Nantes | Hamburg | Helsinki

Ref. Ares(2018)3464771 - 29/06/2018

mySMARTLife

Deliverable due date: M19 – June 2018

D1.12 DESCRIPTION OF 3D MODELS FOR EACH PILOT

WP1, Task 1.4

Transition of EU cities towards a new concept of Smart Life and Economy

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Project Acronym	mySMARTLife	
Project Title	**Transition of EU cities towards a new concept of Smart Life and Economy**	
Project Duration	1st December 2016 – 30th November 2021 (60 Months)	
Deliverable	D1.12 Description of 3D models for each pilot	
Diss. Level	PU	
Status		Working
		Verified by other WPs
	■	Final version
Due date	30/06/2018	
Work Package	WP1	
Lead beneficiary	TEC	
Contributing beneficiary(ies)	CAR, NAN, HAM, HEL, VTT, FVH, NBK	
Task description	Task 1.4 is related to evaluating impacts in lighthouse (NAN, HAM, HEL) and follower cities (BYD, VAR, RIJ, PAL) from the social, economy and environmental field to understand the interaction of the different interventions as a system. These will be clear indicators for the cities to make decisions. These results, combined with their own SEAPs, their sustainable mobility plans, their open data strategy, and related tasks in this WP1 and with WP2, WP3, WP4 and WP6 will serve to develop the integrated urban plans of these cities as an application of the methodology that later will be replicated in the followers. In the subtask 1.4.1 Models (CityGml or similar) of the pilots will be developed by Lighthouses and technical partners to identify the energy model (demand side plus existing supply side) to determine the energy demands and detect passive strategies for each pilot. Information on the socio-economic profile of the inhabitants, use of ICT services, location of industry, building density, etc. is needed. Cities with 3D models will not need to duplicate them.	

Date	Version	Author	Comment
01/03/2018	0.1	Eneko Arrizabalaga (TEC)	Interim Version
17/05/2018	0.2	Eneko Arrizabalaga (TEC)	Initial structure and content sent to the reviewer (NBK)
01/06/2018	0.3	Eneko Arrizabalaga Jose Luis Izkara (TEC)	Advanced version with the general content of all the sections

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

14/06/2018	0.4	Eneko Arrizabalaga Jose Luis Izkara (TEC)	Advanced version sent to the reviewer (NBK, KON)
25/06/2018	0.5	Aurélien Henon (NBK) Klaas Wulff (KON)	Reviewed version (NBK, KON)
26/06/2018	0.4	Eneko Arrizabalaga Jose Luis Izkara (TEC)	Reviewed version
29/06/2018	0.5	CAR	Final overall check

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Table of Content

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Table of Figures

This project has received funding from the European Union‘s Horizon 2020 research and innovation programme under grant agreement No 731297.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Table of Tables

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Abbreviations and Acronyms

Acronym	Description
ACDk	Annual cooling useful energy demand
ACH	Air change per hours
AHDk	Annual heating useful energy demand
Ak	Envelope element surface
BT	Base temperature
CAR	Fundación Cartif (beneficiary from Spain/project coordinator)
CDHi,j	Cooling degree hours
DHW	Domestic Hot Water
DHWDk	Annual domestic hot water useful energy demand
DSM	Digital Surface Model
DTM	Digital Terrain Model
EPSG	Spatial Reference System Code defined by the European Petroleum Survey Group
GDP	Gross Domestic Product
HAM	Hamburg (beneficiary from Germany)
HDHi,j	Heating degree hours
HEL	Helsingin kaupunki
IC	Influence Coefficient
ID	Identifier
IG	Internal gains
KML	Keyhole Markup Language
mySMARTLife	Transition of EU cities towards a new concept of Smart Life and Economy
NAN	Nantes Métropole
NBK	Nobatek
NHAk	Net heated area
ηHR	Heat recovery system efficiency
OT	Outdoor temperature
OSM	OpenStreeMap
SCH	Schedule
SG	Solar gains
SHP	ESRI Shape file format

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

S/W	Summer/winter period
TEC	Fundación Tecnalia Research and Innovation (participant from Spain)
Uk	Thermal transmittance
UTM	Universal Transverse Mercator
U-value	Thermal transmittance
WP	Work Package
WWR	Window to wall ratio

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

1. Executive Summary

The main objective of mySMARTLife project is the demonstration of the Innovative Transformation Strategy concept through piloting different actions, considering advanced technologies, towards the global transformation of the urban life in the cities. The methodology that will be applied in the three Lighthouse cities will foster the replication of the foreseen actions, at different levels, in the follower cities and the smart city network that will be created during the project lifetime.

As a global vision, mySMARTLife will follow the next approach:

Figure 1: Global vision of the mySMARTLife Project

This Urban Transformation Strategy aims to respond in a holistic and integrated way to the transformation process, overcoming the existing technical and non-technical barriers. During this process the technical support to the different phases is a critical issue. In this regard, the application of existing methods and tools, as well as the development and the adaptation of new methods is essential to provide the needed criteria for the prioritization of measures that will guide this transformation.

In this framework, the deliverable D1.12 aims to collect all data and information available in the city, information related to the 3D model, the city cadastre, and the information evaluated in the baseline assessment to process it in a way that it serves as input for the energy modelling of the buildings of the cities. In this sense, for each of the lighthouse cities, a zone for the assessment has been selected. The energy analysis carried out for this zone aims to serve as a preliminary work that can be replicated in other zones of the city or even in the entire city. This energy characterization of the building stock of the cities is a key phase for the urban transformation because an accurate diagnosis can help to identify the priority action lines and zones. Besides, this is a critical step, which combined with the development of the energy scenarios of the cities and the technoeconomic analysis of the interventions of the mySMARTLife project, will allow the ex-ante impact evaluation of the proposed solutions so that it provides some relevant criteria for the prioritization of the actions that will be implemented in the following years.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

2. Introduction

2.1 Purpose and target group

This deliverable is allocated within Task 1.4, which is related to evaluating impacts in lighthouse (NAN, HAM, HEL) cities from the social, economic and environmental field to understand the interaction of the different interventions as a system. The Advanced Integrated Urban Planning is divided in four stages, corresponding with the five deliverables of the task:

- **Deliverable 1.12:** This deliverable is related to the subtask 1.4.1 and is focused on the description of 3D models for each pilot which includes the energy assessment of the area selected by each city. This is a key step which can be scaled-up to cover a larger area of the city so that it can serve to evaluate aspects that can be used to feed the different scenarios that will be evaluated for the cities in the subtask 1.4.2.
- **Deliverable 1.13:** This deliverable is related to the subtask 1.4.2 which is focused on the energy scenario development at city scale. The outcome of the subtask that is described in the Deliverable 1.12 will be used for the definition of scenarios.
- **Deliverable 1.14:** This deliverable is related to the subtask 1.4.3 which is focused on the techno-economic assessment of the interventions that will be implemented in the lighthouse cities.
- **Deliverable 1.15 and 1.16:** These deliverables are related to the subtask 1.4.4 which is focused on the impact assessment and the comparative analysis of all interventions. Here, the outputs described in both deliverables D1.13 and D1.14 will be completed with an energy and environmental assessment which will provide extra indicators and criteria that will be used for the prioritization of interventions in each lighthouse city.

Moreover, all the subtask and outputs described in the mentioned deliverables (focused on the lighthouse cities) will serve as a starting point for the replication plan for the follower cities. Based on the experience gained, the entire process will be replicated in the Task 6.2 of the WP6 for the follower cities of mySMARTLife project.

The present deliverable is structured as follows:

Chapter 3: shows the overall methodological approach to the Advanced Integrated Urban Planning in mySMARTLife project, describing the relation between the different phases of the assessment for the lighthouse cities and the relation with the replication in the follower cities.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Chapter 4: Describes the approach followed for the collection, analysis and processing of the available information for the modelling of the case studies in the three lighthouse cities of the project. The processing of data has been carried out at different scales (district / city) and with different results, depending on the available information and the complementarity of the results. For the case of the city of Nantes, the CityGML model of the entire city has been generated. This file is 1.5GB and is directly provided to the city of Nantes. The rest of the lighthouse cities already have their own CityGML model.

Chapter 5: Describes more in detail the methodological approach followed for the energy analysis of the districts selected for the three lighthouse cities. Here, the entire process is showed from the energy modelling to the sensitivity analysis and the calibration.

Chapter 6: Describes the three case studies evaluated, one for each lighthouse city. The analysis is focused on the characteristics of the buildings included in the area of study taking into account the area, the age and the use of the built environment.

Chapter 7: Describes the three case studies evaluated, one for each lighthouse city. The analysis is focused on the analysis of the characteristics of the buildings included in the area of study, the sensitivity analysis of each model developed, and the description of the adjustment phase carried out for each case depending on the specific information available in the corresponding city.

Chapter 8: Describes the main results obtained in this deliverable. The results of the analysis are provided to each city. Therefore, this section only shows the most representative and visual results obtained by the modelling of each lighthouse city. The files provided to the cities of the project are precisely the main result of the work. The following result files are provided to each lighthouse city:

- The input shapes
- The shape file (“City Results”)
- A XLSX file (“City district energy modelling results”)
- A second XLSX file (“City district energy modelling results aggregated”)
- A third file (“City Hourly Results.db”)

Chapter 9: Describes the main conclusions obtained from the work carried out in the subtask 1.4.1.

Chapter 10: Shows the references of the literature consulted to develop the work.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

2.2 Contributions of partners

The following Table 1 depicts the main contributions from participant partners in the development of this deliverable.

Table 1: Contribution of partners

Participant short name	Contributions
TEC	Overall content and redaction of all the sections of the deliverable
CAR	General review of the content of the deliverable
HEL	Contribution (data provision) to the sections 4.2 and 5.2
HAM	Contribution (data provision) to the sections 4.2 and 5.2
NAN	Contribution (data provision) to the sections 4.2 and 5.2
VTT	Contribution–support to HEL in data gathering for sections 4.2 and 5.5
FVH	Contribution (data provision) to the sections 4.2 and 5.2
NBK	Overall review of the deliverable
KON	Overall review of the deliverable

2.3 Relation to other activities in the project

The following Table 2 depicts the main relationship of this deliverable to other activities (or deliverables) developed within the mySMARTLife project and that should be considered along with this document for further understanding of its contents.

Table 2: Relation to other activities in the project

Deliverable Number	Contributions
D2.1	This deliverable provides the baseline information of Nantes demonstrator area
D3.1	This deliverable provides the baseline information of Hamburg demonstrator area
D4.1	This deliverable provides the baseline information of Helsinki demonstrator area

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

D1.13	This deliverable provides the compilation of energy system scenarios for each lighthouse city which will depend on the results of this deliverable
D1.14	This deliverable provides the techno-economic analysis of each intervention per pilot which will depend on the results of this deliverable
D1.15	This deliverable provides comparative analysis of interventions based on impacts (per pilot) which will use some results of this deliverable
D6.5	This deliverable provides the description of 3D models for each follower city which will follow the same procedure described in this deliverable

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

3. Overall methodological approach to the Advanced Integrated Urban Planning in mySMARTLife project

This section aims to provide a general overview of the overall methodological and modelling approach of the Advanced Integrated Urban Planning of mySMARTLife project. The figure below shows how each of the phases of the methodology corresponds with the different subtask of the Task 1.4 of the project and how each subtask contributes to the rest with their corresponding outcomes.

Advanced Integrated Urban Planning approach of mySMARTLife project

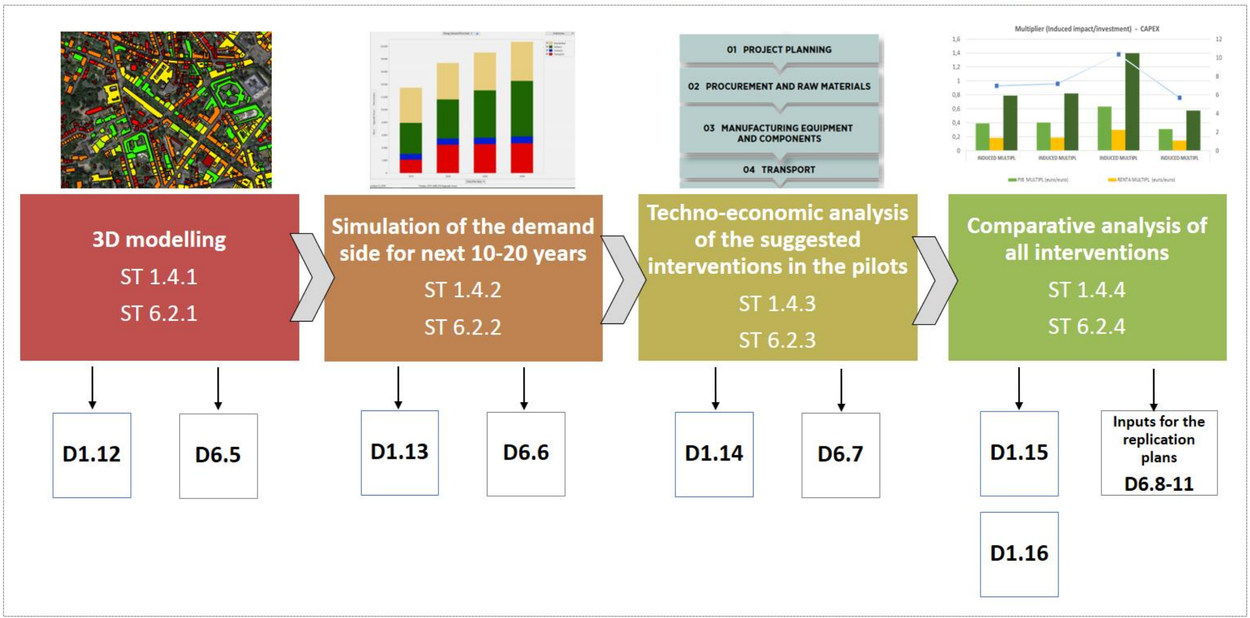

Figure 2: Methodological approach of the Advanced Integrated Urban Planning in mySMARTLife project.

The methodology is composed by four main phases that correspond with the main subtasks showed in the figure above. It can be seen, that the entire process is applied to both the lighthouse and to the follower cities of the project. The analysis is first applied to lighthouse cities (in WP1) and with the experience gained and with the lessons learnt, it is applied in a second step to the follower cities of the project (in the subtasks specified within the WP6).

The **first phase** is focused on the **3D modelling and energy demand analysis** of the three lighthouse cities. The 3D modelling is applied at city scale to prepare the data available in the city in the way that is required for the energy modelling of the building stock. In this phase the area selected in each city is evaluated through an energy model. The energy modelling evaluates the energy demand of the building stock taking into account several characteristics that are specific for each building. The results of the

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

modelling provide the hourly energy demands (heating, cooling, DHW) and the hourly electricity consumption (lighting, equipment, etc.) individually for each building but also in an aggregated way according to a classification depending on the construction period and use of the buildings. The procedure is carried out in a way that the model is calibrated so that it can be used for other areas of the city or for the entire city. The visual representation of the results allows a quick understanding of the energy needs of the city but also an initial idea of the refurbishment potential or the potential for the implementation of renewable energy technologies such as the solar thermal and the solar photovoltaic systems. This is a bottom-up modelling approach that provides some specific results that are useful for the scenario definition in the following phase of the methodology which follows a top-down approach to the city energy modelling. The main outputs of this phase are the deliverables D1.12 and D6.5.

The **second phase** of the modelling methodology is focused on **simulating the energy demand for the next 10-20 years for the city**. In this case the entire city is evaluated including not only the built environment but also the rest of the sectors of the city such as the industry and mobility. In this case other types of modelling tools are required to define the energy matrix of the city (Sankey diagram) for the base year. Then, the evolution of several characteristics (such as the evolution of the socioeconomic characteristics of the city; population, GDP, etc.) are evaluated for each city, establishing the interrelation between these parameters and the future energy needs of the city. This will allow to generate the Business as Usual (BaU) scenario for the city, which defines the expected evolution of the energy demands/consumptions of the different sectors of the city, as well as the required local energy generation or the energy import needs in the following years. This BaU scenario is the base for future evaluations of the expected impact of alternative efficient scenarios that can be proposed for the cities. As explained before, the potential results of the modelling in the first phase can serve to define some aspects of these alternative scenarios. The main outputs of this phase are the deliverables D1.13 and D6.6.

The **third phase** is focused on the **technoeconomic analysis of the suggested interventions in the pilots**. In this case a supply chain analysis is carried out for the interventions that can be implemented in the pilots, evaluating the disaggregation of the cost components that compose the intervention, as well as the existing capabilities at city/regional scale for the manufacturing or distribution of each component. Besides, an analysis of the socioeconomic structure of each city and its corresponding region is carried out in order to define the sectoral disaggregation that is required for the supply chain analysis. The result of this phase will be the specific “shocks” that will serve as input for the macroeconomic modelling that is carried out in the last phase of the methodology. Each intervention will be represented as a specific increase of the production of the corresponding subsectors in the region. The main outputs of this phase are the deliverables D1.14 and D6.7.

Finally, the **fourth phase** is focused on the **comparative analysis of all the interventions based on the impact assessment results**. In this phase the impact assessment of each intervention is carried out based on the results of the previous phases. On the one hand, the shocks created in the third phase are

This project has received funding from the European Union‘s Horizon 2020 research and innovation programme under grant agreement No 731297.

used to evaluate the potential impact associated to each intervention to generate a direct, indirect and induced effect in the development of several socioeconomic characteristics of the cities/regions such as the increase of the GDP or the employment. This information can also be combined with the results of the phases one and two which will provide an idea of the deployment potential of each type of intervention in the cities which will affect the final impact. Finally, this socioeconomic analysis for each intervention is combined with the expected energy and environmental impact analysis which will provide extra criteria that will be useful for the prioritisation of the technologies. Here, a multicriteria methodology will be used to compare the different interventions for each city based on the expected impacts. The main outputs of this phase are the deliverables D1.15 and D1.6.

In the case of the follower cities, a similar process will be carried out to get a better understanding of the potential impact that the future implementation of actions can have in each follower city. This, as well as all the intermediate results obtained for the follower cities will be important inputs for the replication plans (D6.8-11).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

4. Description of the 3D models for the three lighthouse cities

4.1 Approach to the district/city modelling

This section presents the general information and the approach followed in the project to collect, analyse and process the available information that allows carrying out the energy diagnosis for the three cases of study in the lighthouse cities of the project (Hamburg, Helsinki and Nantes). The detailed description of the data modelling for each case study is presented in the following section 4.2

The process of generating the urban model that serves as input for the energy analysis is presented in the following figure (Figure 3). Regarding the data sources that contain cadastral and cartographic information, these are sources that the municipality must provide in order to begin the process. The degree of precision of the results will depend to a large extent on the level of detail and the veracity of the information contained in these sources. To achieve high levels of detail and reliability for the input information, it is recommended to carry out a process of adaptation, cleaning and organization of the input data. The objective of the “Pre-process” is to have detailed geometry at the building level and the greatest number of attributes associated to that geometry. It is also very common the necessity to combine different data sources to have the required information and generally the data sources are not linked. Cadastral and cartographic data sources provide 2D information on real elements that are 3D (buildings). The 3D shape of the buildings is quite relevant for the evaluation of the energy demand. This information can be found as attributes in the cadastral information from the elevation models (DSM and DTM) together with the cartography of the area. Information collected from the data sources provided by the municipality must be conveniently processed to obtain the relevant information for calculating the energy information of each building. These calculations are performed in the "Data process".

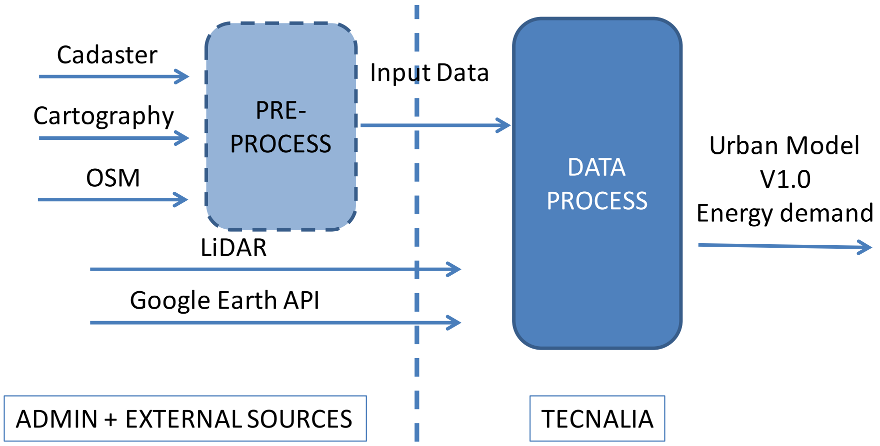

Figure 3 Approach to the urban modelling

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

The process of identifying information sources is critical to the success of the modelling. First, it is important to define the limits of the study area in which the analysis will be carried out. In mySMARTLife, a two-tier analysis is proposed, first, at the district scale or a reduced set of buildings, and then at the city or municipality scale. Modelling is proposed in a similar way and scope in both cases, however in the first case manual work can be carried out to check or complete relevant information when not available. In the city scale, this task is unaffordable. The minimum input information necessary to carry out the modelling is presented in the following table (Table 3). This table is adapted to the requirements for energy modelling of each case study in the detailed description of the modelling process for each lighthouse city.

Table 3: List of minimum data required for the energy modelling

Name	Type	Values / Units
Building Footprint	Geometry	-
Building Height or Number of floors	Year or Number	Meters
Main Use or Function of the building	Text	-
Year of Construction	Number	Year

The required outputs of the modelling process necessary for the energy analysis are shown in the following table (Table 4). The final results of the process for each lighthouse city are adapted to the requirements and the available information in each case study:

Table 4: List of the outputs of the modelling process

Name	Description
Geolocation of the building	Represented by the centroid of the polygon with the geometry of the building.
Height of the building	If not available as an input attribute, it can be estimated from number of floors of the building, considering an average height per floor. If this information is not available, it can be calculated also from the information contained in the elevation models (DSM and DTM) combined with the building footprints.
Number of floors	If not available as an input, it can be estimated from the total height of the building considering an average height per floor.
Building footprint area	Calculated from the building footprint
Roof area	It can be estimated by the floor area of the building, assuming flat roofs.
Gross floor area	Estimated from the area of the floor multiplied by the number of floors.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Envelope area	The total envelope area will be calculated as the sum of the area of each of the facades. It is necessary previously to identify the facades and the adjoining walls. It can be estimated also the area divided by the main orientation of the facades.
Volume	Calculated from the building footprint area and the height of the building
Year of Construction	Mandatory as input data
Building Use	Mandatory as input data

Finally, this task also includes the generation of the CityGML model from those of the lighthouse cities that do not currently have such a model or that even if they have, it needs to be updated (as is the case of Nantes). The process of generating the 3D urban model based on the CityGML data model is presented in the following figure (Figure 4). Data sources for the generation of the geometric 3D model in CityGML format must contain the geometry of the building footprints and the height of the buildings. Files with 2D cartographic information, such as the cadastre or other publicly accessible data sources such as OpenStreetMap, represent the main source of information to obtain the geometry of the building footprints. The height of the buildings can be included in the same files with the cartography or it can be extracted from digital terrain and surface models (DTM and DSM). Through the processing of this information, the CityGML model can be generated in a semi-automatic way with low levels of detail (LoD0: building floors, LoD1: Buildings represented by cubes, LoD2: Buildings as cubes separating facades and roof).

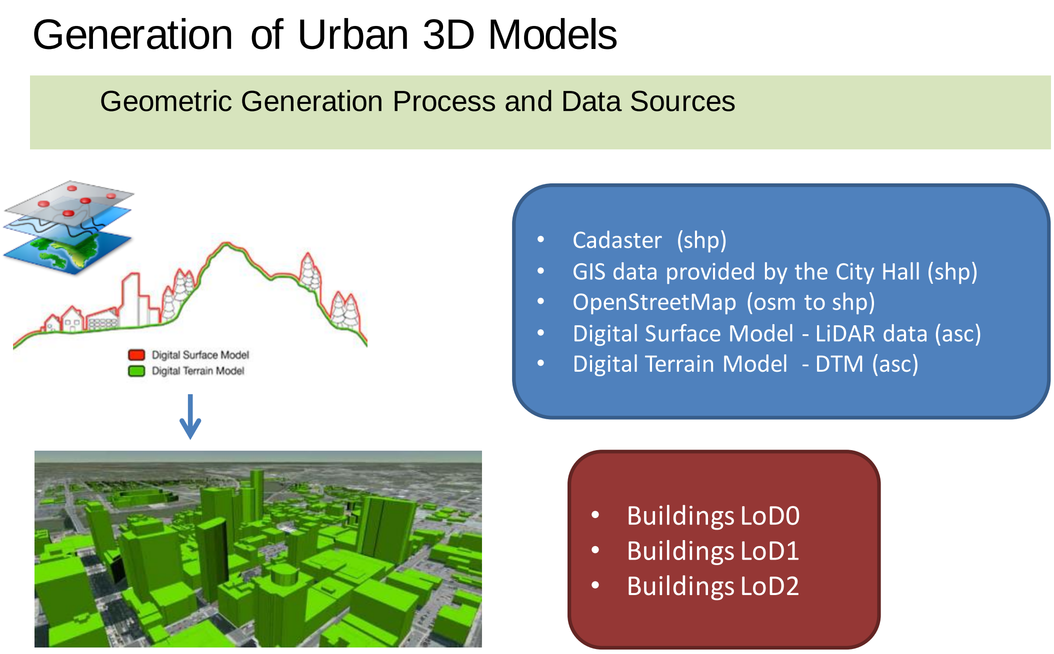

Figure 4 CityGML model generation process

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

4.2 Case study descriptions for the three lighthouse cities

4.2.1 Nantes area of study

This subsection describes the main process followed for the treatment of the data for the case of Nantes. It includes a description of the situation of the city with regard to the information available, a description of the data processing at district scale, the data processing and CityGML generation at city scale and a description of the results obtained in this phase.

4.2.1.1 Description of the situation of the city

The case study of Nantes has a purely geometric CityGML model, without semantic information. There are 4 different versions and the generation date is 2012. The municipality provided the following 4 models:

- Model 1: NANTES\maquette_3D_lod2_idn\3-Maquette_CityGML_LZ2 -> Zona1 (568Mb), Zona2 (945Mb).
- Model 2: NANTES\maquette_3D_lod2_idn\3-Maquette_CityGML_LZ2_Suite -> Zona3 (990Mb, Zona4 (411Mb).
- Model 3: NANTES\Maquette_PSMV\Maquette_PSMV\04_Maquette_3D\Texturation_globale\01-CityGML – 3.11 GB -> Bloc_1 (162 buildings), Bloc_2 (107 buildings), Bloc_3 (126 buildings), Bloc_4 (108 buildings).
- Model 4: NANTES\Maquette_PSMV\Maquette_PSMV\04_Maquette_3D\Texturation_toits\01-CityGML – 2.27GB -> Bloc_1 (81 buildings), Bloc_2 (107 buildings), Bloc_3 (126 buildings), Bloc_4 (108 buildings)

Cartographic information in SHP format has been also provided at the level of the municipality of Nantes. The cadastral information is also available at the same scale. The information available is detailed in the following section (section 4.2.1.2). There is no code or parameter that allows to link the SHP file with the CityGML models, that is why the purely geometrical CityGML models available are not useful for the energy analysis. Therefore, the analysis is based on the available cartographic information and subsequently, a new CityGML model that combines geometric and semantic information is generated.

The analysis of the information is carried out in two steps, firstly, a detailed analysis at the district level and then, the analysis at the municipal level and the generation of the CityGML model.

4.2.1.2 Data processing at district scale

A) General Configuration

For the district scale analysis, the "Île de Nantes" has been selected (See Figure 5)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Figure 5 Selected district in Nantes"Île de Nantes"

First, the necessary information to carry out the development of the energy analysis has been identified. For each of the buildings of the selected district it is necessary to obtain the basic information detailed in the following table (See Table 6).

