in residential and non-residential buildings are depicted in the following figures.

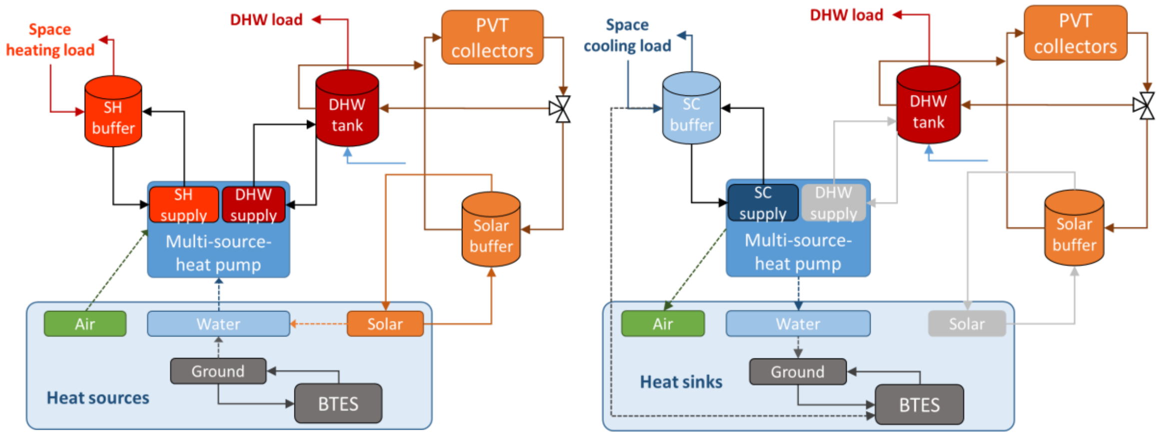

Figure 50 - Layout in residential buildings. Left: heating mode; right: cooling mode

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[9] Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for water heaters and hot water storage tanks, EU Regulation No 814/2013 2 August 2013: https://eurlex. europa.eu/eli/reg/2013/814/2017-01-09.

[10] Pilou M, Kosmadakis G, Meramveliotakis G, Krikas A. Renewable Energy Based Systems with Heat Pumps for Supplying Heating and Cooling in Residential Buildings. In Proceedings of ECOS 2021 – The 34th International Conference On Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems. June-July 2021. Available at: https://RES4BUILD.eu/results/download/ecos2021-proceedings.

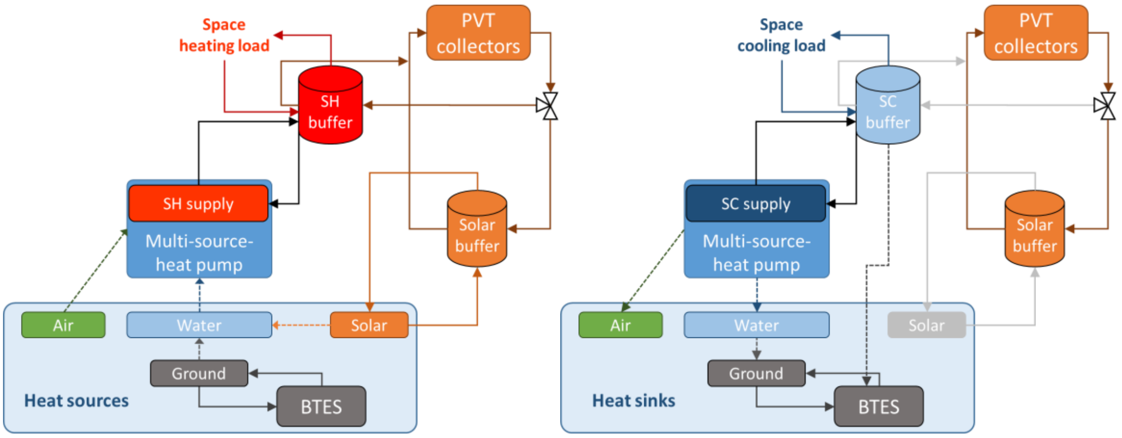

Figure 51 - Layout in non-residential buildings. Left: heating mode; right: cooling mode

The above layouts illustrate the possible heat sources at heating mode (air, BTES or solar buffer) and heat sinks (space heating or DHW tank). These have been considered in the simulation and optimisation work conducted by NCSRD and VITO respectively with the entire work-flow briefly described as follows.

5.2 Work flow

The starting point of this analysis is the availability of the demand profiles that have been produced by Arup with the methodology presented in Section 4. The next step was for NCSRD to process these profiles and proceed with minor adjustments to bring them to the appropriate format needed for the assessment. The main changes performed during this step concern:

(1) The elimination of any simultaneous heating and cooling demand;
(2) The addition of the DHW demand per time-step;
(3) The conversion of the annual values into a 15-min time-step profiles. Moreover, the necessary parameters during the year related to the weather data and the collectors (e.g. incidence angle) have been obtained through the TRNSYS software[11].

The adjusted profiles have then been imported to the system simulation tool that has been developed by NCSRD in Task 3.1, and further improved and enriched after that. Several runs have been conducted, with the main aim to fix the several sizing parameters, such as the specifications of the water tanks (e.g. volume, heat transfer coefficient to calculate the heat losses), the scaling factor of the heat pump, the number of boreholes, and the total surface of the PVT collectors.

This multi-parametric study of NCSRD resulted to a set of sizing parameters of each case, with the effort to keep as many as possible the same for a specific building typology. Once all parameters have been fixed, they have been provided to VITO to proceed with the optimisation of operational aspects. At the same time, NCSRD finalized the simulation runs to predict the system energy-related values (e.g. heat pump power, PVT heat and electricity production, etc.). These results have been provided to Arup for further processing, along with the VITO results.

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[11] Transient System Simulation Tool – TRNSYS software: https://www.trnsys.com/.

5.3 RES4BUILD System Optimization Results

On top of the 16 simulations of the RES4BUILD system executed by NCSRD, the adjusted heat/cooling load profiles together with the sizing parameters of the equipment served as an input to VITO to simulate the system using the optimal control algorithm. The methodology of this approach is discussed in detail in chapter 7 of T3.2 deliverable.

The difference between the simulations done by NCSRD and the simulated optimizations is that the latter adds an objective to the operation of the system. In this case the objective is minimizing the energy consumption of the RES4BUILD system. In order to achieve this, the objective is added together with constraints on the states of the different devices in the system:

- Heating
  - Solar buffer tank
    - T_{min}: 5 °C
    - T_{max}: 30 °C
  - Space buffer tank
    - T_{min}: 38 °C
    - T_{max}: 45 °C
  - DHW buffer tank
    - T_{min}: 25 °C
    - T_{max}: 65 °C
  - Heat pump
    - Tcd_max_sh = 47 °C (max condenser temperature for space heating)
    - Tcd_max_dhw = 55 °C (max condenser temperature for dhw production)
  - BTES
    - Tmin = 6 °C
- Cooling
  - Solar buffer tank
    - T_{min}: 5 °C
    - T_{max}: 30 °C

  - Space buffer tank
    - T_{min}: 7 °C
    - T_{max}: 12.5 °C
  - Heat pump
    - Tev_max_sc = 12 °C (max evaporator temperature for space cooling)
    - Tev_min_sc = 7 °C (min evaporator temperature for space cooling)
    - Tcd_max_sh = 47 °C (max condenser temperature for space heating)
    - Tcd_max_dhw = 55 °C (max condenser temperature for dhw production)
  - BTES
    - Tmin = 6 °C

The difference between the heating and cooling scenario is related to the space tank buffer, which is filled with hot water in the heating season and cold water in the cooling season. The optimization ensures that the above constraints are never violated, in case these constraints cannot be ensured, the problem becomes infeasible, and the optimization will fail. Therefore, the minimum temperature in the solar buffer tank is set low as the PVT collectors are the only heat source for the tank, implying that it will cool down to the ambient temperature if there is no sun for longer periods. As this is an uncontrollable input for our controller, we need to make sure that this will not lead to a constraint violation.

As it is a complex system to optimize, with many different states each having to satisfy a number of constraints, it is hard to calculate a solution for a longer time range (e.g. weeks) in one go. To overcome this, we split the optimization time range into smaller parts which are executed sequentially as shown in **Error! Reference source not found.**. In this sequence, the optimization done for time t takes the output of the optimization at t-1 as initial values. Specifically, we ran the optimizations for a 2-day period with an overlap of 1 day. We calculate the 1st and 2nd of January in one go, the results for 2nd of January are removed and the state at the end of the 1st of January is used to start the next calculation for the 2nd and 3rd of January. It is important to use an overlap period because the optimization will drain the buffers to their minimum temperature by the end of the optimization period as the objective is minimizing the energy consumption. With an overlap of 1-day we remove this undesired behaviour from the results.

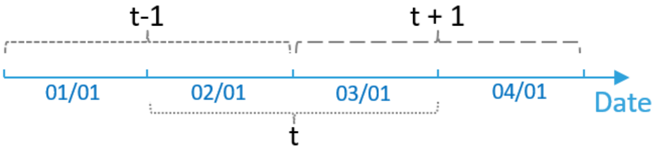


Figure 52: Split optimization time range in 2 days with an overlap of 1 day

During the execution of the optimizations for a whole heating/cooling season, it became clear that it was time consuming to optimize the system for longer periods even with the above split of the time range. The most frequent problem was that at some points in time the maximum output of the heat pump was not sufficient to meet the heating/cooling demand. In order to solve this, the maximum heat load in the input profiles was cut-off at the maximum output of the heat pump.

Another important aspect of the sizing of the RES4BUILD system in these simulation scenarios is the fact that the BTES is dimensioned in a way that it is able to meet the yearly heating and cooling demand of the buildings. This implies that the BTES is the main heat/cold source for the HP over the whole year, this was also seen in the optimization results for the heating season in the commercial office building located in Cork and Gdansk. Due to this, the results of the simulated optimizations are almost identical to the results of the normal simulations as they are already close to optimal. Optimal control will have its benefits when the BTES is not dimensioned to meet the yearly heat/cooling load and when other objectives like peak shaving and maximization of self-consumption are used. Therefore, the remainder of the document will focus solely on the results of the simulation scenarios executed by NCSRD.

5.4 RES4BUILD System Model Results

The numerical results of each of the 16 cases (4 building typologies in 4 locations) concern the energy flows of each main component as follows:

- **PVT collectors:** Heating production directed to any of the tanks (solar buffer, DHW or space buffer) or rejected to the ambient, and electricity production.
- **Multi-source heat pump:** Heating production charging any of the tanks (DHW or space buffer), cooling production charging the space buffer tank, and electricity consumption (without including the auxiliary power, described later).
- **BTES field:** Heat extracted/rejected once coupled with the heat pump for heating/cooling, heat rejected to BTES for passive cooling.

The power consumption of the water circulator pumps is also considered in the global electricity balance. Specifically, the pumps considered are the condenser and evaporator pumps of the heat pump, the solar pump, the BTES pump, as well as the air fan of the heat pump under air-source mode. All these consumptions are summed and correspond to the auxiliary power. It should be stressed that the pump for circulating water from the tanks to the space heating/cooling load is not considered in the energy balance, since this power would be needed anyway for any kind of energy system in buildings.

The final results concern the electricity balance (production vs. consumption), once the energy needs of each building are covered.

As detailed above, the building thermal energy demand profiles for 4 building typologies in 4 climates across Europe were produced using the open system methodology – Rhino-Grasshopper based energy modelling script with EnergyPlus engine and model inputs as summarised in Appendix C. Summarised representation with main findings is provided below.

5.4.1 Single Family Home (SFH)

The Single-Family Home (SFH) RES4BUILD system had the following simulation parameters for each climate location:

- Area of the PVT [m2]: 17.1 m2
- Volume of DHW Tank: 0.4 m3
- Volume of Space Heating/Cooling Tank: 0.4 m3
- Volume of Solar Buffer Tank: 0.4 m3
- Mass of the ground used by the BTES [kg]: 3.257e5 kg (for 4 boreholes with borehole depth of 80m & borehole radius of 0.09m)
- Heatpump (HP) Scaling Factor: 1

The HP scaling factor is used to adjust the size of the heat pump compared to the prototype (15kW)

The simulation results are summarised in table 9 below:

Table 10 – SFH Model Results – Total Thermal Energy EUI

Typology	Location	Total Heating EUI (kWh/m2/yr)	Total Cooling EUI (kWh/m2/yr)	Total DHW EUI (kWh/m2/yr)	% Supplied by PVT Elec
SFH (140m2 GIA)	Athens, Greece	5.96	9.88	0.43	31%
	Cork, Ireland	15.12	0.00	3.03	8%
	Amsterdam, Netherlands	12.60	0.43	1.93	7%
	Gdansk, Poland	20.39	0.00	2.63	7%

In this case the total heating and cooling Energy Use Intensity is electricity consumed by the RES4BUILD heat-pump system (including auxiliary energy of pumps etc.). A varying percentage between 31% in Athens to 7% in Gdansk is offset by the electricity generation of the PVT system, part of the overall RES4BUILD energy system.

Therefore, the net electric energy consumption by the RES4BUILD system from grid electricity, which has related GHG emissions, is the true energy use of the RES4BUILD system. Taking this into account, a summary table of the grid electricity use intensity (per m^2 floor area) for heating, cooling and DHW is provided below.

Table 11– SFH Model Results – Net Grid Thermal Energy EUI

Typology	Location	Heating Grid Elec EUI (kWh/m2/yr)	Cooling Grid Elec EUI (kWh/m2/yr)	DHW Grid Elec EUI (kWh/m2/yr)
SFH (140m2 GIA)	Athens, Greece	5.55	5.39	0.34
	Cork, Ireland	13.94	-	2.83
	Amsterdam, Netherlands	11.78	0.27	1.85
	Gdansk, Poland	18.98	-	2.48

This is a more representative value of the overall RES4BUILD system performance and shows the offsite of additional electricity demand that would be required by the building to heat, cool and produce DHW. This additional grid electricity demand will also have GHG emissions associated with it which can be calculated using the carbon intensity value(s) as outlined in chapter 2. Therefore, it is the grid heating, cooling and DHW Electricity EUI values above that are used in the RES4BUILD impact assessment calculations in chapter 6.

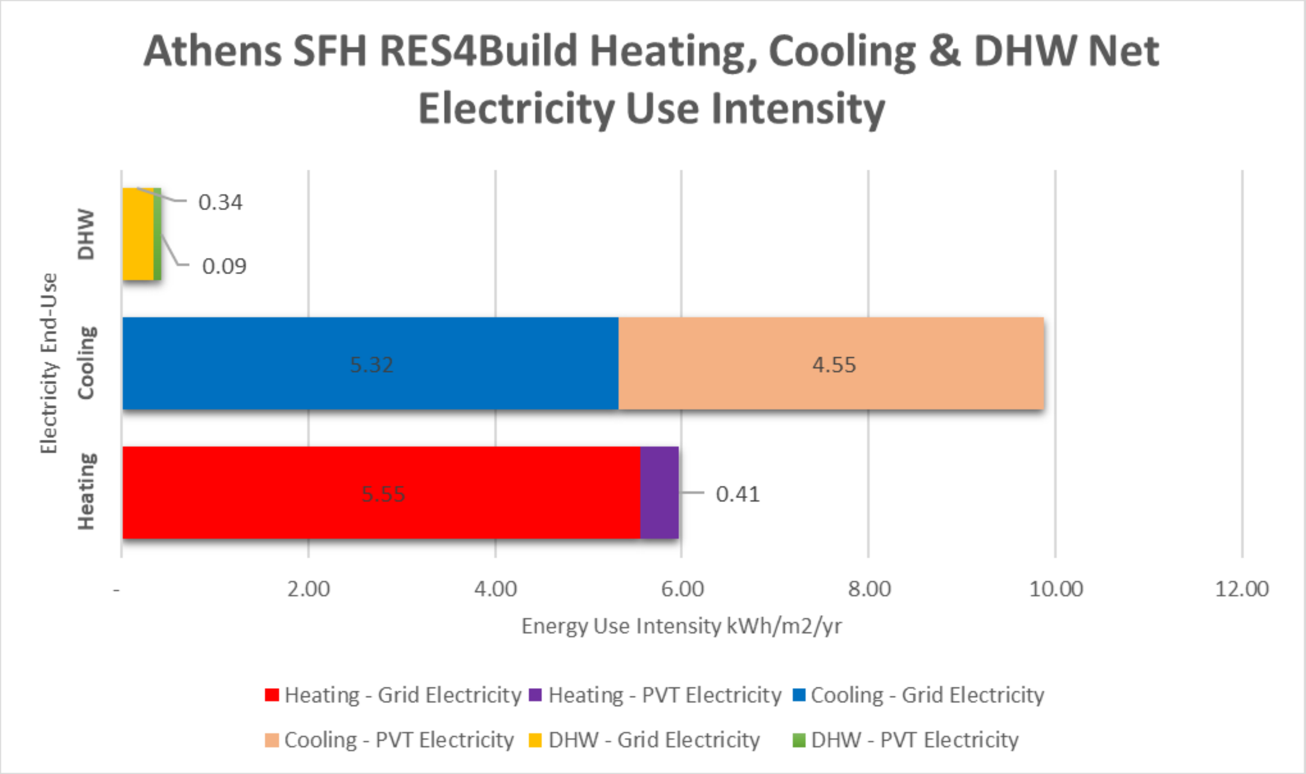
The importance of the performance of the Solar PVT system therefore is great, as the solar thermal function reduced the demand for heat-pump space heating or DHW operation, and the solar PV element offsets the heat pump grid electricity consumption, reducing related GHG emissions. A summary of the PVT system output performance per m^2 building floor area is provided below.

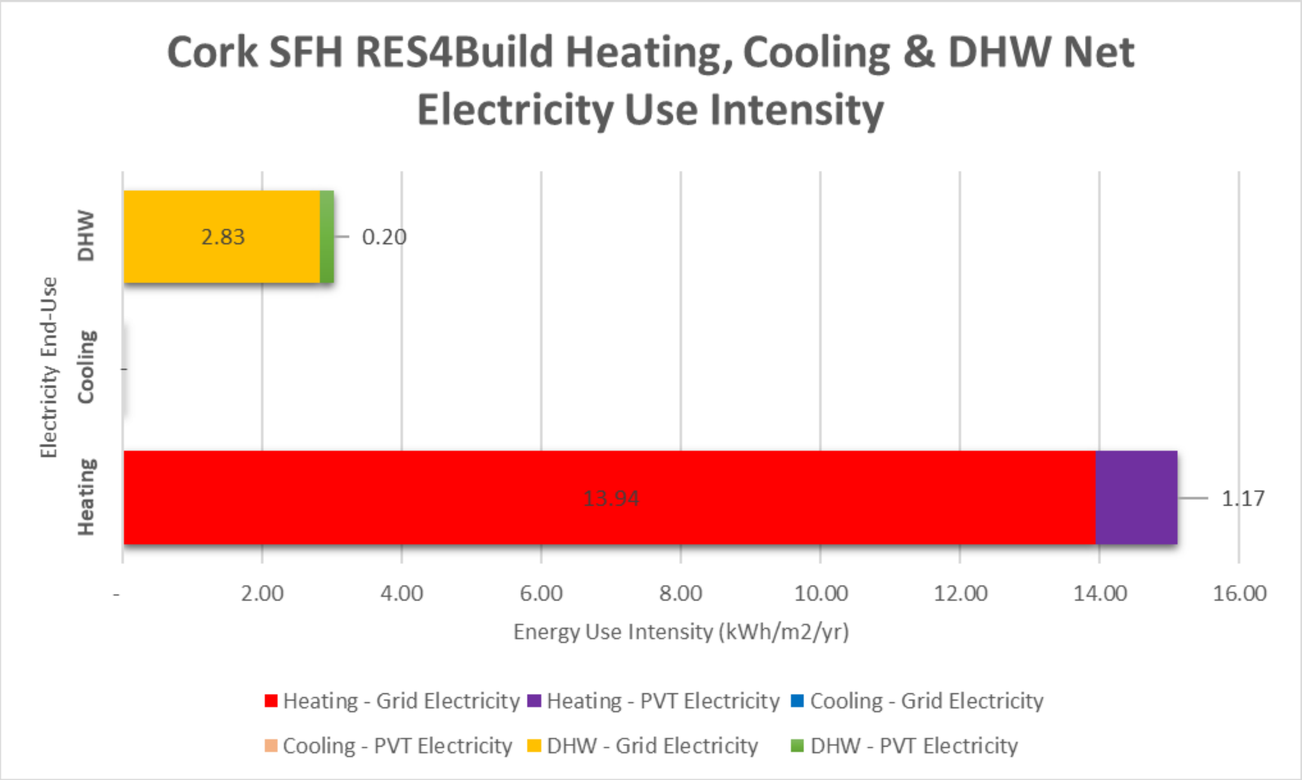
Table 12 - – SFH Model Results – PVT System Performance

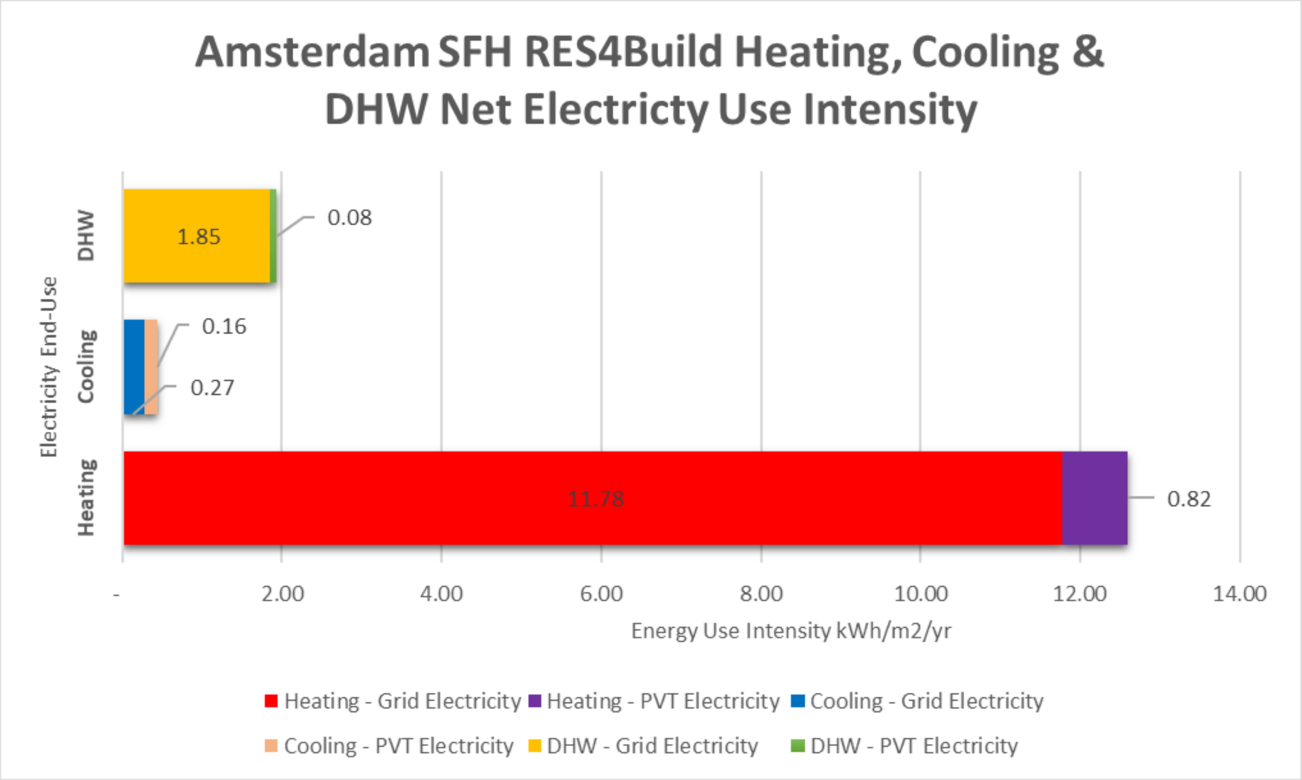
Typology	Location	PVT Electrical Output (kWh/m2/yr)	PVT Electrical Excess %	PVT Thermal Output (kWh/m2/yr)	PVT Thermal DHW Tank %	PVT Thermal Space heating Tank %	PVT Thermal Solar Buffer %	PVT Thermal Reject %
SFH (140m^2 GIA)	Athens, Greece	21.17	76%	48.07	64%	N/A	18%	18%
	Cork, Ireland	11.48	88%	31.19	27%	N/A	64%	9%
	Amsterdam, Netherlands	15.87	93%	36.82	43%	N/A	38%	19%
	Gdansk, Poland	14.21	89%	34.52	36%	N/A	48%	16%

