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Large building stock energy simulation for the design of district heating networks : A case study on building retrofit policies

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Abstract:

The Belgian building sector is responsible for a significant share of greenhouse gas emissions, partly because of the poor quality of its insulation and partly because fossil fuels are the main energy source for heating buildings. To decarbonize the heating of urban housing, district heating networks are good candidates. Indeed, district heating networks allow to improve load factor, to combine heat and power, to recover waste heat or to diversify the energy sources, including renewable sources (biomass, solar, geothermal, etc.). To design an efficient district heating network and take most of the improved load factor, a very precise knowledge of the heating needs of the buildings connected to the network is required. Thus, the first part of this work consists in creating robust, detailed, and automated physical models of the building stock, its equipment, and its use profiles to obtain detailed hourly load curve. The modelling tool used is the existing open-source Modelica library IDEAS, developed by the KU Leuven. The second part of the work includes the construction of a district heating network model and its regulation. This model is then coupled to the building simulation model. The combination of these two models allows to study the impact of a change in setpoint temperature in buildings or a massive insulation of the building stock on the buildings load curves and than on the regulation of the district heating network. The considered case study is a six buildings district of the University of Liège located on the Sart Tilman campus. The application of the building modelling methodology and energy saving policies to the test case shows that the approach considered is appropriate from a practical (easy scalable) and accuracy point of view and that energy saving measures cannot be taken without studying the consequences on the network operation.

Keywords:

District Heating Network, Building Simulation, Retrofit Policies, Large Building Stock

1. Introduction

The building sector is responsible of a significant part of the greenhouse gas emissions in Europe. According to [1], it is second largest contributor to greenhouse gas emissions in Belgium. This state of affair is mainly due to the use of fossil fuel combustion to heat the building and provide domestic hot water. The recourse to other primary energy sources is often expensive or not feasible when considering each building individually. District heating networks, on the other side, offer a different perspective by grouping the heat demands of different buildings on one single infrastructure thus providing economy of scales. District heating networks are also known to better exploit renewable energy resources such as biomass, solar or geothermal energy. Yet, developing and operating district heating networks is a challenging task as heat is difficult to transport efficiently and requires large investments.

Apart from the obvious economy of scales obtained from centralised rather than local heat production, an important advantage of district heating networks resides in the fact that all connected consumers will not need their peak consumption at the same time. Therefore, the rated power of the district heating network may be lower than the sum of the connected peak demand of the individual consumers. This improves the load factor and allows to leverage the high investment costs. Yet, taking advantage of the aggregation of loads requires a very accurate knowledge of the heating demands all throughout the year. To do so, monitoring data could be used to analyse the opportunity of district heating networks and optimise their structure and operation [2], however monitoring data for heating demands are very difficult to find and simulation is very often used instead to deduce heat demand curves.

A very large number of methodologies have been developed to obtain these demand curves from the building characteristics. They range from the very well known degree-days method [3] coupled to daily demand profiles [4] to the use of heating degree-hours and other methods such the one developed in the library *Demandlib* (see [5] for more details) that is based on air temperature and benchmark data. The very first scope of these

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approaches is to simulate very large stock of buildings with synthetic information (the surface and the usage of the building) to determine an average heating demand curve directly from annual energy consumption data. These methods have the advantage of requiring very little data but do not take into account the individual properties of the buildings (e.g., orientation, occupant behaviour, ...) and also depend on a standard base temperature under which the building requires heating [6]. A slightly more advanced approach is considered by the library TEASER (see [7] for more details) where building archetypes, statistical data and national and international standards are used to simulate a large number of buildings from a minimum of information while maintaining the accuracy.

In this work, the aforementioned methods are not appropriate as the individual character of every buildings is overlooked, which prevents from properly predicting the peak loads and therefore to correctly evaluate the opportunity of lumping different loads altogether on one district heating system to improve the load factor. For example, while the tool TEASER enables the simulation of a large number of buildings in a dynamic and rapid manner, it is still built from archetypes. One of the goal of this contribution is to be able to model buildings taking into account their particular characteristics when they are available while considering standard configuration when they are not. It is especially the case for tertiary buildings whose structure changes widely from one building to the other and where different usages will generate totally different heat demand curve. The desired modelling must therefore be parametrised, based on observable characteristics, while remaining fast, robust and, hopefully, accurate. The first contribution of this work consists in defining a quick and accurate modelling methodology applicable to tertiary buildings. Moreover, the fact that the model is parametrised with observable characteristics (insulation thickness, orientation, window type, schedule of heating, regulation, ...) rather than on standards makes it possible to investigate specific energy saving measures in great details and to evaluate their influence on the operation of district heating networks.

