EPOC Task 2.2.3

1. Introduction

Task 2.2.3 formulated reliable and accurate building stock models to estimate the building energy performance and furthermore, evaluate scenarios towards achieving decarbonization by 2050. These building stock models involve forming refined bottom-up models covering residential and non-residential building stock. The residential building stock models are used to predict energy demand, various energy-efficiency measures and the cost associated with these measures. Furthermore, these stock models are further refined based on the retrofit potential of the existing stock. These models are further calibrated to match the national energy balance. The non-residential building stock classification involved a simplified representation of non-residential buildings owing to the limited/no availability of data at the regional level.

~~The improved building stock models follow a bottom-up modeling approach (Figure 1) that defines a set of parametric building energy model descriptions for the diverse groups of building types: residential (single-family and multi-family) and non-residential (offices, schools, retail). Such groups are referred to as **building typologies** or **representative buildings** and associate the parameter values used in the parametric models.~~

2. Bottom-up Typology Generation Workflow

The improved building stock models follow a bottom-up modeling approach (Figure 3~~Figure 1~~) that defines a set of parametric building energy model descriptions for the diverse groups of building types: residential (single-family and multi-family) and non-residential (offices, schools, retail). Such groups are referred to as **building typologies** or **representative buildings** and associate the parameter values used in the parametric models.~~–~~ The methodology implements a standardized archetype characterization procedure that involves the identification of data inputs, formulation of bottom-up energy models, and implementation of optimization routines for various renovation scenarios. The individual steps in the workflow are described below:

2.1 Data Inputs

This step in the typology generation workflow collects inputs relating to bottom-up building variables such as building physical characteristics, and operational characteristics and top-down building variables such as national energy consumption characteristics. This data comprises open as well as confidential datasets.

~~Subtask 0~~

~~As the formulated building stock models are inputs for futuristic scenario calculations, this task identified a data exchange pipeline (in alignment with Task 2.2.1) to disseminate building stock model data for other modeling tasks. This further enhanced the usability of the devised models. Some of the KPIs included retrofit energy saving costs and demand per energy vector.~~

~~Subtask 1: Developing a methodology to extend building typologies from energy domain to retrofit domain~~

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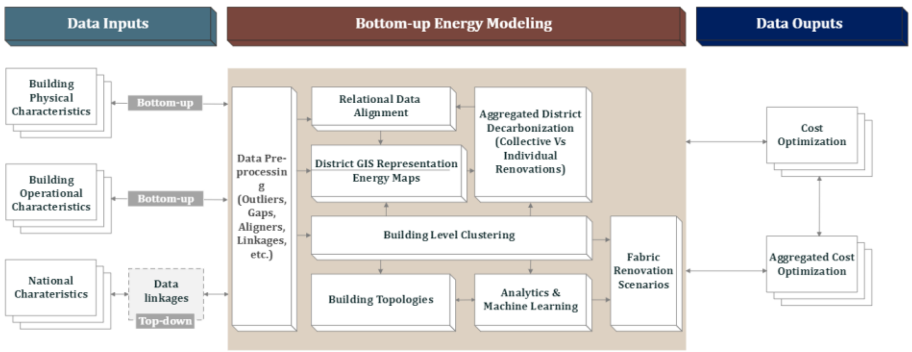

Figure 1 Process workflow to obtain refined typologies and implement bottom-up energy models

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The **openly sourced data (publicly downloadable)** are listed below.

1. ***3D GRB***[1]: The 3D GRB is a 3D model of available Large-scale Reference File (GRB) objects that allows to visualize these GRB objects in 3D and to efficiently query height information per GRB object. The height information comes from the source data of the Digital Elevation Model Flanders (DHMV) and can be extracted from both the DHMV I and the DHMV II depending on the product entity. The appearance of the 3D GRB also depends on the level of detail or the LOD level (level of detail). A 3D Model is available for Flanders. The Wallonia region has an LOD1 model[8]. The Brussels region has an LOD2 model[9].
2. ***Fluvius Consumption Statistics***[2]**:** The open dataset consumption data per street contains the consumption data per energy (electricity/gas), injection/purchase and per main municipality at street level. **This data is specific to the Flanders region**. Such statistics can also be downloaded for the Wallonia region although on an aggregated level with limited resolution[11].
3. ***Heat Map Flanders (Warmtekaart)***[3]: The 'Flanders Heat Map 2019' was commissioned by the Flemish Energy and Climate Agency to implement the EU Directive 2012/27/EU on energy efficiency and the Renewable Energy Directive (EU) 2018/2001. The main products are maps for 2019 for the territory of Flanders with the heat demand of large consumers and small consumers, results at the level of the municipalities and the statistical sectors, maps of the existing and planned heat networks and finally also locations of potential heat supply points. **This data is specific to the Flanders region.**
4. ***Census Statistics***[4]: This contains the cadastral statistics of the building stock – Geographic location, Type of Building and Building features. This data is available on a Belgium wide level.
5. ***VKBO data***[5]: Agentschap Digitaal Vlaanderen maintains a copy of the Crossroads Bank for Enterprises (CBE), the authentic source where all basic data of companies and business units are collected. This copy is enriched with additional data from other relevant sources, resulting in an enriched database, called the VKBO managed by the Digital Flanders agency.
6. ***EPC Public Buildings***[6]: Extensively managed by the Flemish Energy Agency, an energy performance certificate (EPC) for public buildings is mandatory for buildings in which public organizations are located that provide public services to many persons. An EPC for public buildings is drawn up by a recognized energy expert type C or an internal energy expert and is based on the measured (actual) annual consumption of the public organization. The EPC is mandatory for buildings located in the Flemish Region in which public organizations are located that provide public services to many people and that are often visited by the public. The EPC for Public Buildings also exists for the Brussels region[10].
7. ***Cadaster***[7]: The cadastral map or land register plan is a graphic representation on a map of all the cadastral plan parcels on the Belgian territory. You can therefore use it to visualize and locate real estate (parcels and buildings). This data is available on a Belgium wide level.