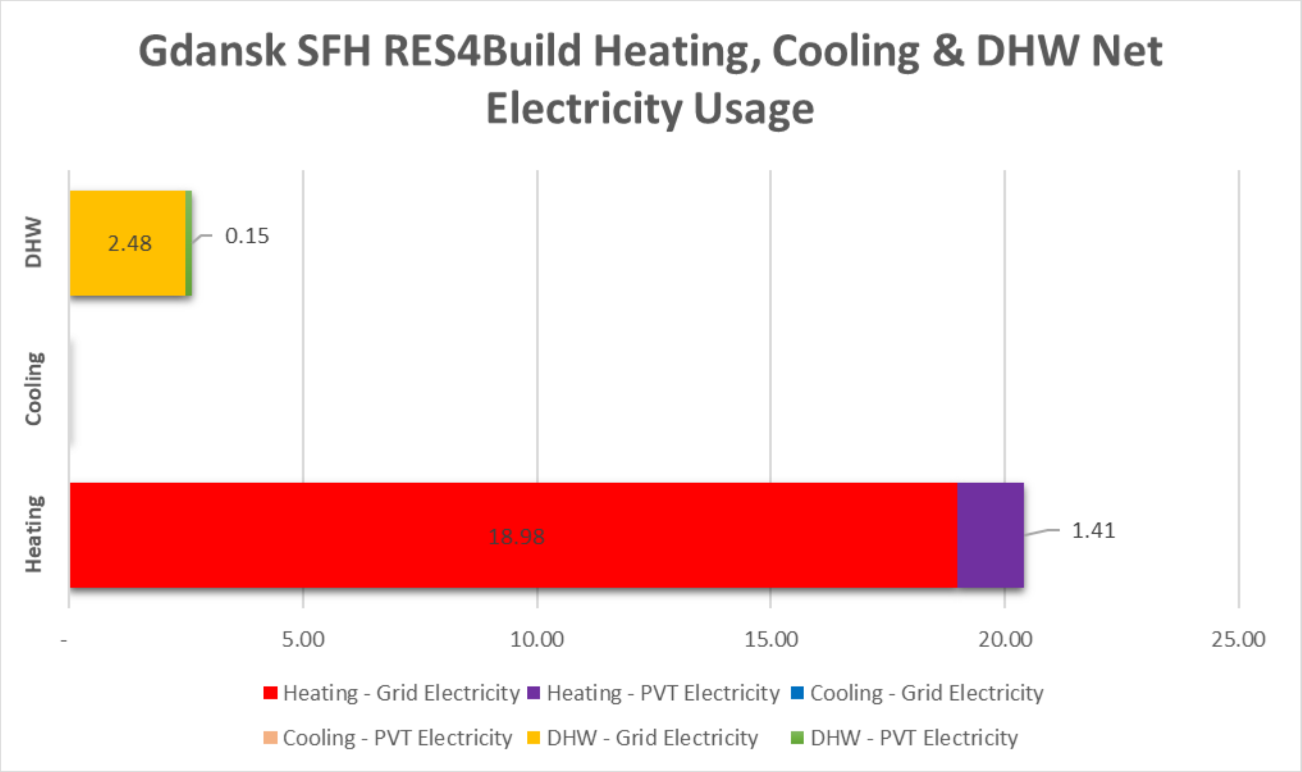
It can be seen that the Solar Thermal output is more than twice that of the PV electrical system, and there is a higher usage rate of the Solar Thermal output with only between 9% (Cork) – 19% (Amsterdam) being rejected to ambient with most utilised in the DHW tank or solar buffer for future space heating. The PVT in contrast had a lot of its generation outside the heat-pumps main consumption hours and therefore the majority of the PVT electricity produced; 93% (Amsterdam) – 76% (Athens) was not self-consumed by the RES4BUILD system but excess to be utilised by other electrical components (e.g. lighting, equipment) in the building or shared back to the grid.

A graphical breakdown of the SFH simulation thermal electrical energy use intensity in kWh/m2/yr for each location, taking into account the PVT system performance and highlighting the net grid electrical demand, is provided in the graphs below.


Athens SFH RES4Build Heating, Cooling & DHW Net Electricity Use Intensity
Electricity End-Use
DHW
Cooling
Heating
0.34
0.09
5.32
4.55
5.55
0.41
-
2.00
4.00
6.00
8.00
10.00
12.00
Energy Use Intensity kWh/m2/yr
Heating - Grid Electricity
Heating - PVT Electricity
Cooling - Grid Electricity
Cooling - PVT Electricity
DHW - Grid Electricity
DHW - PVT Electricity


Cork SFH RES4Build Heating, Cooling & DHW Net Electricity Use Intensity
Electricity End-Use
DHW
Cooling
Heating
2.83
0.20
-
13.94
1.17
-
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
Energy Use Intensity (kWh/m2/yr)
Heating - Grid Electricity
Heating - PVT Electricity
Cooling - Grid Electricity
Cooling - PVT Electricity
DHW - Grid Electricity
DHW - PVT Electricity





5.4.2 Multi-Family Residential Building (MFRB)

The Multi-Family Residential Building (MFRB) RES4BUILD system had the following simulation parameters for each climate location:

- Area of the PVT [m2]: 98.9m^2

- Volume of DHW Tank: 1.5 m^3
- Volume of Space Heating/Cooling Tank: 3 m^3
- Volume of Solar Buffer Tank: 2 m^3
- Mass of the ground used by the BTES [kg]: 11.726e6 kg (for 24 boreholes with borehole depth of 80m & borehole radius of 0.09m)
- Heat-pump (HP) Scaling Factor: 3

The simulation results are summarised in table 12 below:

Table 13 – MFRB Model Results – Total Thermal Energy EUI

Typology	Location	Total Heating EUI (kWh/m2/yr)	Total Cooling EUI (kWh/m2/yr)	Total DHW EUI (kWh/m2/yr)	% Supplied by PVT Elec
MFRB (990 m2 GIA)	Athens, Greece	3.02	6.90	1.94	27%
	Cork, Ireland	10.52	0.05	6.26	17%
	Amsterdam, Netherlands	8.66	0.54	4.51	19%
	Gdansk, Poland	14.05	0.12	5.48	15%

The total heating and cooling Energy Use Intensity is electricity consumed by the RES4BUILD heat-pump system (including auxiliary energy of pumps etc.). A varying percentage between 27% in Athens to 15% in Gdansk is offset by the electricity generation of the PVT system, part of the overall RES4BUILD energy system.

Therefore, the net electric energy consumption by the RES4BUILD system from grid electricity, which has related GHG emissions, is the true energy use of the RES4BUILD system. Taking this into account, a summary table of the grid electricity use intensity (per m2 floor area) for heating, cooling and DHW is provided below.

Table 14 – MFRB Model Results – Net Grid Thermal Energy EUI

Typology	Location	Heating Grid Elec EUI (kWh/m2/yr)	Cooling Grid Elec EUI (kWh/m2/yr)	DHW Grid Elec EUI (kWh/m2/yr)
MFRB (990 m2 GIA)	Athens, Greece	2.58	4.52	1.53
	Cork, Ireland	8.54	0.00	5.45
	Amsterdam, Netherlands	7.11	0.00	3.96
	Gdansk, Poland	5.48	0.00	4.77

This is a more representative value of the overall RES4BUILD system performance and shows the offsite of additional electricity demand that would be required by the building to heat, cool and produce DHW. This additional grid electricity demand will also have GHG emissions associated with it which can be calculated using the carbon intensity value(s) as outlined in chapter 2. Therefore, it is the grid heating, cooling and DHW Electricity EUI values above that are used in the RES4BUILD impact assessment calculations in chapter 6. In Cork, Gdansk and Amsterdam, the low total demand for cooling results in no grid electricity being required to achieve it.

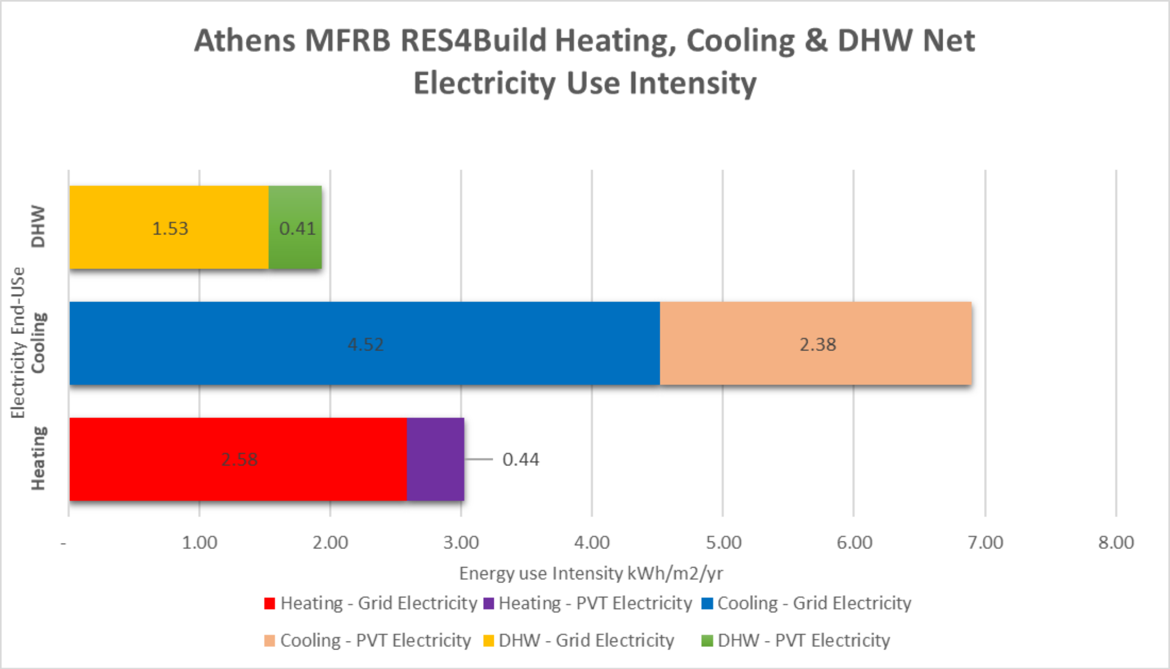
The importance of the performance of the Solar PVT system therefore is great, as the solar thermal function reduced the demand for heat-pump space heating or DHW operation, and the solar PV element offsets the heat pump grid electricity consumption, reducing related GHG emissions. A summary of the PVT system output performance per m2 building floor area is provided below.

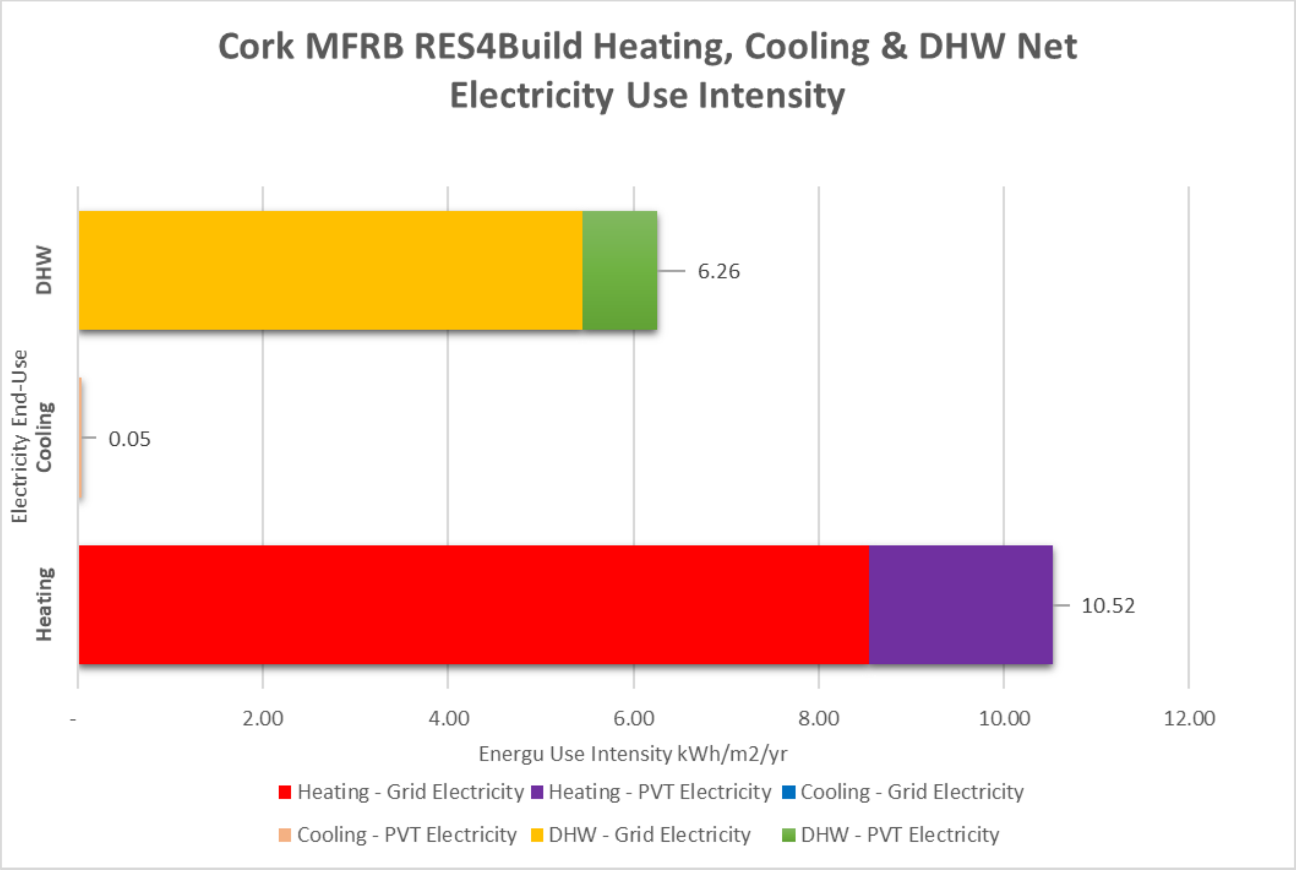
Table 15 - – MFRB Model Results – PVT System Performance

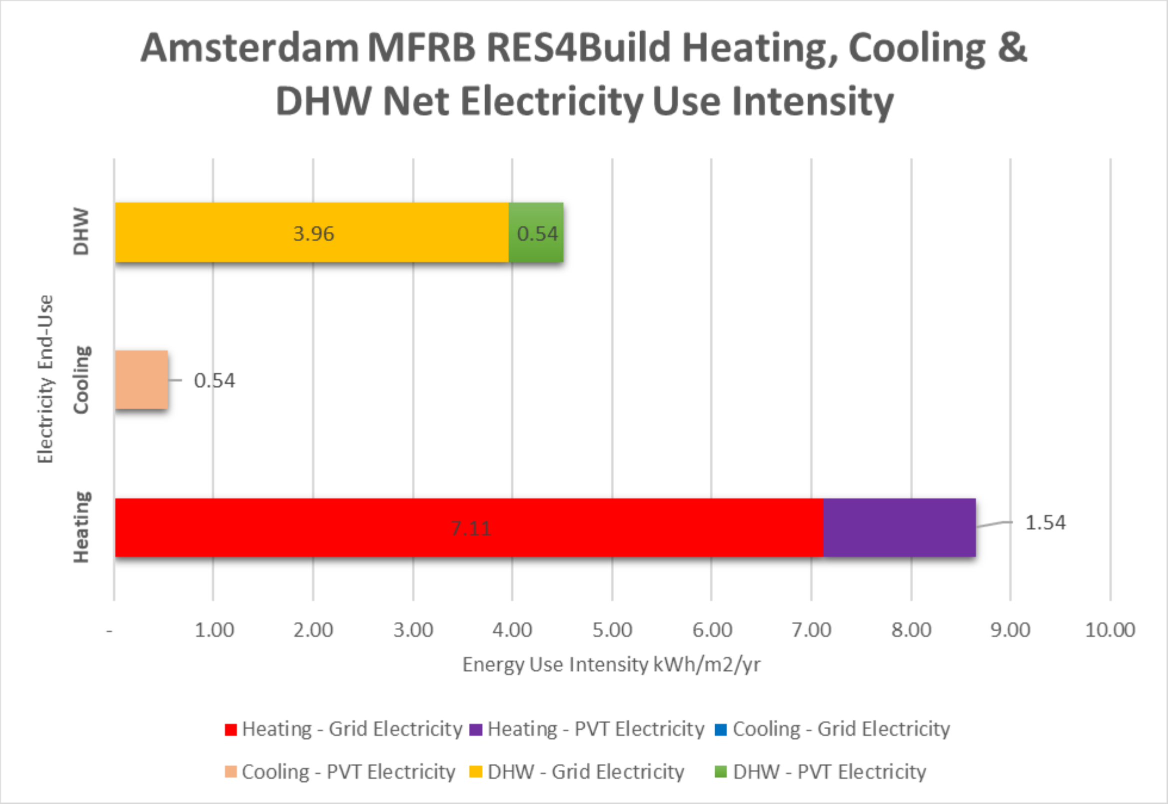
Typology	Location	PVT Electrical Output (kWh/m2/yr)	PVT Electrical Excess %	PVT Thermal Output (kWh/m2/yr)	PVT Thermal DHW Tank %	PVT Thermal Space heating Tank %	PVT Thermal Solar Buffer %	PVT Thermal Reject %
MFRB (990 m2 GIA)	Athens, Greece	17.04	81%	47.63	54%	N/A	16%	30%
	Cork, Ireland	9.44	70%	29.24	25%	N/A	70%	5%
	Amsterdam, Netherlands	12.98	80%	35.30	44%	N/A	42%	14%
	Gdansk, Poland	11.66	74%	32.91	37%	N/A	50%	13%

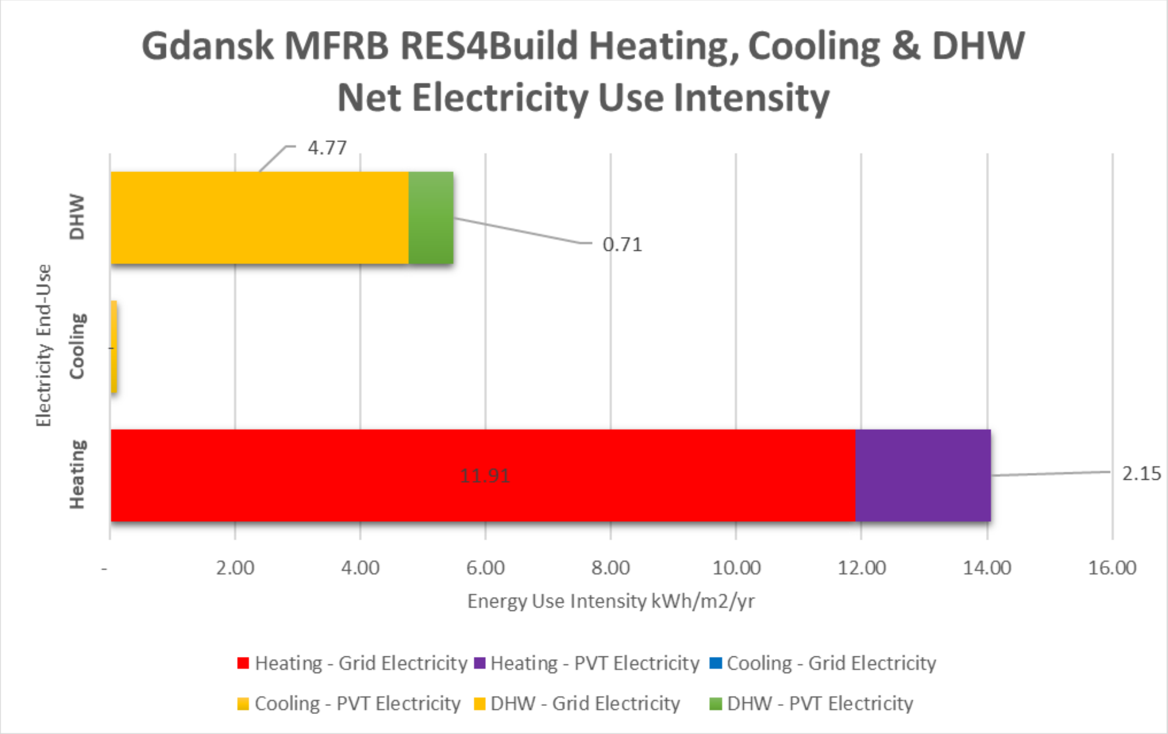
It can be seen that the Solar Thermal output is more than twice that of the PV electrical system, and there is a higher usage rate of the Solar Thermal output with between 5% (Cork) – 30% (Athens) being rejected to ambient with most utilised in the DHW tank or solar buffer for future space heating. This also suggests that location climate has a significant effect not just the Solar Thermal output but the effective utilisation within a building. The PVT in contrast had a lot of its generation outside the heat-pumps main consumption hours and therefore the majority of the PVT electricity produced; 81% (Athens) – 70% (Cork) was not self-consumed by the RES4BUILD system but excess to be utilised by other electrical components (e.g. lighting, equipment) in the building or shared back to the grid.

A graphical breakdown of the SFH simulation thermal electrical energy use intensity in kWh/m^2/yr for each location, taking into account the PVT system performance and highlighting the net grid electrical demand, is provided in the graphs below.


Athens MFRB RES4Build Heating, Cooling & DHW Net Electricity Use Intensity
Electricity End-Use
DHW
Cooling
Heating
1.53
0.41
4.52
2.38
2.58
0.44
-
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
Energy use Intensity kWh/m2/yr
Heating - Grid Electricity
Heating - PVT Electricity
Cooling - Grid Electricity
Cooling - PVT Electricity
DHW - Grid Electricity
DHW - PVT Electricity


Cork MFRB RES4Build Heating, Cooling & DHW Net Electricity Use Intensity
Electricity End-Use
DHW
Cooling
Heating
6.26
0.05
10.52
-
2.00
4.00
6.00
8.00
10.00
12.00
Energergu Use Intensity kWh/m2/yr
Heating - Grid Electricity
Heating - PVT Electricity
Cooling - Grid Electricity
Cooling - PVT Electricity
DHW - Grid Electricity
DHW - PVT Electricity


Amsterdam MFRB RES4Build Heating, Cooling & DHW Net Electricity Use Intensity
Electricity End-Use
DHW
Cooling
Heating
3.96
0.54
0.54
7.11
1.54
-
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
Energy Use Intensity kWh/m2/yr
Heating - Grid Electricity
Heating - PVT Electricity
Cooling - Grid Electricity
Cooling - PVT Electricity
DHW - Grid Electricity
DHW - PVT Electricity


Gdansk MFRB RES4Build Heating, Cooling & DHW Net Electricity Use Intensity
Electricity End-Use
DHW
Cooling
Heating
4.77
0.71
11.91
2.15
-
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
Energy Use Intensity kWh/m2/yr
Heating - Grid Electricity
Heating - PVT Electricity
Cooling - Grid Electricity
Cooling - PVT Electricity
DHW - Grid Electricity
DHW - PVT Electricity

5.4.3 Commercial Office Building

The Commercial Office Building RES4BUILD system had the following simulation parameters for each climate location, with parameters changing across locations summarised in the table below:

- Area of the PVT [m2]: 98.9
- Volume of DHW Tank: N/A – DHW is not simulated in commercial environment
- Mass of the ground used by the BTES [kg]: 187.615e6 kg (for 96 boreholes with borehole depth of 80m & borehole radius of 0.09m)

Parameter / City	Athens	Cork	Amsterdam	Gdansk
Volume of Solar Buffer Tank [m³]	5	6	8	8
Volume of Space Heating/Cooling Tank [m3]	6	8	10	10
Heatpump (HP) Scaling Factor	22	15	20	20

The simulation results are summarised in table 15 below:

Table 16 – Commercial Office Model Results – Total Thermal Energy EUI

Typology	Location	Total Heating EUI (kWh/m2/yr)	Total Cooling EUI (kWh/m2/yr)	Total DHW EUI (kWh/m2/yr)	% Supplied by PVT Elec
Commercial Office (2400m2 GIA)	Athens, Greece	2.62	19.84	N/A	25%
	Cork, Ireland	14.38	0.84	N/A	21%
	Amsterdam, Netherlands	14.56	3.13	N/A	31%
	Gdansk, Poland	19.61	1.33	N/A	22%

The total heating and cooling Energy Use Intensity is electricity consumed by the RES4BUILD heat-pump system (including auxiliary energy of pumps etc.). A varying percentage between 31% in Amsterdam to 21% in Cork is offset by the electricity generation of the PVT system, part of the overall RES4BUILD energy system.

Therefore, the net electric energy consumption by the RES4BUILD system from grid electricity, which has related GHG emissions, is the true energy use of the RES4BUILD system. Taking this into account, a summary table of the grid electricity use intensity (per m2 floor area) for heating and cooling is provided below.

