WP1.1 Technical modelling of electrification of heating (and cooling) profiles

Milestone Report Task 6: Summary of input data and assumptions: 15th April 2024

Report for Centre for New Energy Technologies(C4NET)

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Executive Summary

This report provides an overview of the modelling framework and inputs and assumptions adopted to generate high-resolution electrified heating and cooling buildings' demand profiles for space heating/cooling and domestic hot water (DHW) at different aggregation levels. The profiles are developed for estimating heating and cooling energy requirement profiles within and across many buildings, specifically for the Victorian building sector.

The framework's core element is represented by the individual building-level model, i.e., national meter identifier (NMI) level. This is then used to extrapolate the aggregated demand profile at different aggregation levels following an "archetypical" approach. Representative buildings are determined based on selected attributes such as building type, household size, thermal characteristics and energy efficiency levels, etc. The modelling framework takes into account the impact of weather conditions in different climate zones, in terms of outdoor temperature profiles as well as solar irradiance from the different orientations. In addition, since buiding's occupants' behaviour, occupancy patterns (i.e., whether the occupant is sleeping, or is at home or at work) and preferences vary across multiple households, variations on physical[1] as well as "human-behaviour"-related[2] parameters have been considered. Furthermore, the physical characteristics of each building, including its thermal inertia, as well as heating/cooling technologies and DHW storage tank are incorporated in the model.

To generate the after-diversity average customer-level demand profile $\tilde{P}^{s}{}_{cust}$ for each energy service *s*, multiple buildings (N_{cust}) are simulated. For this purpose, a building number of 300 was selected for the simulations, as a trade-off between computational burden and impact on the peak, as the relative standard deviation of the average peaks for the different numbers of buildings was generally very low, below 4%.

For the simulations, four representative locations for each climate zones in Victoria were identified, namely Ballarat (zone 7), Melbourne (zone 6), Shepparton (zone 4) and Traralgon (zone 6/Gippsland). Then, for each location, representative day types have been identified, namely Winter Peak (WP), Winter Average (WA), Summer Peak (SP), Summer Average (SA) and Shoulder (Sh), defined based on the average value for outdoor temperature as follows:

- **Winter peak day** represents the day with lowest average temperature.
- **Winter average day** represents the day whose average temperature is closer to the season average.
- **Summer peak day** represents the day with the highest average temperature.
- **Summer average day** represents the day whose average temperature is closer to the season average.

[1] For example, variations of building's physical characteristics (and associated thermal parameters) from the "representative" one, or tank water initial temperature in DHW systems.

[2] For example, DHW delivery temperature or indoor temperature setpoint/setback.

- **Shoulder average** day represents the day whose average is closer to the season average (shoulder months).

The specific daily outdoor temperature profiles for each representative day type were obtained by analyzing 10 years (2014-2023) worth of temperature data with 1 min resolution for each location. With regards to feed-in water temperature to generate the domestic hot water demand profiles, this is assumed to vary across season, and it is assumed to be constant throughout the day and the same across all locations. On the other hand, the solar radiation profiles from the Typical Meteorological Year (TMY) for the specific day of the year have been used.

To study the impact of occupants' "energy" behaviour, alternative heating system (for both space conditioning and DHW) activation strategies have been tested, in addition to the profiles obtained strictly following the occupancy profiles. Specifically, for space heating/cooling the "base" activation strategy is complemented by a "Delayed" activation strategy according to which the heating/cooling system is not turned on in the morning but only in the afternoon/evening when occupants come back home, e.g., from work. Similarly, for the DHW system, in addition to the "Temperature controlled" operation mode, the "Off-peak controlled load" and "Solar soaking" modes have been simulated, which assume that water heaters are operated under restricted/specific tariffs (i.e., as a form of load management), or only operate within a specified time window to maximize the consumption from the increasingly widespread rooftop solar PV systems, respectively. Overall, these different behavioural and operational control strategies can be used to model interaction with time-of-use tariffs, basic demand response signals, and so on.

Finally, a description of a tool that has been developed is presented, which allows to combine the different average customer-level demand profiles for each energy service.

Several application use cases are demonstrated, including space heating/cooling and DHW, analyzing the impact of different weather conditions, household size, technology on the corresponding energy vector demand profile and associated peak.

Glossary of Terms / Abbreviations

COP	Coefficient of Performance
DHW	Domestic Hot Water
DNSP	Distribution Network Service Provider
EHP	Electric Heat Pump

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1. Introduction

With the mass adoption of localized renewable energy generators and distributed energy resources, the electrification of residential heating/cooling (e.g., through electric heat pumps) has been proposed to help decarbonize the building sector. However, it becomes crucial to quantify the impact on the energy infrastructure.

In this context, this report provides an overview of the modelling framework and inputs and assumptions adopted to generate high-resolution electrified heating and cooling buildings' demand profiles at different aggregation levels. The profiles are developed for estimating heating and cooling energy requirement profiles within and across many buildings, specifically for the Victorian building sector.

From the findings of the comprehensive literature review conducted for Deliverable 1 – "Literature review", it emerged that a physics-based bottom-up modelling approach is deemed more suitable in the context of this project, and that existing studies and available tools are inadequate for the purpose of informing on distribution networks' adequacy and potential reinforcements/investments required and quantifying the value of potential demand side flexibility that can be accessed. Indeed, because of the high seasonality (weather sensitivity) of the thermal demand, which also shows a comparatively lower diversity (compared to electricity) [4], the diversity may have a less smoothing effect on the aggregated demand profile which could then impact on its peaks.

2. Modelling framework overview

To quantify the impact[3] of different electrification of heating (and cooling) scenarios at the State level (Victoria), this work package developed a (archetype) physics-based bottom-up modelling framework which captures the flexibility inherent in the physical components (e.g., buildings' envelope, technologies' operation, hot water storage) at high spatial and temporal granularity (e.g., sub-hourly, down to 1 min resolution). This feature is fundamental to properly capture consumption peaks which would otherwise be smoothened over a wider timeframe, while accounting for the *diversity* and *coincidence* with an adequate temporal resolution.

An overview of the proposed modelling framework is reported in Figure 1. Specifically, the framework's core element is represented by the individual building-level model, i.e., national meter identifier (NMI) level. This is then used to extrapolate the aggregated demand profile at the areas, suburb, city, levels and so forth, based on the representative weight of the modelled sample. In fact, the generation of the aggregated profiles relies on the simulations of a limited set of "representative" buildings, following an "archetypical" approach. Such strategy identifies the representative buildings of pre-defined categories, which are determined based on selected attributes such as building type, household size, thermal characteristics and energy efficiency levels, etc., in accordance with housing surveys and available data. With this approach, the heating and cooling demand profiles at higher aggregation levels can be obtained by scaling up the results considering the number of buildings which fit in the specific archetype category. In general, the modelling framework allows to capture the impact of weather conditions in different climate zones. It takes as inputs, among the others, the outdoor temperature profiles, which not only determines whether the heater/cooler is required to be on, but also impacts on the operating performance of air-source electric heat pumps. Moreover, the solar irradiance from the different orientations and associated heat gains are accounted for. Nonetheless, while temperature plays a key role in the heating/cooling needs, building's occupants' behaviour and occupancy patterns (i.e., whether the occupant is sleeping, or is at home or at work) throughout the day clearly impact on the heating/cooling system activation strategies and consequently on the thermal demand. Indeed, occupants' preferences vary across multiple households. Therefore, in addition to the diverse occupancy profile "associated" with each simulated building, variations on physical[4] as well as "human-behaviour"-related[5] parameters have been considered to capture as much as possible the diversity in the generated aggregated demand profiles. Furthermore, the physical characteristics of each building, in terms of envelope construction materials and equivalent thermal properties, including building's

[3] In terms of minimum and peak demand, load shape and infrastructure limitations.
[4] For example, variations of building's physical characteristics (and associated thermal parameters) from the "representative" one, or tank water initial temperature in DHW systems.
[5] For example, DHW delivery temperature or indoor temperature setpoint/setback.

intrinsic storage/thermal inertia, as well as heating/cooling technologies and DHW storage tank are incorporated in the model. More details will be provided in the following sections.

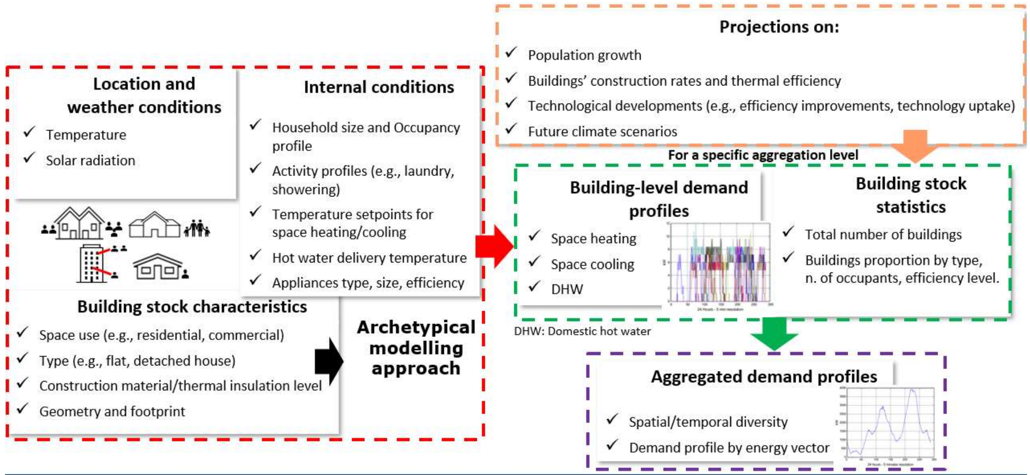


Figure 1 Bottom-up modelling framework overview.

a. Building-level thermal demand model

The building-level thermal demand model consists of two main sub-models, namely the space conditioning model and a DHW demand model. A schematic of the building-level model is reported in Figure 2. This is a physics-based model which directly determines the thermal demand profile for each end-use based on assumptions on the physical parameters, such as the geometry and construction materials of buildings and insulation level, DHW tank size, heating system rated size, and how the indoor space temperature or tank water temperature evolve as thermal energy is supplied (or removed for cooling). It is worth noticing that, in contrast to the most commonly adopted occupancy profiles[6] which only determines if there is anyone "active" at a specific time of the day, the occupancy profiles used for this work are generated using the model in [1] which account for the total number of occupants, simulating when each occupant is active in households with *more* than one occupant. This is fundamental, especially when it comes to determining the DHW volumetric demand of each dwelling which differ by household size.

b. Space conditioning model

The space conditioning model determines the thermal demand for space heating and cooling and consists of a heating/cooling system and building envelope sub-models, as represented in Figure 3. It is worth specifying that in this work the main assumption is that the whole house is heated/cooled through a system of ducts as heat distribution system. Nevertheless, zoning is a common practice which confine the heat requirements to only a portion of the dwelling. A way to consider this possibility is to use the corresponding demand profile of a smaller size building. For instance, if a three bedroom house

[6] which only determine if there is anyone "active" at a specific time of the day or not.

is being considered and only a portion of it is assumed to be heated, then the demand profile of either a one-bedroom or a two-bedrooms house could be used.

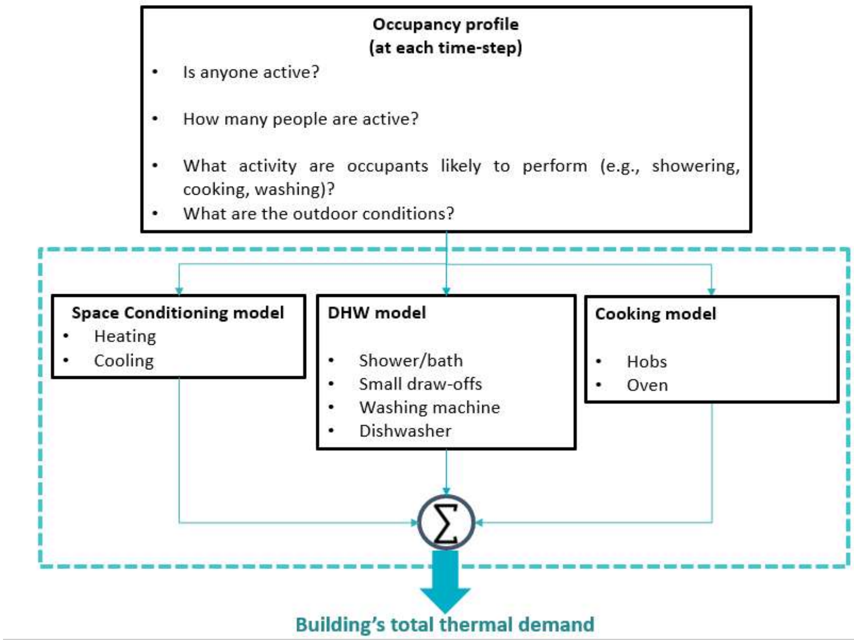


Figure 2 Building-level thermal demand model overview.

