Sizing a collective heat pump system in an apartment building: impact of occupancy profiles

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Abstract.
Current sizing of collective heating systems utilizes conservative methods to size the capacity of the heat production unit, which results in an over sizing of the system. When collective heat pumps (CHP) are considered, an exact sizing would increase their competitiveness on the market. Residential user patterns are often not considered in the sizing strategy, neither is the simultaneity between central heating and domestic hot water (DHW) demand. This paper aims to identify the impact of occupancy patterns on sizing of a collective heat pump in an apartment building. The use of an occupancy-based heat and DHW demand model opens the possibility to reach a more appropriate sizing of the collective heat pump. This occupancy-driven model includes time dependant occupancy, temperature set points and DHW consumption. The impact of the occupancy patterns is analysed by building energy simulations (BES) in Open Studio for a case study apartment building in Belgium. A collective heat pump (CHP) system is considered where the link between consumption (building) and production (CHP) is made through a buffer tank. The production of DHW is individually supported by booster heat pumps heating up a small buffer tank. The simulation results illustrate that only 42% of the summed design capacity for heating and DHW is required to cope with the heat demand. It can be concluded that there is a significant impact of the occupancy profiles on the sizing of the collective heat pump system in this case study.

Keywords. Collective heat pump system, occupancy patterns, sizing
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1. Introduction

The European Green Deal focuses on 7 different topics to create a closed carbon cycle and utilizing the potential of increasing energy efficiency. One topic focusses on a reduction of the energy demand of buildings in order to reach net zero greenhouse gas (GHG) emissions in 2050 [1]. The implementation of collective heat pump (CHP) systems can contribute to reach this goal. A CHP produces heat for a collective low temperature heating system supplying central heating (CH) for several units, e.g., flats in an apartment building. Individual domestic hot water (DHW) can be produced by so-called booster heat pumps (BHP) in the apartments. These BHPs use the low-temperature heating system as a heat source to produce high-temperature hot water in a storage tank. This type of system is considered in this paper and is schematically presented in Figure 2. This system layout avoids high-temperature distribution circuits throughout the building to supply the hot water demand, and the subsequent distribution losses. However, it comes with an increased investment cost due to the individual booster heat pumps. Therefore, a better sizing of the central heat demand in apartment buildings is essential to reduce this increased investment cost and make the system competitive on the market. Second, an exact heat demand determination implies a better sized central heat pump, which will result in a smoother operation (less on-off behaviour). This on its turn results in an increased energy efficient heat pump operation.

In the sizing procedure, DHW is more and more important as this capacity is no longer small compared to the required heating capacity. After all, the latter has decreased significantly during recent years because of stricter insulation requirements. Currently, there are 3 demand sizing methods that take CH and DHW into account: (1) the total summation, (2) the maximum method, and (3) 3 hybrid solutions. The first method, i.e., full summation, is defined as the total sum of the total CH capacity and total DHW capacity. Second, the maximum method takes the maximum of the total CH capacity and total DHW capacity into account. An extra 20% is added in actual sizing when using this method because of a fear of under sizing the system [2].

Moreover, the hybrid solutions are divided based on the type of individual DHW system per apartment with the CHP as its source. For a plate heat exchanger, a summation of both capacities is applied and a diversity factor (f_{sub}) should be added on the total DHW capacity. This diversity factor describes the ratio of the maximum CHP demand to the coincident maximum CHP demand of the whole system. For collective substations, the maximum method is used but for the CH: an extra 1 kW per apartment is added and an extra 5% is applied to the total CH capacity. For the DHW, a diversity factor (f_{sub}) is applied based on the total number of substations. For both cases, the diversity factor (in decimals) decreases with increasing number of apartments.

The methods mentioned in the previous paragraph cannot integrate developments and new insights for CH and DHW determination in their calculation. The DeltaQ method [2] is based on 2 standards: DIN4708 and EN12831 [3] and uses a combination of the full summation and the maximum method. As long the DHW capacity is larger than the CH capacity, only the DHW is considered. If the number of apartments increases and the CH capacity exceeds the DHW's, a full summation is implemented. The same problem of oversizing occurs when the number of apartments increases [2]. Verhaert [2] suggested a method called "the maximum sum of parts" to be used. The collective capacity is a function of the CH- and DHW-function, which results in a sizing in between the full summation and the maximum method. The total collective capacity lies around 20% above the maximum method. This should limit the oversizing of the system. Van Minnebruggen [4] worked on this problem and tried to verify this method.

