BUILDING ENERGY DEMAND AGGREGATION AND SIMULATION TOOLS – A DANISH CASE STUDY

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ABSTRACT

Nowadays, the minimization of energy consumption and the optimization of efficiency of the overall energy grid have been in the agenda of most national and international energy policies. At the same time, urbanization has put cities under the microscope towards achieving cost-effective energy savings due to their compact and highly dense form. Thus, accurate estimation of energy demand of cities is of high importance to policy-makers and energy planners. This calls for automated methods that can be easily expandable to higher levels of aggregation, ranging from clusters of buildings to neighbourhoods and cities. Buildings occupy a key place in the development of smart cities as they represent an important potential to integrate smart energy solutions. Building energy consumption affects significantly the performance of the entire energy network. Therefore, a realistic estimation of the aggregated building energy use will not only ensure security of supply but also enhance the stabilization of national energy balances.

In this study, the aggregation of building energy demand was investigated for a real case in Sønderborg, Denmark. Sixteen single-family houses -mainly built in the 1960s- were examined, all connected to the regional district heating network. The aggregation of building energy demands was carried out according to typologies, being represented by archetype buildings. These houses were modelled with dynamic energy simulation software and with a simplified simulation tool, which is based on monthly quasi-steady state calculations, using a visual parametric programming language (Grasshopper) coupled with a 3D design interface (Rhinoceros). The estimated heat demand of the examined houses from both simulation tools is compared to actual measured data of heat consumption. An assessment of the two different types of tools follows, which will indicate the suitability of each tool depending on the desired accuracy of results and on the purpose of analysis.

Keywords: Building energy, Heat demand, Archetypes, Energy Simulation Tools

INTRODUCTION

Aggregation of building energy demands is key to depicting national building stocks, while supporting urban development decisions and Smart Cities development. In particular, it is considered to be one of the most efficient methods for analysing stock performance due to its bottom-up approach [1]. The building sector within the European Union (EU) accounts for 35%-40% of the final total energy consumption and 25%-40% of the associated CO_2 emissions [2]. Thus, it can play a pivotal role on Smart Cities development. Especially the residential sector has received extended political attention and so, better statistics and knowledge exist for it, which facilitates its analysis. According to [3], building stocks can be represented by sample buildings and archetypes. Their difference lays in the fact that the former require knowledge about the actual building parameters and measurements, while the latter are statistical composites of features of a specific building type [2]. The methodology of archetype buildings can cope with the lack of physical description of buildings which is very common at a large scale.

Building energy simulation software is widely used for load modelling and building energy estimations. Simulation methods are categorized upon their energy balance calculation to dynamic and quasi-steady-state methods. According to dynamic methods, heat balance is calculated with short time-steps (e.g. hourly) considering the thermal inertia of the building. In particular, their main characteristic is that an instantaneous surplus of heat during the heating period results in an increase of the indoor temperature above the set-point, while it removes the surplus heat by extra transmission, ventilation and accumulation, if no mechanical cooling exists [4]. Furthermore, changes in room temperature highly depend on the heat stored in or released from the mass of the building. On the contrary, quasi-steady-state methods calculate heat balance for a long time (e.g. monthly/seasonal) considering dynamic effects through correlation factors. Regarding heating, a utilization factor is introduced, which considers that only a part of the internal and solar heat gains can reduce the heat demand, while the rest of the heat gains result in an increase of the room temperature above the set-point. In this study, both dynamic and quasi-steady-state energy simulation tools were used. The objective is to investigate their suitability and accuracy at an aggregated level of building energy demands, while using archetypes.

METHOD

Sixteen single-family houses located in Sønderborg, Denmark were investigated upon their heat demand. All of them were connected to the local District Heating (DH) network. No mechanical ventilation or auxiliary heating sources were installed in the houses. These were classified into five building types based on their construction age, following changes in building traditions and energy requirements according to the Danish Building Regulations [5]. Some characteristics of the examined buildings are illustrated in Table 1.