Table 5: Basic Information required for each building in Nantes Case Study

Name	Type	Values / Units
Building Unique Identifier	Unique Id	
Geometry of the building footprints	Shp file	
Building footprint area	Number	m^2
Building Height	Number	m
Main Use or Function of the building	Text	

B) Data Sources

The following table shows the data sources provided by the municipality of Nantes and used for the generation of the necessary information to carry out the energy analysis of the selected district.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Table 6: List of data sources for data processing at city scale in Nantes

Name	Source	Type	Data
Building without any specific function	BATI_INDIFFERENCIE_region.shp	Polygons	See table below (Table 7)
Industrial buildings	BATI_INDUSTRIEL_region.shp	Polygons	See table below (**Table 8**)
Non-Industrial buildings: religious, administrative, sports and transport	BATI_REMARQUABLE_region.shp	Polygons	See table below (**Table 8**)
Light structures (cabins, shelters, awnings, etc.)	CONSTRUCTION_LEGERE_region .shp	Polygons	See table below (Table 9)
Outdoor sports equipment	TERRAIN_SPORT_region.shp	Polygons	See table below (Table 10)
Data at parcel level	foncier_bat_2015.shp	Points	ID Parcel Year Of Construction
Parcels geometry	Parc_dgi_region.shp	Polygons	Geometry
Data at parcel level	export_nm_nmd44_2015_pnb10_parcelle_point.shp	Points	Complementary use

Table 7: Detail of data contained in BATI_INDIFFERENCIE_region.shp (Highlighted the used data)

Code	Name
ID	Identifiant du bâtiment
PREC_PLANI	Précision planimétrique*
PREC_ALTI	Précision altimétrique*
ORIGIN_BAT	Source du bâtiment
HAUTEUR	Hauteur du bâtiment
Z_MIN	Altitude minimale du bâtiment

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Z_MAX	Altitude maximale du bâtiment

Table 8: Detail of data contained in BATI_INDUSTRIEL_region.shp y BATI_REMARQUABLE_region.shp (Highlighted the used data)

Code	Name
ID	Identifiant du bâtiment
PREC_PLANI	Précision planimétrique*
PREC_ALTI	Précision altimétrique*
ORIGIN_BAT	Source du bâtiment
NATURE	Permet de distinguer les bâtiments
HAUTEUR	Hauteur du bâtiment
Z_MIN	Altitude minimale du bâtiment
Z_MAX	Altitude maximale du bâtiment

Table 9: Detail of data contained in CONSTRUCTION_LEGERE_region.shp (Highlighted the used data)

Code	Name
ID	Identifiant du bâtiment
PREC_PLANI	Précision planimétrique*
PREC_ALTI	Précision altimétrique*
ORIGIN_BAT	Source du bâtiment
HAUTEUR	Hauteur du bâtiment

Table 10: Detail of data contained in TERRAIN_SPORT_region.shp (Highlighted the used data)

Code	Name
ID	Identifiant du terrain de sport
PREC_PLANI	Précision planimétrique*
PREC_ALTI	Précision altimétrique*
NATURE	Source du terrain de sport
Z_MOYEN	Altitude moyenne des points composant le terrain

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Table 11: Detail of data contained in Foncier_bat_2015.shp

jannatminh	Année de construction du logement le plus ancien
jannatmaxh	Année de construction du logement le plus récent
janbilmin	Année minimale d'immobilisation
nlocal	Nombre de locaux
nlocmaison	Nombre de locaux de type maison
nlocappt	Nombre de locaux de type appartement
nlochabit	Nombre de locaux de type maison ou appartement
nloccom	Nombre de locaux de type commercial ou industriel
nloccomrdc	Nombre de locaux de type commercial ou industriel situés au rez de chaussée
nloccomter	Nombre de locaux d'activité tertiaire (commercial, bureau, etc.)
ncomtersd	Nombre de locaux d'activité tertiaire sans dépendances
nloccomsec	Nombre de locaux d'activité secondaire (industrie)
nlocdep	Nombre de locaux de type dépendances
nlocburx	Nombre de locaux présentant au moins un bureau
nlochab	Nombre de locaux d'habitation
nlogh	Nombre de logements d'habitation
npevph	Nombre de parties principales d'habitations
stoth	Surface totale des pièces d'habitation (en m²)
stotdsueic	Surface des dépendances incorporées aux parties principales d'habitation (en m²)
nloghvac	Nombre de logements d'habitation vacants
nloghmeu	Nombre de logements d'habitation meublés
nloghloue	Nombre de logements d'habitation en location
nloghpp	Nombre de logements d'habitation occupés par le propriétaire
nloghautre	Nombre de logements d'habitation occupés à titre gratuit ou par bail rural.
nloghnonh	Nombre de logements d'habitation considérés pourtant comme autre que de l'habitation
nloghvac2a	Nombre de logements d'habitation vacants depuis plus de 2 ans
nactvacant	Nombre d'activités vacantes
nactvac2a	Nombre de logements d'habitation vacants depuis plus de 2 ans
nloghvac5a	Nombre de logements d'habitation vacants depuis plus de 5 ans
nactvac5a	Nombre d'activités vacantes depuis plus de 5 ans
nmediocre	Nombre de locaux d'habitation au confort médiocre
nloghlm	Nombre de locaux d'habitation HLM et SEM sur la parcelle
npevp	Nombre de parties d'évaluation professionnelles sur la parcelle
stotp	Surface totale des parties professionnelles sur la parcelle (en m²)
npevd	Nombre de pev dépendances sur la parcelle

C) Data Pre-processing

The main tasks carried out in order to obtain the required information for the energy demand analysis of the selected district of the city of Nantes are briefly described below:

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

- **Data reprojection:** Reprojection of the source layers to the EPSG reference system use in the process (27562).
- **Geometry validation:** Some geo-processes require that the geometries of the input layers meet certain requirements that must be previously validated.
- **Limit the extension of layers to the selected district (Île de Nantes):** The extension of the analysis focuses on the "Île de Nantes" however, the extension of the data of the input layers extends the whole municipality of Nantes.
- **Combine layers with different types of buildings:** The sources used contain the information divided by type of building use. The layers have combined into one, adding an attribute with the function of the building. The list of types resulting from the combination of the layers with information at building level is: Light Structure, Significative, Industrial, Indifference and Sport. The number of buildings included in the combined layer is 1.629 (See Figure 6).

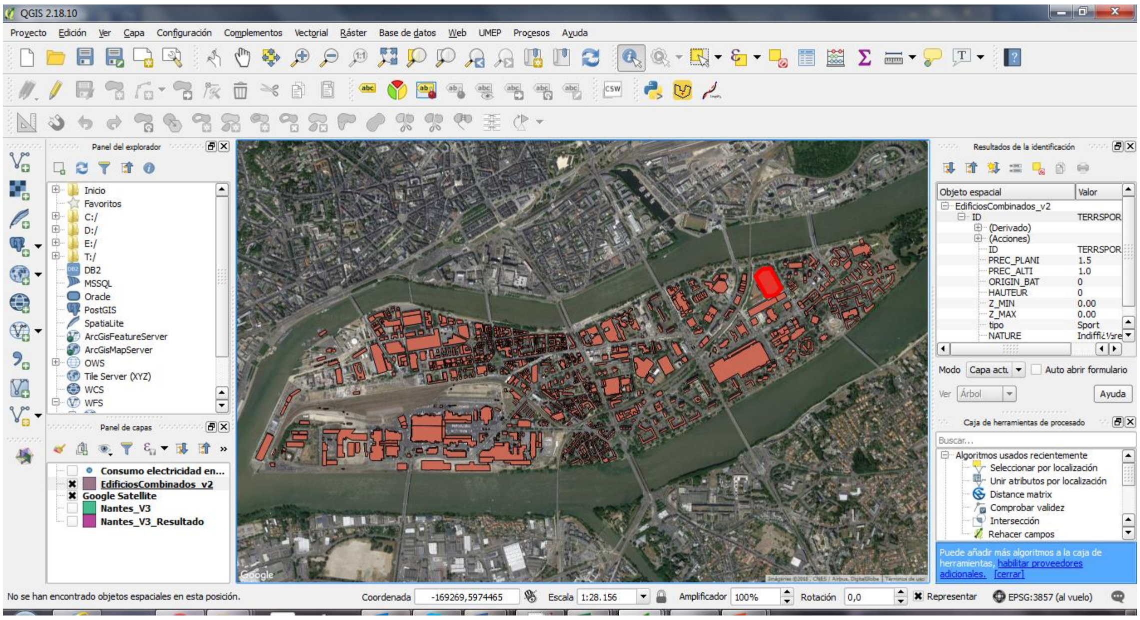

Figure 6 Buildings in the Île de Nantes after the combination of layers

- **Manually complete with relevant buildings:** Some of the geometries included in the previously generated file represents parts of the buildings or elements which are not relevant at all for the posterior analysis (e.g. urban elements smaller than 15m2). Those geometries have been removed from the original file. On the other hand, there are some relevant building which were not represented in the provided layers. OpenStreetMap (OSM) information has been used to identify the location and size of the footprints of these relevant buildings. The resulting layer contains 891 buildings.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

- **Complete the building layer with information from other data sources at parcel level:** The exercise consists mainly of joining all the relevant information in a single layer. The joint is made on the layer of polygons so that this information can be later assigned to all the buildings contained within the same parcel. The following information has been collected from each of the layers:

Table 12: Layers of information at parcel level

Name	Source	Data
Data at parcel level	foncier_bat_2015.shp	ID Parcel (idpar) YearOfConstruction (jannatmin)
Parcels geometry	Parc_dgi_region.shp	Geometry
Data at parcel level	export_nm_nmd44_2015_pnb10_parcelle_point.shp	Complementary use (tlocdomin)

The result is a layer with the geometry of the parcel and with the combined information of the layers indicated above. To apply this information to the buildings, the step is to calculate the centroids of the buildings. Next, apply to these centroids the information contained on the parcel geometries, to all those buildings whose centroid falls within the parcel. Finally, the information of the attributes of the centroids layer that are relevant for processing is added to the layer that contains the geometry of the buildings.

The following figure (Figure 7) shows the parcel layer (in green) which includes all the relevant information at parcel level and the building layer (in pink) on top of the parcel layer.

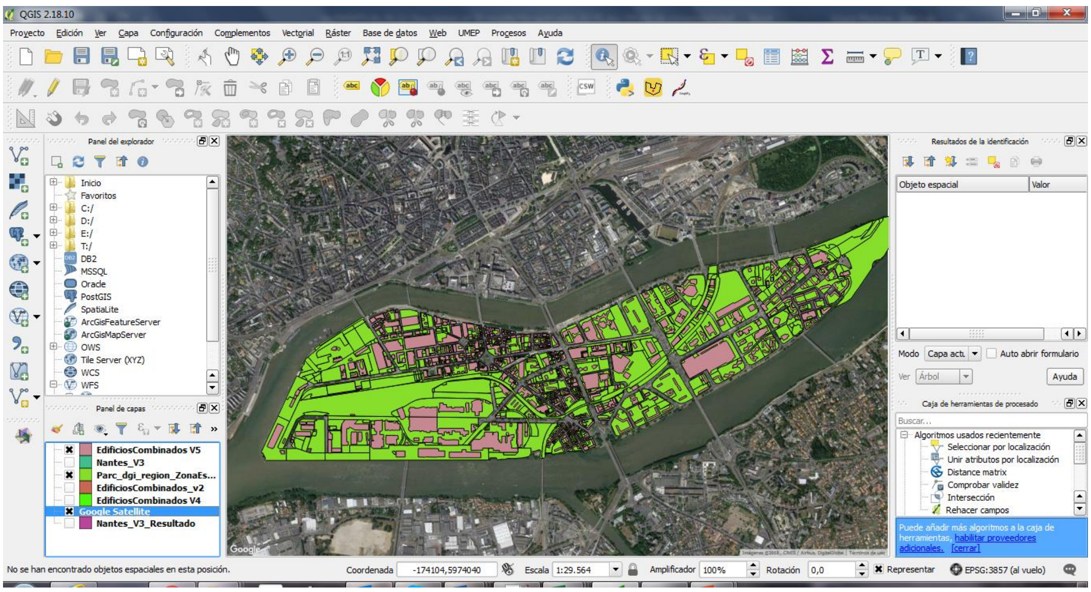

Figure 7 Buildings and Parcels in the Île de Nantes after the combination of layers

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

- **Verification of the information:** The verification of the results carried out consists mainly on the identification of missing values, completing these values with data obtained from other sources or estimation, identification of discrepancies and identification of atypical values.

The result of the pre-processing produces an information layer (Nantes_v3.shp) with 889 buildings with the following attributes:

  - ID: Unique identifier for each building
  - HAUTEUR: Height of the building
  - IDOBJ: Identifier of the building from the buildings shape
  - Idpar: Identifier of the parcel from the parcel shape
  - jannatmin: Year of construction of the building
  - tlocdomin: Main function of the building
  - area: Building footprint area.

D) Data Processing

In this step, the geometric processing of the data resulting from the pre-processing of the district data has been carried out in order to obtain the necessary information for the analysis of energy demand. This processing is done automatically from the SHP resulting from the pre-processing. The result combines information contained in the SHP of the pre-processed, new calculated data and estimated data from the contents of the original SHP.

The main geometric processes that are carried out in this phase are for the calculation of the surfaces of the building envelope. Additionally, simple calculations are made to estimate other geometric parameters of the buildings, such as: number of floors, building volume or roof area. To calculate the surfaces of the envelope, it is necessary to previously identify which of the building's surfaces are facades and which are adjoining walls in order to obtain precisely the area of the facades. Subsequently, the area of each façade is calculated from the footprint geometry and the height of the building. Finally, it is necessary to add the surface of all facades at the building level. It is also possible to identify in this process the orientation of the enveloping surfaces of the building, both for the facades and for the adjoining walls.

The information resulting from the geometric processing is detailed in the following table:

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Table 13: Layers of information at parcel level

Attribute	Data Format	Calculating mode
Building Unique Identifier	Text	An output of the data pre-processing.
Geo-localization of the building	UTM coordinates	It is calculated as the centroid of the polygon that represents the geometry of the building.
Building Height	Number	An output of the data pre-processing.
Number of Floors	Number	Estimated from the height of the building.
Footprint Area	Number (m^2)	An output of the data pre-processing.
Gross Floor Area	Number (m^2)	Estimated from the floor area and number of floors
Roof Area	Number (m^2)	Estimated from the floor area, assuming the roof is flat
Envelope Area	Number (m^2)	Calculated from the surface of each of the exterior facades of the building. Being able to be broken down by its main orientation.
Volume	Number (m^3)	Estimated from the floor area and the height of the building

4.2.1.3 Data processing and CityGML generation at city scale

A) General Configuration

Nantes Metropole is divided into 24 communes. The scope of this process is one of them, specifically the one called Nantes (See Figure 8). It corresponds to 6 519 hectares with 296 027 inhabitants.

The reference system used in the processing at city scale is: NFS (Paris) / Lambert Centre France -> EPSG: 27562

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Figure 8 Nantes commune in Nantes Métropole

B) Data Sources

Data sources used for the generation of the processing and the generation of the 3D City model of the city of Nantes are the same used for the data processing at district scale (See section 4.2.1.2).

C) Data Pre-processing

The main tasks carried out in order to obtain the required information for the energy demand analysis of the city of Nantes are very similar to the ones performed for the data processing at district level (see section 4.2.1.2). Main differences are briefly described below:

- Limit the extension of layers to the commune of Nantes: The extension of the analysis focuses on Nantes and the extension of the data of the input layers include the rest of the communes. The "Île de Nantes" is a small part of Nantes.
- Eliminate irrelevant information and simplify layers: Some of the information contained in the information sources are not relevant for the object of analysis. The scale of the analysis and the excess of information generates huge files that are difficult to manage. The layers keep the relevant information (mainly ID and height). This task is more relevant at the city level due to the size of the managed files.
- Verification of the information: Given the size of the city, the verification of the results has been carried out for a significant sample of buildings.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

- The height of the building is missing for 7.364 of the buildings
- The year of construction is missing for 7.677 of the buildings
- There are 3 attributes associated to the use of the building:
  - FUNCTION: Possible values (Light Structure, Significative, Industrial, Indifference, Sport). All the buildings contain this attribute.
  - NATURE: It is a subtype for those buildings which FUNCTION is Significative, Industrial or Sport. Aprox. 2.000 of the buildings contain this attribute.
  - tlocdomin: Possible values (MAISON, MIXTE, ACTIVITE, APPARTEMENT, DEPENDANCE, AUCUN LOCAL). This data is missing for 344 of the buildings.

- Assignment of values to missing attributes: Finally, missing attributes have been completed based on the rules defined by conversations with city experts and according to the average values depending on the typology of the buildings. The values used listed in the following table.

Table 14: Assignment rules for missing attributes

Use	YoC	Height (m)
MAISON	1950	6,00
MIXTE	1950	8,00
ACTIVITE	2005	9,00
APPARTEMENT	1900	11,00
DEPENDANCE	1985	9,00
AUCUN LOCAL	1985	8,00
Light Structure	1800	7,00
Monument	1800	4,00
BÔtiment religieux d	1950	7,00
BÔtiment sportif	2005	8,00
Eglise	1965	13,00
Chapelle	1900	14,00
ChÔteau	1900	15,00
Mairie	1950	11,00
Tribune	2005	11,00
Tour, donjon, moulin	1900	18,00
Gare	1800	13,00
PrÚfecture	1800	17,00
Serre	2005	4,00
Silo	1950	30,00
BÔtiment commercial	1985	7,00
BÔtiment industriel	2005	6,00
Indiference	2005	7,00
Sport	2005	0,00
Terrain de tennis	2005	0,00
Piste de sport	2005	0,00
Bassin de natation	1800	0,00

The result of the preprocessing produces an information layer (shp file) with 65.770 buildings with the following attributes:

- ID: Unique identifier for each building

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

- Height: Average height of the building
- YoC: Year of construction of the building
- Area: Building footprint area
- Use: Main function of the building.

D) CityGML Generation

The process of generation of the CityGML model of the city of Nantes takes as input the data resulting from the pre-processing carried out at the city scale and previously described. The data sources used are the following ones (See Table 15):

Table 15: Data sources for CityGML generation

Name	Source	**Description**
Data source with geometry for LoD1	LoD1.shp	It contains geometric information of the parcels (43.487 records)
Data source with geometry for LoD2	LoD2.shp	It contains geometric information of the buildings (65.770 records)
Sections in which the model is divided	Agrupaciones.shp	Polygons of $1km^2$ in which the city model is divided (92 groups)
Terrain Height for LoD1	MDTLoD1.xlsx	Contains terrain height data for parcels
Terrain Height for LoD2	MDTLoD2.xlsx	Contains terrain height data for buildings
Surface Height for LoD1	LIDARLoD1.xlsx	Contains the surface height data for the parcels
Surface Height for LoD2	LIDARLoD2.xlsx	Contains the surface height data for the buildings

The following figure shows an overview of the data source layers, both building and parcel scale and the 92 groups in which the model is divided.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

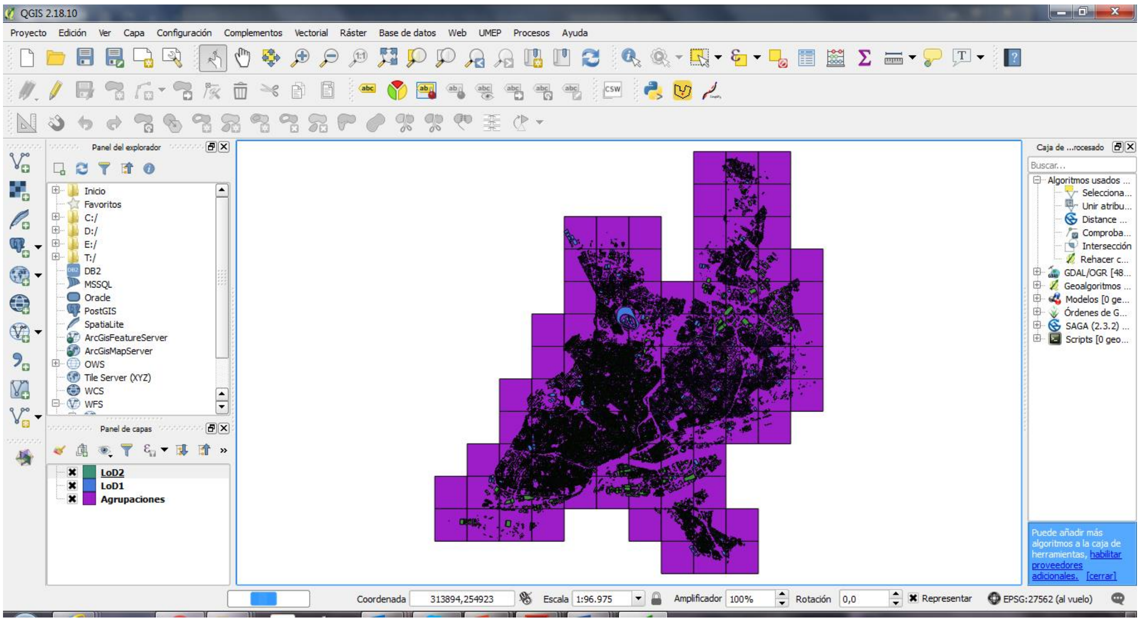

Figure 9 SHP layers with input data for the generation of the CityGML

The generation of the CityGML model is divided into two stages:

- Geometric generation: The geometry of the model elements is generated with two different levels of detail (LoD1 and LoD2).
- Semantization of the model: The geometric model is completed with the available semantic information (attributes).

The results of the generation process of the CityGML model of the city of Nantes are presented below. First, buildings with level of detail LoD1 for one of the 92 parts of the model. Next, the same piece but with the buildings in LoD2 and finally, the information of the properties associated to each building that represent the semantic information. The FZKViewer tool is used to visualize the generated models.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

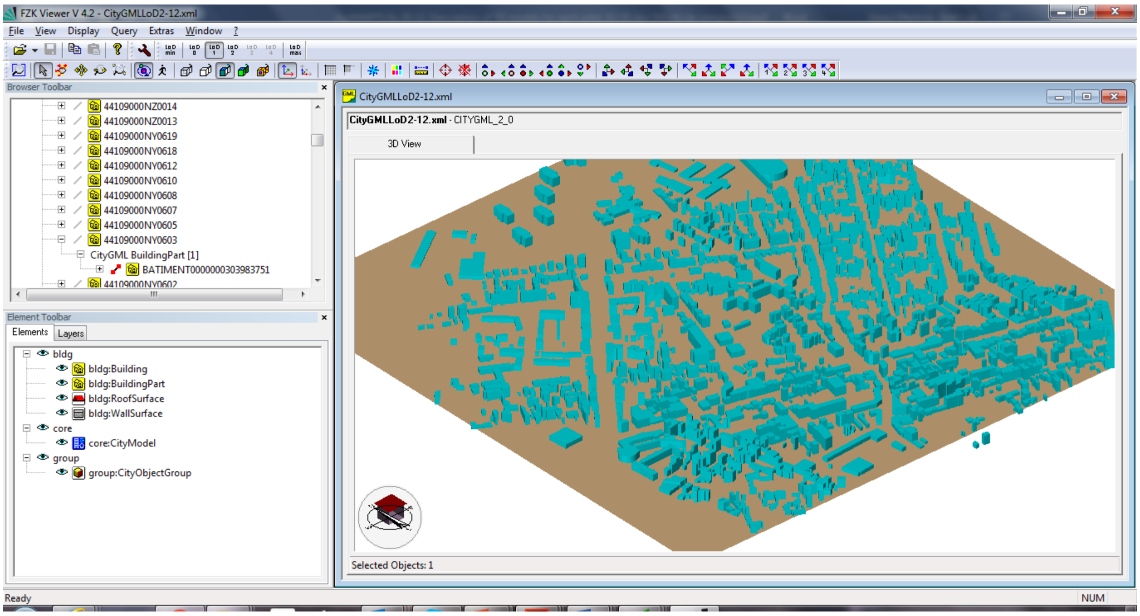

Figure 10 SHP Buildings in LoD1 for one of the areas of the city of Nantes

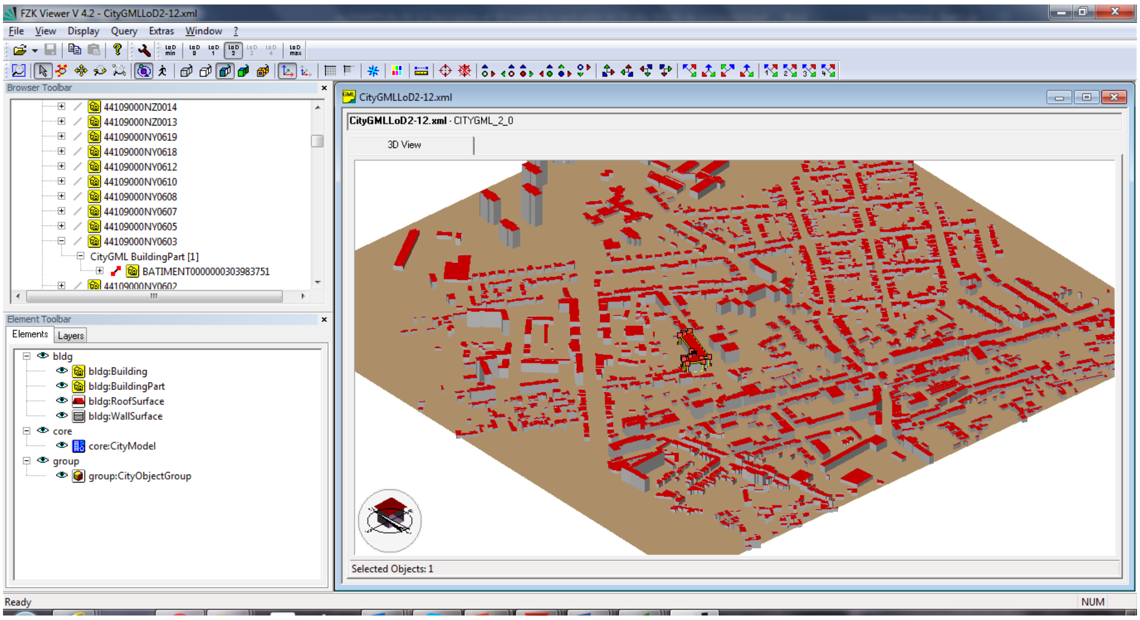

Figure 11 SHP Buildings in LoD2 for one of the areas of the city of Nantes

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

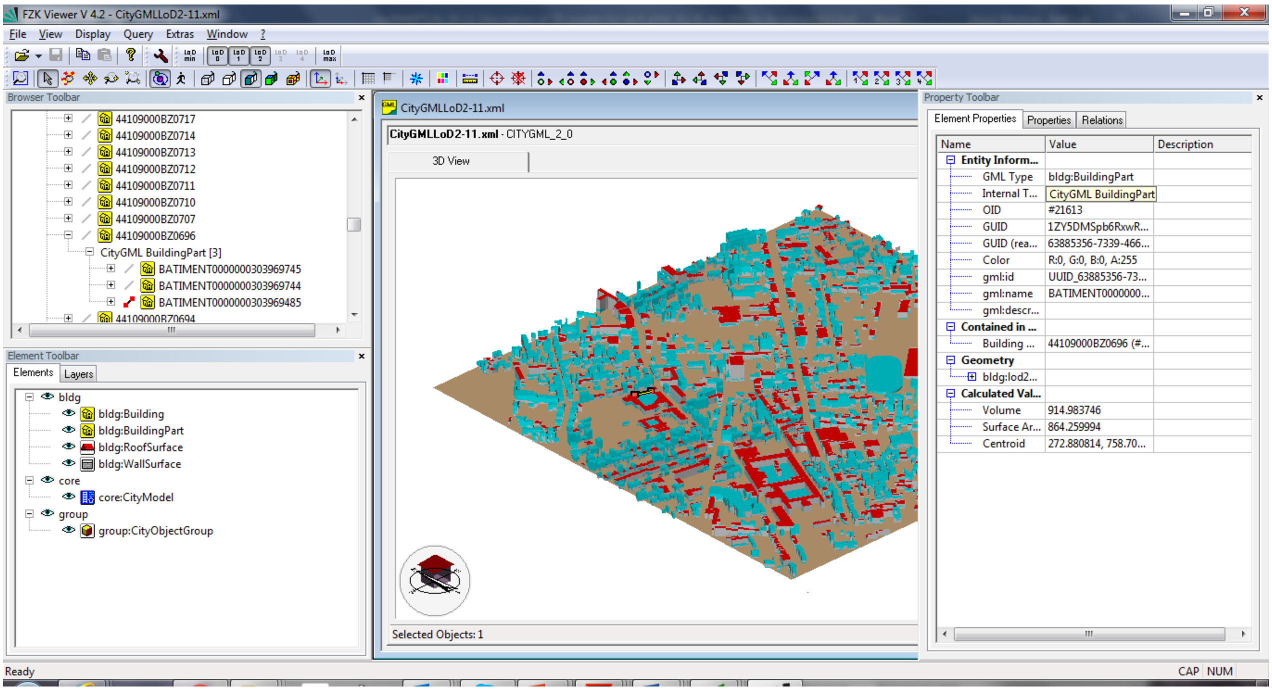

Figure 12 Semantic properties included in the CityGML model of the city of Nantes

4.2.1.4 Description of the results

In the case of Nantes, two different results have been generated. First, for the district scale, a shape file of the district with the information required for the analysis of energy demand is obtained as a result of the modelling process. On the other hand, for the city scale (the commune of Nantes) the shape file with the information for energy modelling and also a CityGML model in LoD1 and LoD2 of the city have been obtained.

A) Results at district level

As a result of the modelling of the Nantes study area, the necessary information for the energy analysis is obtained. The detail of the information resulting from the process is presented in the following table (Table 16). The information is available in different formats: Excel, SHP and KML.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Table 16: Set of parameters contained in the files resulting from the process in Nantes

Parameter	Format	Description
Reference	Unique Id	Building Unique Identifier
Centroid	UTM Coordinates	Geolocation of the building
TotalHeight	Number	Height of the building
NumberOfFloors	Number	Number of Floors
BuildingArea	Number (m^2)	Area of the building footprint
GrossFloorArea	Number (m^2)	Total area of the building
RoofArea	Number (m^2)	Area of the roof of the building
TotalEnvelopeArea	Number (m^2)	Total envelope area, including façade and adjoining walls
ExteriorEnvelopeArea	Number (m^2)	Area of the building façade
AdjoiningEnvelopeArea	Number (m^2)	Area of the adjoining walls
NorthExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is North
SouthExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is South
WestExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is West
EastExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is East
YearOfConstruction	Number (Year)	Year of construction of the building
Use	Text	Main use of the building
Refurbished	True / False	If it has been refurbished
Volume	Number (m^3)	Volume of the building
DistrictCentroid	UTM Coordinates	Approximated geolocation of the centre of the study area

Below it is showed a screenshot of the resulting KML file (see Figure 13). The file is displayed on Google Earth. In addition, the information associated with the selected building is included

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

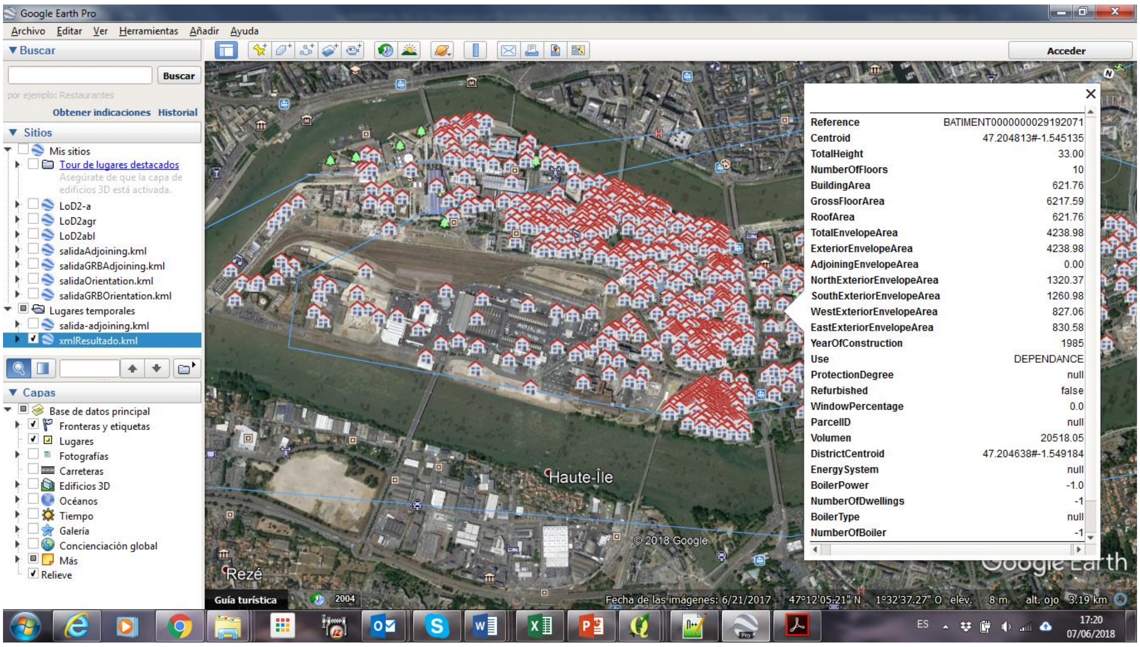

Figure 13 Results at district level in Nantes (KML format)

B) Results at city level

The results at city level contains the same information than in the study area. Due to the size of the files Kml is not generated. Only Excel and SHP files are generated at the city scale.

