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Improving energy efficiency for local energy systems

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HIGHLIGHTS

- Multi-period design methodology for heat recovery in local energy systems.
- A systematic targeting for minimum utility requirements for urban utility systems.
- Integration of industrial waste heat with local energy systems.
- A case study providing insights for the heat recovery of discontinuous systems.

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ABSTRACT

This study aims to develop a novel design method for reducing the energy consumption and CO_2 emissions of local energy systems, simultaneously considering the recovery of industrial waste heat, and effectively dealing with the non-continuous nature of energy usage and heat recovery. A multi-period concept has been adopted for characterizing the change of heat demand and associated heat recovery in local energy systems which is used for targeting of the minimum energy consumption. In addition, techno-economic analysis is used to provide design guidelines for better heat integration. This design methodology also incorporates the impacts of heat storage and part-load performance of energy production equipment. Opportunities for utilization of low grade heat in process industries have been systematically considered for the minimization of energy generation in local energy systems together with the evaluation of the economic feasibility of such systems for integration of industrial low grade heat with local energy systems. Case studies are used to demonstrate the applicability and practicality of the heat integration methodology developed in this work, and to illustrate how a holistic approach can improve the overall energy efficiency of local energy systems.

1. Introduction

The efficient use of low grade heat in process industries is widely believed to be one of the more practical approaches which can be used to achieve significant cost savings as well as environmental emission reductions in practice. The current study focuses on improving heat recovery in local energy systems, together with the effective utilization of low grade heat available through integration with an industrial site. Local energy systems, such as energy infrastructure servicing district heating (DH) systems, service buildings (e.g. hospitals, hotels, etc.) and residential complexes require large amounts of energy for cooling/heating during summer/winter and for the supply of hot water. Therefore, the local energy systems have the opportunity to improve their energy efficiency through utilization of low grade heat from process industries, as shown in Fig. 1.

For the last three decades, Process Integration methodologies have been extensively employed for the reduction of energy demands and a wide range of successful applications have been observed in various industrial activities [1]. One well-known Process Integration method is Pinch Analysis, which systematically examines the recovery of heat within processes, identifies the minimum external utility requirements, and suggests the most appropriate ways for the recovery of heat through HENs (heat exchanger networks) [2]. This graphical design method was initially applied to single processes, and later it has been extended to investigate total sites which include several manufacturing processes and site utility systems [3]. A design methodology commonly used to assess site-wide potentials of steam recovery and power generation is known as Site Analysis, which provides conceptual insights concerning the management of heat and power in an integrated manner [1]. Early development for these techniques was mainly

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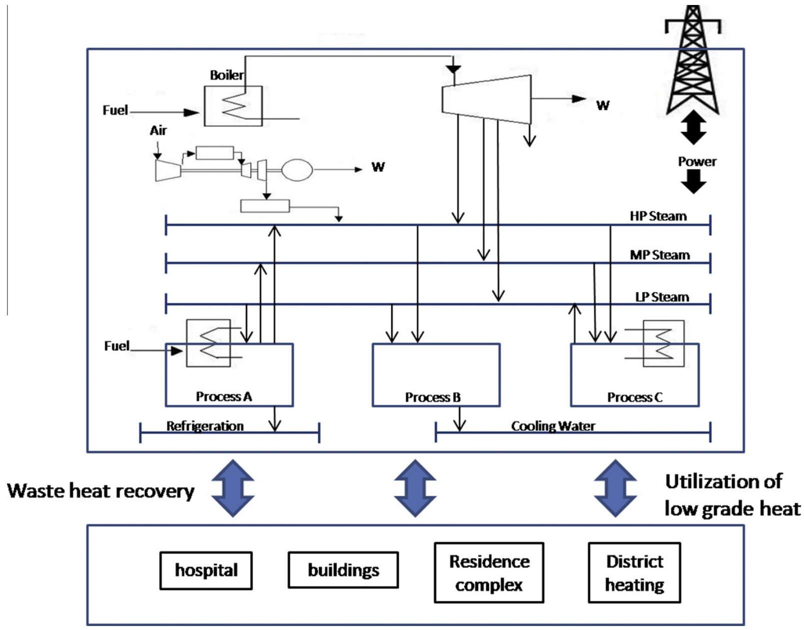

Fig. 1. Integrated heat recovery beyond the plant boundaries.

based on the graphical manipulation of thermodynamic information from processes and design guidelines extracted from conceptual understanding of heat recovery problems. Recent development in the field of energy management for industrial plants has focused on the application of mathematical optimization, typically using superstructure representations of heat recovery problems [4].

Although both graphical and automated Process Integration methods have contributed considerably through the maximization of heat recovery and minimization of unnecessary waste heat disposal from the process, a large amount of low grade heat is still often wasted, and the recovery of this waste heat in process industries has not yet been fully explored [5]. Improving the energy efficiency and techno-economic benefits associated with the utilization of low grade heat in the process industry depends strongly on the quality and properties of the waste heat available [6] as well as the technical characteristics of technologies using low grade heat [7].

In addition, there have been many studies conducted investigating the possible reduction of energy consumption in local energy sectors, including district heating systems. Reducing the demands of district heating systems has been considered by applying energy conservation measures including improved control of the heat load, insulation and the upgrading or replacement of old domestic appliances [8]. Different supply line temperatures inside district heating networks have been investigated by Dalla Rosa and Christensen [9] for district heating in Denmark and later by Dalla Rosa et al. [10] for district heating in Canada. Both studies concluded that there is a strong incentive for supplying heat at low-temperature conditions, because heat loss is considerably reduced for such low-temperature district heating, compared to high-temperature district heating. However, these studies also noted that careful consideration should be made when determining the design and operation of such networks, because of the strong influence of human behavior on heat demand [9] and because of the large capital investment required to accommodate low-temperature operation [10]. Sanaei et al. carried out mathematical modeling and optimization in district heat systems to evaluate the different options inside energy system components and their interactions and to assess the techno-economic impacts of integrated measures [11], while the graphical design method using pinch concept has also been applied to the energy system of a hospital by Herrera et al. [12].

Improving energy efficiency in the building sector has been studied for the supply of energy from combined heat and power (CHP) systems, and an optimization-based approach for the clustering together of buildings was used to identify the optimal locations of CHP plants and equipment sizing, together with their operating strategy [13]. The impacts of policies and non-technical barriers were also studied during the promotion and implementation of technologies and measures for the improvement of energy efficiency at the local level [14].

Due to the sustainable benefits of replacing conventional energy sources with renewable ones, various studies have been conducted with the aim to enhance the acceptability of technologies based on renewable sources with respect to residential and community sectors: for example, the integration of tidal power generation with an existing commercial power network was studied for the purpose of determining improved system-wide strategies for load-leveling in power systems and planning the usage of energy storage [15]. Also, a wide range of technologies based on the utilization of conventional fossil fuels and renewables have been evaluated and their economic and environmental impacts have been assessed in the context of end-use energy savings for district heating systems [16]. Further examples include investigation of the role of renewable sources as peak-saving options in distributed energy infrastructure [17] and the supply of electricity to rural areas based on local biomass resources [18].

However, in these past studies, local energy systems and industrial energy systems have been dealt with separately when considering energy minimization. Due to the strong demand for sustainable development these days, considerable attention has been paid in the industrial and academic communities to address the problem of how the current local energy infrastructure or district heating networks should be evolved. In the context of such a transitional issue, the incentives for integration of industrial energy systems with local energy systems have been recognized and various studies have been carried out. For example, in one study investigating the integration of a pulp and paper plant with a municipal energy infrastructure the facilities generating heat for