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A load profile study of different buildings to identify neighborhood energy flexibility with exchange possibilities

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Abstract

Buildings are a key source of energy flexibility due to their high energy demand. Harnessing the energy flexibility of buildings, however, demands that buildings be considered collectively. This paper presents preliminary results to discover building's energy flexibility, from two different neighborhoods in the Netherlands. The energy demand profiles of three large buildings in each neighborhood are analyzed to identify possible useful simultaneous heating and cooling loads. Finally, the possibility for energy exchange between these buildings is explored.

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Keywords: Buildings; Energy exchange; Flexibility; Load profiles; Neighborhood; Simultaneous heating and cooling

1. Introduction

In recent years there has been great progress in energy management practices on the level of individual buildings. However, the energy consumption in most local communities, towns and cities, is still increasing instead of the necessary decrease to stay in-line with the targets of the sustainability policies [1]. The transition to a cleaner, greener

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energy infrastructure necessitates additional flexibility requirement due to the intermittent and high level of uncertainties associated with renewable energy sources [1]. There is a current focus on buildings as a potential source of achieving energy flexibility by using storage facilities or building services installations [1]. Buildings are considerable energy loads that can provide flexibility to the grid and could play a vital role to reduce uncertainty and provide stability to the grid in the future. According to IEA EBC Annex 67 [1], energy flexibility of a building is defined as “*the ability to manage its energy demand and generation according to local climate conditions, user needs and grid requirements*”.

Energy exchange between the buildings is an emerging concept which can provide flexibility in a decentralized neighborhood energy grid. Neighborhood-level energy exchange might be a practical solution which can reduce curtailment in the case of an over production or grid instability issues in the case of a prosumer sells the excess energy to the grid [2]. It is noted that not only electricity but also thermal energy exchange has a huge capacity for flexibility with well insulated commercial buildings [3]. This, in combination with a massive increase in energy efficient equipment and heightened use of renewables, will lead the way towards the energy and climate targets.

As part of a broader research on the possibility of energy exchange between buildings, neighborhoods and the smart-grid, this paper focuses on the potential for direct thermal energy exchange between neighboring buildings. By analyzing the cooling and heating demand profiles of different buildings in two distinct neighborhoods in the Netherlands, namely Princenhage located in Breda and Merwe-Vierhavens located in Rotterdam, the potential for exchange is outlined in this paper.

The content of this paper is as follows. Section 2 presents literature overview. Section 3 describes the methodology to select neighborhoods and the energy demand profiles of the selected buildings. Results, discussion and conclusions about the possibilities of energy exchange between buildings within a neighborhood are drawn in section 4 and 5.

Nomenclature

| | | | |
|-----|---|----|---------------------------|
| IEA | International Energy Agency | RC | Coefficient of resistance |
| EBC | Energy in Buildings and Communities Program | | |

2. Literature overview of similar studies

Literature search yield, relatively few studies for the topic “*thermal energy exchange between buildings*”. However, the terms “*smart thermal grids*”, “*energy exchange AND smart grids*” appear more popular than “*thermal energy exchange between buildings*”. The search terms were narrowed down to “*Simultaneous heating and cooling AND Buildings AND Heat pumps*” to align it with the paper objective. Ultimately, the revised search yielded 30 papers from Scopus and Web of Science databases (results are presented in Table 1). Out of these, four articles [4–7] are found to be more relevant for simultaneous heating and cooling loads in buildings. The rest of the research papers mainly focused on optimization, control and energy saving potential.

Table 1. Article search

| Search Engine | Search Term | Search date | Number of articles |
|----------------|--|---------------------------|--------------------|
| Scopus | Simultaneous heating and cooling AND Heat pump AND Buildings | 05-04-2017 (All articles) | 36 |
| Web of Science | Simultaneous heating and cooling AND Heat pump AND Buildings | | 32 |

Buildings can demand to heat and cool simultaneously. Dairy plants [7], hotels [5], luxury dwellings, smaller office buildings [6], low-energy buildings, retails buildings [4] are some of the study cases used in the reviewed papers which demand simultaneous heating and cooling loads. Other than that, in spring and autumn seasons and buildings with several functions such as huge shopping complexes, demand heating and cooling at the same time. In such cases, energy exchange can create some flexibility by reducing the primary heating and (or) cooling demands. But the

potential of energy flexibility is heavily dependent on the amount of simultaneous heating and cooling loads. The futuristic concept of energy exchange using an additional smart thermal grid is illustrated in the Fig. 1.