Table 17 – Commercial Office Model Results – Net Grid Thermal Energy EUI

Typology	Location	Heating Grid Elec EUI (kWh/m2/yr)	Cooling Grid Elec EUI (kWh/m2/yr)	DHW Grid Elec EUI (kWh/m2/yr)
Commercial Office (2400m2 GIA)	Athens, Greece	1.71	15.11	N/A
	Cork, Ireland	12.43	0.00	N/A
	Amsterdam, Netherlands	12.57	0.00	N/A
	Gdansk, Poland	17.92	0.00	N/A

This is a more representative value of the overall RES4BUILD system performance and shows the offsite of additional electricity demand that would be required by the building to heat and cool. This additional grid electricity demand will also have GHG emissions associated with it which can be calculated using the carbon intensity value(s) as outlined in chapter 2. Therefore, it is the grid heating, cooling and DHW Electricity EUI values above that are used in the RES4BUILD impact assessment calculations in chapter 6. In Cork, Gdansk and Amsterdam, the relatively low total electricity demand for cooling due to the free cooling available from the BTES ground storage, combined with high simultaneous solar PVT electric output results in no grid electricity being required to achieve it.

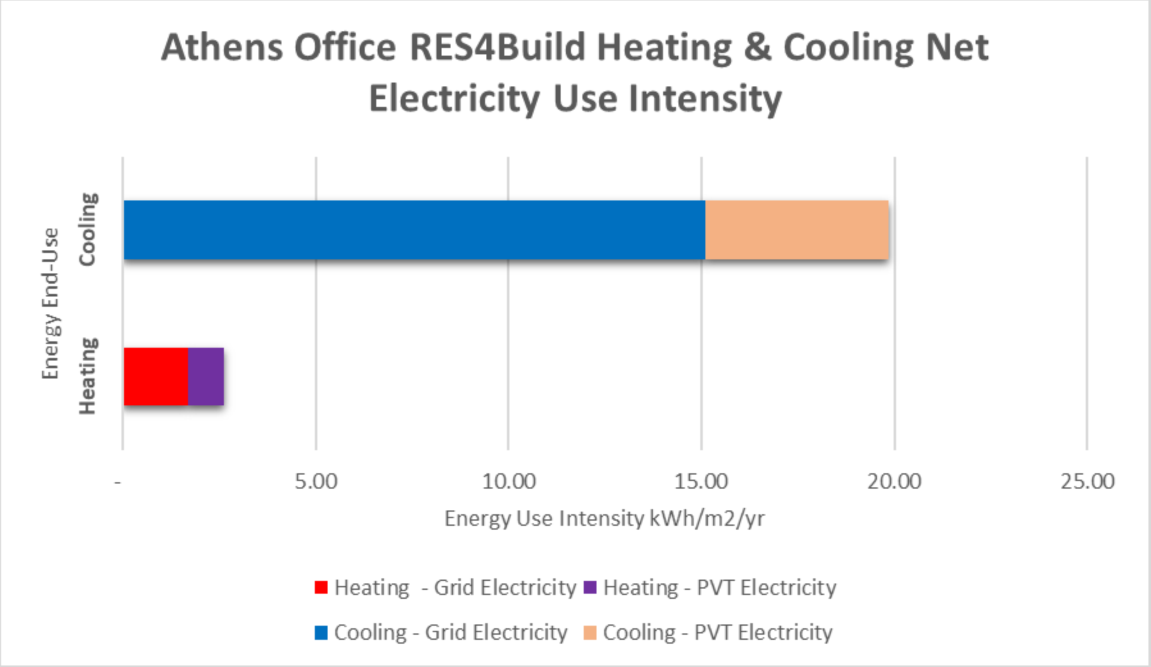
The importance of the performance of the Solar PVT system therefore is great, as the solar thermal function reduced the demand for heat-pump space heating or DHW operation, and the solar PV element offsets the heat pump grid electricity consumption, reducing related GHG emissions. A summary of the PVT system output performance per m2 building floor area is provided below.

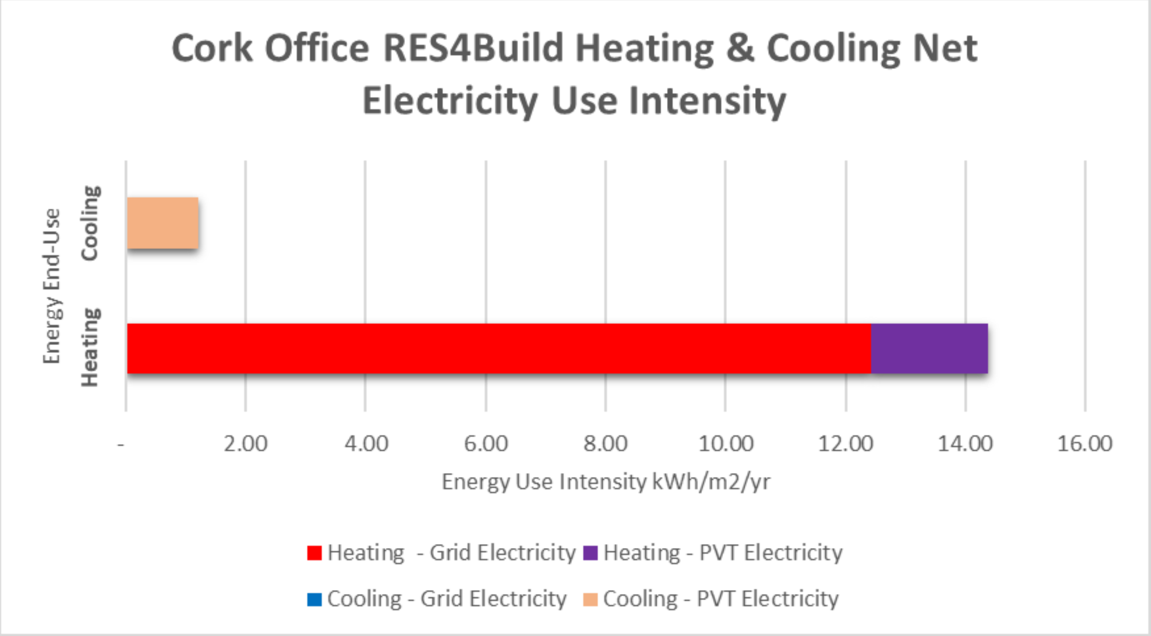
Table 18 – Commercial Office Model Results – PVT System Performance

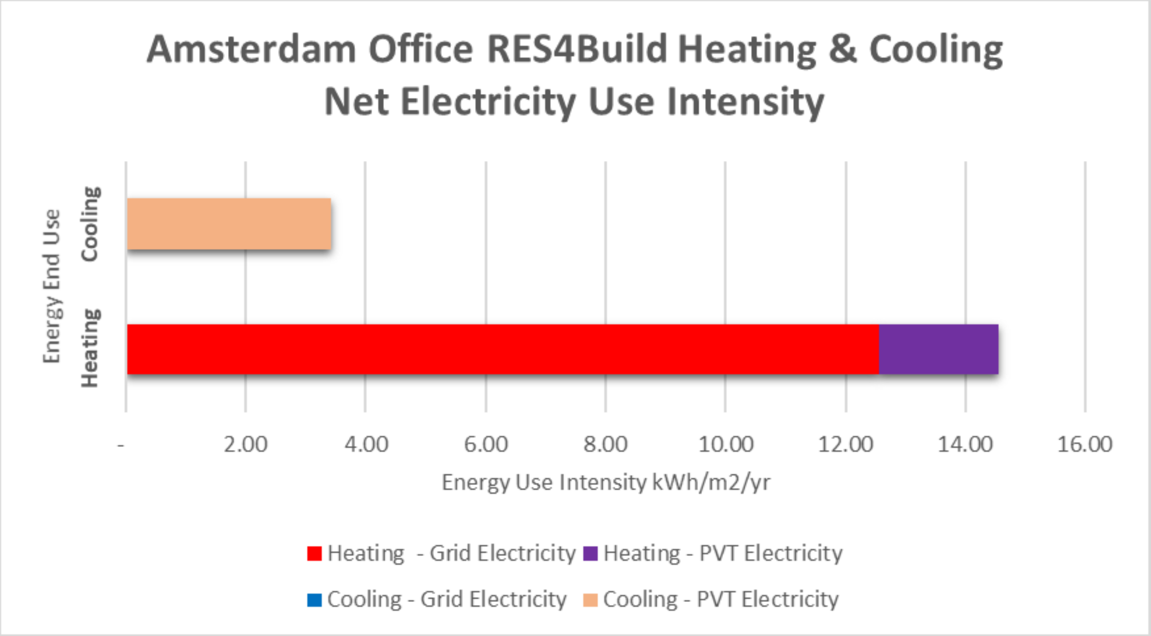
Typology	Location	PVT Electrical Output (kWh/m2/yr)	PVT Electrical Excess %	PVT Thermal Output (kWh/m2/yr)	PVT Thermal DHW Tank %	PVT Thermal Space heating Tank %	PVT Thermal Solar Buffer %	PVT Thermal Reject %
Commercial Office (2400m2 GIA)	Athens, Greece	7.61	26%	23.42	N/A	2%	13%	84%
	Cork, Ireland	4.11	23%	11.83	N/A	2%	68%	30%
	Amsterdam, Netherlands	5.88	8%	18.56	N/A	1%	42%	56%
	Gdansk, Poland	5.20	13%	15.67	N/A	2%	43%	55%

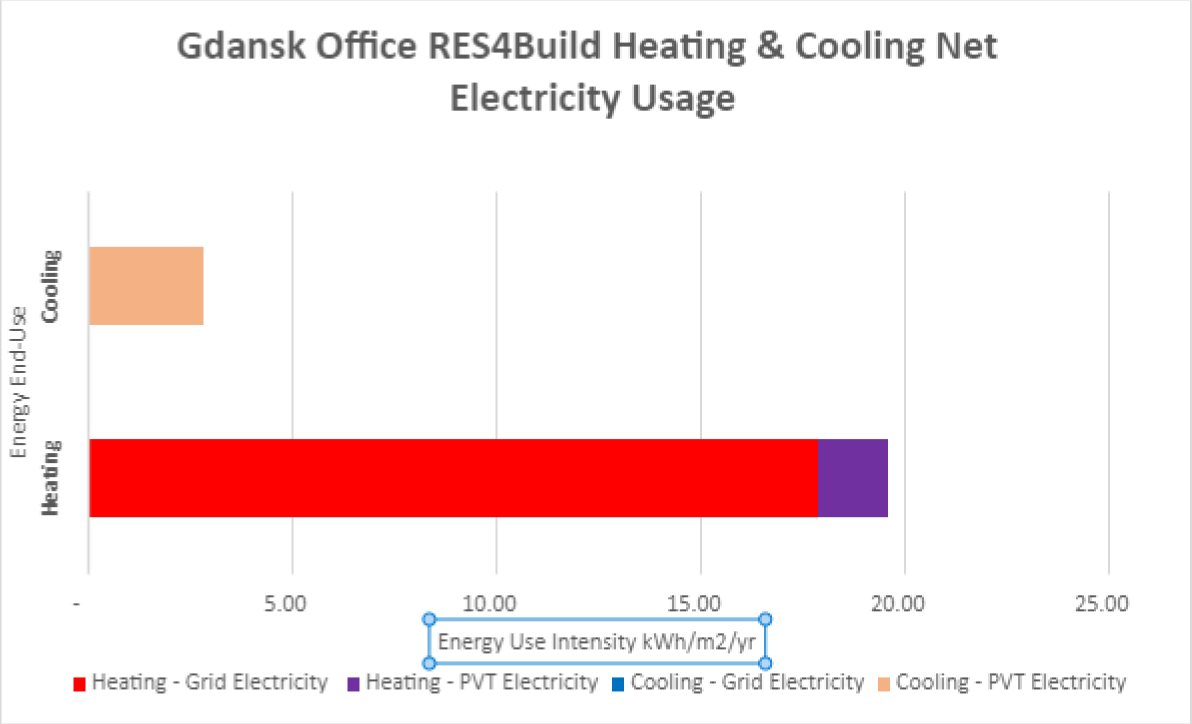
It can be seen that the Solar Thermal output is more than twice that of the PV electrical system, but in contrast to residential building typologies, there is a higher usage rate of the solar electric output than solar thermal with between 30% (Cork) – 84% (Athens) of solar thermal output being rejected to ambient, and the majority of actual usage recorded utilised in the solar buffer for future space heating. This suggests that the building typology and occupancy profile has a significant effect on the Solar PVT systems effective utilisation within a building. The PVT had a lot of its generation during the heat-pumps main consumption hours and therefore only a small portion of the PVT electricity produced; 26% (Athens) – 8% (Cork) was not self-consumed by the RES4BUILD system but excess to be utilised by other electrical components (e.g. lighting, equipment) in the building or shared back to the grid.

A graphical breakdown of the SFH simulation thermal electrical energy use intensity in kWh/m2/yr for each location, taking into account the PVT system performance and highlighting the net grid electrical demand, is provided in the graphs below.









5.4.4 Public School Building

The Public School Building RES4BUILD system had the following simulation parameters for each climate location, with parameters changing across locations summarised in the table below:

- Area of the PVT [m2]: 197.8
- Volume of DHW Tank: N/A – DHW is not simulated in commercial environment
- Mass of the ground used by the BTES [kg]:
  - 187.615e6 kg (for 96 boreholes with borehole depth of 80m & borehole radius of 0.09m) for Athens, Cork & Amsterdam

- 293.148e6 kg (for 120 boreholes with borehole depth of 80m & borehole radius of 0.09m) for Gdansk

Parameter / City	Athens	Cork	Amsterdam	Gdansk
Volume of Solar Buffer Tank [m³]	8	12	14	16
Volume of Space Heating/Cooling Tank [m3]	10	12	12	18
Heat-pump (HP) Scaling Factor	36	40	40	42

The simulation results are summarised in table 18 below:

Table 19 – Public School Model Results – Total Thermal Energy EUI

Typology	Location	Total Heating EUI (kWh/m2/yr)	Total Cooling EUI (kWh/m2/yr)	Total DHW EUI (kWh/m2/yr)	% Supplied by PVT Elec
Public - School (3500m2 GIA)	Athens, Greece	6.43	8.72	N/A	40%
	Cork, Ireland	34.93	0.00	N/A	12%
	Amsterdam, Netherlands	22.32	1.05	N/A	26%
	Gdansk, Poland	31.15	0.46	N/A	17%

The total heating and cooling Energy Use Intensity is electricity consumed by the RES4BUILD heat-pump system (including auxiliary energy of pumps etc.). A varying percentage between 40 % in Amsterdam to 12% in Cork is offset by the electricity generation of the PVT system, part of the overall RES4BUILD energy system.

Therefore, the net electric energy consumption by the RES4BUILD system from grid electricity, which has related GHG emissions, is the true energy use of the RES4BUILD system. Taking this into account, a summary table of the grid electricity use intensity (per m2 floor area) for heating and cooling is provided below.

Table 20 – Public – School Results – Net Grid Thermal Energy EUI

Typology	Location	Heating Grid Elec EUI (kWh/m2/yr)	Cooling Grid Elec EUI (kWh/m2/yr)	DHW Grid Elec EUI (kWh/m2/yr)
Public - School (3500m2 GIA)	Athens, Greece	4.36	4.66	N/A
	Cork, Ireland	30.57	0.00	N/A

	Amsterdam, Netherlands	18.76	0.00	N/A
	Gdansk, Poland	27.96	0.00	N/A

This is a more representative value of the overall RES4BUILD system performance and shows the offsite of additional electricity demand that would be required by the building to heat and cool. This additional grid electricity demand will also have GHG emissions associated with it which can be calculated using the carbon intensity value(s) as outlined in chapter 2. Therefore, it is the grid heating, cooling and DHW Electricity EUI values above that are used in the RES4BUILD impact assessment calculations in chapter 6. In Cork, Amsterdam and Gdansk, the relatively low total electricity demand for cooling due to the free cooling available from the BTES ground storage, combined with high simultaneous solar PVT electric output results in no grid electricity being required to achieve it.

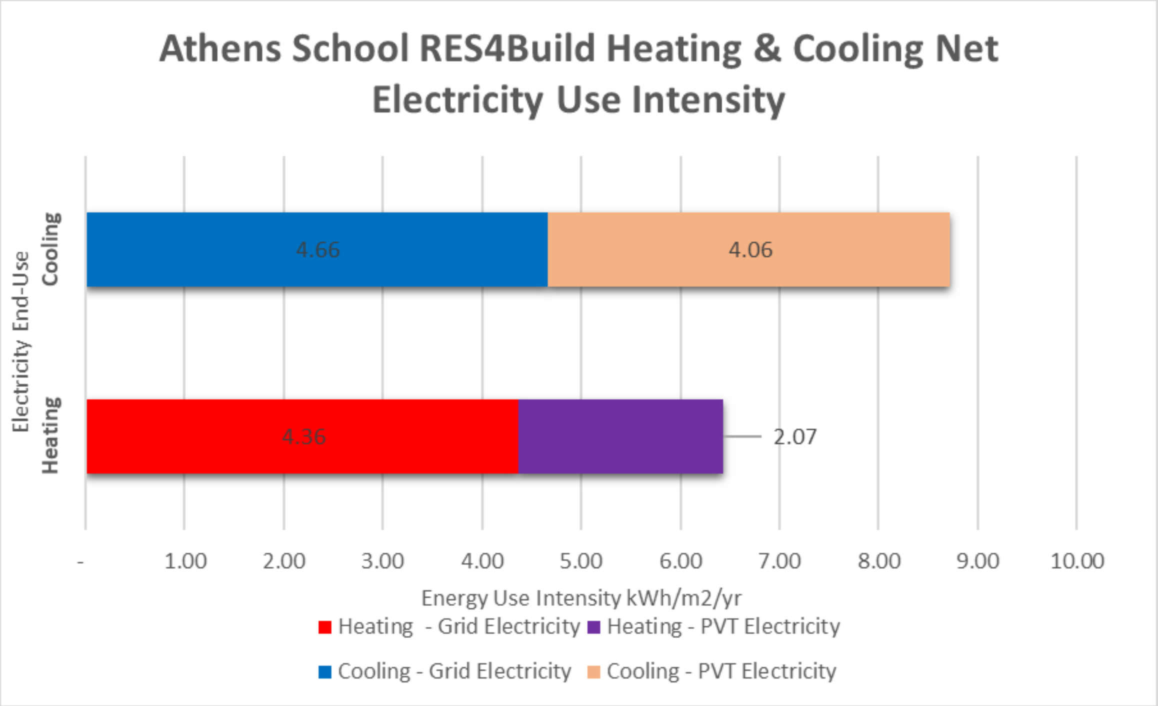
The importance of the performance of the Solar PVT system therefore is great, as the solar thermal function reduced the demand for heat-pump space heating or DHW operation, and the solar PV element offsets the heat pump grid electricity consumption, reducing related GHG emissions. A summary of the PVT system output performance per m2 building floor area is provided below.

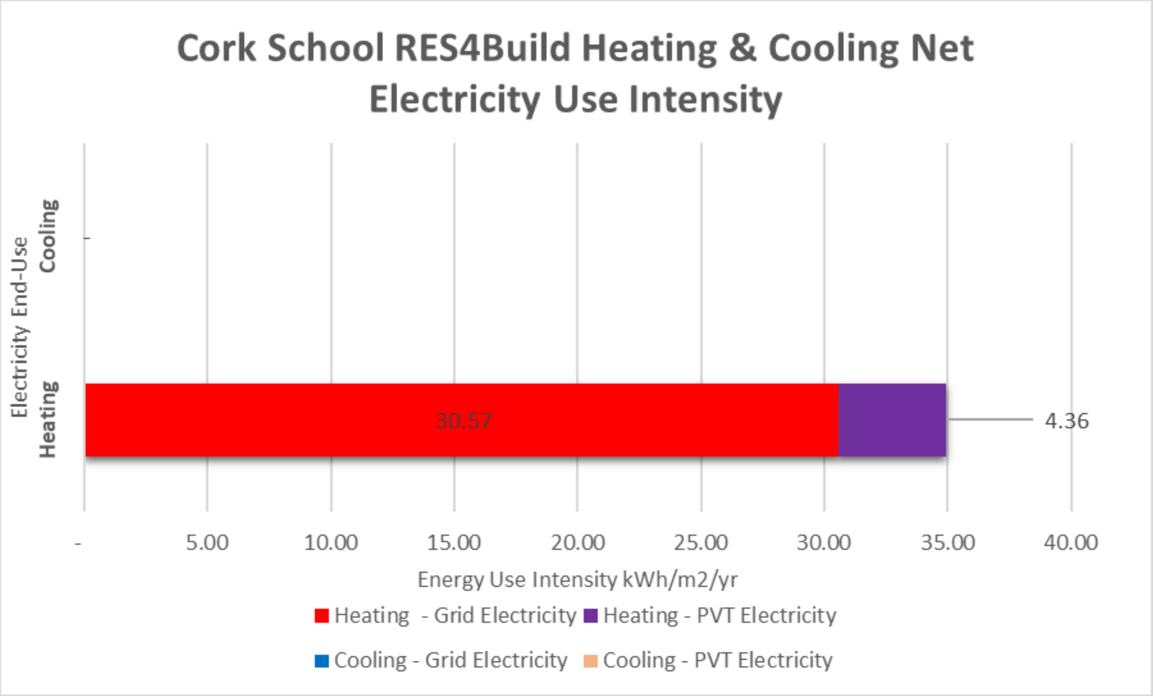
Table 21 – Public – School Results – PVT System Performance

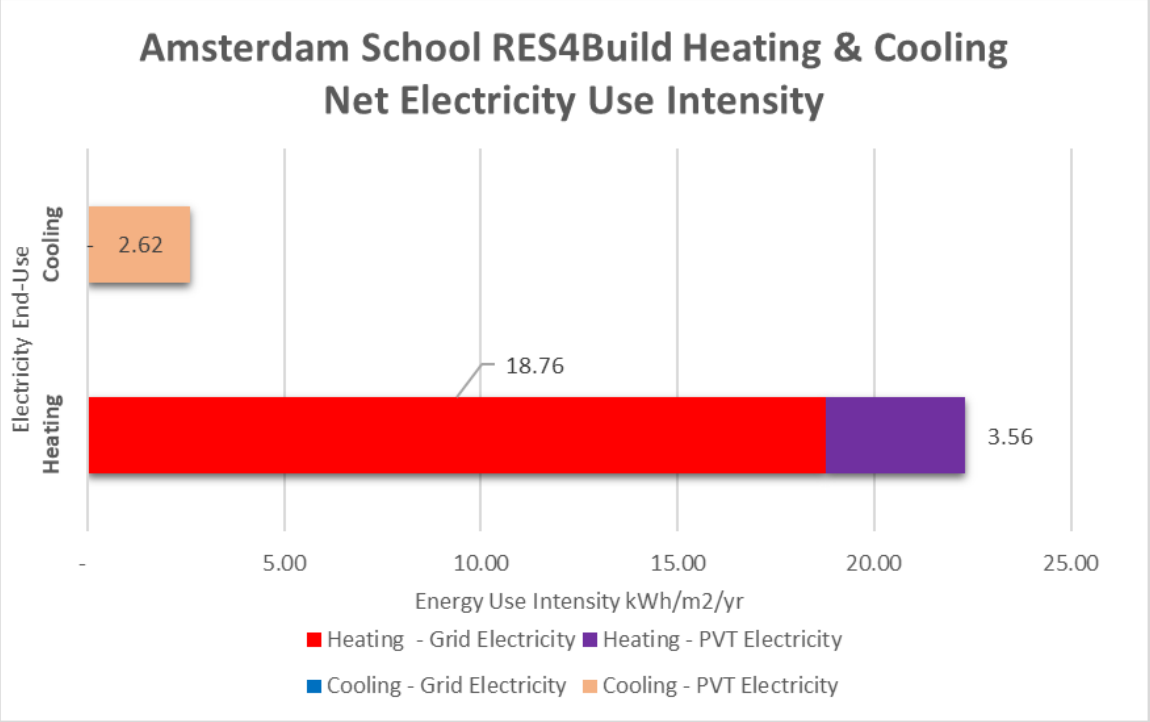
Typology	Location	PVT Electrical Output (kWh/m2/yr)	PVT Electrical Excess %	PVT Thermal Output (kWh/m2/yr)	PVT Thermal DHW Tank %	PVT Thermal Space heating Tank %	PVT Thermal Solar Buffer %	PVT Thermal Reject %
Public - School (3500m2 GIA)	Athens, Greece	10.43	41%	31.68	N/A	3%	19%	77%
	Cork, Ireland	5.76	24%	21.60	N/A	2%	88%	10%
	Amsterdam, Netherlands	8.11	24%	26.53	N/A	1%	53%	46%
	Gdansk, Poland	7.19	23%	23.36	N/A	1%	54%	45%