The important outcome of the simulation are the peak demand (both in time and amplitude), the base demand and the total energy consumption per month and per year. As a result, it is possible to evaluate the impact of energy saving measures on the regulation and operation of the district heating network. On the one hand, a methodology to model the buildings is first established. Then, the district heating network is introduced and the basic assumptions are laid out. Two energy saving measures are considered herein namely, a change in user behaviour (i.e., a modification of the setpoint temperature in the buildings), and an additional thermal insulation.

In this contribution, the building stock model based on the library IDEAS [8] is used to build the simulation model which, in turn, is coupled to a district heating simulation model so as to underline the strong dependency between building renovation and/or regulation strategies and the operation/design of a district heating network. The outcome of a more accurate building simulation based on the actual and specific building architecture/use coupled to a model of the heat distribution is a more accurate evaluation of its thermal losses and pumping work therefore improving the evaluation of the heat transport efficiency. Both the building model and the district heating network model are thermal inertial models, taken into account the heat storage in the structure for the former and the dynamic behaviour of heat transport for the latter. More, these models are intended to compare the energy needs of the buildings and the district heating network for different energy policies and to study their impact on the network operation. Therefore, this article does not quantify the amount of primary energy required to operate the network or the associated emissions.

This contribution is primarily concerned on explaining the basic assumptions and philosophy of the building simulation model and then underlines its usage in the frame of district heating network operation. This is done by following an application framework from the campus of the University of Liège which is already equipped with a district heating network and where energy saving measures are currently discussed. For sake of simplicity, the test case is limited to a subset of 6 buildings among the 60 buildings located on the Campus. This application is insightful to understand the influence of building renovation and occupant behaviour on the future choice for the district heating network.

The methodology followed in this paper is described in Section 2.. Subsections 2.1. aims at describing the proposed building model, the one whose compatibility with the modelling of the tertiary sector must be studied. Subsection 2.2. describes the district heating network model and its assumptions. Then, Subsection 2.3. presents the reference test case studied as well as the variants considered as retrofit policies. The results of the simulations are then presented in Section 3.. This section is divided in different parts. First, the compatibility of the building model with the tertiary sector is assessed thanks to a validation through monitoring data. Then district heating simulation results for the variants are showed.

2. Methodology

The characteristics of a building simulation model is highly dependent upon its final use. Many building simulation models are intended to forecast the comfort conditions or for control of HVAC equipment and thus require a very detailed description of the building architectural structure. These models are usually accurate but require an enormous amount of parameters not always available for existing buildings plus a significant amount of time to setup the model. These approaches are achievable when one is interested in one specific building but is not very accessible when hundreds of buildings or more have to be dealt with. Another important aspect resides in the connection of the building model to the district heating network that must be done in a standardised way whatever the complexity of the connected building, i.e., hourly heating and electrical demand.

2.1. Building simulation model

In order to benefit from previous research works in the modelling of district heating network (see [4]), the platform Dymola [9] has been first selected as a common platform. It has the advantage to support the open language Modelica and possesses numerous libraries for the building energy simulation. One specific library has been used as a building block for the building energy simulation, namely the library IDEAS (Integrated District Energy Assessment by Simulation) and developed by the KU Leuven (the interested reader is merely referred to [8] for a more complete information). It is a proven and robust library with a thorough manual available which provides rapid and safe implementation. It also provides, if necessary, a nice graphical user interface and does not require a very large number of parameters to be used. It is able to handle very simple buildings like houses and appartements but is also easily customisable to create complex building configurations like the ones considered hereafter.

For the buildings models, different assumptions are made. The building is divided into zones representing a set of rooms sharing the same temperature and ventilation requirements. This division into zones represents a simplification of the modelling as the thermal inertia of the internal walls is not taken into account when several rooms are lumped together. As an example, Fig. 1 exhibits the original available drawing of a building and the corresponding zones. A further simplification consists in reducing the shape of the buildings to rectangular zones so as to simplify the representation of complex buildings while keeping the exposed surfaces unchanged as well as their orientation. Each zone consists of a uniform air volume, a heating model, a ventilation model and the exterior surfaces (interior walls, exterior walls, windows, floors and ceilings). The model of a zone can be seen in Fig. 2.