The **confidential data** include (available through VITO):

[1] **3D GRB | Download application Digital Flanders (vlaanderen.be)**
[2] **Consumption data per street — Fluvius Open Data**
[3] **Heat map 2019 - Heat demand density per municipality | Vlaanderen.be**
[4] **Cadastral statistics of the building stock | Statbel (fgov.be)**
[5] **VKBO ondernemingen en vestigingseenheden (vlaanderen.be)**
[6] **Energy performance certificates for public buildings | Data.gov.be**
[7] **Download portal | FPS Finance (belgium.be)**
~~http://metawal.wallonie.be/geonetwork/srv/fre/catalog.search#/metadata/9a8322bd-f53a-4f99-ad9e-753b45bdee85~~
[8] **Metawal (wallonie.be)**
[9] **UrbIS Download | datastore.brussels**
[10] **List of public buildings that have a valid EPB certificate public building (peb-epb.brussels)**
[11] **Catalogue of statistical indicators - WALSTAT (iweps.be)**

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1. **Data related to building geometry service (BGS):** This data is internally maintained within VITO and is not accessible to everyone. This data can be made accessible through a subscription service though.
2. **EPC Residential Buildings (from VEKA)**: This data contains the EPC of the residential building stock and is maintained and owned by the Flemish Energy Agency.
3. **Building and energy technology:** This data contains information regarding the building energy systems and is maintained by VITO together with the BGS dataset.

By joining the aforementioned data sources, the methodology formulates a residential and non-residential database sector database (geometry, energy use, user profile, etc.) initially for the Flanders region. Clustering analysis, based on the database, is conducted to derive the representative residential and non-residential typologies, and further compared with state-of-the-art research outcomes[3].

2.2 Bottom-up Energy Modeling

Existing typology descriptions for the Belgian building stock are established from an energy-performance perspective. In the typology approach, buildings are commonly classified by construction year and type of building to capture differences in energy performance. As the goal of EPOC is to not only capture the current energy use but also quantify the potential and cost of renovation measures towards 2030-2050, current definitions of typologies are reevaluated to not only differentiate in energy performance levels but also potential and cost of retrofit. Building characteristics that drive these two KPI's (potential and cost for retrofit) are identified and incorporated in the typology formulation. The methodology (Figure 1) identifies a generalized process workflow to formulate building typologies using district and building level information and further enriches these typologies to include the renovation potential (collective and individual). As the workflow is generalized, it could be extended to other neighborhoods/districts/cities.

The formation of bottom-up energy models involves data-preprocessing as the initial filtering mechanism whereby we remove data gaps such as missing values, treat outliers, align data fields, and identify links between different datasets. The processed datasets are then run over three parallel workflows. The first workflow, **relational data alignment**, links the datasets together. For instance, missing data in the 3D GRB dataset is enriched with additional building features from the BGS dataset. The second workflow, **district GIS representation and energy maps**, creates a broad overview of the energy consumption statistics at the district scale using GIS regional maps. The last workflow, **building level clustering**, creates building typologies/clusters/archetypes using machine learning techniques such as k-means clustering. These clusters are then used to define fabric renovation scenarios and collective district decarbonization solutions.

2.3 Data Outputs

The clusters formed are then run through cost optimization routines to identify the costs associated with each renovation package. The cost of implementation of the chosen renovation packages are then validated with the costs generated by the TIMES model.

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3. Residential Sector Typologies

The EPISCOOP and TABULA project developed reference building typologies for the Belgian residential building stock[11]. An extensive review of these typologies is conducted and updated based on available data sources. These topologies are further refined using energy performance databases from the regional energy agencies, for instance EPC residential buildings dataset from VEKA. The EPCs are mostly gathered from the publicly available databases, other European projects (ePANACEA, x-tendo) and the Flemish Energy Agency (VEKA). Access to these datasets is available upon request. Additionally, spatial data sources, namely, GIS and open access GRB data are used to gather estimates on actual building geometry. These datasets include the 3D GRB dataset for the Flanders region and business units' data.

By joining various data sources, the methodology formulates a residential sector database (geometry, energy use, user profile, etc.) initially for the Flanders region. Clustering analysis, based on the database, is conducted to derive the representative residential typologies, and further compare with state-of-the-art research outcomes[3]. The data sources are listed below; links and access to these datasets are elaborated in Section 2.

1. 3D GRB
2. Fluvius Consumption Statistics
3. Heat Map Flanders (Warmtekaart)
4. Census Statistics
5. VKBO data
6. Cadaster
7. EPC Residential Buildings

Furthermore, the clustering results are communicated in the format of the building stock model output to maximize the usability for other modelling tasks (

[11] W. Cyx , N. Renders, M. Van Holm en S. Verbeke, IEE TABULA - Typology Approach for Building Stock Energy Assessment (2011/TEM/R/091763), VITO, https://episcope.eu/fileadmin/tabula/public/docs/scientific/BE_TABULA_ScientificReport_VITO.pdf

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ANNEX A). The entire process could be extended to other regions upon additional data collection of geometry, construction year, building function and local energy use data.

3.1 EPOC TIMES model

3.1.1 Residential building inputs

Current status of building inputs of TIMES model

Building stock status in TIMES model:

- The previous building stock TIMES model in Flanders was rather limited, 4 typologies with outdated reference data and sources.
- In Wallonia and Brussels, the ICEDD model (publicly accessible sources: tabula) was mainly prevalent.

Bottom-up energy modeling process workflow is adopted to derive building inputs for TIMES model. This is limited based on the availability of data sources and inputs (e.g., for Wallonia and Brussels, building function and construction year are required to run the same logic as that of Flanders). However, these characteristics are not available for these regions.

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Commented [MHS6R5]: These characteristics are not available. TO our knowledge, Flanders has the most extensive building stock database.