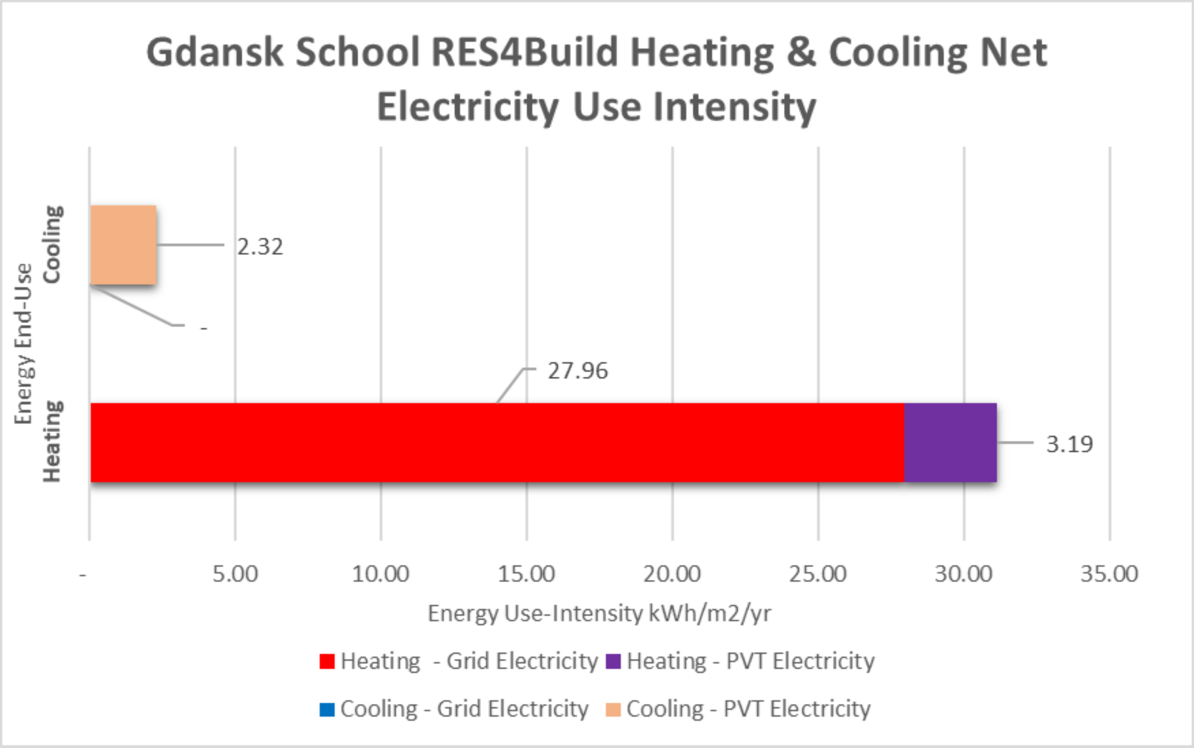
It can be seen that the Solar Thermal output is more than twice that of the PV electrical system, but in contrast to residential building typologies there is a higher usage rate of the Solar Electric output than solar thermal with between 10% (Cork) – 77% (Athens) of solar thermal output being rejected to ambient, and the majority of actual usage recorded utilised in the solar buffer for future space heating. This suggests that the building typology and occupancy profile has a significant effect on the Solar PVT systems effective utilisation within a building. The PVT had relatively good generation during the heat-pumps main consumption hours and therefore only a minor portion of the PVT electricity produced; 41% (Athens) – 8% (Cork) was not self-consumed by the RES4BUILD system but excess to be utilised by other electrical components (e.g. lighting, equipment) in the building or shared back to the grid.

A graphical breakdown of the SFH simulation thermal electrical energy use intensity in kWh/m2/yr for each location, taking into account the PVT system performance and highlighting the net grid electrical demand, is provided in the graphs below.




Cork School RES4Build Heating & Cooling Net Electricity Use Intensity
Electricity End-Use
Cooling
Heating
30.57
4.36
-
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
Energy Use Intensity kWh/m2/yr
Heating - Grid Electricity
Heating - PVT Electricity
Cooling - Grid Electricity
Cooling - PVT Electricity


Amsterdam School RES4Build Heating & Cooling Net Electricity Use Intensity
Electricity End-Use
Cooling
Heating
2.62
18.76
3.56
-
5.00
10.00
15.00
20.00
25.00
Energy Use Intensity kWh/m2/yr
Heating - Grid Electricity
Heating - PVT Electricity
Cooling - Grid Electricity
Cooling - PVT Electricity


Gdansk School RES4Build Heating & Cooling Net Electricity Use Intensity
Energy End-Use
Cooling
Heating
2.32
-
27.96
3.19
-
5.00
10.00
15.00
20.00
25.00
30.00
35.00
Energy Use-Intensity kWh/m2/yr
Heating - Grid Electricity
Heating - PVT Electricity
Cooling - Grid Electricity
Cooling - PVT Electricity

6 RES4BUILD Impact assessment

As described in the introduction chapter, impacts are determined in the following parameters:

No.	**Impact**
1	Reduction in use of fossil fuels for heating in buildings
2	Readiness for displacement of traditional heating solutions
3	Environmental impact
4	Social impact

This report addresses the first and third items, number 2 and 4 are to be addressed in Tasks 7.2 and 7.3. The impact is determined on a technical basis assuming building and system characteristics as outlined throughout this report and excluding specific market trends which are to be covered under Task 7.2.

6.1 Impact on fossil fuels and environmental

Per building type and per location, the impacts on fossil fuel reduction and environmental impact of the RES4BUILD integrated energy system can be calculated. For this, a methodology is applied which combines RES4BUILD data with reference values:

- For building demand profiles, the outcomes of the RES4BUILD typology-location simulations (chapter 4) are used.
- The building demand is converted to building system energy consumption through:
    1. Assumptions on efficiency for gas fired boiler & air conditioning (AC) chiller
    2. Assumptions on efficiency for air source heat pump
    3. Optimized simulations for the RES4BUILD IES concept (as per chapter 5).

The first ‘baseline’ system scenario translates the typologies building energy demand profile for each location into a gas fired boiler heating and air conditioning cooling system with the nominal efficiencies as outlined below.

Table 22 - Baseline Scenario System Efficiencies

System	Efficiency
Gas Boiler	0.95
AC/Chiller	2.6

The gas fired boiler efficiency is assumed consistent throughout Europe regardless of location and is taken from the typical boiler efficiencies calculated according to EN 12952-15. The air condition (AC) system efficiency value was extracted from the European research report of Status Quo of the Air-Conditioning Market in Europe: Assessment of the Building Stock by Simon Pezzutto et al. The study collected cooling systems Seasonal Energy Efficiency Ratio (SEER) for multiple technologies as shown in figure 54 below.

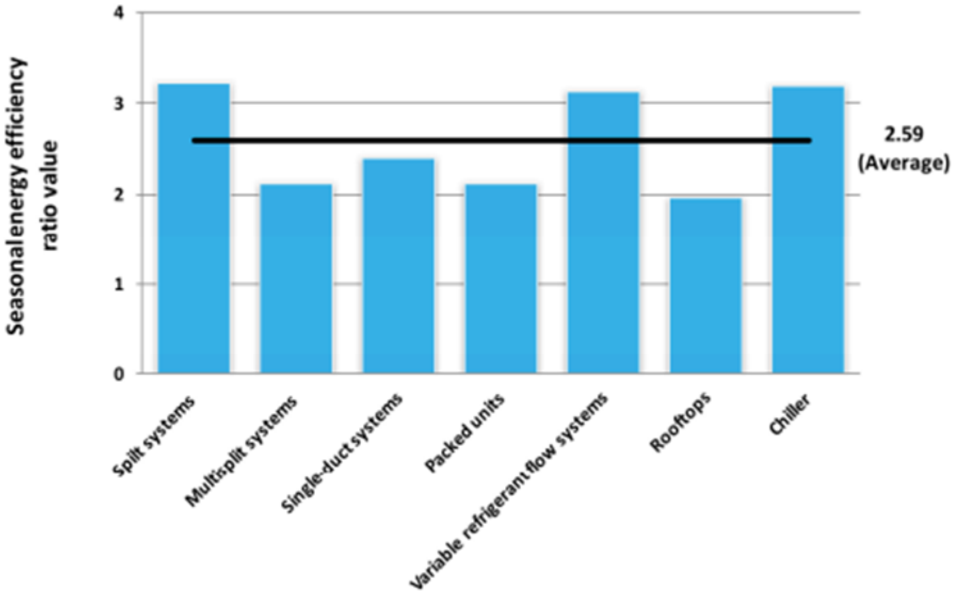


Figure 53 - Cooling Systems Seasonal Energy Efficiency Ratio (SEER)

The values vary significantly per AC technology going from less than 2 for multi-split systems to almost 4 for chiller, with the simple average of SEER values per AC technology is approx. 2.6 and therefore this value is selected as the baseline scenario cooling system efficiency input as cooling technology used can vary across building typology and locations.

For the 2. ASHP scenario the heating and cooling nominal efficiency values for each typology and location are outlined below:

Table 23 – Scenario 2 – ASHP System Efficiencies

ASHP	SCOP	SEER
Poland	2.6	2.6
Netherlands	2.8	2.6
Ireland	3	2.6
Greece	3.2	2.6

The cooling SEER value of 2.6 is used again for all building typologies and locations, as this is also the average value of the split and multi-split systems which would most typically represent an ASHP system.

The ASHP heating efficiency value in the form of Seasonal Coefficient of Performance (SCOP) again varies by climate as outdoor air temperatures effect the operation of heat pumps significantly, unlike gas fired boilers.

Figure 55 below shows this variation across Europe in SCOP bands by the European research paper - European Mapping of Seasonal Performances of Air-source and Geothermal Heat Pumps for Residential Applications and represents the European mapping of SCOP of air-source heat pump which generally varies between 2.4 and 3.4 depending on climate. This aligns with expectations from the European climatic zones as set out in EN14825. The selected representative EU locations ASHP Heating SCOP and Cooling SEER values are summarised in table 22 above.

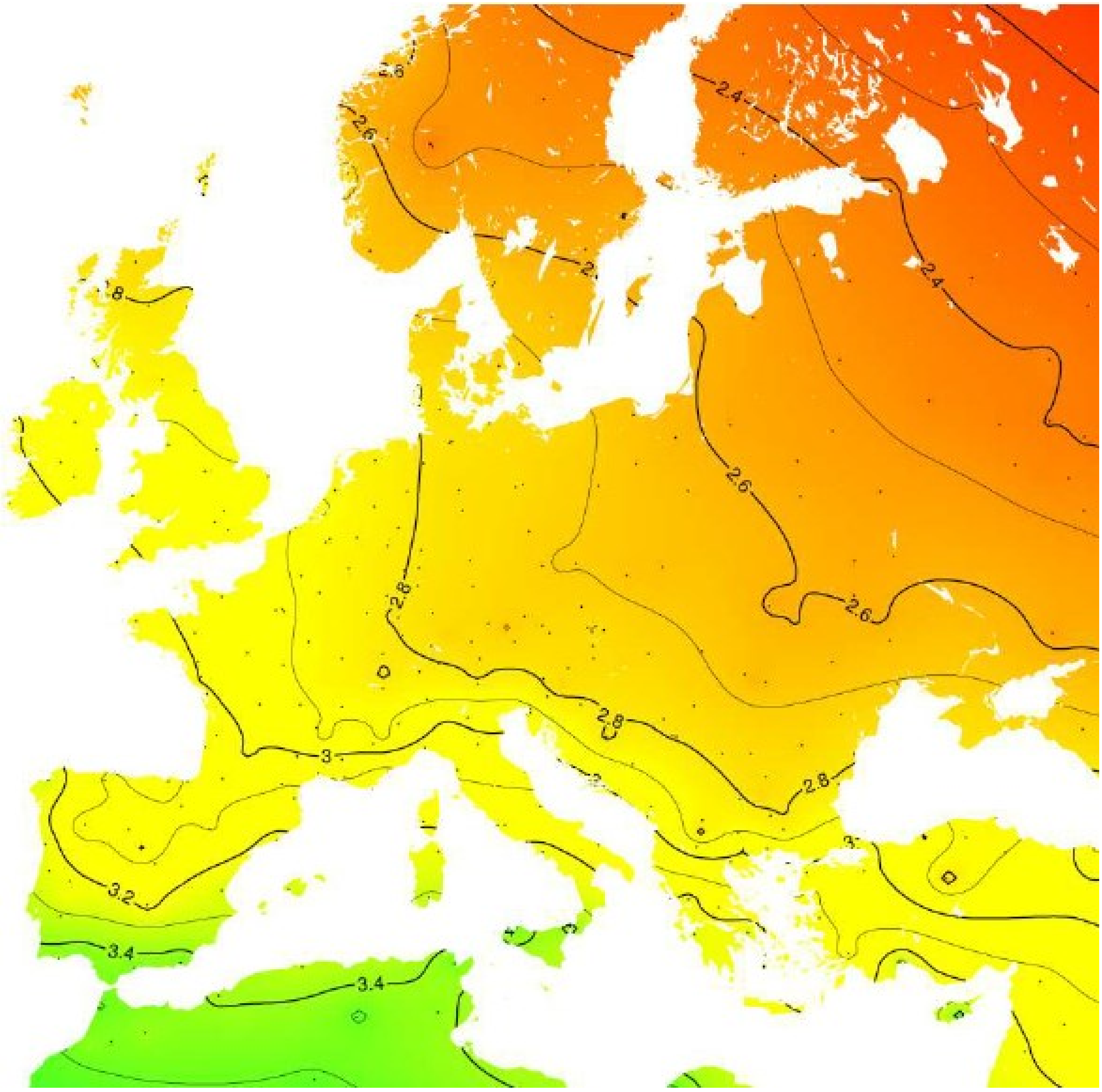


Figure 54 - Variation Across Europe In Heatpump Scop Bands

The final RES4BUILD system scenario utilises the net grid electricity consumption simulation outputs from WP3 RES4BUILD system model detailed in chapter 5.

These 3 scenario building system thermal energy related consumption values are then converted to GHG emission values using the GWP factors summarized below and detailed in chapter 2.4.

Energy Source	EU average Natural Gas GWP [kg CO2 eq.]	EU Average Grid Electricity GWP [kg CO2 eq.]
GHG Emissions Factor	0.2413	0.287

Both the building system energy consumption and GHG emissions values are then normalized using building typology floor area values to create applicable thermal energy and GHG intensity metrics in kWh/m^2 and kgCO2e/m^2 respectively as shown below.

Table 24 – RES4BUILD SFH Energy & Carbon Use Intensities

SFH Energy & Carbon Use Intensities		Athens, GRE		Cork, IRL		Amsterdam, NL		Gdansk, PL	
		kWh/m^2	kgCO$_2$/m^2	kWh/m^2	kgCO$_2$/m^2	kWh/m^2	kgCO$_2$/m^2	kWh/m^2	kgCO$_2$/m^2
Boiler & AC	Heating	27.29	6.59	65.03	15.69	54.11	13.06	84.52	20.39
	Cooling	18.37	5.27	0.82	0.24	7.66	2.2	3.91	1.12
ASHP	Heating	8.1	2.33	19.31	5.54	16.06	4.61	25.09	7.2
	Cooling	18.37	5.27	0.82	0.24	7.66	2.2	3.91	1.12
RES4 - BUILD	Heating	5.55	1.59	13.94	4	11.78	3.38	18.98	5.45
	Cooling	5.39	1.55	-	-	0.27	0.08	-	-

The GWP emissions reduction impact of each system across the 4 locations is displayed graphically below for visual comparison.

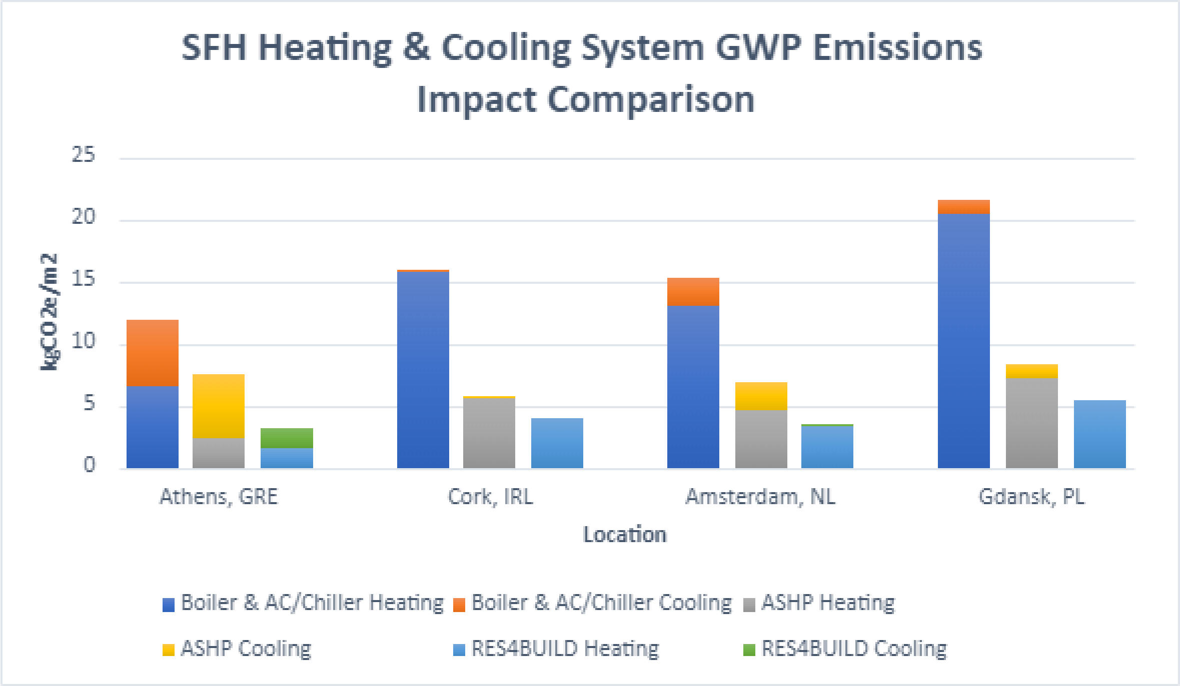


Figure 55 - SFH Heating & Cooling System GWP Emissions Impact Comparison

From the results, there is a clear reduction in both heating and cooling GWP emissions intensity (kgCO2e/m^2) in each location from the RES4BUILD system in a SFH compared to the baseline boiler & AC system, and the typical ASHP system. The RES4BUILD system heating emissions intensity is significantly lower than the gas boiler system and marginally lower than the ASHP system in all locations. Only the Athens RES4BUILD system has cooling related emissions as the high cooling load is not meet by the PVT electrical output and the BTES free cooling and therefore additional grid electricity is required to provide cooling, producing emissions.

Table 25 - RES4BUILD MFRB Energy & Carbon Use Intensities

	Athens, GRE	Cork, IRL	Amsterdam, NL	Gdansk, PL

MFRB Energy & Carbon Use Intensities		kWh/m^2	kgCO$_2$/m^2	kWh/m^2	kgCO$_2$/m^2	kWh/m^2	kgCO$_2$/m^2	kWh/m^2	kgCO$_2$/m^2
Boiler & AC	Heating	8.34	2.01	46.89	11.31	38.92	9.39	62.07	14.98
	Cooling	26.88	7.71	0.13	0.04	2.94	0.84	1.51	0.43
ASHP	Heating	2.48	0.71	14.85	4.26	13.21	3.79	22.68	6.51
	Cooling	26.88	7.71	0.13	0.04	2.94	0.84	1.51	0.43
RES4 - BUILD	Heating	2.58	0.74	8.54	2.45	7.11	2.04	5.48	1.57
	Cooling	4.52	1.30	-		-		-	

The GWP emissions reduction impact of each system across the 4 locations is displayed graphically below for visual comparison.

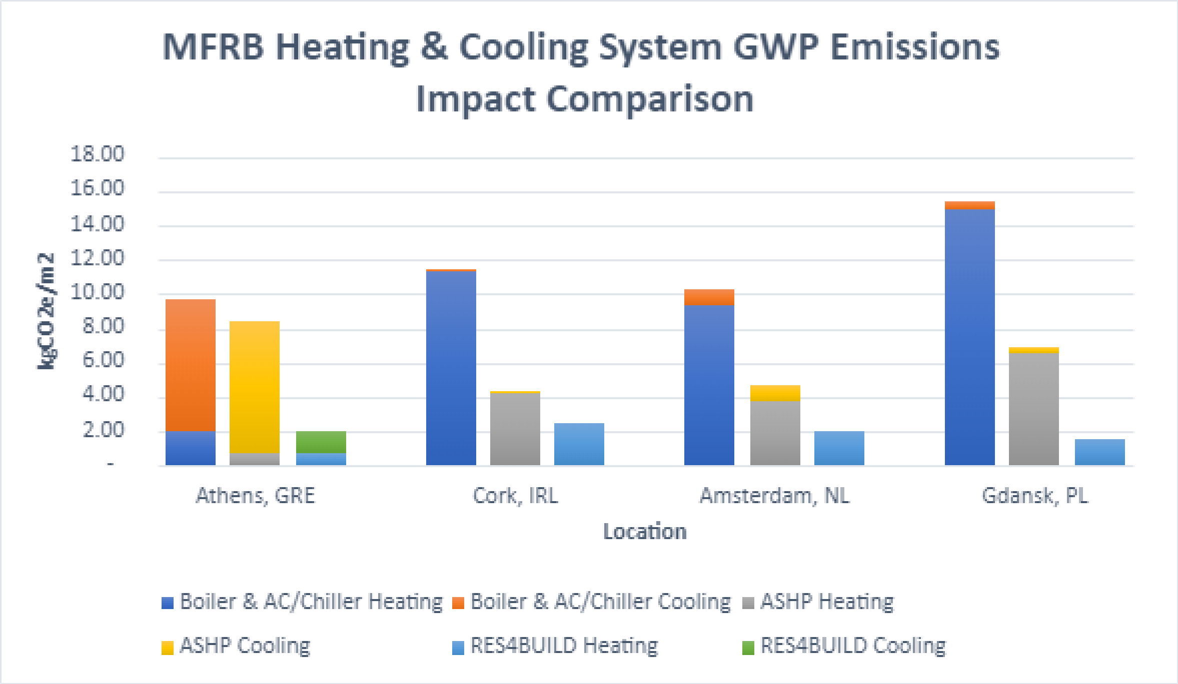


Figure 56 - MFRB Heating & Cooling System GWP Emissions Impact Comparison

From the results, there is a clear reduction in both heating and cooling GWP emissions intensity (kgCO2e/m^2) in each location from the RES4BUILD system in a MFRB compared to the baseline boiler & AC system, and the typical ASHP system. The RES4BUILD system heating emissions intensity is significantly lower than the gas boiler system and marginally lower than the ASHP system in all locations. Only the Athens RES4BUILD system has cooling related emissions as the high cooling load is not meet by the PVT electrical output and the BTES free cooling and therefore additional grid electricity is required to provide cooling, producing emissions.

Table 26 - RES4BUILD Commercial Office Energy & Carbon Use Intensities

	Athens, GRE	Cork, IRL	Amsterdam, NL	Gdansk, PL

Commercial Office Energy & Carbon Use Intensities		kWh/m^2	kgCO$_2$/m^2	kWh/m^2	kgCO$_2$/m^2	kWh/m^2	kgCO$_2$/m^2	kWh/m^2	kgCO$_2$/m^2
Boiler & AC	Heating	4.85	1.17	24.03	5.8	24.43	5.89	31.55	7.61
	Cooling	32.05	9.2	3.79	1.09	13.53	3.88	13.13	3.77
ASHP	Heating	1.44	0.41	7.61	2.18	8.29	2.38	11.53	3.31
	Cooling	32.05	9.2	3.79	1.09	13.53	3.88	13.13	3.77
RES4 - BUILD	Heating	1.71	0.49	12.43	3.57	12.57	3.61	17.92	5.14
	Cooling	15.11	4.34	-	-	-	-	-	-

The GWP emissions reduction impact of each system across the 4 locations is displayed graphically below for visual comparison.