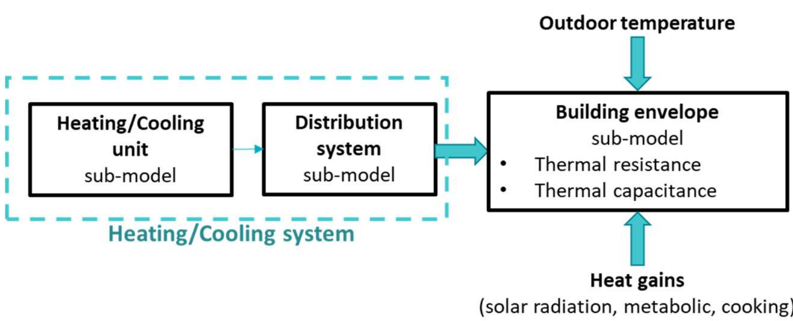
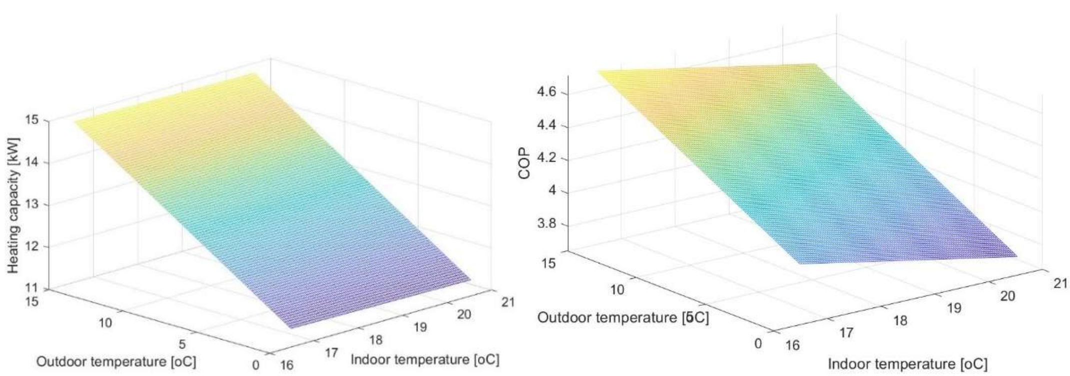


Figure 3 Building-level space conditioning model overview.

i. Heating/cooling system

Within the heating/cooling system model, the heating unit is characterised by its rated as well as maximum and minimum thermal output and efficiency. While it is acknowledged that controls are available to modulate the heat output and that these could be implemented in the model for future work, in this project it is assumed that the heating unit is operated in ON/OFF mode, hence supplying heat at maximum capacity when active. Nonetheless, an air-source electric heat pump (EHP) operational performance is highly dependent on both indoor and outdoor temperature, affecting its heat output capacity and coefficient of performance (COP), which therefore differ from their rated values. In this regard, the capacity of heating unit is determined following two different strategies, depending on whether an EHP[7] or a gas ducted heating system is to be simulated.

In fact, gas ducted systems are typically oversized as the minimum size available in the market is in the order of ~15 kW_{th}, typically up to around 30 kW_{th} [2]. As such, gas ducted system sized following an empirical approach, considering the range of available sizes in the market and the building's size (i.e., number of bedrooms), following a uniform distribution. On the other hand, EHPs come with smaller sizes and the required capacity is determined based on the space heating/cooling demand of the building in design conditions, accounting for a 20% oversize factor to consider the thermal losses through the ducts, following the Australian guidelines [3]-[4]. The design conditions, in terms of indoor and outdoor temperatures, differ by location and are determined in accordance with [3]-[4]. In this respect, when sizing the EHP, it is important to make sure that, given its performance characteristics[8], the heating unit can deliver the required heat demand in design conditions. To account for the operational performance dependency of EHP on temperature not only at the sizing stage but also during its operation in terms of both heat output capacity and COP, a regression model has been developed to determine the coefficients of a multi-variable linear function using performance data points provided by one Australian manufacturer[9]. These coefficients are separately identified for each available size. An example of the heating capacity (left) and COP (right) as functions of indoor and outdoor temperature for a rated 12 kW_{th} EHP are illustrated in Figure 4. In addition, heat losses through the ducts, which are sized following the guidelines [3]-[4], are also included. Moreover, the sizing strategy considers a minimum EHP size, calculated from the equivalent thermal circuit to ensure that the indoor environment can reach, on average, the setpoint (from the setback) temperature within a reasonable amount of time[10]. This becomes particularly relevant in more efficient buildings for which the thermal demand in design conditions decreases along with the required size thus leading to extremely high warm up times. Furthermore, it is assumed that the heating devices are installed as per manufacturers' guidelines.



[7] The term EHP is used here interchangeably to refer to reverse-cycle air conditioners, thus potentially supplying both space heating and cooling.
[8] i.e., Heating capacity as function of indoor and outdoor temperature.
[9] According to which, the COP tends to increase with the size of the EHP.
[10] Assumed 2 hours in this work.

Figure 4 Illustrative examples of heating capacity (left) and COP (right) as functions of indoor and outdoor temperature.

ii. Building envelope

The operation of the space heating/cooling system depends upon the indoor environment conditions. These are evaluated in terms of indoor temperature T_{in} and whether this is kept within the tolerance band around the target temperature. To determine the indoor temperature value at the current time step, a building envelope model is udes. In particular, the building model is described using the electrical analogue approach, in which the building is represented by a four nodes equivalent circuit, following [5]. The circuit is characterised by thermal capacitances and thermal resistances, whose values depend on the construction materials' thermal properties and buildings' geometry, which differ by building type and reflect the ability of the building's envelope to resist heat flow and to absorb, store and release heat. The outdoor environment temperature evolution along with the heat gains from the exposure to solar radiation, cooking activity and occupants metabolism, represent the "perturbation" elements of the system, leading to the indoor temperature changes. In addition, the thermal energy supplied (removed) by the space heating (cooling) system further determines the indoor temperature evolution over time. In this regard, the space conditioning system activation $I_{SC}(t)$ at the current time step is dictated by the current value of $T_{in}(t)$ and its value compared to the target temperature $T_{trg}(t)$, and whether this is above (below) the lower (upper) limit (i.e., $T_{trg}(t) - \Delta T_{tol}$) for space heating (cooling)[11], considering a tolerance[12]. The heating (cooling) system is then kept ON until $T_{in}(t)$ reaches the upper (lower) limit (i.e., $T_{trg}(t) + \Delta T_{tol}$). This strategy tries to emulate the behaviour of a thermostat embedded in the heating/cooling systems.

The target temperature $T_{trg}(t)$ is dependent on dwelling occupancy, under the assumption that there exists a smart energy management system which automatically turns on the space conditioning system even when there is no one in the house, to avoid the indoor temperature from dropping/increasing too much. Specifically, the target temperature at each time step is equal to the setpoint temperature when dwelling occupants' are active, whereas this is set to the setback temperature when no one is active (i.e., either occupants are sleeping or outside). The reference setpoint and setback temperature are taken as 20°C (24°C for cooling) and 15°C (27°C for cooling), respectively, in line with [6]-[7]. Naturally, when looking at multiple dwellings, occupants may have different preferences. Therefore, using 20°C as a reference value, setpoint temperatures values assigned to each building are taken from a uniform distribution between 18°C and 22°C (between 23 °C and 25°C for cooling). Similarly, setback

[11] The rule in cooling mode is the same, apart from reversing the signs as the cooling system is activated as soon as the indoor temperature is *above* the target temperature.
[12] A tolerance of $\pm$0.5°C has been used in this work.

temperatures are taken from a uniform distribution between 14°C and 16°C (between 26 °C and 28°C for cooling). An example of target temperature profile is reported in Figure 5, resulting from a specific occupancy profile.

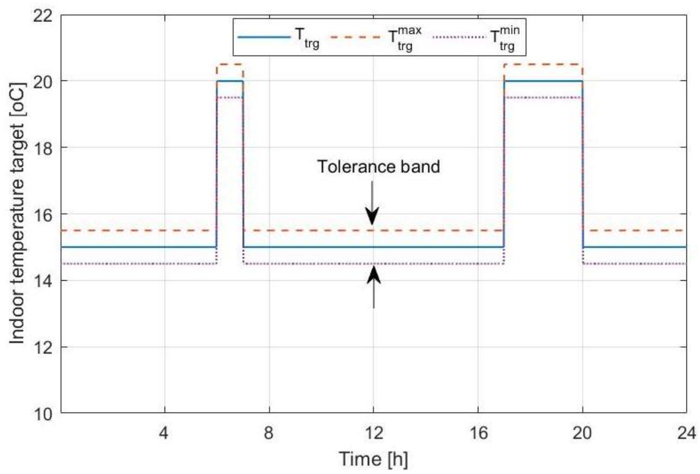


Figure 5 Example of indoor temperature target profile.

c. Representative buildings

To determine the parameters of thermal resistance and capacitance of the thermal equivalent circuit discussed in the previous section, it is fundamental to identify the dimensions of the building, in terms of floor area, height, etc. as well as the construction materials. This calls for the identification of representative Victorian buildings, based on available statistical information, e.g., dwelling type, typical construction materials, number of bedrooms and occupants.

According to the Australian National Construction Code (NCC) [8], buildings are classified into 10 categories and residential buildings are categorized as:

- **Class 1a**: Standalone single dwelling, including separate house, row house, terrace house, town house and villa unit.
- **Class 1b**: includes boarding house, guest house or hostel.
- **Class 2**: Building containing 2 or more sole-occupancy units each being a separate dwelling, such as apartment buildings and flat/unit developments.
- **Class 4**: A dwelling in a building that is not a residential building, such as a caretaker's residence in an office building.

The dominant residential building types in Victoria are Class 1a (detached house, semi-detached house), as illustrated in Figure 6 , and Class 2 (low-rise apartment, high-rise apartment). Therefore, this study focuses on four housing types [9]:

- Detached house
- Semi-detached house
- **Flat or apartment** (High rise/Low-rise, depending on the number of storeys)

Information on the typical construction materials for each building type is critical to understand their thermal performance, e.g., insulation levels. In this regard, the residential buildings in different construction years and climate zones are required to meet the corresponding minimum energy star requirement of NatHERS. Following [9]-[10], residential buildings in Victoria can be further classified by construction year as a proxy of their energy efficiency levels[13]:

- **Old**: pre-1991, characterized by an average energy rating of 1.6 stars, as minimum insulation requirements were introduced in Victoria in 1991 [11].
- **Modern**: 1992–2006, characterized by an average energy rating of 3.2 stars.
- **New**: 2007–2011, for which the minimum energy rating requirement is of 5 stars.
- **Efficient**: 2012–2022, for which the minimum energy rating requirement is of 6 stars.

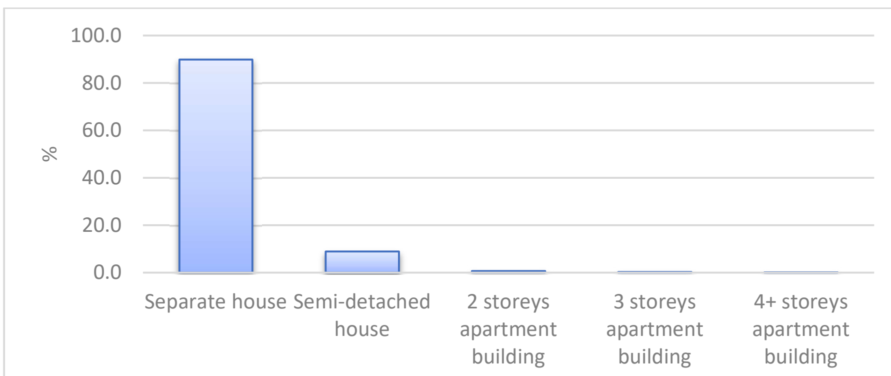


Figure 6 Proportion of building types in Victoria. Elaborated from [12].

A further classification for residential buildings is based on construction types. While the representative construction types for detached and semi-detached houses is brick veneer, the typical construction types for apartments is concrete (precast and reinforced concrete for low and high-rise buildings, respectively) [10],[12]-[14].

Moreover, to account for buildings of different sizes, a further classification can be based on the total number of bedrooms. Figure 7 refers to Victoria, highlighting the fact that most dwellings have between three and four bedrooms. A further breakdown by building type shows that, while this is representative of detached houses, most semi-detached houses have between two and three bedrooms, while flats/apartments have typically between one and two bedrooms, as displayed in Figure 8 [15].

[13] It should be noted that constructions built after 2023 must meet a minimum energy efficiency requirement of 7 stars. [34]

Figure 7 Proportion of buildings in Victoria by number of bedrooms. Elaborated from [15].

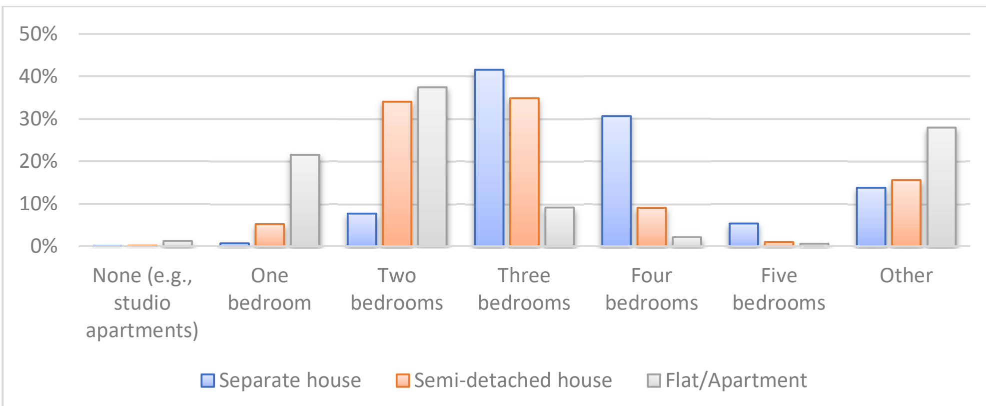


Figure 8 Breakdown by building types in Victoria by number of bedrooms. Elaborated from [15].