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[11] **W. Cyx , N. Renders, M. Van Holm en S. Verbeke, IEE TABULA - Typology Approach for Building Stock Energy Assessment (2011/TEM/R/091763), VITO, https://episcope.eu/fileadmin/tabula/public/docs/scientific/BE_TABULA_ScientificReport_VITO.pdf.**

Geometry for Typology Clustering

For 3 regions, the methodology derives typologies with the geometry data + cadaster data (construction year). In Flanders, the building model is based on the BGS and construction year data. The Building Geometry Service or BGS database is accessible via subscription through VITO. The construction year data is extracted from the cadaster database. For Wallonia and Brussels, building geometrical data are available but needs to be further processed. These datasets do not contain building characteristics and exist in a disintegrated manner without any relational linkages in between datasets. The methodology of deriving typologies is thus streamlined in 3 regions using Flanders as the baseline scenario.

The building stock typology generation (m2/typology and PJ/m2/typology) for residential buildings in Wallonia and Brussels in EPOC model has been carried out in a similar way as for Flanders. We would like to mention that equipment stock development and the calibration of the model for this residential sector requires knowledge of the quantity of energy consumed by usage or type of demand for each energy vector. These data are available by cross-referencing information from Wallonia energy balance sheets[15] ('Domestic Balance 2018' providing overall consumption by typologies and usage, and 'municipal energy balance'). Since equivalent data is not available for Flanders, the distribution key derived from Wallonia to allocate the consumption per energy vector/use has been used instead.

~~**Tabula data typology is taken as the backup solution for Wallonia and Brussels as the geometrical data might be not feasible to deal with/or with low data quality (LOD1 in Wallonia).**~~

The number of typologies (

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For others, we will analyze the request first and then mak decision.

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Commented [PV10]: Can you indicate which of the dat your document is confidential and which could be shared

Commented [MHS11R10]:

Commented [PV12]: Where ? What is the difference w Flanders quality?
Do the data in Wallonia/Brussels have lower quality, or it just that we as VITO have access to more data in Flanders

Commented [PV13]: So, did we do this in EPOC?

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[14] **Le bilan énergétique de la Région | Citoyen - Bruxelles Environnement**
[15] Consommation résidentielle d'énergie - État de l'environnement wallon (wallonie.be)

ANNEX A) is carefully defined/limited due to the calculation capacity of TIMES model, and key parameters of typologies are defined as follows:

- **Basic parameters** for the clustering analysis:
  - **Construction period** (3-4 construction periods – pre-1970, 1970-1990, 1990-2010(or 2006 as boundary), after 2010 (2006)). In the event of existing strong correlations between construction year and geometry, the analysis considers the construction year. Clusters are based on geometrical data when no correlations exist. The clusters identify and assign centroids to each construction period, which are further simulated using different renovation packages. This is followed by merging similar clusters together.
  - **Building type** (4 types: terraced, detached, semi-detached, apartment)
  - **Geometry** (3 geometrical representations – small, medium, large categories are assigned numbers using the centroid values of the cluster.
- **Derived/calculated parameters**: Based on the construction period, building characteristics (U value etc.) are estimated for Flanders, for Wallonia and Brussels, Tabula is identified as the backup solution with similar logic as implemented for Flanders.
  - **Renovation measures**: Only building envelope related measures with the cost's figures.
- Heating source for each typology (gas, oil, electricity, etc.)
- **District heating potential:** yes or no, predefined for each typology, upscaled to estimate the total amount of buildings floor area. The ratio of demand side/supply side for Flanders is taken as 30%/70%.

Demand – Existing buildings

The baseline demand consists of (mainly) heating/DHW/cooling demand(s) of the existing building stock, calculated using EBECS with the derived typologies from clustering analysis. The current heating/DHW/cooling demand(s) are cross checked and verified with the national/regional energy balance data.

Demand - New buildings

The typologies of new buildings are derived from the clustering analysis to define the current new built demand.

Additional crucial inputs include:

- Current total floor area of the new built
- Historical new built rate as reference – assumes a fixed rate or parameter varies over time.
- Availability of land for new built

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Commented [PV17]: This is an assumption, based on Warmtekaart? Can we still somehow quantify this assumption?

Commented [PV18]: Did wil link to EBECS?

Commented [MHS19R18]: The clusters and renovatio packages came directly from EBECS

[14] **Le bilan énergétique de la Région | Citoyen - Bruxelles Environnement**

[15] Consommation résidentielle d'énergie - État de l'environnement wallon (wallonie.be)

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- Policy elements and implementation timeline considered for new building's demand calculation (e.g., EPC requirements in Flanders, and PEB in Wallonia and Brussels).
- Assume X% of new buildings are EPC B, Y% are EPC A

Renovation measures

The renovation measures in TIMES model focus on the building fabric (roof, wall, windows). Constraints are set within the TIMES model when evaluating.

Renovation scenarios include:

- Roof
- Wall
- Window
- Roof + Wall
- Roof + Window
- Wall + Window
- Roof + Wall + Window

The renovation packages are generated by a static energy calculation engine, EBECS and are further fed into the TIMES model. This includes a pre-screening of the measures due to the limitation of TIMES calculation time. These are further used to create time-series consumption profiles for single family dwellings (

_SH_demand	net_dhw_demand	net_heat_demand	ne_sh_demand_reduction	net_dhw_demand_reduction	OUTPUT (PJ/Mm²)	
102.828672	8.301985663	111.1306577	0	0		0
99.82948734	8.704102954	108.5335903	0	0		0
78.48937583	8.832225764	87.32160159	0	0		0
124.7414346	9.901397949	134.6428326	0	0		0
125.4834923	9.268806923	134.7522992	0	0		0
93.54076336	8.717303647	102.258067	0	0		0
92.51174767	9.288775078	101.8005228	0	0		0
67.61794014	9.202736922	76.82067706	0	0		0
98.01343846	9.901397949	107.9148364	0	0		0
98.75553231	9.268806923	108.0243392	0	0		0
63.33940017	8.689290268	72.02869044	0	0		0
64.12912844	9.430153805	73.55928225	0	0		0

Normalized net et space heat, net domestic hot water and net heat demand after considering the system efficiencies.

