DEVELOPMENT AND COMPARATIVE ANALYSIS OF A BOTTOM-UP HEAT DEMAND MODELLING TOOL WITH EXISTING HEAT DEMAND ESTIMATION METHODS FOR GERMANY

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Abstract

Demand modelling is an integral part of energy system modelling and the accuracy of an energy model depends highly on the precise value of demand. Taking into account the limited number of open-source heating demand modelling tools available, this paper aims to present a new bottom-up simplified heating demand modelling tool that can create heating curves of high resolutions for any geographical locations and different building types. The tool is a physical model of demand modelling based on general heat balance equations for buildings. A comparative analysis of the outputs obtained from this tool with existing open-source heat demand modelling tools is then carried out. The results of the simulation shows that the heating duration curves obtained are very comparable to the outputs from the BDEW heating profiles that are considered to be the standard heating load profiles for Germany. On the other hand, the output from VDI 4655 that uses a generalized method and input parameters deviates the most, both in terms of peak demand and heating curve.

Keywords: demand modelling, open-source, bottom-up, heating demand, physical model, demandlib, demand.ninja, vdi 4655

1. Introduction

With increase in the renewable share in energy supply system, the energy supply system is growing more complex. Some of the reasons for the complexity account to intermittent nature of energy supply from renewable energy sources such as PV and wind. Moreover, the concept of sector coupling adds to making energy models more complex. Implementing sector-coupled heating systems with more renewable sources like wind and solar contributing in the heating sector demands for the heating profiles with higher spatial and temporal resolutions. Regarding that factor, the traditional ways of estimating heating demand may have limitations in building efficient energy models. There are several tools and methods that are used for creating heating profiles for buildings. EnergyPlus (U.S Department of Energy, 2020), TRNSYS (TRNSYS Software, 2019), IDA (eQUA AB, 2019) etc. are some of the popular tools used for building energy simulation that also includes the heating demand modelling. All the tools mentioned above are, however, not open-source and thus have limitation in contributing to scientific research. There are very less number of open-source tools dedicated particularly to creating total heating demand and heating profiles with high temporal resolutions. Some of the open-source tools widely used in Germany for demand modelling and used for comparison with the physical model are described in the section below.

The aim of this study is to develop a simplified heating demand modelling tool based on physical demand modelling method using python programming language and compare the tool with some open-source demand modelling tools used predominantly in Germany. A standard building from TABULA Typology (TABULA Project Team, 2012) and the weather data of Nordhausen city of the year 2019 is used for the simulation. The hourly demand and the monthly heating demand is estimated using all the tools that form the basis of comparison.

The tools that are used for the comparison are briefly described below.

1.1. Demandlib

Demandlib (oemof Developer Group, 2016) is an open-source, python-based demand modelling tool that can be used to create heat and electricity load profiles. It utilizes the standard load profiles from BDEW (German Association of Energy and Water Industries) (Meier et al., 1999) to create heating and electricity demand curve by taking the annual energy demand as input. Since the standard load profiles are valid for the context of Germany only, it cannot give precise results to model energy demand outside Germany. It can be used to model the demand in residential as well as commercial buildings.

1.2. VDI 4655

VDI is an abbreviation of 'Verein Deutscher Ingenieure' that translates to Association of German Engineers. VDI 4655 (VDI, 2021) is a guideline that can be used to create reference heat, power and domestic hot water load profiles for residential buildings in Germany. The model uses the weather data from German weather service to differentiate the days of the year into 10 different day types based on the temperature, cloudiness, working or non-working day type and seasons. Each of these 10 day types have a specific energy curve that can be distributed to the days of a whole year to create a yearly load profile with daily resolution. In addition, this approach uses a subdivision of Germany into 15 different climate zones and is capable of producing load profiles for places in Germany only.

1.3. Demand.ninja

Demand.ninja (Staffel et al., 2023) is an open-source grey-box model that models hourly demand for heating and cooling energy and uses the heating degree-days method, which is calculated using building-adjusted internal temperature (BAIT) parameters that describe the building and its occupant's characteristics. The demand obtained using the degree day method is, however, later converted into profiles of high resolution by incorporating the weather variables and other statistical parameters. It also has a graphical user interface where one can input the selected input parameters to create a heating profile for any place globally. The input parameter are however limited and there is not much room for modelling individual buildings, rather a representative demand for a region can be obtained. The tool is a very recent addition in the pre-existing renewables.ninja tool (Pfenninger and Staffel, 2016; Staffel and Pfenninger, 2016), which is used to generate hourly solar and wind generation profiles.