The floor area of each representative building is extrapolated based on the total number of occupants and the average floor area per capita, under the assumption that the total number of bedrooms matches the household size, i.e., one person living in a one-bedroom dwelling, and so forth. Hence, assuming an ideal amount of living space per person between 55-65m², dimensions and construction materials for each house type and energy efficiency level were elaborated from [9]. Based on these, to finally determine the equivalent thermal circuit parameters, the information on thermal properties of the different materials were taken from the NCC (for example [16] for the walls), as well as from [3] and [4].

d. Domestic hot water (DHW) model

The domestic hot water model aims at evaluating the thermal demand for each building for the provision of hot water. It consists of two main sub-models, namely the DHW volumetric demand model and the DHW system model, as illustrated in Figure 9.

A crucial element is represented by the volumetric hot water demand for each household, and this is highly dependent on the total number of occupants. Specifically, the 1 min resolution volumetric DHW demand model adopted in [5][14] has been used, after being modified to better reflect the typical water consumption of different appliances in Australia, combining the information in [17] and [18]. In fact, one of the most water-intensive activities is showering. In this work it is assumed a shower duration of 7 min and a water consumption of 9 L/min [19]. Then, the volume of water at each time step needs to be heated up to a certain DHW delivery temperature. Naturally, this value may be different across households. To account for such diversity factor, the hot water delivery temperature foreach building is selected from a set of values between 40 ^{o}C and 50 ^{o}C, following a uniform distribution. The upper bound of 50 ^{o}C is required by regulations to prevent the risk of scalding [20].

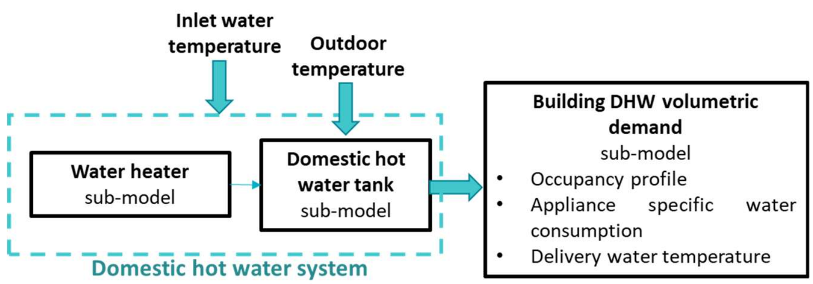


Figure 9 Building-level domestic hot water model overview.

The DHW system model includes the water heater model, which is characterised by its rated as well as maximum and minimum thermal output and efficiency. Similar to the case of EHP for space heating, air-source EHP water heaters performance is affected by temperature, which is accounted for in the modelling. As two basic types of water heaters are available on the market, i.e., instantaneous (continuous) flow systems15 and storage systems, the DHW system also incorporates the DHW tank model. The main difference between the two system types is that, while instantaneous flow systems heat[16] only the water required17, storage water heaters use an insulated tank to store heated water. In this regard, it is required that the water is stored at a pre-set temperature >60^{o}C to prevent Legionella bacteria growth, in accordance with AS/NZS 3498. In fact, the water temperature decreases not only because of hot water draw-offs (usage), but also through heat losses[18] from the storage tank. Hence, the operation of the water heater in storage DHW systems is dictated by the evolution of the tank water temperature over time, and this is greatly impacted by the DHW tank size. Particularly, the heater is turned on if the water temperature falls below the setpoint (e.g., 60^{o}C) considering a deadband of 8^{o}C (downward only) [21]. Then, the water heater is turned off as soon as the water temperature reaches

[14] The model takes as input the occupancy and activity profiles generated by the model in [1].

[15] ~71% of gas water heaters currently available in Victoria are instantaneous. [35]

[16]Instantaneous water heaters can deliver hot water at temperatures around 70 ^{o}C for 1 second.
[17] As such, instantaneous hot can typically deliver higher hot water flow rates per minute (e.g., between 10 litres/min and 30 litres/min), depending on the model.
[18] In this work it is assumed that the tank is located outdoor.

the desired setpoint. Moreover, If DHW tank temperature falls below the desired DHW delivery temperature, DHW is curtailed, i.e., water heater is still operated to heat up the water in the tank but no draw-off is allowed. In both cases, tempering valves are needed to reduce the temperature of the water at the outlets of the water heater/DHW tank to temperatures below 50^{o}C to be delivered to the household [20]. In this respect, instantaneous gas water heaters can modulate the heat output based on the hot water flow rate, which depends on the inlet water temperature, hot water delivery temperature and water volumetric flow rate. With regards to the sizing of the DHW systems, instantaneous systems are assumed to have enough capacity to exactly match the energy requirements to heat the corresponding DHW volumetric demand. On the other hand, the sizing of storage DHW systems is based on the number of occupants, following an empirical approach. In particular, the DHW tank size (and corresponding thermal capacity of the heating element) is determined, considering the range of available sizes in the market and the building's size (i.e., number of bedrooms), that is, the available market sizes are grouped by their potential installation in a specific dwelling size and randomly selected according to a uniform distribution.

Comments about the DHW model

It is worth making a few comments about potential limitations of the DHW model. One limitation of this model is that it does not consider stratification when modelling hot water storage tank and assumes that water in the tank is fully mixed. While this may not be impacting too much in case of electric water heaters, there may be some inaccuracies in the case of heat pump water heaters. In fact, in the case of electric water heaters, the sensor is typically placed at the bottom of the tank (where water is cold) and as water taps are turned on, it soon senses the cold water flow in to refill the tank and turns the water heater on. However, in the case of EHP, the sensor is place midway and the water around there may still be above the lower threshold (e.g., 52 ^{o}C) and even though cold water is flowing in the tank, the sensor does not sense the temperature decrease immediately and water heater is turned on with a delay compared to the electric one. In this regard, under the assumption of ideal stratification, there would be two zones, one hot and one cold (at the inlet water temperature). However, the "refilling" phenomenon with cold water is not instantaneous but evolves over time. Therefore, if for example we switch from a time instance in which DHW demand is very high (and therefore perfect mixing), it is unlikely that, with the 1 min resolution adopted in this work, there would be perfect stratification in the following timestep. Hence, with the fully mixed fluid assumption, this work takes a conservative approach by underestimating the actual energy stored in the tank and calculating the energy consumption from the "high" side. Another limitation of the model is that it is assumed that the COP of EHP water heaters is modelled as function of outdoor temperature only. However, it is acknowledged that the COP is also affected by the humidity level as well as the inlet and discharge water temperature. In this respect, to have a more accurate value of the discharge water temperature, stratification should also be modelled. Finally, given the lack of detailed specific information, defrost cycles of EHP water heaters have not been modelled. Overall, given the uncertainty in several of the parameters involved in both the analysis of DHW consumption and its modelling for individual buildings and relevant aggregates, and the broader parameter and modelling uncertainty of electricity usage for both space heating and DHW aggregate profiles, the limitations discussed above are likely to only have a minor, if not negligible at all, impact across system studies.

e. Cooking model

The cooking model combines the activity profiles generated by the model in [1], which identifies the specific time instances in which hobs and oven is being used, and the specific electricity (or gas) consumption (kW), elaborated from [22]. The output of this model is used to evaluate the heat gains when determining the demand for space conditioning.

f. Aggregated profiles: Modelling diversity

As mentioned in the previous sections, multiple factors have been incorporated in the model to capture as much as possible the diversity. Particularly, for a specific building type, size and efficiency level, variations on the following parameters have been included:

- Occupancy profiles.
- Variation on indoor temperature setpoint and setback as well as DHW delivery temperature, according to a uniform distribution between a pre-defined temperature range, to account for different indoor environment preferences.
- Variation on indoor temperature and DHW tank water temperature initial conditions according to a uniform distribution between a pre-defined temperature range.
- Variation on buildings' equivalent thermal parameters of 5% from a reference value according to a unform distribution. This directly impacts on the EHP size as the space heating/cooling demand in design conditions would change.
- Building orientation along with solar gain ratio to account for presence of shading.
- Space heating/cooling system and DHW system sizing.

In general, the choice for a uniform distribution arises from the high uncertainty around the model parameters.

3. Simulations

To generate the after-diversity average customer-level demand profile $\tilde{P^s}_{cust}$ for each energy service *s*, i.e., space heating/cooling and DHW, multiple buildings (N_{cust}) are simulated to obtain $P^s_{cust,i}(t)$, aggregated and the average profile is extracted according to (1):

$$\tilde{P^s}_{cust}(t) = \frac{\sum_{i=1}^{N_{cust}} P^s_{cust,i}(t)}{N_{cust}} \tag{1}$$

For this purpose, it is fundamental to choose the right number of buildings (N_{cust}) to be simulated, as a trade-off between computational burden and impact on the peak. In this regard, multiple combinations of buildings' types, size, efficiency levels and day type (i.e., Winter peak/average day) have been simulated to determine the after-diversity average customer-level demand profile for different numbers of buildings. In particular, simulations have been run for a number of buildings between 200 and 600 with steps of 100 buildings and the peak of the resulting average profile was evaluated, along with the associated relative standard deviations. From the analysis, it emerged that the relative standard deviation of the average peaks for the different numbers of buildings was generally very low, below 4%. Therefore, a building number of 300 was selected for the simulations.

a. Input data

The profiles are obtained for a single day analysis with 1 min resolution, accounting for the outdoor temperature as well as the solar radiation profiles. Naturally, these vary across multiple locations in Victoria. Therefore, it is fundamental to identify some representative locations for each climate zones in Victoria to account for such diversity.

i. Weather zones and representative locations

In Victoria, four climate zone are identified, namely zones 4,6,7 and 8, as reported in Figure 10 [23]. However, also in discussion with project partners, zone 8 (Alpine) is excluded given the relatively smaller geographical significance. This work thus focuses on climate zone 4,6 and 7. For each zone, a representative city is selected, as summarized in Table 3.1. It should be noted that for climate zone 6, two representative cities have been considered, namely Melbourne and Traralgon, the latter being located in Gippsland.

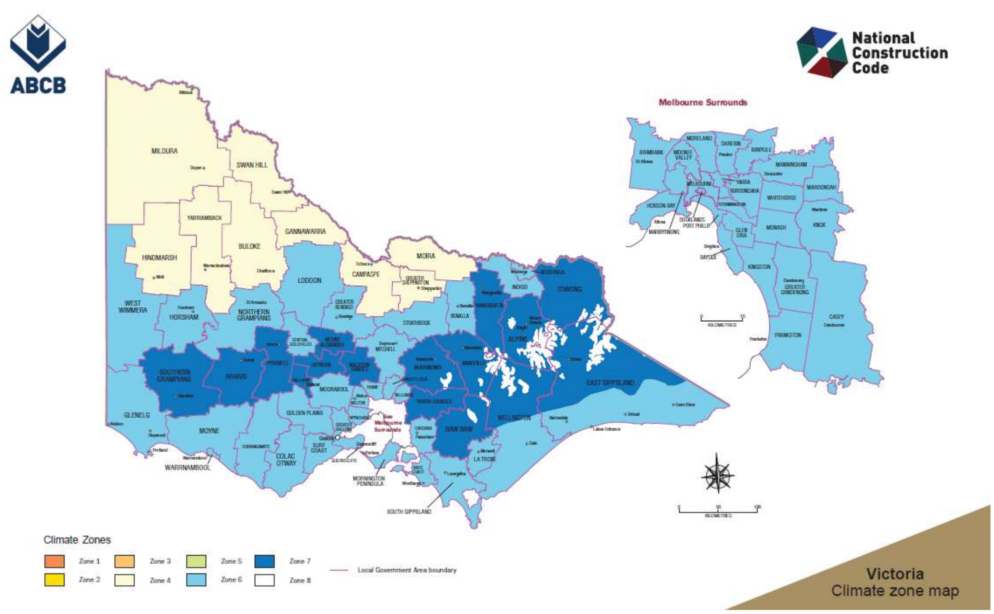


Figure 10 Climate zone map for Victoria [23].

Table 3.1 Representative location corresponding to each climate zone under analysis.

Climate zone	Representative location
Zone 4	Shepparton
Zone 6	Melbourne
Zone 6	Traralgon
Zone 7	Ballarat

Based on these locations, it is also possible to determine the location-specific design conditions, which are essential in the process of sizing the technologies (i.e., EHP)[19]. The design conditions, reported in Table 3.2, have been retrieved from [4].

Table 3.2 Design conditions (outdoor temperature) for each representative location under analysis.