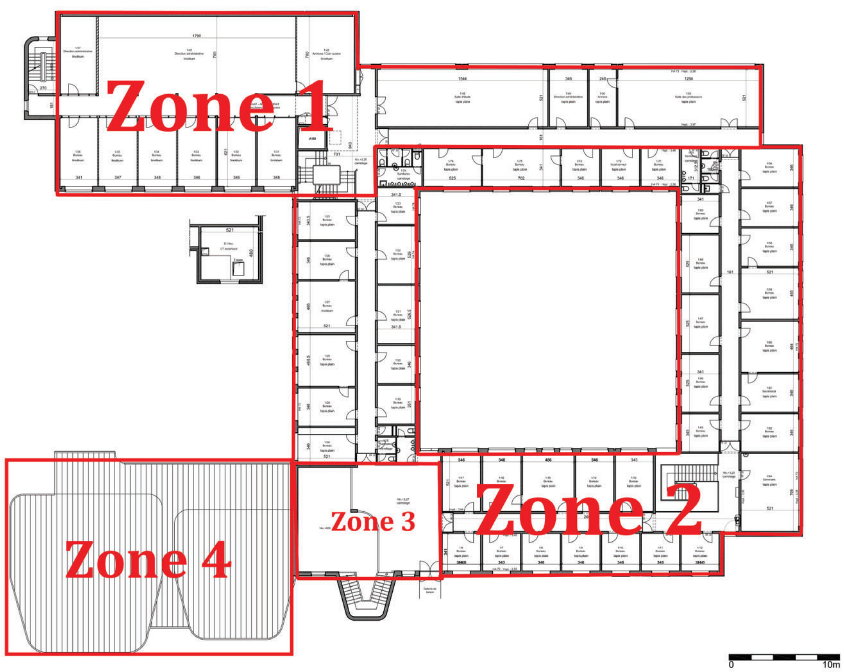

Figure 1: Building B37 first floor and its zones simplification.

The main air volume considers the large wavelength radiative heat exchanges and the radiative heat gain distribution, as well as the air infiltrations. It is very important to highlight the fact that the model computes the heat demand necessary to maintain the comfort conditions but does not assume any type of heating device used in the building and therefore imposes no restriction on level of temperature at which the heat should be delivered. This is done on purpose to focus on the energy demand as the building model is intended to be integrated to a district heating network for which different levels of temperatures can be considered. The

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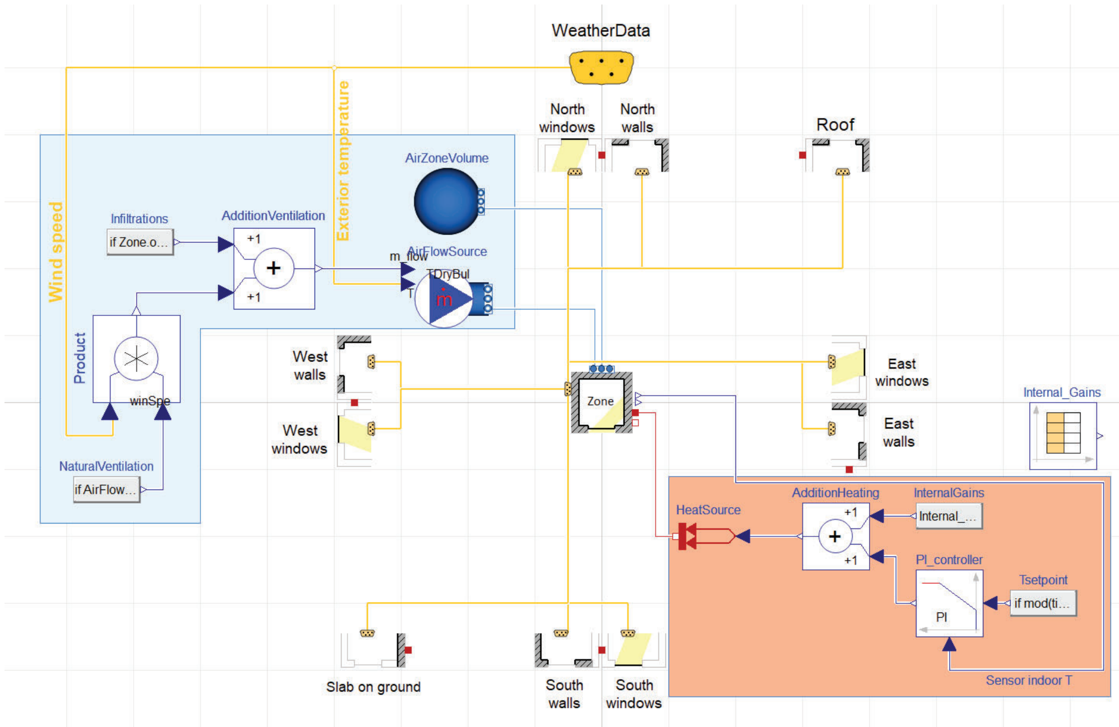

Figure 2: Dymola model for buildings zone model. The blue zone is the ventilation model, with infiltrations and natural ventilation based on wind speed. The red zone is the heating model which depends on the setpoint temperature, indoor temperature and internal gains. The weather data block contains the weather file. The walls, windows, roof and slab on ground models main parameters are the surface, the construction materials and the orientation.

necessary heating power to be extracted from the district heating network to maintain the indoor temperature is controlled by a PI controller comparing the measured temperature in the zone to the setpoint temperature.

