TECHPED – IDENTIFYING TECHNICALLY FEASIBLE AND EFFECTIVE SOLUTIONS TOWARDS POSITIVE ENERGY DISTRICTS (PEDs)

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ABSTRACT

Positive Energy Districts (PEDs) are considered an appealing solution for decarbonising the urban environment. However, as of today, no standard modelling procedure, nor assessment methodology exists for the design and control of PEDs. Therefore, the research project "TECHPED" is carried out to identify technically feasible solutions for the design and operation of PEDs. The envisioned solutions include both the system layout and the control, rendering a "workable" concept of PEDs with all their (inter)connections. Firstly, this paper presents a new PED definition as this is critical for the identification and assessment of feasible solutions. Secondly, this paper explains the applied method that allows to easily compare multiple system layouts, control strategies, and pricing schemes. The core of this method is a template for district modelling, which is a base class that can describe every district. This template includes a demand, a supply, a storage, and a network block. A connection to the wider network and a control agent are present as well. Finally, an illustration for modelling a tiny cluster shows the strengths of this method in terms of structure, modularity and scalability.

INTRODUCTION

In the twenty-first century, human society relies on an increasingly rising energy demand, despite all efforts made to increase energy efficiency. More than 80% of the global final energy use in 2019 originated from fossil fuel combustion processes (International Energy Agency), which are responsible for the emission of mainly CO_2 and some other pollutants, hence contributing to climate change and other environmental problems. To minimise these negative impacts, a number of European and international targets have been set (United Nations, United Nations Framework Convention on Climate Change, European Commission 2050 long-term strategy). A necessary path to achieve these targets is to decarbonise the urban environment, as the residential, commercial, and public sectors account for 29% of the global final energy use (2019) (International Energy Agency). Moreover, depending on the share of the transportation sector that can be allocated to the urban environment (passenger and light-duty vehicle transport), the urban environment accounts for more than 40% of the global final energy use (2019) (International Energy Agency, U.S. Energy Information Agency).

An appealing solution for decarbonising the urban environment is the deployment of Positive Energy Districts (PEDs). Even though there is still no solid and universally accepted definition that imposes minimum requirements on PEDs, it is generally accepted that PEDs are neighbourhoods that aim to maintain an annual positive energy balance by integrating renewable energy technologies and thus reducing climate impact of the PED's energy system. However, a clear and appropriate approach to implement PEDs does not exist yet. A PED is a complex integrated system. Several energy technologies are connected in a cluster of buildings and they interact with that cluster and with each other. To provide the required energy services to the end-users, i.e. thermal comfort and electrical appliances, there are multiple possible designs, each with a different selection and sizing of technologies. Moreover, the operation of the energy system depends on many degrees of freedom (e.g. setpoint temperatures, flow rates, operation modes) and variables (e.g. solar irradiation, outside temperature, energy prices, user behaviour). Changing one parameter often affects the whole system and not only one specific (set of) parameter(s). Furthermore, the realisation of a PED requires a substantial effort (technical, economical, legal, practical…). Therefore, it is important to identify a workable, reliable and affordable solution upfront to make the efforts rewarding and profitable.

The identification of such solutions can be done through simulations, which are less time-consuming and less expensive compared to physical experiments. Simulations by a digital twin enable the analysis and assessment of selected integrated energy systems and control strategies within various clusters of buildings. Numerous methods, approaches, and tools have been developed to model and optimise multi-carrier energy systems in mixed-use clusters of buildings (Klemm and Vennemann). However, these tools are not yet able to identify *workable* solutions for PEDs due to one or more of the following shortcomings. A first issue is posed by the scale and resolution of the problem, which both need to be meaningful in spatial and temporal dimensions. A PED is a cluster of buildings, hence the analysis of results at the building level is more relevant than an aggregated regional or national level. Besides, a PED aims for an annual positive energy balance, so shorter periods cannot assess the overall performance of a PED, unless representative days are used and scaled to a full year (Poncelet et al.). From a building control perspective, small time steps are desired. This is because the time constants of the Heating, Ventilation and Air Conditioning (HVAC) and electrical systems are typically small. A second issue relates to the level of detail of the simulation (and optimisation) model. Ideally, all physics are modelled to best describe the real system in a virtual environment. Although simplifications are necessary in some cases, they are not always justified. Replacing a building with a simple energy demand profile is an inadequate practice as the building can offer flexibility thanks to its thermal inertia. Linearising or neglecting the dynamic behaviour of some components in the PED also threatens the validity of the result, so well-motivated choices should be made. Coupling supply and demand agents while neglecting the network hampers the validity of the end result, as it is not supported by a physical concept. All these issues influence both the design and the operational control strategy, and hence the PED performance.