These current sizing methods do not consider the residential user patterns, which define at which time CH and DHW is demanded and how CH and DHW demand contributes to the collective demanded capacity. By neglecting this, it is unknown whether the sized capacity would be sufficient for a certain building by which a safety factor is often introduced to avoid undersized systems. These user patterns give the opportunity to avoid over and under sizing.

This paper aims to identify the impact of occupancy patterns on sizing of a collective heat pump in an apartment building. This is based on the master thesis of Criel [5] and is structured as follows.

Section 2 describes the most important definitions used in this paper. Section 3 gives a description of the case study building and collective system. Section 4 describes the different steps taken for creating a feasible sizing method for a CHP. This is divided in 3 parts: building and system modelling, the usage profiles and interpretation of the results. Section 5 discusses the results of the simulations and ends with the feasible sizing method of the collective heat pump in the case study apartment building, which is followed by conclusions in Section 6.

2. Definitions

Collective heat pump (CHP) system: This is a collective low temperature heating system supplying central heating using a central heat pump.

Booster heat pump: small heat pump connected to a hot water storage tank in one housing, located in the separate apartments. The heat source is the central heating system.

Diversity factor: ratio of the maximum central peak demand to the sum of individual peak loads.

Residential user patterns/profile: defines the times at which the user demands DHW and/ or CH.

Occupancy profile: the times at which a user is active, inactive or absent. Based on this profile, residential user patterns are extracted.

3. Case study of building and system

The studied case (Figure 1) is a newly built apartment building in Ghent (Belgium). The building contains 4 floors with a total of 31 three persons apartments with each a floor area of about 80m^2.

Table 1 shows the heat transfer coefficient of the walls. The shared floors and walls describe the boundaries between apartments. The window to wall ratio equals 0.19 and the airtightness (v_{50}) equals 5 m^3/h.m^2.

A balanced mechanical ventilation system is implemented. The total airflow per apartment is equal to 175 m^3/h, which is distributed over the different zones in an apartment.

The examined system of the apartment building is presented in Figure 2. In the building, the CHP extracts heat from the ground. It produces water at low temperature to a buffer tank (not shown in Figure 2 however) from where the different distribution circuits leave to provide heat to the underfloor heating of the different apartments. The DHW is provided by a booster heat pump, which uses the heating system as its heat source. This produced DHW is collected in a 180l storage tank for every apartment. The advantages of this CHP system are the lower distribution losses (no high temperature distribution for the DHW is required).