The model for the ventilation is, for the time being kept at its simplest expression and considers only natural ventilation through window opening. When the indoor temperature rises above 23℃, the windows are open and the exchanged air flow rate is calculated based on the wind speed and the indoor and outdoor pressures. The heat transfers (by conduction, convection and radiation) between one zone and the adjacent ones or the exterior environment are considered in the exterior surfaces models. This model also takes into account internal free gains related to occupancy, lighting and appliances. A typical meteorological year weather file is linked to each building model in order to use external conditions such as temperature, solar radiation, humidity and wind speed.

The different data needed to make the building model described above are the main dimensions of the building required to estimate the heated volume and the exterior surface areas (solid and windowed), their orientation, the infiltration rate, the building materials, a local weather file and the usage of the building. By the *usage*, it is meant the control strategy, the occupancy level, the lighting and the appliances. This model is of course simplified but has the advantage of rapid development mainly because of the zone blocks that can be easily parameterised from accessible data. The most influencing parameters in terms of accuracy are the control strategy (schedule and setpoint), the occupancy, the building envelope and the air flow interactions (infiltrations and ventilation) (a more detailed explanation of these aspects can be found in [11]).

The construction of building models from the IDEAS library according to the proposed method has been developed on the basis of the test case of the International Energy Agency EBC Annex 60 [12]. To prove the easy scalability of the approach, an automated procedure to build the models for this test case has been realized. It allows an automatic model generation based on standard configurations customised according to the specific building location, orientation and size. This test case includes a set of 23 residential buildings, detached, semi-detached and terraced houses, and an office building. That approach proved to be satisfactory in terms of accuracy both individually and globally. In this contribution, an important question addresses the accuracy and feasibility of the approach on tertiary buildings where it is much more difficult to replicate

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standard configurations.

2.2. District Heating Network Simulation

In this contribution a particular focus is put on the heat transport efficiency to satisfy the needs of the connected buildings. The basic brick of this network is the district heating piping made of one supply and one return pipe thermally insulated and buried into the ground. The model used for the pipes is the one collaboratively developed in the context of the Annex 60 Modelica Library and the IBPSA Project 1 Modelica Library [14]. This model is very simple to setup as it is based on a plug flow model (i.e., non-compressible fluid) to forecast the dynamic behaviour of the heat transport (i.e., the transport delays) and requires only the pipe length and diameter to be specified. The friction (i.e., pressure) and thermal losses are calculated to provide an accurate and complete picture of the transport losses. The general layout of the model is exhibited in Fig. 3 showing that all the buildings are connected by deriving a portion of the flow to supply heat to the substation. The only dynamic effect in the one-dimensional flow model is the thermal inertia. Both the mass and the momentum inertia are considered negligible on the time scale of one-hour which is the basic time step considered in this study.

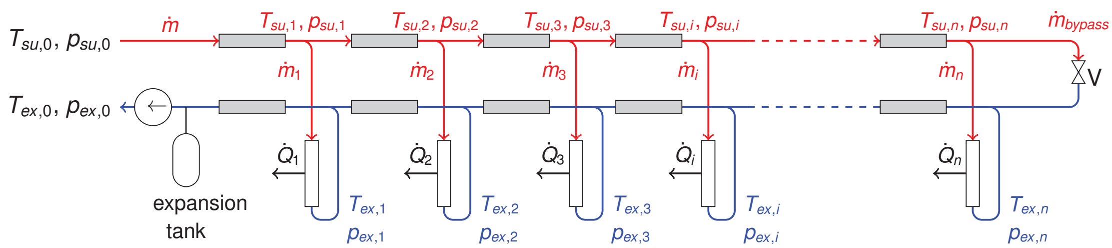

Figure 3: The model of district heating network where the pipes are in grey and the substation heat exchangers are in white. The supply flow is in red and the return flow is in blue.

The mass and momentum conservation involve:

$$\dot{m} = \sum_{i=1}^{i=n} \dot{m}_i + \dot{m}_{bypass} \text{ and } p_{su,i} - p_{ex,i} = K_{hex,i}\dot{m}_i^2, \tag{1}$$

together with pipe friction losses:

$$p_{su,i} - p_{su,i-1} = K_{su,i}\left(\dot{m} - \sum_{k=1}^{k=i-1} \dot{m}_i\right)^2 \text{ and } p_{ex,i-1} - p_{ex,i} = K_{ex,i}\left(\dot{m} - \sum_{k=1}^{k=i-1} \dot{m}_i\right)^2 \tag{2}$$

where $K_{hex,i}$, $K_{su,i}$ and $K_{ex,i}$ are constant characteristics of the heat exchanger and pipe configuration. The mass flow rate in the piping system is forced by a circulation pump with a characteristic:

$$p_{su,0} - p_{ex,0} = \frac{\Delta p_0}{N_{nom}^2} \cdot N^2 + c_2 \cdot \dot{m}^2, \text{ such that, } W_{pump} = \frac{\dot{m}}{\rho} \cdot (p_{su,0} - p_{ex,0}) \cdot \Delta t, \tag{3}$$

where Δp_0 is the no flow head at nominal rotational speed that is a function of the squared rotational speed, c_2 a constant specifying the nominal operating conditions and Δt is the considered time period. The rotational speed N is controlled by a PI controller between 20% and 100% of its nominal value so as to maintain the return temperature $T_{ex,0}$ at the setpoint value. For low flow conditions (i.e., that would correspond to $N < 20\% N_0$) the return temperature is allowed to fluctuate. An efficiency of 60% is considered to compute the electricity consumption of the pumps.