To move a step forward in this domain, the collaborative research project “TECHPED - TECHnically feasible PEDs” has started at KU Leuven. In this project, four research groups with backgrounds in thermal and electrical systems simulation, optimal control, machine learning and energy markets, bundle their knowledge and expertise. The main goal is to develop scientifically sound technical solutions that are feasible and affordable to realise the systematic deployment of PEDs thereby reducing climate impact in the built environment. The envisioned solutions in this project include both the system layout and the operation/control, rendering a workable concept of PEDs with all their (inter)connections. Moreover, the project takes existing building clusters as a starting point because it is an enormous challenge to decarbonise the existing building stock, more than only considering newly built buildings and sites. To incentivise the identified solutions, meaningful pricing and tariffication schemes are analysed and developed.

The goal of this paper is to introduce the TECHPED research project approach. First, this paper discusses a new PED definition as this is critical for the identification and assessment of feasible solutions. The second part explains the applied method, which is based on a template developed for (Positive Energy) Districts. This part also motivates the chosen modelling approach. The third part illustrates the method by modelling a tiny cluster consisting of three residential houses. A conclusion section finalises this paper.

DEFINITION OF A PED

This section describes the PED definition that is chosen for this work. First, a literature review motivates the configuration of a new definition and emphasizes the points that have to be tackled. Then, the definition is formally introduced.

Literature review

Brozovsky et al. include 144 scientific papers in their review on zero-emission neighbourhoods, positive energy districts, and similar concepts of Climate Friendly Neighbourhoods (CFNs). First, they observed that there is some ambiguity and sometimes even disagreement on how to name a cluster of buildings. The words *neighbourhood, district, block, community, settlement*, or *precinct* are all used. Additionally, they found several combinations with the words *net-zero, nearly zero, zero, plus, positive, energy* and *carbon* to describe all forms of CFNs. In total, the authors identified 35 different terms for CFNs of which Zero Emission Neighbourhood (ZEN) is used most frequently (30 times out of 144). Positive Energy District is the second most frequently used term (13 times out of 144). 21 terminologies are used only 2 times or less. However, the term PED is becoming more common. There are currently multiple international and EU organisations, programmes, and projects that use the term PED and work on the development and deployment of PEDs (Albert-Seifried et al., IEA-EBC). Given the review results of Brozovsky et al. and the use of PED as terminology by multiple international stakeholders (including researchers), the term PED is also used in this work.

Albert-Seifried et al. list and compare the PED definitions of five prominent EU programmes and nine PED-relevant projects across Europe. They distinguish several key elements from the thirteen analysed definitions. These key elements relate to the calculation of the energy balance, the energy concepts the scale of the district, the boundary conditions and non-energy issues. Almost all identified key elements of Albert-Seifried et al. are present in the definition of Ala-Juusela et al., which is a very extensive and complete definition of an energy positive neighbourhood. On top of the key elements of Albert-Seifried et al., Ala-Juusela et al. add another important key element, namely the 'contribution to the wider energy networks'. This means that, if a PED is connected to the wider energy networks, the PED should strictly avoid an increasing mismatch between energy demand and supply in the wider networks, and even try to decrease that mismatch and balance the wider grid. Concerning the connection with the wider energy networks, Wyckmans et al. distinguish two types of PEDs, namely a dynamic PED, and an autonomous PED, also discussed by Lindholm et al. A dynamic PED has a connection with the wider energy networks and can import and export energy as long as it supports the wider networks. An autonomous PED has no connection with the wider networks and should continuously balance its own network.