The proposed tool will be able to create demand curves for any locations based on the input data fed. An overview of the existing tools and the proposed tool is shown in table 1.

Tab. 1: Overview of considered modelling tools

Tool	Modelling Approach	Resolution	Building Types	Application
Demandlib	Top-down	15 min	All	Germany
VDI 4655	Top-down	hourly	Residential	Germany
Demand.ninja	Bottom-up	hourly	All	No restriction
Proposed tool	Bottom-up	Up to 1 min	All	No restriction

2. Methodology

The physical model of heating demand is developed based on the following heat balance equation for buildings (Wesselak et al., 2017).

$$Q_H(h) = Q_T(h) + Q_V(h) - Q_S(h) - Q_I(h) \ for \ T_a(h) < T_{BP} \qquad \text{(eq. 1)}$$

where,

$Q_H(h)$ = heating demand (for temporal resolution h)

$Q_T(h)$ = transmission (fabric) heat losses

$Q_V(h)$ = ventilation losses

$Q_S(h)$ = solar gains

$Q_I(h)$ = internal gains

T_a = ambient temperature

T_{BP} = balance point temperature

The individual heating losses and gains depend on several other factors, which are described below in brief.

2.1. Transmission heat losses

Transmission heat loss is the amount of heat that is lost from a room through various components such as walls, windows, roof etc. and is calculated using the following equation.

$$Q_T = H_T \,.\, (T_i - T_a) \qquad \text{(eq. 2)}$$

$$H_T = F_{x,i} \,.\, U_i \,.\, A_i \qquad \text{(eq. 3)}$$

where, T_i represents the required internal temperature in the building and the terms F, U and A represent the correction factors, the u values and the area respectively.

2.2. Ventilation heat losses

Transmission heat loss is the amount of heat lost through ventilation (opening of windows and doors and other openings) and is calculated using the equation below.

$$Q_V = H_V \,.\, (T_i - T_a) \qquad \text{(eq. 4)}$$

$$H_V = \mathrm{n} \,.\, 0.34 \,.\, V_L \qquad \text{(eq. 5)}$$

where, the terms n and V represent the airflow rate and the effective volume that is heated.

2.3. Solar heat gains

It is the total amount of heat gained due to the energy gained from the solar irradiation falling on the object. The solar gain is dependent on the factors like g value and area of the windows, and the amount of irradiation entering inside through the windows.

$$Q_s = 0.567 \,.\, g_F \,.\, A_{F,i} \,.\, G_{T,i} \qquad \text{(eq. 6)}$$

2.4. Internal heat gains

Internal heat gains account to the amount of heat produced inside the building because of the internal conditions such as due to the heat gains from electrical appliances and the heat produced by the people living inside. For simplicity, the hourly electricity demand of the object is taken as the internal heat gain in the model.

The balance point temperature (T_{BP}) is the ambient temperature above which the building requires no heating. The value of the balance point temperature in this simulation is taken as 15 °C.

For simplicity, the thermal energy stored in various objects of the building is neglected in this model by setting the thermal capacity to zero. The equation 1 is used to develop a model in python programming language to calculate the corresponding heating profiles. The heating profiles obtained from this model are then compared with the profiles form other methods of heating load determination.

Based on the equations presented above, it is evident that several input parameters are required to create a heating demand profile for a building. Comparison of the heating profile obtained from different tools is not always a simple task, since different tools take different parameters and methods into consideration. For the comparison purpose, to maintain uniformity, the dimensions of a single family house built within the construction period 2002 to 2009 in Germany is taken from the TABULA Web tool (TABULA Project Team, 2012). The weather data is taken from the renewables ninja website (Staffel and Pfenninger, 2016; Pfenninger and Staffel, 2016) for the year 2019 for all cases. The following table presents the input parameters considered to model a heating demand using the proposed physical model.

Tab. 2: Input parameters used for the heating demand modelling using the proposed tool

Parameters	Unit	Value
Total Floor area	m^2	147
Height	m	2.5
Window area north	m^2	3.1
Window area east	m^2	3.9
Window area south	m^2	19.3
Window area west	m^2	3.9
Window area roof	m^2	0
Envelope area	m^2	219
Ground floor area	m^2	80
u value wall	W/m^2K	0.3
u value window	W/m^2K	1.4
u value roof	W/m^2K	0.25
u value floor	W/m^2K	0.28
air flow rate	1/h	0.5
Required temperature	°C	20
Balance point temperature	°C	15
Night setback temperature	°C	15
gF	-	0.486

3. Results and Discussion

The heating demand is estimated for the reference building using the simplified physical model with the input parameters described in section 2. The total amount of heating energy required to heat the reference building is obtained as 12.504 MWh that corresponds to around 85 kWh / m^2. The total heating demand obtained from the physical model is fed into the other tools to create a heating curve using each tool. The results from all the four tools used for comparison are shown in figure 1. It is apparent from the figure that the profiles have a fair daily and seasonal variation for the first three tools whereas the output from the VDI 4655 tool shows comparatively lesser variation.