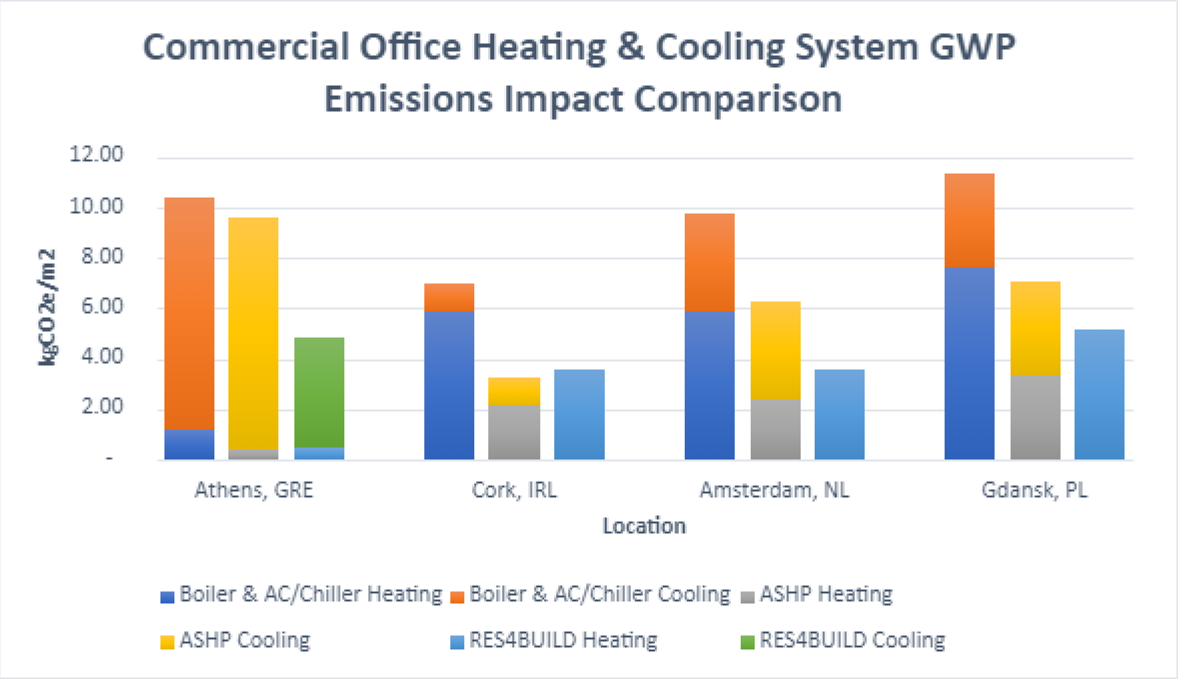


Figure 57 – Commercial Office Heating & Cooling System GWP Emissions Impact Comparison

From the results, there is a clear reduction in the total heating and cooling GWP emissions intensity (kgCO2e/m^2) in each location from the RES4BUILD system in a Commercial office compared to the baseline boiler & AC system, and the typical ASHP system. However, the RES4BUILD system heating emissions intensity is higher than the ASHP system in all locations, although is significantly lower than the baseline gas boiler system. It is possible that this occurs due to the limitation of the simulation RES4BUILD heat pump size which is scaled massively for larger commercial buildings in this case and this negatively effects system energy consumption. The overall system emissions reduction is from the low cooling emissions with only the Athens RES4BUILD system having cooling related emissions due to the high cooling load requiring grid electricity, and all other locations having zero cooling related emissions.

Table 27 - RES4BUILD Publci-School Energy & Carbon Use Intensities

	Athens, GRE	Cork, IRL	Amsterdam, NL	Gdansk, PL

Public - School Energy & Carbon Use Intensities		kWh/m^2	$kgCO_2$/m^2	kWh/m^2	$kgCO_2$/m^2	kWh/m^2	$kgCO_2$/m^2	kWh/m^2	$kgCO_2$/m^2
Boiler & AC	Heating	13.82	3.33	40.67	9.81	25.81	6.23	34.7	8.37
	Cooling	10.42	2.99	0.78	0.22	7.4	2.12	7.06	2.03
ASHP	Heating	4.1	1.18	12.88	3.70	8.76	2.51	12.68	3.64
	Cooling	10.42	2.99	0.78	0.22	7.4	2.12	7.06	2.03
RES4 - BUILD	Heating	4.36	1.25	30.57	8.77	18.76	5.38	27.96	8.02
	Cooling	4.66	1.34	-		-		-	

The GWP emissions reduction impact of each system across the 4 locations is displayed graphically below for visual comparison.

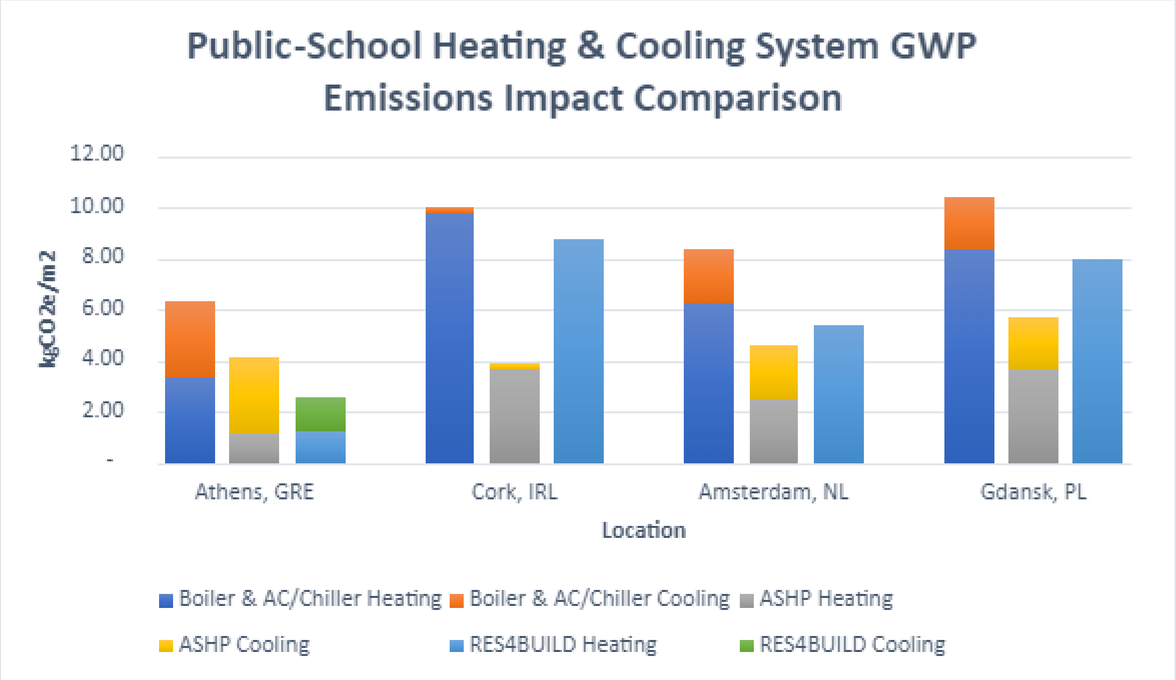


Figure 58 – Public School Heating & Cooling System GWP Emissions Impact Comparison

From the results, there is a clear reduction in the total heating and cooling GWP emissions intensity (kgCO2e/m^2) in each location from the RES4BUILD system in a Public-School building compared to the baseline boiler & AC system. However, the RES4BUILD system heating emissions intensity is higher than the ASHP system in all locations, although is significantly lower than the baseline gas boiler system. It is possible that this occurs due to the limitation of the simulation RES4BUILD heat pump size which is scaled massively for larger school-public buildings in this case and this negatively effects system energy consumption. The overall system emissions reduction is from the low cooling emissions with only the Athens RES4BUILD system having cooling related emissions due to the high cooling load requiring grid electricity, and all other locations having zero cooling related emissions.

From the results, it is demonstrated that in general the RES4BUILD system outperforms the alternatives, as would be expected with the benefit of the PVT system and BTES. Even with the RES4BUILD system high commercial and public-school heating electricity consumption and related emissions compared to ASHP, the system has the capability to significantly reduce the overall EU building stock thermal energy related emissions.

The actual energy data from property in the EU building stock (as per chapter 2) is to be used as reference for high-level comparison of existing building stock to future RES4BUILD system integrated building stock and not for the calculated impact analysis of the RES4BUILD system versus alternative technologies. The existing building stock data is a mix of buildings with poor, medium and high level of building fabric thermal insulation. The RES4BUILD system is designed for and only applicable for at a minimum, the cost-optimal renovated building quality which would be a medium-high level of building fabric thermal insulation. Therefore, a portion of the predicted energy and GHG emissions savings related to the installation of RES4BUILD system on the Existing European building stock would be related to building fabric improvements and not directly to the RES4BUILD integrated energy system.

In the systems comparison analysis, all estimated energy and GHG emissions savings are directly related to the RES4BUILD system. Therefore this comparison analysis, of the baseline gas boiler & AC system compared to the RES4BUILD system thermal energy and carbon emissions intensity is utilised and extrapolated for the EU building stock using the building floor area calculated in chapter 2.3 Locations. Both systems estimated total thermal energy consumption from gas and grid electricity, and the calculated GWP savings in % CO2e of the RES4BUILD system are summarised below.

Table 28 – EU Building Stock Thermal Energy & Emissions Impact Assessment Results Summary

EU Building Stock Thermal Energy & Emissions Impact Assessment			Baseline: gas boiler + AC Chiller		RES4BUILD		Impact
Location	**Typology**	**Est. EU Representative Building Floor Area**	**Gas use**	**Electricity use**	**Gas use**	**Electricity use**	**EN 15804 – GWP Saving**
		million m2	GWh/yr	GWh/yr	GWh/yr	GWh/yr	% CO_2-e Saved per annum
Athens, GRE - Warm Climate	SFH	3,253	88,786	59,766	0	35,593	74%
	MFRB	1,830	15,263	49,192	0	16,507	73%
	Commercial Office	521	2,528	16,706	0	8,767	53%
	Public - School	295	4,082	3,078	0	2,097	68%
Cork, IRL - Moderate-mixed Climate	SFH	1,884	122,506	1,545	0	26,261	75%
	MFRB	1,060	49,687	138	0	9,049	78%
	Commercial Office	324	7,778	1,227	0	4,023	48%
	Public - School	183	7,459	143	0	5,607	13%
Amsterdam, NL - Average Climate	SFH	5,088	275,329	38,977	0	61,314	77%
	MFRB	2,862	111,396	8,415	0	20,350	80%
	Commercial Office	858	20,950	11,603	0	10,779	63%
	Public - School	486	12,542	3,596	0	9,116	36%
Gdansk, PL - Cold Climate	SFH	3,610	305,154	14,117	0	68,526	75%
	MFRB	2,031	126,056	3,067	0	11,129	90%
	Commercial Office	590	18,620	7,749	0	10575.7	55%
	Public - School	334	11,605	2,361	0	9,350	23%
Total building stock	**EU28**	**25,211**	**1,179,741**	**221,677**	**0**	**309,046**	**75%**

Note that these GWP emissions reduction results differ slightly to those presented in T6.2. This is due to the difference in energy demand profiles input for GWP calculations which as stated above for T7.1 is based on the RES4BUILD system simulation results whereas the T6.2 GWP calculations are based on the recorded electricity consumption from the electricity grid of the IES (Integrated Energy System) in the pilots in WP5. Additionally the GWP emissions factor used for T7.1 is a representative single European value in contrast to the country specific electricity environmental profiles (or datasets) utilised in T6.2. Even with these difference the general conclusions remain the same in this scenario analysis, there is a full reduction in fossil fuel consumption as the RES4BUILD system is electricity based. However, the EU28 model only represents an estimated 86% of the building stock and therefore assuming fossil fuel use in all other buildings it is an 86% reduction in fossil-fuel consumption, higher than the initial analysis estimate of 77%.

Similarly from the initial analysis, the environmental impact was expected to be at least 68% GWP saving in for CO_2e emissions, The results from detailed comparison analysis indicate implementation of the RES4BUILD system on the building typologies of SFH, MFRB, Commercial office, and Public-School across the EU would result in an estimated 75% reduction in GWP CO_2e emissions compared to a typical gas boiler and AC system. The GWP % CO2e savings will improve as the electricity grid continues to decarbonise.

It is noted that this a high level ‘best case’ scenario with full implementation of the RES4BUILD system. In reality, there is likely to be several barriers and market constraints to the RES4BUILD system that will limit implementation. This will be investigated further in T7.2.

Additionally, from the model results there are several learnings for further analysis in the future;

- In the simulation, scaling the RES4BUILD heatpump for large buildings negatively effects the system energy consumption which is to be reviewed in future research.
- Residential building typologies (SFH & MFRB) have a low percentage of RES4BUILD system PVT electric generation self-consumption by the heat pump which should be investigated further to optimise system performance and economics.
- Athens Commercial and Public–School building models have high Solar PVT thermal heat rejection values which suggest that a large solar thermal element of the RES4BUILD is not required.
- The BTES element of the RES4BUILD system in the above energy model has unlimited capacity and availability which greatly improves free cooling ability but may not reflect trough market conditions

6.2 Further research

As this work preludes the analyses in Task 7.2 and Task 7.3, recommendations are given for alignment and elaboration on certain aspects.

Cost and social impact

Assess the impact (2-4) on cost competitiveness and social impact. For cost competitiveness, the results of the LCE (in WP6) and the economic optimization with algorithms (WP3) are to be used for a refined economic assessment. The variable character of capital and energy costs are to be highlighted.

Location & type specific design

Identify the RES4BUILD layout variations that are most suitable for specific building typologies and/or locations. For example, some layouts can be combined with standard components such as PV, which will replace some PVT collectors so that to reduce the excess heat during the summer season (typically in office buildings). In other cases, the constraints of applying BTES could outweigh the limited positive effect on the energy performance. In some cases, the organizational or financial structure (e.g. ownership and maintenance responsibility) could lead to specific system choices. Space requirements for the system components will also be a point of consideration, especially in dense urban areas.

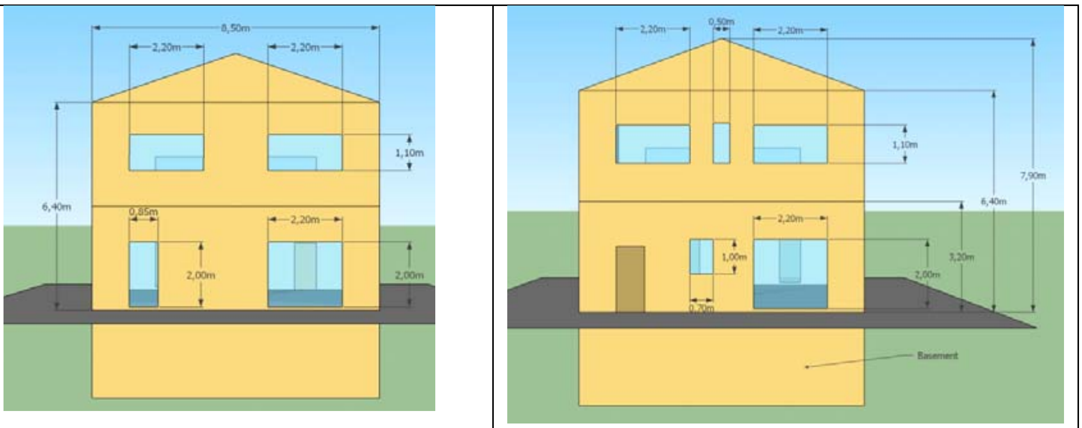
Sensitivity

Assess the possible scenarios over time for these impacts in order to determine the sensitivity of the business case. For this, it is relevant to map a number of probable scenario’s, which combine the effects of e.g. climate change, economic influence and regulatory change on the willingness of property owners to implement the system.

Appendix A

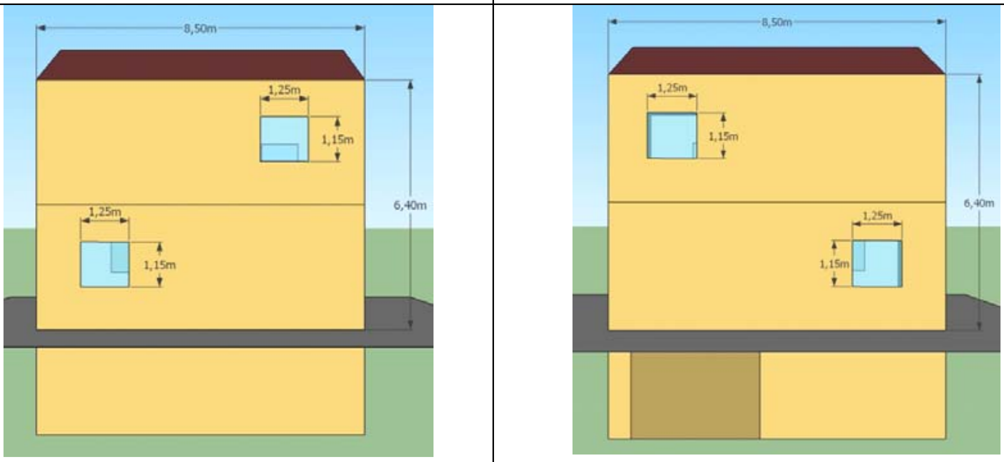
1.2.1 Single house

The building which has been selected as reference for single family house, (composed by an underground level and two floors over ground level) has a conditioned surface of about 140 m^2 and a S/V ratio of 0.7. The main other characteristics (fixed and variable by Country) involved on the simulation task are shown below.



North façade

South façade



East façade

West façade

Fig. 4: Prospects of the single house model.

Tab. 1: Fixed characteristics of the single house model.

		All Countries
Building geometry	**N° of heated floor =**	2
	S/V ratio =	0.7 m^2/m^3
	Orientation:	S/N
	Net dimensions of heated volume =	8.5 x 8.5 x 6 m
	Net floor area of heated zones =	140 m^2
	Area of S façade =	51 m^2
	Area of E façade =	51 m^2
	Area of N façade =	51 m^2
	Area of W façade =	51 m^2
	Area of Roof =	72.25 m2
	Area of Basement =	72.25 m2
	Window area on S façade =	25%
	Window area on E façade =	7%
	Window area on N façade =	25%
	Window area on W façade =	7%
Internal gains	**People design level =**	50 m^2/people
	Lighting design level =	3.5 W/m2
	Appliances design level =	4 W/m^2

Tab. 2: Variable characteristics of the single house model.

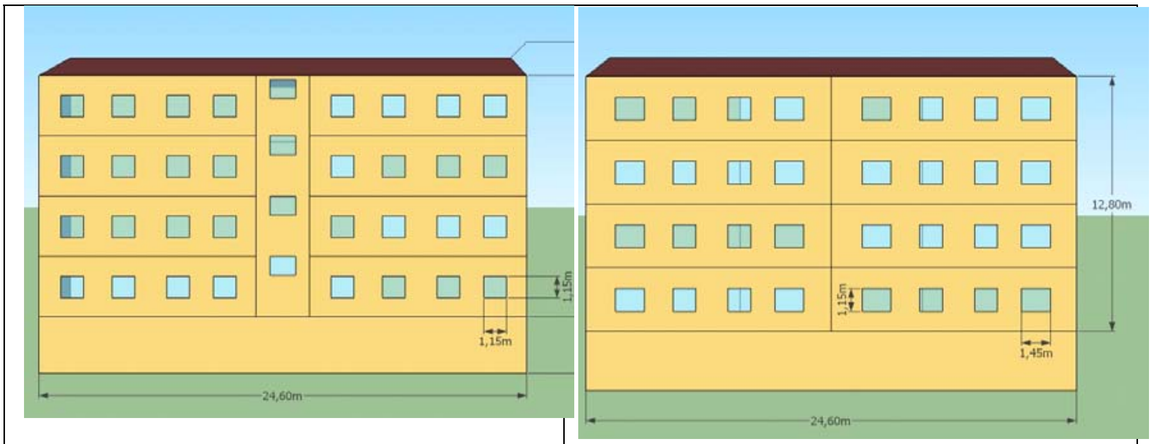
		ES	**IT**	**RO**	**AT**	**FR**	**CZ**	**DE**	**FI**	
Building technologies	**Construction materials:**	A	A	A	A	A	A	A	B	
	Typical infiltration rate:	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	h^{-1}
	U value of wall =	1.46	1.21	1.45	1.25	1.54	1.32	0.93	0.48	W/m^2K
	U value of roof =	1.92	1.69	1.60	1.39	1.20	1.32	1.10	0.30	W/m^2K
	U value of basement =	1.30	1.69	1.30	1.77	1.97	1.24	1.01	0.48	W/m^2K
	U value of glass =	5.70	3.20	2.40	2.70	4.20	2.90	2.57	2.79	W/m^2K
	g value of glass =	0.89	0.80	0.75	0.75	0.80	0.75	0.75	0.75	-
	Passive strategies:	In Summer: shading device + ventilation at night								

A: Brick, concrete, plaster

B: Brick, insulation, concrete, plaster

1.2.2 Apartment block

The building which has been selected as reference for apartment block (four floors + cellar) is composed by about 12-16 flats and its conditioned area is around 1000 m^2 and a S/V ratio of 0.33. The main other characteristics (fixed and variable by Country) involved on the simulation task are shown below.



North façade

South façade

Fig. 5: Prospects of the apartment block model.

Tab. 3: Fixed characteristics of the apartment block model.

		ES, IT, FR	RO, AT, CZ, DE, FI
Building geometry	N° of heated floor =	4	
	S/V ratio =	0.33 m^2/m^3	
	Orientation:	S/N	
	Net dimensions of heated volume =	24.6 x 11.2 x 12.8 m	
	Net floor area of heated zones =	990 m^2	
	Area of S façade =	315 m^2	
	Area of E façade =	143 m^2	
	Area of N façade =	315 m^2	
	Area of W façade =	143 m^2	
	Area of Roof =	54 m^2	
	Area of Basement =	54 m2	
	Window area on S façade =	15%	30%
	Window area on E façade =	0%	0%
	Window area on N façade =	15%	30%
	Window area on W façade =	0%	0%
Internal gains	People design level =	25 m^2/people	
	Lighting design level =	3.5 W/m^2	
	Appliances design level =	4 W/m^2	

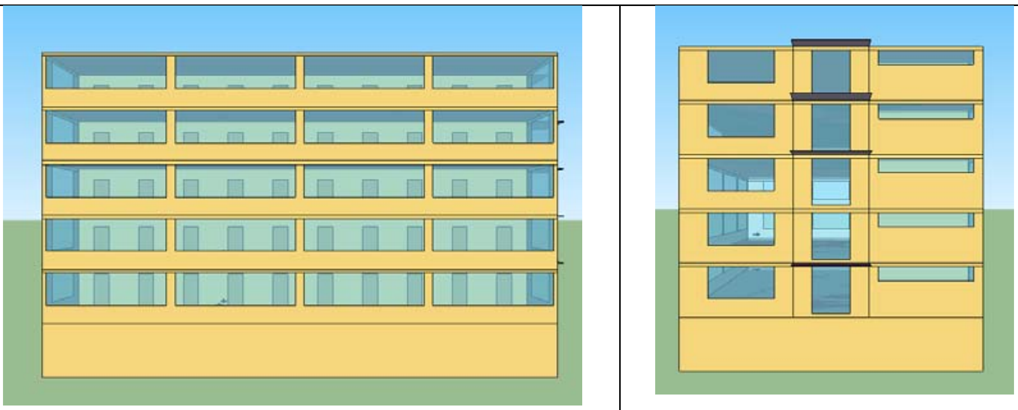
Tab. 4: Variable characteristics of the apartment block model.

		ES	IT	RO	AT	FR	CZ	DE	FI	
Building technologies	Construction materials:	A	A	C	B	B	B	B	B	
	Typical ACH rate:	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	h^{-1}
	U value of wall =	1.46	1.21	1.45	1.25	2.86	0.65	1.44	0.60	W/m^{2}K
	U value of roof =	1.92	1.69	1.20	1.39	2.56	0.65	1.17	0.39	W/m^{2}K
	U value of basement =	1.30	1.69	1.30	1.77	1.98	1.26	1.50	0.47	W/m^{2}K
	U value of glass =	5.70	3.30	2.40	2.70	3.80	2.90	2.11	2.79	W/m^{2}K
	g value of glass =	0.89	0.80	0.75	0.75	0.80	0.75	0.75	0.75	-
	Passive strategies:	In Summer: shading device + ventilation at night								

A: Hollow brick, air gap, concrete, plaster
B: Concrete, plaster
C: Prefabricated panel, concrete, plaster

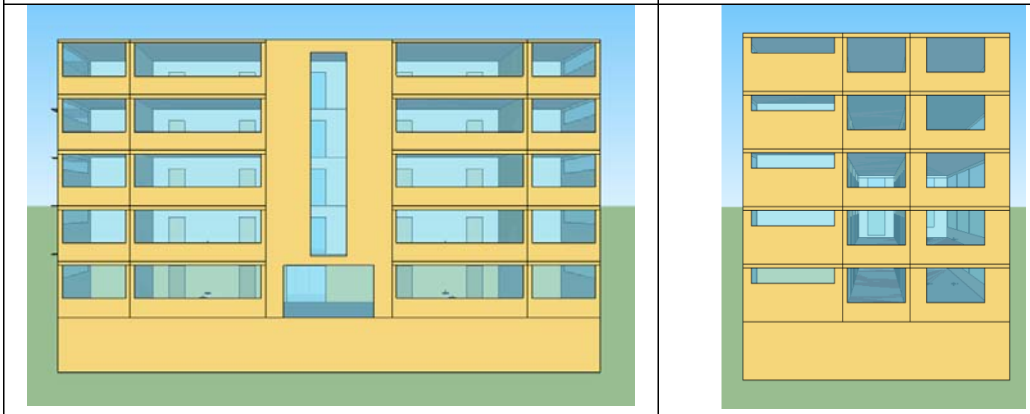
1.2.3 Office

As reference of office building, a medium-size and highly-glazed office building has been selected, with 5 floors (of 3 m height each) an S/V ratio of 0,33 and a net heated area of 2400 m^2. The main other characteristics (fixed and variable by Country) involved on the simulation task are shown in the following tables.