Proposal of new definition

Based on the aforementioned literature and other reviewed literature (SET-Plan Temporary Working Group 3.2, European Commission Smart Cities & Communities, European Commission Joint Research Centre, Urban Europe, European Energy Research Alliance), a new definition is suggested that completes some of the previously proposed definitions and shortens the definition of Ala-Juusela et al. to make it more practical and concise. Our definition is as follows:

> **Positive Energy Districts** (PEDs) *are* <u>*clusters of buildings*</u> *in well-defined geographical areas that yield an* <u>*annual surplus of energy*</u> *while fulfilling the* <u>*needs of their occupants*</u>*. They reduce energy-related* <u>*climate impact*</u>*, maximise* <u>*energy efficiency*</u>*, and offer* <u>*flexibility*</u> *services to the wider grid. PEDs support the integration of* <u>*distributed renewable energy*</u> *sources by using* <u>*multi-carrier*</u> *energy systems and* <u>*energy storage*</u>*.*

The first sentence describes a PED very concisely. A 'cluster of buildings' is the most general term to refer to a group of buildings. It does not refer to a specific size or building type since these aspects are not restricted for a PED, as long as no heavy industrial processes are included. In that way, the ambiguity that Brozovsky et al. explain, can be avoided, at least at the building level. These buildings are contained in a physical and thus geographical area and everything within these boundaries is part of the district (e.g. open space, streets, infrastructure, air, soil). As long as the area is well-defined and meaningful, even if the district consists of geographically separated parts, the district boundaries should be clear. In that way, renewable technologies that do not fit in a residential district (e.g. off-shore wind turbines), can nonetheless be assigned to the PED's energy system. Wyckmans et al. use the term virtual PED in such a situation. Furthermore, a main aspect of a PED is the annual surplus of energy while fulfilling the needs of its users. The energy surplus equals the total amount of energy generated in the PED minus the total amount of energy used for the needs in the district. Fulfilling the needs stresses that a situation without energy use does not make sense as the primary objective of a PED is to satisfy the energy needs of its users, including thermal comfort (heating/cooling) and electrical services (use of appliances), among others.

The second sentence stresses three requirements that a PED should fulfil. The main reason to implement a PED is its opportunity to reduce climate impact of energy supply in the built environment. So, the reduction of energy-related climate impact is a strong requirement for PEDs. The choice to go for 'climate impact reduction' rather than 'CO_2 emissions reduction' has been made intentionally as it points more towards a holistic life-cycle analysis of the energy system instead of only considering CO_2 emissions during operation. The land use and material use of renewable energy sources are, for instance, non-negligible parameters (United Nations Economic Commission for Europe). In this light, it is beneficial to reduce the total final energy use, which can be done by increasing the energy efficiency of the whole PED in the broadest sense of the word (encouraging energy sharing and reducing losses on component and system level). A third requirement relates to the flexibility services. As stated before, a PED is not allowed to misuse the wider energy networks to manage its power flows and energy balance. In general, energy flexibility stands for the ability to adapt the energy demand to the energy supply (or the other way around) in order to keep a balanced energy system. A dynamic PED can offer flexibility services to the wider grid by importing energy when the grid has an excess and exporting energy when the grid has a shortage.

The last sentence of the definition stresses that distributed renewable energy sources (RES) should be preferred above fossil fuel-based sources and names multi-carrier energy systems and energy storage as two enablers for integration of RES in order to achieve the requirements set for a PED.

The presence of the key elements mentioned by Albert-Seifried et al. and Ala-Juusela et al. is checked in our proposed definition. The majority of key elements are present. Note that the definition of the boundaries should make clear whether transport is included in a particular PED or not. The remaining key elements (which are social, economic and ICT related aspects) are intentionally not included in this definition as they do not bring a significant added value to this work.