The only time dependency is due to the dynamic of the heat transport into the pipe introducing a delay between the entry temperature and the exhaust. Therefore, the pipe exhaust temperature $T_{su,i}(t)$ and the thermal losses $\dot{Q}_{loss,i}(t)$ depend on the past history of temperatures $\{T_{su,i-1}(0) \ldots T_{su,i-1}(t)\}$ and mass flow rates $\{\dot{m}(0) \ldots \dot{m}(t)\}$ and $\{\dot{m}_i(0) \ldots \dot{m}_i(t)\}$. A similar reasoning holds for the return pipes. The detailed resolution algorithm used to determine the pipe exhaust temperature and thermal losses is beyond the scope of this contribution and the interested reader is merely referred to [14] for a more thorough information.

The supply temperature $T_{su,0}$ is ensured by a heat source (from the Modelica library *Buildings* [13]) representing the centralised heat generation. The return pipe temperature results from the heat extraction at each of the substation according to the building heat demand. Again for sake of simplicity, the heat transfer across

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the substation is not fully modelled and the heat demand is directly extracted from the primary flow with a minimum bound on the exhaust temperature $T_{ex,i}$ in order to ensure it is always above the inner temperature of the building (plus the pinch point of the different heat exchangers) according to:

$$\dot{Q}_i = \min\left[\dot{m}_i \cdot c_p \cdot (T_{su,i} - T_{ex,i})\ ;\ \dot{m}_i \cdot c_p \cdot (T_{su,i} - T_{ex,min})\right] \tag{4}$$

where $T_{ex,min}$ is fixed according to the heat exchanger and substation configuration (here $T_{ex,min} = 35\,°C$).

The different aforementioned equations are implemented in Modelica on the Dymola program with the hourly heat demand curves of the buildings as an input for the substation models. This implies that the indoor comfort conditions of the buildings are not evaluated inside the district heating network model. The goal of the network through the substation model is to satisfy the load as much as possible.

Finally, the network is equipped with a bypass circuit whose mass flow rate is controlled by a valve according to:

$$p_{su,n} - p_{ex,n} = K_{valve}\dot{m}_{bypass} \tag{5}$$

where again K_{valve} is constant characteristic. An expansion tank upstream of the pump is also installed to ensure a constant pressure $p_{ex,0}$ at the pump supply.

The independent variables are the supply temperature $T_{su,0}$, the return pressure $p_{ex,0}$, the setpoint for the return temperature $T_{ex,0}$ and the set of heat rates $\dot{Q}_i\ \forall i \in [1, 6]$. With these boundary conditions and a suitable initial state of the system, the set of differential algebraic equations is solved by Dymola.

It is important to note that, according to equation 4, the required heat might not be available at the substation if the mass flow rate is not sufficient. If such conditions happen, there is no feedback on the building model to adapt the inner conditions accordingly to ensure the robustness of the resolution algorithm. Instead, an alarm is triggered that comfort conditions might not be met.

2.3. Case studies

2.3.1. Description

The objective of this test case is twofold. At first, it is intended to verify the accuracy of the model for tertiary buildings. The case of the university campus is particularly suited as lots of monitoring data are easily accessible for validation in terms in supply and exhaust temperature and mass flow rate. Secondly, the set of buildings is a good test to verify the integration of the building models into the district heating network in terms of robustness and accuracy. It is also a nice way to verify the scalability of the approach by replicating the procedure for the implementation of the model on existing buildings with very different characteristics.

The studied test case is the district heating network of the Polytech district on the Sart-Tilman campus of the University of Liège. This considered district is composed of 6 buildings: B28, B37, B47, B49, B52 and B65. They have various functions, such as classrooms, offices, laboratories, cafeteria, and a library. They, consequently, have different heating schedules or temperature settings. These buildings were also built in different time periods, between the 1970s and 2010s, and therefore have varying levels of insulation. The case studies only take into account the heating of the buildings and not the domestic hot water. The network is operated between 80 °C and 60 °C. The weather file used is a TMY file of the weather station of Uccle, the reference weather station in Belgium, with some modifications for the exterior temperature, to account for specific extreme conditions.

