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Local sharing of cogeneration energy through individually prioritized controls for increased on-site energy utilization

Janne Hirvonen [a,*], Genku Kayo [a], Ala Hasan [b], Kai Sirén [a]

[a] Aalto University School of Engineering, Department of Energy Technology, P.O. Box 14400, FI-00076 Aalto, Finland
[b] VTT Technical Research Centre of Finland, Tekniikantie 4A, Espoo, P.O. Box 1000, FI-02044 VTT, Finland

HIGHLIGHTS

- Sharing of surplus heat and electricity produced by CHP plants in different types of buildings.
- Individually prioritized control of CHP plants with direct local sharing and minimal storage capacity.
- Energy sharing reduced primary energy consumption by 1–9% with biogas.
- Excess energy minimized by thermal tracking.

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ABSTRACT

All over the world, including Japan, there are targets to decrease building energy consumption and increase renewable energy utilization. Combined heat and power (CHP) plants increase energy efficiency and are becoming popular in Japan. CHP plants produce both heat and power simultaneously, but there is not always a need for both. A cluster of several different buildings can increase total efficiency and reduce primary energy (PE) consumption by sharing excess heat and electricity between neighboring buildings. If the generated energy comes from renewable sources, energy sharing makes it easier to reach the net zero energy balance. By adjusting CHP sizes and operation patterns, the wasted heat and primary energy consumption can be minimized.

Energy sharing has been explored in situations with identical buildings and centrally administered energy systems before, but not with different building types with separate systems. In this study, a cluster of Japanese office and residential buildings were combined to allow heat and electricity sharing based on cogeneration, using individually prioritized control (IPC) systems. TRNSYS simulation was used to match energy generation with pregenerated demand profiles. Absorption cooling was utilized to increase the benefits of local heat generation. Different CHP operation modes and plant sizes were tested.

The benefit of surplus energy sharing depends on the CHP capacities and the fuel type. When using biogas, larger CHP plants provided lower total primary energy consumption, in the most extreme case lowering it by 71%, compared to the conventional case. Using natural gas provided only a 6% decrease. The savings resulting from energy sharing were between 1% and 9% with biogas and between 1% and 6% using natural gas. The least amount of PE was consumed by having large CHP plants with biogas, due to the value of renewable electricity. Using natural gas, thermal tracking had the lowest PE consumption.

1. Introduction

As concern for global climate change grows, the countries all over the world are trying to lower their emissions and energy consumption. Japan has been under the Energy Conservation Law since 1979, with the goal of lower energy consumption. Today the government is accelerating its effort towards zero energy buildings (ZEB). A research board for realizing and developing ZEB was launched in 2009 to ensure that all new Japanese public buildings are ZEB by the year 2030. The Japanese Ministry of Economy defines a ZEB 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 using renewable energy” [1].

Combined heat and power (CHP) is an increasingly popular option for enhancing energy efficiency in Japan. In the last decades, Japan’s CHP capacity has increased from 200 kW to more than

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* Corresponding author. Tel.: +358 50 431 5780.
E-mail address: janne.p.hirvonen@aalto.fi (J. Hirvonen).

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Nomenclature

ICP	individually prioritized control
CHP	combined heat and power
nZEB	nearly zero energy building
PE	primary energy
PEF	primary energy factor
COP	coefficient of performance
$P_{E,CHP}$	electric power generated by the CHP plant
$P_{E,deficit}$	electric power demand remaining after CHP
$P_{E,dem}$	electric power demand of building devices
$P_{E,export}$	electric power that was exported to grid
$P_{E,import}$	electric power demand after sharing
$P_{E,share,out}$	electric power that was shared to neighbor
$P_{E,surplus}$	electric power surplus remaining after demand
$P_{H,boiler}$	thermal power to meet heat deficit after sharing
$P_{H,CHP}$	thermal power generated by the CHP plant
$P_{H,deficit}$	thermal power demand remaining after CHP
$P_{H,dem,heat}$	thermal power demand of hot water and space heating
$P_{H,excess}$	thermal power that was wasted after sharing
$P_{H,share,out}$	thermal power that was shared to neighbor
$P_{H,surplus}$	thermal power surplus remaining after demand
η_{boiler}	thermal efficiency of boiler
η_{el}	electric efficiency of CHP plant
η_{th}	thermal efficiency of CHP plant

9000 MW. 72% of CHP applications are in the commercial sector, which shows the great potential for building CHP plants in Japanese markets. CHP based on fuel cell technology has also been gaining in popularity [2].