METHOD

A key task in the collaborative TECHPED project is to compare multiple system layouts, control strategies, and pricing schemes to identify workable and affordable concepts for PEDs. We distinguish between district *use cases* and *layouts* as follows. A use case describes the existing boundary conditions, i.e. the cluster of buildings without specifying a particular energy system. It is characterized by the district location, type of buildings (and thus occupancy), the number of buildings, and the wider grid market. Possible use cases are for instance a tiny cluster with three residential buildings or a cluster of ten one-family houses, two multi-dwelling buildings, one hospital, and one office building. The layout is then the energy concept consisting of a selection of technologies for energy supply, storage, and emission and all (inter)connections between the technologies and the buildings in a particular use case. If a layout within a use case fulfils all requirements of a PED (cf. definition), then that layout is one possible solution for that use case and comprises a PED. Comparing multiple layouts using carefully selected Key Performance Indicators (KPIs) allows to find the feasible and effective ones.

To reach this goal, we aim to develop a general and modular method that can simulate and assess the performance of these solutions (i.e. layouts, given a specific use case). The core of this method is a template for district modelling, which is a base class that can describe every district, i.e. use case and layout. Models are developed using this template to simulate a specific layout for a particular use case. For this, Modelica has been chosen as the modelling language. Once the models have been developed, the KPIs can be calculated from model simulations and the layouts can be assessed such that one can determine whether the layout is a workable and affordable solution for a PED or not. Note that the method follows a white-box approach, which means all models are configured from physical equations (for which the parameters are physics-based) to describe reality. Furthermore, the template is meant to make district modelling consistent, structured, and compact, while keeping a one-to-one mapping between the real system and the virtual model.

Template for a (Positive Energy) District

In this section, the structure of the template for consistent modelling of different district use cases and layouts is described. Figure 1 schematically shows the simplified template. This simplification makes, for now, abstraction of the energy carrier type, as the idea is equal for each energy carrier. In a district, supply agents provide energy to the district (e.g. solar panels, a heat pump …). All n_s supply agents belong to the supply block, which specifies all supply agents. On the other side, the demand agents use the energy supplied to the district. n_d demand agents (e.g. multiple buildings) are grouped and specified in the demand block. To come to a workable system, there is the need for a network that physically connects the demand and supply agents. The network is characterised by a matrix that describes all connections. The next block in the template is the storage block that contains all n_{st} centralised (i.e. shared) storage components. A PED may also exchange energy with the outside world via a connection with the external network. Another very important element is the operational control, which is distributed among the whole district. As control is present in the different blocks and at different levels, it is visualised by a cloud icon in the template.

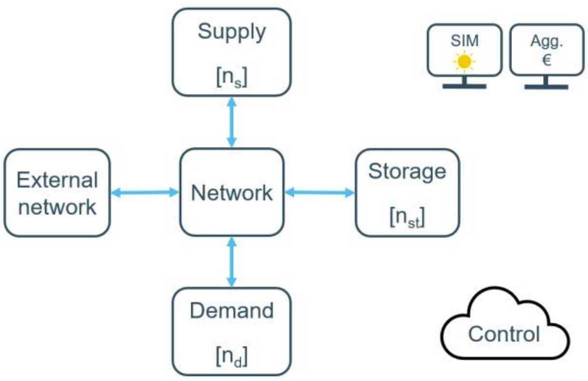

Figure 1: Template for a (Positive Energy) District

The two last blocks in the template are separated from the physical district as these are two information blocks. The Simulation Info Manager (SIM) contains all weather data that is required for the simulations (e.g. outside temperature, solar irradiance, …) and is inherited from the IDEAS Modelica library (Jorissen et al.). The Aggregator (Agg.) represents the internal energy market and propagates the internal pricing scheme and the external energy price. It is assumed that the external energy price is a prevailing market price that is not influenced by the activity of the PED.

Not all components should be present in each district. If a district can be considered as an energy island, the connection with the external grid disappears. A district does not require a shared storage, so this block can also disappear. However, in the latter case, it will be more challenging to meet the requirements of a PED. The supply and network components could also disappear if there is no shared supply agent.

Figure 2 represents the template for a district in which three carriers are present: heat (including cold), electricity and molecules. As the majority of dwellings in Belgium currently have (condensing) gas boilers as supply units for heating (Vlaams Energieagentschap), a connection to the gas network is present. Even though the goal of the project is to decarbonise the energy systems in the built environment, it is good practice to maintain resources that are already in-place (for their life time) and thus to possibly keep the individual gas boilers as units to cover peak demands within a hybrid energy system. Note that in the future, natural gas can be replaced by biofuels or hydrogen to still have a working solution while banning all fossil fuels.