Location	Heating	Cooling
Ballarat	0.2	33.6
Melbourne	3.9	35.5
Shepparton	-0.9	38
Traralgon	0.1	35.4

ii. Weather conditions

The simulations are run to determine the profiles, for each location, on specific representative day types, namely Winter Peak (WP), Winter Average (WA), Summer Peak (SP), Summer Average (SA) and Shoulder (Sh). These are defined based on the average value for outdoor temperature as follows:

- **Winter peak day** represents the day with lowest average temperature.
- **Winter average day** represents the day whose average is closer to the season average.
- **Summer peak day** represents the day with the highest average temperature.
- **Summer average day** represents the day whose average is closer to the season average.
- **Shoulder average** day represents the day whose average is closer to the season average (shoulder months).

iii. Temperature profiles

To identify the specific daily outdoor temperature profiles for each representative day type, 10 years (2014-2023) worth of temperature data [24] with 1 min resolution has been analyzed for each location. The temperature profiles used in this work are reported in Figures Figure 11Figure 15, along with

[19] A lower outdoor design temperature would most likely lead to bigger EHP sizes which, based on the performance data available and adopted in this work, have higher COP compared to smaller sizes. As a result, this would impact on the total electricity consumption.

information on the average temperature and specific day when this occurred in Tables Table 3Table 3.7.

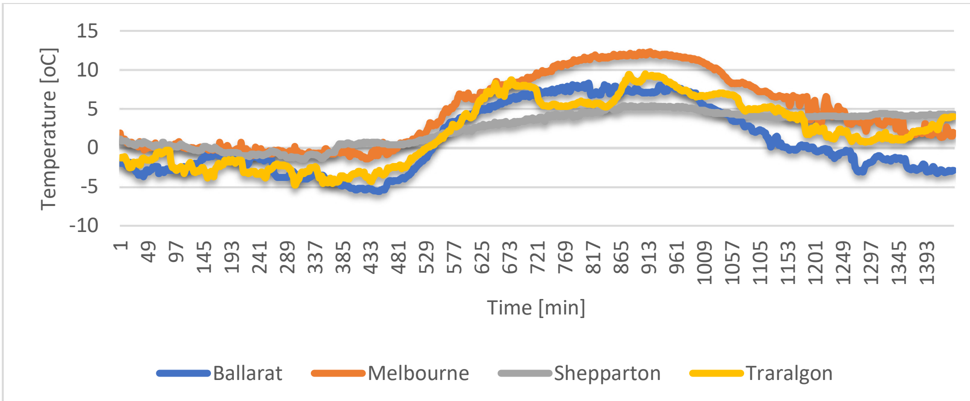


Figure 11 Temperature profiles on the representative Winter peak day for each location under analysis.

Table 3 Winter peak dates and average temperature for each representative location.

Ballarat	Melbourne	Shepparton	Traralgon
19/7/2015	20/7/2022	21/6/2023	3/7/2017
Avg: 0.9 °C	Avg: 4.6 °C	Avg: 2.5 °C	Avg: 2.1 °C

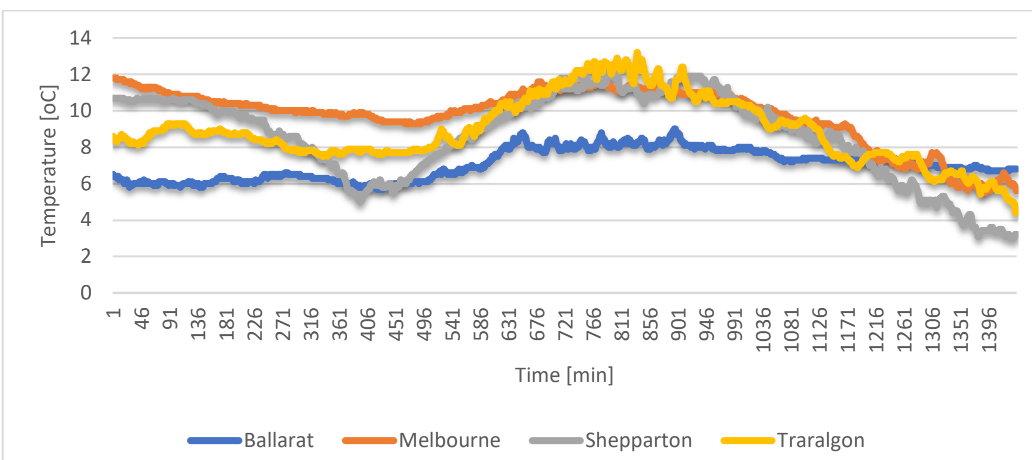


Figure 12 Temperature profiles on the representative Winter average day for each location under analysis.

Table 4 Winter average dates and average temperature for each representative location.

Ballarat	Melbourne	Shepparton	Traralgon

18/8/2014	18/6/2016	11/6/2016	21/7/2023
Avg: 7.0 °C	Avg: 9.8 °C	Avg: 8.7 °C	Avg: 8.9 °C

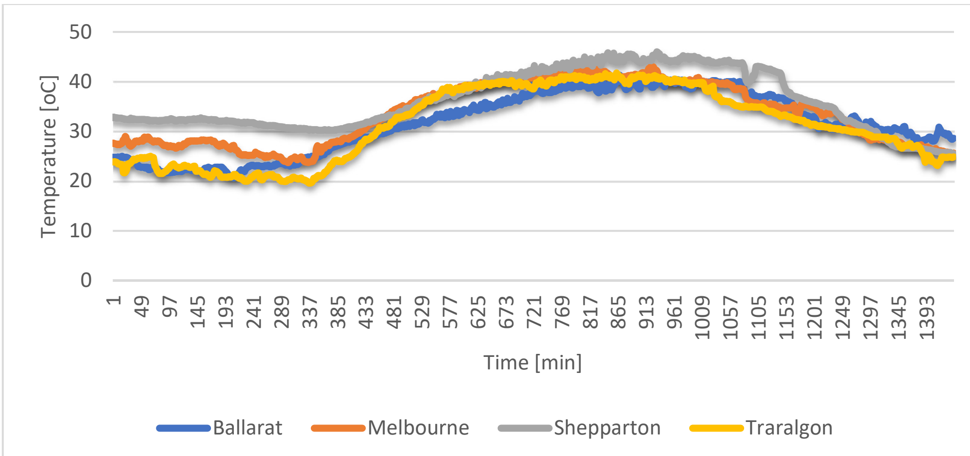


Figure 13 Temperature profiles on the representative Summer peak day for each location under analysis.

Table 3.5 Summer peak dates and average temperature for each representative location.

Ballarat	Melbourne	Shepparton	Traralgon
14/1/2014	16/1/2014	25/1/2019	15/1/2014
Avg: 31.6 °C	Avg: 33.5 °C	Avg: 36.1 °C	Avg: 31.3 °C

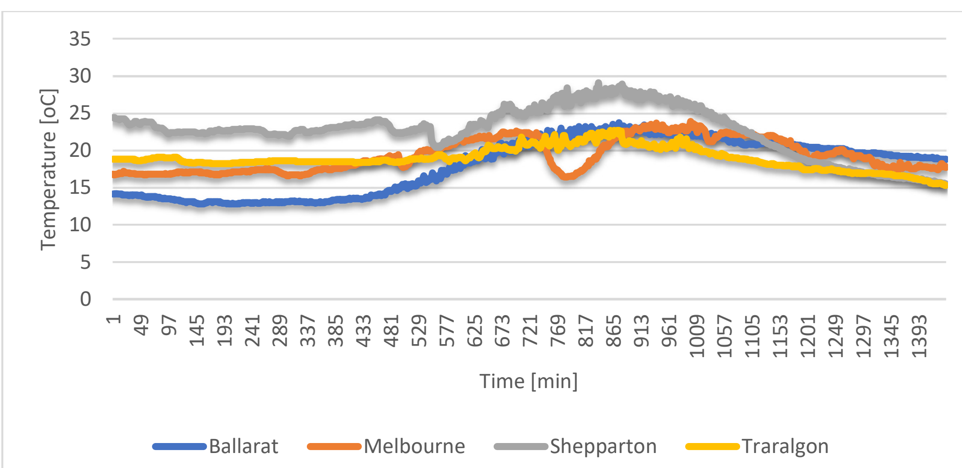


Figure 14 Temperature profiles on the representative Summer average day for each location under analysis.

Table 3.6 Summer average dates and average temperature for each representative location.

Ballarat	Melbourne	Shepparton	Traralgon

5/2/2019	15/12/2018	26/1/2021	14/1/2015
Avg: 18.0 °C	Avg: 19.4 °C	Avg: 22.7 °C	Avg: 18.9 °C

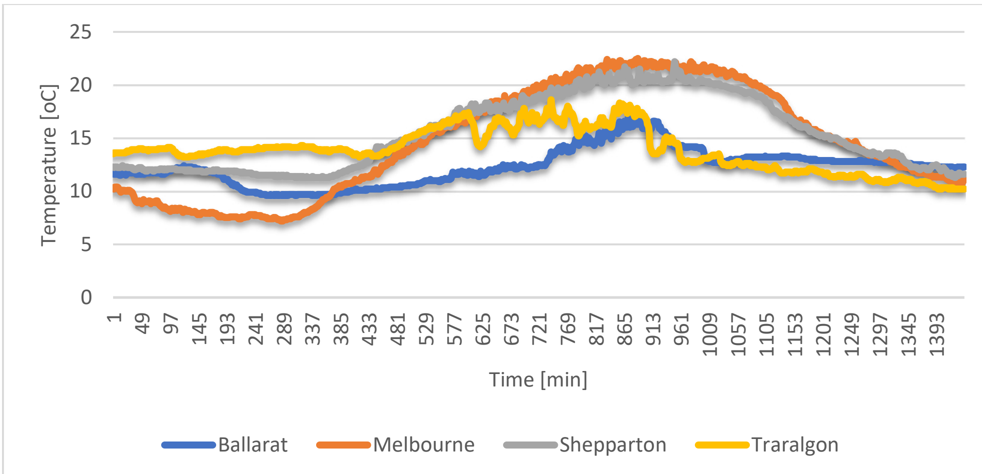


Figure 15 Temperature profiles on the representative Shoulder day for each location under analysis.

Table 3.7 Shoulder dates and average temperature for each representative location.

Ballarat	Melbourne	Shepparton	Traralgon
12/4/2023	28/11/2021	27/10/2020	8/4/2023
Avg: 12.3 °C	Avg: 14.7 °C	Avg: 15.5 °C	Avg: 13.9 °C

With respect to the feed-in water temperature, this is assumed to vary across season, and it is assumed to be constant throughout the day and the same across all locations. The water temperature adopted in this work have been elaborate from [25] and are reported in Figure 16.

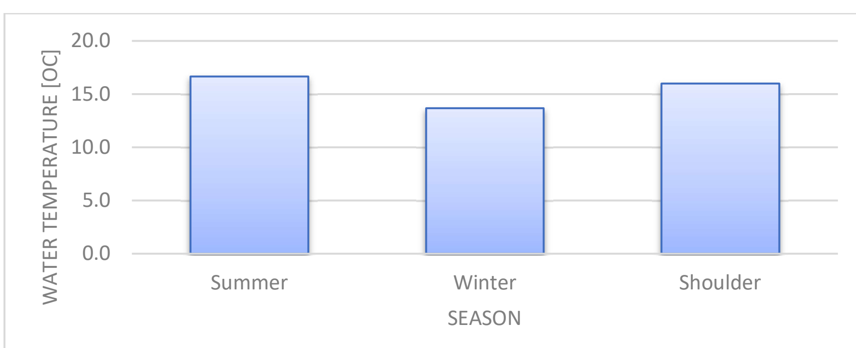


Figure 16 Inlet water temperature for each season.

iv. Solar irradiance profiles

Given the uncertainty around the solar gains, for the purpose of this project, the solar radiation profiles from the Typical Meteorological Year (TMY) for the specific day of the year have been used [26]. For example, if the WP day in Ballarat occurs on the 19th of July, the "typical" solar profile on that day form the TMY is selected. The data is provided as direct normal irradiance (DNI) and diffuse horizontal irradiance (DHI), already accounting for clouds. Nevertheless, these represent the solar gains for a horizontal surface, whereas each side of a building can be seen as a surface tilted 90°. Moreover, buildings can have different orientations which would influence the total solar gains, in addition to shadings. Therefore, from the values provided of DHI and DNI, and by calculating the incidence angle over a surface (i.e., building) tilted 90° and different azimuth angles (i.e., orientations), it is possible to determine the solar irradiance for different orientations, also considering the impact of reflected radiation [27]. An illustrative example is provided for Melbourne during a Winter and Summer peak days. Specifically, the DNI on the two days under analysis are reported in Figure 17 and **Error! Reference source not found.**, which also display the "clear sky" corresponding profile. It can be noticed that, on the Winter peak day, the actual solar radiation reaching the ground is lower than the clear sky radiation, due to the presence of clouds, which is more frequent in Winter. On the other hand, the actual and clear sky solar radiation profiles on the Summer peak day coincide. The resulting solar gains from different orientations on a Summer peak days is illustrated in Figure 19.

