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# Micro-combined cooling, heating and power systems hybrid electric-thermal load following operation

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ABSTRACT

Micro-combined cooling, heating and power (mCCHP), typically designated as less than 30 kW electric, is a technology that generates electricity at or near the place where it is used. The waste heat from the electricity generation can be used for space cooling, space heating, or water heating. The operation of mCCHP systems, while obviously dependent upon the seasonal atmospheric conditions, which determine the building thermal and power demand, is ultimately controlled by the operation strategy. Two of the most common operation strategies are to run the prime mover in accordance to either electrical or thermal demand. In this study, a mCCHP system operating following a hybrid electric-thermal load (FHL) is proposed and investigated. This operation strategy is evaluated and compared with mCCHP systems operating following the electric load (FEL) and operating following the thermal load (FTL). This evaluation and comparison is based on site energy consumption (SEC), primary energy consumption (PEC), operational cost, and carbon dioxide emission reduction (CDE). Results show that mCCHP systems operated following the hybrid electric-thermal load have better performance than mCCHP-FEL and mCCHP-FTL. mCCHP-FHL showed higher reductions of PEC, operational cost, and carbon dioxide emissions than the ones obtained for the other two operation strategies for the evaluated case.



## 1. Introduction

A typical mCCHP system consists of a power generation unit (PGU), a heat exchanger to recover heat from the PGU exhaust, an absorption chiller system to generate chilled water, a heating coil, and an auxiliary boiler (see Fig. 1). The difference between mCCHP systems and the typical methods of power plant electric generation is the use of the waste heat rejected from the PGU in order to satisfy the thermal demand of a facility. Traditional power plants convert about 30% of the fuel's available energy into electric power since most of the energy content of the fuel is lost at the power plant through the discharge of waste heat. In addition, energy losses occur in the transmission and distribution of electric power to individual users. However, mCCHP systems produce both electric and useable thermal energy onsite or near site, reducing the energy losses that occur in the transmission and distribution, converting as much as 80% of the fuel into useable energy.

The operation of mCCHP systems depends on the weather conditions and the building thermal and power demand. However, mCCHP systems operation is controlled by the selected operation strategy. Two of the most common operation strategies are to run the prime mover in accordance to either electrical or thermal demand. Cardona and Piacentino [1] called these two styles as electric demand management (EDM) and thermal demand management (TDM). The choice between EDM and TDM is usually governed by the loading of the prime mover as well as a few extraneous circumstances including the ability to sell back electricity to the grid or store it on site for later use via some battery system. Also, the price of fuel versus that of electricity purchased from a traditional source can affect the management of a plant [2]. According to Cardona and Piacentino [1], the TDM strategy is most commonly used where excess electricity produced can be sold back to the grid. On the other hand, EDM is used in the desire to not waste any thermal energy rejected from the prime mover [1]. Jalalzadeh-Azar [3] performed a non-dimensional analysis of energy cost and primary energy consumption of combined hating and power (CHP) systems utilizing a gas fired micro-turbine. In his analysis, CHP following the electric load and following the thermal load were evaluated. The results yielded an 11% reduction in total energy consumption when the system operates following the thermal load versus the system following the electric load. This reduction was deemed to be in large part due to the higher level of waste heat utilization when the system followed the thermal load. It is important to note here, that under his analysis surplus electricity could be sold back to the grid. Mago et al. [4] performed an analysis of CCHP and CHP systems operating following the thermal and electric loads for different climate conditions. They reported that

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**Nomenclature**

| | |
|---|---|
| CDE | carbon dioxide emissions reduction |
| mCCHP | micro-combined cooling, heating and power |
| *COP* | coefficient of performance |
| *cost* | cost |
| *E* | electric energy |
| $e_{grid}$ | emission conversion factor for electricity |
| $e_{fuel}$ | emission conversion factor for natural gas |
| $E_m$ | electric energy registered at the meter |
| $E_{pgu}$ | PGU electricity |
| $F_{pgu}$ | PGU fuel energy consumption |
| $F_{boiler}$ | boiler fuel energy consumption |
| FEL | following the electric load |
| FHL | following a hybrid electric-thermal load |
| FTL | following the thermal load |
| CHP | combined heating and power |
| $pec_{grid}$ | site-to-energy conversion factor for electricity |
| $pec_{fuel}$ | site-to-energy conversion factor for natural gas |
| PEC | primary energy consumption |
| PGU | power generation unit |
| SEC | site energy consumption |
| Q | thermal energy from fuel |