South façade

East façade



North façade

West façade

Fig. 6: Prospects of the office building model.

Tab. 5: Fixed characteristics of the office building model.

		All Countries
Building geometry	N° of heated floor =	5
	S/V ratio =	0.33 m²/m³
	Orientation:	S/N
	Net dimensions of heated volume =	30 x 16 x 15 m
	Net floor area of heated zones =	2400 m²
	Area of S façade =	450 m²
	Area of E façade =	240 m²
	Area of N façade =	450 m²
	Area of W façade =	240 m²
	Area of Roof =	480 m2
	Area of Basement =	480 m2
	Window area on S façade =	56%
	Window area on E façade =	32%
	Window area on N façade =	50%
	Window area on W façade =	35%
Internal gains	People design level =	18 m²/people
	Lighting design level =	14 W/m2
	Appliances design level =	9 W/m²

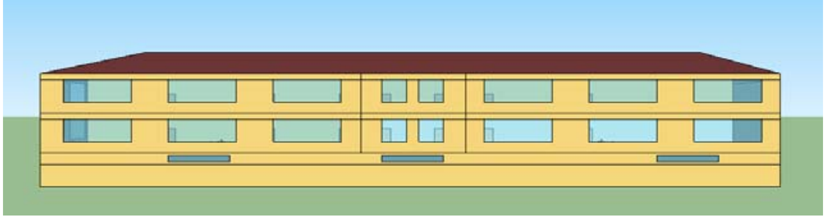
Tab. 6: Variable characteristics of the office building model.

		ES	IT	RO	AT	FR	CZ	DE	FI	
Building technologies	Construction materials:	A	A	C	B	A	C	B	B	
	Typical ACH rate:	1.15	1.15	0.92	1.60	1.15	1.15	1.15	1.45	h^{-1}
	U value of wall =	1.37	1.17	1.34	1.16	1.06	1.07	1.42	0.46	W/m²K
	U value of roof =	1.29	1.28	1.01	1.11	1.65	0.50	0.68	0.39	W/m²K
	U value of basement =	1.36	1.74	1.10	1.24	1.74	3.93	1.14	0.52	W/m²K
	U value of glass =	5.70	3.20 - 5.70	2.40	2.70	5.70	4.00	2.90	3.20	W/m²K
	g value of glass =	0.89	0.80 - 0.89	0.75	0.80	0.89	0.85	0.80	0.85	-
	Passive strategies:	Shading device controlled in summer by occupant								

A: Hollow brick, air gap, concrete, plaster
B: Concrete, insulation, plaster
C: Prefabricated panel, concrete, plaster

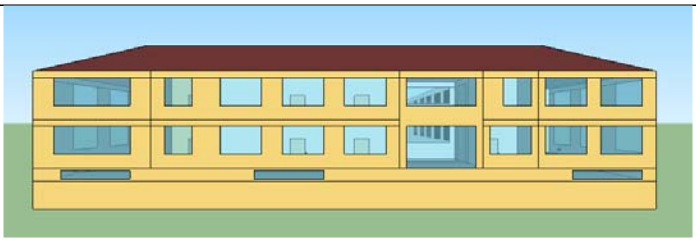
1.2.4 School

As reference model of school a two-floors building has been selected. It is “U” shaped with a heated surface of 3500 m^2 and its S/V ratio is 0.46. The main other characteristics (fixed and variable by Country) involved on the simulation task are shown in the following tables.



South/North façade

East façade



West façade

Fig. 7: Prospects of the school model.

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Programme of the European Union

Tab. 7: Fixed characteristics of the school model.

		All Countries
Building geometry	**N° of heated floor =**	2
	S/V ratio =	0.46 m2/m3
	Orientation:	S/N
	Net dimensions of heated volume =	45 x 60 x 7 m (U shape)
	Net floor area of heated zones =	3500 m^2
	Area of S façade =	752.5 m^2
	Area of E façade =	315 m^2
	Area of N façade =	752.5 m^2
	Area of W façade =	315 m^2
	Area of Roof =	1750 m2
	Area of Basement =	1750 m2
	Window area on S façade =	32%
	Window area on E façade =	22%
	Window area on N façade =	29%
	Window area on W façade =	40%
Internal gains	**People design level =**	5.6 m^2/people
	Lighting design level =	12 W/m2
	Appliances design level =	1.75 W/m^2

Tab. 8: Variable characteristics of the school model.

		ES	IT	RO	AT	FR	CZ	DE	FI	
Building technologies	**Construction materials:**	A	A	C	B	A	B	B	A	
	Typical ACH rate:	0.94	1.13	0.75	1.51	1.13	0.94	1.51	0.94	h^{-1}
	U value of wall =	1.37	1.17	1.34	2.59	1.17	1.41	1.42	0.62	W/m^2K
	U value of roof =	2.19	1.57	0.72	1.50	1.57	0.63	0.88	0.43	W/m^2K
	U value of basement =	2.56	1.74	1.10	1.24	1.74	3.93	1.14	0.70	W/m^2K
	U value of glass =	5.70	5.70	2.40	3.00	5.00	2.90	2.90	2.00	W/m^2K
	g value of glass =	0.89	0.89	0.75	0.80	0.85	0.80	0.80	0.70	-
	Passive strategies:	In Summer: shading device + ventilation at night								

A: Hollow brick, air gap or insulation, concrete, plaster
B: Concrete, insulation, plaster
C: Prefabricated panel, concrete, plaster

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Appendix B

2.5 Summary

Table 10: Summary of simulated energy needs for heating, cooling and DHW for the single house base cases.

	Target Country	Reference weather	end-use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	TOTAL EN
Single House	**ES**	**Seville**	Heating	11,2	6,2	2,6	1,5	0,1	0,0	0,0	0,0	0,0	0,1	5,2	9,8	36,7	123,7 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	14,0	25,4	20,7	12,8	0,0	0,0	0,0	72,9	
			DHW	1,2	1,1	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	14,1	
	ES	**Madrid**	Heating	25,9	18,2	8,5	6,2	0,6	0,0	0,0	0,0	0,0	3,9	14,0	26,6	103,9	166,4 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	8,2	19,2	15,6	4,7	0,0	0,0	0,0	47,7	
			DHW	1,3	1,1	1,3	1,2	1,3	1,2	1,3	1,3	1,2	1,3	1,2	1,3	14,8	
	IT	**Rome**	Heating	18,8	11,7	7,3	2,1	0,3	0,0	0,0	0,0	0,0	2,8	7,5	16,7	67,1	127,7 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	8,0	16,5	15,2	6,0	0,0	0,0	0,0	45,8	
			DHW	1,3	1,1	1,3	1,2	1,3	1,2	1,3	1,3	1,2	1,3	1,2	1,3	14,8	
	IT	**Milan**	Heating	39,9	30,1	14,2	8,0	1,1	0,0	0,0	0,0	0,0	7,2	23,4	37,0	160,9	208,9 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	7,4	14,4	8,7	1,8	0,0	0,0	0,0	32,4	
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,6	
	RO	**Bucharest**	Heating	45,5	30,6	21,1	6,6	1,5	0,0	0,0	0,0	1,5	11,7	28,5	42,1	189,1	236,0 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	7,9	13,0	10,1	0,0	0,0	0,0	0,0	31,0	
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,9	
	AT	**Vienna**	Heating	43,4	35,5	21,3	10,0	2,1	0,3	0,0	0,0	1,9	12,3	29,2	43,5	199,5	229,9 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	1,2	7,1	6,2	0,0	0,0	0,0	0,0	14,5	
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,9	
	FR	**Paris**	Heating	35,1	29,5	21,8	11,6	3,2	0,5	0,0	0,0	2,5	11,6	25,9	34,2	176,0	199,3 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	0,0	4,3	3,1	0,0	0,0	0,0	0,0	7,4	
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,9	
	CZ	**Prague**	Heating	48,5	40,1	28,0	14,9	5,3	0,0	0,0	0,0	5,2	18,5	35,9	43,0	239,4	260,5 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	1,2	2,1	1,8	0,0	0,0	0,0	0,0	5,2	
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,9	
	DE	**Berlin**	Heating	33,4	30,0	21,2	9,5	3,2	0,0	0,0	0,0	2,2	11,4	24,9	32,9	168,7	193,5 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	3,1	3,5	2,2	0,0	0,0	0,0	0,0	8,9	
			DHW	1,3	1,2	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	15,9	
	FI	**Helsinki**	Heating	31,2	26,9	20,9	9,8	1,6	0,0	0,0	0,0	4,2	13,3	26,4	31,0	165,2	183,1 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,1	0,0	0,0	0,0	0,0	1,1	
			DHW	1,4	1,3	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	16,8	

Table 11: Summary of simulated energy needs for heating, cooling and DHW for the apartment block base cases.

	Target Country	Reference weather	end-use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	TOTAL EN
Apartment block	**ES**	**Seville**	Heating	6,8	3,9	1,8	1,1	0,2	0,0	0,0	0,0	0,0	0,0	3,0	5,7	22,5	83,9 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	6,6	14,5	11,5	7,1	0,0	0,1	0,0	39,8	
			DHW	1,8	1,7	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	21,6	
	ES	**Madrid**	Heating	15,9	11,3	6,1	4,7	0,3	0,0	0,0	0,0	0,0	2,3	8,3	15,8	64,7	110,7 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	3,2	9,7	8,3	2,1	0,0	0,0	0,0	23,2	
			DHW	1,9	1,7	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9	22,7	
	IT	**Rome**	Heating	11,0	7,2	5,0	1,7	0,2	0,0	0,0	0,0	0,0	1,5	4,1	9,5	40,3	87,7 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	3,4	9,2	8,9	3,0	0,1	0,1	0,0	24,7	
			DHW	1,9	1,7	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9	22,7	
	IT	**Milan**	Heating	24,9	19,3	9,3	5,2	0,7	0,0	0,0	0,0	0,0	3,9	13,7	23,0	99,9	139,6 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	3,4	7,4	4,5	0,6	0,0	0,0	0,0	15,9	
			DHW	2,0	1,8	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0	23,8	
	RO	**Bucharest**	Heating	28,4	18,8	13,1	4,3	1,6	0,4	0,3	0,5	1,5	6,8	17,2	26,1	118,9	163,8 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	5,3	8,7	6,6	0,0	0,0	0,0	0,0	20,6	
			DHW	2,1	1,9	2,1	2,0	2,1	2,0	2,1	2,1	2,0	2,1	2,0	2,1	24,3	
	AT	**Vienna**	Heating	27,8	22,5	13,4	6,7	2,2	1,2	0,9	0,9	1,9	7,4	18,1	28,0	131,0	162,6 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	0,0	3,9	3,5	0,0	0,0	0,0	0,0	7,4	
			DHW	2,1	1,9	2,1	2,0	2,1	2,0	2,1	2,1	2,0	2,1	2,0	2,1	24,3	
	FR	**Paris**	Heating	28,7	24,9	18,8	10,3	3,0	0,5	0,0	0,0	2,1	9,2	20,8	27,6	146,0	173,3 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	0,0	1,8	1,2	0,0	0,0	0,0	0,0	3,0	
			DHW	2,1	1,9	2,1	2,0	2,1	2,0	2,1	2,1	2,0	2,1	2,0	2,1	24,3	
	CZ	**Prague**	Heating	24,3	19,8	13,3	6,8	2,6	0,7	0,9	0,7	2,2	8,0	17,5	21,1	117,9	145,8 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	0,8	1,4	1,4	0,0	0,0	0,0	0,0	3,6	
			DHW	2,1	1,9	2,1	2,0	2,1	2,0	2,1	2,1	2,0	2,1	2,0	2,1	24,3	
	DE	**Berlin**	Heating	26,2	23,5	16,5	8,2	3,5	1,0	1,1	1,1	2,3	8,8	19,0	25,8	136,8	167,5 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	2,2	2,6	1,6	0,0	0,0	0,0	0,0	6,4	
			DHW	2,1	1,9	2,1	2,0	2,1	2,0	2,1	2,1	2,0	2,1	2,0	2,1	24,3	
	FI	**Helsinki**	Heating	25,3	21,8	16,8	8,1	2,0	1,0	1,2	0,7	3,1	10,3	21,4	25,3	137,1	163,6 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,8	0,0	0,0	0,0	0,0	0,8	
			DHW	2,2	2,0	2,2	2,1	2,2	2,1	2,2	2,2	2,1	2,2	2,1	2,2	25,7	

Table 12: Summary of simulated energy needs for heating, cooling and DHW for the office building base cases.

	Target Country	Reference weather	end-use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	TOTAL EN
Office	ES	Seville	Heating	8,7	5,3	3,0	1,5	0,3	0,0	0,0	0,0	0,0	0,2	4,2	7,2	30,5	102,4 kWh/m^2
			Cooling	0,1	0,3	1,3	1,4	3,3	9,1	18,3	14,8	10,9	4,3	0,5	0,1	64,3	
			DHW	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	7,6	
	ES	Madrid	Heating	22,7	15,7	9,9	7,7	0,8	0,3	0,1	0,1	0,5	3,6	11,6	21,4	94,4	138,8 kWh/m^2
			Cooling	0,0	0,0	0,2	0,5	1,9	5,5	11,7	10,9	4,6	0,8	0,1	0,0	36,2	
			DHW	0,7	0,6	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	8,3	
	IT	Rome	Heating	18,2	12,6	9,3	3,4	0,5	0,0	0,0	0,0	0,0	2,6	7,5	14,9	68,9	136,4 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	2,7	9,3	17,1	16,5	10,1	3,5	0,1	0,0	59,2	
			DHW	0,7	0,6	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	8,3	
	IT	Milan	Heating	30,3	24,8	12,6	6,6	0,9	0,0	0,1	0,0	0,3	4,9	17,0	28,2	125,7	171,3 kWh/m^2
			Cooling	0,0	0,0	0,0	0,1	1,5	7,9	13,7	9,3	3,9	0,4	0,0	0,0	36,6	
			DHW	0,8	0,7	0,8	0,7	0,8	0,7	0,8	0,8	0,7	0,8	0,7	0,8	9,0	
	RO	Bucharest	Heating	29,9	20,5	14,1	3,1	0,6	0,0	0,0	0,0	0,5	6,1	17,3	26,5	118,6	165,3 kWh/m^2
			Cooling	0,0	0,0	0,0	0,2	3,4	7,4	12,7	10,1	2,4	1,2	0,0	0,0	37,4	
			DHW	0,8	0,7	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	9,3	
	AT	Vienna	Heating	40,0	33,7	23,0	11,1	2,0	0,3	0,0	0,1	1,7	11,8	26,7	39,3	189,7	212,5 kWh/m^2
			Cooling	0,0	0,0	0,0	0,1	0,8	2,0	5,7	4,6	0,3	0,0	0,0	0,0	13,5	
			DHW	0,8	0,7	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	9,3	
	FR	Paris	Heating	32,0	28,4	22,2	12,2	3,5	0,8	0,1	0,1	2,5	11,1	23,7	30,8	167,4	186,6 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,3	1,6	3,8	3,5	0,5	0,1	0,0	0,0	9,9	
			DHW	0,8	0,7	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	9,3	
	CZ	Prague	Heating	36,8	32,2	23,9	13,2	4,9	1,5	0,4	0,6	4,0	14,4	27,2	32,0	191,1	206,6 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,8	1,0	2,0	2,2	0,2	0,0	0,0	0,0	6,1	
			DHW	0,8	0,7	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	9,3	
	DE	Berlin	Heating	30,4	28,2	19,6	9,5	3,3	0,2	0,1	0,0	1,4	9,2	21,9	28,4	152,2	170,2 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,5	2,3	3,0	2,5	0,4	0,0	0,0	0,0	8,7	
			DHW	0,8	0,7	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	9,3	
	FI	Helsinki	Heating	42,8	39,0	33,1	18,7	6,1	0,9	0,3	0,6	6,7	19,0	35,8	41,6	244,7	259,6 kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,1	0,4	2,3	1,8	0,0	0,0	0,0	0,0	4,7	
			DHW	0,9	0,8	0,9	0,8	0,9	0,8	0,9	0,9	0,8	0,9	0,8	0,9	10,2	

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Table 13: Summary of simulated energy needs for heating, cooling and DHW for the school building base cases.

	Target Country	Reference weather	end-use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	TOTAL EN	
School	**ES**	**Seville**	Heating	12,0	8,7	4,6	2,5	0,3	0,0	0,0	0,0	0,0	0,3	6,5	8,0	42,9	98,3	kWh/m^2
			Cooling	0,0	0,0	0,1	0,4	1,6	8,4	19,4	2,2	10,7	2,6	0,2	0,0	45,6		
			DHW	0,8	0,7	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	9,7		
	ES	**Madrid**	Heating	23,8	18,9	11,9	10,0	1,1	0,3	0,1	0,0	0,4	4,5	14,1	20,6	105,6	137,5	kWh/m^2
			Cooling	0,0	0,0	0,0	0,1	0,6	4,2	11,7	1,0	3,4	0,1	0,0	0,0	21,2		
			DHW	0,9	0,8	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	10,6		
	IT	**Rome**	Heating	20,5	16,7	12,2	6,0	1,0	0,0	0,0	0,0	0,0	3,3	10,3	14,3	84,4	135,1	kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	1,4	8,0	18,1	0,8	9,0	2,5	0,2	0,0	40,1		
			DHW	0,9	0,8	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	10,6		
	IT	**Milan**	Heating	36,6	32,4	17,5	11,5	1,9	0,1	0,1	0,0	0,5	8,6	23,4	31,2	163,9	198,9	kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,5	6,7	13,5	0,3	2,4	0,1	0,0	0,0	23,5		
			DHW	1,0	0,9	1,0	0,9	1,0	0,9	1,0	1,0	0,9	1,0	0,9	1,0	11,6		
	RO	**Bucharest**	Heating	33,3	25,9	17,1	6,0	1,2	0,0	0,0	0,0	0,8	8,5	21,6	27,7	142,1	175,1	kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	2,0	5,5	11,7	0,1	1,2	0,5	0,0	0,0	21,0		
			DHW	1,0	0,9	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	11,9		
	AT	**Vienna**	Heating	46,4	42,3	28,6	17,2	5,4	1,9	0,1	0,0	4,3	17,7	34,0	42,8	240,8	259,1	kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,3	1,4	4,5	0,0	0,1	0,0	0,0	0,0	6,4		
			DHW	1,0	0,9	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	11,9		
	FR	**Paris**	Heating	32,9	31,1	23,5	15,7	5,2	1,5	0,2	0,0	3,4	13,8	26,3	28,7	182,3	197,9	kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,1	0,6	2,6	0,0	0,3	0,0	0,0	0,0	3,6		
			DHW	1,0	0,9	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	11,9		
	CZ	**Prague**	Heating	37,8	35,6	25,5	16,9	7,4	3,1	1,0	0,1	6,2	17,8	30,0	31,1	212,6	226,0	kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,2	0,3	0,9	0,0	0,0	0,0	0,0	0,0	1,4		
			DHW	1,0	0,9	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	11,9		
	DE	**Berlin**	Heating	38,6	38,4	27,5	18,7	7,0	1,1	0,4	0,1	4,4	16,5	31,2	33,1	216,9	231,8	kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,1	1,5	1,3	0,0	0,1	0,0	0,0	0,0	3,0		
			DHW	1,0	0,9	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	11,9		
	FI	**Helsinki**	Heating	39,1	37,5	30,0	19,5	6,6	0,9	0,3	0,1	7,7	18,6	32,9	33,6	226,8	241,1	kWh/m^2
			Cooling	0,0	0,0	0,0	0,0	0,0	0,0	1,1	0,0	0,0	0,0	0,0	0,0	1,2		
			DHW	1,1	1,0	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	13,1		

Appendix C

ARUP

	Note: All gray cells in this file are completed automatically.
Project Name:	RES4BUILD
Project #:	268695-00
Sofware:	EnergyPlus (as engine, via RH/GH/LB/HB/OS)
Software version:	OS 2.9.0
Folder Location with Simulation Files:	

MODEL INPUTS SUMMARY

	Units	Details	Baseline / Typical	Cost Optimal	New Build	Other?	Reference
GENERAL PROJECT INFO							
Project Location	--	Street address, City, State, Country	Cork, Ireland				
Climate Zone	--	ASHRAE Climate Zone (or other, e.g. CA climate zone)	5A				
Climate Zone Type	--	Reference provided climate zone description	Cool - Humid				
Weather File	--	Weather file name used for annual simulation	IRL_EM_Dublin.AP.039690_TMYx				
Main Building Type	--	Residential, Office, School, Hospital, etc.	Office				
Geometry File	--	DOE, PNNL, ENTRANZE, Custom	Entranze				
Orientation	--	N, S, E, W…					
Number of floors	--	Total number of floors including above ground, below ground and parking	5				
Room Height	m	Floor to ceiling height	3				
Applicable Energy Code/Standard	--	Code source and cycle year (e.g. ASHRAE 90.1-2013, or CA T24 2016)	Part L 2019, BCO 2019				
BUILDING AREA SUMMARY							
Total Area	m^2		2400	2400	2400		
Conditioned Area	m^2		2400	2400	2400		
	%		100%	100%	100%	Calculated	
Space Types							
Residential	m^2						
Commercial	m^2		2400	2400	2400		
Office	m^2						
Core	m^2						
Circulation	m^2						
Plant	m^2						
Unconditioned	m^2						
Parking	m^2						
Storage	m^2						
Void	m^2						
ENVELOPE							
Exterior Wall U-Value	W/m^2K		0,45	0,21	0,18		ns/files/200407_i
Exterior Roof U-Value	W/m^2K		0,25	0,25	0,15		
Exposed Floor U-value	W/m^2K		0,45	0,25	0,15		
Glazing U-Value	W/m^2K	Assembly U-value	2,2	1,6	1,4		
Glazing SHGC	--	Center of glass	0,7	0,4	0,4		
Glazing VLT	--	Center of glass					
Window-to-Wall Ratio (WWR)	%	Gross and per façade orientation if desired	34	34	34		
Exterior Shading Type	--	Included? Y or N, and brief description as necessary	N	N	N		
BUILDING SERVICES LOADS							
Lighting Power Density (LPD)	W/m^2		14	14	14		Entranze
Occ. Density	m^2/person		18	18	18		Entranze
Equipment Power Density (EPD)	W/m^2		9	9	9		Entranze
ICT Power Density	W/m^2		0	0	0		
Total EPD	W/m^2		9	9	9	Calculated	
Heating Set Point	°C		21	21	21		
Heating Setbacks	°C		15,5	15,5	15,5		
Cooling Set Point	°C		24	24	24		
Cooling Setbacks	°C		27	27	27		
Infiltration	m3/s/m2 façad	'@4Pa ~ q50 (Pa) / 20 ~~ then m3/hr to m3/s /(60*60)	0,000138889	0,000069	0,000042		
Ventilation Per Area	m3/s/m2		0,001	0,0014	0,0014		BSEN
Ventilation Per Person	m3/s/person		0,01	0,014	0,014		BSEN
Recirculated Air Per Area	m3/s/person		0	0	0		
DOMESTIC HOT WATER							

ARUP

	Note: All gray cells in this file are completed automatically.
Project Name:	RES4BUILD
Project #:	268695-00
Sofware:	EnergyPlus (as engine, via RH/GH/LB/HB/OS)
Software version:	OS 2.9.0
Folder Location with Simulation Files:	

