Data-Driven Flexibility-oriented Energy Management Strategy for Building Cluster Meso Energy Hubs

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***Abstract*—Buildings owned by a single person or set of occupants can be identified as a cluster, while they may not be located in the same area. Market-related interconnection of buildings enables a company or operator to benefit from the energy flexibility of the buildings by managing them as a whole cluster. This paper proposes a clustering method that divides multiple buildings into different clusters based on building cluster Pearson correlations coefficient (PCC). Further, this research introduces a building cluster as a meso energy hub (MEEH) as an integrated and synergistic managerial framework in multi-carrier energy systems. The proposed data-driven clustering method aims to increase the PCC between the energy generations and demands of buildings divided in the same cluster MEEH. Besides PCC, on-site energy ratio (OER), on-site mismatch ratio (OMR), maximum hourly surplus (MHS), and maximum hourly deficit (MHD) are employed as energy flexible building cluster indicators to demonstrate the effectiveness of the proposed approach towards net zero energy communities (NZECs) The numerical results show that the proposed method yields 33% decrement in operation cost, 70% increment in the average value of PCC, and significant improvements in OER, OMR, MHS, and MHD as energy flexible building cluster indicators.**

***Keywords*— Energy hub, Building clusters, Data-driven, Flexibility, Net zero energy communities.**

I. INTRODUCTION

In recent years, European countries have been concentrating on improving building energy efficiency as a key target, since 40% of the energy consumption is related to the building sector [1]. Hence, improving building energy efficiency has been followed by introducing a directive in building construction in 2006, which classified buildings as ‘‘low-energy building class 1’’ or a ‘‘low-energy building class 2’’. However, a large potential for energy efficiency exists in the existing buildings [2], [3]. In this regard, smart buildings, which increasingly interact with the grid as a prosumer can be mentioned as a promising framework for improving energy efficiency. However, paying attention to the buildings' interactions and seeing them as interconnected units can efficiently facilitate the realization of energy management and efficiency politics. Building cluster approaches as an effective strategy for energy efficiency retrofit can maximize the synergies of building performance, distributed energy resources (DERs) harvesting, and management [4-6]. In recent years, researchers proposed innovative clustering algorithms as well as innovative energy management and scheduling framework aiming at realizing energy efficient energy management of buildings [7].

Data-driven approaches can be mentioned as the most popular methods extensively used in building energy classification and building grouping based on energy profiles [7, 8]. Among data-driven approaches, the most favored approaches include self-organizing map-based approaches, hierarchically-based approaches, and K-means-based approaches [8]. The authors in [9] propose a clustering method based on the k-shape algorithm in which buildings are divided into different clusters according to their hourly consumption. In Ref. [10] a k-means clustering method is proposed based on the energy use pattern analysis in a building. Ref. [11] presents an innovative approach for identifying homogeneous clusters based on their energy-saving potential. The innovative approach of [12], includes improvements in every stage in load profiling-based consumer categorization, and also a new stage to whole procedure improvement. Further, a two-stage approach based on pattern recognition methods including k-means, Kohonen adaptive vector quantization, fuzzy k-means, and hierarchical clustering is introduced in [13]. The proposed methodology in [14] follows a multi-dimensional clustering concept that introduces a new standpoint to analyze building performance typology. The authors in [15] analyze k-means, k-medoid, and self-organizing maps as three widely used clustering methods to select the best performance for dividing different buildings to form clusters based on their electricity consumption pattern.

Furthermore, the innovative frameworks through game theory, data mining, and optimization aim to realize efficient energy management and scheduling in building clusters. In game theory-based approaches, [16] presents a game theory-based decentralized energy management framework to optimize buildings energy management in a building cluster collectively, and [17] introduces a game theory-based decentralized framework which simultaneously optimizes the indoor air temperature and the operation of active thermal storage. From data-driven approaches categories, [18] employs deep reinforcement learning (DRL) in thermal energy storage management in a cluster of four buildings, and [19] proposes a multi-agent deep deterministic policy gradient (MADDPG) approach to optimal scheduling of building clusters. In optimization-based approaches, [20] and [21] propose a multi-objective optimization problem to minimize the cost, emissions, and peak load, and a multi-level optimal dispatch approach to maximize flexibility profits, respectively.