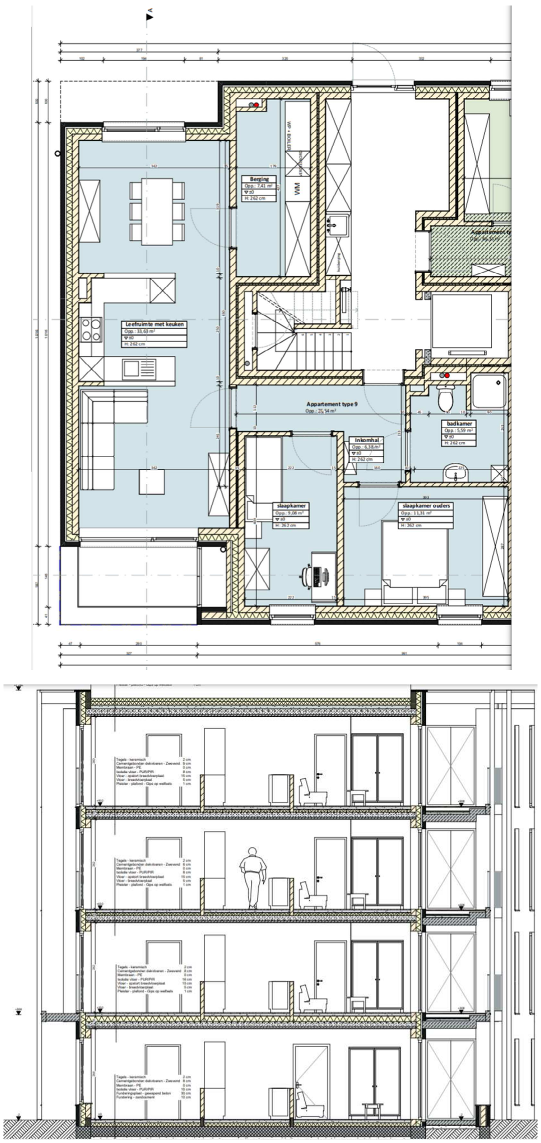

Figure 1: Floor plan of 1 apartment (above) and cross section of the building (below)

Table 1: Heat transfer coefficients U of the walls of the apartment building

Wall type	U (W/m^{2}K)
External walls	0.14
Floor	0.16
Shared floors	0.53
Roof	0.15
Shared walls	0.4
Internal walls	1.4
Internal doors	2.3
Windows	1.12

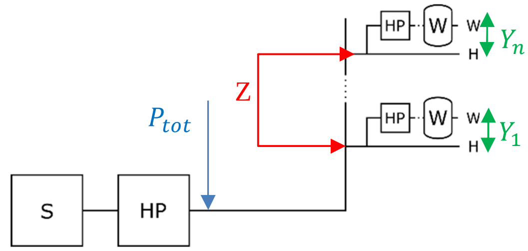

Figure 2: Schematic drawing of the CHP-system

The schematic drawing in Figure 2 presents the CHP-system where every apartment has underfloor heating (H) and a booster heat pump with storage tank (HP+W). S is the environmental heat source (ground in this case), HP in the bottom is the CHP. Z and Y indicate the two locations in the system where simultaneity is considered: between heating and DHW demand (Y_i), and between the demand of the individual apartments (Z) (and therefore influenced by the occupancy profiles. P_{tot} is the calculated total capacity.

It is important to notice that this paper investigates how the total capacity P_{tot} is influenced by the user occupancy profiles. Therefore, the CHP, nor its buffer tank is considered in the rest of this paper.

The CHP provides water at 35°C (low temperature level) for CH and in the booster heat pump the hot water is produced at 65°C. The booster heat pump provides this transition from 35°C (heating circuit) to 65 °C with an assumed COP of 5.

The heat loss of 1 apartment is calculated according to the standard NBN EN12831:2003 and the user guide of BBRI [6]. The steady state heat capacity is equal to 2032W and if the heating up capacity is considered, the required heat is equal to 4000W. For the entire building, a steady state heat capacity of 63 kW and a capacity of 124 kW is considered if temperature drops are considered.

For the capacity of DHW, 2000W is assumed, corresponding to the designed capacity in this project. This is the capacity the booster heat pump can deliver (see Figure 2). A COP of 5 is assumed, which results in 1600 W that is supplied by the CHP and the rest is supplied by electricity. The temperature of the produced water equals 65 °C and is stored in the tank.

4. Method

4.1 Building and system modelling

Building energy simulations (BES) are executed in OpenStudio [7] , which uses Energy+ as calculation software, to determine the impact of occupancy on the capacity of the collective heat pump system.

In the following paragraphs, different modelling assumptions are made. Only 1 apartment is modelled and extrapolated afterwards, as the difference in CH requirements between apartments is negligible because the apartments are similar in size. Second, strict insulation and airtightness requirements causes that differences between DHW and CH demand per apartment only depends on the user profile (demand). A conservative approach is chosen by considering an apartment on the ground floor (larger heat loss compared to second and third floor) with 3 external walls (see Figure 1).

In Figure 3, the apartment is split up in 3 different thermal zones depending on the use and temperature set point: a day-time zone, a night-time zone, and the bathroom. The characteristics of these zones are described in Table 2. These zones are connected to each other via designed ventilation system that includes supply in the day and night-time zone and extract in the bathroom and day-time zone. The temperature set points in Table 2 are based on NBN EN12383-1:2017 [8].