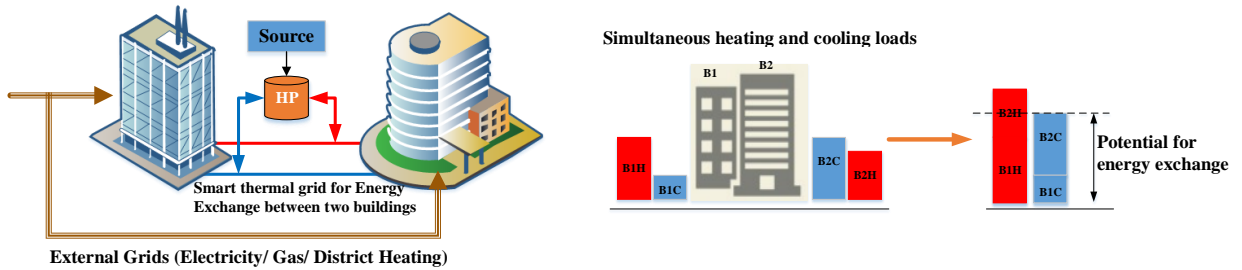


Fig. 1. Illustration of the concept with the smart thermal grid for energy exchange and the illustration of maximum possible energy exchange in a certain time interval (B1 – Building 1, B1H – B1 heating load, B1C – B1 cooling load, likewise for B2, B2H and B2C)

3. Methodology

3.1. Description of the selected independent neighborhoods

In the recent report, ‘Op weg naar een klimaatneutrale gebouwde omgeving in 2050’ published by CE Delft, all neighborhoods in the Netherlands are divided into fifteen different types [8]. To test the possibilities, two different types of neighborhoods were selected namely Princenhage and Merwe-Vierhavens. According to CE Delft report, Princenhage is qualified as type 6 (a high urban district with mainly residential buildings built between 1965-1990) and Merwe-Vierhavens is qualified as type 15 (a district with mainly industrial buildings built in various years).

The neighborhood Princenhage is with 8,535 inhabitants, one of the largest districts of Breda. The district is located in the southwest part of the city and has a surface of about 264 hectares. It has an old village center, a 70s and 80s neighborhood and an area with new dwellings. Currently, all buildings are connected to a non-renewable electricity and gas network. However, the municipality of Breda has the goal to be a CO₂ neutral city by 2044. According to the plans, this goal can be achieved if in 2044, 50% less energy is being used compared to 2009 and the remaining 50% is generated sustainably.

Merwe-Vierhavens is a harbor district in the city of Rotterdam and has a surface of about 100 hectares. This neighborhood will be redeveloped into an urban area in the coming decades, with the goal of energy neutrality. All buildings are connected to the electricity and gas network in the area and some buildings are also connected to the district heating grid.

3.2. Different functions of each neighborhood

The ratio of the different functions of each neighborhood type is shown in Fig. 2. Office functions, shop functions, care functions, education functions and other functions are included in the commercial section. As can be seen in Fig. 2, Princenhage has a higher number of residents while Merwe-Vierhavens has a higher number of industrial buildings. The analysis of each neighborhood was done independently.



Fig. 2. Distribution of different functions in the neighborhood (Left) Princenhage (Breda); (Right) Merwe-Vierhavens (Rotterdam)

3.3. Selected buildings for energy exchange

Three buildings were chosen in each case (Fig. 3.). In Princenhage, one office of a building services company and two car dealers including display rooms, workshop and warehouse were selected. In Merwe-Vierhavens the following buildings were selected. One multi-functional office building with an auditorium, exposure areas, workplaces and meeting facilities. Another office, which is a science tower with laboratory facilities for a medical center and a shop which is a multi-functional building with retail (restaurants, shops) and large roof park on top.

These buildings were selected because they are representative for buildings of these types in urban areas in the Netherlands. Moreover, the distances between the buildings are short; subsequently, associated thermal losses with energy exchange will be small. In addition, the buildings are already connected to each other by means of the existing electricity network and gas network.

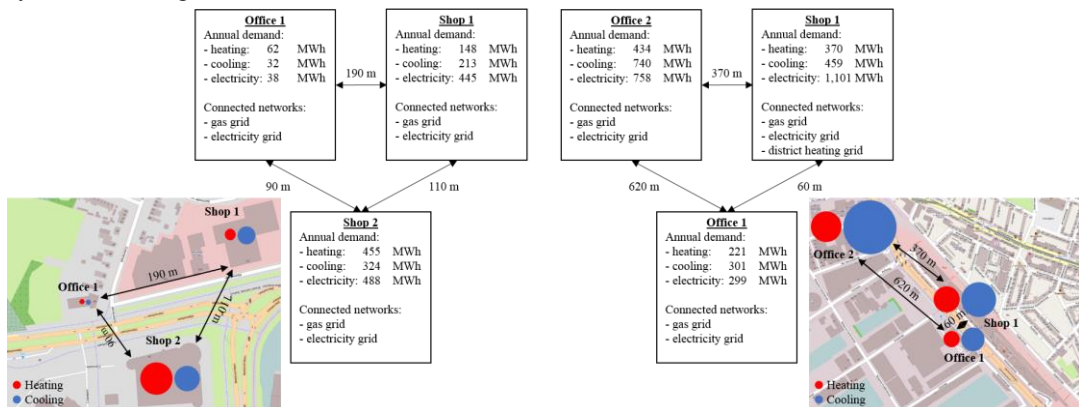


Fig. 3. Selected buildings for energy exchange (Left) Princenhage (Breda); (Right) Merwe-Vierhavens (Rotterdam)

3.4. Demand profiles of the buildings

To get a potential output from this concept, it is important that the selected buildings have diversified load patterns with heating and cooling simultaneously. Table 2 represents the parameters of the selected buildings.