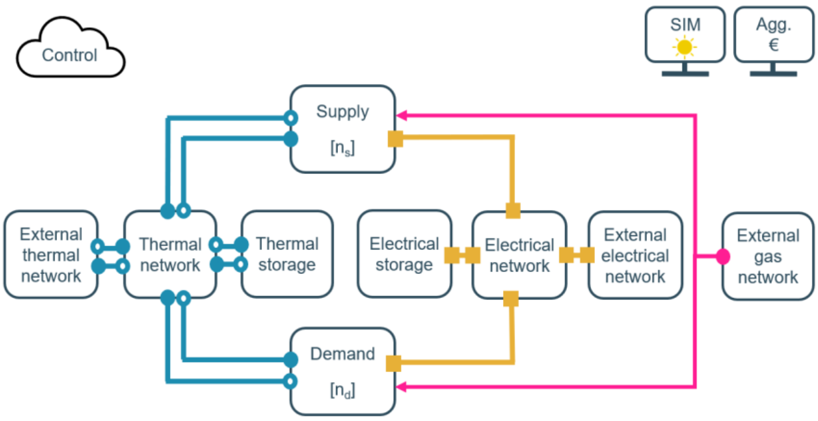

Figure 2: Elaborated template with heat, electricity and gas

Selection of the modelling approach

Before simulating a cluster of buildings with an energy system, (an) appropriate modelling tool(s) should be selected. Multiple tools have already been developed for modelling and optimisation of multi-carrier energy systems in mixed-use districts (residential and tertiary sector). Klemm and Vennemann reviewed 145 energy system modelling tools and selected 13 tools suitable for modelling and optimisation purposes, based on application area, methodology, geographic coverage, sectoral coverage and temporal resolution. However, none of the 13 selected tools are appropriate for our goal. Some are rather simple and do not cover a sufficient level of detail or lack relevant technologies, which means that the tools should be extended to a large extent. Others are not modular, but hard-coded. However, to assess different energy systems in clusters of buildings quickly, the configuration of the system layouts should be easy and preferably automated. Tools that are not open-source are also discarded because they do not allow to have a full understanding of the models behind and to make changes if necessary. In a nutshell, there is not yet a ready-to-use tool for simulating multi-carrier energy systems of mixed-use districts.

For the aforementioned reasons, the authors have chosen to set up their own framework relying on existing component libraries. In this sense, the Modelica language (Mattsson and Elmqvist) is the most appropriate. Modelica is an equation-based language used to model multi-physical systems. It supports acausal and object-oriented modelling which facilitates a modular structure of models. Multiple libraries are already available containing numerous models for components in energy systems (supply agents, demand agents, network components…), e.g. Modelica Standard Library (Modelica

Association), IDEAS (Jorissen et al.), Buildings library (Wetter et al.), which are verified and often validated… These aspects make Modelica very suitable for the modular white-box approach that is aimed for. Moreover, there is a broad and active community for the development and maintenance of the component libraries as well as the Modelica specification. Dymola (Dassault Systems) is used as modelling and simulation environment. Modelica supports simulation, but does not support optimisation, which is required for optimal control problems (OCP). However, it is possible to couple other programming languages (like Python, Julia, etc.) to the Modelica models which are suitable for OCPs, via the Functional Mock-up Interface (FMI) (Blochwitz et al.).

Hence, our objective is to complement the template with a new Modelica library for district energy modelling based on existing component libraries. Building up the library will allow to assess different levels of modelling detail. Coupling these models to external modelling and optimisation environments allows to compare different district layouts as well as to implement different advanced control strategies such as model predictive control (MPC) or reinforcement learning (RL).

DEMONSTRATION OF THE METHOD

In this section, the use and potential of the novel framework is demonstrated by a first implementation of the district template. The template is adopted to model and simulate a tiny cluster of three houses heated by a collective heat pump using Modelica. The district model and results are shown to illustrate the modularity, structure, and scalability of the template approach.