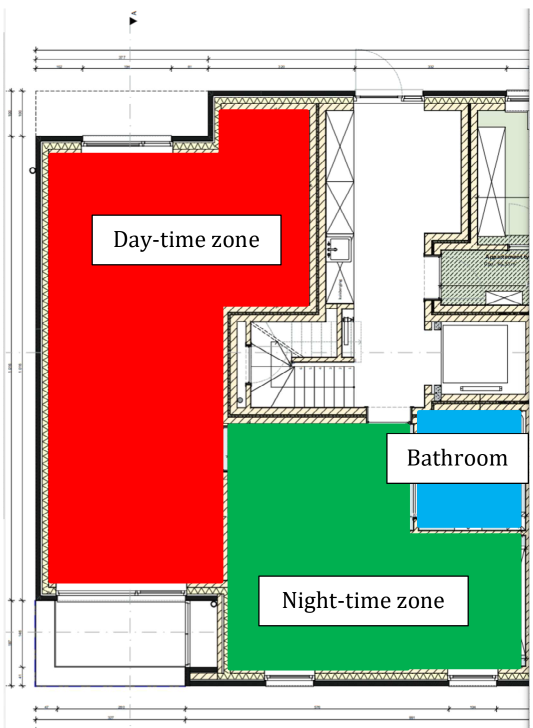

Figure 3: Thermal zoning of the apartment

Table 2: Characteristics of thermal zones

	Zones		
	Day-time zone	Night-time zone	Bathroom
Floor area (m^2)	41	27	6
Temperature (°C)	20	18	22
Ventilation airflow (m^3/h)	75	50	50

4.2. Usage profiles

The implementation of usage profiles, an outside temperature profile and solar irradiation gives the model its dynamic properties by which it differentiates itself from static calculations [6].

When implementing usage profiles, it is required to envelop the entire population. To incorporate the population, the occupancy profiles are based on the models of Buttitta et al. [9]. From these occupancy profiles, the usage profiles can be defined. Buttitta et al. [9] created a model dividing the households in the UK into 5 standard cases describing the hours of the day that the residential users are absent, active, or not active, as shown on Figure 4. For example, occupancy profile 1 has an “absent character” while occupancy profile 4 and 5 have an “active character”. The fractional division of the households into these profiles is shown in Table 3.

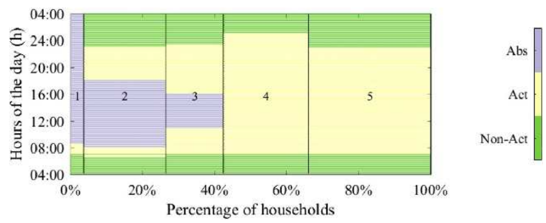

Figure 4: The division in 5 occupancy profiles. Abs means absent, Act means active and Non-Act means not active [9]

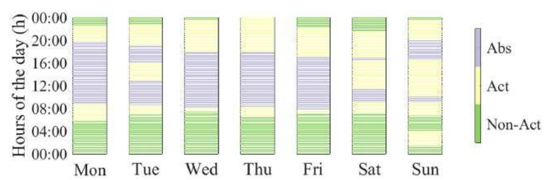

Figure 5: Refined occupancy profile n°2. Abs means absent, Act means active and Non-Act means non-active [10]

This division is used to determine the usage profiles of the 31 flats in the apartment building in Table 3 in 3 different ways. The first division of occupancy profiles over the various flats is based on the fractions proposed by Buttitta et al. [9] and is referred as (N) in this work: 11 flats have an occupancy profile n°5, while only 1 flat has the occupancy profile n°1. The 2 other divisions are extreme distributions, characterised by users with an extreme absent (i.e., only user profile n°1 and 2) (L) or extreme active character (i.e., only occupancy profile n°4 and 5) (Z).

Buttitta et al. [10] refined these profiles to weekly occupancy profiles, as shown in Figure 5 for occupancy profile n°2.