Additionally, for the study case of Nantes, the CityGML model of the city has been generated. The results of the generation process are 92 CityGML files corresponding to each of the sections into which the model has been divided (see Figure 9). Finally, the 92 sections of the model have been grouped into a single file. The size of this file is 1.52GB, which contains the following CityGML objects.

- BUILDING: 43.957
- BUILDING_PART: 65.653
- BUILDING_ROOF_SURFACE: 63.899
- BUILDING_WALL_SURFACE: 607.017
- CITY_OBJECT_GROUP: 92
- Processed geometry objects: 4.836.416

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

4.2.2 Hamburg area of study

This subsection describes the main process followed for the treatment of the data for the case of Hamburg. It includes a description of the situation of the city with regard to the information available, a description of the data processing at district scale and a description of the results obtained in this phase.

4.2.2.1 Description of the situation of the city

The city of Hamburg has the 3D City model in CityGML format in LoD1 and recently also LoD2. The models are available for download in the following links:

- Link to the English description of 3D City Model Hamburg in Level of Detail 1: http://suche.transparenz.hamburg.de/dataset/3d-stadtmodell-hamburg1#
- Link to the English description of 3D City Model Hamburg in Level of Detail 2 from the EU Open Data Portal: https://www.europeandataportal.eu/data/dataset/https-ckan-govdata-de-dataset-baeb7047-2eba-4af3-8337-10b2d470b071

These links have been provided by the municipality of Hamburg. Cartographic information in SHP format has been also provided at the level of the retrofitting zone of Hamburg. The information available is detailed in the following section (section 4.2.2.2). The modelling process has been based on the information contained in the 3D model and the information of the cartography in 2D. The analysis has been carried out for the selected area in the city of Hamburg.

4.2.2.2 Data processing at district scale

A) General Configuration

The detailed analysis has been done for one of the Areas of intervention in Hamburg, Bergedorf Borough. It is represented as Zone2 in the following figure (Figure 14). The selection of the zone has been proposed by the municipality of Hamburg.

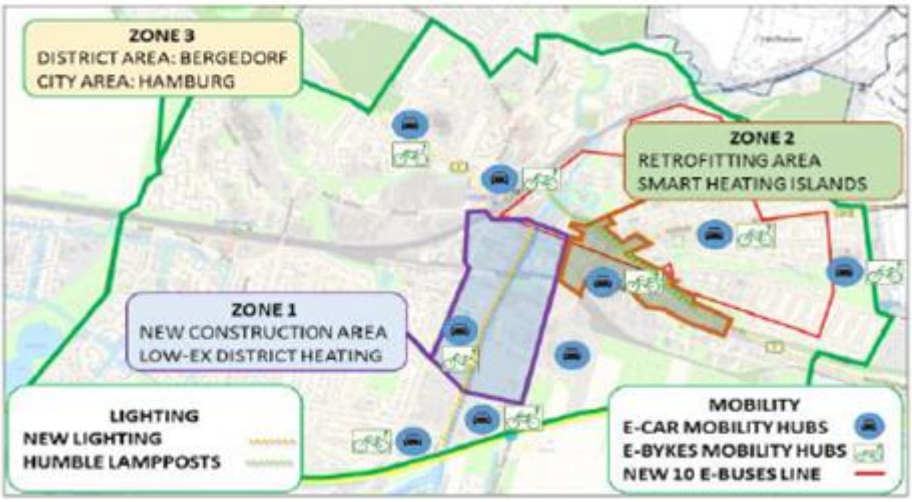

Figure 14 Areas of intervention in Hamburg. Zone 2 selected for the analysis.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

First, the necessary information to carry out the development of the energy analysis has been identified. For each of the buildings of the selected zone it is necessary to obtain the basic information detailed in the following table (See Table 17).

Table 17: Basic Information required for each building in Hamburg Case Study

Name	Type	Values / Units
Building Unique Identifier	Unique Id	
Building footprint area	Number	m^2
Building Height	Number	m
Main Use or Function of the building	Text	
Year of Construction	Number	
Number of floors	Number	

B) Data Sources

The following table (See Table 18) shows the data sources provided by the municipality of Hamburg and used for the generation of the necessary information to carry out the energy analysis of the buildings in the selected zone.

Table 18: List of data sources used for the case study of Hamburg

Name	Source	Type
3D City Model	LoD1_580_5927_1_HH.xml LoD1_580_5928_1_HH.xml LoD1_581_5927_1_HH.xml LoD1_581_5928_1_HH.xml	CityGML LoD1
Footprints and building data of selected zone	retrofitting_buildings.shp retrofitting_buildings_bja.shp retrofitting_buildings_new.shp	Polygons
Selected zone	Zone2.shp	Polygons

CityGML resources (see Figure 15) has been downloaded from the following link provided the municipality of Hamburg: http://suche.transparenz.hamburg.de/dataset/3d-stadtmodell-hamburg1#.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

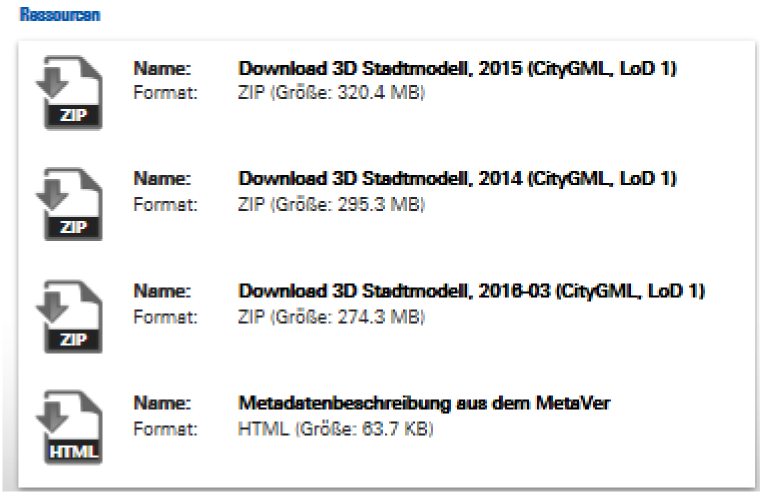

Figure 15 CityGML resources available to be downloaded

The following figure (Figure 16) shows one of the parts in which is divided the CityGML LoD1 available for the city of Hamburg.

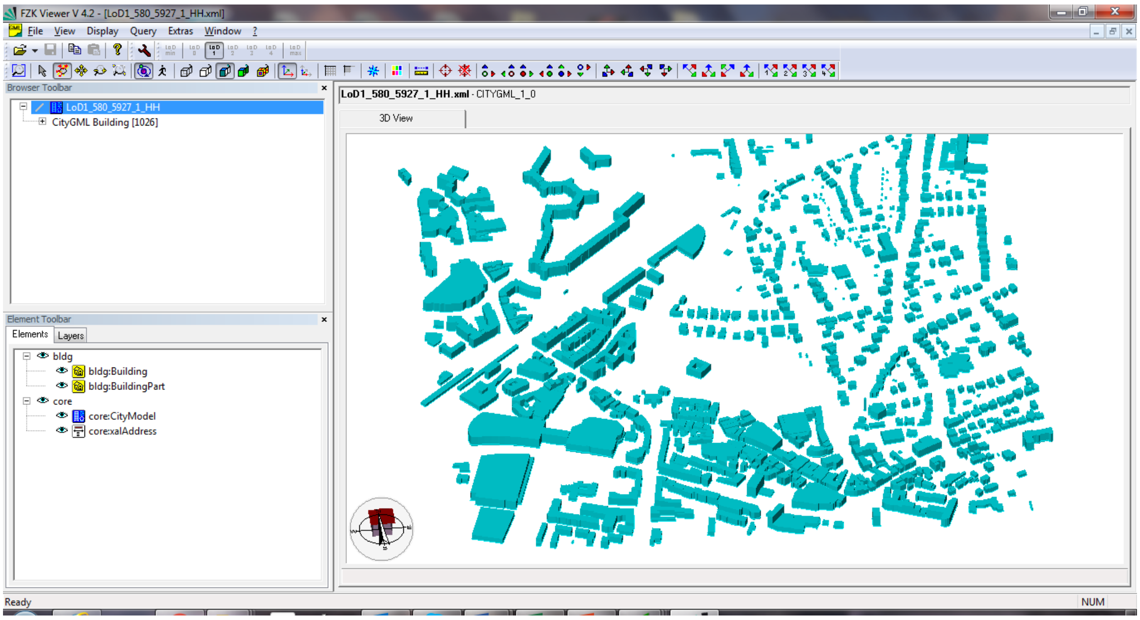

Figure 16 Small area of the CityGML of the city of Hamburg (using FZK Viewer)

C) Data Pre-processing

The main tasks carried out in order to obtain the required information for the energy demand analysis of the selected district of the city of Hamburg are briefly described below:

- **From CityGML to SHP:** First, the CityGML models representing the buildings in the study area have been downloaded. These files have been converted to 2D geometries with the associated semantic information using the FME tool. However, the conversion from CityGML to SHP has not

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

been performed properly due to the specific structure definition of the CityGML models. Some of the relevant attributes of the model, such as the function, are lost in the conversion process. In addition, the conversion generates a shape of polylines instead of polygons. The GML file is not properly imported in QGIS as a single layer, since there are different types of geometries in the same gml file.

As a result of the process, we have obtained a building layer with some attributes relevant for the analysis. The most relevant attributes are: measured height, storeysAboveGround and function.

- **Combine information from different layers:** In addition to the CityGML model, the municipality has provided some SHP layers with geometric information and attributes of the buildings in the study area. This layer is "retrofitting_buildings" of which there have been different versions that completed the information of the other versions. The first version of this layer has been used as the base geometry and it has been completed with the information obtained from the CityGML and the successive versions of the building layers. The following figure (Figure 17) show the layers used in this process. The set of attributes included in the building footprints layer after this process are:
    - Number of Floors: anzahlgs
    - Building Use: funktion
    - Total Height: UN_measure
    - Year of Construction: YoC
    - Building ID: gml_id

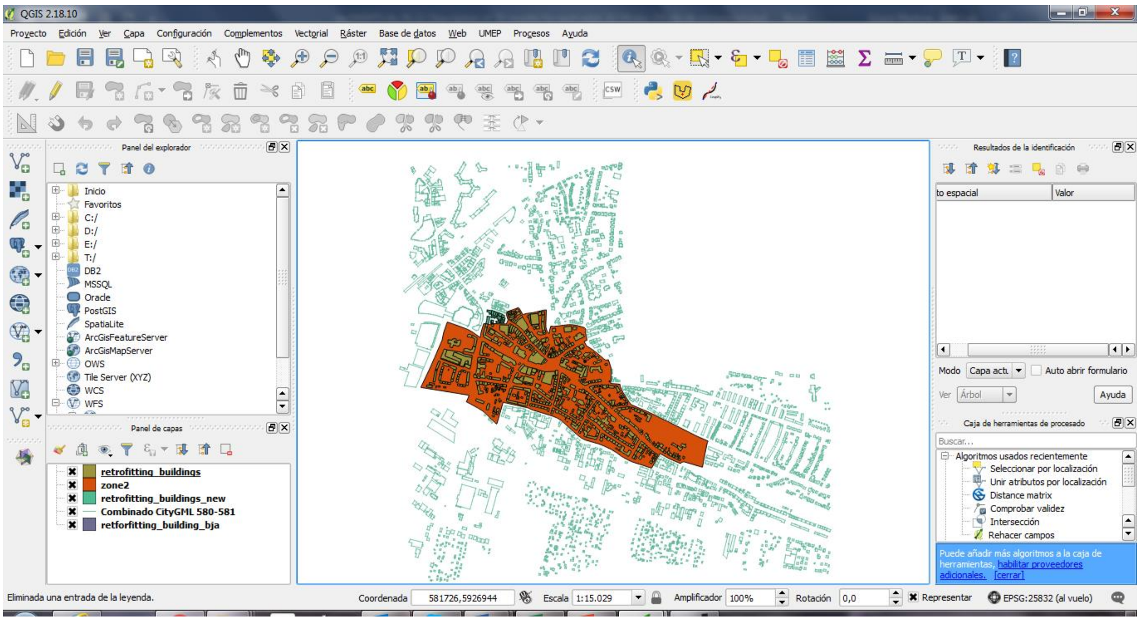

Figure 17 Main layers used in the data processing in Hamburg Case Study

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

- **Limit the extension of layers to the study area:** The building layer has been cut to the limits of the sturdy area (zone 2).
- **Completion and Verification of the information:** The resulting layer is complete with the surface of the building footprint and roof calculated in QGIS. For several buildings of the study area the year of construction was missing, it has been manually inserted in the buildings layer following the indications of the municipality. Also, there was some buildings without the height data and it has been estimated using the number of floors. Finally, the buildings representing garages have been eliminated from the layer.

The result of the pre-processing produces an information layer (EdificiosHamburgo_v1.shp) with 684 buildings with the following attributes:

  - **gml_id:** Unique identifier for each building
  - **funktion:** Main function of the building
  - **anzahlgs:** Number of floors
  - **UN_measure:** Height of the building
  - **YoC:** Year of construction of the building
  - **area:** Building footprint area.
  - **RoofArea:** Building roof area

D) Data Processing

In this task, the geometric processing of the data resulting from the pre-processing of the district data has been carried out in order to obtain the necessary information for the analysis of energy demand. This processing is done automatically from the SHP resulting from the pre-processing. The result combines information contained in the SHP of the pre-processed, new calculated data and estimated data from the contents of the original SHP.

The main geometric processes that are carried out in this phase are for the calculation of the surfaces of the building envelope. Additionally, simple calculations are made to estimate other geometric parameters of the buildings, such as: building volume. To calculate the surfaces of the envelope, it is necessary to previously identify which of the building's surfaces are facades and which are adjoining walls in order to obtain precisely the area of the facades. Subsequently, the area of each façade is calculated from the footprint geometry and the height of the building. Finally, it is necessary to add the surface of all facades at the building level. It is also possible to identify in this process the orientation of the enveloping surfaces of the building, both for the facades and for the adjoining walls.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

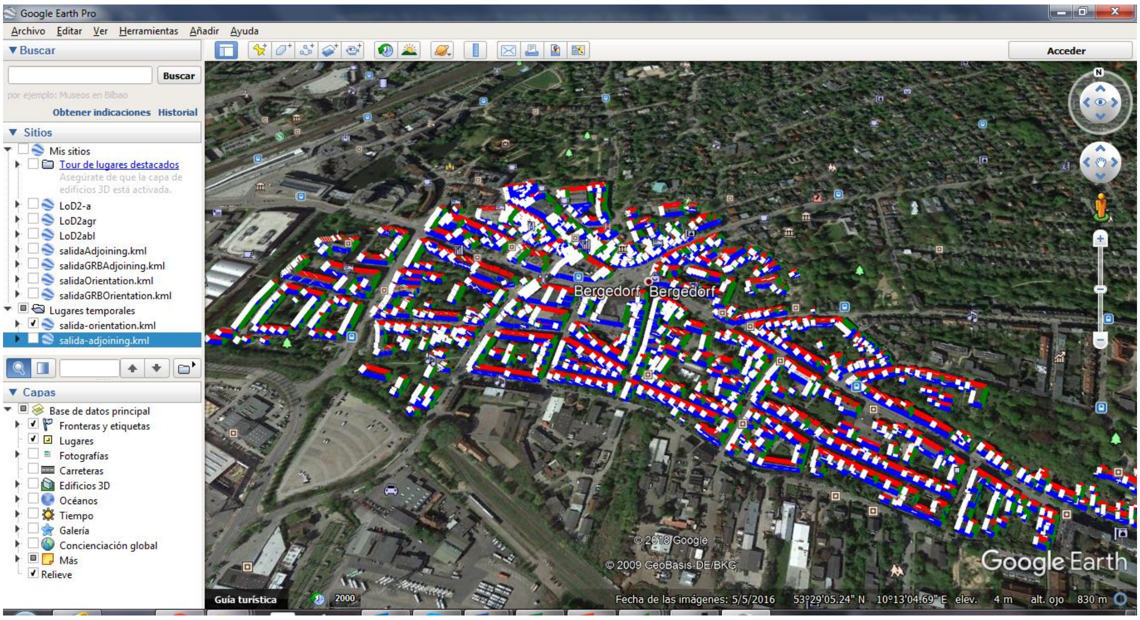

Figure 18 Main orientation of building façades in Hamburg study area (Red=North, Blue=South, White=West, Green=East)

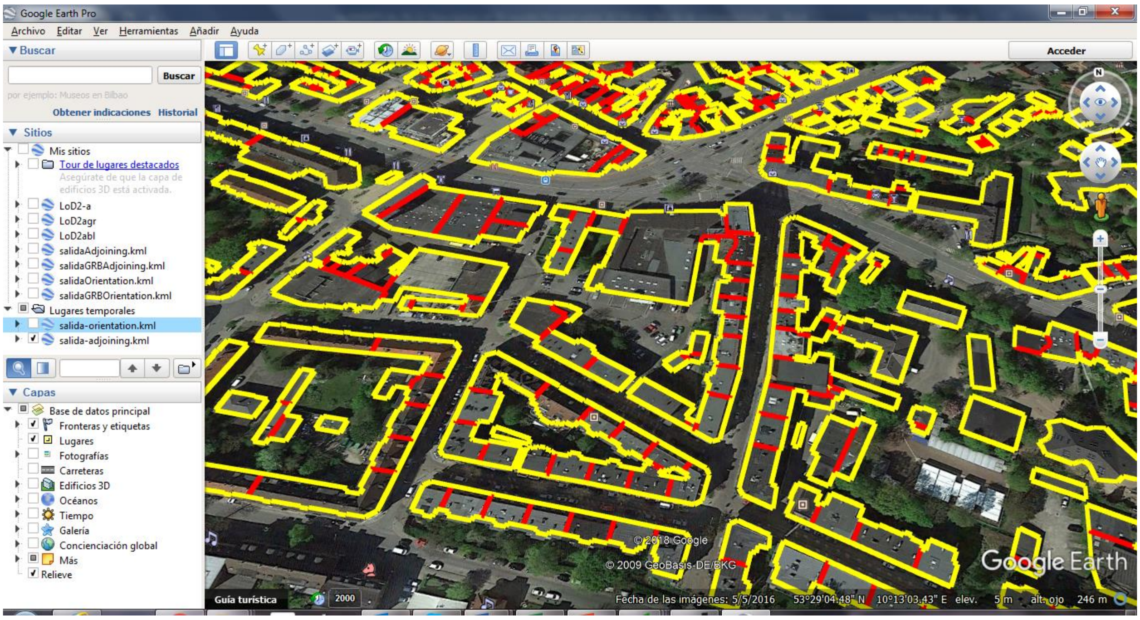

Figure 19 Building façades (in Yellow) and adjoining walls (in Red) in Hamburg study area

4.2.2.3 Description of the results

The energy analysis of the city of Hamburg will be performed at the level of the study district and not at the city level. Only results at district level are shown in this section.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

As a result of the modeling of the Hamburg study area, the necessary information for the energy analysis is obtained. The detail of the information resulting from the process is presented in the following table (Table 24). The information is available in different formats: Excel, SHP and KML.

Table 19: Set of parameters contained in the files resulting from the process

Parameter	Format	Description
Reference	Unique Id	Building Unique Identifier
Centroid	UTM Coordinates	Geolocation of the building
TotalHeight	Number	Height of the building
NumberOfFloors	Number	Number of Floors
BuildingArea	Number (m^2)	Area of the building footprint
GrossFloorArea	Number (m^2)	Total area of the building
RoofArea	Number (m^2)	Area of the roof of the building
TotalEnvelopeArea	Number (m^2)	Total envelope area, including façade and adjoining walls
ExteriorEnvelopeArea	Number (m^2)	Area of the building façade
AdjoiningEnvelopeArea	Number (m^2)	Area of the adjoining walls
NorthExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is North
SouthExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is South
WestExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is West
EastExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is East
YearOfConstruction	Number (Year)	Year of construction of the building
Use	Text	Main use of the building
Refurbished	True / False	If it has been refurbished
Volume	Number (m^3)	Volume of the building
DistrictCentroid	UTM Coordinates	Approximated geolocation of the centre of the study area

Below is a screenshot of the resulting KML file (See Figure 31). The file is displayed on Google Earth. In addition, the information associated with the selected building is included

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

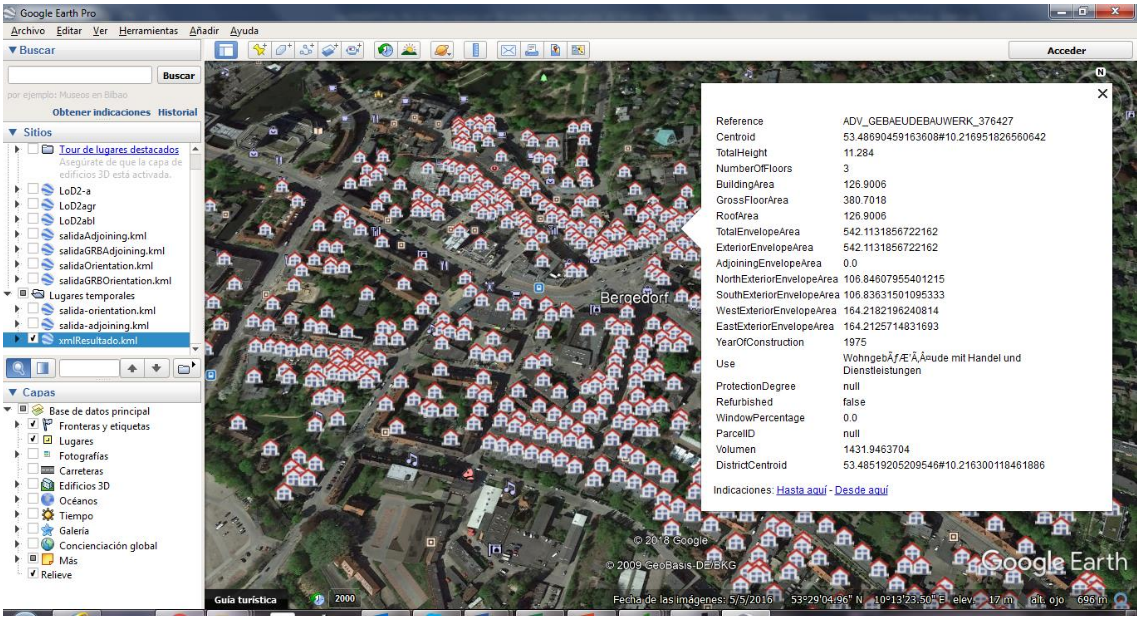

Figure 20 Results at district level in Hamburg (KML format)

4.2.3 Helsinki area of study

This subsection describes the main process followed for the treatment of the data for the case of Helsinki. It includes a description of the situation of the city with regard to the information available, a description of the data processing at district scale, the data processing at city scale and a description of the results obtained in this phase.

4.2.3.1 Description of the situation of the city

The case study of Helsinki has a complete set of models and services available at the level of the City.

- The zip files of the CityGML buildings: http://3d.hel.ninja/data/citygml/ (with textures and without textures). The code numbers (e.g. CityGML_BUILDINGS_LOD2_NOTEXTURES_662488x2.zip) are the area codes and are referring to a base map. The corresponding areas and the area codes: https://www.hel.fi/hel2/tietokeskus/data/helsinki/kaupunginkanslia/3D-malli/Karttaliite2.pdf
- The 3D city information model service as open data: http://kartta.hel.fi/3d/
- 2D footprints of building. Web Feature Service (WFS) Interface: https://kartta.hel.fi/ws/geoserver/avoindata/wfs -> Rakennukset_alue (in Finnish it means Buildings_area). This exact data includes buildings' footprints and attributes like the usage and address.)

All these links have been provided by the municipality of Helsinki. In the modelling process for the energy analysis. It has been based on the information contained in the 3D model and the information of the

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

cartography and 2D cadastre. The analysis has been carried out in two steps: First a detailed analysis for a small number of buildings and then the analysis at the Helsinki Centre level.

4.2.3.2 Data processing at district scale

A) General Configuration

The detailed analysis has been done for a selected group of buildings. The selection of the buildings has been proposed by the municipality of Helsinki. The selected area can be seen in the following figure (Figure 21)

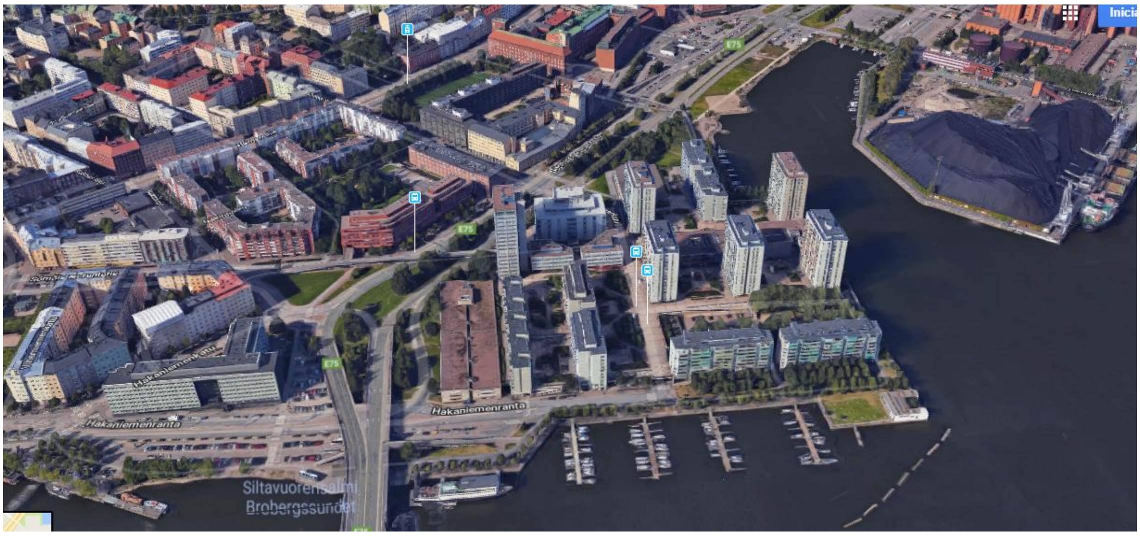

Figure 21 Selected area for detailed modelling in Helsinki (source: Google maps)

First, the necessary information to carry out the development of the energy analysis has been identified. For each of the buildings of the selected district it is necessary to obtain the basic information detailed in the following table (See Table 6). The study area is made up of 21 buildings.

Table 20: Basic Information required for each building in Helsinki Case Study

Name	Type	Values / Units
Building Unique Identifier	Unique Id	
Building footprint area	Number	m^2
Building Height	Number	m
Main Use or Function of the building	Text	
Year of Construction	Number	
Number of floors	Number	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

B) Data Sources

The following table (See Table 21) shows the data sources provided by the municipality of Helsinki and used for the generation of the necessary information to carry out the energy analysis of the selected group of buildings.

Table 21: List of data sources used for the case study of Helsinki

Name	Source	Type
3D City Model	CityGML_BUILDINGS_LOD2_NOTEXTURES_672496x2.gml CityGML_BUILDINGS_LOD2_NOTEXTURES_674496x2.gml	GML LoD2 without textures
Zone Map 3D Model	Karttaliite2.pdf	PDF
Cadaster 2D data	Helsinki.shp	Polygons
Footprints from 3D Model	http://kartta.hel.fi/3d/	Polygons

The following figures show the different alternatives used to access and download the available information.

- https://kartta.hel.fi/3d, it allows downloading SHP but with a limit of 4.000.000m2 (2km by 2km).