From different perspectives, a portfolio of buildings not necessarily in the same geographical area but owned by a single person or set of occupants is also can be considered a building cluster [22], [23], [24]. This paper contributes to the literature on proposing a clustering method that divides multiple buildings into different clusters based on building cluster Pearson correlations coefficient (PCC). Furthermore, this paper introduces the meso energy hub (MEEH) to realize an integrated and synergistic management of building clusters in multi-carrier energy systems. Furthermore, on-site energy ratio (OER), on-site mismatch ratio (OMR), maximum hourly surplus (MHS), and maximum hourly deficit (MHD) have been employed as energy flexible building cluster indicators to demonstrate the effectiveness of the proposed approach towards net zero energy communities (NZECs). The contributions of this manuscript can be summarized as follows:

- ✓ Developing a data-driven flexibility-oriented method for building cluster organizing based on PCC,
- ✓ Introducing building cluster MEEH concept as an integrated and synergistic managerial framework in multi-carrier energy systems,
- ✓ Evaluating the effectiveness of the proposed approach towards net zero energy communities (NZECs) through OER, OMR, MHS, and MHD as energy-flexible building cluster indicators.

II. Research Methodology

A. Problem Statement

The energy hub (EH) concept has many different applications and does not have a limit on the size. Different energy systems from small residential buildings, offices, shopping malls, hospitals, hotels, and institutional units to large residential complexes, an urban area, a rural or an entire city can be considered as EH [25]. Today, smart buildings, with considerable ability in generation, consumption, and storage of different energy carriers, are increasingly interacting with the energy infrastructures by operating as micro energy hubs (MIEHs) [4]. Furthermore, a city can be seen as a macro energy hub (MAEH) including EHs that are controlled and scheduled coordinately [26, 27]. As described in [5], "The building cluster scale, also known as 'building block or neighborhood', represents an intermediate level between a single building and district or urban scale". As the middle or intermediate level in analytical levels is also known as "meso" which is specifically designed to reveal connections between micro and macro [28], this research defines a building cluster as a meso energy hub (MEEH). This conceptualization can realize an integrated and synergistic management of building clusters in multi-carrier energy systems. This paper proposes a clustering method that divides multiple buildings into different clusters and organizes MEEH as a managerial framework based on PCC. In the next step, organized MEEHs based on the proposed clustering approach are scheduled and OER, OMR, MHS, and MHD as energy flexible building cluster indicators are calculated to demonstrate the effectiveness of the proposed approach towards net zero energy communities (NZECs). Fig. 1 describes proposed data-driven flexibility-oriented energy management strategy for building cluster MEEHs.

B. Problem Formulation

In the proposed framework, in the first step, the proposed MINLP optimization-based clustering approach is implemented to organize MEEHs. In the next step, organized MEEHs are scheduled to maximize their profits while being constrained by generation, conversion, and storage unit limitations. In the last step, energy-flexible building cluster indicators are calculated based on the results of the second step.

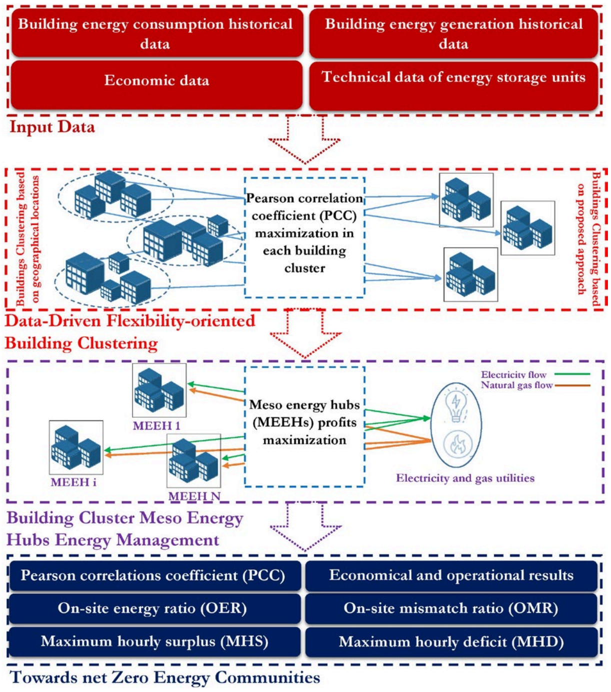

Fig.1. Proposed data-driven flexibility-oriented energy management strategy for building cluster meso energy hubs.