Nearly zero energy buildings need to have their own energy generation systems to balance out their energy consumption. With individual buildings, this may require excessive system capacity or inefficient operation and may come at a high cost. Instead of just singular zero energy buildings, we should look at zero energy clusters (ZEC), where several buildings with energy generation are connected to the same local grid. Such clusters can benefit from economics of scale, decrease energy waste and lower reliance on the grid.

It is assumed that in net or nearly zero energy buildings excess energy from undispatchable sources, such as solar and wind, can be exported to the utility grid. However, without special feed-in tariffs, the selling price for exported energy is always less than the price of buying energy from the utility, because the price of bought energy also includes the costs from distribution and taxation. If the energy was sold in a local grid instead, both parties could benefit. Firstly, the seller could get a better price than from selling to the utility, while still being cheaper for the buyer than buying from the utility. Secondly, the buyer would get the credits for buying green energy instead of conventionally generated main grid energy, helping them to reach net zero energy status. Even if these trades did not happen, energy sharing can help utilize energy that would otherwise go to waste, such as excess heat.

Most research in the field seems to focus on individual buildings and their systems, but there have been some studies about a community approach as well, often with centralized energy systems. The zero energy community concept was compared to separate zero energy buildings in a study by Katipamula et al. [3]. They demonstrated that the economics of scale introduced by the community approach can help in providing the same overall energy-performance with lower costs. In this study, the energy generation was based on hourly models, but the energy demand was just the sum of the annual demands for each building. Similarly, energy-efficient construction and both active and passive solar design have been used at a Californian university campus as reported by Wheeler and Segar [4]. The study claims that net zero energy status can be achieved in a community without increasing costs for the residents through strong public/private collaboration. A local centralized solar power plant with concentrated PV and solar thermal collectors was used in a simulation study to provide for all of the heat and electricity needs of a community of 1000 identical residential buildings. Burch et al. found that the centralized plant reduced costs compared to single-family systems and made it possible to use seasonal heat storage [5]. In a smaller scale study by Mohamed et al., a group of houses was powered by a single shared CHP plant, which was found to increase total efficiency [6].

The building cluster point of view has been examined in a study by Zhivov et al. [7]. They point out that buildings should be first optimized to their individual economic energy efficiency peaks and then combined into a cluster for additional benefits. An important benefit of the community approach is the balanced energy demand coming from the combined energy profiles of different buildings. A study by Cho et al. looked into combining a residential and an office building [8]. A comparison of completely separate systems and a building combination with a single shared HVAC system demonstrated that the latter used more energy due to inefficient part-load behavior. Centralized control of separate air-conditioner units was tried by Cole et al. in [9] for a community of 900 homes. The combined control system reduced peak power demand, but increased total energy demand. The community energy demand profiles were created by modifying building simulation models with varying occupancy profiles.

The utilization of excess heat production from net zero energy buildings connected to a district heating network was considered by Nielsen and Möller [10]. A heat atlas was used to find the total number of different buildings in Denmark and the heat consumption based on type, period and usage, as well as to calculate the connection costs to a DH network. The scale was national, with the planning target set for the year 2050. Excess solar thermal energy was exported to the DH grid. A cost-effective, centralized ST solution with thermal storage was compared to a space-effective, roof-top ST solution. Solar thermal exporting from zero energy buildings would lower the fuel use of CHP. Heat storage is needed to fully utilize the heat. In a similar vein, a regional heat market with several participating industrial facilities and energy companies was considered in a study by Karlsson et al. [11]. This way of utilizing waste heat in a shared system demonstrates both economic and ecological potential. On the other hand, small-scale district heating was examined in [12] by Truong and Gustavsson and it was found out that if the value of cogenerated electricity is similar to that produced by stand-alone plants, heat-only boiler may be the only economical option.

Smaller local energy networks have been examined as well. Twenty residential buildings, each with their own fuel cell CHP system, were connected so they can share electricity in studies by Wakui et al. [13,14]. When energy exports to the main grids were not allowed, the joint operation of the fuel cells increased energy efficiency. Hot water demands were covered by the fuel cells, but no heat was exchanged between the buildings. All fuel cells were controlled together to allow total electricity demand to be met.

In a study by Kopanos et al. [15], a large group of micro-CHP systems was simulated for residential buildings that were connected to a local microgrid. In one scenario, only electricity could be shared between neighbors. In another scenario, subgroups of buildings could also share heat through a common heat storage