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Matching analysis for on-site hybrid renewable energy systems of office buildings with extended indices

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HIGHLIGHTS

- Matching analysis for hybrid on-site renewable energy systems with extended indices.
- Parametric analysis of design parameters for system components from matching aspect.
- Matching analysis for hybrid on-site energy systems with hybrid grid feed-in options.
- Instantaneous matching analysis for hybrid on-site energy systems at each time-step.

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ABSTRACT

The objective of this paper is to close the scientific gap that there is a lack of comprehensive matching analysis for the increasingly complicated on-site hybrid energy systems with a continuously decreased annual primary energy consumption/equivalent CO_2 emission. Thus, a thorough matching analysis is conducted for the on-site hybrid systems of two office buildings under distinct climate conditions. Both of the studied buildings are equipped with PV and solar thermal assisted ground source heat pumps (GSHP), which can be controlled by six excess renewable electrical (REe) and one excess renewable thermal (REth) treatments with respect to certain thermal storage recharging and grid exporting strategies. The assessment criteria are six recently defined indices. With the aid of these indices, the key methodology is to conduct parametric analyses from the aspect of matching for solar thermal collector area and connection type, PV panel area, and electrical battery size regarding certain excess REe or REth treatments. The outcomes of matching analyses show the advantages of solar thermal collectors connected in a parallel fashion in meeting office heating demands, the consistency between electrical generation and demand in the daytime in office buildings, the enhancement of on-site heating and cooling by GSHP and free ground cooling, and the battery effect in technically improving electrical matching. Furthermore, the fluctuations of indices in the instantaneous matching analysis clearly reflect the matching situations of on-site renewable energy resources and demand conditions at each time-step, which will be helpful for the detailed investigation of specific system operations and user behaviours. It has been shown that the methodology used in the study can be helpful for aiding the design of increasingly complicated on-site hybrid energy systems.

1. Introduction and background

1.1. Increasingly complicated on-site hybrid energy systems and review of methodology

With the fast development of energy technology, the on-site renewable energy systems are becoming more complicated and diversified, and thus are often presented in a hybrid form. Firstly, the hybrid system can involve various energy forms, which include electrical, heating, and cooling energy, such as the hybrid system of on-site photovoltaic (PV) and solar thermal collectors [1]. Secondly, the hybrid system can involve energy conversions between different energy forms, such as solar thermal driven absorption chiller between heating and cooling energy [2], and PV driven vapour compression chiller between electrical and cooling energy [3]. Thirdly, the hybrid system often includes various types of storages, such as electrical battery and hot water storage tank for the hybrid system of PV and solar thermal collectors [4].

In order to analyse these increasingly complicated on-site hybrid systems, many researchers focused on various aspects. Rezaie et al. [5] analysed both single and hybrid on-site energy systems