1) Data-Driven Flexibility-oriented Building Clustering

An optimization-based clustering is implemented that aims to maximize PCC between the generation and demands of each cluster. The objective function in the clustering process is formulated in (1) [29].

$$BCPCC_{cl} = \frac{\sum_{t=1}^{N_T}(CG_{cl,t} - \overline{CG}_{cl})(CD_{cl,t} - \overline{CD}_{cl})}{\sqrt{\sum_{t=1}^{N_T}(CG_{cl,t} - \overline{CG}_{cl})^2 \sum_{t=1}^{N_T}(CD_{cl,t} - \overline{CD}_{cl})^2}} \quad (1)$$

In (1), $CG_{cl,t}$ and $CD_{cl,t}$ are the clusters generation and demand which formulated in (2) and (3), which $\overline{CG}_{cl}$ and $\overline{CD}_{cl}$ are their averages.

$$CG_{cl,t} = \sum_{bi \in GB_{PV}} P_{bi,t}^{PV} I_{cl,bi} + \sum_{bi \in GB_{WT}} P_{bi,t}^{WT} I_{cl,bi} + \sum_{bi \in GB_{CHP}} P_{bi,t}^{CHP} I_{cl,bi} + \sum_{bi \in GB_{ESS}} P_{bi,t}^{EES} I_{cl,bi} \quad \forall cl,t \quad (2)$$

$$CD_{cl,t} = \sum_{bi} P_{bi,t}^{D} I_{cl,bi} \quad \forall cl,t \quad (3)$$

where $P_{bi,t}^{PV}, P_{bi,t}^{WT}, P_{bi,t}^{CHP}$ are power generation of photovoltaic units (PVs), wind turbines (WTs) and combined heat and power generation units (CHPs), which only one of them may be available in each building. In these equations, $P_{bi,t}^{D}$ represents its building demand and $I_{cl,bi}$ is a binary variable that represents the status of divided buildings into each cluster (1 a building is divided in cluster and 0 otherwise). As for energy storage systems (EESs), historical data was not available, through the available characteristics, it is assumed that the EESs can help clusters in satisfying their demand up to the maximum of their capacity and considering operational constraints described in (11)-(17). To prevent the asymmetric division of buildings in clusters, constraint (4) is also considered. Constraint (5) imposes each building be divided into only one cluster.

$$BC^{Min} \le \sum_{bi} I_{cl,bi} \le BC^{Max} \quad \forall cl \tag{4}$$

$$\sum_{cl} I_{cl,bi} = 1 \quad \forall bi \tag{5}$$

2) Building Cluster Meso Energy Hubs Energy Management

In the energy management process, organized MEEHs aim to maximize their profits in the power and gas exchanging process with the main grid, as expressed by (6).

$$\sum_{cl,t} CE^{Ele}_{cl,t} \lambda^{Ele}_{t} + CE^{Gas}_{cl,t} \lambda^{Gas}_{t} \tag{6}$$

where $CE^{Ele}_{cl,t}, CE^{Gas}_{cl,t}, \lambda^{Gas}_{t}, \lambda^{Ele}_{t}$ indicate the MEEHs-main grid exchanged power and gas and their hourly exchanging prices. Furthermore, equality constraint (7) expresses the balance equation of active power in each MEEH.

$$CG_{cl,t} - CD_{cl,t} + CE^{Ele}_{cl,t} = 0 \quad \forall cl,t \tag{7}$$

WTs and PVs generation as non-despicable generation units in the energy management process are also modeled based on available historical data. Furthermore, generated power by CHPs as dispatchable generation units are modeled by Eqs. (8)-(10) [30]. Eq. (8) represents the generated power of each CHP, which is limited by (9). MEEHs-main grid exchanged gas formulated as (10) that depends on consumed gas by CHPs in each MEEH.

$$P^{CHP}_{bi,t} = \eta_{chp,e} P^{Gas}_{bi,t} \quad \forall bi,t \tag{8}$$

$$P^{CHP,Min}_{bi} I^{CHP}_{bi,t} \le P^{CHP}_{bi} \le P^{CHP,Max}_{bi,t} I^{CHP}_{bi,t} \quad \forall bi,t \tag{9}$$

$$CE^{Gas}_{cl,t} = \sum_{bi \in cl} P^{Gas}_{bi,t} \quad \forall cl,t \tag{10}$$

where $\eta_{chp,e}$ and $P^{Gas}_{bi,t}$ are consumed gas by CHP in each building and CHP efficiency, respectively. In these equations, $I^{CHP}_{bi,t}$ indicates the operation state of CHP. Further, EESs performance are constrained based on available parameters through Eqs. (11)-(17) [30].