Reduction in net space heat and domestic hot water demand after the consideration of different renovation packages

Normalized total output energy consumption

Figure 5 EPOC Output Snippet 2: Cluster Details

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ANNEX B~~ANNEX B~~).

District heating potential: Flagged as a binary object in TIMES

District heating links to some specific typologies in some districts.

3.2 Calibration of bottom-up model to national and sectoral energy statistics

The developed bottom-up model for the Belgian building stock is verified and calibrated against national and sectoral statistics. This calibration primarily focusses on the energy use of buildings along the different energy vectors: gas, electricity, etc. Such a calibration is essential to assure the bottom-up model is compliant with the overall Belgian energy balance.

A hierarchical approach is followed whereby sectoral and regional data (e.g., gas consumption data) is used to verify and calibrate specific typologies. The clusters are identified using the Warmtekaart data at the individual building level, based on building type and construction year. The building stock typology definition is further enriched with geometrical definition from the TABULA database.

The clusters are further refined using national level stats from the Joint Research Centre Data Catalogue[12]. JRC-IDEES offers a consistent set of disaggregated energy-economy-environment data, compliant with the EUROSTAT energy balances, as well as widely acknowledged data on existing technologies. It provides a plausible decomposition of energy consumption, allocating it to specific processes and end-uses. The end uses are further refined using the energy balance data for the Flanders regions[13].

3.3 Retrofit Scenarios

In addition to the calibrated building stock model describing the existing state of the Belgian building stock, retrofit measures and scenarios for 2030 and 2050 are established for representative districts

[12]**Mantzos, Leonidas; Matei, Nicoleta Anca; Mulholland, Eamonn; Rózsai, Máté; Tamba, Marie; Wiesenthal, Tobias (2018): JRC-IDEES 2015. European Commission, Joint Research Centre (JRC) [Dataset] doi: 10.2905/JRC-10110-10001 PID: http://data.europa.eu/89h/jrc-10110-10001.**

[13]**Flemish Energy Balance | Vlaanderen.be**

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in Belgium, which are extensively described in a **published article [2]** (please refer to EPOC publications section). This task not only specifies technical measures but also includes retrofit cost estimations and prognosis for 2030-2050. These economic data are aligned with other tasks including Task 1.1 and Task 1.2. These scenarios and associated costs are further elaborated and discussed in detail in the same article [2].

4. Non-residential Sector Typologies

While energy performance typology approaches and data are commonly available for residential buildings, a Belgian non-residential building stock typology does not yet exist. Therefore, a similar clustering approach (as that for residential buildings) is used to develop a baseline archetype representation for:

- Small and medium size offices
- Retail buildings
- Schools
- Hotels & restaurants

The **classification** is based on the **publicly available database** which contains more than 9000 public buildings with detailed building energy performance related characteristic data including building construction year, building type, geometrical properties, measured final energy consumption and further geographical information of the public buildings in Flanders. Please refer to **[1]** for further details on the clustering method implementation. The data generated from this analysis is illustrated in **Annex C**.

By analyzing the recently published EPC database of public building sector in Flanders, a qualitive and quantitative overview of the current energy performance of different building categories are conducted. The non-residential building types (office, educational, healthcare etc.) are categorized. Within each category, a set of typologically representative non-residential buildings are further identified, while a data driven cluster analysis is carried out to define these non-residential archetypes. A conference paper, entitled "Data-driven statistical analysis of energy performance and energy saving potential in the Flemish public building sector", has been presented in the CISBAT international conference[1] and further published in IOP Journal of Physics Conference Series. This paper was the first step to achieve non-residential building typologies within the Belgian context.

5. Links with other tasks

5.1 Task 2.2.4 (District Heating)

The r~~r~~epresentative districts are composed based on the defined building typologies. These representative districts serve scenario analysis for e.g., district heating potential (~~(2.2.4.~~Figure 2). Calibration of representative districts to specific local context is not in the project's scope. Benchmarking is done for 5 districts spanning various levels of urban densification (city centers, urban residential blocks, and rural areas) and different composition of building types (semi-detached, detached, and terraced). The district heating potential is calculated using the warmtekaart data on a street segment level. Clusters are identified that produce similarities in the cost of implementing a district heating network for a specific district.

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Commented [MHS22R21]: This has all been elaborate in the paper for a 3 use cases.

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Commented [MHS24R23]: Updated

Commented [PV25]: Again, I would have to know here exactly which typologies you added, how you got the data (Glenn mentioned once workshops with industries? Or international literature?). Where can the data be found?

Commented [MHS26R25]: The dataset used for classification is the EPC Public Buildings dataset from VEK publicly available.

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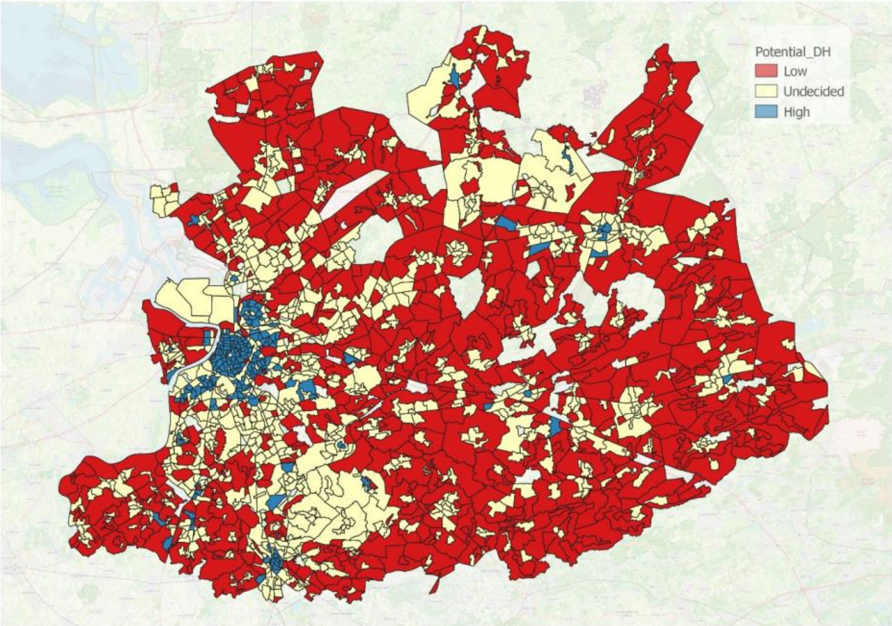