District template for a tiny cluster

The tiny cluster mentioned above is modelled in Modelica by using the district template approach and component models from the IDEAS Modelica library (Jorissen et al.). The resulting model is shown in Figure 3, which clearly shows four different blocks: a supply block (with green +), a demand block (with red -), a network block, and a control block, the so-called District Control Unit (DCU). Each of these blocks has its own parameters to adapt the models contained in the model layers behind. Additionally, the current rule based control is carefully defined to be representative of the envisaged building. The last component in Figure 3 is the SIM block that propagates all required weather data, as explained in Figure 1.

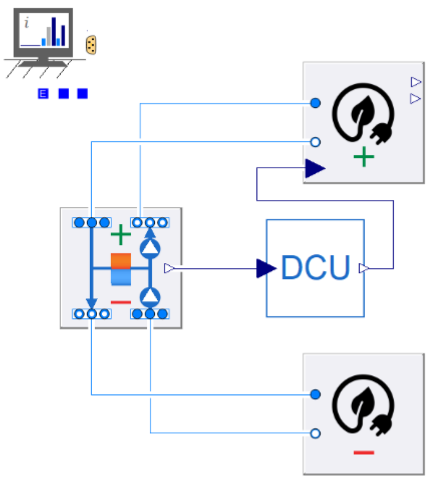

Figure 3: Resulting district model using template approach

To illustrate the modularity and scalability of this approach, variations in the demand block are investigated. A first input for the demand block is the number of buildings, which is always 3 for the considered tiny cluster. A second input is the type of model used to represent each building. In this illustration, three types of models are compared: a prescribed heat demand profile, a one-zone building model, and a two-zone building model. Note that each district model is configured from the template by simply replacing the demand block with each of the predefined demand models.

Table 1: Heat demand profile

Month	Time		Heat demand
Apr., May.	Day	8h – 18h	1800 *kW*
	Night	18h – 8h	0 *kW*
Jun., Jul., Aug., Sep.	Day	8h – 18h	0 *kW*
	Night	18h – 8h	0 *kW*
Oct., Nov.	Day	8h – 18h	1700 *kW*
	Night	18h – 8h	0 *kW*
Dec., Jan., Feb., Mar.	Day	8h – 18h	3500 *kW*
	Night	18h – 8h	1300 *kW*

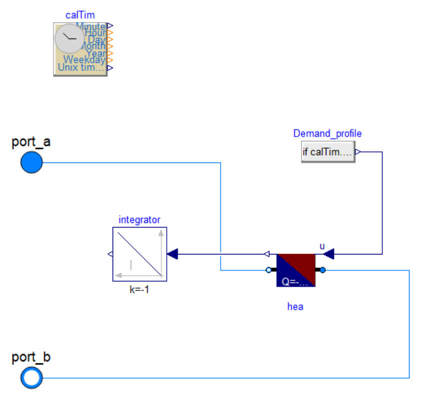

Figure 4: Representation of the building with heat demand profile model

These three demand models are shown in Figures 4, 5 and 6, respectively. All three models have fluid ports (visualised by the blue circles at the left) that connect to the network block. Firstly, the central component in the prescribed heat demand profile (Figure 4) is an ideal heat exchanger that takes heat from the fluid to mimic the building heat demand using a predefined and fixed heat profile. The heat demand profile is equal for the three buildings and is given in Table 1. This is an artificially composed profile based on three assumptions: (i) the heat demand is highest in winter and there is no heat demand in summer, (ii) the heat demand is higher during the day than during the night, and (iii) the total annual heat demand is similar to the simulated heat demand of the two-zone building model. This heat demand profile is an input for that heat exchanger. Secondly, the one-zone building model (Figure 5) is investigated. In this model, the building is represented by one room (one zone), four walls including windows, a floor and a ceiling. The heat to the zone is supplied by a radiator with a thermostatic radiator valve (TRV). Controllable screens, ventilation and individual chillers are added to prevent that the room temperature increases too much during summer due to solar gains. Thirdly, the two-zone building model (Figure 6), in which there is a “day zone” and a “night zone”, or a ground floor and a first floor, is considered. Each zone still has four walls including windows, a radiator with TRV, controllable screens, ventilation and individual chillers. The roof and floor of the two-zone building are equal to those of the one-zone building, but the two zones are separated by an internal wall.