The reference case is based on the current use of the buildings and 6 buildings have been modelled and divided into zones based on the available existing drawings. The parameters specific to each building are collected namely, the heated volumes, the window areas, the wall orientations, the insulation materials, the heating schedules, the occupancy rates, the internal free gains and the setpoint temperature. For example, for the building B37, which is mainly an office and classroom building, the heating schedule is from 8 am to 5 pm, internal gains of a computer are considered by occupant, the temperature setpoint is 21 °C, etc.

The proposed model is particularly well suited for testing the influence of user behaviour as the inner setpoint temperature are easily accessible. Moreover, as the building model is essentially dynamic, transient effects due to thermal inertia are taken into account so that the effect of user behaviour on the heat demand can be expected to be accurately assessed.

Also changing thermal insulation and/or adding some insulation is straightforward and can be done by changing the value of different parameters, without having to rebuild the model from scratch. Quantifying load curve changes following a building modification is therefore quick and easy and can be done in less than 2 hours, computation time included. The time required depend on the number of zones and surfaces. The fewer zones and areas there are, the faster the modification, hence the interest in optimizing the zones and areas.

2.3.2. Change in user behaviour

The first modification to be considered is a change in user behaviour realised by modifying the inner setpoint temperature and to check the influence on the operation of the district heating network. For each building, the setpoint temperature in each zone is lowered from 21 °C to 19 °C, while keeping all other parameters unchanged. This modification follows closely what happened during the energy crisis during the year 2022 and the results are great interest for the authorities of the university.

2.3.3. Insulation of the building stock

The second modification consists in increasing the thermal insulation of the building stock. Not all the buildings are equal with such a modification as some pretty old buildings will see their heat demand greatly influenced while more recent ones will not. Again, this case study reflects some of the actions taken by the authorities of the university to decrease on the long term the building energy consumption. The following rules are followed:

- For buildings with single glazing, replace the existing frames with new PVC and double glazing frames.
- For buildings already having double glazing, do not replace frames and glazing.
- For all buildings, add a 14 cm thick layer of glass wool insulation, in addition to any existing insulation.

Glass wool is an affordable and commonly used material. Its price ranges between 20 and 25 €/m^2 [1] and its thermal conductivity between 0.03 and 0.05 $\mathrm{W\,m^{-1}\,K^{-1}}$ [15] which is superior to the insulation already installed on the buildings.

3. Results

3.1. Validation of the buildings models

Before proceeding to the different test cases, a validation phase is carried out to check whether or not the accuracy of the model is compatible with our application framework, namely the simulation of tertiary buildings. The simulation results of the 6 buildings of the Sart Tilman campus are compared to the available monitoring data in Table 1. Fig. 4 exhibits the heating demand curve of the B52 building offices during one winter day. It shows that the simulation results compare well to the monitoring results. The curves show the same pattern, with similar peak demands occurring at the same time of day. The root mean squared (RMS) error between the simulation results and the monitoring data is 85 kW. Accordingly, it can be concluded that the proposed methodology is applicable to tertiary building. In addition to the result accuracy, the modelling method allows the building models to be quickly setup (between half a day and two days depending on the number of zones in the building) and exhibits great robustness in terms of computation. Moreover, the standardisation of the approach enables different people to collaborate and associate their model as an input to the district heating network model.

Table 1: Buildings heating consumptions from monitoring data and simulation heating needs for the 3 scenarios [MWh]

	Monitoring data [MWh]	Reference scenario [MWh]	Scenario A [MWh]	Scenario B [MWh]
B28	642	544	482	299
B37	242	186	162	160
B47	Not available	66	59	44
B49	Not available	112	89	89
B52	1396	1219	1062	1129
B65	17	13	10	11
Total	/	2140	1864	1732

3.2. Impact on peak load and buildings annual energy consumption

As detailed in the previous section, two improvement scenarios are considered: the so-called *scenario A* where the setpoint is decreased to 19 °C and the *scenario B* consisting of an increased thermal insulation.

An interesting point of view is to compare the load curves of the different scenarios as exhibited in Fig. 5 and representing the cumulative number of hours during which a certain level of power is at least required. The intercept of the load curve with the y-axis (the heating power) is the peak load which is unchanged for scenario A with respect to the reference case while scenario B exhibits a decreased peak load from 3.9 MW to 3.5 MW (minus 10 %). The area under the load curve being the total energy consumed within a year, Fig. 5 shows that the reference case forecasts an annual energy demand of 2140 MWh which decreases to 1864 MWh and 1732 MWh respectively for the scenarios A and B respectively. The energy savings are therefore respectively 13% and 19% for each of the two variants.