Figure 2 District heating potential for districts spread in Flanders. The evaluation is based on net present value offered by district heating and is subjected to data availability.

5.2 Task 3.3.2 User Centric Data

The end-use consumption profiles for single family dwellings are generated to be extensively employed in T3.3.2 for user centric models. These profiles are time-series data with a resolution of 15 min and include consumption statistics related to electricity, gas, domestic hot water, heat pump, and rooftop PV generation. Further details can be found in **ANNEX B.**

~~As the formulated building stock models are inputs for futuristic scenario calculations, this task identified a data exchange pipeline (in alignment with Task 2.2.1) to disseminate building stock model data for other modeling tasks. This further enhanced the usability of the devised models. Some of the KPIs included retrofit energy saving costs and demand per energy vector.~~

~~Subtask 1: Developing a methodology to extend building typologies from energy domain to retrofit domain~~

~~Existing typology descriptions for the (residential) Belgian building stock~~ are ~~established from an energy performance perspective. In the typology approach, buildings are commonly classified by construction year and type of building to capture differences in energy performance. As the goal of EPOC is to not only capture the current energy use but also quantify the potential and cost of renovation measures towards 2030-2050, current definitions of typologies are reevaluated to not only differentiate in energy performance levels but also potential and cost of retrofit. Building~~

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Commented [MHS65R64]: Added

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~~characteristics that drive these two KPI's (potential and cost for retrofit) are identified and incorporated in the typology formulation.~~

~~Subtask 2: Extending and updating typology-based building stock descriptions for the residential sector~~

~~The EPISCOOP and TABULA project developed reference building typologies for the Belgian residential building stock. An extensive review of these typologies is conducted and updated based on available data sources. These topologies are further refined using energy performance databases from the regional energy agencies. Additionally, data sources such as GIS and access GRB are used to gather estimates on actual building geometry.~~

~~In addition to updating existing building typology descriptions, these descriptions are mapped to the outcome of subtask 1 to transition from "energy performance typologies" to "retrofit potential typologies."~~

Figure 331 ~~Process workflow to obtain refined typologies and implement bottom-up energy models~~.

~~Subtask 3: Defining non-residential building stock typologies~~

~~While energy performance typology approaches and data are commonly available for residential buildings, a Belgian non-residential building stock typology does not yet exist. Therefore, this subtask ambitions the development of such descriptions for:~~

- ~~Small and medium size offices~~
- ~~Retail buildings~~
- ~~Schools~~
- ~~Hotels & restaurants~~

~~Other categories such as hospitals, large scale offices, public swimming pools, industry, etc. are not considered as their energy demand and retrofit potential are too case specific to accurately capture in a typology model.~~

~~Subtask 4: Calibration of bottom-up model to national and sectoral energy statistics~~

~~In this subtask the developed bottom-up model for the Belgian building stock is verified and calibrated against national and sectoral statistics. This calibration primarily focusses on the energy use of buildings along the different energy vectors: gas, electricity, etc. Such a calibration is essential to assure the bottom-up model is compliant with the overall Belgian energy balance.~~

~~A hierarchical approach is followed whereby sectoral and regional data (e.g., gas consumption data) is used to verify and calibrate specific typologies.~~

~~Subtask 5: Retrofit scenarios for 2030 and 2050~~

~~In addition to the calibrated building stock model describing the existing state of the Belgian building stock, retrofit measures and scenarios for 2030 and 2050 are established, and described in a publication[2]. This task not only specifies technical measures but includes retrofit cost estimations and prognosis for 2030-2050. These economic data are aligned with tasks 1.1 and 1.2.~~

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Commented [PV52]: A short word on how the Warmtekaart data are constructed? And where they can found? What about Wallonia/Brussels, are they assumed to be th same?

Commented [PV53]: Again, I need more detail on the analysis procedure and the data used. I believe you have some kind of analysis that starts from the Warmtekaart? then calibrates the building topologies to the Warmtekaa

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Commented [PV55]: Add scientific reference. Is this ar

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~~For tasks 2.2.4 and 3.1.1. representative districts are composed based on the defined building typologies. These representative districts serve scenario analysis for e.g., district heating potential (2.2.4.) or heat island effects in cities (3.1.1.).~~

~~Output~~

~~The main establishment of this task is the extended, bottom-up, typology-based building stock model for Belgium. Using this model, the following outputs are generated as input for the other tasks:~~

- ~~A detailed description of the building typologies in terms of energy performance and retrofit characteristics~~
- ~~Cost and energy demand reductions associated to retrofit options~~

~~The methodology extends and improves existing topology-based bottom-up models to predict the energy demand, energy savings options and associated costs by including non-residential typologies and refining residential typologies.~~

~~By analyzing the recently published EPC database of public building sector in Flanders, a qualitive and quantitative overview of the current energy performance of different building categories are conducted. The non-residential building types (office, educational, healthcare etc.) are categorized. Within each category, a set of typologically representative non-residential buildings are further identified, while a data driven cluster analysis is carried out to define these non-residential archetypes. A conference paper, entitled "Data-driven statistical analysis of energy performance and energy saving potential in the Flemish public building sector", has been presented in the CISBAT international conference[2] and further published in IOP Journal of Physics Conference Series. This paper is considered as the first step to achieve non-residential building typologies.~~

