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# Energy sharing and matching in different combinations of buildings, CHP capacities and operation strategy

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ABSTRACT

Nowadays, micro-generation technologies are well developed and these make local energy production more possible. In terms of building scale, in April 2009 the Japanese government decided to accelerate its efforts towards zero energy building (ZEB). However, it is said that achieving a ZEB status without a grid connection would be quite difficult. In this study, thus, the definition of zero energy building (ZEB) is extended to the community level, 'energy community', which is defined here as a cluster of buildings in which every building generates both heat and electricity using micro-generation technologies and shares both types of energy with the other buildings. This article describes energy-sharing possibilities among four buildings in Japan: an office building, a hotel, a hospital and a shopping centre. The comparisons of primary energy consumption of the separate and shared cases of buildings show that the energy-sharing cases have the advantage of energy management within the boundary compared with the buildings studied as separated cases. The combination of hotel and hospital has the higher potential for achieving ZEB status. The results of this study show that the advantages of energy sharing are dependent on the type of buildings in the combination and CHP operation strategy.



## 1. Introduction

### 1.1. Energy community

Sustainable development requires various solutions at different scales and levels, such as that of a building, district, region, city or nation. Nowadays, micro-generation technologies are well developed and they make local energy production more possible. Also, economic solutions such as a Feed-in Tariff (FIT), which was launched in 2011 in Japan [1], are expected to push the introduction of renewable energy and local energy production forward. In terms of building scale, the Japanese government decided to accelerate its efforts towards zero energy building (ZEB) in April 2009 [2]. By the year 2030, all new public buildings must be ZEBs; thus, in May 2009 Japan created a research board for realising and developing ZEBs. In Japan, ZEB is defined by the Ministry of Economy, Trade and Industry (METI) as 'a building that consumes zero or almost zero energy on annual net primary energy consumption basis by enhancing the energy efficiency performance of buildings and equipment, Area Energy Network, using the renewable energy, etc. on site' [2]. Thus, on-site energy production and consumption is one of the key ZEB strategy in Japan. In Europe, the recast directive on the energy performance of buildings (EPBD) stipulates that by 2020, all new buildings constructed within the European Union should reach nearly zero energy levels. A nearly zero energy building (nZEB) is a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant degree by energy from renewable sources, including energy from renewable sources produced on-site or nearby [3,4]. However, achieving a ZEB status without a grid would be quite difficult. This study, thus, focuses on the boundary not only of a single building but also the boundary of a cluster of buildings, that is, of a so-called 'energy community'. The key motivation behind ZEB is to utilise distributed energy resources and energy efficiency in energy systems in the building. To increase energy efficiency even more, approaches focus not only on a single building but also on a group of buildings that might have the possibility to reach a closer to zero energy situation, a so-called 'zero energy community'.

Local energy generation is related to the use of small generating units installed close to load centres [5,6]. In particular, the systems based on cogeneration systems afford an excellent energy-saving potential through the effective use of waste heat from power generators [7–9]. In the case of a building that has its

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**Nomenclature**

| | |
|---|---|
| $CEF_e$ | cogeneration energy fraction factor in terms of electricity [–] |
| $CEF_h$ | cogeneration energy fraction factor in terms of heat [–] |
| $CEM_e$ | cogeneration energy matching factor in terms of electricity [–] |
| $CEM_h$ | cogeneration energy matching factor in terms of heat [–] |
| CHP | combined heat and power generator |
| const | constant output operation |
| $D_{ele}$ | electricity demand (hourly) [kWh] |
| $D_{dhw}$ | domestic hot water demand (hourly) [kWh] |
| $D_{spc}$ | space cooling demand (hourly) [kWh] |
| $D_{sph}$ | space heating demand (hourly) [kWh] |
| EC | electric chiller |
| $E_{chp}$ | electricity production by CHP (hourly) [kWh] |
| $E_{deficit}$ | amount of electricity deficit (hourly) [kWh] |
| $E_{dem}$ | total demand of electricity (hourly) [kWh] |
| $E_{export}$ | electricity export to the commercial grid (hourly) [kWh] |
| $E_{grid}$ | electricity from the commercial grid (hourly) [kWh] |
| el tr | electricity tracking operation |
| $E_{prod}$ | total production of electricity (hourly) [kWh] |
| $E_{share}$ | shared electricity among buildings (hourly) [kWh] |
| $E_{surplus}$ | amount of electricity surplus (hourly) [kWh] |
| GB | gas boiler |
| $H_{chp}$ | heat production by CHP (hourly) [kWh] |
| $H_{deficit}$ | amount of heat deficit (hourly) [kWh] |
| $H_{dem}$ | total demand of heat (hourly) [kWh] |
| he tr | heat tracking operation |
| HEX | heat exchanger |
| $H_{exhaust}$ | exhausted heat to the air (hourly) [kWh] |
| $H_{gb}$ | heat production by gas boiler (hourly) [kWh] |
| $H_{prod}$ | total production of heat (hourly) [kWh] |
| $H_{share}$ | shared heat among buildings (hourly) [kWh] |
| $H_{surplus}$ | amount of heat surplus (hourly) [kWh] |
| OEF | on-site energy fraction factor [–] |
| OEM | on-site energy matching factor [–] |
| $P_{chp.e}$ | constant power of CHP (electricity production) [kW] |
| $P_{chp.h}$ | constant power of CHP (heat production) [kW] |
| $RT$ | partial load rate of CHP [–] |
| $\eta^e$ | efficiency of electricity generation [–] |
| $\eta^h$ | efficiency of heat generation [–] |