Building type	Construction Period	No. of incl. buildings	Total floor area [m^2]
A	1931-1950	2	238
B	1951-1960	2	180
C	1961-1972	10	1,530
D	1973-1978	1	117
E	1979-1998	1	122

Table 1: Characteristics of archetype buildings

One archetype building was created to represent each type. The characterization of the archetype buildings was based on information gathered by national building databases, TABULA Webtool and on statistical values applied by the Danish Building Research Institute on a national evaluation of the energy demand for the Danish building stock in total. This included information about the median floor and glazing area, U-values of the thermal envelope and glazing, internal gains, as well as infiltration. In particular, the window area of single-family houses is 16% compared to the floor area for those built in the 1930s [6], 22% for those built in the 1960s [6] and 15% for those built in the 1980s and 1990s [7]. Some houses had undergone usual energy refurbishments mainly affecting the U-values of the thermal envelope and glazing, which was taken into account in the building models.

The examined sixteen single-family houses were modelled initially with IDA-ICE. This required extensive information about the building parameters. Multi-zone models were created for all five archetypes according to the standardized parameters. Their space heat and

domestic hot water (DHW) demand was simulated for one whole year. Afterwards, a simplified simulation tool was implemented, Termite, which required a much smaller amount of inputs in the models. Termite is a newly-developed parametric modelling tool, which uses Rhinoceros design interface, Grasshopper parametric options and Danish building performance simulation engine Be10 for energy performance calculations according to EN ISO 13790 [8]. Be10 calculates the energy needs of buildings in accordance with the energy requirements of the Danish Building Regulations BR10 and DS418, based on steady state monthly calculations [9]. For the calculation of energy consumption it uses only a whole building approach (single-zone building models). Be10 includes both static and non-static parameters in the energy performance calculation [10], but it does not enable the change of the input weather data, which are based on the Danish Design Reference Year (DRY) [11]. During the energy performance calculation with Termite, input lists were created to enable the fast modelling of all sixteen houses while using only one model setup. Analytical description of the model setup in Termite can be found in [12]. The results of both tools were compared to hourly heat consumption measured data obtained from the examined houses.

RESULTS

Figure 1 and Figure 2 present monthly heat demand (DH and DHW) as calculated by IDA-ICE and Termite for the five building types, being represented by the respective archetype buildings. These are compared to the measured data of heat consumption, which were averaged for each building type.
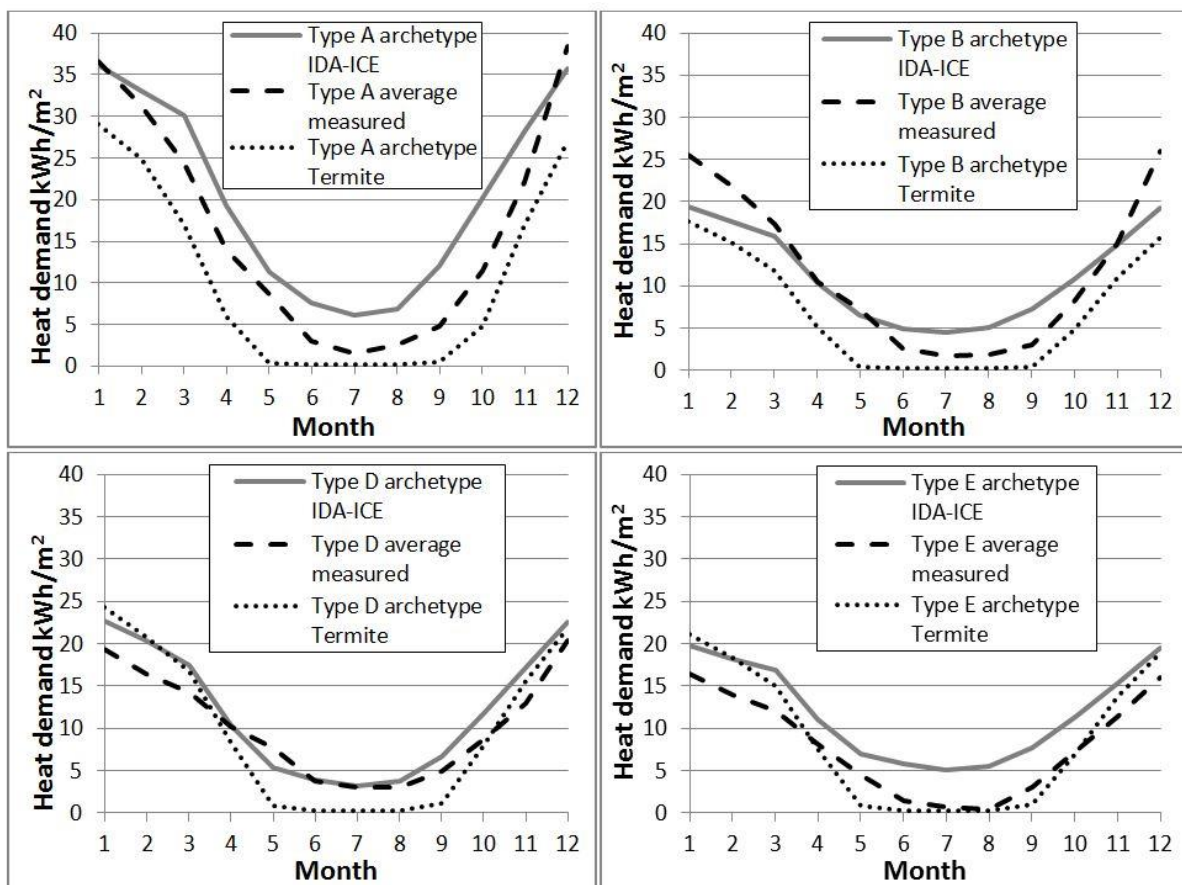