MODEL INPUTS SUMMARY

	Units	**Details**	**Baseline / Typical**	**Cost Optimal**	**New Build**	**Other?**	**Reference**
GENERAL PROJECT INFO							
Project Location	--	Street address, City, State, Country	Athens, Greece				
Climate Zone	--	ASHRAE Climate Zone (or other, e.g. CA climate zone)	3B				
Climate Zone Type	--	Reference provided climate zone description	Warm - Dry				
Weather File	--	Weather file name used for annual simulation	GRC_AT_Athinai-Hellinikon.AFB.167160_TMYx.2004-2018				
Main Building Type	--	Residential, Office, School, Hospital, etc.	Office				
Geometry File	--	DOE, PNNL, ENTRANZE, Custom	Entranze				
Orientation	--	N, S, E, W...					
Number of floors	--	Total number of floors including above ground, below ground and parking	5				
Room Height	m	Floor to ceiling height	3				
Applicable Energy Code/Standard	--	Code source and cycle year (e.g. ASHRAE 90.1-2013, or CA T24 2016)					
BUILDING AREA SUMMARY							
Total Area	m^2		2400	2400	2400		
Conditioned Area	m^2		2400	2400	2400		
	%		100%	100%	100%	Calculated	
Space Types							
Residential	m^2						
Commercial	m^2		2400	2400	2400		
Office	m^2						
Core	m^2						
Circulation	m^2						
Plant	m^2						
Unconditioned	m^2						
Parking	m^2						
Storage	m^2						
Void	m^2						
ENVELOPE							
Exterior Wall U-Value	W/m^{2}K		0,7	0,5	0,45		03%2D01%20Bu
Exterior Roof U-Value	W/m^{2}K		0,5	0,45	0,4		
Exposed Floor U-value	W/m^{2}K		1,9	0,9	0,9		
Glazing U-Value	W/m^{2}K	Assembly U-value	2,2	3	2,6		
Glazing SHGC	--	Center of glass	0,7	0,4	0,4		
Glazing VLT	--	Center of glass					
Window-to-Wall Ratio (WWR)	%	Gross and per façade orientation if desired	34	34	34		
Exterior Shading Type	--	Included? Y or N, and brief description as necessary	N	N	N		
BUILDING SERVICES LOADS							
Lighting Power Density (LPD)	W/m^2		14	14	14		Entranze
Occ. Density	m^2/person		18	18	18		Entranze
Equipment Power Density (EPD)	W/m^2		9	9	9		Entranze
ICT Power Density	W/m^2		0	0	0		
Total EPD	W/m^2		9	9	9	Calculated	
Heating Set Point	°C		21	21	21		
Heating Setbacks	°C		18	18	18		
Cooling Set Point	°C		26	26	26		
Cooling Setbacks	°C		28	28	28		
Infiltration	m3/s/m2 faça	'@4Pa ~ q50 (Pa) / 20 ~~ then m3/hr to m3/s /(60*60)	0,000138889	0,000069	0,000042		
Ventilation Per Area	m3/s/m2		0,001	0,0014	0,0014		BSEN
Ventilation Per Person	m3/s/person		0,01	0,014	0,014		BSEN
Recirculated Air Per Area	m3/s/person		0	0	0		
DOMESTIC HOT WATER							

ARUP

	Note: All gray cells in this file are completed automatically.
Project Name:	RES4BUILD
Project #:	268695-00
Sofware:	EnergyPlus (as engine, via RH/GH/LB/HB/OS)
Software version:	OS 2.9.0
Folder Location with Simulation Files:	

MODEL INPUTS SUMMARY

	Units	Details	Baseline / Typical	Cost Optimal	New Build	Other?	Reference
GENERAL PROJECT INFO							
Project Location	--	Street address, City, State, Country	Haarlem, Netherlands				
Climate Zone	--	ASHRAE Climate Zone (or other, e.g. CA climate zone)	4A				
Climate Zone Type	--	Reference provided climate zone description	Mixed - Humid				
Weather File	--	Weather file name used for annual simulation	NEN 5060 – energie				
Main Building Type	--	Residential, Office, School, Hospital, etc.	Office				
Geometry File	--	DOE, PNNL, ENTRANZE, Custom	Entranze				
Orientation	--	N, S, E, W…					
Number of floors	--	Total number of floors including above ground, below ground and parking	5				
Room Height	m	Floor to ceiling height	3				
Applicable Energy Code/Standard	--	Code source and cycle year (e.g. ASHRAE 90.1-2013, or CA T24 2016)	BCO 2019				
BUILDING AREA SUMMARY							
Total Area	m^2		2400	2400	2400		
Conditioned Area	m^2		2400	2400	2400		
	%		100%	100%	100%	Calculated	
Space Types							
Residential	m^2						
Commercial	m^2		2400	2400	2400		
Office	m^2						
Core	m^2						
Circulation	m^2						
Plant	m^2						
Unconditioned	m^2						
Parking	m^2						
Storage	m^2						
Void	m^2						
ENVELOPE							
Exterior Wall U-Value	W/m^{2}K			0,21	0,21		%2D01%20Buildi
Exterior Roof U-Value	W/m^{2}K			0,15	0,15		
Exposed Floor U-value	W/m^{2}K			0,26	0,26		
Glazing U-Value	W/m^{2}K	Assembly U-value		1,65	1,65		
Glazing SHGC	--	Center of glass		0,4	0,4		
Glazing VLT	--	Center of glass					
Window-to-Wall Ratio (WWR)	%	Gross and per façade orientation if desired	34	34	34		
Exterior Shading Type	--	Included? Y or N, and brief description as necessary	N	N	N		
BUILDING SERVICES LOADS							
Lighting Power Density (LPD)	W/m^2		14	14	14		Entranze
Occ. Density	m^2/person		18	18	18		Entranze
Equipment Power Density (EPD)	W/m^2		9	9	9		Entranze
ICT Power Density	W/m^2		0	0	0		
Total EPD	W/m^2		9	9	9	Calculated	
Heating Set Point	°C		21	21	21		
Heating Setbacks	°C		16	16	16		
Cooling Set Point	°C		24	24	24		
Cooling Setbacks	°C		24	24	24		
Infiltration	m3/s/m2 faça	'@4Pa ~ q50 (Pa) / 20 ~~ then m3/hr to m3/s /(60*60)	0,000138889	0,000069	0,000042		
Ventilation Per Area	m3/s/m2		0,001	0,0014	0,0014		
Ventilation Per Person	m3/s/person		0,01	0,014	0,014		
Recirculated Air Per Area	m3/s/person		0	0	0		
DOMESTIC HOT WATER							

ARUP

	Note: All gray cells in this file are completed automatically.
Project Name:	RES4BUILD
Project #:	268695-00
Sofware:	EnergyPlus (as engine, via RH/GH/LB/HB/OS)
Software version:	OS 2.9.0
Folder Location with Simulation Files:	

MODEL INPUTS SUMMARY

	Units	**Details**	**Baseline / Typical**	**Cost Optimal**	**New Build**	**Other?**	**Reference**
GENERAL PROJECT INFO							
Project Location	--	Street address, City, State, Country	Gdansk, Poland				
Climate Zone	--	ASHRAE Climate Zone (or other, e.g. CA climate zone)	6A				
Climate Zone Type	--	Reference provided climate zone description	Cold - Humid				
Weather File	--	Weather file name used for annual simulation	OL_PM_Gdansk-Walesy.Intl.AP-Rebiechowo.Intl.AP.121500_TMYx.2004-201				
Main Building Type	--	Residential, Office, School, Hospital, etc.	Office				
Geometry File	--	DOE, PNNL, ENTRANZE, Custom	Entranze				
Orientation	--	N, S, E, W...					
Number of floors	--	Total number of floors including above ground, below ground and parking	5				
Room Height	m	Floor to ceiling height	3				
Applicable Energy Code/Standard	--	Code source and cycle year (e.g. ASHRAE 90.1-2013, or CA T24 2016)	BCO 2019				
BUILDING AREA SUMMARY							
Total Area	m²		2400	2400	2400		
Conditioned Area	m²		2400	2400	2400		
	%		100%	100%	100%	Calculated	
Space Types							
Residential	m²						
Commercial	m²		2400	2400	2400		
Office	m²						
Core	m²						
Circulation	m²						
Plant	m²						
Unconditioned	m²						
Parking	m²						
Storage	m²						
Void	m²						
ENVELOPE							
Exterior Wall U-Value	W/m²K			0,2	0,2		%2D03%2D01%2
Exterior Roof U-Value	W/m²K			0,15	0,15		
Exposed Floor U-value	W/m²K			0,25	0,25		
Glazing U-Value	W/m²K	Assembly U-value		0,9	0,9		
Glazing SHGC	--	Center of glass		0,4	0,4		
Glazing VLT	--	Center of glass					
Window-to-Wall Ratio (WWR)	%	Gross and per façade orientation if desired	34	34	34		
Exterior Shading Type	--	Included? Y or N, and brief description as necessary	N	N	N		
BUILDING SERVICES LOADS							
Lighting Power Density (LPD)	W/m²		14	14	14		Entranze
Occ. Density	m²/person		18	18	18		Entranze
Equipment Power Density (EPD)	W/m²		9	9	9		Entranze
ICT Power Density	W/m²		0	0	0		
Total EPD	W/m²		9	9	9	Calculated	
Heating Set Point	°C		21	21	21		
Heating Setbacks	°C		15,5	15,5	15,5		
Cooling Set Point	°C		24	24	24		
Cooling Setbacks	°C		27	27	27		
Infiltration	m3/s/m2 faça	'@4Pa ~ q50 (Pa) / 20 ~~ then m3/hr to m3/s /(60*60)	0,000138889	0,000069	0,000042		
Ventilation Per Area	m3/s/m2		0,001	0,0014	0,0014		
Ventilation Per Person	m3/s/person		0,01	0,014	0,014		
Recirculated Air Per Area	m3/s/person		0	0	0		
DOMESTIC HOT WATER							

ARUP

	Note: All gray cells in this file are completed automatically.
Project Name:	RES4BUILD
Project #:	268695-00
Sofware:	EnergyPlus (as engine, via RH/GH/LB/HB/OS)
Software version:	OS 2.9.0
Folder Location with Simulation Files:	

MODEL INPUTS SUMMARY

	Units	**Details**	**Baseline / Typical**	**Cost Optimal**	**New Build**	**Other?**	**Reference**
GENERAL PROJECT INFO							
Project Location	--	Street address, City, State, Country	Cork, Ireland				
Climate Zone	--	ASHRAE Climate Zone (or other, e.g. CA climate zone)	5A				
Climate Zone Type	--	Reference provided climate zone description	Cool - Humid				
Weather File	--	Weather file name used for annual simulation	IRL_EM_Dublin.AP.039690_TMYx				
Main Building Type	--	Residential, Office, School, Hospital, etc.	Mult-family Residential Building (MFRB)				
Geometry File	--	DOE, PNNL, ENTRANZE, Custom	Entranze				
Orientation	--	N, S, E, W...					
Number of floors	--	Total number of floors including above ground, below ground and parking	4				
Room Height	m	Floor to ceiling height	3,2				
Applicable Energy Code/Standard	--	Code source and cycle year (e.g. ASHRAE 90.1-2013, or CA T24 2016)	Part L 2019				
BUILDING AREA SUMMARY							
Total Area	m²		990	990	990		
Conditioned Area	m²		990	990	990		
	%		100%	100%	100%	Calculated	
Space Types							
Residential	m²		990	990	990		
Commercial	m²						
Office	m²						
Core	m²						
Circulation	m²						
Plant	m²						
Unconditioned	m²						
Parking	m²						
Storage	m²						
Void	m²						
ENVELOPE							
Exterior Wall U-Value	W/m²K		0,45	0,31	0,18		ns/files/200407_
Exterior Roof U-Value	W/m²K		0,25	0,13	0,16		
Exposed Floor U-value	W/m²K		0,45	0,22	0,18		
Glazing U-Value	W/m²K	Assembly U-value	2,2	1,4	1,4		
Glazing SHGC	--	Center of glass	0,7	0,5	0,3		
Glazing VLT	--	Center of glass					
Window-to-Wall Ratio (WWR)	%	Gross and per façade orientation if desired	15	15	15		
Exterior Shading Type	--	Included? Y or N, and brief description as necessary	N	N	N		
BUILDING SERVICES LOADS							
Lighting Power Density (LPD)	W/m²		3,5	3,5	3,5		Entranze
Occ. Density	m²/person		25	25	25		Entranze
Equipment Power Density (EPD)	W/m²		4	4	4		Entranze
ICT Power Density	W/m²		0	0	0		
Total EPD	W/m²		4	4	4	Calculated	
Heating Set Point	°C		20	20	20		
Heating Setbacks	°C		16	16	16		
Cooling Set Point	°C		24	24	24		
Cooling Setbacks	°C		27	27	27		
Infiltration	m3/s/m2 faça	'@4Pa ~ q50 (Pa) / 20 ~~ then m3/hr to m3/s /(60*60)	0,000138889	0,000069	0,000042		
Ventilation Per Area	m3/s/m2		0,0003	0,0003	0,0003		
Ventilation Per Person	m3/s/person		0,0045	0,0045	0,0045		
Recirculated Air Per Area	m3/s/person		0	0	0		
DOMESTIC HOT WATER							

ARUP

	Note: All gray cells in this file are completed automatically.
Project Name:	RES4BUILD
Project #:	268695-00
Sofware:	EnergyPlus (as engine, via RH/GH/LB/HB/OS)
Software version:	OS 2.9.0
Folder Location with Simulation Files:	

MODEL INPUTS SUMMARY

	Units	Details	Baseline / Typical	Cost Optimal	New Build	Other?	Reference
GENERAL PROJECT INFO							
Project Location	--	Street address, City, State, Country	Athens, Greece				
Climate Zone	--	ASHRAE Climate Zone (or other, e.g. CA climate zone)	3B				
Climate Zone Type	--	Reference provided climate zone description	Warm - Dry				
Weather File	--	Weather file name used for annual simulation	GRC_AT_Athinai-Hellinikon.AFB.167160_TMYx.2004-2018				
Main Building Type	--	Residential, Office, School, Hospital, etc.	Mult-family Residential Building (MFRB)				
Geometry File	--	DOE, PNNL, ENTRANZE, Custom	Entranze				
Orientation	--	N, S, E, W...					
Number of floors	--	Total number of floors including above ground, below ground and parking	4				
Room Height	m	Floor to ceiling height	3,2				
Applicable Energy Code/Standard	--	Code source and cycle year (e.g. ASHRAE 90.1-2013, or CA T24 2016)					
BUILDING AREA SUMMARY							
Total Area	m²		990	990	990		
Conditioned Area	m²		990	990	990		
	%		100%	100%	100%	Calculated	
Space Types							
Residential	m²		990	990	990		
Commercial	m²						
Office	m²						
Core	m²						
Circulation	m²						
Plant	m²						
Unconditioned	m²						
Parking	m²						
Storage	m²						
Void	m²						
ENVELOPE							
Exterior Wall U-Value	W/m²K		0,7	0,5	0,45		D03%2D01%20Bu
Exterior Roof U-Value	W/m²K		0,5	0,45	0,4		
Exposed Floor U-value	W/m²K		1,9	0,9	0,9		
Glazing U-Value	W/m²K	Assembly U-value	5	3	2,6		
Glazing SHGC	--	Center of glass	0,7	0,4	0,4		
Glazing VLT	--	Center of glass					
Window-to-Wall Ratio (WWR)	%	Gross and per façade orientation if desired	34	34	34		
Exterior Shading Type	--	Included? Y or N, and brief description as necessary	N	N	N		
BUILDING SERVICES LOADS							
Lighting Power Density (LPD)	W/m²		3,5	3,5	3,5		Entranze
Occ. Density	m²/person		25	25	25		Entranze
Equipment Power Density (EPD)	W/m²		4	4	4		Entranze
ICT Power Density	W/m²		0	0	0		
Total EPD	W/m²		4	4	4	Calculated	
Heating Set Point	°C		18	18	18		
Heating Setbacks	°C		18	18	18		
Cooling Set Point	°C		28	28	28		
Cooling Setbacks	°C		28	28	28		
Infiltration	m3/s/m2 faça	'@4Pa ~ q50 (Pa) / 20 ~~ then m3/hr to m3/s /(60*60)	0,000138889	0,000069	0,000042		
Ventilation Per Area	m3/s/m2		0,0003	0,0003	0,0003		
Ventilation Per Person	m3/s/person		0,0045	0,0045	0,0045		
Recirculated Air Per Area	m3/s/person		0	0	0		
DOMESTIC HOT WATER							

ARUP

	Note: All gray cells in this file are completed automatically.
Project Name:	RES4BUILD
Project #:	268695-00
Sofware:	EnergyPlus (as engine, via RH/GH/LB/HB/OS)
Software version:	OS 2.9.0
Folder Location with Simulation Files:	

MODEL INPUTS SUMMARY

	Units	**Details**	**Baseline / Typical**	**Cost Optimal**	**New Build**	**Other?**	**Reference**
GENERAL PROJECT INFO							
Project Location	--	Street address, City, State, Country	Haarlem, Netherlands				
Climate Zone	--	ASHRAE Climate Zone (or other, e.g. CA climate zone)	4A				
Climate Zone Type	--	Reference provided climate zone description	Mixed - Humid				
Weather File	--	Weather file name used for annual simulation	NEN 5060 – energie				
Main Building Type	--	Residential, Office, School, Hospital, etc.	Mult-family Residential Building (MFRB)				
Geometry File	--	DOE, PNNL, ENTRANZE, Custom	Entranze				
Orientation	--	N, S, E, W...					
Number of floors	--	Total number of floors including above ground, below ground and parking	4				
Room Height	m	Floor to ceiling height	3,2				
Applicable Energy Code/Standard	--	Code source and cycle year (e.g. ASHRAE 90.1-2013, or CA T24 2016)	BCO 2019, NTA 8800				
BUILDING AREA SUMMARY							
Total Area	m²		990	990	990		
Conditioned Area	m²		990	990	990		
	%		100%	100%	100%	Calculated	
Space Types							
Residential	m²		990	990	990		
Commercial	m²						
Office	m²						
Core	m²						
Circulation	m²						
Plant	m²						
Unconditioned	m²						
Parking	m²						
Storage	m²						
Void	m²						
ENVELOPE							
Exterior Wall U-Value	W/m²K			0,21	0,21		%2D01%20Buildi
Exterior Roof U-Value	W/m²K			0,15	0,15		
Exposed Floor U-value	W/m²K			0,26	0,26		
Glazing U-Value	W/m²K	Assembly U-value		1,65	1,65		
Glazing SHGC	--	Center of glass		0,60	0,6		
Glazing VLT	--	Center of glass					
Window-to-Wall Ratio (WWR)	%	Gross and per façade orientation if desired	34	34	34		
Exterior Shading Type	--	Included? Y or N, and brief description as necessary	N	N	N		
BUILDING SERVICES LOADS							
Lighting Power Density (LPD)	W/m²		3,5	3,5	3,5		Entranze
Occ. Density	m²/person		25	25	25		Entranze
Equipment Power Density (EPD)	W/m²		4	4	4		Entranze
ICT Power Density	W/m²		0	0	0		
Total EPD	W/m²		4	4	4	Calculated	
Heating Set Point	°C		20	20	20		
Heating Setbacks	°C		16	16	16		
Cooling Set Point	°C		24	24	24		
Cooling Setbacks	°C		27	27	27		
Infiltration	m3/s/m2 faça	'@4Pa ~ q50 (Pa) / 20 ~~ then m3/hr to m3/s /(60*60)	0,000138889	0,000069	0,000042		
Ventilation Per Area	m3/s/m2		0,0003	0,0003	0,0003		
Ventilation Per Person	m3/s/person		0,0045	0,0045	0,0045		
Recirculated Air Per Area	m3/s/person		0	0	0		
DOMESTIC HOT WATER							

	Note: All gray cells in this file are completed automatically.
Project Name:	RES4BUILD
Project #:	268695-00
Sofware:	EnergyPlus (as engine, via RH/GH/LB/HB/OS)
Software version:	OS 2.9.0
Folder Location with Simulation Files:	

MODEL INPUTS SUMMARY

	Units	**Details**	**Baseline / Typical**	**Cost Optimal**	**New Build**	**Other?**	**Reference**
GENERAL PROJECT INFO							
Project Location	--	Street address, City, State, Country	Gdansk, Poland				
Climate Zone	--	ASHRAE Climate Zone (or other, e.g. CA climate zone)	6A				
Climate Zone Type	--	Reference provided climate zone description	Cold - Humid				
Weather File	--	Weather file name used for annual simulation	OL_PM_Gdansk-Walesy.Intl.AP-Rebiechowo.Intl.AP.121500_TMYx.2004-201				
Main Building Type	--	Residential, Office, School, Hospital, etc.	Mult-family Residential Building (MFRB)				
Geometry File	--	DOE, PNNL, ENTRANZE, Custom	Entranze				
Orientation	--	N, S, E, W...					
Number of floors	--	Total number of floors including above ground, below ground and parking	4				
Room Height	m	Floor to ceiling height	3,2				
Applicable Energy Code/Standard	--	Code source and cycle year (e.g. ASHRAE 90.1-2013, or CA T24 2016)	BCO 2019				
BUILDING AREA SUMMARY							
Total Area	m²		990	990	990		
Conditioned Area	m²		990	990	990		
	%		100%	100%	100%	Calculated	
Space Types							
Residential	m²		990	990	990		
Commercial	m²						
Office	m²						
Core	m²						
Circulation	m²						
Plant	m²						
Unconditioned	m²						
Parking	m²						
Storage	m²						
Void	m²						
ENVELOPE							
Exterior Wall U-Value	W/m²K			0,2	0,2		%2D03%2D01%2
Exterior Roof U-Value	W/m²K			0,15	0,15		
Exposed Floor U-value	W/m²K			0,25	0,25		
Glazing U-Value	W/m²K	Assembly U-value		0,9	0,9		
Glazing SHGC	--	Center of glass		0,4	0,4		
Glazing VLT	--	Center of glass					
Window-to-Wall Ratio (WWR)	%	Gross and per façade orientation if desired	34	34	34		
Exterior Shading Type	--	Included? Y or N, and brief description as necessary	N	N	N		
BUILDING SERVICES LOADS							
Lighting Power Density (LPD)	W/m²		3,5	3,5	3,5		Entranze
Occ. Density	m²/person		25	25	25		Entranze
Equipment Power Density (EPD)	W/m²		4	4	4		Entranze
ICT Power Density	W/m²		0	0	0		
Total EPD	W/m²		4	4	4	Calculated	
Heating Set Point	°C		20	20	20		
Heating Setbacks	°C		16	16	16		
Cooling Set Point	°C		24	24	24		
Cooling Setbacks	°C		27	27	27		
Infiltration	m3/s/m2 faça	'@4Pa ~ q50 (Pa) / 20 ~~ then m3/hr to m3/s /(60*60)	0,000138889	0,000069	0,000042		
Ventilation Per Area	m3/s/m2		0,0003	0,0003	0,0003		
Ventilation Per Person	m3/s/person		0,0045	0,0045	0,0045		
Recirculated Air Per Area	m3/s/person		0	0	0		
DOMESTIC HOT WATER							

ARUP

	Note: All gray cells in this file are completed automatically.
Project Name:	RES4BUILD
Project #:	268695-00
Sofware:	EnergyPlus (as engine, via RH/GH/LB/HB/OS)
Software version:	OS 2.9.0
Folder Location with Simulation Files:	

MODEL INPUTS SUMMARY

	Units	**Details**	**Baseline / Typical**	**Cost Optimal**	**New Build**	**Other?**	**Reference**
GENERAL PROJECT INFO							
Project Location	--	Street address, City, State, Country	Cork, Ireland				
Climate Zone	--	ASHRAE Climate Zone (or other, e.g. CA climate zone)	5A				
Climate Zone Type	--	Reference provided climate zone description	Cool - Humid				
Weather File	--	Weather file name used for annual simulation	IRL_EM_Dublin.AP.039690_TMYx				
Main Building Type	--	Residential, Office, School, Hospital, etc.	School				
Geometry File	--	DOE, PNNL, ENTRANZE, Custom	Entranze				
Orientation	--	N, S, E, W...					
Number of floors	--	Total number of floors including above ground, below ground and parking	2				
Room Height	m	Floor to ceiling height	3				
Applicable Energy Code/Standard	--	Code source and cycle year (e.g. ASHRAE 90.1-2013, or CA T24 2016)	Part L 2019				
BUILDING AREA SUMMARY							
Total Area	m²		3500	3500	3500		
Conditioned Area	m²		3500	3500	3500		
	%		100%	100%	100%	Calculated	
Space Types							
Residential	m²						
Commercial	m²		3500	3500	3500		
Office	m²						
Core	m²						
Circulation	m²						
Plant	m²						
Unconditioned	m²						
Parking	m²						
Storage	m²						
Void	m²						
ENVELOPE							
Exterior Wall U-Value	W/m²K			0,31	0,18		ns/files/200407_
Exterior Roof U-Value	W/m²K			0,25	0,16		
Exposed Floor U-value	W/m²K			0,25	0,18		
Glazing U-Value	W/m²K	Assembly U-value		1,6	1,4		
Glazing SHGC	--	Center of glass		0,4	0,4		
Glazing VLT	--	Center of glass					
Window-to-Wall Ratio (WWR)	%	Gross and per façade orientation if desired	34	34	34		
Exterior Shading Type	--	Included? Y or N, and brief description as necessary	N	N	N		
BUILDING SERVICES LOADS							
Lighting Power Density (LPD)	W/m²		12	12	12		Entranze
Occ. Density	m²/person		5,6	5,6	5,6		Entranze
Equipment Power Density (EPD)	W/m²		1,75	1,75	1,75		Entranze
ICT Power Density	W/m²		0	0	0		
Total EPD	W/m²		1,75	1,75	1,75	Calculated	
Heating Set Point	°C		21	21	21		
Heating Setbacks	°C		16	16	16		
Cooling Set Point	°C		24	24	24		
Cooling Setbacks	°C		27	27	27		
Infiltration	m3/s/m2 faça	'@4Pa ~ q50 (Pa) / 20 ~~ then m3/hr to m3/s /(60*60)	0,000138889	0,000069	0,000042		
Ventilation Per Area	m3/s/m2		0,001	0,001	0,001		BSEN
Ventilation Per Person	m3/s/person		0,01	0,01	0,01		BSEN
Recirculated Air Per Area	m3/s/person		0	0	0		
DOMESTIC HOT WATER							