Table 3: Division of the different users over the 31 apartments for the 3 different occupancy distributions. Each type of user gets assigned a certain amount of apartments described by the table

Type of user profile	Fractional division of the population	Division for Buttitta et all. [9] [N]	Division with absent character [L]	Division with active character [Z]
USER1	3.7%	1	4	-
USER2	22.9%	7	27	-
USER3	15.9%	5	-	-
USER4	23.7%	7	-	13
USER5	33.8%	11	-	18

Based on these occupancy profiles, 5 different usage profiles are made for the 3 different thermal zones as follows. During the time that the user is active (Act), the day-time zone is heated up to its set point (see Table 2). Based on the SHW peak consumptions described by Fuentes et al. [11], the bathroom is heated between 6h-9h and 18h-21h for all users unless users are absent (Abs). If users are non-active (Non-Act), the night-time zone is heated up to the set point. When the users are absent (Abs), the set point in all zones is set to 16 °C.

The DHW profile of Fuentes et al. [11] is implemented in this model. The average use of DHW is 45 l/day/person of which 70% is attributed to the bathroom zone. The DHW tapped in bathroom area is fixed at 40 °C while the rest of the consumption in de day-time zone is fixed at 60 °C. The occupancy profile is than matched with the DHW profile, where no DHW is consumed if the users are Abs.

The result is a unique CH and SHW profile for the 5 standard users. An example of the CHP profile for user profile n°2 on Wednesday is shown in Figure 6. These combined profiles are for further reference defined as "usage profiles".

4.3. Determination of the equivalent diversity factor

Figure 2 defines diversity factors Y and Z. Diversity factor Z (%) represents the difference in energy demand between the different apartments, which originates from different types of users in a building. Second, per apartment the CH- and DHW- energy demand do not coincide for the different timesteps, which is represented by factor Y (%). A difference in time occurs when a user demands CH or DHW.

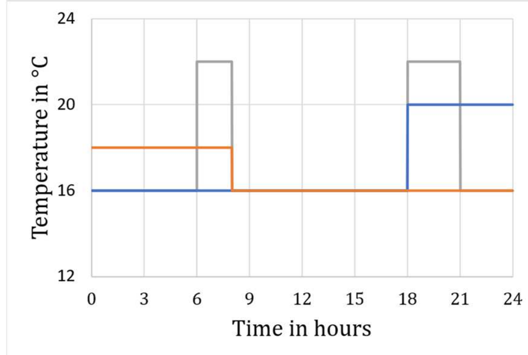

Figure 6: The requested temperature profile (CH) of n°2 on Wednesday. The grey line represents the bathroom profile, the orange line represents the night-time profile and the blue line represents the day-time profile.

The total capacity (P_{total}) is the minimal capacity that must be delivered by the CHP to provide the different apartments with their individual CH and DHW demands. The sizing problem is than translated to a mathematical expression, which is used to calculate the P_{total}:

$$P_{total} = (\sum_{i}^{N} (P_{CH_i} + P_{DHW_i}) \times Y_i) \times Z\, ; 0 \leq Y_i, Z \leq 1;$$

Where P_{Chi} and P_{DHWi} are the CH and DHW capacity per apartment respectively and N is the total amount of apartments. Y is the diversity factor between CH and DHW per apartment and Z is the diversity factor between the different apartments.

A simplification of the formula is possible if Y, Z are replaced by an equivalent diversity factor X:

$$P_{total} = (\sum_{i}^{N} (P_{CH_i} + P_{DHW_i})) \times X\, ;\ 0 \leq X \leq 1$$

If the value of X is calculated, a solution for the problem has been found and the capacity of the CHP is determined.

The result of these simulations is the capacity of the CHP system as a function of time. Based on this dynamic behaviour, it is assumed to size the system on 97.5% of the maximum value. After this point, the rise in sizing capacity is not justified compared to the rise in time the requested capacity is met. Based on this 97.5%, the value of the equivalent diversity factor X is determined.

5. Results

5.1. Capacity curves of CHP

Figure 7 shows the delivered capacity of the collective system over 1 week in January for occupancy distribution N. In function of time, a central capacity is deliverd by the CHP.

When assuming the occupancy distribution N according to Buttitta [10], the total delivered capacity is almost always different from zero (only during 12 hours, no heat is supplied during the week in Figure 7). The delivered capacity with a maximum value of 150 kW, is always smaller than a total sumation sizing method, i.e; 173.6 kW. Second, only during 16h of the year more than 80% of this summation is required. Furthermore, the maximum of 174 kW is never requested. This can be found in

Table 4. If usage profiles L and Z are implemented, similar results are reached. For L, a peaked trend is observed: 72h of the year more than 80% of a total summation is required and only during 3h a total summation is required. For Z, the trend lies between N and L where during 37h more than 80% is delivered and only 11h the maximum of 173.6 kW is requested.