Figure 1: IDA-ICE and Termite monthly results of heat demand for building Type A, B, D and E compared to average measured data
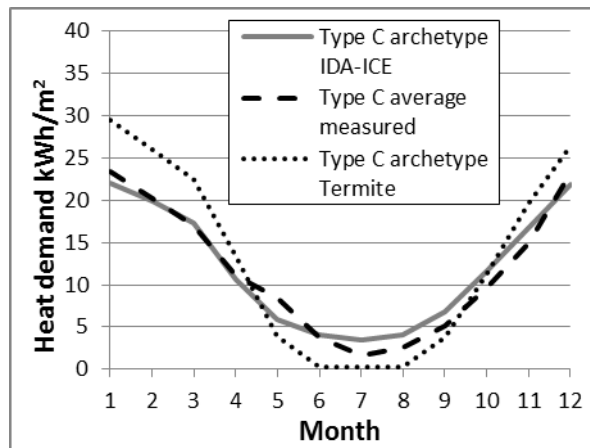
Figure 2: IDA-ICE monthly results of heat demand for building Type C (most representative) compared to average measured data

The calculated heat demands presented in Figure 1 and Figure 2 generally follow similar trends with the measured consumption for all types. The heat demand of the houses reduces as the construction age decreases, as expected. Type C, presented in Figure 2, is considered to be the most representative since the highest number of the examined houses are classified to this type. The rest building types consist only of one or two houses. The deviation between IDA-ICE heat demand and measured heat consumption is quite low for Type C. On the other hand, Termite heat demand differentiates more from the measured heat consumption during both winter and summer period for this type. This may be attributed to the fact that Be10, which is the energy simulation core of Termite, uses DRY climate data that are characterized by very low temperatures in winter and very high temperatures in summer. On the contrary, IDA-ICE makes use of real weather data. The estimated DHW demand by both simulation tools was not estimated accurately, which is due to no information about occupant behaviour.
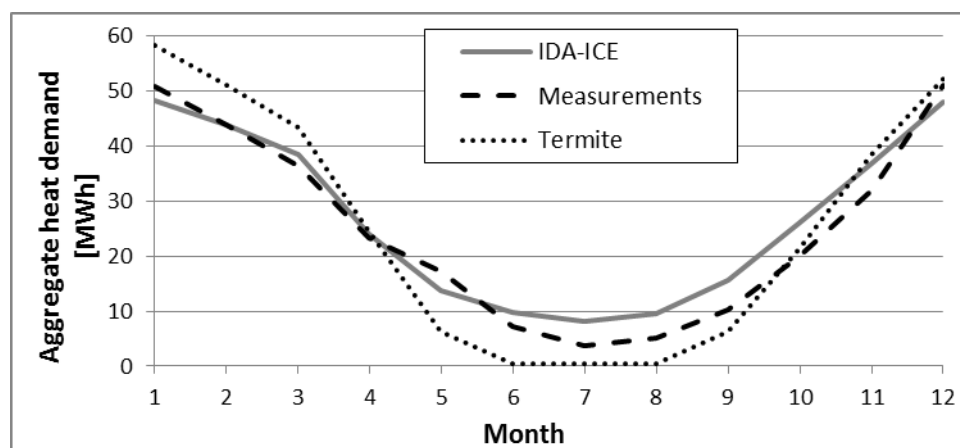