[1] https://conseils-thermiques.org/contenu/laine-de-verre.php

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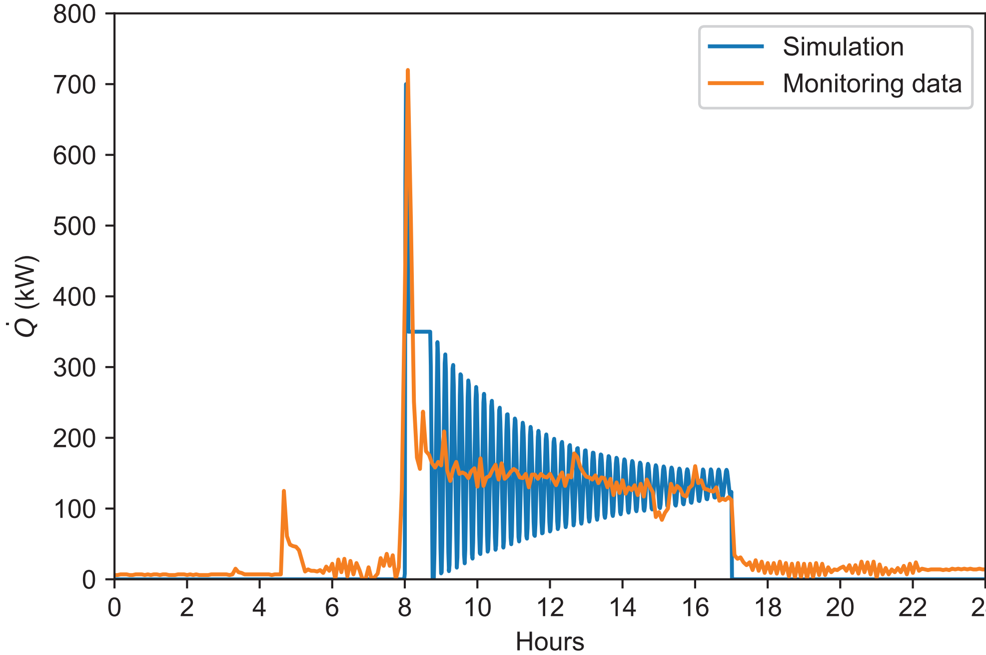

Figure 4: Heating demand profile of B52 offices over a winter day in 2022, simulation and monitoring results. RMS error over the year is 85 kW.

If one take a closer look at a smaller scale for the different buildings, it is is also insightful to see the discrepancies between the efficiency of one single measure on different buildings. Table 1 contains the simulated annual heating consumption for the three cases and the six buildings. It is interesting to see that already insulated buildings are less sensitive to energy saving measures. Indeed, for scenario B, with the added insulation layer, the average energy saving is around 23%. But by focusing on already insulated buildings, this economy is only of 12%, while it is of 33% for older buildings. For scenario A, the average energy savings are around 15%, and the results are quite similar for insulated and not insulated buildings. The conclusion is that a decrease of the setpoint temperature allows a uniform savings on the whole buildings, while the massive insulation of the building stock gives better energy savings on the least well insulated buildings.

3.3. Impact on electrical consumption of pumps and thermal losses

Heat transport efficiency is defined here as the ratio between the heat delivered to the building to the heat supplied to the district network and is a very important performance indicator, yet not the only one, as it characterises the rational energy use.

Table 2 summarizes the annual energy supplied to the district heating network, the annual heat losses and the annual pumping electricity consumption for the three considered cases. Reducing the setpoint temperature to 19 °C decreases energy consumption (minus 8.3%) while insulating the buildings results in an energy saving of 12.3%. In terms of electricity consumption from the pumps, the savings are 10.9% and 19.6% respectively for scenarios A and B.

This can readily be understood by a decrease of the mass flow rate for scenarios A and B which has a major effect on pumping consumption that is directly proportional to the mass flow rate while thermal losses are not significantly impacted as they are mainly driven by the pipe diameter and the supply and return temperatures that remained constant across the different test cases.

The heat losses represent 38.2% of the total injected energy into the district heating network for the 19 °C case. This figure goes to 40.0% for the scenario B, against 34.5% for the reference case. This shows that in the reference case, 65.5% of the energy consumed by the entire network is used for buildings heating while for the two scenarios this figure decreases to 61.8% and 60.0% of the total energy supply.

Heat transport efficiency might be a misleading figure as improving the energy efficiency of the buildings de-