Figure 22 Download footprints from 3D Model

- http://www.hri.fi/en/dataset/helsingin-3d-kaupunkimalli -> Data and Resources: Kolmioverkkomalli karttapalvelussa.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

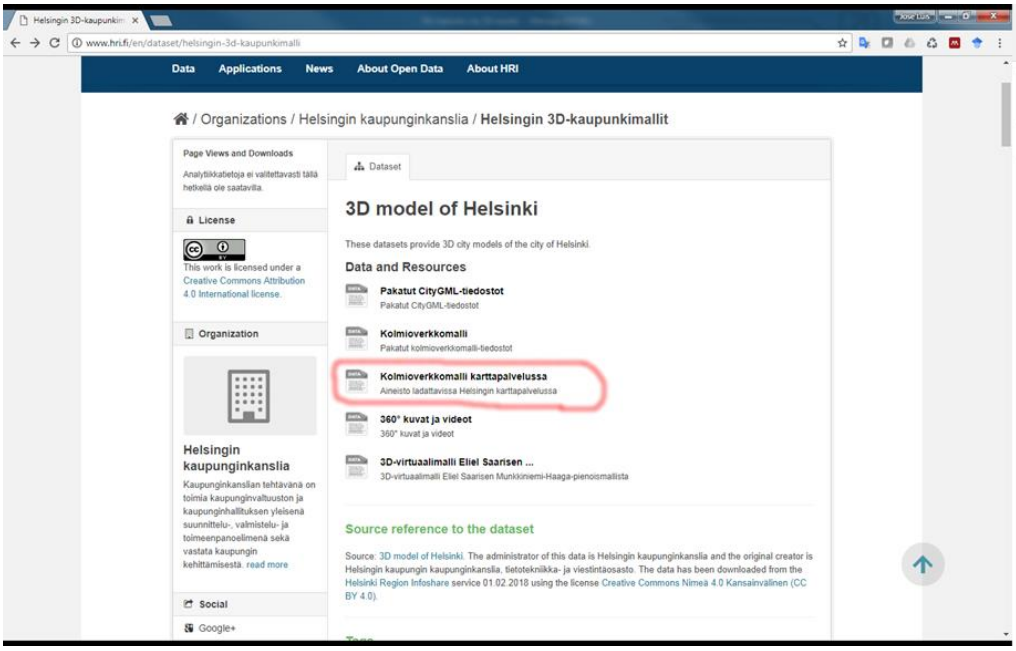

Figure 23 Resources of 3D Model of Helsinki

- http://www.hri.fi/en/dataset/helsingin-3d-kaupunkimalli. Select the Buildings (areas) layer, and Share->Export to File, Export all data and select Shape, however the download fails.

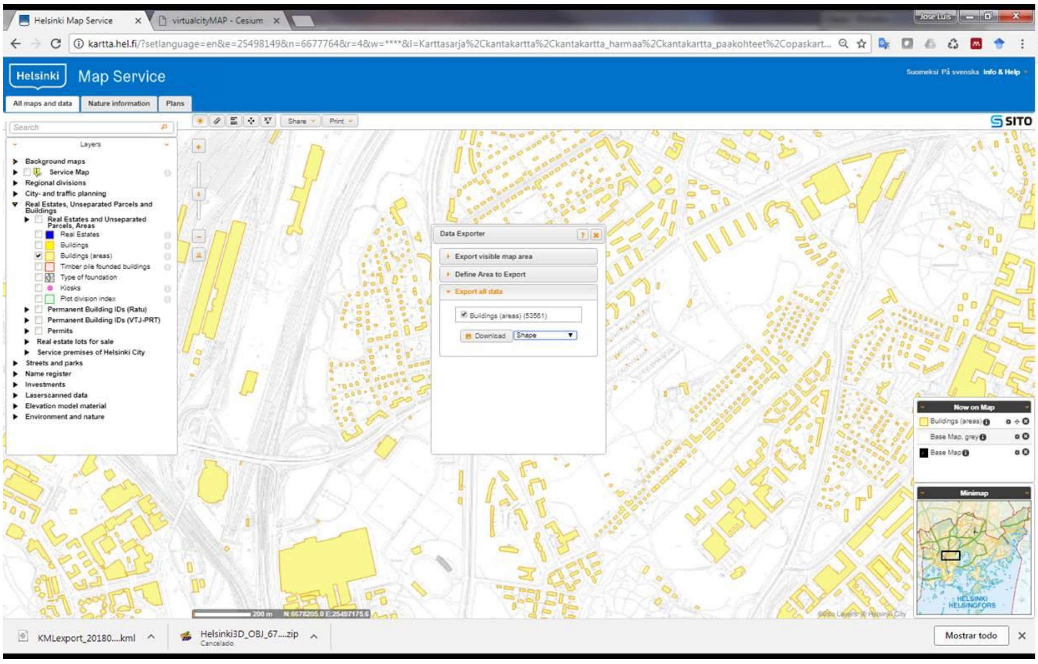

Figure 24 Download building footprints from Map Service

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

C) Data Pre-processing

The main tasks carried out in order to obtain the required information for the energy demand analysis of the selected district of the city of Helsinki are briefly described below:

- **From CityGML to SHP:** First, the available CityGML models have been downloaded and those corresponding to the buildings in the study area have been identified (Karttaliite2.pdf). The study area is distributed between the zones 672496x2 and 674496x2. These files have been converted to 2D geometries (polygons) with the associated semantic information using the FME tool. The conversion process generates several files with the information of the elements represented in the CityGML model. The layer that best represents the geometry of the building floor is "GroundSurface_surface.shp". However, this layer does not contain any information relevant for the geometric processing. The following figure (see Figure 25) shows the result of shp conversion of the CityGML files of the two mentioned zones.

  The same result is obtained if the SHP download option is chosen from the web resource http://kartta.hel.fi/3d/.

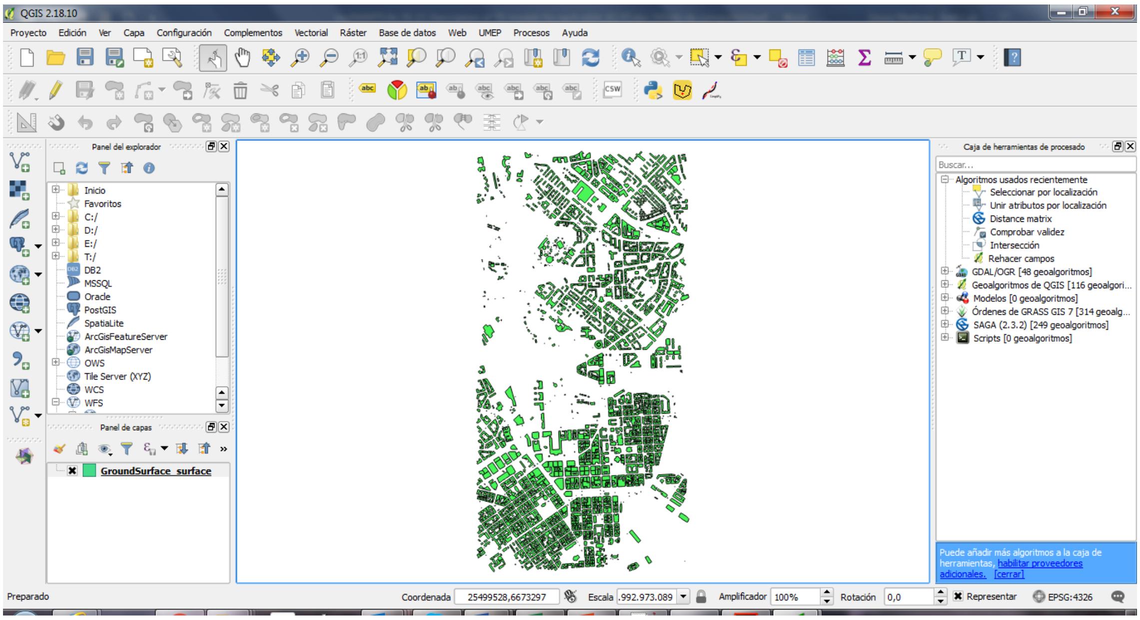

Figure 25 Result of the process of exporting to shp the selected zones in CityGML

- **Data reprojection and limit to the study area:** Reprojection of the generated layer ("GroundSurface_surface.shp") to the EPSG reference system use in the process (3879). The layer is also reduced to the limits of the study area.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

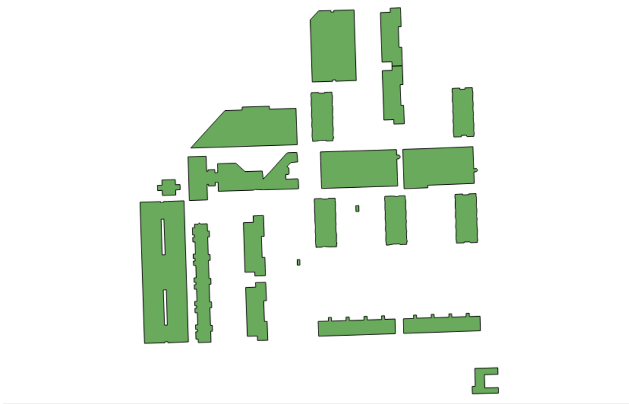

Figure 26 Building footprints of the selected study area

- **Complete the layer with semantic information:** The geometric information contained in the "GroundSurface" layer is completed with the semantic information necessary to carry out the geometric processing. The semantic information is contained in another of the files obtained from the conversion of CityGML to SHP. The relevant information of the buildings is in the layer "Building_surface.shp". This layer is combined with the geometric layer, completing, among others, the following parameters:
    - BREC_Builld = Height
    - Kayttotark = Building Use
    - Kerroksia = Number of floors
    - Valmistunu = Year of Construction
- **Completion and Verification of the information:** The resulting layer is complete with the surface of the building footprint calculated in QGIS. The verification of the results carried out consists mainly on the checking that all the data are complete and they are coherent with the expected data.

The result of the preprocessing produces an information layer (Helsinki_v7.shp) with 21 buildings with the following attributes:

- ID: Unique identifier for each building
- Height: Height of the building
- BuildingUs: Main function of the building
- NumberFloo: Number of floors
- YoC: Year of construction of the building

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

- area: Building footprint area.

D) Data Processing

In this task, the geometric processing of the data resulting from the pre-processing of the district data has been carried out in order to obtain the necessary information for the analysis of energy demand. This processing is done automatically from the SHP resulting from the pre-processing. The result combines information contained in the SHP of the pre-processed, new calculated data and estimated data from the contents of the original SHP.

The main geometric processes that are carried out in this phase are for the calculation of the surfaces of the building envelope. Additionally, simple calculations are made to estimate other geometric parameters of the buildings, such as: number of floors, building volume or roof area. To calculate the surfaces of the envelope, it is necessary to previously identify which of the building's surfaces are facades and which are adjoining walls in order to obtain precisely the area of the facades. Subsequently, the area of each façade is calculated from the footprint geometry and the height of the building. Finally, it is necessary to add the surface of all facades at the building level. It is also possible to identify in this process the orientation of the enveloping surfaces of the building, both for the facades and for the adjoining walls.

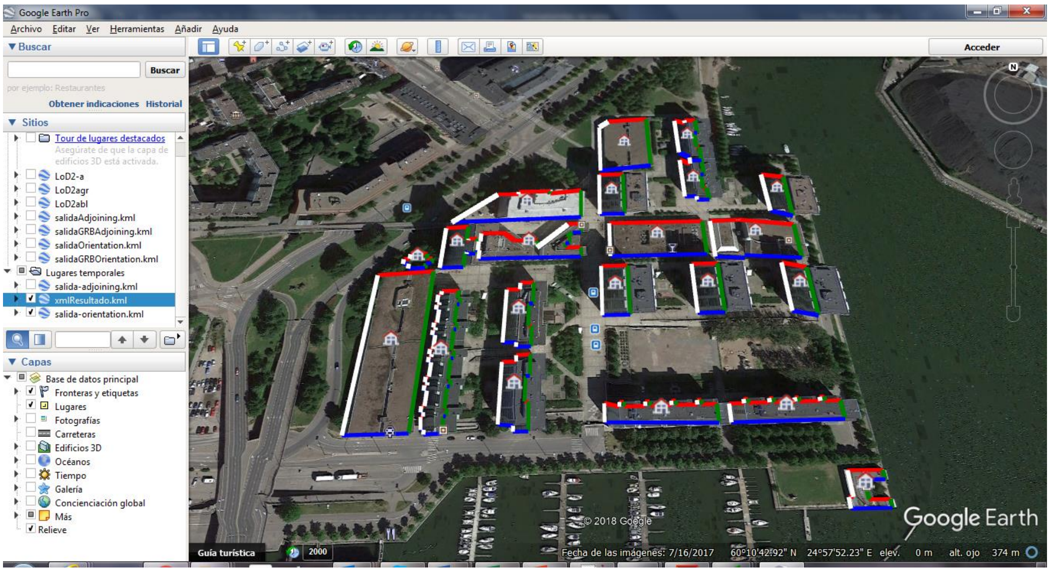

Figure 27 Main orientation of building façades in Helsinki study area (Red=North, Blue=South, White=West, Green=East)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

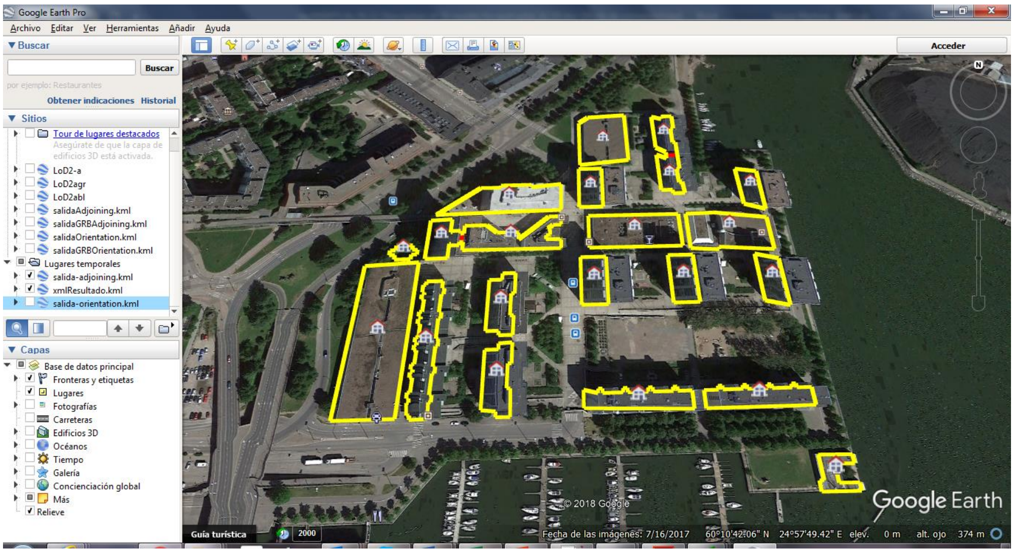

Figure 28 Building façades (in Yellow) and adjoining walls (in Red) in Helsinki study area

4.2.3.3 Data processing at city scale

A) General Configuration

The scope of this process is the Center of Helsinki Region (See Figure 29) with around 600.000 inhabitants. The reference system used in the processing at city scale is EPSG: 3879.

Figure 29 Helsinki Center in Helsinki Region

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

B) Data Sources

Data source used for the processing at city scale of the Helsinki Center are presented in the following table (Table 22). Both shp files have been downloaded from the Web Feature Service (WFS) Interface: https://kartta.hel.fi/ws/geoserver/avoindata/wfs.

Table 22: List of data sources used for the Helsinki Center

Name	Source	Type
Building Footprints	Helsinki_Building_footprints.shp	Polygons
Building attributes	Helsinki_Points.shp	Points

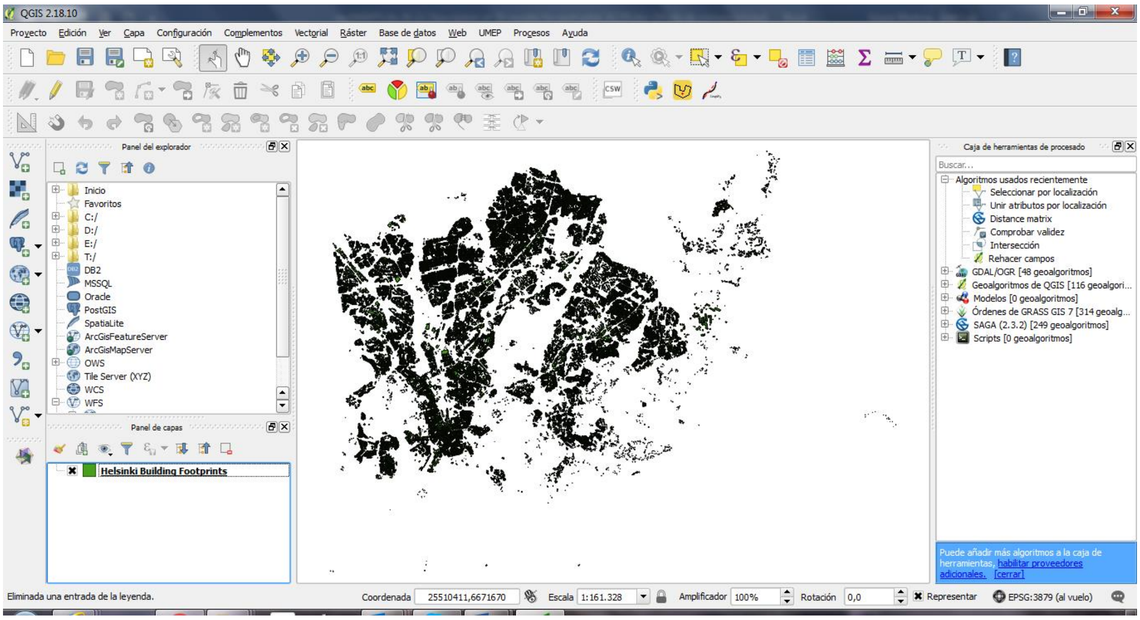

Figure 30 Building footprints of the Helsinki Centre

C) Data Pre-processing

The main tasks carried out in order to obtain the required information for the energy demand analysis of the city of Helsinki are briefly described below:

- **Combine information from both layers:** The exercise consists of joining the building geometry of one of the data sources (building footprints) with the relevant attributes included in the other data source (building attributes). The information of the attributes of the points layer that are relevant for processing is added to the polygons layer that contains the geometry of the buildings. Attributes included in the building footprints layer are:
    - Id: Building ID

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

- Tyyppi: Building Use
- I_kerrlkm: Number of floors
- Year: Year of Construction

- **Verification of the information:** Given the size of the city, the verification of the results has been carried out for a significant sample of buildings. For a total number of 47.145 buildings
  - The number of floors is missing for 5.925 buildings
  - The year of construction is missing for 6.400 buildings
- **Assignment of values to missing attributes:** Finally, missing attributes have been completed based on rules associated with the typology of the buildings. These rules have been defined according to the average values of each parameter for each building type. The values used for the assignment are listed in the following table.

Table 23: List of data sources used for the Helsinki Center

Building Use	Year of Construction	Number of Floors
Asuinrakennus	1950	3
Talousrakennus	2000	2
Ei k├â┬ñytt├â┬Âmerkint├â┬ñ ├â┬ñ kartalla	2012	2
Teollisuusrakennus	Not Applicable	Not Applicable
Muu k├â┬ñytt├â┬Âtarkoitus	1950	2
Yleinen tai liikerakennus	1950	4

The result of the pre-processing produces an information layer (shp file) with 47.145 buildings with the following attributes:

- ID: Unique identifier for each building
- Use: Main function of the building.
- Number of Floors: Number of floors of the building
- Year: Year of construction of the building
- Area: Building footprint area

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

D) Data Processing

The same geometric processing performed for the study area has been carried out at city scale in order to obtain the necessary information for the analysis of energy demand.

4.2.3.4 Description of the results

A) Results at district level

As a result of the modeling of the Helsinki study area, the necessary information for the energy analysis is obtained. The detail of the information resulting from the process is presented in the following table (Table 24). The information is available in different formats: Excel, SHP and KML.

Table 24: Set of parameters contained in the files resulting from the process

Parameter	Format	Description
Reference	Unique Id	Building Unique Identifier
Centroid	UTM Coordinates	Geolocation of the building
TotalHeight	Number	Height of the building
NumberOfFloors	Number	Number of Floors
FootprintArea	Number (m^2)	Area of the building footprint
GrossFloorArea	Number (m^2)	Total area of the building
RoofArea	Number (m^2)	Area of the roof of the building
TotalEnvelopeArea	Number (m^2)	Total envelope area, including façade and adjoining walls
ExteriorEnvelopeArea	Number (m^2)	Area of the building façade
AdjoiningEnvelopeArea	Number (m^2)	Area of the adjoining walls
NorthExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is North
SouthExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is South
WestExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is West
EastExteriorEnvelopeArea	Number (m^2)	Area of façade whose main orientation is East
YearOfConstruction	Number (Year)	Year of construction of the building
Use	Text	Main use of the building
Refurbished	True / False	If it has been refurbished
Volume	Number (m^3)	Volume of the building
DistrictCentroid	UTM Coordinates	Approximated geolocation of the centre of the study area

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Below it is showed a screenshot of the resulting KML file (See Figure 31). The file is displayed on Google Earth. In addition, the information associated with the selected building is included.

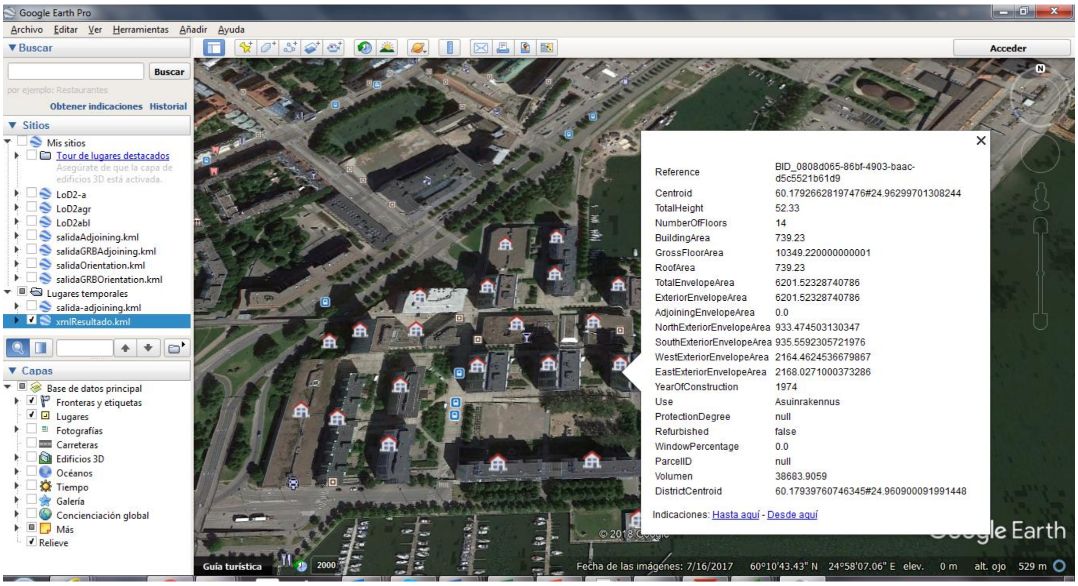

Figure 31 Results at district level in Helsinki (KML format)

B) *Results at city level*

The results at city level contains the same information than in the study area. Due to the size of the files Kml is not generated. Only Excel and SHP files are generated at the city scale.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

5. Methodological approach to the energy analysis of the three lighthouse cities

5.1 General description and purpose

Based on the results obtained in the Section 4 the energy demand analysis of the areas selected for each city are evaluated. This section describes the general approach adopted for the energy demand analysis.

As described above, the main objective of the analysis is to obtain a quick characterization of the energy performance at district level for each of the lighthouse cities. This provides the baseline situation of each district. This baseline situation allows a better understanding of the initial situation and the existing improvement potential in each case. The improvement potential is understood in this context as the potential for reducing the energy demand/consumption of the district, for reducing the environmental emissions associated to it and the potential for the integration of renewable energy technologies within the boundaries of the district in order to increase in a sustainable way the energy self-sufficiency degree of the districts and the city in general.

In contrast to other approaches, in this case an energy analysis methodology is used for evaluating the specific energy demand of each house or building block taking into account their specific characteristics such as the envelope surfaces (opaque, transparent), building use, area, year of construction, etc. These building attributes are obtained from the previous phase related to the 3D modelling, City GML and city cadastre analysis and treated and used for the energy analysis in this phase.

Besides, it needs to be understood that although the methodology allows the energy demand calculations in an hourly basis for each building, it is designed in a way that allows its application to larger areas following the same procedure. Therefore, the energy demand analysis of a city is initiated at district scale and once that it is adjusted and calibrated for this district, it can be relatively easily extended to the entire city if necessary.

This procedure is very useful for obtaining a good energy demand and consumption characterization of the city, which is one of the first stages of the Integrated Urban Planning. Besides, the information obtained will allow in the following steps of the energy planning process the identification of the potential for the deployment of energy related interventions that can be implemented at both the district and the city scales.

This energy characterization has been applied to the three lighthouse cities of the project Helsinki, Nantes and Hamburg for the districts that have been selected by the municipalities.

Finally, the experience gained with the lighthouse cities and the results obtained will be useful for the replication of the entire process in the follower cities of the project.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

5.2 Description of the energy demand calculation

The energy characterization of the districts selected in the project by the three lighthouse cities has been carried out following an innovative method that allows municipalities to carry out energy studies of their existing building stock using cadastral information. This method for the building energy demand characterization at city scale was developed by Tecnalia in the European research project PlanHeat [1] and has been completed and improved to allow also the electricity energy consumption analysis.

A complete description of the energy demand analysis methodology can be consulted in the public deliverable "D2.1 –Models for mapping and quantifying current and future H&C demand in cities" of the PLANHEAT project (H2020-EE-2016-RIA-IA). However, in this section a summary of the most relevant aspects of the calculation method are included. Besides, part of the information described here has also been presented as a conference paper titled "Sensitivity assessment of a district energy assessment characterisation model based on cadastral data" at the International Scientific Conference "Environmental and Climate Technologies", CONECT 2018, held in Riga, Latvia.

The methodology needs the following information to calculating the energy demand of the district: flat geometry, height (or number of floors), use and age. This information is extracted automatically from the pre-processing of the cadastral map of the city. After this pre-processing step, a shape file with a unique geometry for each building is created. Table 25 includes the most relevant information used for the analysis. In the case of the height, if the information is not available, it can be directly calculated using the LiDAR data when it is available.

Table 25: Inputs for the energy modelling phase obtained from the 3D model information pre-processing.

Parameter	Mandatory or Optional
Building ID	Mandatory
Building Geometry	Mandatory
Footprint area	Mandatory
Height 1	Mandatory
Height 2	Optional
Number of floors 2	Mandatory
Number of floors 1	Optional
Hourly outside air temperature	Mandatory
Year of construction	Mandatory
Building Use	Mandatory
Gross floor area	Optional
Roof area	Optional

5.2.1 Energy demand and consumption calculations

The energy demand profiles at district scale are obtained following a bottom-up approach and following the Energy Performance of Buildings Directive [2], which proposes the static equations [3] for the calculation of the heating, cooling and domestic hot water (DHW) energy demands based on the Degree-

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Days method. However, in order to obtain a more detailed analysis, the calculation is done on an hourly basis and also considers internal gains, solar gains, ventilation losses.

The energy demand and consumption analysis is carried out for each of the building uses covering in principle the following uses;

- Residential
- Office
- Health care
- Education
- Commerce
- Public administration
- Hotel
- Restaurant
- Sport centre

However, taking into account that the analysis carried out is at district scale the most relevant part of the building stock is covered by the residential and tertiary (offices, commerce, public buildings). This classification of buildings is complemented also with the consideration of the period of construction of the buildings. The period considered are defined according to the information available in the city cadastre or the information available for the calibration of the model.

Therefore, it can be said that the building stock of the district is characterized with a high level of detail of building classification.

With regard to the energy demand calculations, the hourly heating demand of each building is determined by multiplying the number of heating degree hours of the location, the heat transfer coefficient of the envelope areas and the heating schedule of each hour. The annual demand is calculated as the sum of the hourly heating demands.

Different internal gains related to occupancy, lighting, appliances and solar gains are taken into account. Ventilation losses (calculated considering different base temperatures for heating-h or cooling-c) are also assumed. These ventilation losses are reduced (according to the efficiency of the heat recovery system) in the case that a mechanical ventilation system with heat recovery is installed.

The following equation shows the calculation method for the heating demand where all the aforementioned parameters are considered.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

$$AHD_k = \sum_{i,j=1}^{8760} \left(HDH_{i,j} \times A_k \times U_k - Gains_{i,j} + hventilation\ losses_{i,j} \times (1 - n_{HR}) \right) \cdot heating\ schedule_{i,j}$$

Equation 1

Where AHDk is the annual heating useful energy demand (kWh/year), HDHi,j is the heating degree hours (°C), Ak is the envelope element surface (m^2), Uk is the thermal transmittance (W/(m^2·K)), ηHR is the heat recovery system efficiency (%), i is the hour of the day and j is the day of the year.

A similar procedure is used for the calculation of the annual cooling demand of buildings but in this case the heating degree hours are replaced by the cooling degree hours, the heating ventilation losses are replaced by the cooling ventilation losses, and the heating schedule by the cooling schedule.

$$ACD_k = \sum_{i,j=1}^{8760} \left(CDH_{i,j} \times A_k \times U_k + Gains_{i,j} + cventilation\ losses_{i,j} \times (1 - n_{HR}) \right) \cdot cooling\ schedule_{i,j}$$

Equation 2

Where ACDk is the annual cooling useful energy demand (kWh/year), CDHi,j is the cooling degree hours (°C), Ak is the envelope element surface (m2), Uk is the thermal transmittance (W/(m^2·K)), ηHR is the heat recovery system efficiency (%), i is the hour of the day and j is the day of the year.

Finally, the annual domestic hot water demand is determined by multiplying the annual DWH demand per square meter, the gross floor area of the building and the normalized usage factor of the DHW.

$$DHWD_k = \sum_{i,j=1}^{8760} DHW\ demand_k \times NHA_k \times \frac{Hourly\ usage\ factor_{DHW_{i,j}}}{\sum_{i,j=1}^{8760} Hourly\ usage\ factor_{DHW_{i,j}}}$$

Equation 3

Where DHWDk is the annual domestic hot water useful energy demand (kWh/year), DHWk is the domestic hot water demand (kWh/m^2), NHAk is the net heated area (m^2), i is the hour of the day and j is the day of the year.