Table 4: The first row descibes the number of hours where 80% of the maximum capacity is exceeded for the different occupancy distributions. The second row describes the number of hours where the maximum capacity is required.

	Occupancy distribution		
Time capacity is	N	L	Z
> 0.8 × 174 kW	16h	72h	37h
= 174 kW	0h	3h	11h

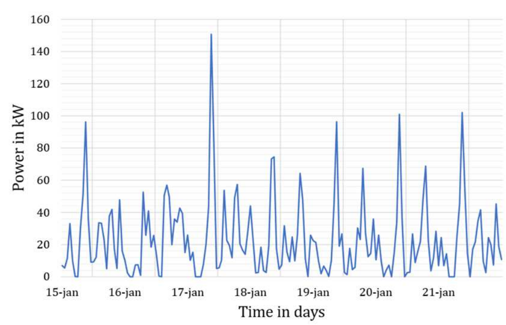

Figure 7: Delivered capacity (in kW) of collective systems for the 3rd week of January with N as occupancy distribution

A comparison to the heat loss calculation (NBN EN 12831:2003) is possible if the total capacity is seperated in a SHW- and CH-part (see Figure 8). During this week, only during 2 hours the steady state heat loss calculation capacity (2032W per apartment) is exceeded and the heating up capacity (4000W per apartment) is not reached during this week.

An annual analysis has also been made. The hours when the steady state heat capacity (required capacity in absence of temperature drop [6]) is exceeded or the heating up capacity (required capacity with including temperature drop [6]) is reached, are shown in Table 5. For the occupancy distribution N, there is a negligible number of hours observed where the heating up capacity is reached. Altough the steady state heat capacity is exceeded several times, the value reamains small compared to the other occupancy distributions. Occupancy distribution L has the most extreme profile because during 432h the steady state loss is exceeded, but even here the absolute maximum is not reached on a regular basis.

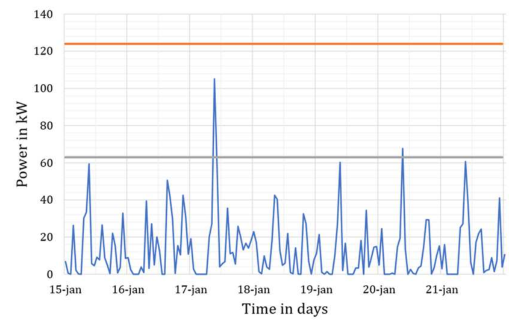

Figure 8: Comparison heat loss calculation and deliverd CH capacity by CHP for the 3rd week of January with N as occupancy distribution. The orange line represents the heat loss calculation including the heating up loss. The grey line represents the steady state heat loss.

A similar type of analysis is done for the DHW. The hours when the full sanitairy capacity is reached, is described in Table 5. The duration that the maximum capacity is supplied for occupancy distribution N is 50% smaller than L and 83% smaller than Z. This implies that distribution N supplies a negligible amount of times the full sanitairy capacity. In this case, occupancy distribution Z is the most extreme due to the residents being present in the apartment for large fractions of the day. Nevertheless, 154 h is still a small fraction of the entire year.

Table 5: The number of hours the steady state heat loss capacity is exceeded (required capacity exclusion of temperature drop) and the number of hours the heating up capacity is reached (required capacity including of temperature drop)

	Occupancy distribution		
	N	L	Z
Steady state heat capacity	89h	432h	221h
Heating up capacity	1h	18h	15h
Sanitary capacity	26h	52h	154h

5.2. Diversity factors

Figure 9 shows the cumulative distribution of the capacity as a functon of the diversity factor for all three occupancy distributions. These functions describe the frequency that a capacity equal or smaller than a chosen delivered capacity occurs. For example, 52 kW of the central capacity (diversity factor of 30 percent), satisfies demand during 94 % of the time for N, 87,4 % for L and 90.4 % for Z.