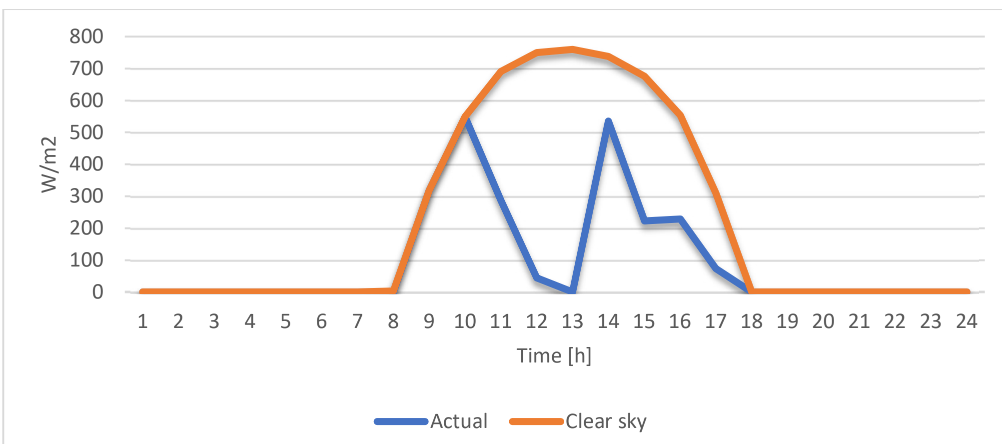


Figure 17 Illustrative example of direct normal irradiance on the representative Winter peak day in Melbourne.

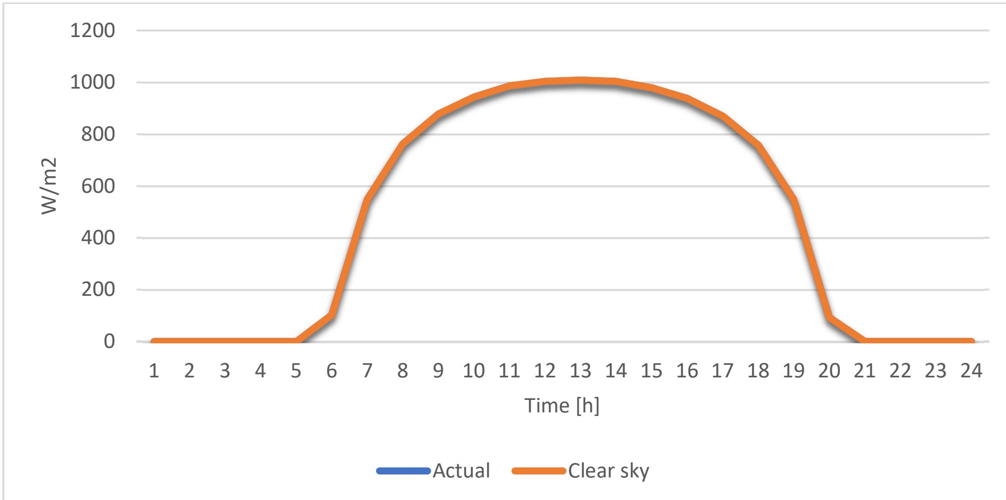


Figure 18 Illustrative example of direct normal irradiance on the representative Summer peak day in Melbourne.

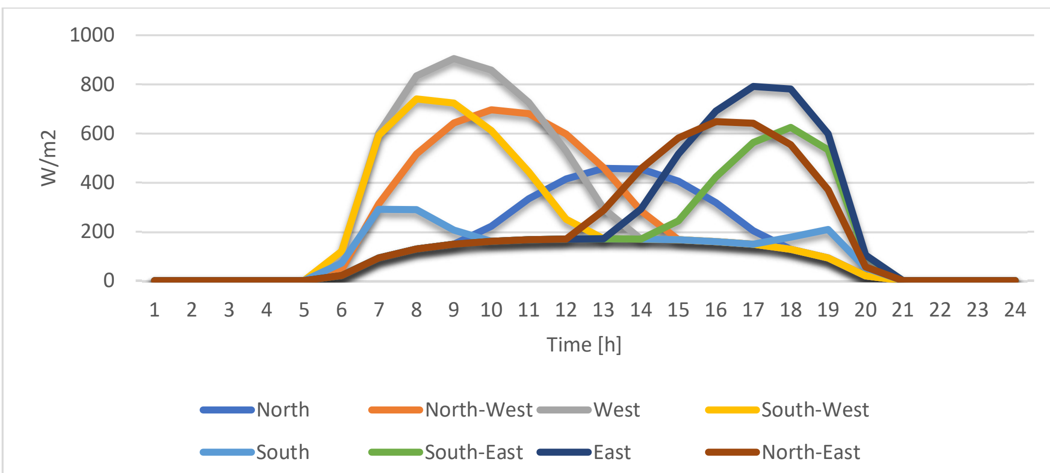


Figure 19 Illustrative example of solar irradiance on a surface tilted 90o from different orientations on representative Summer peak day in Melbourne.

v. Heating/Cooling system activation strategies

In addition to the profiles obtained strictly following the occupancy profiles, alternative heating system (for both space conditioning and DHW) activation strategies have been tested.

In particular, for space heating/cooling the "base" activation strategy assumes that, in the morning, as soon as any of the occupants wakes up, the indoor target temperature goes from the setback to the setpoint, under the assumption that the occupant would turn on the heater before going to work. Nonetheless, there may be cases in which the heating/cooling system is not turned on in the morning but rather in the afternoon/evening when occupants come back home, e.g., form work. Therefore, to account for this possibility, the alternative "Late" activation strategy assumes that, in the time window between 12 am and 3 pm, the indoor target temperature is at the setback regardless of whether occupants are active at home. Then, the activation strategy goes back to following the “base” strategy based on the occupancy, starting from a time between 3 pm and 8 pm, which is selected according to a uniform distribution with mean value around 5.30 pm.

Similarly, for the DHW system, in addition to the “Temperature controlled” operation mode, two additional strategies have been simulated, namely “Off-peak controlled load” and “Solar soaking” modes. Unlike water heaters operating on a continuous electric tariff in which the electric elements are turned on when the water temperature drops below the thermostat set point, when operated under restricted tariffs, these are controlled by electricity suppliers as a form of load management and can only be operated within specific time windows. To account for this possibility, the “Off-peak controlled load” operating mode is implemented considering the peak time window defined as between 3 pm and 9 pm based on Victorian DNSPs [28]. To evaluate the potential demand from DHW that could be deployed to balance out the electricity production from the increasingly widespread rooftop solar PV systems, the “Solar soaking” activation strategy forces the DHW system to only operate within a specified time window, here defined between 10 am and 3 pm in accordance with [29]. In this case, the model sets the tank water temperature upper bound to 70 ^{o}C.

4. Tool description

A specific tool has developed, coded in Python, which allows combining the different average customer-level demand profiles for each energy service, i.e., space heating/cooling and DHW, given the total number of buildings in the area under analysis and the proportion of building with specific attributes.

In particular, each average customer-level demand profile for each energy service is provided with the following name, reflecting the attributes:

Space heating/cooling:

Loc_**A**_Day_**B**_TechSH/C_**C**_Material_**D**_Nocc_**E**_Insul_**F**_Btype_**G**_ActStrat_**H**_**X**

Where:

- **A** refers to the location under analysis, and it has values 1=Ballarat, 2=Melbourne, 3=Shepparton, 4=Traralgon.
- **B** refers to the day type under analysis, and it has values 1=Winter Peak, 2=Winter Average, 3=Summer Peak, 4=Summer Average, 5=Shoulder.
- **C** refers to the technology used for space heating, and it has values 1=reverse cycle EHP, 2=Gas ducted system, whereas for space cooling the value is set to 1 (i.e., reverse cycle EHP).
- **D** refers to the construction material which can be set to 1=Brick, 2=Double brick, 3=Timber if the building type is a detached or semi-detached house. However, only the profiles for brick

have been generated since it is the most common construction material for these building types. In the case of a flat/apartment type, this value is always set to 1.

- **E** refers to the building/household size, and it has values 1=1 bedroom dwelling, 2=2 bedrooms dwelling, 3=3 bedrooms dwelling, 4=4 bedrooms dwelling.
- **F** refers to the building insulation level, and it has values 1=Efficient, 2=New, 3=Modern, 4=Old.
- **G** refers to the building type, and it has values 1=Detached house, 2=Semi-detached house, 3=Flat/Apartment.
- **H** refers to the heating/cooling system activation strategy, and it has values 0=Late activation and 1=Base.
- **X** refers to the specific variable saved:
    - '_Avg_Ele_SH' refers to the average electricity consumption profile for space heating when this is provided via EHP (kW_{ele}). It is a 1440x1 matrix.
    - '_Avg_Ele_SC' refers to the average electricity consumption profile for space cooling when this is provided via EHP (kW_{ele}). It is a 1440x1 matrix.
    - '_Avg_Gas_SH' refers to the average gas consumption profile for space heating when this is provided via gas ducted system (kW_{gas}). It is a 1440x1 matrix, obtained considering a gas heater efficiency of 85%.
    - '_Ele_SH' refers to the building-level electricity consumption profiles for space heating when this is provided via EHP for 300 buildings (kW_{ele}). It is a 1440x300 matrix.
    - '_Ele_SC' refers to the building-level electricity consumption profiles for space cooling when this is provided via EHP for 300 buildings (kW_{ele}). It is a 1440x300 matrix.
    - '_Heat_SH' refers to the building-level heat consumption profiles for space heating for 300 buildings (kJ/min). It is a 1440x300 matrix. Negative values correspond to time instances in which defrost cycles take place.
    - '_Heat_SC' refers to the building-level heat (negative) consumption profiles for space cooling (sensible[20] cooling) for 300 buildings (kJ/min). It is a 1440x300 matrix.
    - '_Gas_SH' refers to the building-level gas consumption profiles for space heating when this is provided via gas ducted system for 300 buildings (kW_{gas}). It is a 1440x300 matrix, obtained considering a gas heater efficiency of 85%.
    - 'COP' refers to the building-level evolution of COP of each EHP installed in each one of the 300 buildings (dimensionless). It is a 1440x300 matrix. It should be noted that the first row (i.e., t=1) represents the initialization value and it should be ignored.

[20] Responsible for temperature decrease, whereas the total cooling capacity also includes the capacity used to dehumidify the air.

- ‘Tin’[21] refers to the building-level evolution of indoor temperature in each one of the 300 buildings (°C). It is a 1440x300 matrix.

Domestic hot water:

Loc_**A**_Day_**B**_TechDHW_**C**_Nocc_**D**_OffPeak_**E**_SolSoak_**F**_**X**

Where:

- **A** refers to the location under analysis, and it has values 1=Ballarat, 2=Melbourne, 3=Shepparton, 4=Traralgon.
- **B** refers to the day type under analysis, and it has values 1=Winter Peak, 2=Winter Average, 3=Summer Peak, 4=Summer Average, 5=Shoulder.
- **C** refers to the technology used for DHW, and it has values 1= EHP water heater (storage-based), 2= Resistive storage, 3= Gas instantaneous.
- **D** refers to the building/household size, and it has values 1=1 occupant, 2=2 occupants, 3=3 occupants, 4=4 occupants.
- **E** refers to whether the “Off-peak controlled load” strategy is active, and it has values 0=Inactive, 1=Active.
- **F** refers to whether the “Solar soaking” strategy is active, and it has values 0=Inactive, 1=Active.
- **X** refers to the specific variable saved:
  - '_Avg_E_DHW' refers to the average electricity consumption for DHW when this is provided via EHP or resistive storage water heaters (obtained considering an efficiency of 99%) (kW_{ele}). It is a 1440x1 matrix.
  - '_E_DHW' refers to the building-level electricity consumption profiles for DHW when this is provided via EHP or resistive storage water heaters for 300 buildings (kW_{ele}). It is a 1440x300 matrix.
  - '_COP_DHW' refers to the building-level evolution of COP of each EHP water heater installed in each one of the 300 buildings (dimensionless). It is a 1440x300 matrix. It should be noted that the first row (i.e., t=1) represents the initialization value and it should therefore be ignored.
  - '_Avg_G_DHW' refers to the average gas consumption for DHW when this is provided via instantaneous gas water heaters, obtained considering an efficiency of 85% (kW_{gas}). It is a 1440x1 matrix.
  - '_G_DHW' refers to the building-level gas consumption for DHW when this is provided via instantaneous gas water heaters for 300 buildings (kW_{gas}). It is a 1440x300 matrix.

[21] This information could be used, in combination with the outdoor temperature profile and heat output stored in the '_Heat_SH' output file provided, to generate new electricity demand profiles based on alternative modelling of the COP based on tool user’s available information.

a. Python tool for aggregated profiles

i. Excel input file

The tool comes with an Excel file in which the inputs are defined. More specifically, in the tab "**Inputs**", the user is required to specify, in the "**Selection**" column, the location, the day type (e.g., Winter peak day), the type of energy service to be studied (i.e., space conditioning or DHW or both), the total number of buildings in the area to be analyzed, the energy vector for energy service (i.e., electricity or gas) and finally the proportion of buildings for which the space conditioning activation strategy is "delayed" (i.e., "ActStrat" attribute is set to 0). An example of the Excel spreadsheet is provided in Figure 20.