These equations have been used for the energy demand characterization of each building of each of the lighthouse cities. Several parameters are especially relevant to particularize this generic methodology to each of the case studies. A short description of these parameters is included;

- **Year of construction:** The year of construction of each building follows in principle a common classification based on 7 ranks: Pre-1945, 1945-1969, 1970-1979, 1980-1989, 1990-1999, 2000-2010, Post 2010. This classification will help to organize and consider the definition of parameters such as the U-value or the number of air changes per hour for each of the cases. These rages can vary for each of the cities evaluated depending on the information available both for the

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

baseline definition of the year and for the adjustment or validation of the information obtained with the modelling.

- **Schedules:** The schedules can vary considerably depending on the use of the building. The schedules that can vary include the occupancy pattern, the use pattern of the lighting and the electric equipment which will influence both the electrical energy consumption and the internal gains that will affect heating and cooling energy demand calculations.
- **Internal gains:** The internal gains vary depending on the use of the building, because their occupation pattern and the equipment used. These contributions are mainly given by occupation sensible and latent loads; lighting sensible loads and equipment sensible loads.
- **Window to wall ratio:** Based on several scientific studies, the values of the window to wall ratio (%) are considered and calculated for each building depending on their use.
- **U-value:** The insulation of a building varies according to its location, typology, construction period or element to be evaluated, and is determined by the U-value of the elements that compose the envelope.
- **Ventilation losses:** The flow of heat loss through ventilation is also considered for the calculation of the heating demands.
- **Solar gains:** Useful thermal energy that reaches the interior of the buildings through the windows (direct solar gains) are also considered in the analysis. A dynamic simulation of a residential (27% of WWR) and a service (office) building (50% of WWR) has been carried out in Design Builder® software to obtain the hourly solar gains per window surface area (W/m^2) for each of the location of the districts evaluated.

Therefore, the values of the parameters described above and that are used in the energy analysis are particularized according to the location, the age and the use of the buildings. The values for each of the cases are described in the sections corresponding to each case study.

The next table shows the existing dependence in the calculations of those parameters respect to the location, the age and the use.

Table 26: Dependence of the parameters according to the characteristics of the buildings

	Schedules	**Internal gains**	**WWR**	**U-value**	**Ventilation losses**	**Solar gains**	**DHW demand**
Location				X	X	X	
Age				X	X		
Use	X	X	X	X		X	X

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

5.2.2 Results obtained with the analysis for each building of the district

Two different results are obtained with the described analysis for each building within the boundaries of the selected district. The first output is the georeferenced generic and energetic information per building (see Table 27). This information is obtained in two different file-formats;

- XLSX file and
- SHAPE file.

In this way, the end-user could analyse the results with different tools (for example an “excel” for the XLSX file and the QGIS for the SHAPE file).

Table 27: Outputs of the energetic analysis of each building of the district.

Parameter	Unit
Building generic data	
Building ID	-
Centroid of the building	Coordinates
Use	Name
Footprint area	m^2
Height	Number
Number of floors	Number
Gross floor area	m^2
External opaque facade area	m^2
Roof area	m^2
Window area	m^2
Volume	m^3
Year of construction	Number
Building energetic data	
Annual heating demand	$kWh \cdot year^{-1}$
Annual cooling demand	$kWh \cdot year^{-1}$
Annual DHW demand	$kWh \cdot year^{-1}$
Annual heating demand per square meter	$kWh \cdot m^{-2} \cdot year^{-1}$
Annual cooling demand per square meter	$kWh \cdot m^{-2} \cdot year^{-1}$
Annual DHW demand per square meter	$kWh \cdot m^{-2} \cdot year^{-1}$
Annual lighting electricity energy consumption	$kWh \cdot year^{-1}$
Annual equipment electricity energy consumption	$kWh \cdot year^{-1}$
Annual lighting electricity energy consumption per square meter	$kWh \cdot m^{-2} \cdot year^{-1}$
Annual equipment electricity energy consumption per square meter	$kWh \cdot m^{-2} \cdot year^{-1}$

The second output is the hourly heating, cooling and DHW energy demand data per each building of the area under study. This information can be obtained in a XLSX file.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

5.3 Description of the calibration/adjustment of the results obtained

The methodology described above for the energy demand calculation is generic and can be used for the analysis of different districts of different locations and with different conditions. Moreover, the calculations need to be particularized to each case study by providing specific value for each of the parameters used in the equations mentioned.

This particularization is usually done as a first step by using existing values obtained from literature. However, experience and several studies show that the obtained values can have relevant differences respect to the actual data obtained from other sources such as monitoring data or energy bills [4]. The reason of obtaining these differences come from aspects that are difficult to foresee or control, aspects such as the user behaviour or the actual situation of the building envelope, infiltrations, etc.

This is the reason why it is recommended to adjust or calibrate the model with existing data. But in a previous step it is also recommendable to evaluate the relevance of each parameter considered in the results obtained. This sensitivity analysis will allow to understand better the relevance of obtaining the most accurate data for each of the parameters that affect the final energy characterization.

5.3.1 Sensitivity analysis

In order to get a better understanding of the influence of each parameter in the results for each of the case studies of the lighthouse cities, a sensitivity analysis is carried out. This allows detecting the impact of each parameter in results of each case study. In this case the Influence Coefficient (IC) is evaluated to calculate this relevance. The following equation [4] is used for its calculation:

$$IC = \frac{\Delta OP/OP_{baseline}}{\Delta IP/IP_{baseline}}$$

Equation 4

Where ΔOP and ΔIP are variations in the output (OPbaseline - OPscenario) and the input respectively; and OPbaseline and IPbaseline are the baseline values of the output and the input. The influence coefficient is a dimensionless parameter that represents the variation in the output due to a perturbation in the input.

The sensitivity analysis considers the variations in the following parameters;

- Window to wall ratio (WWR): Although there are regulations that establish maximum permitted values for this parameter depending on the building’s use, it varies for real case studies affecting directly to the heating and the cooling demands.
- U-values (U): There are different sources that provide U values for different countries [5] [6]. However, these values differ from the values used by the DMM [7]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

- Air change per hours (ACH): There is not any unified database which classifies the ventilation air change per hour according to their building construction period, use and location.
- Base temperature (BT): Building standards assume that the base temperature for heating varies between 18°C - 22°C and between 24°C - 26°C for cooling. This range represents a large difference in energy demand.
- Schedule (SC): This parameter adds a remarkable uncertainty to the results, as it has a critical role when estimating energy loads in buildings [8].
- Internal gains (IG): User behaviour is a difficult aspect to predict and affects to the internal gains related to the occupancy, appliances and lighting.
- Solar gains (SG): There are several approached and algorithms to compute the solar irradiance on building surfaces taking into account the effect of the shadowing [9],[10]. However, the methodology defined in this study is limited to a 2D assessment making impossible the assessment of the solar gains with the same accuracy.
- Summer/winter period (S/W): This parameter has a great influence on the heating and cooling demand since the heating and cooling schedules are directly associated to it. Summer period is defined in this case according to the average monthly temperatures of each location.
- Outdoor temperature (OT): The real hourly outdoor temperature from monitoring will differ from the hourly average values used in the modelling.

The variations considered are the followings;

- ± 1 ºC for the heating and cooling base temperature, ± 1 month for the summer winter period
- ± 2 hours for the heating and cooling schedule
- ±15% for the rest of the parameters described below

5.3.2 Calibration of the model

Once that the relevance of each of the evaluated parameters of the energy calculation equations has been evaluated for each case study. In the calibration the modeller will try to obtain real information that can be useful to define these parameters as realistic as possible. This will allow to reduce the error obtained with the energy modelling respect to actual values.

However, in the most common situation the information of the energy demand or consumption obtained from monitoring is not always available since this analysis aims to serve as an ex-ante assessment for the estimation of the energy demands of the building stock of large areas. In this case, the calibration phase needs to be flexible enough to adapt to the information and data available.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Therefore, the calibration of the energy model can follow different approaches. Based on the experience in mySMARTLife project, the most common approaches could be described as follows; the list is organized from the most desirable situation to the less desirable situation.

- Data from monitoring is available for both the building scale and for the district scale: Data related to the energy demands and consumptions is available for each of the building uses and ages considered in the modelling. Besides, specific actual information related to the main parameters described in the sensitivity analysis section are also available. In this situation the modelling of each (or some) of the buildings of the district can be adjusted by defining more in detail the most critical parameters of the model. Besides, the total energy demand and consumption of the entire district would also be checked. This situation would allow a good adjustment of the main parameters of the model which would allow an optimum replication of the modelling in other districts of the city.
- Data from monitoring is available only for some of the buildings of the district. Data related to the energy demands and consumptions is available for some of the building uses and ages considered in the modelling. Besides, theoretical but city particularized information related to the main parameters described in the sensitivity analysis section are also available. This situation would allow a good adjustment of the main parameters of the model which would allow a reasonable replication of the modelling in other districts of the city, at least for those building uses and periods for which the information is available.
- Data from monitoring is available for the entire district but not for specific buildings. Besides, theoretical but city particularized information related to the main parameters described in the sensitivity analysis section are also available. This situation would allow a good adjustment of the district which would allow a reasonable replication of the modelling in other districts of the city. However, the results of specific buildings would have a higher error that in some cases would be difficult to estimate and literature values related to the energy consumption of buildings located in the same city or country would be used for adjusting their values.
- Data from monitoring is available for some buildings of the city and for some of the periods. Besides, information related to some of the parameters described in the sensitivity analysis section are also available. This situation would allow a reasonable adjustment of the main parameters of the model which would allow a good replication of the modelling in other districts of the city.
- Data form monitoring is not available, but results of the modelling of the energy demand/consumption of the buildings of the city are available and theoretical values of the main modelling parameters particularized for the city are available. This situation would allow a reasonable adjustment of the main parameters of the model. This situation would be more

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

reasonable for the initial analysis of large areas for which more detailed analysis of each building is not possible.

More situations would be possible depending on each of the case study evaluated. In any case, the most relevant is to describe in a transparent way the information used for the modelling and for the calibration of the model describing in detail the hypothesis that have been adopted in each case. This will allow to replicate the analysis in other studies and will allow a good understanding of the accuracy of the results provided with the modelling.

In the following sections both the aspects considered in the sensitivity analysis phase and the information considered for the adjustment of the energy models are described for each of the districts evaluated.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

6. Energy modelling analysis: Case studies

6.1 Case study description for the three lighthouse cities

This section includes the description of the districts selected by each lighthouse cities as the case studies for the energy demand analysis. The selection has been done taking into account the specific interests of each city and also taking into account that the district evaluated is interesting for this type of analysis which aims to serve also as an initial point for the evaluation of the replication potential of this analysis in other areas of the city and in the follower cities of the project.

6.1.1 Nantes area of study

The area selected by Nantes Metropole is the Isle of Nantes. With a total area of 4.6 Km2, the Isle of Nantes is composed by a wide variety of building typologies both in terms of the age of each building and in terms the use of the buildings. The table below shows the detailed disaggregation of the buildings included within the boundaries of the Isle which has an approximate building area 1.8 Million of square meters.

Table 28: Building area of the Isle of Nantes by building type and age.

Gros Floor Area (m^2)	Pre-1914	1915-1939	1940-1975	1976-1981	1982-1989	1990-1999	Post-2000	Total	%
Residential	72552	21987	250745	23231	153285	139126	400413	1061338	58%
Office	612	868	21211	32583	34347	98001	290548	478170	26%
Sport	0	0	45707	0	0	0	10998	56705	3%
Education	0	0	5497	30238	0	10126	39623	85485	5%
Commerce	552	128	4948	0	1412	47543	3141	57724	3%
Hotel	0	0	444	0	62023	0	9355	71823	4%
Restaurant	0	0	0	0	0	713	831	1545	0%
Health care	0	0	0	0	3574	0	0	3574	0%
Total	**73717**	**22983**	**328552**	**86052**	**254640**	**295509**	**754911**	**1816363**	**100%**

It is observed that according to the information available in the cadastre of the city and according also the assumptions done by the city experts for these buildings with no data, more than the 40% of the built area corresponds to buildings constructed after the year 2000, 16% to buildings between 1990 and 1999, 14% to buildings between 1982 and 1989, 18% to buildings between 1949 and 1975, 5% to buildings between 1976 and 1981 and the rest to buildings constructed before 1939. Besides, as it is also shown in the figure below the most common building use is the residential (58%) followed by the offices (26%). Other uses such as the sport, education commerce and hotels have a lower presence (between 3% and 5% each). In the figure below, it can be observed that there is a relevant part of the area of study covered by industrial buildings (in white). The industry is in this case out of the scope of the study since the energy use of industrial buildings can vary a lot depending on their specific activity and this is not covered by the model used.

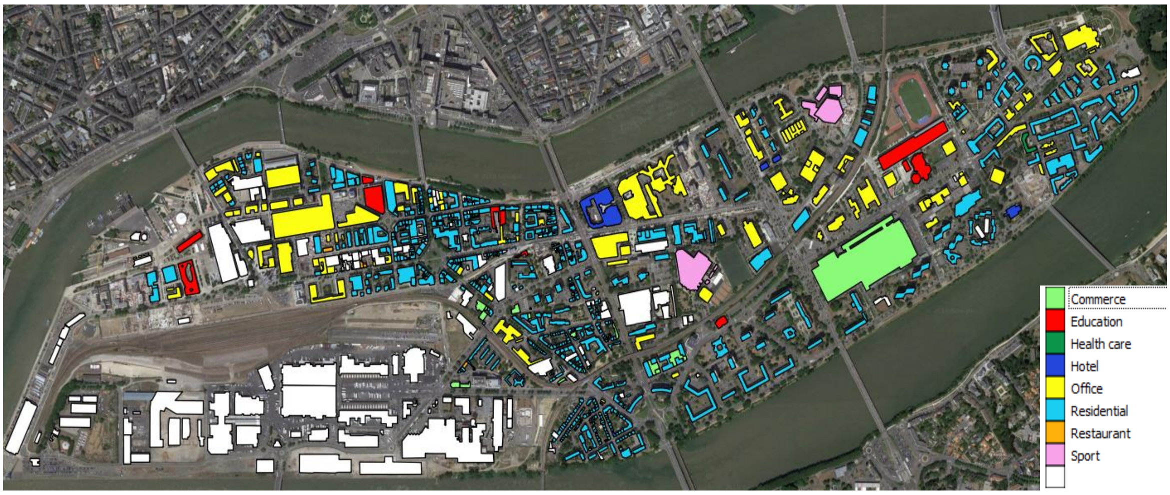

Figure 32: Different building uses of the built area of the Isle of Nantes.

Evaluating not only the built area but also the number of buildings of the Isle of Nantes, there is a total of 737 buildings (excluding the industrial buildings) from which the 78% are residential buildings and the 15% office buildings. The disaggregation of the amount of buildings by use and by age is showed in the figure below.

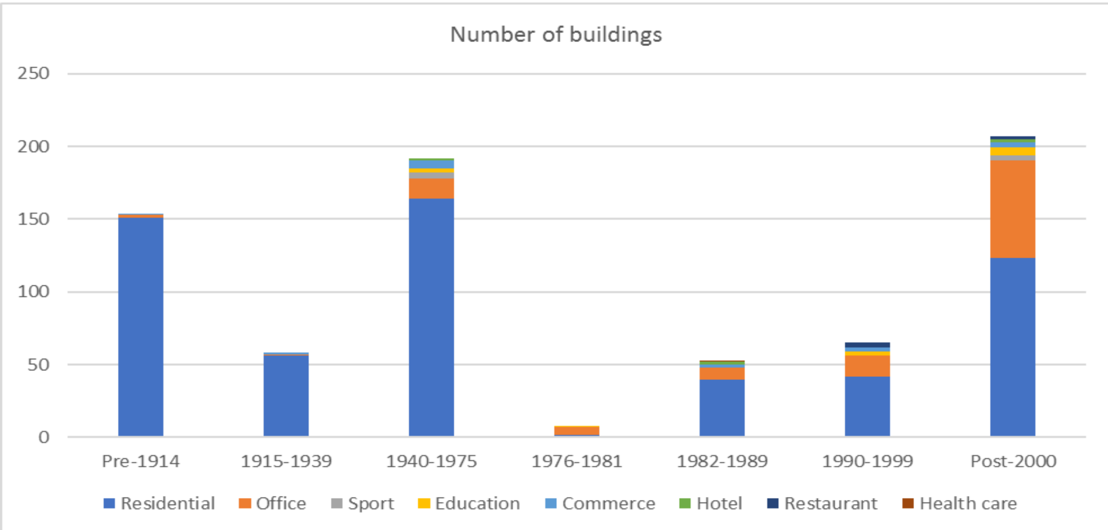

Figure 33: Number of buildings of the Isle of Nantes by use and age.

6.1.2 Hamburg area of study

The area selected by the city of Hamburg is located in Bergedorf. With a total area of 3.3 Km2, the area selected for the analysis combines also different building typologies and uses. The table below shows the detailed disaggregation of the buildings included within the boundaries of the district which has an approximate building area 376.346 square meters.

Table 29: Building area of the case study of Bergedorf by building type and age.

Gros Floor Area (m^2)	Pre-1859	1860-1918	1919-1957	1958-1978	1979-1994	1995-2001	Post-2002	Total	
Residential	1377	11136	41140	28824	53834	139981	19581	295872	79%
Office	5479	0	693	3398	1158	5386	3950	20064	5%
Education	0	0	11689	380	0	67	0	12135	3%
Health care	0	0	0	0	0	0	0	0	0%
Commerce	0	396	7820	21200	0	332	378	30126	8%
Hotel	0	0	829	0	0	10688	0	11517	3%
Public administration	268	0	2020	167	0	69	0	2524	1%
Sport	0	2685	0	0	0	0	0	2685	1%
Restaurant	0	0	824	69	0	529	0	1422	0%
Total	**7124**	**14216**	**65015**	**54039**	**54992**	**157052**	**23908**	**376346**	**100%**

According to the information available in the cadastre of the city, most of the buildings were constructed between 1919 and 1957 and between 1995 and 2001. Besides, as is also shown in the figure below the most common building use is the residential (83%) followed by commerce (5%) and offices (4%). Other uses such as the education, public administration and restaurants have a lower presence.

Figure 34: Different building uses of the built area of the district selected for Hamburg.

There are more than 500 buildings that are evaluated in the area of study. Residential buildings (83%), commercial buildings (5%), office buildings (4%), public buildings (3%) and the rest corresponds to hotels, education and restaurants. The disaggregation of the amount of buildings by use and by age is showed in the figure below.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

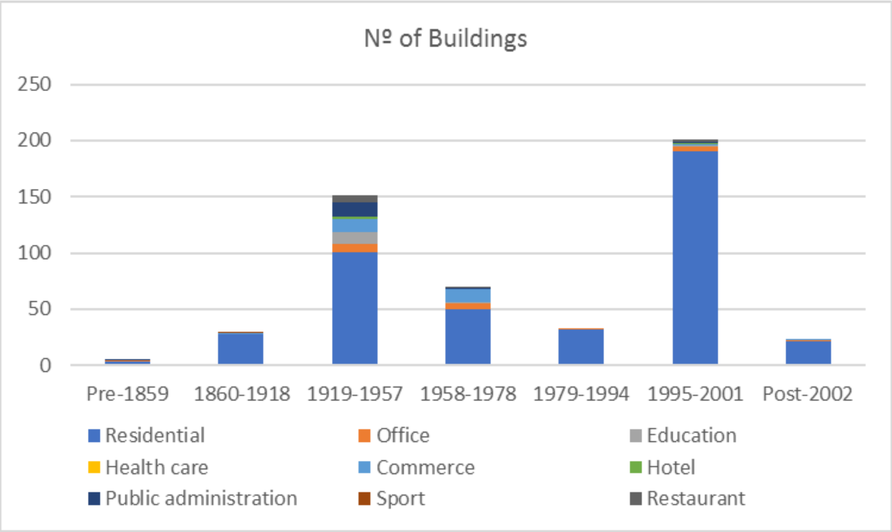

Figure 35: Number of buildings of the Isle of Nantes by use and age.

6.1.3 Helsinki area of study

In the case of Helsinki, the selected area corresponds to Merihaka. In this case the case study has a much lower area than in the case of the other two cities. However, at the moment of the study it is relevant area for the municipality and also complies with the minimum requisites in terms of building typologies for the analysis. The district has an approximated area of more than 80.000m^2 in which the considered heated building are sums 162.528 m^2 (Considering all the heated area in all the floors of the buildings).

The table below shows the detailed disaggregation of the buildings included within the boundaries of the district.

Table 30: Building area of the area of study of Merihaka by building type and age.

Gros Floor Area (m^2)	Pre-1975	1975-1978	1979-1985	1986-2003	Post-2010	Total	%
Residential	37358	16839	41276	0	0	95472	59%
Oher uses (tertiary)	0	0	19729	7850	309	27887	17%
Commerce	16875	22293	0	0	0	39168	24%
Total	**54233**	**39132**	**61004**	**7850**	**309**	**162528**	**100%**

The most relevant part of the built area corresponds to the residential buildings which represent the 59% of the total heated surface followed by the commercial buildings and by tertiary buildings with other uses. Besides, all the residential buildings were constructed before 1985 and the commerce buildings before 1978.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

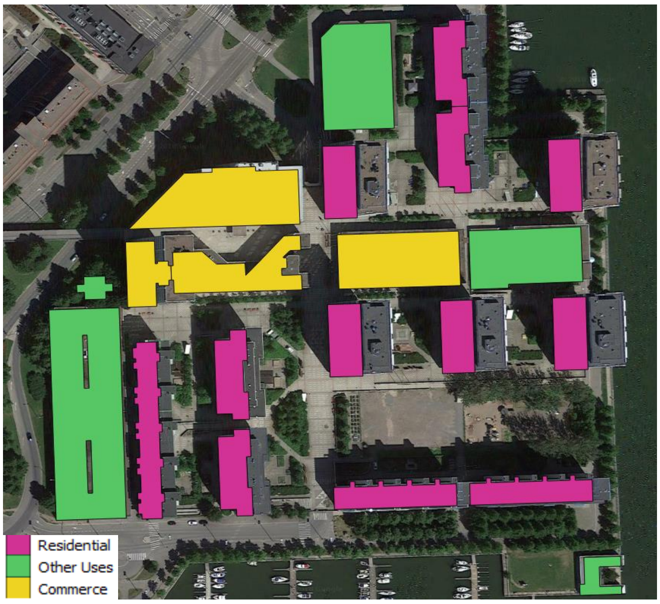

Figure 36: Different building uses of the built area of the district selected for Helsinki.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

6.2 Energy modelling and sensitivity analysis results

6.2.1 Sensitivity analysis

Following the procedure described in the section 5.3.1 a sensitivity analysis has been carried out for each of the districts evaluated in each city. The main results of this sensitivity analysis are showed in this section for the three lighthouse cities. As described above the analysis has been done for the following nine parameters of the model: Window to wall ratio (WWR), U-values (U), Air change per hours (ACH), Base temperature (BT), Schedule (SCH), Internal gains (IG), Solar gains (SG), Summer/winter period (SWP), and Outdoor temperature (OT). The variations considered in the analysis for the three cities are the followings: ± 1 ºC for the heating and cooling base temperature; ± 1 month for the summer winter period; ± 2 hours for the heating and cooling schedule; ±15% for the rest of the parameters mentioned above.

The sensitivity analysis has been carried out for the energy model developed which includes all the buildings of each district evaluated and not only for individual buildings. This means that different buildings are simultaneously considered in the analysis depending their use, but also depending their construction period or their shape factor. This is a relevant aspect since in many sensitivity analysis studies applied to building energy modelling, individual buildings are evaluated separately in different locations or in different conditions in order to understand effects such as influence of the climatic zone in the results. This provides a good understanding of the replication potential of the analysis under different conditions. However, in this case this is not the main aim of the sensitivity analysis. In this study, other various aspects apart from the location, aspects such as the heterogeneity in the uses and ages included in each district evaluated has a great importance in the final energy demand results. This is the reason why the influence of the critical parameters is evaluated respect to the energy demands of all the buildings with the same use. This aspect increases the difficulty for the interpretation of the results of the analysis but also provides a good overview of the overall influence of the correct definition of each parameter in the modelling of the district. This is in line with the general philosophy of the quick energy modelling at district scale which aims to serve to provide reasonable values for the energy demands of the district in a way that it allows the identification of the potential interventions that can be implemented in the district.

The results obtained for the sensitivity analysis are shown in the figures below using the Influence Coefficient (IC) in absolute values calculated for the heating and the cooling demand, distinguishing between the residential and the tertiary (in this case represented by office buildings) building uses. In all the cases the highest value obtained for the IC is shown for each parameter.

The results are represented in two figures for all the districts and cities evaluated.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

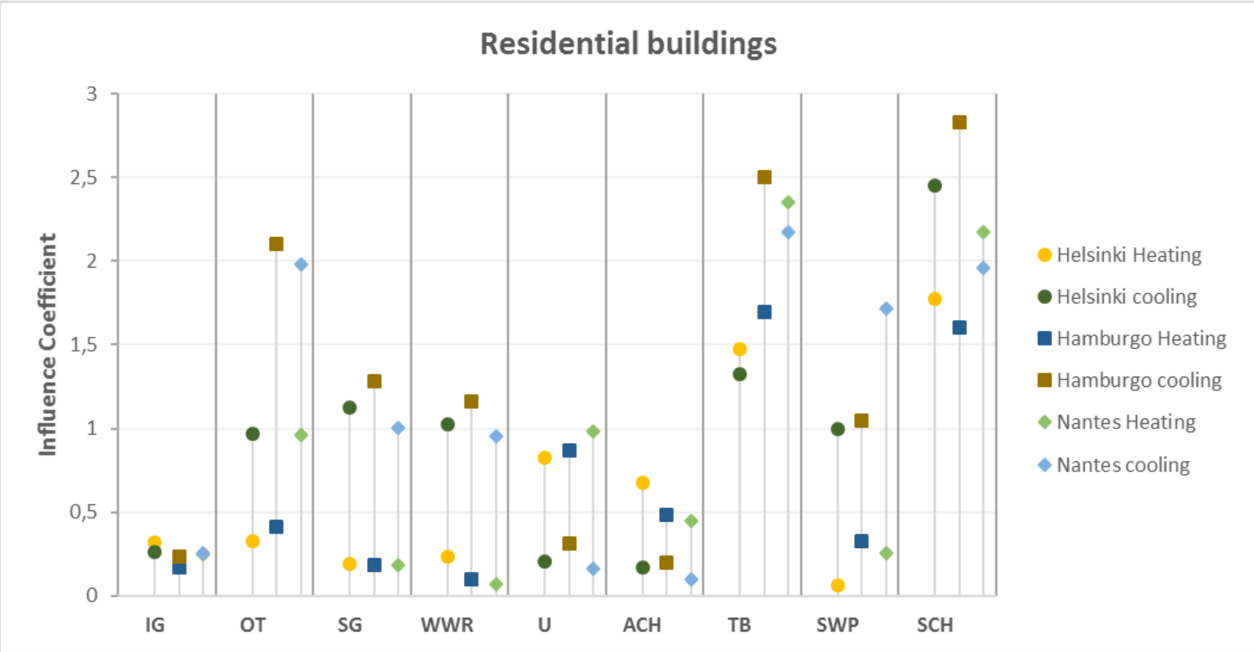

Figure 37: Influence Coefficient results for the critical parameters evaluated for the residential buildings of the three districts evaluated in the Lighthouse Cities of mySMARTLife project.

Figure 37 shows the results of the IC respect to the heating and the cooling demands for the residential buildings of the districts evaluated in the three lighthouse cities. Results show that for the heating demand of residential buildings, no large discrepancies are observed between the case studies except for the Base Temperature, the Outdoor temperature and the Schedule. Furthermore, it is shown that the parameters with the greatest influence for the heating demand are the Base Temperature, the Schedule and the U values.

The accurate definition of the outdoor temperature in the district energy model has a great influence in the results obtained for the residential buildings of the district. Moreover, it is observed that its influence increases as increases its value. The same tendency is observed for the Base Temperature with IC values of 1.4 for Helsinki, 1.69 for Hamburg, and 2.35 for Nantes. The main reason for this effect is that the U value of the buildings decreases (improves) till very good thermal transmittance levels in the districts of Hamburg and Helsinki in comparison to the districts of Nantes.

In the case of the ACH, the opposite effect is identified. The losses from ventilation increase in the cases that the outside temperature is lower. And therefore, its influence is higher.

Regarding the influence of the correct definition of the Summer/Winter period, it is observed that a greater influence is obtained in the cooling demand of Nantes respect to the case of Helsinki and Hamburg.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

The Base Temperature and the Schedule are the parameters with the greatest influence in both the heating and the cooling demands. However, in the case of the Schedule, it is not easy to relate its tendency directly to any climatic parameter since in this case there are many factors that can affect both to the heating and the cooling demand, which provokes a non-linear relationship that is difficult to predict.

The influence of the U values on the other hand, is very similar for all the case studies since the required thermal transmittance values of the envelope of the buildings are higher in areas with severe climatic conditions.

With regards to the cooling demand, the parameters that have the greatest influence are the Schedule and the Base Temperature. However, in contrast to the case of heating, the third place is for the Outside Temperature.

The influence of varying the outside temperature is lower in the district of Helsinki due to the low U values. In the case of Hamburg and Nantes on the other hand, it is observed a similar influence, since the lower average annual temperatures of Hamburg respect to the case of Nantes are compensated by the lower U values of its buildings. The same tendency is also observed for the base temperature in which the results follow a very similar distribution between the different case studies.

It can be also observed that the Solar Gains and the WWR are very linked, and their influence is practically the same in each case study.