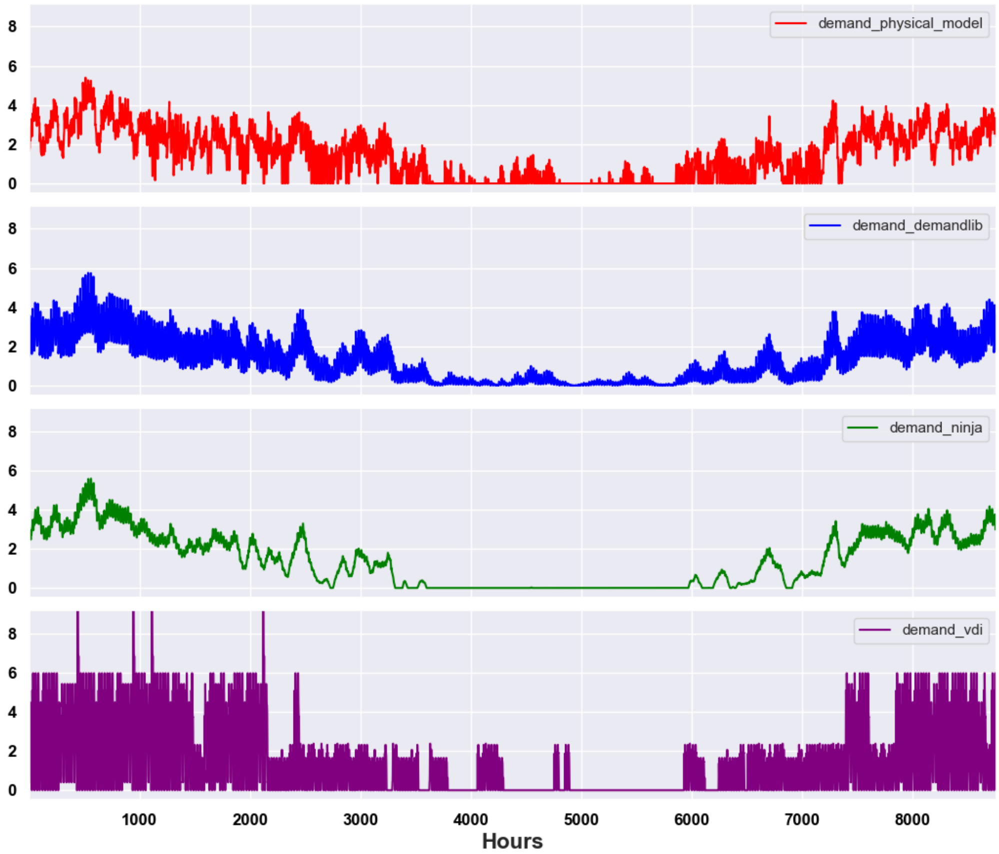

Fig. 1: Hourly heating demand curve generated using the four modelling tools

Figure 2 shows the yearly load duration curve of the demand profiles obtained using the four tools. On comparison of the duration curves, it can be seen that the duration curves for the physical model and the demandlib are comparable except for the rightmost part of the curve i.e. for the lowest heat demand hours. The physical model assumes that the heating demand for the hours with temperature greater than 15 °C is zero whereas the demandlib has non-zero demand estimation throughout the year. Greatest deviation in the profile is seen in the output of VDI 4655 where the peak demand is about 65 % greater than the other three cases and both the hourly curve and load duration curve shows a large difference compared to other three tools.