ARUP

	Note: All gray cells in this file are completed automatically.
Project Name:	RES4BUILD
Project #:	268695-00
Sofware:	EnergyPlus (as engine, via RH/GH/LB/HB/OS)
Software version:	OS 2.9.0
Folder Location with Simulation Files:	

MODEL INPUTS SUMMARY

	Units	**Details**	**Baseline / Typical**	**Cost Optimal**	**New Build**	**Other?**	**Reference**
GENERAL PROJECT INFO							
Project Location	--	Street address, City, State, Country	Athens, Greece				
Climate Zone	--	ASHRAE Climate Zone (or other, e.g. CA climate zone)	3B				
Climate Zone Type	--	Reference provided climate zone description	Warm - Dry				
Weather File	--	Weather file name used for annual simulation	GRC_AT_Athinai-Hellinikon.AFB.167160_TMYx.2004-2018				
Main Building Type	--	Residential, Office, School, Hospital, etc.	School				
Geometry File	--	DOE, PNNL, ENTRANZE, Custom	Entranze				
Orientation	--	N, S, E, W…					
Number of floors	--	Total number of floors including above ground, below ground and parking	2				
Room Height	m	Floor to ceiling height	3				
Applicable Energy Code/Standard	--	Code source and cycle year (e.g. ASHRAE 90.1-2013, or CA T24 2016)					
BUILDING AREA SUMMARY							
Total Area	m²		3500	3500	3500		
Conditioned Area	m²		3500	3500	3500		
	%		100%	100%	100%	Calculated	
Space Types							
Residential	m²						
Commercial	m²		3500	3500	3500		
Office	m²						
Core	m²						
Circulation	m²						
Plant	m²						
Unconditioned	m²						
Parking	m²						
Storage	m²						
Void	m²						
ENVELOPE							
Exterior Wall U-Value	W/m²K			0,5	0,45		03%2D01%20Bu
Exterior Roof U-Value	W/m²K			0,45	0,4		
Exposed Floor U-value	W/m²K			0,9	0,9		
Glazing U-Value	W/m²K	Assembly U-value		3	2,6		
Glazing SHGC	--	Center of glass		0,4	0,4		
Glazing VLT	--	Center of glass					
Window-to-Wall Ratio (WWR)	%	Gross and per façade orientation if desired		34	34		
Exterior Shading Type	--	Included? Y or N, and brief description as necessary	N	N	N		
BUILDING SERVICES LOADS							
Lighting Power Density (LPD)	W/m²		12	12	12		Entranze
Occ. Density	m²/person		5,6	5,6	5,6		Entranze
Equipment Power Density (EPD)	W/m²		1,75	1,75	1,75		Entranze
ICT Power Density	W/m²		0	0	0		
Total EPD	W/m²		1,75	1,75	1,75	Calculated	
Heating Set Point	°C		21	21	21		
Heating Setbacks	°C		16	16	16		
Cooling Set Point	°C		26	26	26		
Cooling Setbacks	°C		28	28	28		
Infiltration	m3/s/m2 faça	'@4Pa ~ q50 (Pa) / 20 ~~ then m3/hr to m3/s /(60*60)	0,000138889	0,000069	0,000042		
Ventilation Per Area	m3/s/m2		0,001	0,001	0,001		
Ventilation Per Person	m3/s/person		0,01	0,01	0,01		
Recirculated Air Per Area	m3/s/person		0	0	0		
DOMESTIC HOT WATER							

ARUP

	Note: All gray cells in this file are completed automatically.
Project Name:	RES4BUILD
Project #:	268695-00
Sofware:	EnergyPlus (as engine, via RH/GH/LB/HB/OS)
Software version:	OS 2.9.0
Folder Location with Simulation Files:	

MODEL INPUTS SUMMARY

	Units	Details	Baseline / Typical	Cost Optimal	New Build	Other?	Reference
GENERAL PROJECT INFO							
Project Location	--	Street address, City, State, Country	Haarlem, Netherlands				
Climate Zone	--	ASHRAE Climate Zone (or other, e.g. CA climate zone)	4A				
Climate Zone Type	--	Reference provided climate zone description	Mixed - Humid				
Weather File	--	Weather file name used for annual simulation	NEN 5060 – energie				
Main Building Type	--	Residential, Office, School, Hospital, etc.	School				
Geometry File	--	DOE, PNNL, ENTRANZE, Custom	Entranze				
Orientation	--	N, S, E, W...					
Number of floors	--	Total number of floors including above ground, below ground and parking	2				
Room Height	m	Floor to ceiling height	3				
Applicable Energy Code/Standard	--	Code source and cycle year (e.g. ASHRAE 90.1-2013, or CA T24 2016)					
BUILDING AREA SUMMARY							
Total Area	m²		3500	3500	3500		
Conditioned Area	m²		3500	3500	3500		
	%		100%	100%	100%	Calculated	
Space Types							
Residential	m²						
Commercial	m²		3500	3500	3500		
Office	m²						
Core	m²						
Circulation	m²						
Plant	m²						
Unconditioned	m²						
Parking	m²						
Storage	m²						
Void	m²						
ENVELOPE							
Exterior Wall U-Value	W/m²K			0,21	0,21		%2D01%20Buildi
Exterior Roof U-Value	W/m²K			0,15	0,15		
Exposed Floor U-value	W/m²K			0,26	0,26		
Glazing U-Value	W/m²K	Assembly U-value		1,65	1,65		
Glazing SHGC	--	Center of glass		0,40	0,4		
Glazing VLT	--	Center of glass					
Window-to-Wall Ratio (WWR)	%	Gross and per façade orientation if desired	34	34	34		
Exterior Shading Type	--	Included? Y or N, and brief description as necessary	N	N	N		
BUILDING SERVICES LOADS							
Lighting Power Density (LPD)	W/m²		12	12	12		Entranze
Occ. Density	m²/person		5,6	5,6	5,6		Entranze
Equipment Power Density (EPD)	W/m²		1,75	1,75	1,75		Entranze
ICT Power Density	W/m²		0	0	0		
Total EPD	W/m²		1,75	1,75	1,75	Calculated	
Heating Set Point	°C		21	21	21		
Heating Setbacks	°C		16	16	16		
Cooling Set Point	°C		24	24	24		
Cooling Setbacks	°C		24	24	24		
Infiltration	m3/s/m2 faça	'@4Pa ~ q50 (Pa) / 20 ~~ then m3/hr to m3/s /(60*60)	0,000138889	0,000069	0,000042		
Ventilation Per Area	m3/s/m2		0,001	0,001	0,001		BSEN
Ventilation Per Person	m3/s/person		0,01	0,01	0,01		BSEN
Recirculated Air Per Area	m3/s/person		0	0	0		
DOMESTIC HOT WATER							

	Note: All gray cells in this file are completed automatically.
Project Name:	RES4BUILD
Project #:	268695-00
Sofware:	EnergyPlus (as engine, via RH/GH/LB/HB/OS)
Software version:	OS 2.9.0
Folder Location with Simulation Files:	

MODEL INPUTS SUMMARY

	Units	**Details**	**Baseline / Typical**	**Cost Optimal**	**New Build**	**Other?**	**Reference**
GENERAL PROJECT INFO							
Project Location	--	Street address, City, State, Country	Gdansk, Poland				
Climate Zone	--	ASHRAE Climate Zone (or other, e.g. CA climate zone)	6A				
Climate Zone Type	--	Reference provided climate zone description	Cold - Humid				
Weather File	--	Weather file name used for annual simulation	OL_PM_Gdansk-Walesy.Intl.AP-Rebiechowo.Intl.AP.121500_TMYx.2004-201				
Main Building Type	--	Residential, Office, School, Hospital, etc.	School				
Geometry File	--	DOE, PNNL, ENTRANZE, Custom	Entranze				
Orientation	--	N, S, E, W...					
Number of floors	--	Total number of floors including above ground, below ground and parking	2				
Room Height	m	Floor to ceiling height	3				
Applicable Energy Code/Standard	--	Code source and cycle year (e.g. ASHRAE 90.1-2013, or CA T24 2016)					
BUILDING AREA SUMMARY							
Total Area	m²		3500	3500	3500		
Conditioned Area	m²		3500	3500	3500		
	%		100%	100%	100%	Calculated	
Space Types							
Residential	m²						
Commercial	m²		3500	3500	3500		
Office	m²						
Core	m²						
Circulation	m²						
Plant	m²						
Unconditioned	m²						
Parking	m²						
Storage	m²						
Void	m²						
ENVELOPE							
Exterior Wall U-Value	W/m²K			0,2	0,2		%2D03%2D01%2
Exterior Roof U-Value	W/m²K			0,15	0,15		
Exposed Floor U-value	W/m²K			0,25	0,25		
Glazing U-Value	W/m²K	Assembly U-value		0,9	0,9		
Glazing SHGC	--	Center of glass		0,4	0,4		
Glazing VLT	--	Center of glass					
Window-to-Wall Ratio (WWR)	%	Gross and per façade orientation if desired	34	34	34		
Exterior Shading Type	--	Included? Y or N, and brief description as necessary	N	N	N		
BUILDING SERVICES LOADS							
Lighting Power Density (LPD)	W/m²		12	12	12		Entranze
Occ. Density	m²/person		5,6	5,6	5,6		Entranze
Equipment Power Density (EPD)	W/m²		1,75	1,75	1,75		Entranze
ICT Power Density	W/m²		0	0	0		
Total EPD	W/m²		1,75	1,75	1,75	Calculated	
Heating Set Point	°C		21	21	21		
Heating Setbacks	°C		16	16	16		
Cooling Set Point	°C		24	24	24		
Cooling Setbacks	°C		27	27	27		
Infiltration	m3/s/m2 faça	'@4Pa ~ q50 (Pa) / 20 ~~ then m3/hr to m3/s /(60*60)	0,000138889	0,000069	0,000042		
Ventilation Per Area	m3/s/m2		0,001	0,001	0,001		
Ventilation Per Person	m3/s/person		0,01	0,01	0,01		
Recirculated Air Per Area	m3/s/person		0	0	0		
DOMESTIC HOT WATER							

ARUP

	Note: All gray cells in this file are completed automatically.
Project Name:	RES4BUILD
Project #:	268695-00
Sofware:	EnergyPlus (as engine, via RH/GH/LB/HB/OS)
Software version:	OS 2.9.0
Folder Location with Simulation Files:	

MODEL INPUTS SUMMARY

	Units	Details	Baseline / Typical	Cost Optimal	New Build	Other?	Reference
GENERAL PROJECT INFO							
Project Location	--	Street address, City, State, Country	Cork, Ireland				
Climate Zone	--	ASHRAE Climate Zone (or other, e.g. CA climate zone)	5A				
Climate Zone Type	--	Reference provided climate zone description	Cool - Humid				
Weather File	--	Weather file name used for annual simulation	IRL_EM_Dublin.AP.039690_TMYx				
Main Building Type	--	Residential, Office, School, Hospital, etc.	Mult-family Residential Building (MFRB)				
Geometry File	--	DOE, PNNL, ENTRANZE, Custom	Entranze				
Orientation	--	N, S, E, W…					
Number of floors	--	Total number of floors including above ground, below ground and parking	2				
Room Height	m	Floor to ceiling height	3,2				
Applicable Energy Code/Standard	--	Code source and cycle year (e.g. ASHRAE 90.1-2013, or CA T24 2016)	Part L 2019				
BUILDING AREA SUMMARY							
Total Area	m²		140	140	140		
Conditioned Area	m²		140	140	140		
	%		100%	100%	100%	Calculated	
Space Types							
Residential	m²		140	140	140		
Commercial	m²						
Office	m²						
Core	m²						
Circulation	m²						
Plant	m²						
Unconditioned	m²						
Parking	m²						
Storage	m²						
Void	m²						
ENVELOPE							
Exterior Wall U-Value	W/m²K		0,45	0,31	0,18		ns/files/200407_
Exterior Roof U-Value	W/m²K		0,25	0,13	0,16		
Exposed Floor U-value	W/m²K		0,45	0,22	0,18		
Glazing U-Value	W/m²K	Assembly U-value	2,2	1,4	1,4		
Glazing SHGC	--	Center of glass	0,7	0,5	0,3		
Glazing VLT	--	Center of glass					
Window-to-Wall Ratio (WWR)	%	Gross and per façade orientation if desired	15	15	15		
Exterior Shading Type	--	Included? Y or N, and brief description as necessary	N	N	N		
BUILDING SERVICES LOADS							
Lighting Power Density (LPD)	W/m²		3,5	3,5	3,5		Entranze
Occ. Density	m²/person		25	25	25		Entranze
Equipment Power Density (EPD)	W/m²		4	4	4		Entranze
ICT Power Density	W/m²		0	0	0		
Total EPD	W/m²		4	4	4	Calculated	
Heating Set Point	°C		20	20	20		
Heating Setbacks	°C		16	16	16		
Cooling Set Point	°C		24	24	24		
Cooling Setbacks	°C		27	27	27		
Infiltration	m3/s/m2 faça	'@4Pa ~ q50 (Pa) / 20 ~~ then m3/hr to m3/s /(60*60)	0,000138889	0,000069	0,000042		
Ventilation Per Area	m3/s/m2		0,0003	0,0003	0,0003		
Ventilation Per Person	m3/s/person		0,0045	0,0045	0,0045		
Recirculated Air Per Area	m3/s/person		0	0	0		
DOMESTIC HOT WATER							

ARUP

	Note: All gray cells in this file are completed automatically.
Project Name:	RES4BUILD
Project #:	268695-00
Sofware:	EnergyPlus (as engine, via RH/GH/LB/HB/OS)
Software version:	OS 2.9.0
Folder Location with Simulation Files:	

MODEL INPUTS SUMMARY

	Units	**Details**	**Baseline / Typical**	**Cost Optimal**	**New Build**	**Other?**	**Reference**
GENERAL PROJECT INFO							
Project Location	--	Street address, City, State, Country	Athens, Greece				
Climate Zone	--	ASHRAE Climate Zone (or other, e.g. CA climate zone)	3B				
Climate Zone Type	--	Reference provided climate zone description	Warm - Dry				
Weather File	--	Weather file name used for annual simulation	GRC_AT_Athinai-Hellinikon.AFB.167160_TMYx.2004-2018				
Main Building Type	--	Residential, Office, School, Hospital, etc.	Mult-family Residential Building (MFRB)				
Geometry File	--	DOE, PNNL, ENTRANZE, Custom	Entranze				
Orientation	--	N, S, E, W...					
Number of floors	--	Total number of floors including above ground, below ground and parking	2				
Room Height	m	Floor to ceiling height	3,2				
Applicable Energy Code/Standard	--	Code source and cycle year (e.g. ASHRAE 90.1-2013, or CA T24 2016)	Local Regs				
BUILDING AREA SUMMARY							
Total Area	m²		140	140	140		
Conditioned Area	m²		140	140	140		
	%		100%	100%	100%	Calculated	
Space Types							
Residential	m²		140	140	140		
Commercial	m²						
Office	m²						
Core	m²						
Circulation	m²						
Plant	m²						
Unconditioned	m²						
Parking	m²						
Storage	m²						
Void	m²						
ENVELOPE							
Exterior Wall U-Value	W/m²K		0,7	0,5	0,45		D03%2D01%20Bu
Exterior Roof U-Value	W/m²K		0,5	0,45	0,4		
Exposed Floor U-value	W/m²K		1,9	0,9	0,9		
Glazing U-Value	W/m²K	Assembly U-value	5	3	2,6		
Glazing SHGC	--	Center of glass	0,7	0,4	0,4		
Glazing VLT	--	Center of glass					
Window-to-Wall Ratio (WWR)	%	Gross and per façade orientation if desired	34	34	34		
Exterior Shading Type	--	Included? Y or N, and brief description as necessary	N	N	N		
BUILDING SERVICES LOADS							
Lighting Power Density (LPD)	W/m²		3,5	3,5	3,5		Entranze
Occ. Density	m²/person		25	25	25		Entranze
Equipment Power Density (EPD)	W/m²		4	4	4		Entranze
ICT Power Density	W/m²		0	0	0		
Total EPD	W/m²		4	4	4	Calculated	
Heating Set Point	°C		18	18	18		
Heating Setbacks	°C		18	18	18		
Cooling Set Point	°C		28	28	28		
Cooling Setbacks	°C		28	28	28		
Infiltration	m3/s/m2 faça	'@4Pa ~ q50 (Pa) / 20 ~~ then m3/hr to m3/s /(60*60)	0,000138889	0,000069	0,000042		
Ventilation Per Area	m3/s/m2		0,0003	0,0003	0,0003		
Ventilation Per Person	m3/s/person		0,0045	0,0045	0,0045		
Recirculated Air Per Area	m3/s/person		0	0	0		
DOMESTIC HOT WATER							

ARUP

	Note: All gray cells in this file are completed automatically.
Project Name:	RES4BUILD
Project #:	268695-00
Sofware:	EnergyPlus (as engine, via RH/GH/LB/HB/OS)
Software version:	OS 2.9.0
Folder Location with Simulation Files:	

MODEL INPUTS SUMMARY

	Units	Details	Baseline / Typical	Cost Optimal	New Build	Other?	Reference
GENERAL PROJECT INFO							
Project Location	--	Street address, City, State, Country	Haarlem, Netherlands				
Climate Zone	--	ASHRAE Climate Zone (or other, e.g. CA climate zone)	4A				
Climate Zone Type	--	Reference provided climate zone description	Mixed - Humid				
Weather File	--	Weather file name used for annual simulation	NEN 5060 – energie				
Main Building Type	--	Residential, Office, School, Hospital, etc.	Mult-family Residential Building (MFRB)				
Geometry File	--	DOE, PNNL, ENTRANZE, Custom	Entranze				
Orientation	--	N, S, E, W…					
Number of floors	--	Total number of floors including above ground, below ground and parking	2				
Room Height	m	Floor to ceiling height	3,2				
Applicable Energy Code/Standard	--	Code source and cycle year (e.g. ASHRAE 90.1-2013, or CA T24 2016)	Local Regs				
BUILDING AREA SUMMARY							
Total Area	m^2		140	140	140		
Conditioned Area	m^2		140	140	140		
	%		100%	100%	100%	Calculated	
Space Types							
Residential	m^2		140	140	140		
Commercial	m^2						
Office	m^2						
Core	m^2						
Circulation	m^2						
Plant	m^2						
Unconditioned	m^2						
Parking	m^2						
Storage	m^2						
Void	m^2						
ENVELOPE							
Exterior Wall U-Value	W/m^{2}K			0,21	0,21		%2D01%20Buildi
Exterior Roof U-Value	W/m^{2}K			0,15	0,15		
Exposed Floor U-value	W/m^{2}K			0,26	0,26		
Glazing U-Value	W/m^{2}K	Assembly U-value		1,65	1,65		
Glazing SHGC	--	Center of glass		0,60	0,6		
Glazing VLT	--	Center of glass					
Window-to-Wall Ratio (WWR)	%	Gross and per façade orientation if desired	34	34	34		
Exterior Shading Type	--	Included? Y or N, and brief description as necessary	N	N	N		
BUILDING SERVICES LOADS							
Lighting Power Density (LPD)	W/m^2		3,5	3,5	3,5		Entranze
Occ. Density	m^2/person		25	25	25		Entranze
Equipment Power Density (EPD)	W/m^2		4	4	4		Entranze
ICT Power Density	W/m^2		0	0	0		
Total EPD	W/m^2		4	4	4	Calculated	
Heating Set Point	°C		20	20	20		
Heating Setbacks	°C		16	16	16		
Cooling Set Point	°C		24	24	24		
Cooling Setbacks	°C		27	27	27		
Infiltration	m3/s/m2 faça	'@4Pa ~ q50 (Pa) / 20 ~~ then m3/hr to m3/s /(60*60)	0,000138889	0,000069	0,000042		
Ventilation Per Area	m3/s/m2		0,0003	0,0003	0,0003		
Ventilation Per Person	m3/s/person		0,0045	0,0045	0,0045		
Recirculated Air Per Area	m3/s/person		0	0	0		
DOMESTIC HOT WATER							

ARUP

	Note: All gray cells in this file are completed automatically.
Project Name:	RES4BUILD
Project #:	268695-00
Sofware:	EnergyPlus (as engine, via RH/GH/LB/HB/OS)
Software version:	OS 2.9.0
Folder Location with Simulation Files:	

MODEL INPUTS SUMMARY

	Units	Details	Baseline / Typical	Cost Optimal	New Build	Other?	Reference
GENERAL PROJECT INFO							
Project Location	--	Street address, City, State, Country	Gdansk, Poland				
Climate Zone	--	ASHRAE Climate Zone (or other, e.g. CA climate zone)	6A				
Climate Zone Type	--	Reference provided climate zone description	Cold - Humid				
Weather File	--	Weather file name used for annual simulation	OL_PM_Gdansk-Walesy.Intl.AP-Rebiechowo.Intl.AP.121500_TMYx.2004-201				
Main Building Type	--	Residential, Office, School, Hospital, etc.	Mult-family Residential Building (MFRB)				
Geometry File	--	DOE, PNNL, ENTRANZE, Custom	Entranze				
Orientation	--	N, S, E, W...					
Number of floors	--	Total number of floors including above ground, below ground and parking	2				
Room Height	m	Floor to ceiling height	3,2				
Applicable Energy Code/Standard	--	Code source and cycle year (e.g. ASHRAE 90.1-2013, or CA T24 2016)	Local Regs				
BUILDING AREA SUMMARY							
Total Area	m²		140	140	140		
Conditioned Area	m²		140	140	140		
	%		100%	100%	100%	Calculated	
Space Types							
Residential	m²		140	140	140		
Commercial	m²						
Office	m²						
Core	m²						
Circulation	m²						
Plant	m²						
Unconditioned	m²						
Parking	m²						
Storage	m²						
Void	m²						
ENVELOPE							
Exterior Wall U-Value	W/m²K			0,2	0,2		%2D03%2D01%2
Exterior Roof U-Value	W/m²K			0,15	0,15		
Exposed Floor U-value	W/m²K			0,25	0,25		
Glazing U-Value	W/m²K	Assembly U-value		0,9	0,9		
Glazing SHGC	--	Center of glass		0,4	0,4		
Glazing VLT	--	Center of glass					
Window-to-Wall Ratio (WWR)	%	Gross and per façade orientation if desired	34	34	34		
Exterior Shading Type	--	Included? Y or N, and brief description as necessary	N	N	N		
BUILDING SERVICES LOADS							
Lighting Power Density (LPD)	W/m²		3,5	3,5	3,5		Entranze
Occ. Density	m²/person		25	25	25		Entranze
Equipment Power Density (EPD)	W/m²		4	4	4		Entranze
ICT Power Density	W/m²		0	0	0		
Total EPD	W/m²		4	4	4	Calculated	
Heating Set Point	°C		20	20	20		
Heating Setbacks	°C		16	16	16		
Cooling Set Point	°C		24	24	24		
Cooling Setbacks	°C		27	27	27		
Infiltration	m3/s/m2 faça	'@4Pa ~ q50 (Pa) / 20 ~~ then m3/hr to m3/s /(60*60)	0,000138889	0,000069	0,000042		
Ventilation Per Area	m3/s/m2		0,0003	0,0003	0,0003		
Ventilation Per Person	m3/s/person		0,0045	0,0045	0,0045		
Recirculated Air Per Area	m3/s/person		0	0	0		
DOMESTIC HOT WATER							