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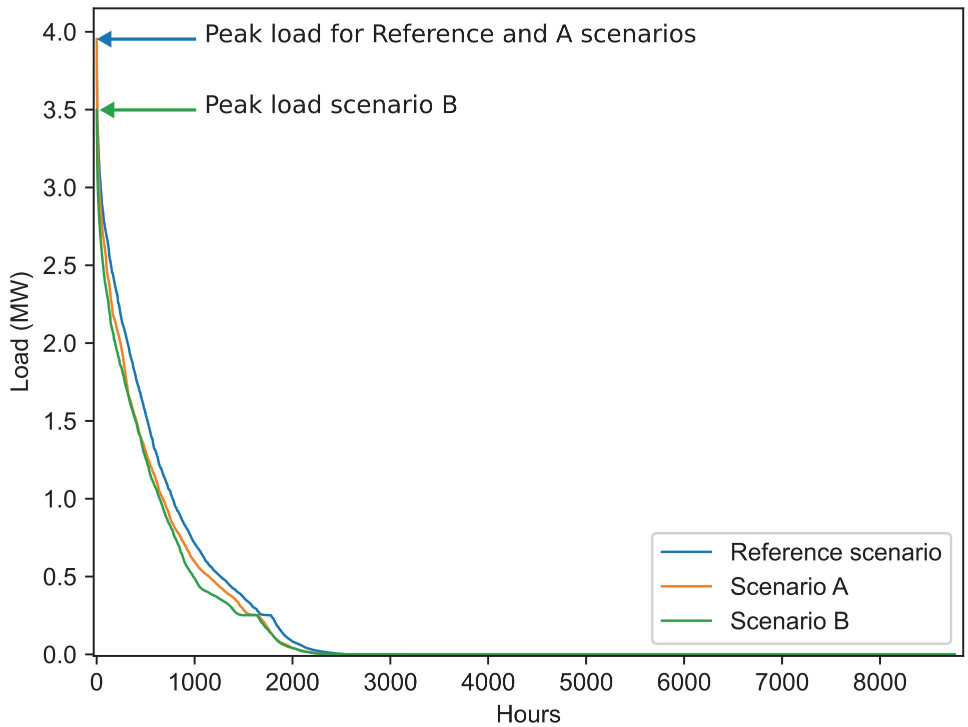

Figure 5: Overall load duration curves for the reference scenario and the two variants.

creases the energy efficiency of the network. Yet, one must bear in mind that the total energy input decreased but the transport losses are more difficult to decrease.

Moreover, the present analysis is purely made on an energy basis but the economic and/or environmental cost of heat and electricity should be taken into account. Nonetheless, these discussions also show that energy saving policies on building connected to district heating network cannot be done without studying the consequences on the operation of the network.

Table 2: DHN energy supply, heat losses and electrical pump consumption for the 3 cases (expressed in MWh)

	Reference scenario [MWh]	Scenario A [MWh]	Scenario B [MWh]
DHN energy supply	3292	3018	2886
DHN heat losses	1152	1154	1154
Electrical pump consumption	46	41	37

4. Conclusion

This work is primarily dedicated to the development of an integrated approach of building energy simulation for large building stock. This modelling approach allows a quick yet accurate simulation so as to obtain hourly buildings heat demand. The final objective is to connect these building models to a district heating network model. The knowledge of the load curves and peak demand (both in time and amplitude) has been shown to be essential. The main assumptions have been explained to introduce the building simulation model, based on the IDEAS Modelica library providing ease of use and robustness.

One important question also concerned the validity of the approach, already validated for residential building, for the tertiary buildings that are more heterogeneous in nature and use. The test case presented herein tends to demonstrate that the approach is purposeful both from a practical (it is easily scalable) and from an accuracy

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point of view. The different models have been validated based on monitoring data showing that both the peak demand and the annual energy consumption represent faithfully the actual situation.

One important aspect characterising the present approach is that most of the methodologies for large scale building simulation are based on a top-down approaches starting from the annual energy consumption (based on benchmark) spread across the year on an hourly basis using pre-defined daily profiles and average daily or hourly temperature profiles. Contrarily, the presented method is a bottom-up approach based on the structure and use of the building able to predict both the peak demand and annual energy accurately thus providing a straightforward way to forecast the efficiency of energy saving measures.

In a second step, two energy saving scenarios are applied to evaluate their impact on the load curve and, in turn, on the operation of the district heating network. The considered energy saving measures are a modification of the setpoint temperature in the buildings and an increased insulation of the building envelope. The main conclusions drawn from the simulations is that when a district heating network is used it is very difficult to separate building energy saving measures from the network operation/design.

The presented model still requires some improvements mainly on the side of a better regulation by adapting more actively the supply temperature to the heat demand to decrease the thermal losses. The model of the substation also needs to be improved to avoid the recourse to a minimum exhaust temperature and model the heat exchanger efficiency to forecast the maximum heat demand supplied by the substation. However, the basic philosophy of the different developed models seems to be purposeful to consider very large district with thousands of buildings.

Nomenclature

$\dot{m}$ mass flow rate, kg/s

p pressure, Pa

K pressure drop coefficient, $\text{kg}^{-1}\text{m}^{-2}$

N pump rotation speed, rpm

W pump work, J

ρ density, kg/m^3

$\dot{Q}$ power, W

$\dot{T}$ temperature, K

c_p specific heat, J/(kgK)

Subscripts and superscripts

i substation index

su supply to the substation

ex exhaust of the substation

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