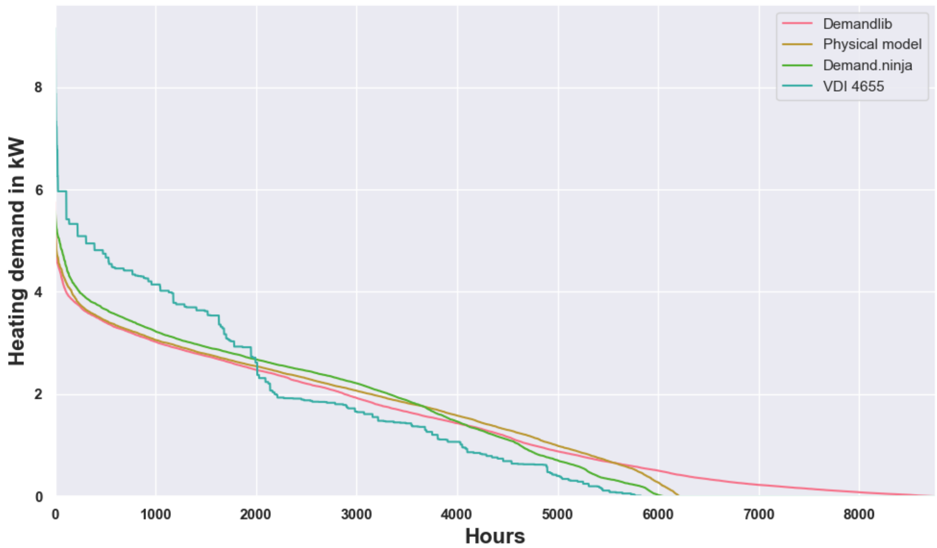

Fig. 2: Load duration curves of the hourly heating demand obtained from the four tools

Table 3 depicts the peak heating demand obtained using each tool. It can be seen that the peak demand obtained using the physical model, demandlib and the demand.ninja tool are almost equal whereas the peak demand obtained using the VDI method largely deviates from the other tool.

Tab. 3: Peak demand values obtained using each modelling tool

Tool	Peak demand (kW)
Physical model	5.39
Demandlib	5.75
Demand.ninja	5.57
VDI 4655	9.15

The aggregated monthly heating demand obtained using each of the four tools is represented in figure 3. It is apparent from the figure that the monthly demand obtained using the proposed tool are consistent with the demand data obtained from the demandlib tool.

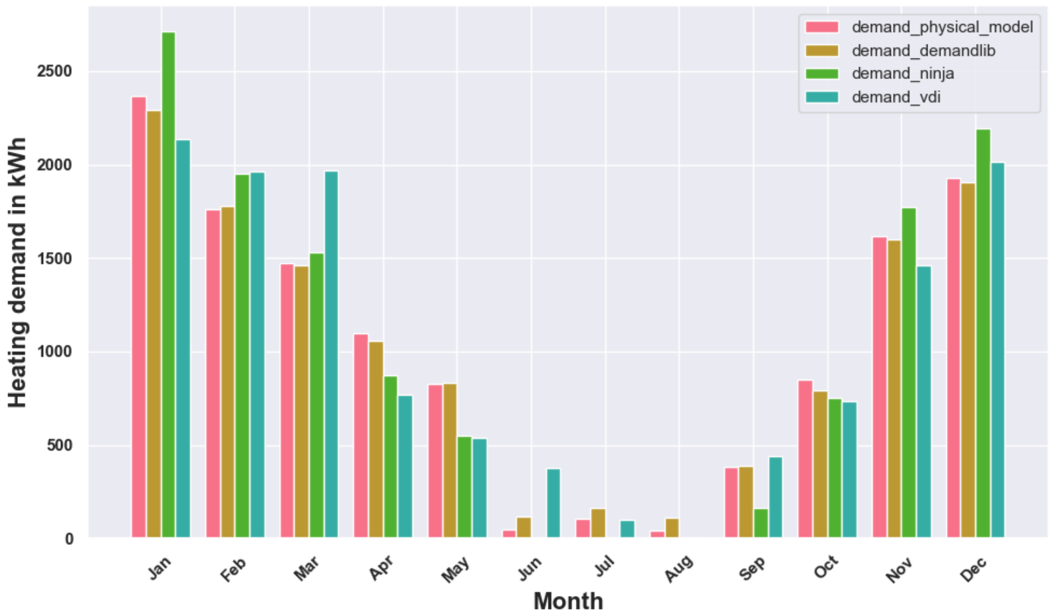

Fig. 3: Bar plot showing the monthly demand data for each of the modelling tools

4. Conclusion

In this study, we have presented a simplified heating demand modelling tool using the physical demand modelling method that gives the total heating demand as well as an hourly heating curve for any type of buildings using some building characteristics and weather data as input parameters. We have then compared the outputs of the tool to some of the existing open-source tools used to create demand curves in Germany. The advantages of the tools to the existing tools are its simplicity and flexibility to create demand profiles using given input parameters. The tool, however, has limitations and is open for further development. The results from the comparison shows that the methods like VDI 4655 that uses conventional methods for demand estimation may deviate largely in estimating demand curves and must be used with additional consideration for precise heating demand estimation. The proposed tool gives demand estimation comparable to the standard heating demand profile used in Germany.

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