Table 2. Parameters of the selected buildings in Breda and Rotterdam

| Building Properties | Unit | Princenhage (Breda) | | | Merwe-Vierhavens (Rotterdam) | | |
|---------------------------------|-----------------------|---------------------|--------|--------|------------------------------|----------|---------|
| | | Office 1 | Shop 1 | Shop 2 | Office 1 | Office 2 | Shop 1 |
| Building geometry | | | | | | | |
| - Length | m | 42 | 85 | 108 | 100 | 47 | 650 |
| - Width | m | 13 | 62 | 94 | 20 | 33 | 40 |
| - Height | m | 12 | 8 | 12.5 | 26 | 92 | 4 |
| - Gross Floor Area | m ² | 1,650 | 10,500 | 11,515 | 13,000 | 33,000 | 26,000 |
| - Volume | m ³ | 6,552 | 42,160 | 65,978 | 52,000 | 142,692 | 104,000 |
| - Number of floors | - | 3 | 2 | 3 | 7 | 21 | 1 |
| Walls, floor and roof | | | | | | | |
| - A _{floor} (surface) | m ² | 550 | 5,270 | 10,152 | 2,000 | 1,551 | 26,000 |
| - A _{roof} (surface) | m ² | 550 | 5,270 | 10,152 | 2,000 | 1,551 | 26,000 |
| - A _{wall} (surface) | m ² | 1,030 | 1,176 | 2,525 | 4,056 | 10,304 | 3,036 |
| - RC _{floor} | (m ² ·K)/W | 2.5 | 3.5 | 2.5 | 4.0 | 4.0 | 5.0 |
| - RC _{roof} | (m ² ·K)/W | 2.5 | 3.5 | 2.5 | 4.0 | 4.0 | 5.0 |
| - RC _{wall} | (m ² ·K)/W | 2.5 | 3.5 | 2.5 | 4.0 | 4.0 | 5.0 |
| Windows | | | | | | | |
| - A _{window} (surface) | m ² | 290 | 1,176 | 2,525 | 2,184 | 4,416 | 2,484 |
| - Window percentage | % | 22% | 50% | 50% | 35% | 30% | 45% |
| - U _{window} | W/(m ² ·K) | 3.2 | 1.6 | 2.9 | 1.6 | 1.4 | 1.2 |
| - g-value | - | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.6 |

Demand profiles for heating and cooling separately are illustrated in Fig. 4. During the off working hours and weekends the demand data were taken as zero because compared to the working hours these resulted values are insignificant.

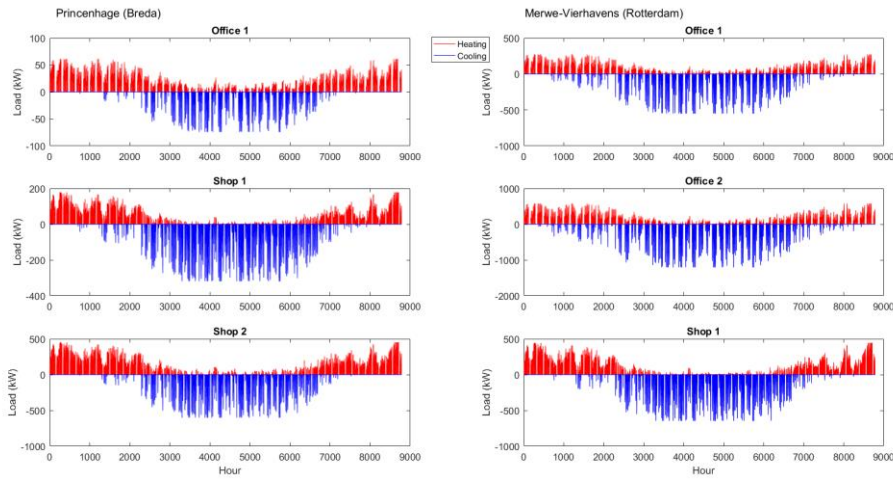


Fig. 4. Hourly heating and cooling demand patterns of the selected buildings

4. Results

Following a similar method used in [4], a ratio for simultaneous heating and cooling needs was defined as given by equation 1. From the three buildings in each neighborhood, all combinations of two buildings were taken to find the simultaneous thermal load ratios.