- ~~By various data sources, the methodology formulates a residential sector database (geometry, energy use, user profile, etc.). Clustering analysis, based on the database, is conducted to derive the representative residential typologies, and further compare with state-of-the-art research outcomes[3].~~

~~Residential building inputs~~

~~Current status of building inputs of TIMES model~~

~~Building stock status in TIMES model:~~

- ~~The previousCurrent building stock TIMES model in Flanders wasis rather limited, 4 typologies with outdatedwith no valid reference data and sources.~~
- ~~In Wallonia and Brussels, ICEDD model (tabula only, non-residential mainly)~~

~~[2] https://cisbat.epfl.ch/~~
~~[2] Potential macro-economic benefits of optimizing building renovation roadmaps towards 2050 on a city scale: A Belgian case study (ibpsa.org)~~
~~[3] bs2021_30603.pdf (ibpsa.org)~~

Commented [PV62]: And, what is the result for Flande
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Commented [PV71]: Is this true for Flanders, Wallonia
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Commented [PV77]: Remove this sentence? 'probably
Commented [PV78]: Are they not available, or did we
Commented [MHS79R78]: These characteristics are n
Commented [PV80]: For everyone? What are the
Commented [PV81]: What is BGS data? Where do you
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Commented [PV83]: Where ? What is the difference w
Commented [PV84]: So, did we do this in EPOC?
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Commented [PV88]: In general, what was the data

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~~For EPOC, the three regions (Flanders, Wallonia, Brussels) tend to use one integrated TIMES model. Similar process workflow is adopted to derive building inputs for TIMES model. This is limited based on the availability of data sources and inputs (e.g., for Wallonia and Brussels, building function and construction year should be available to run the same logic of Flanders)However, simplifications and adjustments are before the actual implementation.~~

~~Geometry for Typology Clustering~~

~~For 3 regions, the methodology derives typologies with the geometry data + cadaster data (construction year). In Flanders, the building model is based on the BGS and construction year data. For Wallonia and Brussels, building geometrical data are available but needs to be further processed. The methodology of deriving typologies is thus streamlined in 3 regions.~~

~~Tabula data typology acts as the backup solution for Wallonia and Brussels as the geometrical data might be not feasible to deal with/or with low data quality (LOD1 in Wallonia).~~

~~The number of typologies is carefully defined/limited due to the calculation capacity of TIMES model, and key parameters of typologies are defined as follows:~~

- ~~**Basic parameters** for the clustering analysis:~~
  - ~~**Construction period** (3-4 construction periods – pre-1970, 1970-1990, 1990-2010(or 2006 as boundary), after 2010 (2006)). In the event of existing strong correlations between construction year and geometry, the analysis considers the construction year. Clusters are based on geometrical data when no correlations exist. The clusters identify and assign centroids to each construction period, which are further run centroid in EBECS using different renovation packages. This is followed by merging clusters together.~~
  - ~~**Building type** (4 types: terraced, detached, semi-detached, apartment)~~
  - ~~**Geometry** (3 geometrical representations – small, medium, large categories are assigned numbers using the centroid values of the cluster.~~
- ~~**Derived/calculated parameters**: Based on the construction period, building characteristics (U value etc.) are estimated for Flanders, f. For Wallonia and Brussels, Tabula is identified as the backup solution with similar logic as implemented for Flanders.~~
  - ~~**Renovation measures**: Only building envelope related measures with the cost's figures.~~
- ~~Heating source for each typology (gas, oil, electricity, etc.)~~
- ~~**District heatingH potential:** yes or no, predefined for each typology, upscaled to estimate the total amount of buildings floor area. The ratio of demand side/supply side for Flanders is taken as 30%/70%.~~

~~Demand – Existing buildings~~

~~The baseline demand consists of (mainly) heating/DHW/cooling demand(s) of the existing building stock, calculated using EBECS with the derived typologies from clustering analysis. The current heating/DHW/cooling demand(s) are cross checked and verified with the national/regional energy balance data.~~

~~Demand - New buildings~~

~~The typologies of new buildings are derived from the clustering analysis to define the current new built demand.~~

Commented [PV80]: For everyone? What are the conditions here?

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Commented [PV81]: What is BGS data? Where do you geometry/cadaster/BGS and construction year data?

Commented [PV81]: What is BGS data? Where do you geometry/cadaster/BGS and construction year data?

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Commented [PV75]: This sentence was not correct, we built a three-regional model in EPOC

Commented [PV76]: And isn't it? Which data sources a missing that are available in Flanders and not in Wallonia/Brussels? It is interesting to note for FOD!

Commented [PV76]: And isn't it? Which data sources a missing that are available in Flanders and not in Wallonia/Brussels? It is interesting to note for FOD!

Commented [PV77]: Remove this sentence? 'probably required', what does that mean? Maybe this sentence is

Commented [PV77]: Remove this sentence? 'probably required', what does that mean? Maybe this sentence is

Commented [PV78]: Are they not available, or did we never ask for it?

Commented [PV78]: Are they not available, or did we never ask for it?

Commented [MHS79R78]: These characteristics are n available. TO our knowledge, Flanders has the most

Commented [MHS79R78]: These characteristics are n available. TO our knowledge, Flanders has the most

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Commented [PV82]: Can you indicate which of the dat your document is confidential and which could be shared

Commented [PV83]: Where ? What is the difference w Flanders quality?

Commented [PV83]: Where ? What is the difference w Flanders quality?

Commented [PV84]: So, did we do this in EPOC?

Commented [PV84]: So, did we do this in EPOC?

Commented [PV85]: I don't think you described and referred to EBECS already in this document?