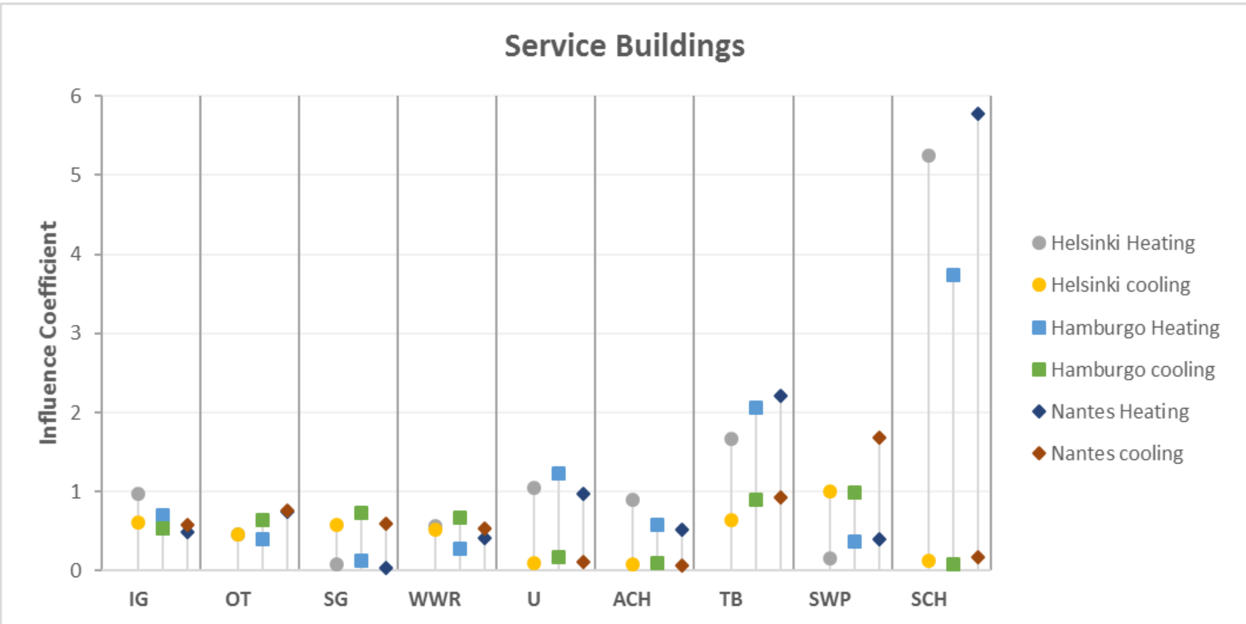

Figure 38: Influence Coefficient results for the critical parameters evaluated for the service buildings of the three districts evaluated in the Lighthouse Cities of mySMARTLife project.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

The results obtained for the service buildings are presented in the Figure 38. Similar tendencies can be observed compared to the residential buildings when observing the IC results for each parameter for heating demand. The parameter with the higher influence is the Schedule followed by the Base Temperature and the U values.

However, for the cooling demand the variation introduced in the Schedule has a reduced influence. This is precisely the main difference respect to the residential buildings. The main reason is that the variation introduced in the schedule of office buildings mainly affects to the first and the last hours of the working days when the internal loads related to lighting, occupancy, and equipment are very low.

6.3 Adjustment of the energy models

6.3.1 Nantes area of study

In the case of Nantes, the information that has been used for the adjustment of the model has different origins. The existing building energy consumption data in the city has been combined with the results of a literature review related to the main characteristics of the modelling parameters for France.

The information provided by Nantes Metropole is the following (all data sets georeferenced and according to the data protection requisites);

- "Chaleur_ERENA_Sous_Station": Energy consumption data from the district heating network for the Ile of Nantes.
- "Electricite_ENEDIS_2011-2015_Adresse": Electricity consumption data for the Ile of Nantes for the years between 2011 and 2015. The information is provided by address and corresponding building use.
- "Gaz_GRDF_2016_Adresse_et_Iris": Gas consumption data for the Ile of Nantes for the years between 2011 and 2015. The information is provided by address and corresponding building use.

All this information has been included in the shape file and can be visualized in the Figure 39 where gas consumptions are represented with blue points, electricity consumptions are represented with green points and district heating consumptions are represented with orange points.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Figure 39: Energy consumption information used for the adjustment of the energy model of the Ile of Nantes. Gas consumptions in blue, electricity consumptions in green and district heating consumptions in orange.

The information facilitated by the city has resulted essential for the calibration of the model. However, it is necessary to understand that this information cannot be directly used to compare the results obtained with the model since in some cases the correspondence of each information point does not correspond to any specific building and in some other cases one point corresponds to more than one building without specifying this correspondence. Besides, in some cases the energy consumption data is provided for a specific area of buildings that does not correspond with the area measured by the 3D modelling as described above. Nevertheless, a selection of the most reliable data has been carried out and the results of the model has been compared respect this data set.

Taking this into account the main parameters of the model that are more susceptible to be adjusted using the information mentioned above are described in the tables below.

Table 31: Thermal transmittance values of the different construction solutions of the building envelope and the considered air changes per hour (ACH)

U values [11]	Pre-1914	1915-1939	1940-1975	1976-1981	1982-1989	1990-1999	Post-2000
Roof	2,50	2,50	2,40	1,10	1,10	0,60	0,27
Wall	1,89	2,09	2,80	1,80	1,80	0,65	0,29
Window	4,19	4,19	4,19	2,80	2,80	1,20	1,53
ACH [6]	1,2	1,2	1,2	0,9	0,9	0,8	0,7

Other parameters adjusted respect to the initial modelling, in this case related to the internal gains, window to wall ratio (WWR) and the domestic hot water demand are described in the table below.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Table 32: Main parameters adjusted in the district energy model according to the building use.

Modelling characteristics	Residential	Hotel	Health care	Education	Office	Commerce	Restaurant	Sport	Public adm.
Equipment internal gains [W/m2] [12]	4,40	3,15	3,58	4,70	11,77	5,20	18,88	16,02	5,48
Occupancy internal gains [W/m2] [12]	1,76	4,72	7,33	29,82	7,05	8,18	11,00	25,50	5,94
Lighting power [W/m2] [12]	6,46	10,76	13,02	10,66	15,00	15,07	9,69	10,76	9,69
WWR [13]–[17]	0,27	0,17	0,23	0,28	0,50	0,20	0,30	0,20	0,50
Annual DHW demand [Kwh/m^2] [18]	13,90	126,40	133,40	57,20	3,20	3,20	35,30	256,00	3,20

Apart from these parameters, the base temperature for heating and cooling has been set in 21ºC and 25ºC respectively, the summer period has been defined from June 1 to September 30 [19], the solar gains have been obtained from reference building simulated in Design Builder dynamic energy modelling software under the climatic conditions of Nantes. The rest of the climatic conditions such as the outside temperatures have also been obtained from the database of the Design Builder software.

Finally, the summary of all the schedules used for each building use are described in the Table 42.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Table 33: Schedules used for the modelling of the Ile of Nantes (According to the database of Design Builder).

	Heating	Cooling	Occupancy	Lighting	Equipment
Residential	Winter: Until: 07:00, 0; Until: 23:00, 1; Until: 24:00, 0;	Summer: Until: 15:00, 0; Until: 23:00, 1; Until: 24:00, 0;	Until: 07:00, 1; Until: 08:00, 0.5; Until: 15:00, 0.25; Until: 23:00, 0.5; Until: 24:00, 1	Until: 07:00, 0.1; Until: 18:00, 0.3; Until: 19:00, 0.5; Until: 23:00, 1; Until: 24:00, 0	Until: 07:00, 0.1; Until: 18:00, 0.3; Until: 19:00, 0.5; Until: 23:00, 1; Until: 24:00, 0
	Summer: Until: 24:00, 0.	Winter: Until: 24:00, 0.			
Hotel	Winter: Until: 24:00, 1	Summer: Until: 24:00, 1	Until: 08:00, 1; Until: 09:00, 0.25; Until: 21:00, 0; Until: 22:00, 0.25; Until: 23:00, 0.75; Until: 24:00, 1	Until: 08:00, 0; Until: 09:00, 1; Until: 21:00, 0; Until: 24:00, 1	Until: 07:00, 0; Until: 08:00, 0.53; Until: 09:00, 1; Until: 10:00, 0.53; Until: 17:00, 0; Until: 18:00, 0.3; Until: 19:00, 0.53; Until: 20:00, 0.77; Until: 22:00, 1; Until: 23:00, 0.77; Until: 24:00, 0.3
	Summer: Until: 24:00, 0	Winter: Until: 24:00, 0			
	Summer: Until: 24:00, 0	Winter: Until: 24:00, 0			
Education	Winter: Until: 05:00, 0; Until: 18:00, 1; Until: 24:00, 0;	Summer: Until: 05:00, 0; Until: 18:00, 1; Until: 24:00, 0;	Until: 07:00, 0; Until: 08:00, 0.1; Until: 09:00, 0.25; Until: 10:00, 0.75; Until: 12:00, 1; Until: 14:00, 0.5; Until: 16:00, 1; Until: 18:00, 0.5; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; Until: 19:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; 21:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0
	Summer, weekends and holidays: Until 24:00: 0	Winter, weekends and holidays: Until 24:00: 0			
Office	Winter: Until: 05:00, 0; Until: 19:00, 1; Until: 24:00, 0;	Summer: Until: 05:00, 0; Until: 19:00, 1; Until: 24:00, 0;	Until: 07:00, 0; Until: 08:00, 0.25; Until: 09:00, 0.5; Until: 12:00, 1; Until: 14:00, 0.75; Until: 17:00, 1; Until: 18:00, 0.5; Until: 19:00, 0.25; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; Until: 19:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; 20:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0
	Summer, weekends and holidays: Until 24:00: 0	Winter, weekends and holidays: Until 24:00: 0			
Commerce	Winter: Until: 07:00, 0; Until: 18:00, 1; Until: 24:00, 0;	Summer: Until: 07:00, 0; Until: 18:00, 1; Until: 24:00, 0;	Until: 09:00, 0; Until: 10:00, 0.75; Until: 12:00, 1; Until: 14:00, 0.75; Until: 17:00, 1; Until: 18:00, 0.75; Until: 24:00, 0; Sundays and holidays: Until 24:00: 0	Until: 09:00, 0; Until: 18:00, 1; Until: 24:00, 0; Sundays and holidays: Until 24:00: 0	Until: 08:00, 0; 18:00, 1; Until: 24:00, 0; Sundays and holidays: Until 24:00: 0
	Summer, Sundays and holidays: Until 24:00: 0	Winter, Sundays and holidays: Until 24:00: 0			
Public adm.	Winter: Until: 05:00, 0; Until: 19:00, 1; Until: 24:00, 0;	Summer: Until: 05:00, 0; Until: 19:00, 1; Until: 24:00, 0;	Until: 07:00, 0; Until: 08:00, 0.25; Until: 09:00, 0.5; Until: 12:00, 1; Until: 14:00, 0.75; Until: 17:00, 1; Until: 18:00, 0.5; Until: 19:00, 0.25; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; Until: 19:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; 18:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0
	Summer, weekends and holidays: Until 24:00: 0	Winter, weekends and holidays: Until 24:00: 0			
	Summer and holidays: Until 24:00: 0	Winter and holidays: Until 24:00: 0			
Sport	Winter: Until: 05:00, 0; Until: 21:00, 1; Until: 24:00, 0;	Summer: Until: 05:00, 0; Until: 21:00, 1; Until: 24:00, 0;	Until: 06:00, 0; Until: 07:00, 0.25; Until: 09:00, 1; Until: 12:00, 1; Until: 14:00, 0.5; Until: 18:00, 0.5; Until: 20:00, 1; Until: 22:00, 0.5; Until: 24:00, 0	Until: 06:00, 0; Until: 22:00, 1; Until: 24:00, 0	Until: 06:00, 0; Until: 22:00, 1; Until: 24:00, 0
	Summer and holidays: Until 24:00: 0	Winter and holidays: Until 24:00: 0			

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

<u>Conclusions of the adjustment phase:</u>

Once that the parameters of the district energy model are adjusted according the description above, the results obtained are compared with the information that is available. As a first step, the energy intensities obtained per square meter for the residential heating demand are compared respect to actual heating demands monitored for some buildings in Paris [11]. This comparison is interesting because the energy demands can be compared by building age according to the period described in the table below. Results show that the tendencies in both cases are similar for each building age periods. Evidently there are some differences in the absolute values due to the differences in the climatic conditions between Nantes and Paris.

Table 34: Comparison of the residential heating demand by building ages between real data for Paris and the mySMARTLife modelling results for Nantes.

	Heating demand (kWh/m^2)	
Building ages	Nantes modelled	Paris
Pre-1914	169	131
1915-1939	176	145
1940-1975	154	157
1976-1981	71	90
1982-1989	82	77
1990-1999	26	39
Post-2000	17	-

In a second stage the modelling results are compared respect to the real data provided by the municipality. As explained before, not all the information available is comparable since in some cases the building area corresponding to these consumptions is not clear or does not correspond exactly with the measured areas from the City GML file. Therefore, although the data available is real data, the obtained difference need to be correctly interpreted. For those cases in which the difference of between the provided area and the measured area is very high have not been considered during the calibration phase because they cannot be considered as representative.

The Figure 40 shows the differences obtained between the modelling results and the measured gas consumptions for the residential buildings. Five buildings have been compared and the observed differences in most cases are below 5% and other two between 10% and 20%.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

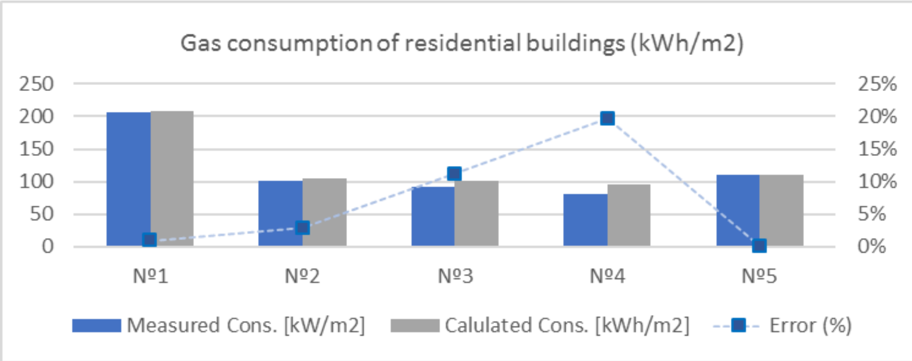

Figure 40: Comparison between the measured gas consumptions and the mySMARTLife modelling results for residential buildings.

The Figure 41 on the other hand shows the differences obtained between the modelling results and the measured electricity consumptions for the residential buildings. Thirteen buildings have been compared in this case and the observed differences in most cases are between 5%-10% and other buildings between 15% and 27%. In the last cases, the differences come from the existing discrepancies between the assumed area of the buildings (the number of clients has also been considered in this case as it can be observed in the Table 35) and the calculated with the City GML of the city.

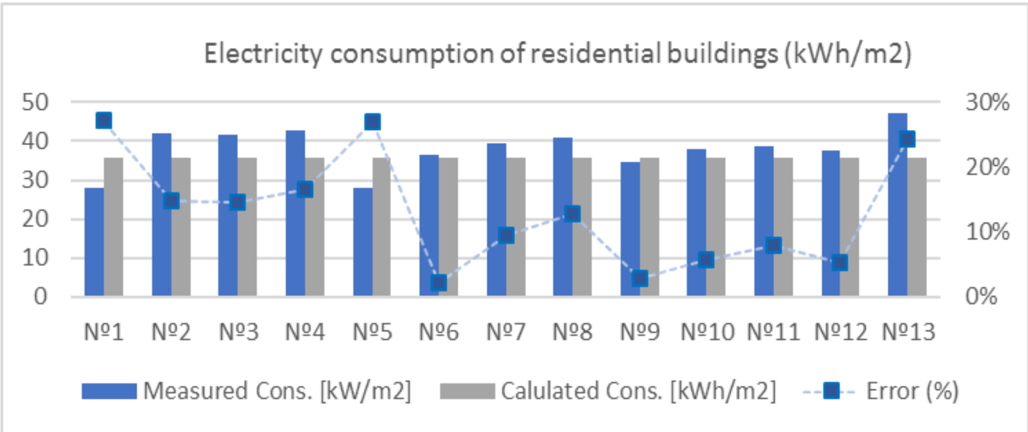

Figure 41: Comparison between the measured electricity consumptions and the mySMARTLife modelling results for residential buildings.

The cases compared represent the main part of the cases of the building tipologies covered different building ares as it can be seeen the Table 35. In buildings with the service use on the other hand, the comparison of the electricity consumption was possible only for only three buildings and the observed differences are between 4% and 16%.

Table 35: Comparison of the measured residential electricity consumption and the mySMARTLife modelling results.

Building ID	Age	N. of clients	Real Cons. [Kwh/m^2]	Difference respect to the modelling results
Nº1	1972	115	28,08	**27%**
Nº2	1935	34	41,87	**15%**
Nº3	2008	18	41,73	**14%**
Nº4	2008	20	42,72	**16%**
Nº5	1974	106	28,07	**27%**
Nº6	1870	15	36,44	**2%**
Nº7	1982	34	39,37	**9%**
Nº8	1940	14	40,91	**13%**
Nº9	1900	19	34,67	**3%**
Nº10	1955	16	37,86	**6%**
Nº11	1870	13	38,76	**8%**
Nº12	1955	101	37,69	**5%**
Nº13	2009	88	47,07	**24%**

Finally, the information provided for the buildings connected to the district heating network has been also used. The Figure 42 shows the comparison for the residential and service or tertiary buildings. The results show that lower differences (16% average) are obtained in the case of the service buildings in comparison with the results of the residential buildings (50% average). The main reason is that the information available is related to the substations of the district heating that in some cases can correspond with specific individual large tertiary buildings, but in the case of the residential buildings can correspond to more than one building block which makes difficult to use the exact heated area.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

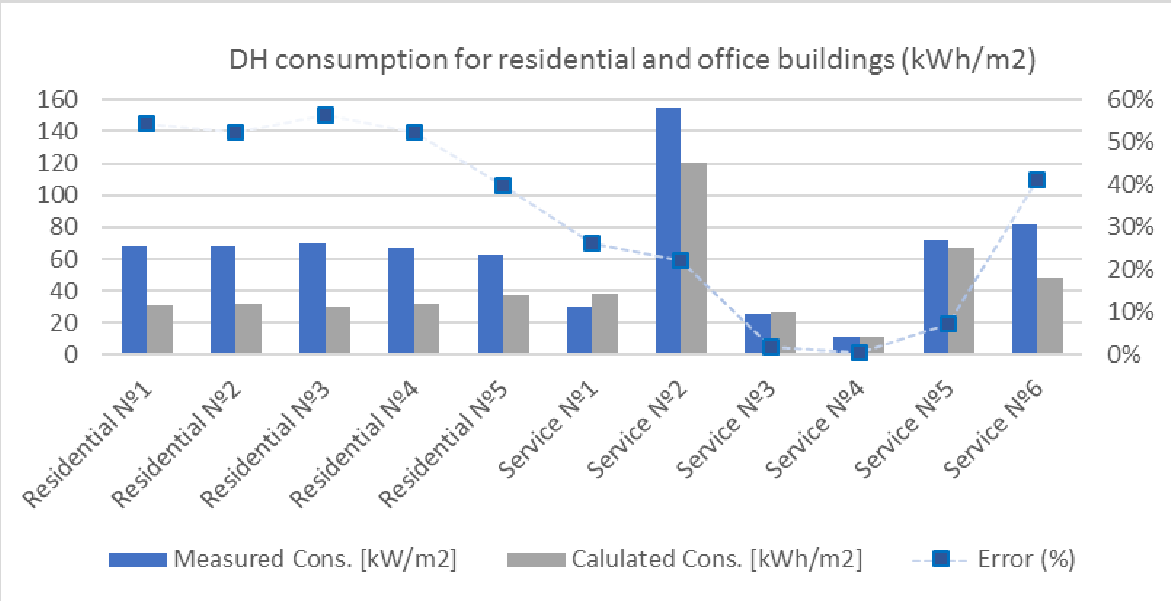

Figure 42: Comparison between the measured heat consumption and the mySMARTLife modelling results for buildings connected to the district heating network.

6.3.2 Hamburg area of study

In the case of Hamburg, the information that has been used for the adjustment of the model has different origins. The existing building energy consumption data in the city has been combined with the results of a literature review related to the main characteristics of the modelling parameters for Hamburg. More precisely the main information used has been obtained from the heat cadastre of Hamburg (Wärmekataster) [20] which provides the aggregated values of the heat and domestic hot water demands of the city. For the area evaluated the heat cadastre provides these values divided in 41 groups. This information is useful for the calibration of the model. However, it is necessary to highlight that it needs to be carefully used to compare the results obtained with the mySMARTLife modelling since this information is provided much more aggregated and in some cases the corresponding area provided for each energy demand data does not correspond correctly with the areas measured from the city GML of the city.

Taking this into account the main parameters of the model that are more susceptible to be adjusted using the information mentioned above are described in the tables below.

Table 36: Thermal transmittance values of the different construction solutions of the building envelope and the considered air changes per hour (ACH).

U values [21]	Pre-1859	1860-1918	1919-1957	1958-1978	1979-1994	1995-2001	Post-2002
Roof	1,90	1,90	1,20	1,10	0,35	0,20	0,20
Wall	1,80	1,80	1,10	1,03	0,68	0,40	0,40
Window	3,20	3,20	2,70	2,85	2,80	1,60	1,60
ACH [5]	0,6	0,6	0,6	0,6	0,6	0,6	0,6

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Other parameters adjusted respect to the initial modelling, in this case related to the internal gains, window to wall ratio (WWR) and the domestic hot water demand are described in the table below.

Table 37: Main parameters adjusted in the district energy model according to the building use.

Modelling characteristics	Residential	Hotel	Health care	Education	Office	Commerce	Restaurant	Sport	Public adm.
Equipment internal gains [W/m2] [12]	4,40	3,15	3,58	4,70	11,77	5,20	18,88	16,02	5,48
Occupancy internal gains [W/m2] [12]	1,76	4,72	7,33	29,82	7,05	8,18	11,00	25,50	5,94
Lighting power [W/m2] [12]	6,46	10,76	13,02	10,66	12,00	15,07	9,69	10,76	9,69
WWR*	0,27	0,17	0,23	0,28	0,50	0,20	0,30	0,20	0,50
Annual DHW demand [kWh/m^2]	47,70	3,20	133,40	57,20	3,20	126,40	256,00	35,30	3,20

*Same references as Nantes and Helsinki tables

Apart of these parameters, the base temperature for heating and cooling has been set in 21ºC and 25ºC respectively, the summer period has been defined from May 1 to August 31 [19], the solar gains have been obtained from reference building of Hamburg. The rest of the climatic conditions such as the outside temperatures have also been obtained from the database of the Design Builder software.

Finally, the summary of all the schedules used for each building use are described in the

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Table 38.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Table 38: Schedules used for the modelling of the Ile of Hamburg (According to the database of Design Builder).

	Heating	Cooling	Occupancy	Lighting	Equipment
Residential	Winter: Until: 07:00, 0; Until: 23:00, 1; Until: 24:00, 0; Summer: Until: 24:00, 0.	Summer: Until: 15:00, 0; Until: 23:00, 1; Until: 24:00, 0; Winter: Until: 24:00, 0.	Until: 07:00, 1; Until: 15:00, 0.25; Until: 23:00, 0.5; Until: 24:00, 1	Until: 07:00, 0.1; Until: 18:00, 0.3; Until: 19:00, 0.5; Until: 23:00, 1; Until: 24:00, 0	Until: 07:00, 0.1; Until: 18:00, 0.3; Until: 19:00, 0.5; Until: 23:00, 1; Until: 24:00, 0
Hotel	Winter: Until: 24:00, 1 Summer: Until: 24:00, 0	Summer: Until: 24:00, 1 Winter: Until: 24:00, 0	Until: 08:00, 1; Until: 09:00, 0.25; Until: 21:00, 0; Until: 22:00, 0.25; Until: 23:00, 0.75; Until: 24:00, 1	Until: 08:00, 0; Until: 09:00, 1; Until: 21:00, 0; Until: 24:00, 1	Until: 07:00, 0; Until: 08:00, 0.53; Until: 09:00, 1; Until: 10:00, 0.53; Until: 17:00, 0; Until: 18:00, 0.3; Until: 19:00, 0.53; Until: 20:00, 0.77; Until: 22:00, 1; Until: 23:00, 0.77; Until: 24:00, 0.3
Health care	Winter: Until: 24:00, 1 Summer: Until: 24:00, 0	Summer: Until: 24:00, 1 Winter: Until: 24:00, 0	Until: 24:00, 1	Until: 07:00, 0; Until: 08:00, 0.5; Until: 09:00, 1; Until: 10:00, 0.5; Until: 17:00, 0; Until: 18:00, 0.25; Until: 19:00, 0.5; Until: 20:00, 0.75; Until: 22:00, 1; Until: 23:00, 0.75; Until: 24:00, 0.25	Until: 24:00, 1
Education	Winter: Until: 05:00, 0; Until: 18:00, 1; Until: 24:00, 0; Summer, weekends and holidays: Until 24:00: 0	Summer: Until: 05:00, 0; Until: 18:00, 1; Until: 24:00, 0; Winter, weekends and holidays: Until 24:00: 0	Until: 07:00, 0; Until: 08:00, 0.1; Until: 09:00, 0.25; Until: 10:00, 0.75; Until: 12:00, 1; Until: 14:00, 0.5; Until: 16:00, 1; Until: 18:00, 0.5; Until: 24:00, 0 ; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; Until: 19:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 07:00, 0; 21:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0
Office	Winter: Until: 06:00, 0; Until: 19:00, 1; Until: 24:00, 0; Summer, weekends and holidays: Until 24:00: 0	Summer: Until: 05:00, 0; Until: 19:00, 1; Until: 24:00, 0; Winter, weekends and holidays: Until 24:00: 0	Until: 08:00, 0; Until: 09:00, 0.5; Until: 10:00, 06; Until: 11:00, 0.7; Until: 12:00, 0.5; Until: 13:00, 0.6; Until: 14:00, 0.7; Until: 15:00, 0.8; Until: 16:00, 0.7; Until: 17:00, 0.4; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 08:00, 0; Until: 09:00, 0.5; Until: 10:00, 06; Until: 11:00, 0.7; Until: 12:00, 0.5; Until: 13:00, 0.6; Until: 14:00, 0.7; Until: 15:00, 0.8; Until: 16:00, 0.7; Until: 17:00, 0.4; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 08:00, 0; Until: 09:00, 0.5; Until: 10:00, 06; Until: 11:00, 0.7; Until: 12:00, 0.5; Until: 13:00, 0.6; Until: 14:00, 0.7; Until: 15:00, 0.8; Until: 16:00, 0.7; Until: 17:00, 0.4; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0
Commerce	Winter: Until: 07:00, 0; Until: 18:00, 1; Until: 24:00, 0; Summer, Sundays and holidays: Until 24:00: 0	Summer: Until: 07:00, 0; Until: 18:00, 1; Until: 24:00, 0; Winter, Sundays and holidays: Until 24:00: 0	Until: 09:00, 0; Until: 10:00, 0.75; Until: 12:00, 1; Until: 14:00, 0.75; Until: 17:00, 1; Until: 18:00, 0.75; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 09:00, 0; Until: 18:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 08:00, 0; 18:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0
Public adm.	Winter: Until: 06:00, 0; Until: 19:00, 1; Until: 24:00, 0; Summer, weekends and holidays: Until 24:00: 0	Summer: Until: 05:00, 0; Until: 19:00, 1; Until: 24:00, 0; Winter, weekends and holidays: Until 24:00: 0	Until: 08:00, 0; Until: 09:00, 0.5; Until: 10:00, 06; Until: 11:00, 0.7; Until: 12:00, 0.5; Until: 13:00, 0.6; Until: 14:00, 0.7; Until: 15:00, 0.8; Until: 16:00, 0.7; Until: 17:00, 0.4; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 08:00, 0; Until: 09:00, 0.5; Until: 10:00, 06; Until: 11:00, 0.7; Until: 12:00, 0.5; Until: 13:00, 0.6; Until: 14:00, 0.7; Until: 15:00, 0.8; Until: 16:00, 0.7; Until: 17:00, 0.4; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 08:00, 0; Until: 09:00, 0.5; Until: 10:00, 06; Until: 11:00, 0.7; Until: 12:00, 0.5; Until: 13:00, 0.6; Until: 14:00, 0.7; Until: 15:00, 0.8; Until: 16:00, 0.7; Until: 17:00, 0.4; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0
Restaurant	Winter: Until: 05:00, 0; Until: 23:00, 1; Until: 24:00, 0; Summer and holidays: Until 24:00: 0	Summer: Until: 05:00, 0; Until: 23:00, 1; Until: 24:00, 0; Winter and holidays: Until 24:00: 0	Until: 07:00, 0; Until: 09:00, 0.25; Until: 12:00, 0.5; Until: 14:00, 1; Until: 15:00, 0.5; Until: 18:00, 0.25; Until: 19:00, 0.5; Until: 22:00, 1; Until: 23:00, 0.5; Until: 24:00, 0	Until: 07:00, 0; Until: 23:00, 1; Until: 24:00, 0	Until: 07:00, 0; 23:00, 1; Until: 24:00, 0.34
Sport	Winter: Until: 06:00, 0; Until: 22:00, 1; Until: 24:00, 0; Summer and holidays: Until 24:00: 0	Summer: Until: 06:00, 0; Until: 22:00, 1; Until: 24:00, 0; Winter and holidays: Til 24:00: 0	Until: 06:00, 0; Until: 07:00, 0.25; Until: 09:00, 1; Until: 12:00, 1; Until: 14:00, 0.5; Until: 18:00, 0.5; Until: 20:00, 1; Until: 22:00, 0.5; Until: 24:00, 0	Until: 06:00, 0; Until: 22:00, 1; Until: 24:00, 0;	Until: 06:00, 0; Until: 22:00, 1; Until: 24:00, 0;

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Conclusions of the adjustment phase:

Once that the parameters of the district energy model have been adjusted according the values provided in the tables above, the results obtained have been compared with the information available.