$$Ratio_{Simul-loads} = \min\left(\frac{\sum Q_{H,i,hour}}{X}, \frac{\sum Q_{C,i,hour}}{X}\right); X = \max\{\min(\sum Q_{H,i,hour}, \sum Q_{C,i,hour})\}_{year} \quad (1)$$

When two buildings have heating and cooling loads;

- $\sum Q_{H,i,hour}$: the sum of heating loads of the two buildings in a particular hour
- $\sum Q_{C,i,hour}$: the sum of cooling loads of the two buildings in the same hour

The minimum out of these two (i.e. $\sum Q_{H,i,hour}$ and $\sum Q_{C,i,hour}$) is the potential for energy exchange (see Fig. 1) at each hour. In order to normalize these values the potential for energy exchange at each hour was divided by the maximum possible energy exchange of the whole year (X). Therefore, at a certain hour, 0% represents no simultaneous needs and 100% represents maximum possible simultaneous heating and cooling load between the selected two buildings.

Fig. 5 illustrates the simultaneous heating and cooling load ratios between the selected buildings in hourly intervals throughout the whole year and the possible energy exchange. Only one case for each neighborhood is presented in Fig.5. Maximum exchange capacity denotes the highest conceivable energy savings from either heating or cooling. Table 3 indicates the percentage of hours that the simultaneous heating and cooling loads appear during the whole year (Simul-Hours) and the energy savings as a ratio of the total heating energy demand (ES-Heating).

Table 3. Percentage of hours of simultaneous heating and cooling occurrences and possible energy exchange

| Princenhage | (%) Simul-Hours | Total maximum possible exchange capacity p.a. (MWh) | (%) ES-Heating | Merwe-Vierhavens | (%) Simul-Hours | Total maximum possible exchange capacity p.a. (MWh) | (%) ES-Heating |
|---------------------|-----------------|---|----------------|-----------------------|-----------------|---|----------------|
| Office 1 and Shop 1 | 20.1 | 4.36 | 2.0 | Office 1 and Office 2 | 20.0 | 35.80 | 5.5 |
| Office 1 and Shop 2 | 17.7 | 3.47 | 0.7 | Office 1 and Shop 1 | 21.8 | 15.11 | 2.9 |
| Shop 1 and Shop 2 | 18.4 | 8.00 | 1.3 | Office 2 and Shop 1 | 23.7 | 42.85 | 5.3 |

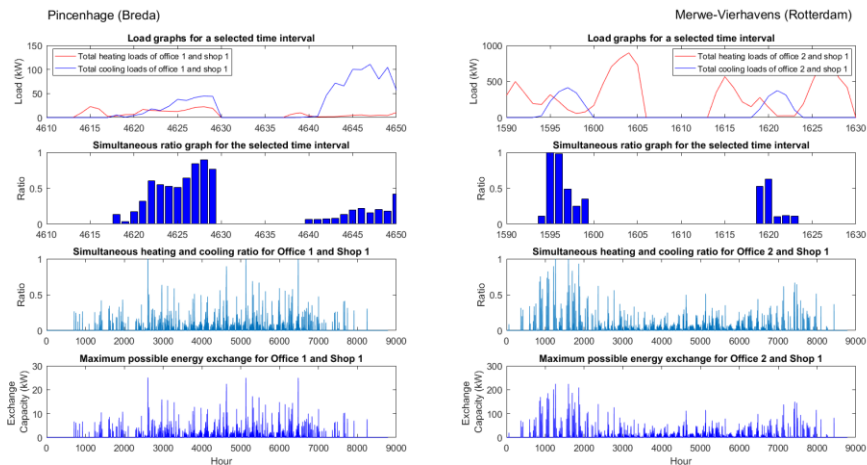


Fig. 5. Simultaneous heating and cooling load ratios and maximum possible energy exchange between two buildings in each neighborhood

5. Discussion and Conclusion

This paper presented a load profile study to identify simultaneous heating and cooling hours of nearby buildings. The aim of doing so was to check the possibility of thermal energy exchange between buildings. In both cases, simultaneous heating and cooling demands occurred around 20% of the total number of hours in a year. When comparing the energy exchange possibilities, it was found out that some combinations of buildings have a higher advantage than the others.

As a prequel to detailed calculations and implementation, this study emphasized importance of understanding the possibilities of simultaneous heating and cooling for different buildings in a neighborhood. This study focused on utility buildings since they have the highest energy saving potential. As the next step of this research, the real energy savings and the return on investments need to be evaluated. Also, the same concept will be spread to the whole area including residential buildings. In a broader perspective, the ultimate goal is to identify some form of flexibility through energy exchange.

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