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Commented [PV86]: This is an assumption, based on Warmtekaart? Can we still somehow quantify this

Commented [PV86]: This is an assumption, based on Warmtekaart? Can we still somehow quantify this

- ~~Current total floor area of the new built~~
- ~~Historical new built rate as reference – assumes a fixed rate or parameter time.~~
- ~~Availability of land for new built~~
- ~~Policy elements and implementation timeline considered for new building's demand calculation (e.g., EPC requirements in Flanders, and PEB in Wallonia and Brussels).~~
- ~~Assume X% of new buildings are EPC B, Y% are EPC A~~

~~Renovation measures~~

~~The renovation measures in TIMES model focus the building fabric (roof, wall, windows). Constraints are set within the TIMES model when evaluating.~~

~~Renovation scenarios include:~~
- ~~Roof~~
- ~~Wall~~
- ~~Window~~
- ~~Roof + Wall~~
- ~~Roof + Window~~
- ~~Wall + Window~~
- ~~Roof + Wall + Window~~

~~The renovation packages are generated by EBECS and are further fed into the TIMES model. This includes a pre-screening of the measures due to the limitation of TIMES calculation time.~~

~~District heating potential: Flagged as a binary object in TIMES~~
- ~~District heating links to some specific typologies in some districts.~~

~~Data sources~~
~~The available data sources are listed below.~~

~~Wallonia 3D LOD1 data available at:~~
~~http://metawal.wallonie.be/geonetwork/srv/fre/catalog.search#/metadata/9a8322bd-f53a-4f99-ad9e-753b45bdee85~~

~~Brussels 3D LOD2 data available at:~~
~~https://datastore.brussels/web/data/dataset/93b1bcb1-2adb-4cf8-9e5d-381e9904536c~~
~~https://datastore.brussels/web/urbis-download~~

~~Kadaster geometry data available at:~~
~~https://eservices.minfin.fgov.be/ecad-web/#/~~
~~https://financien.belgium.be/nl/particulieren/woning/kadaster/kadastraal-plan/webservices~~
~~https://eservices.minfin.fgov.be/myminfin-web/pages/cadastral-plans?_ga=2.258821898.1682011347.1611238518-1808881337.1608389553~~
~~https://eservices.minfin.fgov.be/myminfin-web/pages/cadastral-plans~~

Commented [PV87]: @Joris, I think all TIMES related d are already in our EPOC database, correct?

Commented [PV88]: In general, what was the data exchange with ULB and vITO – district heating?

Commented [MHS89R88]:

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~~https://ac.ngi.be/catalogue?language=en&tab=overview&subtab=overview_catalogue~~
~~https://ac.ngi.be/catalogue?language=en&autoSelect=false&order=ngi-standard%2FVectordata%2FL08%2FShape%2FTop10Vector%2FTop10Vector_Constructions_shp_L08.zip~~

~~Brussels building datasets~~

- ~~Social indicators: https://wijkmonitoring.brussels/tables/~~
- ~~Retrofit typologies: https://www.brusselsretrofitxl.be/documentation/retrofitting-themes/brussels-housing-typologies/~~
- ~~Brussels non-residential actual energy use data – large public buildings (all large public buildings (incl. EC) have now their metered annual energy consumption (EP) online available online): https://www.peb-epb.brussels/pub-frontoffice/pages/anybody.xhtml~~
- ~~Other open data (energy consumption available): https://opendata.brussels.be/explore/?q=building&sort=modified~~

~~Wallonia dataset:~~

- ~~Energy: https://walstat.iweps.be/walstat-catalogue.php?indicateur_id=811400&ordre=7~~

~~National dataset:~~

- ~~https://www.geo.be/catalog/details/5cfe8a91-3dc9-4cf6-a40a-6a6d6f3124ab?l=en~~

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Beyond EPOC: Future Work

The residential typologies defined in the EPOC project scope will work as the basis to conduct future policy support studies. Some of the already implemented work on clustering include hybrid heat pump analysis for VEKA and developing a heat zoning map for VVSG. The devised typologies could further be used to create city-wide heat zoning plans through the available local data. The broad scope of implementation would eventually merge with national level councils, for instance, Minaraad (Environment, Nature, and Energy Council of Flanders). The non-residential stock will form the basis of harmonized and aligned research into the existing performance characteristics of public buildings.

Some recommendations for additional data enhancement for the region of Flanders include the availability of regional energy balances and availability of equipment stock information. Recommendations for Brussels and Wallonia region include the availability of anonymized EPC related information, building characteristic values and GIS related information (geometry).

Publications (EPOC)

[1] Ma, Y. and G. Reynders (2019). "Data-driven statistical analysis of energy performance and energy saving potential in the Flemish public building sector." Journal of Physics: Conference Series **1343**.
[2] Glenn, R., et al. (2020). Potential macro-economic benefits of optimizing building renovation roadmaps towards 2050 on a city scale: A Belgian case study. Proceedings of uSim Conference 2020: 2nd uSim Conference of IBPSA-Scotland, IBPSA-Scotland. **2:** 60-67.
[3] Borragán, G., et al. (2021). Renovating Herentals: a building classification approach to assess large-scale renovation costs Proceedings of 17th IBPSA Conference 2021. Bruges, Belgium, IBPSA**: 337-341**.

Commented [PV90]: So what happened for Wallonia/Brussels?

Commented [PV91]: This is not an EPOC paper…

Commented [MHS92R91]: They forgot to include an acknowledgement but once you go through the paper, th entire methodology of EPOC is replicated in this research and showcased for Herentals.

Commented [MHS93R91]: Is there a hard rule that th research cannot be included if the name is not there? I th the content in itself describes the scope of EPOC.

Commented [PV94]: Are these EPOC papers?

Commented [MHS95R94]: Yes

Commented [PV96]: Also not an EPOC paper, neither i the EnergyVille position paper?