First, the energy intensities obtained per square meter for the residential heating demand are compared respect to the values provided as a reference in Tabula [5] and ENTRANZE project [21]. This comparison is interesting because the energy demands can be compared by building age according to the period described in the table below.

Table 39: Reference energy demands considered for the comparison of residential buildings of Hamburg district.

Building age	mySMARTLife Modelling results					Values from Tabula		Values from ENTRANZE	
	Heating	Cooling	DHW	Equipment	Lighting	Heating	Difference	Heating	Difference
	[KWh/m²]	[KWh/m²]	[KWh/m²]	[KWh/m²]	[KWh/m²]	[KWh/m²]	%	[KWh/m²]	%
1860-1918	236	15	48	20	14	152	**55%**	-	-
1919-1957	150	15	48	20	14	149	**1%**	-	-
1958-1978	118	13	48	20	14	117	**0%**	-	-
1979-1994	67	12	48	20	14	106	37%	60	**11%**
1995-2001	55	19	48	20	14	91	40%	45	**22%**
Post-2002	36	14	48	20	14	69	47%	35	**3%**

Obtained results correspond well with the values obtained in other studies. The main difference is clearly achieved for those buildings constructed between 1860 and 1918. Lower values are provided in literature in the latter case. The reason can be that those buildings have been the subject of some refurbishment actions that have reduced their heating demands. In the rest of cases the obtained values are in line with the results obtained in the other two references. Low differences can be observed for the newest buildings respect to the ENTRANZE results (3%, 22%, and 11%) and very low differences also in the case of the older buildings respect to the values provided in Tabula (lower than 1%). It can be concluded that according to the existing literature the model results provide reasonable results for the heat demand intensities.

In a second stage the modelling results are compared respect to the data provided in the heat cadastre. As explained before, in some cases the building area corresponding to these heat demands does not correspond exactly with the measured areas from the City GML file. Therefore, although the data available is useful for the adjustment of the model, the obtained differences need to be correctly interpreted. In the cases in which the difference between the provided area in the heat cadastre and the measured area is very high, the difference observed in the heat demand is very high but cannot be considered as

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

representative for the adjustment phase. The figure below shows the heat demands provided in the heat cadastre for the district evaluated.

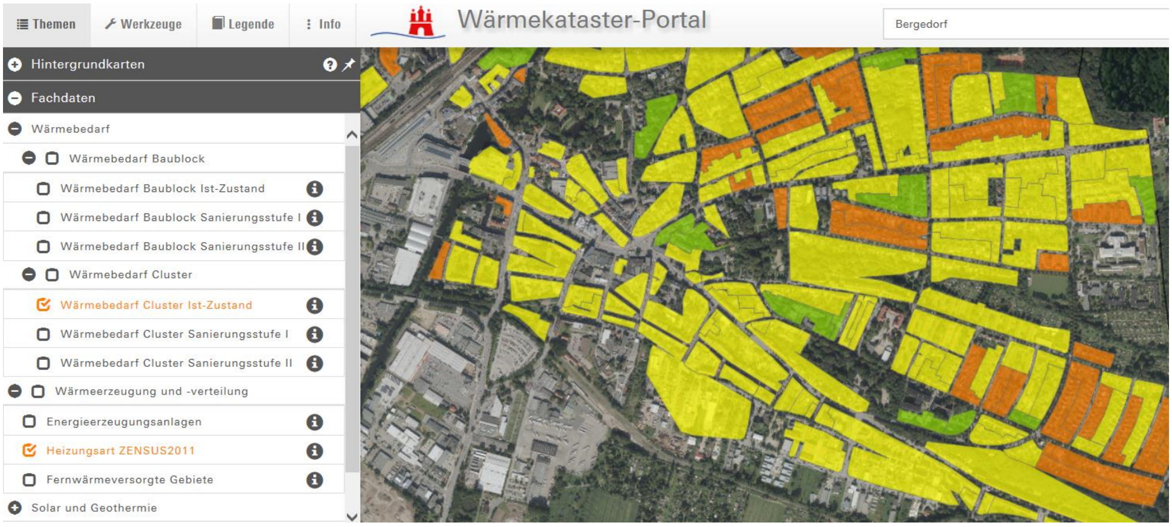

Figure 43: Wärmekataster-Portal of Hamburg. Heat and DHW demands for the case study (Bergedorf).

The differences obtained between the modelling results and the information provided by the heat cadastre of Hamburg are showed in the Figure 44. From the 41 building groups included in the heat cadastre for the district evaluated, 34 have showed a reasonable good correspondence with the area calculated from the City GML of Hamburg. For those cases, both the heat intensity and the percentage of the difference respect to the modelling results are included in the figure below. Results show that the average difference for all the groups evaluated is of 14%.

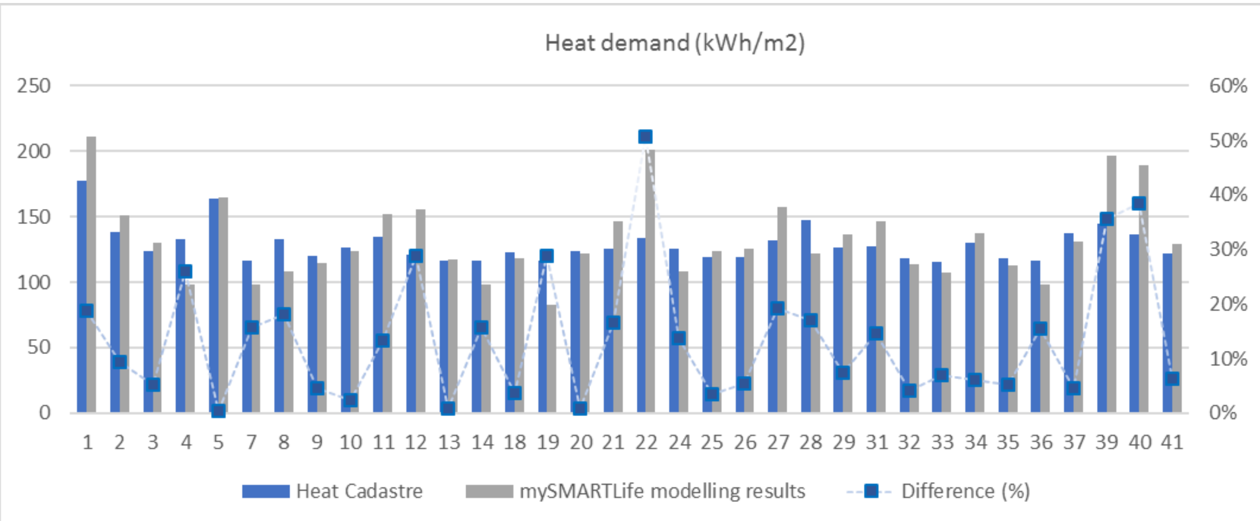

Figure 44: Comparison between the heat demand of the Hamburg heat cadastre and the mySMARTLife modelling results for the district evaluated.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

6.3.3 Helsinki area of study

In the case of Helsinki, the information used for the adjustment of the model has had different origins. The existing building energy consumption data available in the Energy and Climate Atlas of the Helsinki 3D Model (which combines estimations for most of the buildings and real measured data for city owned buildings) has been combined with the results of a literature review related to the main characteristics of the modelling parameters for Helsinki. From the literature review two main references have been considered for this phase the case 1 [22] [ref] and the case 2 [23]. Taking this into account the main parameters of the model that are more susceptible to be adjusted using the information mentioned above are described in the tables below.

Table 40: Thermal transmittance values of the different construction solutions of the building envelope and the considered air changes per hour (ACH)

U values*	Pre-1975	1975-1978	1979-1985	1986-2003	2004-2007	2008-2010	Post-2010
Roof	0,47	0,35	0,23	0,22	0,16	0,15	0,09
Wall	0,81	0,40	0,29	0,28	0,25	0,24	0,17
Window	3,14	3,10	2,10	2,10	1,40	1,40	1,00
ACH [6] *	0,9	0,9	0,6	0,6	0,5	0,5	0,5

*The marked values have been provided by local expert.

Other parameters adjusted respect to the initial modelling, in this case related to the internal gains, window to wall ratio (WWR) and the domestic hot water demand are described in the table below. The values are provided for all the building uses although there are not included in the area evaluated because one of the objectives is to scale ups this analysis to the entire city of Helsinki.

Table 41: Main parameters adjusted in the district energy model according to the building use.

Modelling characteristics	Residential	Hotel	Health care	Education	Office	Commerce	Restaurant	Sport	Public adm.
Equipment internal gains [W/m2]*	6,13	14,00	9,00	8,00	15,00	1,00	0,00	0,00	15,00
Occupancy internal gains [W/m2]*	1,76	4,72	7,33	29,82	7,05	8,18	11,00	25,50	5,94
Lighting power [W/m2]*	8,00	14,00	9,00	18,00	12,00	19,00	19,00	12,00	12,00
WWR [13]–[17]	0,27	0,17	0,23	0,28	0,50	0,20	0,30	0,20	0,50
Annual DHW demand [Kwh/m^2] [18] *****	40,00	3,20	133,40	57,20	3,20	126,40	256,00	35,30	5,98

*The marked values have been provided by local expert.

Besides, the base temperature for heating and cooling has been set in 21ºC and 27ºC respectively, the summer period has been defined from July 1 to August 30 [19], the solar gains have been obtained from reference building simulated in Design Builder dynamic energy modelling software under the climatic conditions of Helsinki. The outside temperature has been provided by Helsinki experts.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Table 42: Schedules used for the modelling of the district (Adapted according to values provided by Helsinki experts)

	Heating	Cooling	Occupancy	Lighting	Equipment
Residential	Winter: Until: 09:00, 1; Until: 16:00, 0; Until: 24:00, 1; Summer: Until: 24:00, 0.	Summer: Until: 09:00, 1; Until: 16:00, 0; Until: 24:00, 1 Winter: Until: 24:00, 0.	Until: 09:00, 1; Until: 16:00, 0; Until: 17:00, 0.25; Until: 18:00, 0.5; Until: 24:00, 1;	Until: 06:00, 0; Until: 9:00, 1; Until: 16:00, 0; Until: 23:00, 1; Until: 24:00, 0	Until: 07:00, 0.05; Until: 8:00, 0.96; Until: 17:00, 0.05; Until: 18:00, 0.21; Until: 19:00, 0.98; Until: 21:00, 0.96; Until: 22:00, 0.81; Until: 24:00, 0.05
Hotel	Winter: Until: 08:00, 1; Until: 21:00, 0; Until: 24:00, 1 Summer: Until: 24:00, 0	Summer: Until: 08:00, 1; Until: 21:00, 0; Until: 24:00, 1 Winter: Until: 24:00, 0	Until: 07:00, 0.5; Until: 08:00, .0.25; Until: 21:00, 0; Until: 23:00, 0.25; Until: 24:00, 0.5;	Until: 07:00, 0; Until: 09:00, 1; Until: 21:00, 0; Until: 23:00, 1; Until: 24:00, 0	Until: 07:00, 0.05; Until: 09:00, 1; Until: 21:00, 0.05; Until: 23:00, 1; Until: 24:00, 0.05
Hospital	Winter: Until: 24:00, 1 Summer: Until: 24:00, 0	Summer: Until: 24:00, 1 Winter: Until: 24:00, 0	Until: 24:00, 0.6	Until: 07:00, 0.1; Until: 23:00, 1; Until: 24:00, 0.1	Until: 07:00, 0.05; Until: 09:00, 1; Until: 18:00, 0.05; Until: 23:00, 1; Until: 24:00, 0.05
Education	Winter: Until: 08:00, 0; Until: 11:00, 1; Until: 12:00, 0; Until: 16:00, 1; Until: 24:00, 0; Summer, weekends and holidays: Until 24:00: 0	Summer: Until: 08:00, 0; Until: 11:00, 1; Until: 12:00, 0; Until: 16:00, 1; Until: 24:00, 0; Winter, weekends and holidays: Until 24:00: 0	Until: 08:00, 0; Until: 09:00, 0.5; Until: 11:00, 1; Until: 12:00, 0; Until: 13:00, 1; Until: 14:00, 0.5; Until: 15:00, 1; Until: 16:00, 0.5; Until: 24:00, 0 ; Weekends and holidays: Until 24:00: 0	Until: 08:00, 0; Until: 16:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 08:00, 0; Until: 09:00, 0.5; Until: 11:00, 1; Until: 12:00, 0; Until: 13:00, 0.5; Until: 14:00, 0.5; Until: 15:00, 1; Until: 16:00, 0.5; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0
Office	Winter: Until: 24:00, 1; Summer, weekends and holidays: Until 24:00: 0	Summer: Until: 08:00, 0; Until: 9:00, 1; Until: 24:00, 0; Winter, weekends and holidays: Until 24:00: 0	Until: 08:00, 0; Until: 09:00, 0.5; Until: 10:00, 06; Until: 11:00, 0.7; Until: 12:00, 0.5; Until: 13:00, 0.6; Until: 14:00, 0.7; Until: 15:00, 0.8; Until: 16:00, 0.7; Until: 17:00, 0.4; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 09:00, 0; Until: 18:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 08:00, 0; Until: 09:00, 0.5; Until: 10:00, 06; Until: 11:00, 0.7; Until: 12:00, 0.5; Until: 13:00, 0.6; Until: 14:00, 0.7; Until: 15:00, 0.8; Until: 16:00, 0.7; Until: 17:00, 0.4; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0
Commerce	Winter: Until: 08:00, 0; Until: 21:00, 1; Until: 24:00, 0; Weekends: Until: 12:00, 0; Until: 20:00, 1; Until: 24:00, 0; Summer and holidays: Until 24:00: 0	Summer: Until: 08:00, 0; Until: 21:00, 1; Until: 24:00, 0; Weekends: Until: 12:00, 0; Until: 20:00, 1; Until: 24:00, 0; Winter and holidays: Until 24:00: 0	Until: 08:00, 0; Until: 09:00, 0.1; Until: 11:00, 0.3; Until: 12:00, 0.7; Until: 13:00, 0.6; Until: 14:00, 0.5; Until: 16:00, 0.6; Until: 18:00, 0.9; Until: 19:00, 1; Until: 20:00, 0.9; Until: 21:00, 0.7; Until: 24:00, 0; Weekends: Until: 12:00, 0; Until: 21:00, 0.45; Until: 24:00, 0; Holidays: Until 24:00: 0	Until: 08:00, 0; Until: 21:00, 1; Until: 24:00, 0; Weekends: Until: 12:00, 0; Until: 20:00, 1; Until: 24:00, 0; Holidays: Until 24:00: 0	Until: 08:00, 0; Until: 21:00, 1; Until: 24:00, 0; Weekends: Until: 12:00, 0; Until: 20:00, 1; Until: 24:00, 0; Holidays: Until 24:00: 0
Public adm.	Winter: Until: 08:00, 0; Until: 17:00, 1; Until: 24:00, 0; Summer, weekends and holidays: Until 24:00: 0	Summer: Until: 08:00, 0; Until: 17:00, 1; Until: 24:00, 0; Winter, weekends and holidays: Until 24:00: 0	Until: 08:00, 0; Until: 09:00, 0.5; Until: 10:00, 06; Until: 11:00, 0.7; Until: 12:00, 0.5; Until: 13:00, 0.6; Until: 14:00, 0.7; Until: 15:00, 0.8; Until: 16:00, 0.7; Until: 17:00, 0.4; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 09:00, 0; Until: 18:00, 1; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0	Until: 08:00, 0; Until: 09:00, 0.5; Until: 10:00, 06; Until: 11:00, 0.7; Until: 12:00, 0.5; Until: 13:00, 0.6; Until: 14:00, 0.7; Until: 15:00, 0.8; Until: 16:00, 0.7; Until: 17:00, 0.4; Until: 24:00, 0; Weekends and holidays: Until 24:00: 0
Restaurant	Winter: Until: 08:00, 0; Until: 21:00, 1; Until: 24:00, 0 Summer and holidays: Until 24:00: 0	Summer: Until: 08:00, 0; Until: 21:00, 1; Until: 24:00, 0 Winter and holidays: Until 24:00: 0	Until: 08:00, 0; Until: 21:00, 0.5; Until: 24:00, 0	Until: 08:00, 0; Until: 21:00, 1; Until: 24:00, 0	Until: 24:00, 0
Sport	Winter: Until: 08:00, 0; Until: 22:00, 1; Until: 24:00, 0 Summer: Until: 24:00, 0	Summer: Until: 08:00, 0; Until: 22:00, 1; Until: 24:00, 0 Winter: Until: 24:00, 0	Until: 08:00, 0; Until: 22:00, 0.6; Until: 24:00, 0	Until: 08:00, 0; Until: 22:00, 1; Until: 24:00, 0	Until 24:00: 0

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Conclusions of the adjustment phase:

Once that the parameters of the district energy model are adjusted according the description above, the results obtained are compared with the information available for Helsinki (the three cases mentioned above). In this section a comparison between the mySMARTLife modelling results and the three cases is provided distinguishing between the residential buildings and the tertiary buildings.

Residential buildings:

The Table 43 shows the energy demand and consumption values available for residential buildings of Helsinki distinguishing the sources of information. It needs to be taken into account that the initial values of the references have been adapted to the construction year periods used in the mySMARTLife Helsinki model.

Table 43: Reference energy demand and consumption values considered for the residential buildings of Helsinki

Building age	3D model of Helsinki				Case 1		Case 2		
	Space heating	DHW	Electricity (Equipment)	Electricity (Lighting)	Space heating	DHW	Heating	DHW	Electricity
	[KWh/m²]	[KWh/m²]	[KWh/m²]	[KWh/m²]	[KWh/m²]	[KWh/m²]	[KWh/m²]	[KWh/m²]	[KWh/m²]
Pre-1975	103	37	14	40	163	48	158	48	39
1975-1978	99	37	14	40	125	47	162	46	39
1979-1985	98	37	15	40	88	46	131	45	42
1986-2003	95	37	15	40	51	45	99	44	45
2004-2007	75	37	16	40	22	44	99	44	45
2008-2010	75	37	16	40	22	44	30	39	36
Post-2010	45	37	16	40	11	43	30	39	36

It can be seen that there are considerable discrepancies between the three information sources evaluated. This seems reasonable considering that different modelling approaches are compared in some cases with actual consumptions and considering also that different buildings are considered as case studies.

Comparing the results obtained with the mySMARTLife model, the initial conclusion is the values obtained follow a tendency that corresponds better to with the case 2. The Table 39 shows the heating and DHW demands and the electricity consumption of residential buildings. Besides, it shows the differences respect to the values provided in the case 2 of the literature review.

The observed differences range between the 5% to the 51% depending on the building age with an average difference of 18% when considering all the residential building types. In the case of the DHW on the other hand, an average difference of 8% is observed. These are reasonable values considering that the comparison is done between two different modelling approaches

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Table 44: Heating and DHW demand and electricity consumptions of the mySMARTLife model and the Reference energy demand and consumption values considered for the residential buildings of Helsinki.

Building age	mySMARTLlife Modelling results				Diff.respect to the Case 2	
	Heating	DHW	Equipment	Lighting	Space heating	DHW
	[KWh/m²]	[KWh/m²]	[KWh/m²]	[KWh/m²]	Diff. %	Diff. %
Pre-1975	176	41	13	29	11%	14%
1975-1978	153	41	13	29	5%	11%
1979-1985	107	41	13	29	18%	10%
1986-2003	88	41	13	29	11%	7%
2004-2007	49	41	13	29	51%	7%
2008-2010	37	41	13	29	24%	4%
Post-2010	31	41	13	29	3%	4%

Moreover, the results of the mySMARTLife model are compared also respect to the values available from monitoring for a residential building of Helsinki built in 1975. In this case the table below shows that the difference between the model and actual values obtained from monitoring is of 7%.

Table 45: Heating and DHW demand and electricity consumptions of the mySMARTLife model and the Reference energy demand and consumption values considered for the residential buildings of Helsinki.

Use	Age	Heat demand (kWh/m^2)	Diff. respect to the modelling (%)
Residential	1975	164,64	7%

Tertiary buildings:

The Table 46 shows the energy demand and consumption values available for tertiary (office) buildings of Helsinki distinguishing the sources of information. In this case the initial values of the references have also been adapted to the construction year periods used in the mySMARTLife Helsinki model.

Table 46: Reference energy demand and consumption values considered for the tertiary buildings of Helsinki.

Building age	3D model of Helsinki				Case 1		Case 2			
	Space heating	DHW	Electricity (Equipment)	Electricity (Lighting)	Space heating	DHW	Heating	DHW	Electricity	Cooling
	[KWh/m²]				[KWh/m²]		[KWh/m²]			
Pre-1975	224	8	15	53	184	6	238	48	133	10
1975-1978	165	8	16	53	135	6	242	46	135	10
1979-1985	148	8	21	53	120	6	211	45	145	10
1986-2003	130	8	26	53	105	6	179	44	155	10
2004-2007	130	8	26	53	52	6	179	44	155	10
2008-2010	130	8	26	53	52	6	65	42	105	0
Post-2010	57	8	27	53	41	6	65	42	105	0

It is observed that large differences are also obtained between the three reference cases used for the comparison of the results obtained with the mySMARTLife modelling. The table below shows the values obtained with the model for each of the construction period defined.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Table 47: Reference energy demand and consumption values considered for the tertiary buildings of Helsinki

Building age	mySMARTLife Modelling results				
	Heating [KWh/m²]	Cooling [KWh/m²]	DHW [KWh/m²]	Equipment [KWh/m²]	Lighting [KWh/m²]
Pre-1975	203	3	6	21	28
1975-1978	191	3	6	21	28
1979-1985	111	3	6	21	28
1986-2003	92	3	6	21	28
2004-2007	66	4	6	21	28
2008-2010	54	3	6	21	28
Post-2010	44	4	6	21	28

Comparing the obtained heating energy demand with the three information sources evaluated, in the figure below it can be seen the differences obtained for each case.

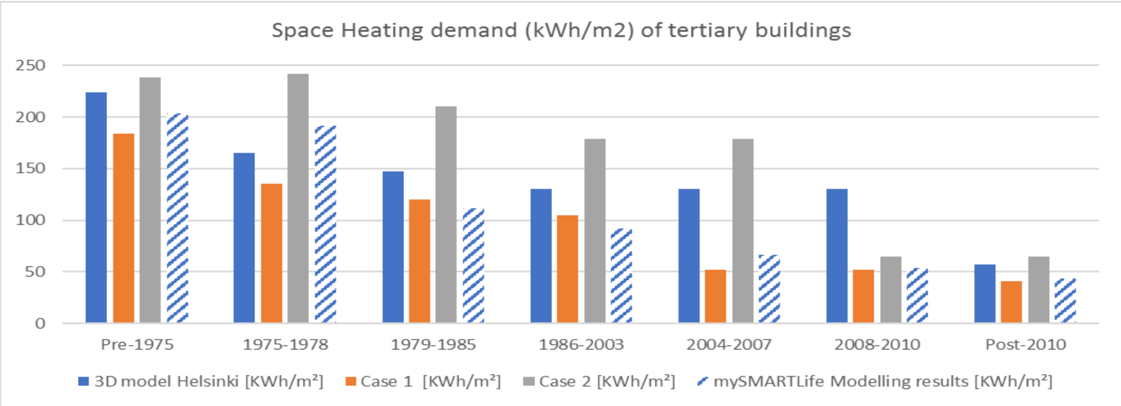

Figure 45: Comparison between the results obtained with the mySMARTLife modelling respect to the three reference cases.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

7. Case study results

The case study results are included in the files that are linked to this deliverable and that provided to the cities. These files include for each city and for each of the selected district all the information and the results obtained in this task. Considering that the output of the task includes a great amount of information, this section is focused on providing a general overview and a brief description of the results obtained. This section includes some of the most representative figures of the results obtained.

Therefore, for each city/district the following files are provided;

- **The input shapes** of the area evaluated for each city.
- **The shape file ("City Results")** of the area evaluated for each district which includes the following information specifically for each building;

Table 48: Information included in the shape files

Information included
Building ID
Annual Heating Demand
Annual Heating Demand Square Meter
Annual Cooling Demand
Annual Cooling Demand Square Meter
Annual DHW Demand
Annual DHW Demand Square Meter
Use Map (Use of the building)
Year of Construction
Total Height
Foot Print Area
Gross Floor Area
Number of Floors
Roof Area
Exterior Envelope Area
Window Area
Volume
Annual Light Consumption
Annual Light Consumption Square Meter
Annual Equipment Consumption
Annual Equipment Consumption Square Meter
Annual Electricity Consumption
Annual Electricity Consumption Square Meter

- **A XLSX file ("City district energy modelling results")** which includes the same type of information as the included in the shape file.
- **A second XLSX file ("City district energy modelling results aggregated")** which includes aggregated information and results by building typology and age groups. In this case the following results are included for each building group;

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Table 49: Information included in the second XLSX file

Information included
Use
Period
Number of Buildings
Total Gross Floor Area
Net Heated Floor Area
Annual Useful Heating Demand
Annual Useful Cooling Demand
Annual Useful DHW Demand
Annual Useful Heating Demand Square Meter
Annual Useful Cooling Demand Square Meter
Annual Useful DHW Demand Square Meter

- **A third file ("City Hourly Results.db")** that should be opened with database (such us DB Browser for SQLite). This file includes information for each of the buildings of the district but in this case in an hourly basis. The information included for each building is the following;

Table 50: Information included in the second XLSX file

Information included
Period
Use
Day of Year
Hour of Day
Season
Heating
Cooling
DHW

7.1 Nantes area of study

In the case of the Isle of Nantes, the results of the calculations obtained with the energy modelling have been included in the corresponding shape and files as explained above. Besides, the table below shows the total demands and consumptions of all the buildings evaluated for the Isle of Nantes.

Table 51: Total heating, cooling and DHW demand and electric consumptions of the buildings of the Isle of Nantes.

Age	Heating (kWh/year)	Cooling (kWh/year)	DHW (kWh/year)	Lighting (kWh/year)	Equipment (kWh/year)
Pre-1914	7867895	840927	644327	1015384	689055
1915-1939	2504562	271639	196478	325650	224676
1940-1975	26324791	2911139	2522305	4251268	2919919
1976-1981	1861910	853157	1400238	1891106	1333624
1982-1989	12994976	2777601	6653217	5057060	3701787
1990-1999	3575440	3839866	2603752	9861987	5732867
Post-2000	6676025	9635461	6663734	15420649	11779003
Total	**61805598**	**21129789**	**20684052**	**37823103**	**26380931**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

The following figures show the results obtained both the heating demands and for the electricity consumptions distinguishing between the buildings uses and ages. The values obtained for the residential buildings are showed in the figure with a secondary axis because the values are much higher.

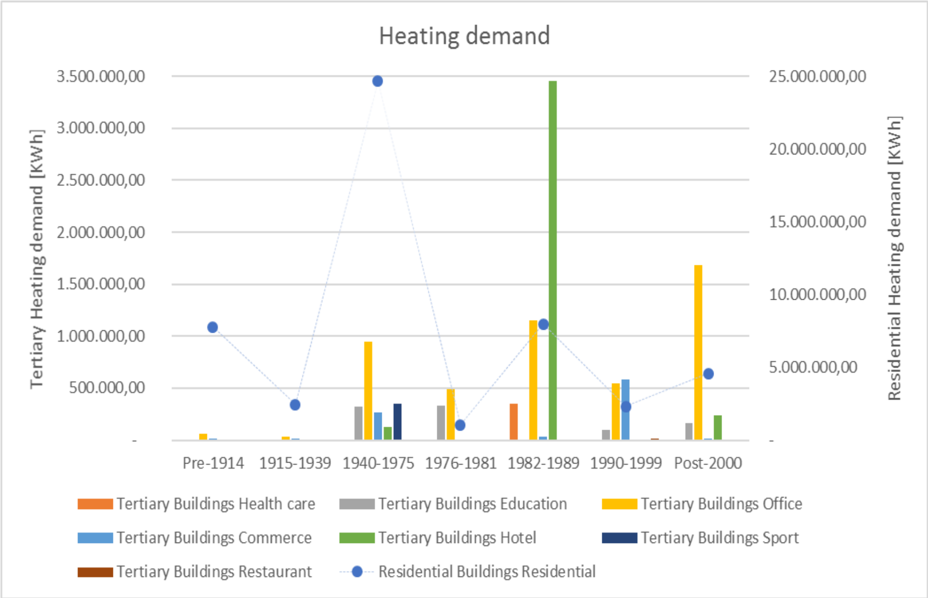

Figure 46: Heating demand of the buildings evaluated in the Isle of Nantes.