$$0 \le P^{EES,Ch}_{bi,t} \le P^{EES,ChMax}_{bi} I^{EES,Ch}_{bi,t} \quad \forall bi,t \tag{11}$$

$$0 \le P^{EES,Dch}_{bi,t} \le P^{EES,DchMax}_{bi} I^{EES,Dch}_{bi,t} \quad \forall bi,t \tag{12}$$

$$I^{EES,Ch}_{bi,t} + I^{EES,Dch}_{bi,t} \le 1 \quad \forall bi,t \tag{13}$$

$$P^{EES}_{bi,t} = P^{EES,Dch}_{bi,t} - P^{EES,Ch}_{bi,t} \quad \forall bi,t \tag{14}$$

$$C^{EES}_{bi,t} = C^{EES}_{bi,t-1} - (\eta_{dch} P^{EES,Dch}_{bi,t} - \eta_{ch} P^{EES,Ch}_{bi,t}) \forall bi,t \tag{15}$$

$$0 \le C^{EES}_{bi,t} \le C^{EES,Max}_{bi,t} \quad \forall bi,t \tag{16}$$

$$C^{EES}_{bi,0} = C^{EES}_{bi,N_T} \quad \forall bi \tag{17}$$

where $P^{EES,Ch}_{bi,t}$, $P^{EES,Dch}_{bi,t}$ indicate the charge/discharge performance of EESs which are formulated and limited by (11)-(14). C_{es} is the energy capacity of EESs which is modeled and constrained by $C^{EES,Max}_{bi,t}$ and the necessity of its balance at the end and beginning of the operation horizon through (15) -(17). In these equations, $I^{EES,Ch}_{bi,t}, I^{EES,Dch}_{bi,t}$ are the charge/discharge state of EESs.

3) Energy Flexible Building Cluster Indicators

The numerical results of the energy management and scheduling process have been used to calculate indices in this step [6, 31].

- On-site energy ratio (OER)

The ratio between energy supply and energy demand in a cluster of buildings is defined as the on-site energy ratio (OER) formulated in (18) [31].

$$OER_{cl} = \frac{\sum_{bi \in cl,t} BG_{bi,t}}{\sum_{bi \in cl,t} BD_{bi,t}} \tag{18}$$

where $BG_{bi,t} = \sum_{bi \in GB_{PV}} P^{PV}_{bi,t} + \sum_{bi \in GB_{WT}} P^{WT}_{bi,t} + \sum_{bi \in GB_{CHP}} P^{CHP}_{bi,t}$ is the on-site energy generation and $BD_{bi,t} = P^{D}_{bi,t}$ is the on-site electrical load.

- On-site mismatch ratio (OMR)

The difference between demand and energy supply in a cluster of buildings is introduced as the on-site mismatch ratio, which is formulated by (19) [31].

$$OMR_{cl} = \frac{\sum_{bi \in cl,t} BG_{bi,t} - BD_{bi,t}}{T} \tag{19}$$

- Maximum hourly surplus (MHS)

In a cluster of buildings maximum hourly ratio of the difference between on-site generation and load and storage charging or discharge to load is defined as maximum hourly surplus (MHS) is described in (20) [31].

$$MHS_{cl} = \underset{t}{Max}\left[\frac{\sum_{bi \in cl} BG_{bi,t} - BD_{bi,t} - (P^{EES,Ch}_{bi,t} - P^{EES,Dch}_{bi,t})}{\sum_{bi \in cl} BD_{bi,t}}\right] \tag{20}$$

- Maximum hourly deficit (MHD)

In a cluster of buildings maximum hourly ratio of difference between on-site load and generation and storage discharge to load is defined as maximum hourly deficit (MHD) which formulated in (21) [31].

$$MHD_{cl} = \underset{t}{Max}\left[\frac{\sum_{bi \in cl} BD_{bi,t} - BG_{bi,t} + (-P^{EES,Dch}_{bi,t})}{\sum_{bi \in cl} BD_{bi,t}}\right] \tag{21}$$