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ANNEX A Residential Cluster Dataset

Dataset Description (File Location: Y:\Unit_SEB\1_MACS\Projecten duwobo\1810428-01 EPOC subproject MACS\3 Working documents\Export to TIMES)

File Name: EBECS_output_v_eff_jrc.xlsx

This excel sheet lists the building clusters identified in this task. Users can filter out the clusters based on different dwelling types (column D), construction age bands (Column C) and renovation packages (Column BU). Other building properties of the clusters are hidden as the default setting, but users can unhide these columns to check individual properties.

	addres			eating_consumption/m		production_efficiency	SH_total_efficiency	DHW_total_efficiency	net
0	Type_1	<1945	detached	146	14	0.798410018	0.705	0.601	
36	Type_2	<1945	semi_detached	142	14	0.726685241	0.705	0.601	
72	Type_3	<1945	terraced	111	15	0.962622007	0.705	0.601	
108	Type_4	<1945	apart_flanders	177	16	0.962622007	0.705	0.601	
144	Type_5	<1945	apart_brussels	178	15	0.962622007	0.705	0.601	
180	Type_6	1946-1970	detached	133	15	0.962622007	0.705	0.601	
216	Type_7	1946-1970	semi_detached	131	15	0.962622007	0.705	0.601	
252	Type_8	1946-1970	terraced	96	15	0.962622007	0.705	0.601	
288	Type_9	1946-1970	apart_flanders	139	16	0.962622007	0.705	0.601	
324	Type_10	1946-1970	apart_brussels	140	15	0.798410018	0.705	0.601	
360	Type_11	1971-1990	detached	90	14	0.798410018	0.705	0.601	
414	Type_12	1971-1990	semi_detached	91	16	0.798410018	0.705	0.601	

Age Band and Dwelling Type Clusters

Normalized (per m²) space heating and domestic hot water consumption along with production, space heating and domestic hot water efficiencies.

Figure 4 EPOC Output Snippet 1: Cluster Details

The snippets represent the residential clusters identified within the scope of the EPOC project. The excel files could be referred directly for details on the calculation of individual columns.

_SH_demand	net_dhw_demand	net_heat_demand	net_sh_demand_reduction	net_dhw_demand_reduction	OUTPUT (PJ/Mm²)
102.828672	8.301985663	111.1306577	0	0	0
99.82948734	8.704102954	108.5335903	0	0	0
78.48937583	8.832225764	87.32160159	0	0	0
124.7414346	9.901397949	134.6428326	0	0	0
125.4834923	9.268806923	134.7522992	0	0	0
93.54076336	8.717303647	102.258067	0	0	0
92.51174767	9.288775078	101.8005228	0	0	0
67.61794014	9.202736922	76.82067706	0	0	0
98.01343846	9.901397949	107.9148364	0	0	0
98.75553231	9.268806923	108.0243392	0	0	0
63.33940017	8.689290268	72.02869044	0	0	0
64.12912844	9.430153805	73.55928225	0	0	0

Normalized net et space heat, net domestic hot water and net heat demand after considering the system efficiencies.

Reduction in net space heat and domestic hot water demand after the consideration of different renovation packages

Normalized total output energy consumption

Figure 5 EPOC Output Snippet 2: Cluster Details

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ANNEX B Time-series Profile Dataset

Dataset (File Location: Time-series end use consumer profiles)

This dataset contains the end use consumption profiles of single-family dwellings. The following profiles (yearly time-series and 15 minutes resolution) are available via the link above.

1. Electricity consumption profile
2. Gas consumption profile
3. Dry-bulb temperature
4. Space heating consumption
5. Domestic hot water consumption profile
6. PV on-site generation profile
7. Global Solar Irradiation

The following scenarios have been simulated to create 700 end-use time-series profiles for single family dwellings.

1. Non-renovated households with gas boilers
2. Renovated households with gas boilers and fabric upgrades (U-values)
3. Renovated households with heat pump
4. Renovated households with heat pump and on-site PV
5. Renovated households with heat pump and on-site PV for past weather data
6. Renovated households with heat pump and on-site PV for current weather data
7. Renovated households with heat pump and on-site PV for future weather data

Annex C Non-residential Typologies Dataset

Dataset File Location: Y:\Unit_SEB\1_MACS\Projecten duwobo\1810428-01 EPOC subproject MACS\3 Working documents\Non-residential\CISBAT paper\EPC public database analysis

File Name: CISBAT statistical results.xlsx and simplified_UEP.xlsx

Construction Year Category	Public Building Category	Useful Floor Area (m2) Category	Median EPC Score
>2010	cultural buildings	5000-6000	271.96
>2010	cultural buildings	3000-4000	209.775
>2010	cultural buildings	2000-3000	186.375
>2010	cultural buildings	1000-2000	152.75
>2010	cultural buildings	<1000	151.58
2000-2010	cultural buildings	>20000	396.76
2000-2010	cultural buildings	10000-15000	386.75
2000-2010	cultural buildings	9000-10000	338.69
2000-2010	cultural buildings	8000-9000	92.2
2000-2010	cultural buildings	7000-8000	220.085
2000-2010	cultural buildings	5000-6000	180.54
2000-2010	cultural buildings	4000-5000	310.56
2000-2010	cultural buildings	3000-4000	242.835

Figure 6 Snippet 1: Non-residential clusters with quantified EPCs.

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ID	Public Building Type	Median EPC Score	Avg. EPC Score	S
7	administrative building	214	242	
18	airport building	888	888	
14	cultural or meeting building	194	223	
1	daycare and/or after school care	202	230	
9	elderly home	307	333	
5	higher education and universities	198	229	
8	hospital	396	393	
21	justice court	208	208	
16	library	200	229	
15	museum	242	271	
6	other educational infrastructure	194	220	
10	other welfare provision	227	254	
19	police office	286	299	
20	post office	287	300	
2	pre-primary school	165	188	
3	primary school	152	172	
4	secondary school	145	165	
13	sports hall	230	270	
11	sports hall with swimming pool	634	978	
17	station building	430	490	
12	swimming pool	1064	1146	

Figure 7 Snippet 2: Non-residential Building Archetypes.

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