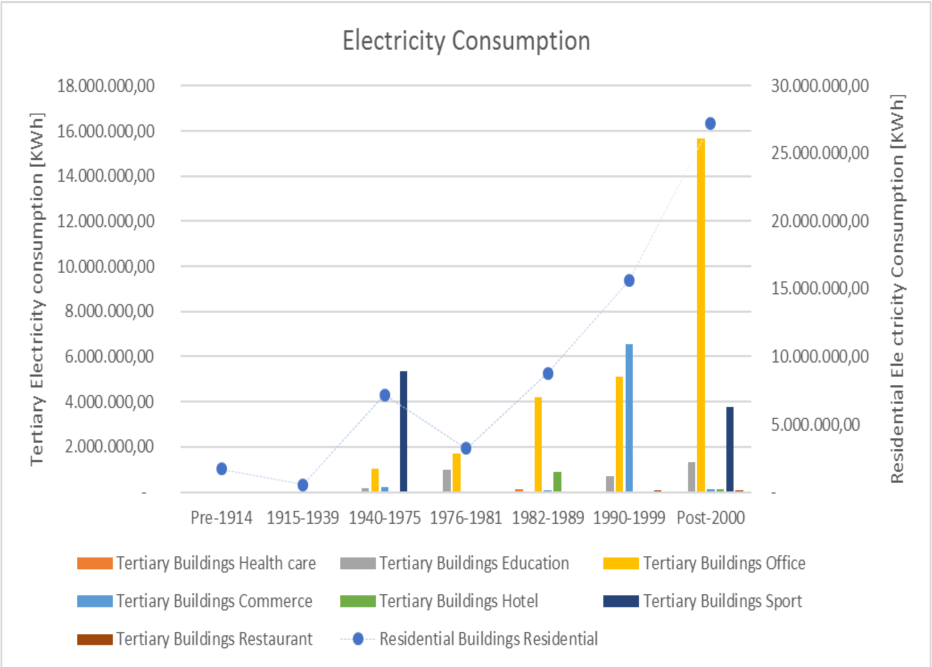

Figure 47: Electricity consumptions of the buildings evaluated in the Isle of Nantes.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

The energy modelling also allows the analysis of the results in an hourly basis. The following figure show as an example, the results obtained for a residential building modelled for the Isle of Nantes. Equivalent results are obtained for every building included in the area of study. These results have been provided to the cities.

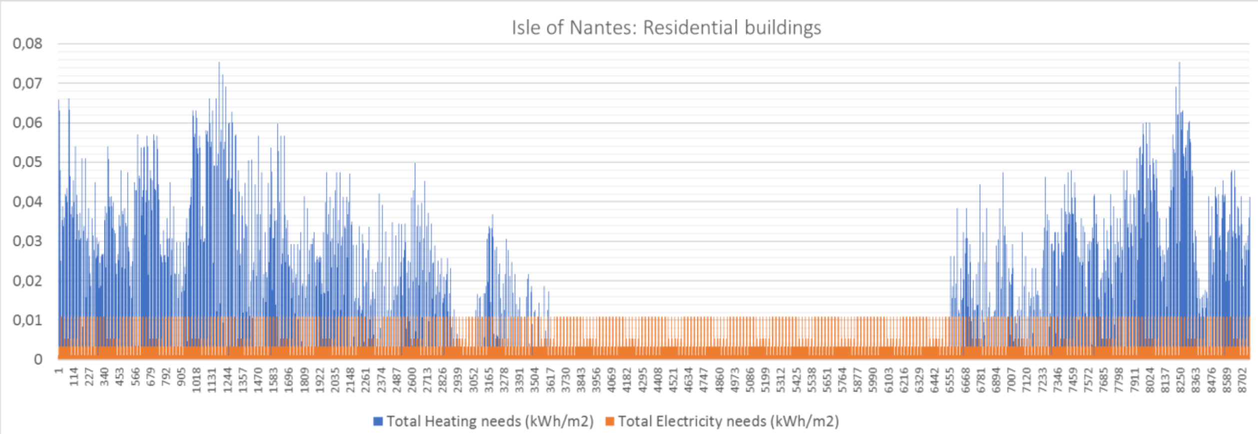

Figure 48: Hourly heating and electricity needs of a residential building modelled for the Isle of Nantes.

Further information is obtained by evaluating the output of the model once that it is represented in the shape of the area of study. The following figures show some of those possible results with the color code detailed in each of them. Figure 49 shows the het demand intensity (kWh/m^2) of each of the buildings evaluated in the Isle of Nantes. It is observed that the heat demand of the main part of the residential buildings is in the lower range (directly related to the year of construction of these buildings).

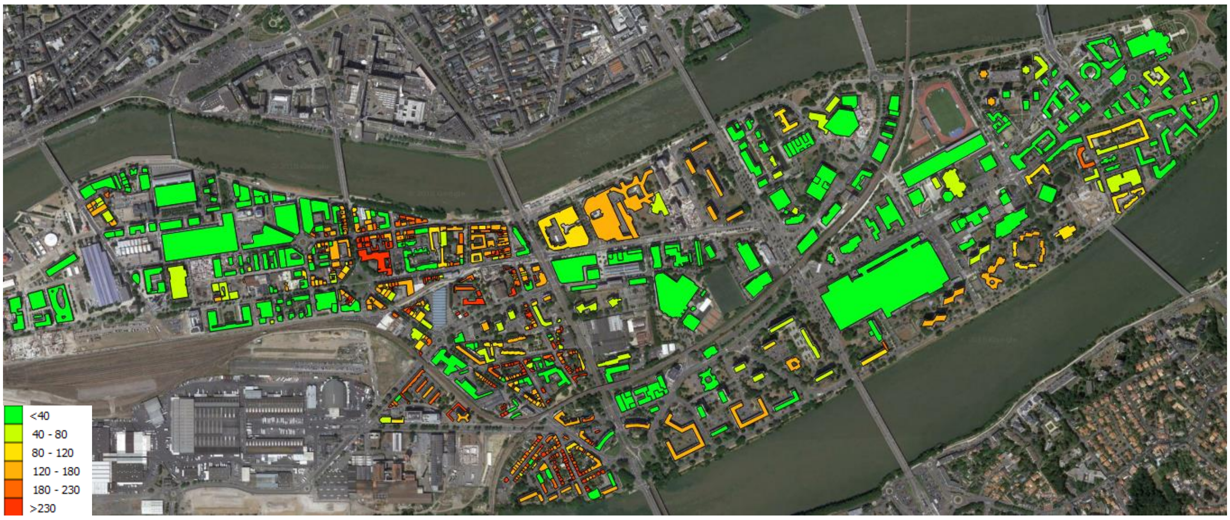

Figure 49: Heat demand (kWh/m^2) of the Isle of Nantes

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Figure 50 on the other hand, shows the electricity consumption intensity (kWh/m^2) of each of the buildings evaluated in the Isle of Nantes.

Figure 50: Total electricity demand (kWh/m^2) of the Isle of Nantes

Therefore, these types of figures (the ones showed above combined with others such as the total energy requirements of the buildings, instead only the energy intensities) help to get a quick overview of the energy needs of each building or district. This information combined with the information such as the age of the building provides for example a good understanding of the refurbishment potential of the area evaluated. The total surface of the envelope of the buildings of the district provide also an initial idea of the costs that would be associated to the refurbishment interventions. Besides, this information related to the energy demands, provides useful data for the preliminary analysis of the viability of the implementation of other interventions such as district heating systems.

Other data such as the total roof surface of the buildings can also be useful for other type of analysis such us the evaluation of the potential of the implementation of renewable energy technologies such as the solar thermal or the solar photovoltaic systems.

It is clear that the obtained georeferenced information, which is integrated within the initial shape file of the cities, opens many possibilities at district scale. However, the most interesting output of this analysis is the potential for scaling-up it to the entire city. The figure below represents only a reduced zone of Nantes as part of the results of the energy modelling analysis that has been applied to the entire city of Nantes. This analysis will be useful also to evaluate the replication potential within the city of the improvement interventions that will be implemented in mySMARTLife project which will be useful for the evaluation of the alternative scenarios for the entire city in the Subtask 1.4.2.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Figure 51: Heat demand (kWh/m^2) of a larger area of Nantes (the analysis has been carried out for the entire city of Nantes)

7.2 Hamburg area of study

As in the case of Nantes, all the results of the calculations obtained for Hamburg are included in the corresponding shape and file. The table below shows the total demands and consumptions of all the buildings evaluated. It is observed that the main energy demand of the buildings corresponds to heating and DHW.

Table 52: Total heating, cooling and DHW demand and electric consumptions of the buildings of area evaluated in Hamburg.

Age	Heating (kWh/year)	Cooling (kWh/year)	DHW (kWh/year)	Lighting (kWh/year)	Equipment (kWh/year)
1860-1918	2032297	167979	391898	236802	184819
1919-1957	4903199	701770	1794837	1097843	689765
1958-1978	2500699	439411	950786	1120340	585123
1979-1994	2297512	418899	1636355	692467	508837
1995-2001	5312104	1775601	5118905	1965901	1442385
Post-2002	476935	216415	602929	306895	231548
Total	**17522747**	**3720076**	**10495710**	**5420248**	**3642476**

The following figures on the other hand, show the results obtained both the heating demands and for the electricity consumptions distinguishing between the buildings uses and ages.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

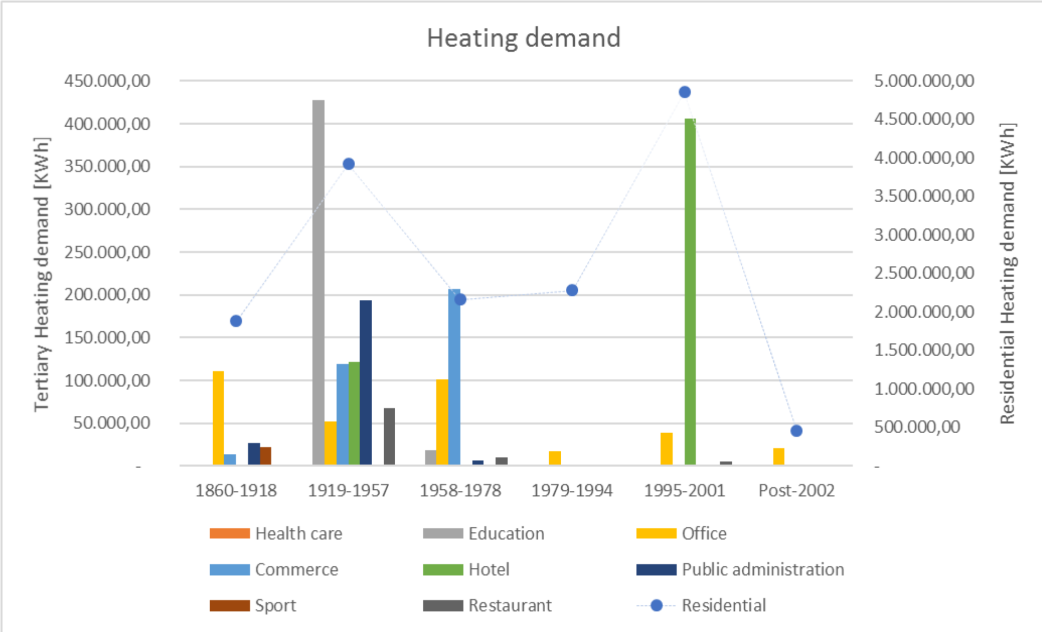

Figure 52: Heating demand of the buildings evaluated for Hamburg.

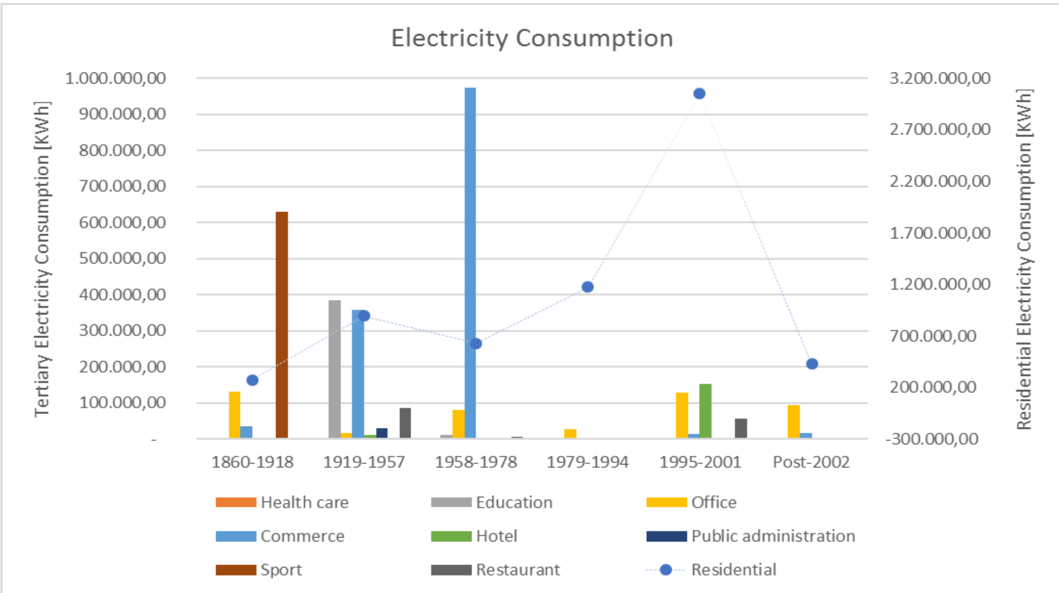

Figure 53: Electricity consumption of the buildings evaluated for Hamburg.

As described in the previous case, the energy modelling also allows the analysis of the results in an hourly basis. The following figure show as an example, the results obtained for a residential building modelled for the area evaluated for Hamburg. Equivalent results are obtained for every building included in the area of study. These results are provided to the city.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

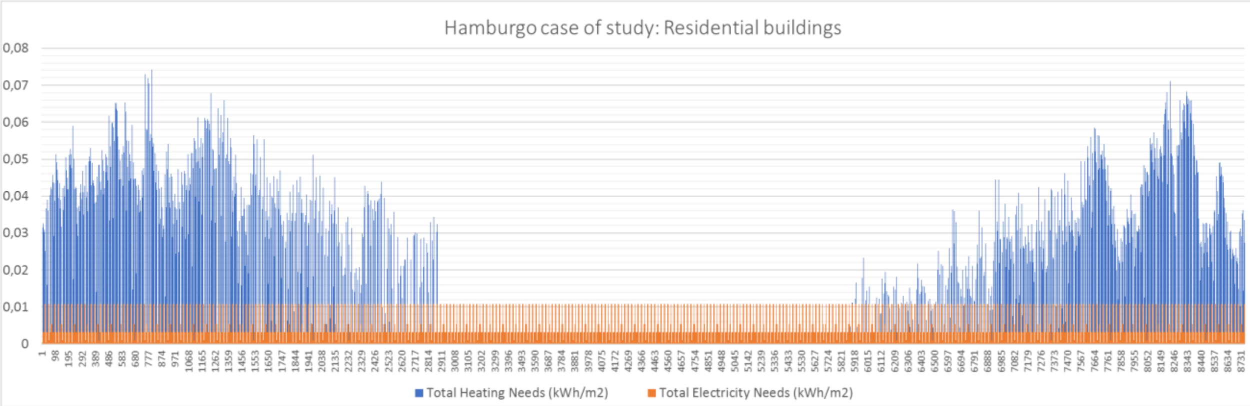

Figure 54: Hourly heating and electricity needs of a residential building modelled for the case study of Hamburg.

Finally, further information is showed in the following two figures, which show some of those results included with the color code detailed in each of them. More precisely Figure 49 shows the het demand intensity (kWh/m^2) of each of the buildings evaluated in the area selected for Hamburg.

Figure 55: Heat demand (kWh/m^2) of the district selected in Hamburg

Figure 56 shows the electricity consumption intensity (kWh/m^2) of each of the buildings evaluated in the area of Hamburg.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Figure 56: Total electricity consumption (kWh/m^2) of the district selected in Hamburg

7.3 Helsinki area of study

This section includes a summary of the most representative results of the area of study selected for Helsinki. The following table describes the energy demands and consumptions evaluated for each building type and construction period.

Table 53: Total heating, cooling and DHW demand and electric consumptions of the buildings of area evaluated in Helsinki.

Age	Heating (kWh/year)	Cooling (kWh/year)	DHW (kWh/year)	Lighting (kWh/year)	Equipment (kWh/year)
Pre-1975	4643271	261431	1010506	1795129	366384
1975-1978	2001106	232249	492354	1767284	215576
1979-1985	3457320	367199	1140796	1100936	595895
1986-2003	424864	36655	28298	132878	101504
Post-2010	22159	4681	1113	5227	3993
Total	**10548720**	**902215**	**2673068**	**4801455**	**1283352**

The Figure 57 shows the graphical representation of the heating demand intensity (left) and the electricity consumption intensity (right) of the buildings included in the area of study. Different results are obtained according to the age, use and shape factor of each building.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

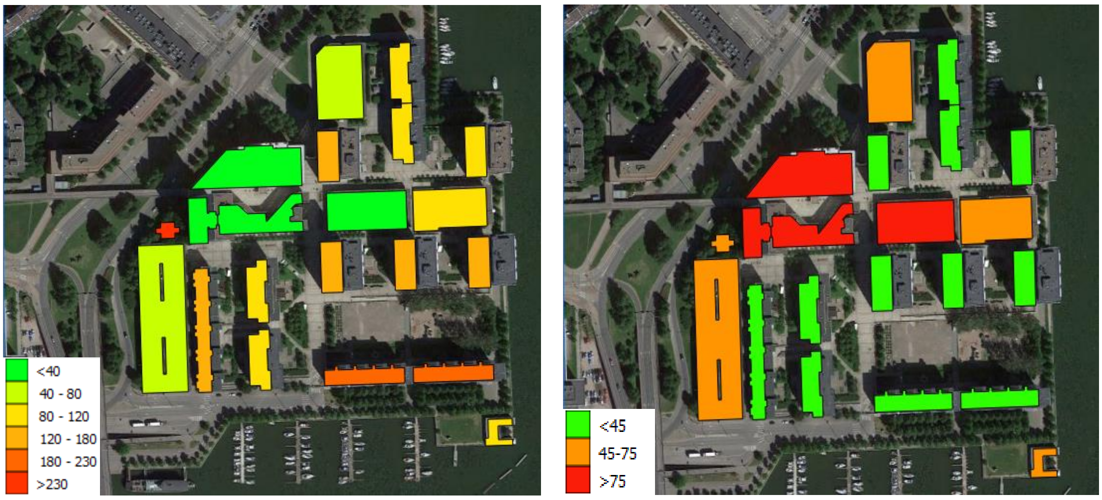

Figure 57: Heat demand (left) and electricity consumption (right) (kWh/m^2) of the district selected in Helsinki

As described in the previous case, the energy modelling also allows the analysis of the results in an hourly basis. The following figure show as an example, the results obtained for a residential building modelled for the area evaluated for Helsinki. Equivalent results are obtained for every building included in the area of study. These results are provided to the city.

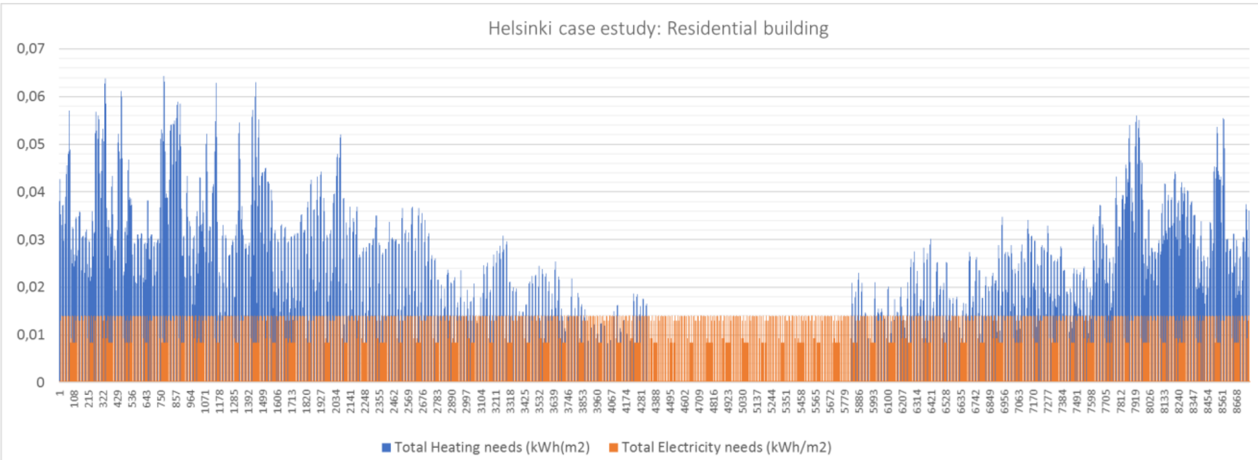

Figure 58: Hourly heating and electricity needs of a residential building modelled for the case study of Helsinki.

The selected area for the analysis is a very small area with few building types, and although it includes some buildings with different uses and periods of constructions, in this case it is especially interesting to scale-up the analysis to a larger scale.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

This is the reason why the energy assessment has been expanded to cover a larger area. In this case the analysis has been expanded to cover the entire city of Helsinki. The energy characterization of all the building types and categories evaluated in the adjustment phase (described in the section 6.3) are used.

As explained before, this will be useful the following phases of the planning process in which the energy scenarios for the entire city will be evaluated.

The Figure 59 serves as a visual example of the type of results obtained for the city of Helsinki. More precisely the heat demand intensity at building scale is showed in it. This type of figures need to be carefully considered, since there are many factors that influence the energy intensity at building scale and these results need to be evaluated simultaneously with other figures such as the total energy demand and consumptions or the age and use of the buildings among others depending on the specific aim of analysis that is more interesting in each moment.

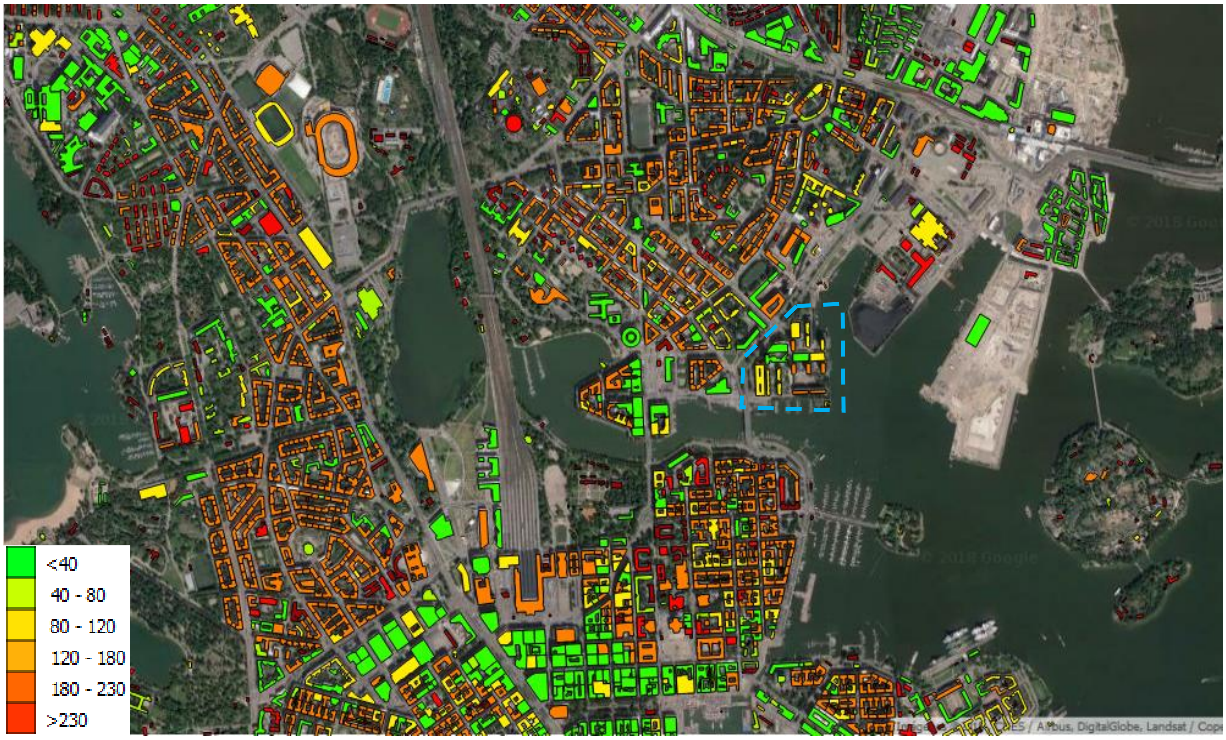

Figure 59: Heat demand (kWh/m^2) of a larger area of Helsinki

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

8. Conclusions

This deliverable includes a description of the work carried out in mySMARTLife project related to the energy analysis of the three lighthouse cities which integrates as a basis the processing of the information available in the 3D model of each city. It has been observed that depending on the level of information available in each city there have been different requisites. In some cases, such as in the case of Nantes the City-GML of the entire city has been developed. In the rest of the cities this was previously available and the efforts have been more focused on the treatment of the information in a way that is useful for the energy analysis. Many difficulties such as the lack of information of many buildings (age and use) have also been overcome.

The results obtained in the Subtask 1.4.1 (described in this deliverable) have contributed to a better understanding of the energy performance of the built environment of the area selected for each lighthouse city. Besides, the effort made during the calibration phase of the model has contributed in most of the cases to facilitate the scale-up analysis of the cases study to a larger area of the cities. This will be really useful in the following subtasks of the mySMARTLife project such as in the ST1.4.2 related to the energy scenario analysis of the following 10-20 years considering that it allows the generation of reliable scenarios for the deployment of different interventions that will be implemented in the cities as part of the project.

Regarding the energy modelling carried out. The results obtained have been adjusted as much as possible to the most realistic values. This phase has also been different for each city although in all the cases a similar process has been followed. This will be helpful also to replicate the process in the follower cities of the project. Each model has been evaluated through a sensitivity analysis to understand better which the most influencing parameters in the results are. Besides, each model has been adjusted according to the information that was available in each city. In this regard the calibration, or the contrast done for each district, needs to be carefully interpreted because in most of the cases there was no actual monitoring data related to the energy consumptions of the buildings and the differences shown in the tables correspond to the variations obtained respect to other modelling results. In any case, good results have been obtained for all the models.

Finally, it needs to be mentioned that apart of this deliverable many files have been generated and provided specifically to each city. These files provide information to the municipalities that can be used in different ways depending on their necessities and capabilities.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

9. References

[1] European Union's H2020 Programme, "PLANHEAT Project." "Grant Agreeement" 723757, 2016-2019, as part of the call H2020-EE-2016-RIA-IA.

[2] S. C. No, *Energy Performance of Buildings Directive (EPBD) Compliance Study*, no. December. 2015.

[3] International Organization for Standardization, "ISO 52016-1:2017. Energy performance of buildings -- Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads -- Part 1: Calculation procedures," *ISO*, p. 204, 2017.

[4] B. Allibe, "Modélisation des consommations d ' énergie du secteur résidentiel français à long terme - Amélioration du réalisme comportemental et scénarios volontaristes," 2013.

[5] European Union, "TABULA WebTool." [Online]. Available: http://webtool.building-typology.eu/#bm.

[6] R. Kemna and J. Acedo, "Average EU building heat load for HVAC equipment," *Final Rep. Framew. Contract ENER C*, no. August, 2014.

[7] European Union, "EU Building Stock Observatory database." [Online]. Available: http://ec.europa.eu/energy/en/eu-buildings-database. [Accessed: 13-May-2017].

[8] M. Topouzi, "The effect of default user inputs in modelling tools and methodsin energy use," *Proc. PLEA 2011*, pp. 35–40, 2011.

[9] S. Freitas, C. Catita, P. Redweik, and M. C. Brito, "Modelling solar potential in the urban environment: State-of-the-art review," *Renewable and Sustainable Energy Reviews*, vol. 41. pp. 915–931, 2015.

[10] E. Walter and J. H. Kämpf, "A verification of CitySim results using the BESTEST and monitored consumption values," in *Proceedings of the 2nd Building Simulation Applications conference*, 2015, pp. 215–222.

[11] B. D. Morland, "Consommations d'énergie et émissions de gaz à effet de serre liées au chauffage....," 2007.

[12] DesignBuilder Software Ltd, "Design Builder Simulation Tool." Version: 3.04.041.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

[13] X. Oregi, P. Hernandez, and R. Hernandez, “Analysis of life-cycle boundaries for environmental and economic assessment of building energy refurbishment projects,” *Energy Build.*, vol. 136, pp. 12–25, 2017.

[14] F. Ascione, N. Bianco, C. De Stasio, G. M. Mauro, and G. P. Vanoli, “Multi-stage and multi-objective optimization for energy retrofitting a developed hospital reference building: A new approach to assess cost-optimality,” *Appl. Energy*, vol. 174, pp. 37–68, 2016.

[15] N. Harmati and Z. Magyar, “Influence of WWR, WG and glazing properties on the annual heating and cooling energy demand in buildings,” in *Energy Procedia*, 2015, vol. 78, pp. 2458–2463.

[16] A. P. Melo and R. Lamberts, “Envelope insulation and heat balance in commercial buildings,” *Build. Simul.*, pp. 2243–2250, 2009.

[17] T. Buso, F. Dell’Anna, C. Becchio, M. C. Bottero, and S. P. Corgnati, “Of comfort and cost: Examining indoor comfort conditions and guests’ valuations in Italian hotel rooms,” *Energy Research and Social Science*, 2016.

[18] Ministerio de Fomento, “Código Técnico de la Edificación. Documento Básico de Ahorro de Energía.” .

[19] European Commission, “Heating degree-days by NUTS 2 regions - annual data [nrg_esdgr_a],” *EUROSTAT*. [Online]. Available: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_esdgr_a&lang=en. [Accessed: 12-Jul-2017].

[20] Hamburg Department of Environment and Energy, “Wärmekataster - Portal.” [Online]. Available: https://geoportal-hamburg.de/waermekataster/#. [Accessed: 15-Apr-2018].

[21] Entranze Project, “The challenges , dynamics and activities in the building sector and its energy demand in Germany,” 2012.

[22] P. Tuominen, R. Holopainen, L. Eskola, J. Jokisalo, and M. Airaksinen, “Calculation method and tool for assessing energy consumption in the building stock,” *Build. Environ.*, vol. 75, pp. 153–160, 2014.

[23] M. Hukkalainen (née Sepponen), M. Virtanen, S. Paiho, and M. Airaksinen, “Energy planning of low carbon urban areas - Examples from Finland,” *Sustain. Cities Soc.*, vol. 35, no. April, pp. 715–728, 2017.

This project has received funding from the European Union‘s Horizon 2020 research and innovation programme under grant agreement No 731297.