III. IMPLEMENTATION AND RESULTS

A. Implementation

The proposed clustering approach is implemented in a case study that includes 50 buildings that are equipped with distributed energy resources (DERs) [32]. The proposed clustering approach is formulated as a mixed integer nonlinear programming (MINLP) model and is solved by the standard branch-and-bound (SBB) solver. The proposed energy management model is formulated as a mixed integer linear programming (MILP) problem and is solved by the CPLEX solver. The optimal buildings clustering, organization as a MEEH, as well as energy management scheduling of organized MEEH, is implemented in GAMS (generic algebraic modeling system) software [33]. We have utilized a personal Corei5 laptop with the specification of a 2.5GHz CPU and 4GB of memory to perform the simulations. Four scenarios are examined to investigate the performance of the proposed model as follows:

- **Scenario 1: MEEHs organizing based on geographical locations criteria,**
- **Scenario 2: MEEHs organizing based on PCC criteria,**
- **Scenario 3: MEEHs organizing based on PCC criteria, considering EES**.

B. Results

The numerical results of the energy management and scheduling process are described in this section.

Scenario 1: MEEHs organizing based on geographical locations criteria,

In this scenario, multiple buildings are divided into different clusters or the same MEEHs based on geographical location criteria. Hence, the building in a specific geographic area is categorized in the same cluster. Table I reports the result of Scenario 1. As is evident from Table I, the correlation between the generation and load of buildings divided into the same clusters in this scenario is inadequate.

Scenario 2: MEEHs organizing, based on PCC criteria

In this scenario, multiple buildings are divided into different clusters or the same MEEHs based on the proposed approach which intends to maximize PCC, as described in Table II. Hence, buildings while may not have same geographical locations, can divide into the same clusters or MEEHs. Market-related interconnection of these buildings enables a MEEH operator benefits from the energy flexibility of the buildings in the cluster by the management of the whole cluster. As is evident from Table II, the correlation between the generation and load of buildings divided into the same clusters have acceptable values.

TABLE I. THE RESULTS OF SCENARIO 1.

MEEHs energy management					
Costs ($	Electrical energy (kWh)				
Operation	Imported	Exported	PVs	WTs	CHPs
136.53	3763.47	5000.84	2856.11	1841.14	4320.00
Building clustering and MEEHs organizing					
	MEEH 1	MEEH 2	MEEH 3	MEEH 4	MEEH 5
PCC	-0.519	0.023	0.367	0.305	0.679
Numbers of building	15	5	10	10	10

TABLE II. THE RESULTS OF SCENARIO 2.

MEEHs energy management					
Costs ($)	Electrical energy (kWh)				
Operation	Imported	Exported	PVs	WTs	CHPs
128.7	2391.56	3881.24	2856.11	1841.13	4800.00
Building clustering and MEEHs organizing					
	MEEH 1	MEEH 2	MEEH 3	MEEH 4	MEEH 5
PCC	0.074	0.337	0.614	0.798	0.923
Numbers of building	15	15	10	5	5

Scenario 3: MEEHs organizing based on PCC criteria, considering EES

In this scenario, like Scenario 2, the MEEH are organized to increase PCC to the value of 1, while EESs are utilized as a facilitator tool in this process. As illustrated in Table III, in this scenario, the presence of EES leads to appropriate values for PCC in most of the clusters.

IV. DISCUSSION : TOWARDS FLEXIBLE NET ZERO ENERGY COMMUNITIES

Integration of DERs in buildings energy systems to provide electrical demand locally, enables buildings to operate as net zero energy buildings (NZEBs). NZEBs defines as energy-efficient buildings that are capable in supply their own demand over time through the available renewable resources. However, buildings may be faced whit surplus or additional stored energy, while their own demand has been supplied. In this regard, NZEBs through energy sharing can act as net positive energy buildings (NPEBs) and support other buildings in a cluster in energy balance and help to realize the net zero energy concept on a community scale. Hence, net zero energy communities (NZECs) can be defined as zero energy realization at the community, building cluster, or neighborhood scale [34, 35].

The proposed approach of this paper divides buildings into communities whose generation and demand in the whole of the community have the highest correlation (PCC), and asses its performance to achieve NZECs. This paper proposes clustering based on PCC criteria realize the net zero energy MEEHs community concept. The Pearson correlation coefficient has a number between –1 and 1 that measures the direction of the relationship between two variables A and B. While 0 value indicates no correlation, 1 reports a total positive correlation, and − 1 represents a total negative correlation. A negative correlation value indicates that increasing in variable A coincides with decreasing in variable B, while a positive correlation implies that if variable A increases, then variable B will also be increased [36].