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Nomenclature

ACH	air changes per hour
AHU	air handling unit
$C_{\text{eoff-c}}$	cooling power generated by the electrically driven cooling machines by the off-site part of the electricity (kW)
$C_{\text{eon-c}}$	cooling power generated by the electrically driven cooling machines by the on-site part of the electricity (kW)
$C_{\text{hoff-c}}$	cooling power generated by the thermally driven cooling machines by the off-site part of the heat (kW)
$C_{\text{hon-c}}$	cooling power generated by the thermally driven cooling machines by the on-site part of the heat (kW)
CHP	combined heat and power
COP	coefficient of performance
CS_{off}	net off-site part of the cooling power sent to cold storage, charge in '+' sign, and discharge in '−' sign (kW)
CS_{on}	net on-site part of the cooling power sent to cold storage, charge in '+' sign, and discharge in '−' sign (kW)
DHW	domestic hot water
dt	the time-step used in the research
$E_{\text{off-h}}$	off-site part of the electrical power sent to the electrically driven heating machines (kW)
$E_{\text{on-h}}$	on-site part of the electrical power sent to the electrically driven heating machines (kW)
$E_{\text{off-c}}$	off-site part of the electrical power sent to the electrically driven cooling machines (kW)
$E_{\text{on-c}}$	on-site part of the electrical power sent to the electrically driven cooling machines (kW)
ES_{off}	net off-site part of the electrical power sent to electrical storage, charge in '+' sign, and discharge in '−' sign (kW)
ES_{on}	net on-site part of the electrical power sent to electrical storage, charge in '+' sign, and discharge in '−' sign (kW)
EU	European Union
F_{eg}	interactive electrical power with the electrical grid, exporting in '+' sign, and importing in '−' sign (kW)
F_{dh}	interactive heating power with the heating grid, exporting in '+' sign, and importing in '−' sign (kW)
F_{dc}	interactive cooling power with the cooling grid, exporting in '+' sign, and importing in '−' sign (kW)
G	on-site generated power (kW)
GSHP	ground source heat pump
G_{elec}	electrical power generated by the on-site electrical energy production system (kW)
$G_{\text{h\_th}}$	heating power generated by the on-site thermal energy production system (kW)
$G_{\text{c\_th}}$	cooling power generated by the on-site thermal energy production system (kW)
$H_{\text{eoff-h}}$	heating power generated by the electrically driven heating machines by the off-site part of the electricity (kW)
$H_{\text{eon-h}}$	heating power generated by the electrically driven heating machines by the on-site part of the electricity (kW)
$H_{\text{off-c}}$	off-site part of the heating power sent to the thermally driven cooling machines (kW)
$H_{\text{on-c}}$	on-site part of the heating power sent to the thermally driven cooling machines (kW)
HS_{off}	net off-site part of the heating power sent to heat storage, charge in '+' sign, and discharge in '−' sign (kW)
HS_{on}	net on-site part of the heating power sent to heat storage, charge in '+' sign, and discharge in '−' sign (kW)
HTF	heat transfer fluid
HX	heat exchanger
L	load power (kW)
L_{elec}	electrical load power excluding the electrical load from the electrically driven heating and cooling machines (kW)
L_{heat}	heating load power excluding the heating load from the thermally driven cooling machines (kW)
L_{cold}	cooling load power (kW)
l_{e}	loss of on-site electrical power during the distribution process (kW)
l_{h}	loss of on-site heating power during the distribution process (kW)
l_{c}	loss of on-site cooling power during the distribution process (kW)
MPP	maximum power point
nZEB	nearly zero-energy buildings
OEF	on-site energy fraction
OEM	on-site energy matching
OEFe	on-site electrical energy fraction
OEFh	on-site heating energy fraction
OEFc	on-site cooling energy fraction
OEMe	on-site electrical energy matching
OEMh	on-site heating energy matching
OEMc	on-site cooling energy matching
PV	photovoltaic
P_{amb}	heating power entering the thermal process of the conversion machine (electrically driven heating machine, electrically driven cooling machine, or thermally driven cooling machine) from the ambient outside the boundary of the building (kW)
$P_{\text{drive,on}}$	on-site part of the heating power entering the thermal process of the machine, which is directly converted from the on-site part of the power driving the machine (kW)
$P_{\text{drive,off}}$	off-site part of the heating power entering the thermal process of the machine, which is directly converted from the off-site part of the power driving the machine (kW)
r	on-site proportion of the heating or cooling power generated by the electrically driven heating machine, the electrically driven cooling machine, or the thermally driven cooling machine
REe	renewable electrical
REth	renewable thermal
t_1	starting point of the time span
t_2	ending point of the time span

for one commercial, one industrial, and two residential buildings from three aspects: technological (on-site energy supplier solutions, combination types of on-site systems, and reduction of energy consumptions), environmental (equivalent CO_2 emissions), and total cost, which also constitute the sizing methodology for the analysed on-site energy systems. Their utilised on-site energy technologies include PV, solar thermal collector, and ground source heat pump; they concluded that the hybrid systems can provide higher efficiency, less cost, and lower emissions. With the same sizing methodology and similar combinations of the on-site hybrid systems as [5], Rezaie et al. [6] further conducted the assessment for two residential buildings from the aspects of environmental, energy and exergy aspects, which were aided with three corresponding non-dimensionless indices: environmental impact index (reduction percentage of CO_2 emissions compared to conventional or reference systems), renewable energy index (renewable energy percentage in total energy demand), and renewable exergy index (renewable exergy percentage in total