The different distributions are fairly similar, which would imply the diversity factors are similar in size. Nevertheless, large differences occur at the upper part of the different graphs (above 90 % occurrence for the different occupancy distributions). To obtain energy security throughout the year, the capacity of the CHP should be able to supply the requested heat almost all the time. Occupancy distribution N reaches around 90% coverage at 43 kW (diversity factor of 0.25), while 69 kW (diversity factor of 0.4) is required for L to obtain the same coverage. This means the occupancy distribution has a large influence on the final result (diversity factor) and occupancy profile L is less stable and hard to size the CHP on.

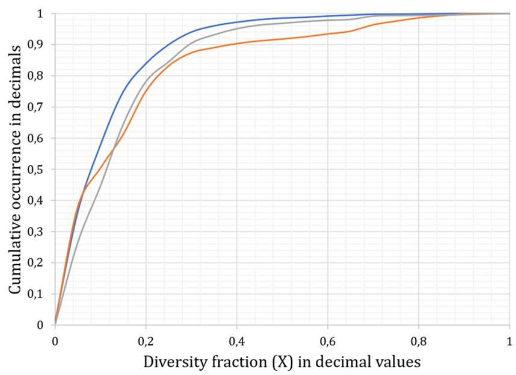

Figure 9: Cumulative distribution of the total capacity output of CHP for different occupancy distributions during 1 year. The blue lines describes the distribution for N, the grey line describes the distribution for L and the grey line describes the distribution for Z.

Based on section 4.3, the diversity factor is determined for the various occupancy distributions as shown in Table 6. As explained before, the diversity factor of N is based on the study of Buttitta et al. [10] and describes the presumed reality, while the other two profiles describe extreme cases. Second, the occupancy distribution N locates itself in an optimum. When a deviation occurs from the presumed reality to users with a more active charater, the diversity factor should rise for the same coverage. The same trend occurs for users with an absent character.

As already mentioned, it is observed that the sizing for occupancy distribution N finds itself in an optimum. A difference of 58.6 kW is observed with L (rise of 78%) and a difference of 25.3 kW with Z (rise of 34%).

This implies an increase in diversity factor occurs to cope with the peaked profile. Occupancy distribution Z has a profile that is more extreme than N but remains quite average. An increase in diversity factor should occur but this increase should be limited compared to the occupancy distribution L.

Table 6: Resulting diversity factors X for different occupancy distributions at 97,5% coverage

	Occupancy distribution		
	N	L	Z
Diversity factor (%)	42	74.9	56.2

5.3. Comparison with existing methods

If a comparison of the diversity factor method is made with the current sizing methods, the differences are noticed to be signficant as shown on Figure 10. If the current sizing methods are compared to the a diversity fraction of 42% (N), the following results are noticed: a reduction of 98.7 kW (56.9%) occurs compared to the total summation, a reduction of 49.1 kW (39.6%) occurs compared to the maximum method and a reduction of 87.9 kW (54%) occurs compared to the hybrid solution.

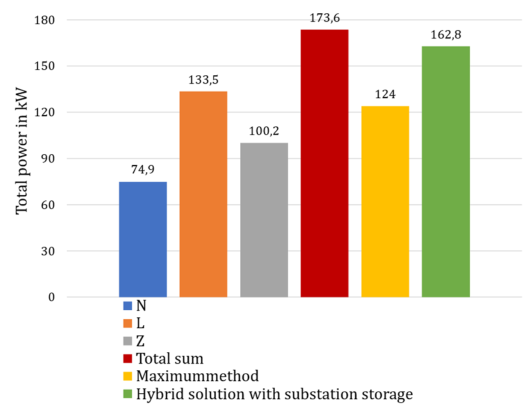

Figure 10: Comparison of total capacity of CHP sizing

6. Conclusions

This paper aimed to identify the impact of occupancy patterns on sizing of a collective heat pump in an apartment building.

To solve the formula described in section 4.3, 3 different occupancy distributions were created where every user in an apartment had its own type of CH and DHW consumption. These occupancy distributions were applied to an actual case in Ghent.