Figure 3: Monthly aggregated heat demand results from IDA-ICE and Termite compared to measured data

Afterwards, the monthly Energy Use Intensity (EUI) [kWh/m^2] estimated by IDA-ICE and Termite for each archetype building was multiplied by the total floor area of all houses classified in the specific type. This aggregated heat demand is illustrated in Figure 3 as calculated by IDA-ICE and Termite for a whole year and is compared to the measured total

heat consumption for the specific year. It is observed that IDA-ICE led to slightly more accurate estimation of the heat demand at an aggregated level compared to Termite. Especially during the winter period, IDA-ICE seems to result in more realistic calculations than Termite. However, it still does not match fully the measured aggregated heat consumption.

DISCUSSION

The lack of information about the building physical properties as well as the occupants' behaviour is a common problem met at large-scale analyses. This was overcome to some extent through the use of archetypes. Even though the sample of the examined houses was small, the methodology described in the present study aims at city-scale projects. For that reason, the values of many building parameters were assumed according to statistical data and national building databases. However, information about the occupants of the houses was not known which would be useful to draw realistically their profiles. The uncertainty in describing physically the examined houses affected the accuracy of results of both IDA-ICE and Termite. Furthermore, the monthly time-step was selected to enable the comparison between these two energy simulation software. Thus, the ability of IDA-ICE to produce hourly results was not exploited. If a yearly time-step had been selected instead, the results would be quite different, but no detailed analysis could be made. Type C was the most representative one, as it included the highest number of houses. The rest of the building types including only one or two houses could not lead to very representative archetypes.

CONCLUSION

The reported results indicated that the estimation of heat demand of clusters of building is a demanding procedure, where uncertainty plays an important role. The latter affected both simple building models, which require fewer inputs and more advanced models, where the number of parameters increases and therefore, the demand for detailed insight into the building construction and user behaviour increases. At aggregated level, it was found that IDA-ICE archetype models represented slightly better the heat demand of the sixteen single-family houses than Termite. Even though the energy calculations conducted by IDA-ICE were more advanced than Termite, the uncertainty in several model parameters counterbalanced its accuracy. However, its estimation of heat demand still remained the closest to the actual measured heat consumption.

Moreover, it was expected that the application of standardized parameter values would lead to rather exact results which was not the case for the current very limited sample of buildings. This could be attributed to the fact that the current buildings were not representative of Danish buildings, or it could be due to the fact that the variability is a dominating factor. The next step of the present work would be to expand the sample of examined buildings, which likely will lead to a more representative case.

The suitability of simulation tools depends highly on the purpose of analysis. If the purpose of this work was to study energy demand shifting in residential buildings, then dynamic simulation software would be the only way to go, since high resolution results would be needed. As the scale moves from building level to district or city level, simplified energy simulation tools may be seen as more preferable. Nevertheless, the methodology of building typologies and archetypes enables the use of advanced dynamic simulation tools, which in any another case would have vast and thus, restrictive computation times. Lastly, the combination of quasi-steady-state and dynamic energy simulation methods could be the solution towards fitting measured consumption data.

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