own micro-generation system, such as combined heat and power (CHP) systems, it could be possible to generate and supply not only electricity but also heat. Generally, the balances between electricity and heat are different every hour, every month or every season. To increase the energy efficiency, there is the possibility to share energy among buildings by managing energy surplus and deficit situations. However, it is difficult for energy system designers to plan appropriate operation strategy regarding when and how much energy should be shared. This article describes the possibility of creating an energy-sharing community by trying to match the energy generation and demands of each building. The problems have to do with the building combinations, the capacity of gas engines and the existing storage systems. Several studies are discussed below to support the practical adoption of local energy generation technologies, for instance the study by Ruan et al. [10], who simulated the adoptability of micro-generation technologies for commercial buildings, the study by Pouresmaeil et al. [11], who presented flexible control strategy for connecting distributed generation resources to a distribution network, and the study by Mancarella and Chicco [12], who formulated a comprehensive emission assessment framework suitable for distributed cogeneration systems. Additionally, van Sxchijndel [13] evaluated the operation of CHP systems in the case of an academic hospital. These researches dealt with specific buildings or energy systems, while the study in this article focuses on the planning of energy systems considering different combinations of buildings and operation strategy in order to maximise the utilisation of the local energy systems. In previous studies by the first author [14–16], a case study for existing office and apartment buildings was investigated using Genetic Algorithms (GA). Individual energy systems and distributed energy systems were simulated in order to ascertain optimal heat balance among the studied buildings. The results demonstrate that if a distributed energy system is established among various office and apartment buildings, the primary energy consumption can then be significantly reduced. In the case of an office building and apartment building, a distributed energy system has the potential to reduce energy consumption. These results raise a question regarding other combinations of buildings that might benefit from energy sharing. Therefore, different combinations of buildings are investigated in this study.

### 1.2. Definition

In this study, an energy community is defined as a cluster of buildings in which every building can generate both electricity and heat using micro-generation technologies, such as CHP systems or photovoltaic panels, and can share both types of energy with the other buildings. Some studies describe the possibility and advantages of energy sharing among buildings. For example, Kopanos et al. [17] studied the case of residential buildings and a large group of micro-CHP systems that were connected to the local micro-grid. In one scenario, only electricity can be shared between neighbours and various subgroups of buildings can also share heat through common heat storage. Likewise, Chung et al. [18] simulated different building mixtures with varying energy system capacities to find out the payback times for such systems in Korea.

### 1.3. Issues for study

As a starting point for the study, we focus on three main issues for addressing the possibilities of creating an energy community. The first issue concerns the advantage of energy sharing among buildings, i.e. the extent to which energy sharing can minimise the energy input to the boundary or the amount of local energy production and consumption that is possible. The second issue concerns the feasible combinations of buildings. Shifting demands for energy and the existing energy supply can lead to either surplus or deficient amounts of energy at various hours of the day depending on variations in the demand profile. These surpluses and deficits can also be shared with neighbouring buildings. The third issue concerns the CHP system, which pertains to all buildings. The capacity, efficiency or operation strategy of the CHP system has the possibility to affect the amount of energy sharing that occurs between buildings. Depending on the balance between the CHP capacity and energy demand, the amount of surplus and deficit energy can be changed. Sometimes in the morning or at midnight, when energy demands are relatively small, CHP systems need to operate with very low efficiency. Moreover, improving energy efficiency by shifting the partial load is one of the advantages of energy sharing. Our calculations and analysis have yielded interesting results and findings in relation to these issues.