	A	B	C	D
1	**Parameter**	**Selection**	**Notes**	**Value**
2	Location	Ballarat		1
3	Day type	Winter Peak		1
4	Energy services	Space conditioning		1
5	Total number of buildings	100	Value must be greater than 0	100
6	Energy vector for space heating	Electricity	[1]	0
7	Energy vector for domestic hot water	Gas	[2]	1
8	Proportion LATE space conditioning activation strategy (%)	100%		1

Figure 20 Excel inputs interface to the Python tool for the aggregated profiles.

The Excel file also includes two additional tabs, namely "**Proportions space conditioning**" and "**Proportions DHW**". In the former, the user can define, for the specific area under analysis, the proportion of building types as well as the breakdown by household size, building insulation level and construction material by building type. Similarly, in the tab "Proportions DHW", it is possible to define the proportions by household size, as well as the breakdown of water heater technology[22] , and the type of operational strategy by household size. Examples of these proportion tables are provided in Figure 21 and Figure 22.

	A	B	C	D	E	F
1	**Building type**	**Detached house**	**Semi-detached house**	**Apartment**	**Check**	
2	%	21.00%	19.00%	60.00%	OK	
3						
4						
5	**Household size (%)**	**1 occupant**	**2 occupants**	**3 occupants**	**4 occupants**	**Check**
6	**Detached house**	25%	35%	30%	10%	OK
7	**Semi-detached house**	25%	25%	25%	25%	OK
8	**Apartment**	50%	25%	25%	0%	OK
9						
10						
11	**Building insulation level (%)**	**Efficient**	**New**	**Modern**	**Old**	**Check**
12	**Detached house**	10%	27%	13%	50%	OK
13	**Semi-detached house**	20%	40%	10%	30%	OK
14	**Apartment**	50%	20%	20%	10%	OK

Figure 21 Example of proportion tables to generate space conditioning aggregated profiles.

[22] These are required only in the case that DHW is electrified. If the energy vector for DHW is selected to be "gas" in the "Inputs" tab, then the only technology option would be the instantaneous gas water heater.

	A	B	C	D	E	F
1	Household size	1 occupant	2 occupants	3 occupants	4 occupants	Check
2	%	25%	35%	30%	10%	OK
3						
4						
5	DHW technology	EHP water heater	Resistive storage water heater	Check		
6	1 occupant	30%	70%	OK		
7	2 occupants	23%	77%	OK		
8	3 occupants	47%	53%	OK		
9	4 occupants	30%	70%	OK		
10						
11						
12	DHW activation stategy	Temperature controlled	Off-peak controlled load	Solar soaking	Check	
13	1 occupant	20%	30%	50%	OK	
14	2 occupants	50%	10%	40%	OK	
15	3 occupants	40%	15%	45%	OK	
16	4 occupants	10%	50%	40%	OK	

Figure 22 Example of proportion tables required to generate DHW aggregated profiles.

ii. Python engine

Once the Excel file has been populated, to generate the aggregated profiles it is necessary to run a Python file, called “Run.py”. To be able to do that, another Python file “Generate_Profiles.py” is required to be located in the same folder as the “Run.py” file, along with the folder containing the profiles database (unzipped). To be able to run the engine, the NumPy [30], Pandas [31] and Matplotlib [32] packages are installed in the machine, along with the Random and Os Python modules.

With the “Run.py” engine, there are two main functions available, namely “*export_profiles*” and “*plot_profiles*”. The former generates and saves, in a single Excel file, the demand profile for the specific energy service, one in each separate spreadsheets (i.e., space conditioning or DHW), in kW[23] with 1 min resolution. The name format of the saved file is "*Output_filename*" where "filename" refers to the Excel file where the input data have been defined.

The second function “*plot_profiles*” allow to directly plot in Python the demand profile for the specific energy service (i.e., space conditioning or DHW) of the corresponding energy vector (i.e., electricity or gas) in kW with 1 min resolution. More detailed instructions on the input format is provided in the “Run.py” file.

5. Application use cases

a. After diversity average customer-level demand profile for space conditioning

An example of demand profiles for space heating, supplied by EHP, on a Winter Peak day in Melbourne for different building types with the same insulation level and household size is illustrated in Figure 23. Because of the different geometry and construction materials’ thermal properties, these profiles differ

[23] of the corresponding energy vector (i.e., electricity/active power or gas).

not only in terms of magnitude of peaks but also when these peaks occur and for how long they are sustained.

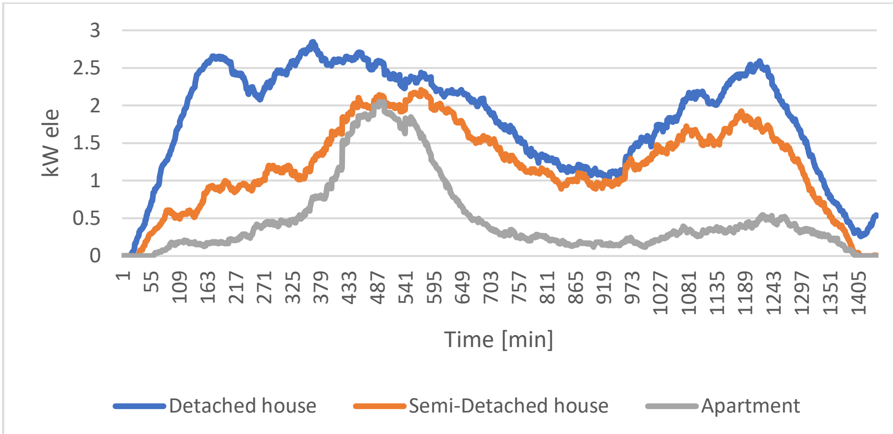


Figure 23 Electricity demand profile for space heating on a Winter Peak day in Melbourne for different building types with three bedrooms and "new" insulation level.

Naturally, taking a three-bedrooms "new" detached house as an example, Winter Peak days differ by location in terms of temperature profile as well as solar gains. This is reflected onto the resulting electricity demand profile, as demonstrated in Figure 24.

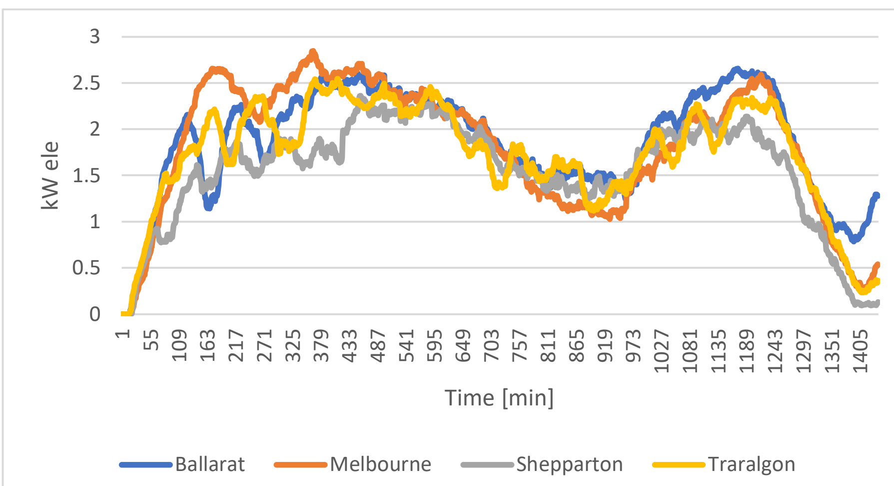


Figure 24 Electricity demand profile for space heating on a Winter Peak day for a "new" three-bedrooms detached house in different locations.

On a Winter average day, however, the peaks are lower. For example, while on a Winter Peak day the electricity peak demand for space heating may reach ~3 kW_{ele}, as showed in Figure 23, this drops to ~2 kW_{ele}, as demonstrated in Figure 25.

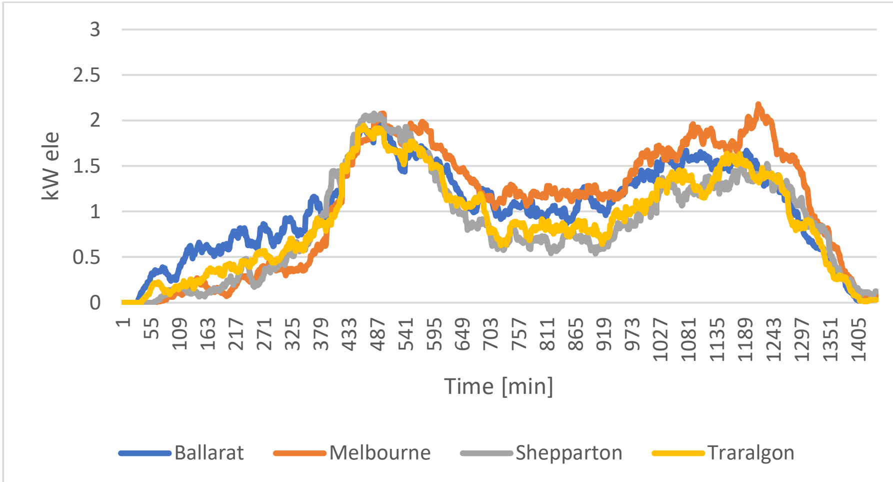


Figure 25 Electricity demand profile for space heating on a Winter Average day for a "new" three-bedrooms detached house in different locations.

The impact of the building' size as well as insulation level is highlighted in Figure 26 and Figure 27 , respectively. In fact, different building sizes lead to profiles which differ by magnitude (i.e., peaks) of consumption and duration. Similarly, as energy efficiency measures for the building envelope are deployed, peaks may be reduced, in addition to lower energy consumption.

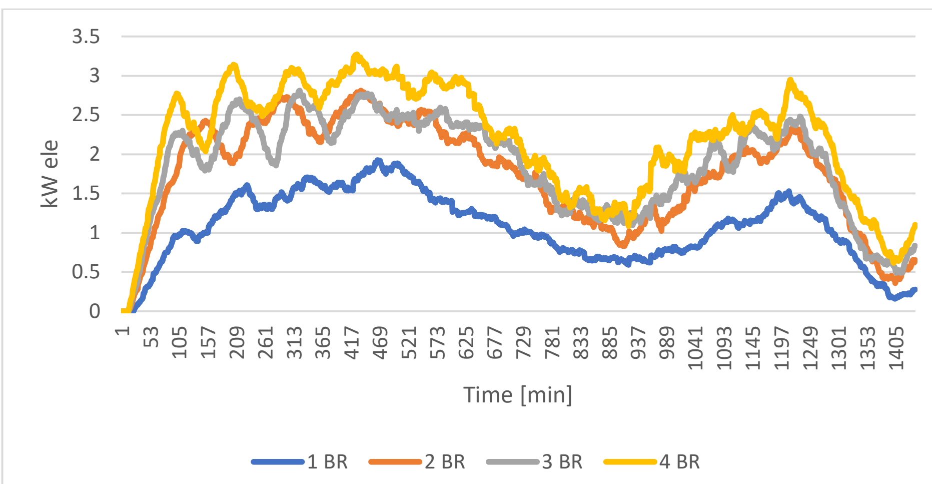


Figure 26 Electricity demand profile for space heating on a Winter Peak day for a "modern" detached house in Melbourne of different sizes.

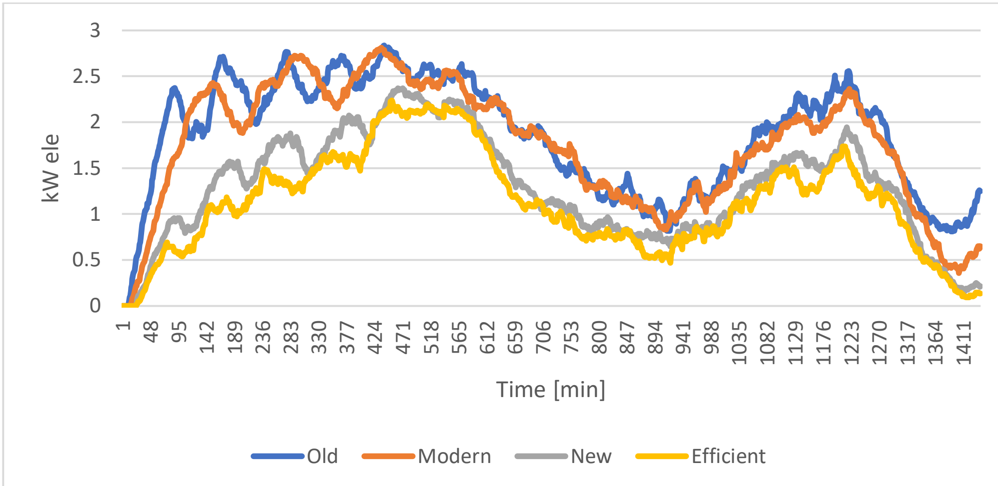


Figure 27 Electricity demand profile for space heating on a Winter Peak day for a two-bedrooms detached house in Melbourne with different insulation levels.

Furthermore, the different demand profiles, for the corresponding energy vector, depending on whether space heating is supplied via ducted EHP or gas heating system, are showcased in Figure 28. In fact, depending on the technology adopted to supply the space heating demand, and therefore energy vector, the magnitude and time at which peak occurs greatly vary.