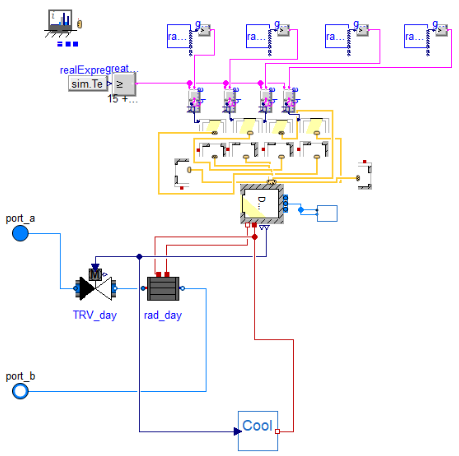

Figure 5: Representation of the one-zone building model

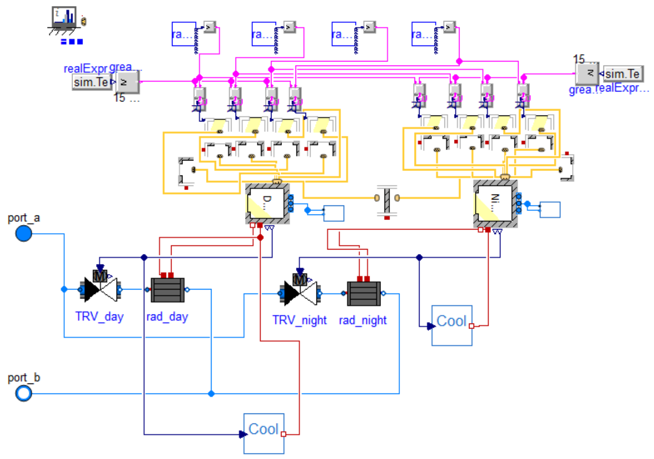

Figure 6: Representation of the two-zone building model

The main differences between the three demand agent models are the level of detail and complexity. A prescribed heat demand profile is simple and allows for quick simulations, but cannot exploit the building’s behaviour (e.g. to offer flexibility to the thermal network). Modelling a physical building allows for dynamic simulations that are computationally more demanding, but can take the building’s behaviour (i.e. building thermal inertia, heat gains and losses, weather, etc.) into account. The advantage of a two-zone model compared to a one-zone model is that both zones can be controlled separately. The temperature setpoint in a bedroom is usually lower than the temperature setpoint in a living room and a lower temperature setpoint for heating results in a lower energy use. Hence, to make a more realistic estimation of the energy use of a residential building, it is more appropriate to consider a day zone with a higher setpoint temperature and a night zone with a lower setpoint temperature. As switching between different building models is just changing a parameter in the overall district model, multiple layouts and levels of detail can conveniently be compared and assessed. This simple example illustrates the main aim of the district template: easily generating and comparing different district layouts.

Comparison of three demand block agents for a tiny cluster

In this example, the simulation results obtained by using the three different models for the demand block (cf. Figure 4, 5 and 6) are compared with each other. The demand block always represents a (virtual) tiny cluster in Belgium, consisting of three identical houses. Only the orientation of the houses varies, which means that, in case of the one-zone and two-zone building demand blocks, the rear façades of the houses (with a large window) respectively have an east, south, and west orientation.

Rule based control is applied for the screens and chillers. The screens are controlled based on the incident solar irradiation and outdoor temperature, while the chillers (each 1.5 kW) are on/off controlled between 24°C and 21.5°C. More parameters of the demand block models can be found in Table 2. The supply block contains in all three situations a collective ground source heat pump of 10.8 kW, and is coupled to the network block that contains a stratified (2 layers) buffer tank of 500 l and two pumps (one at each side of the tank). The heat pump is on/off controlled based on the temperature of the upper (hot) layer of the buffer tank which needs to be between 35°C and 55°C.