*Symbols*

| | |
|---|---|
| $\eta$ | efficiency level, ratio between useful output and input amount |

*Subscripts*

| | |
|---|---|
| *boiler* | boiler |
| *c* | cooling |
| *ch* | absorption chiller |
| *excess* | excess electricity |
| *grid* | electricity required from the grid |
| *h* | heating |
| *pgu* | power generation unit |
| *rec* | recovered heat |

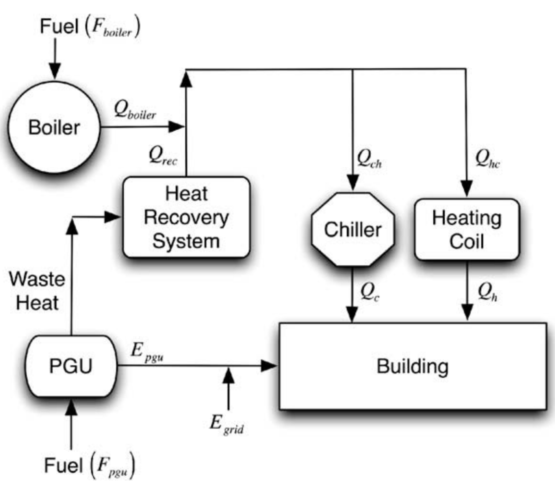


**Fig. 1.** Schematic of the mCCHP system.

CCHP and CHP systems operated following the thermal load reduced the PEC for all the evaluated cities. Furthermore, CHP systems operated following the electric load always increases the PEC. Although Cardona and Piacentino [1,2], Jalalzadeh-Azar [3], and Mago et al. [4] have performed analysis on CHP and CCHP systems operation following the thermal and electric loads, this paper investigates the effect of a hybrid electric-thermal following operation strategy on the SEC, PEC and operational cost. The effect of the proposed operation strategy (FHL) on the reduction of carbon dioxide is also considered in this investigation. Reduction of carbon dioxide is important on CCHP and CHP systems analysis since it provides the environmental benefits to adopt this technology. Several researchers have evaluated and analyzed the benefits of CCHP and CHP systems in terms of reduction of pollutants for different applications. Some of them include: Mago et al. [5], Pierluigi et al. [6], Möllersten et al. [7], Wahlund et al. [8], Möllersten et al. [9], Chicco and Mancarella [10], and Savola and Fogelholm [11], among others. In general, they reported that CCHP systems have the potential and the ability to reduce the emission of carbon dioxide.

The objective of this investigation is to analyze the performance of mCCHP systems operating following a hybrid electric-thermal load (FHL) and compare the results with mCCHP systems operating following the electric load (FEL) and operating following the thermal load (FTL). The comparison of the different mCCHP operation strategies is based on SEC, PEC, operational cost, and CDE reduction.

## 2. Analysis

This section presents the equations used to model the mCCHP-FHL evaluated in this investigation. The new proposed operation strategy is compared with mCCHP-FEL and mCCHP-FTL. A schematic of the mCCHP system is shown in Fig. 1. For mCCHP systems the fuel is supplied to the prime mover to produce the electricity needed for the building including lights, equipments, etc. Then, the waste heat from the prime mover is used to provide heating or cooling when needed.

The mathematical model for the mCCHP system is dependent upon the amount of energy input into the power generation unit (PGU). The PGU efficiency can be determined as

$$\eta_{pgu} = \frac{E_{pgu}}{F_{pgu}} \tag{1}$$

where $E_{pgu}$ is the total electric energy that has to be supplied by the power generation unit and $F_{pgu}$ is the PGU fuel energy consumption. The efficiency of the power generation unit is assumed to be constant independent of the electric demand.

The recovered waste heat from the prime mover can be estimated as

$$Q_{rec} = F_{pgu}\eta_{rec}(1 - \eta_{pgu}) \tag{2}$$

where $Q_{rec}$ is the recovered thermal energy and $\eta_{rec}$ is the heat recovery system efficiency.

The heat required by the absorption chiller to handle the cooling load is estimated as

$$Q_{ch} = \frac{Q_c}{COP_{ch}} \tag{3}$$

where $Q_c$ is the building thermal cooling load and $COP_{ch}$ is the coefficient of performance of the absorption chiller.

The heat required for the heating coil to handle the heating load is determine as

$$Q_{hc} = Q_h/\eta_{hc} \tag{4}$$

where $Q_h$ is the building heating load and $\eta_{hc}$ is the heating coil efficiency.