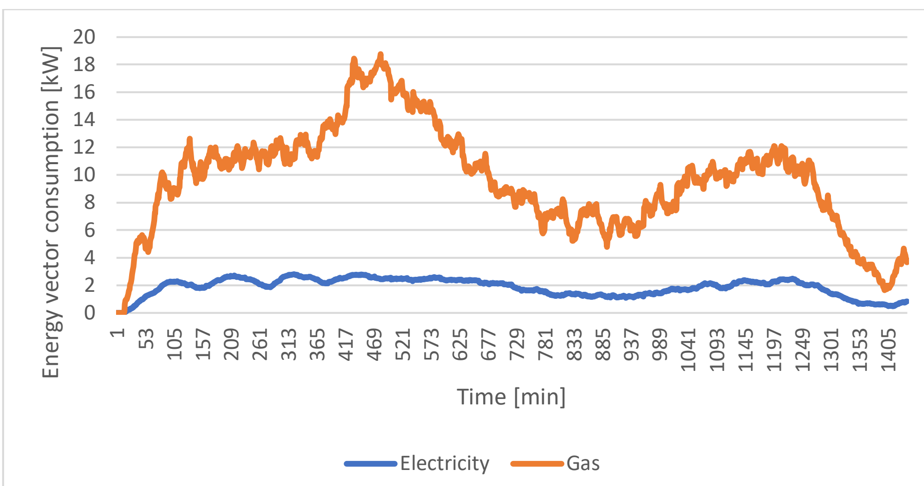


Figure 28 Demand profile, for the specific energy vector, for space heating on a Winter Peak day for a three-bedrooms modern detached house in Melbourne, supplied by different space heating technologies (i.e., EHP and gas ducted heating systems).

Finally, as discussed in Section 3.a.v, the "base" activation strategy assumes that, in the morning, as soon as any of the occupants wake up, the indoor target temperature goes from the setback to the setpoint, under the assumption that the occupant would turn on the heater in the morning before going to work. On the other hand, when the occupants turn on the heating/cooling system in the afternoon/evening when occupants come back home, e.g., after work, the peak occurs later in the evening and its magnitude may also increase as demonstrated in Figure 29.

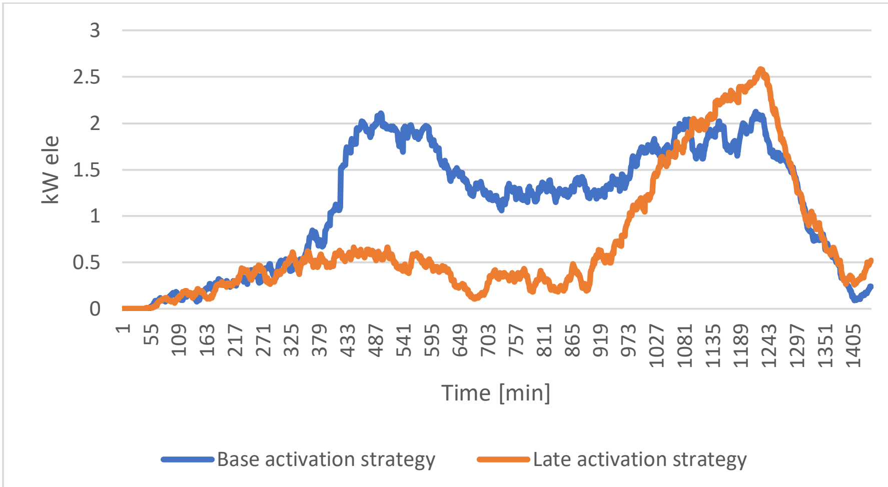


Figure 29 Demand profile for space heating on a Winter Average day for a three-bedrooms modern detached house in Melbourne, obtained with different heating system activation strategy.

Similar to space heating, the model can also generate electricity profiles for space cooling. In fact, the same impact of building size as well as temperature profiles on the electricity consumption profile and its peak is showcase in Figure 30, Figure 31 and Figure Figure 32.

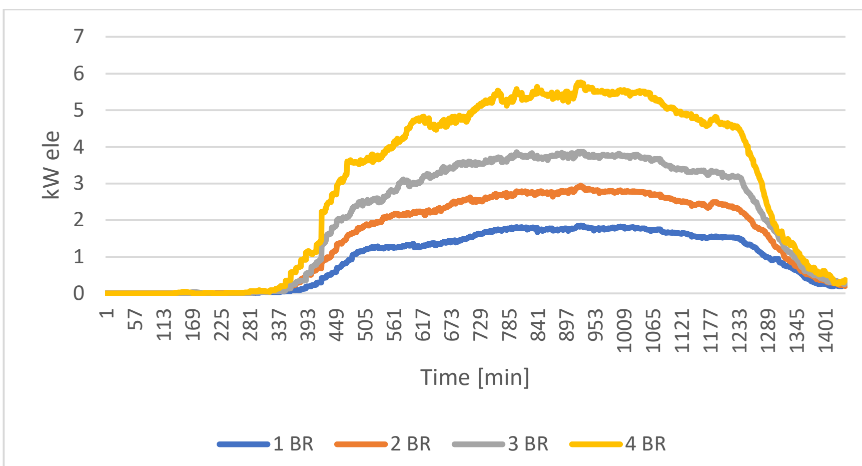


Figure 30 Electricity demand profile for space cooling on a Summer Peak day for a modern detached house of different sizes in Melbourne.

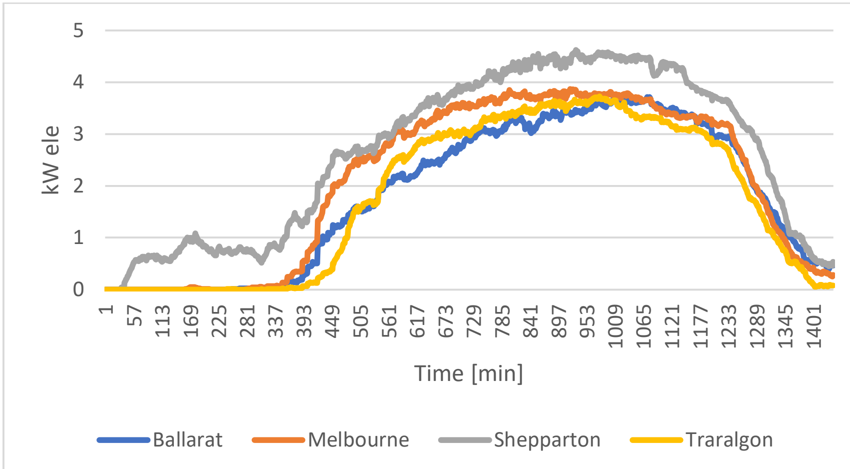


Figure 31 Electricity demand profile for space cooling on a Summer Peak day for a three-bedrooms modern detached house in different locations.

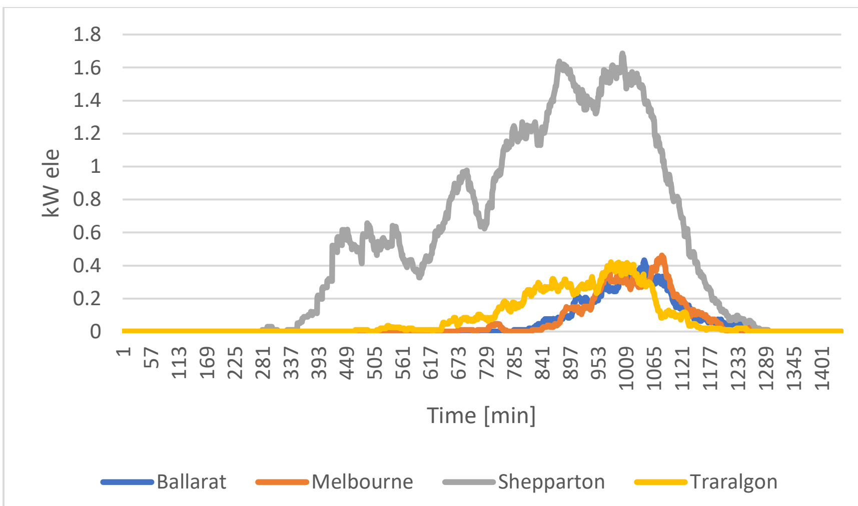


Figure 32 Electricity demand profile for space cooling on a Summer Average day for a three-bedrooms modern detached house in different locations.

b. After diversity average customer-level demand profile for DHW

In this section, the model is applied to generate average building-level DHW demand profiles by energy vector, depending on whether electricity or gas is used to supply DHW. As an illustrative example, the average building-level DHW volumetric demand profile for a three people household is reported in Figure 33. This is then used to generate the electricity/gas demand profile considering different DHW water heater technologies. Ad demonstrated in Figure 34, in the case of instantaneous gas water heater, the gas demand profile exactly follows the DHW volumetric demand profile, depending only on the inlet water temperature. The same situation would occur if DHW was supplied by an instantaneous electric water heater.

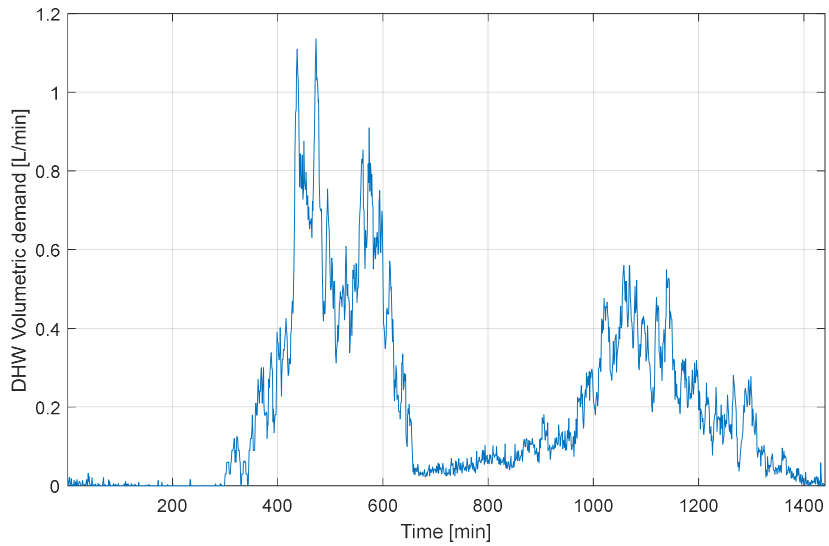


Figure 33 Average building-level volumetric DHW demand profile for a three people household.

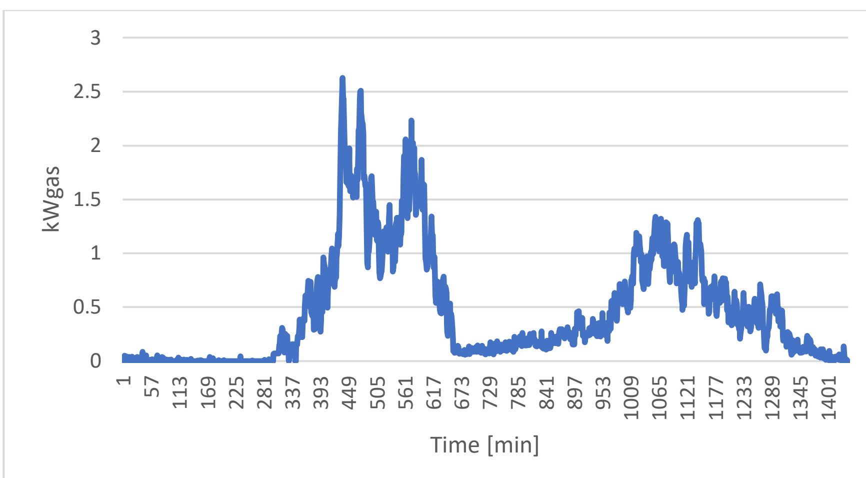


Figure 34 Average building-level DHW demand profile for a three people household in Winter supplied by instantaneous gas water heater.

On the other hand, in the case of storage-based water heaters, the electricity demand profile would be greatly impacted by the outdoor temperature as this affects the water tank losses. As reported in Figure 35 for an EHP water heater, the electricity demand on a Winter Peak day is higher with a higher peak, not only caused by the additional losses in the water tank, but also by the reduction of the COP, thus requiring more electricity to heat up the water tank. The impact of the household size on the DHW electricity demand profile (similarly for gas) and its peaks is highlighted in Figure 36. When comparing the two storage water heater technology alternatives, namely EHP and resistive, it is clear from Figure

37 that the higher efficiency of EHP water heaters leads to lower electricity demand peaks and overall energy consumption.