Table 2: Information on simulation parameters

	Heat demand profile	One-zone building model	Two-zone building model
Day zone	NA	10m x 10m x 5.6m	10m x 10m x 2.8m
Night zone	NA	NA	10m x 10m x 2.8m
Total window area	NA	22 m^2	22 m^2
Temperature setpoint day zone	NA	21°C	21°C
Temperature setpoint night zone	NA	NA	18°C

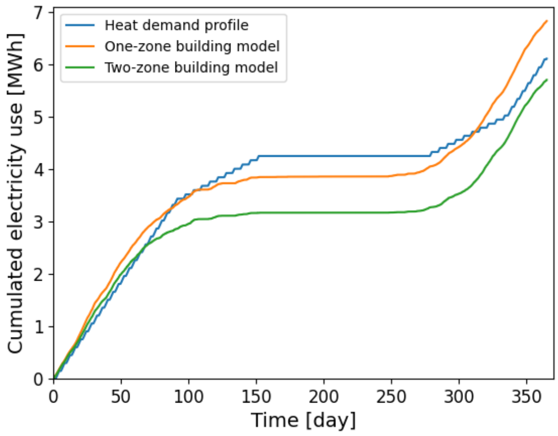

Figure 7: Cumulated electricity use of the collective heat pump

The three different demand block models are compared through annual simulations and the values of relevant KPIs are determined for each layout based on the simulation results. Figure 7 shows the cumulated electricity use of the collective heat pump for one year in all three cases. The total cumulated electricity use can be found in Table 3. The total energy use is compared with the Flemish average heating demand of a household. The energy flows, mass flow rates and temperatures in the energy system are verified to see whether these are realistic and logical.

As stated before, the heat demand profile (cf. Table 1) has been composed artificially, hence this result has no significance for now. Nevertheless, the difference in cumulated electricity use between the one-zone and two-zone building model is interesting. This difference proves that splitting a house into a day and a night zone, where the temperature setpoint of the night zone is lower than the one of the day zone, can reduce the energy use for heating the building. However, executing simulations with a complex two-zone building model more than doubles the computational time with respect to the simulations with the one-zone building model, as indicated in Table 3. The trade-off between the level of detail and computational time can be determined with this approach and is a subject for further analysis. For the sake of completeness, Table 3 presents two additional results that are relevant for a heat pump: (i) the cumulated condenser heat, which is the heat supplied by the heat pump to the thermal network, and (ii) the annual Coefficient of Performance (COP), which corresponds to an average COP calculated as the ratio of the annual heat supplied (condenser heat) to the annual electricity use. Besides these outputs, many other KPIs, that are more relevant for the assessment of PEDs, could be calculated from the simulations. However, this example is only an illustration of the district template and its structured, modular and scalable approach.

Table 3: Simulation results

	Heat demand profile	One-zone building model	Two-zone building model
Cumulated electricity use [MWh/year]	6.11	6.82	5.70
Cumulated condenser heat [MWh/year]	26.89	30.70	26.50
Annual COP [-]	4.40	4.50	4.65
Computational time [s]	24	120	261

CONCLUSION

An appealing approach to decarbonising the urban environment is the deployment of PEDs. However, until now there does not exist a clear and appropriate method to implement a PED as it is a complex integrated system. This paper contributes to the identification of workable solutions for PEDs by proposing a novel framework built around a template and model library. To be able to assess a solution in the end, a solid definition of a PED is required. Therefore, the first part of this paper discusses and proposes a new definition. Briefly, a PED is a cluster of buildings that generates an annual surplus of energy and fulfils the needs of its occupants. A PED should reduce energy-related climate impact, maximise energy efficiency and offer flexibility services to the wider grid. In order to meet these requirements, a PED relies on distributed renewable energy sources, multi-carrier energy systems and energy storage. The second part of this paper discusses the applied method for the identification of workable solutions. The method is based on a template for a (Positive Energy) District. The main components in the template are the demand, the supply, the storage and the network blocks. Besides, there is a connection to the external networks for each carrier in the district. The control, the Simulation Information Manager and the Aggregator blocks complete the template and allow for dynamic simulations. Modelica has been chosen as modelling language and can be coupled to any other programming language via the Functional Mock-up Interface for the implementation of advanced control strategies such as MPC and RL. The last part of this paper presents an illustration of the implementation of the template. This illustration shows that the approach is modular, structured and scalable, which are requirements for the identification and assessment of solutions for PEDs under multiple existing boundary conditions.

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