A diversity factor of 42 % (N) is chosen to be the result of the formula from section 4.3, because it is the only occupancy distribution with a theoretical background is from Buttatti et al. [10]. The rest are extreme cases which describe deviations where the diversity factor could evolve to. This implies that the main limitation of the result is the size of the apartment building. It should be large enough (greater than 24 apartments) to apply a diversity factor of 42 %. In this way, every type of user gets assigned at least 1 apartment. Moreover, different usage profiles and occupancy distributions give specific results. More research is required to develop better general applicable and accepted profiles and distributions.

From the BES simulations in a case study apartment building, it can be concluded that the occupancy distributions have a large effect on the required capacity (diversity factor). This can be noticed if the differences between N and L/ Z are observed. A difference of 25.3 kW (33,8 %) occurs compared to Z or 58.6 kW (78,2 %) occurs compared to L could occur compared to the optimal value.

If the different methods on the market are compared to the diversity factor of 42 %, they seem too conservative. This implies new methods should give more specific results.

Data access statement

The datasets generated during and analysed during the current study are not available but the authors will make every reasonable effort to publish them in near future.

References

[1] European Union, "Going climate-neutral by 2050," 16 07 2019. [Online]. Available: https://op.europa.eu/en/publication-detail/-/publication/92f6d5bc-76bc-11e9-9f05-01aa75ed71a1. [Accessed 2021 12 14].

[2] I. Verhaert, "Design methodology for combined production and distribution," *E3S Web of Conferences,* vol. 111, 2019.

[3] Vlaamse overheid, "Transmissie referentiedocument," *Belgische staatsblad,* pp. 1-88, 29 Oktober 2007.

[4] S. Van Minnebruggen, "Analyse meetdata combilus: Validatie van een dimensioneringsmethode," Universiteit Antwerpen, Antwerpen, 2020.

[5] M. Criel, M. Sourbron, H. Breesch and B. Merema, "Dimensionering van een collective warmtepompinstallatie in een appartementsgebouw: Impact van gebruikersgedrag," Catholic University of Leuven, Sint-Katelijne-Waver, 2021.

[6] WTCB, "Warmtebelasting van gebouwen," WTCB, 25 August 2021. [Online]. Available: https://www.wtcb.be/expertise-ondersteuning/wtcb-tools/warmtebelasting-van-gebouwen/.

[7] Alliance for Sustainable Energy, "OpenStudio," National Laboratory of the US, 05 11 2021. [Online]. Available: https://openstudio.net/.

[8] European Committee for Standardization, "Energy performance of buildings - Method for calculation of the design heat load - Part 1: Space heating load, Module M3-3," European Committee for Standarization, Brussels, 2017.

[9] G. Buttitta, W. J. Turner, O. Neu and D. P. Finn, "Development of occupancy-integrated archetypes: Use of data mining clustering techniques to embed occupant behaviour profiles in archetypes," *Energy and Buildings,* vol. 198, pp. 84-99, 2019.

[10] G. Buttitta and D. P. Finn, "A high-temporal resolution residential building occupancy model to generate high-temporal resolution heating load profiles of occupancy-integrated archetypes," *Energy and Building,* vol. 206, no. 109577, 2020.

[11] E. Fuentes, L. Arce and J. Salom, "A review of domestic hot water consumption profiles for application insystems and buildings energy performance analysis," *Renewable and Sustainable Energy Reviews,* vol. 81, pp. 1530-1547, 2018.

[12] Koninklijke vereniging van de verwarmingsventilatie- en klimaatbeheersingstechniek, «Praktijkgids voor de berekening van de warmteverliezen van gebouwen,» 04 08 2016.

[13] Wienerberger, «Thermobrick 15N,» Wienerberger, 2020. [Online]. Available: https://www.wienerberger.be/Binnenmuur/productzoeker/thermobrick-15n.html.

[14] WTCB, «Luchtdichtheid van gebouwen,» *TECHNISCHE VOORLICHTING,* vol. 255, pp. 19-24, 2015.

[15] Itho Daalderop, "Booster warmtepomp 2 kW W/W WP tapwater," 1 4 2021. [Online]. Available: https://www.ithodaalderop.nl/nl-NL/professional/product/576-0020#downloads. [Accessed 1 4 2021].