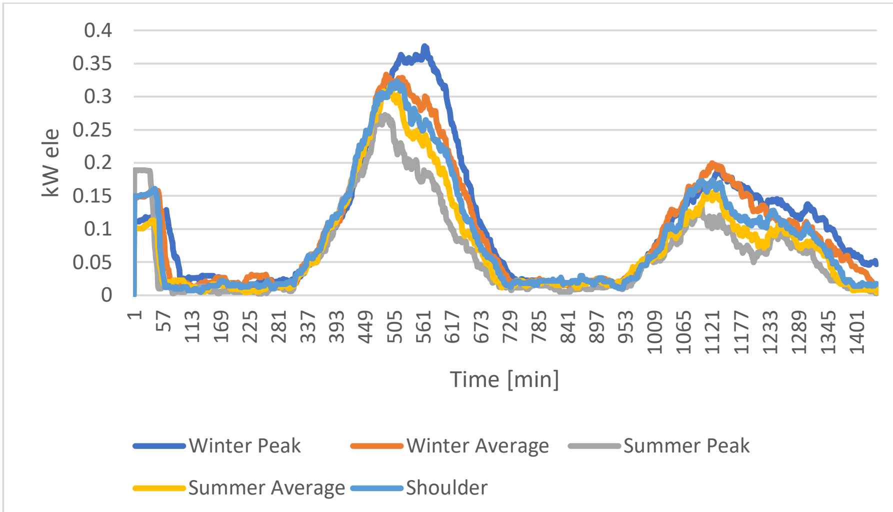


Figure 35 Average building-level DHW demand profile for a two people household in Ballarat on different day types supplied by EHP water heater.

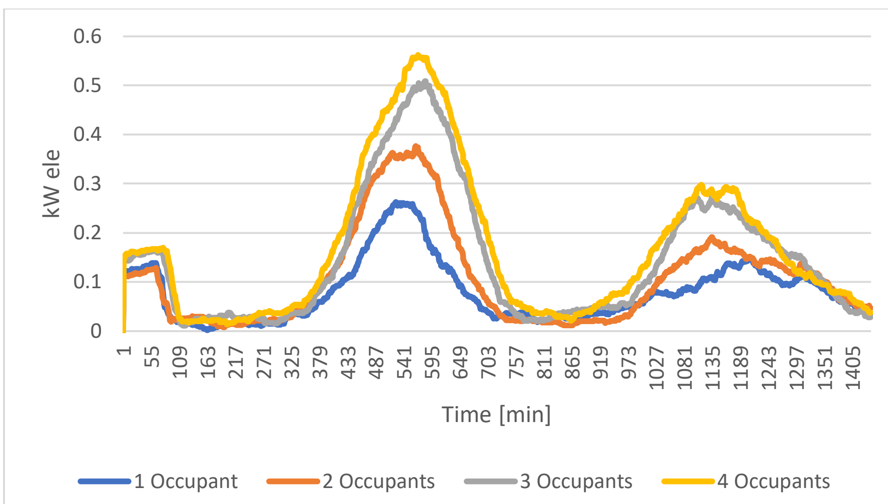


Figure 36 Average building-level DHW demand profile for a household of different sizes in Ballarat on a Winter Peak day supplied by EHP water heater.

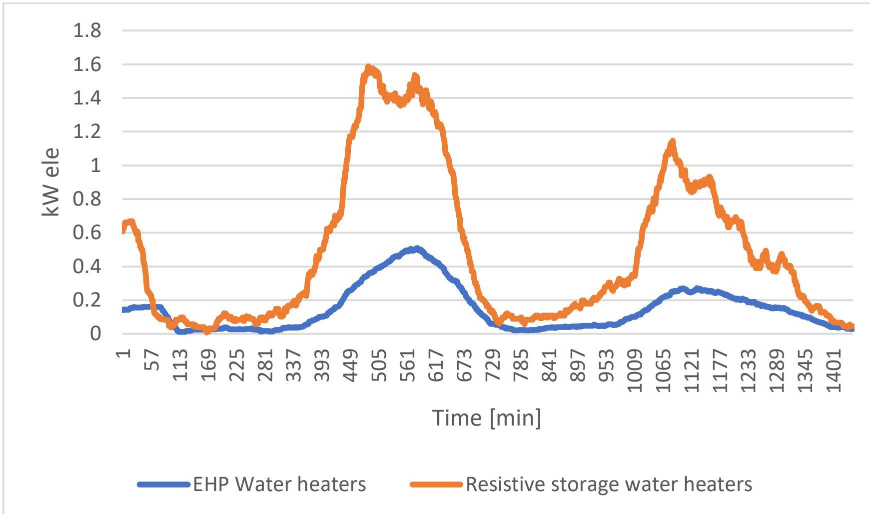


Figure 37 Average building-level DHW demand profile for a three people household in Ballarat on a Winter Peak day supplied by EHP or resistive storage water heater.

Finally, Figure 38 compares the three different operational strategies for EHP water heaters. In solar soaking mode, the water heater limits its operation within a specific time window defined to potentially maximize the utilization of rooftop solar PV electricity production. It can be noticed that the peak is higher than in the other two operational strategies, and this is also due to the fact the tank water temperature is allowed to increase up to 70ºC, instead of 60ºC. Moreover, while the profiles resulting from the off-peak and temperature-controlled modes coincide until 3 pm, in off-peak mode water heaters are shut-down from 3 pm and turned on later at 9 pm causing a shifted and higher peak.

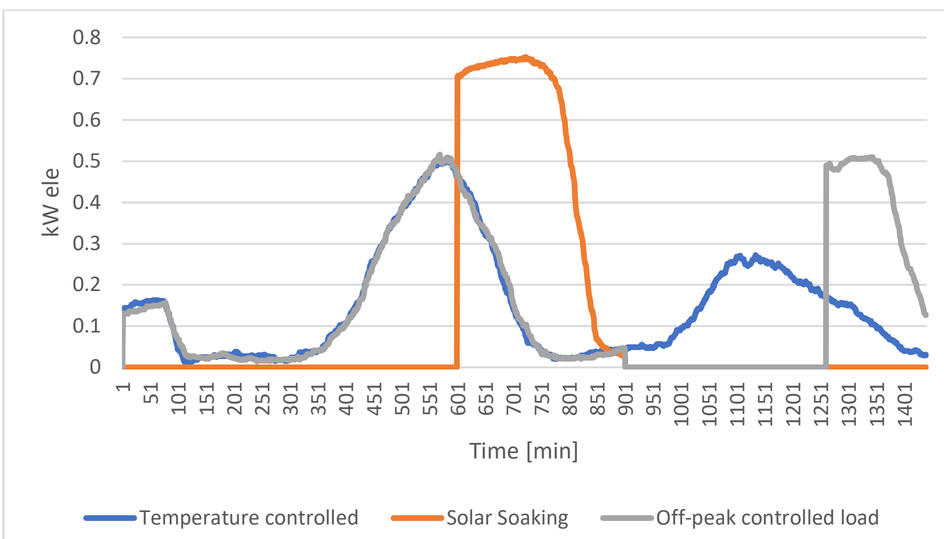


Figure 38 Average building-level DHW demand profile for a three people household in Ballarat on a Winter Peak day supplied by an EHP water heater under different operating strategies.

c. Aggregated profiles example for space heating

In this illustrative example, the tool is used to generate the aggregated electricity profile considering a total number of 100 two-bedrooms modern buildings, supplied by ducted EHP, with different proportions of building types, as summarized in Table 1. A "Base" heating system activation strategy is assumed in these cases, and the resulting profiles are displayed in Figure 39.

Table 1 Case studies for aggregated space heating profiles

Case	Detached house	Semi-detached	Apartment
A	100%	0%	0%
B	75%	25%	0%
C	25%	50%	25%
D	20%	40%	40%

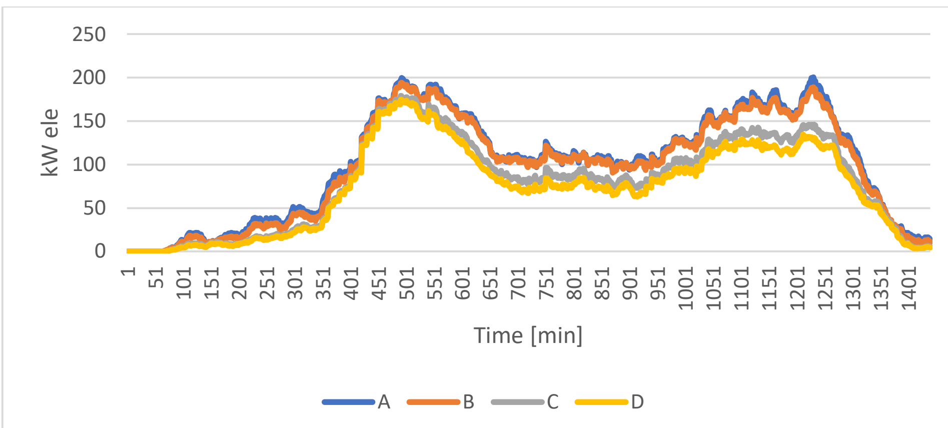


Figure 39 Demand profile for space heating on a Winter Average day for a two-bedrooms modern buildings in Melbourne, with different building types proportions.

Taking case D as reference case, with the tool it is also possible to explore the impact of the space heating activation strategy for the aggregated profile under different assumptions on the percentages of the buildings with "delayed" activation strategy (i.e., by modifying the corresponding cell in Figure 20). An example is provided in Figure 40.

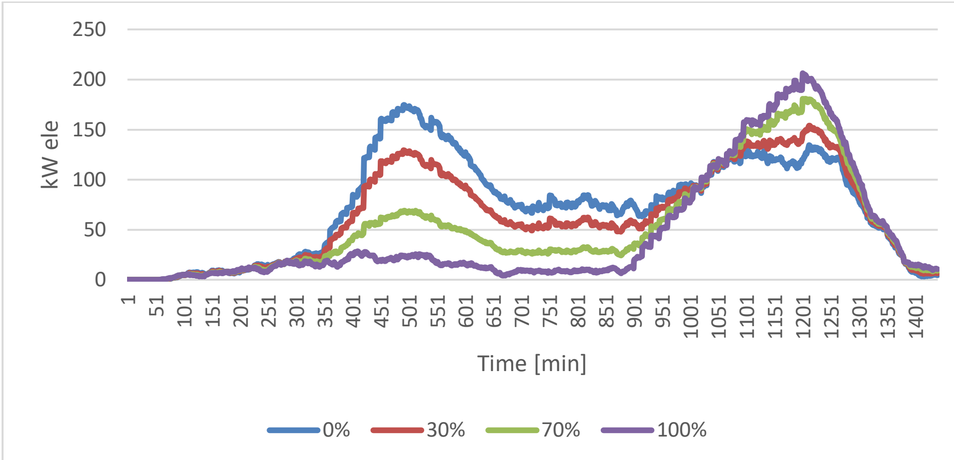


Figure 40 Demand profile for space heating on a Winter Average day for Case D in Table 8 considering different proportions of buildings with "delayed" activation strategy.

Conclusions

This report presented an overview of the modelling framework, inputs and assumptions used to generate high-resolution electrified heating and cooling buildings' demand profiles for space heating/cooling and domestic hot water for the Victorian building sector. To generate the demand profiles at different aggregation levels, the framework relies on the individual building-level model, i.e., national meter identifier (NMI) level, to extrapolate the aggregated demand profile following an "archetypical" approach based on specific attributes (e.g., building type, household size, energy efficiency levels, etc). The modelling framework considers the impact of weather conditions taking as inputs the outdoor temperature profile as well as solar irradiance, which differ by location and time of the year/day. Furthermore, the physical characteristics of each building as well as heating/cooling technologies and DHW storage tank are accounted for in the model, along with alternative heating system (for both space conditioning and DHW) activation strategies. The features of the model have been demonstrated through different application use cases, which highlighted the impact of different weather conditions, household size and thermal insulation level, technology, on the corresponding energy vector demand profile and magnitude of peak.

Key insights from this work are summarized as below:

- Air-source EHP operational performance is highly dependent on both indoor and outdoor temperature, affecting its heat output capacity and COP.
- Peaks magnitude (and duration) affected by building/household size, building's energy efficiency, weather conditions.
- Depending on the technology and therefore on the energy vector used to supply the space heating demand (electricity vs gas), the magnitude and time at which peak occurs greatly vary.

- Different heating system activation strategies dictated by occupants' behaviour and occupancy patterns throughout the day (e.g., space heating turned on in the afternoon/evening when occupants come back home, e.g., after work), could lead to delayed peaks and greater in magnitude.

While this research tried to capture "bottom up" the physics and associated behaviour of building envelopes for space conditioning to the best of our knowledge and using all the possible available information that could be gathered with the support of various stakeholders involved in the study, it is of course not exempt from limitations and would benefit from additional work. Further studies would aim to better tune and validate the parameters of the thermal equivalent circuit to better reflect, from an energy consumption point of view, the thermal characteristics of the buildings. In this regard, since Victorian buildings' space heating is most commonly supplied by gas, further validation of the model could be conducted by comparing the typical gas consumption by season (e.g., in Winter) by household size, for example available in [33], considering appropriate weighing factors to account for "peak" as well as "average" days. This would require more detailed information on the breakdown by energy service, i.e., space heating, DHW and cooking, buildings' thermal properties/size as well as outdoor environment conditions these refer to. The same approach could be adopted for DHW. Furthermore, the electricity demand profiles obtained considering EHP as space heating/cooling technologies have been obtained considering the performance parameters available from only one manufacturer. According to these, the COP not only depends on both indoor and outdoor temperatures, but also on EHP size, as it tends to be higher for bigger EHP. Additional information from real-world tests on EHP performance from multiple manufacturers would be ideal to better inform the modelling of the EHP operation.

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