Energy flexible building cluster indicators resulting from different scenarios indicate that organized MEEHs based on PCC criteria resulted in increasing in OER. As the OER index value be closer to one, the community's capability in meeting energy demand through its local generations can be guaranteed more and more. A value of 1 for OER indicates that the energy demand is completely covered by local supply,

TABLE III. THE RESULTS OF SCENARIO 3.

MEEHs energy management					
Costs ($)	Electrical energy (kWh)				
Operation	Imported	Exported	PVs	WTs	CHPs
90.2	2771.57	4449.92	2856.11	1841.13	4800.00
Building clustering and MEEHs organizing					
	MEEH 1	MEEH 2	MEEH 3	MEEH 4	MEEH 5
PCC	0.826	0.946	0.754	0.926	0.846
Numbers of building	15	7	15	8	5

and when OER was bigger than 1 implies that the energy demand in the studied horizon is lower than the energy supply and a net positive energy community is realized. As reported in Table IV, organized MEEH based on the proposed method in Scenarios 2 and 3 have a noteworthy superiority in the OER index, while in Scenario 1, only MEEH 5 has acceptable OER.

OMR can be defined as the average of the mismatch percentages in the studied horizon. This index will have low values when the local supply, which can include stored energy, does not fully meet the demand. However, a more positive value for OMR indicates a lower mismatch in capability energy demand and generations of local energy resources. As reported in Table IV, the OMR index in organized MEEH based on the proposed method in Scenarios 2 and 3 have more positive values which indicate a less mismatch in capability energy demand and generations of local energy resources, while in Scenario 1 MEEH 1-MEEH 4, have considerable weakness in matching energy demand and generations of local energy resources.

The Simultaneous evaluation of OER and MHS volumes can be more beneficial indicate in assessing the ability of the community in matching the demand and supply. High values for both OER and MHS indicate the capability of the community in supplying more than its energy demand, while the low value for OER and high value for MHS indicate that the local energy supply of the community is not optimally scheduled [6, 31]. While OER and MHS index values in Scenario 1 denote nonoptimal scheduling of the local energy resources, relatively high values of both OER and MHS in scenarios 2 and 3 show the ability of the proposed method to optimal Scheduling of MEEHs.

TABLE IV. KEY PERFORMANCE INDICATORS

	On-site Energy Ratio (OER)		
	Scenario 1	**Scenario 2**	**Scenario 3**
MEEH 1	0.745	0.753	1.3
MEEH 2	0.774	1.876	1.472
MEEH 3	0.687	0.617	0.851
MEEH 4	0.683	1.628	1.735
MEEH 5	3.402	1.496	0.963
	On-site Mismatch Ratio (OMR)		
	Scenario 1	**Scenario 2**	**Scenario 3**
MEEH 1	-6.56	-6.75	8.759
MEEH 2	-1.381	19.358	5.042
MEEH 3	-5.619	-6.549	-3.223
MEEH 4	-5.323	5.166	5.48
MEEH 5	31.772	4.293	-0.54
	Maximum Hourly Surplus (MHS)		
	Scenario 1	**Scenario 2**	**Scenario 3**
MEEH 1	5.238	1.84	2.799
MEEH 2	3.026	4.749	9.102
MEEH 3	1.643	0.728	4.198
MEEH 4	1.593	8.973	9.591
MEEH 5	7.009	5.467	4.409
	Maximum Hourly Deficit (MHD)		
	Scenario 1	**Scenario 2**	**Scenario 3**
MEEH 1	0.967	0.941	0.419
MEEH 2	1	0.507	0.393
MEEH 3	1	0.925	0.822
MEEH 4	1	0.288	0.247
MEEH 5	0	0.223	0.657

The MHD value can be mentioned as the maximum ratio of the difference in load and on-site generation including energy retrieved from local storage to cover the load. As much as the MHD value is closer to 1 this indicates that in the scheduling horizon, there are hours for which more percentage of demand cannot be covered through on-site generation and storage. The resulting value for MHD indices in Scenario 1 illustrates that in MEEH 2-MEEH 3 in some hours there is a significant weakness in meeting demand through on-site generation and storage. However, in Scenarios 2 and 3 MHD values have been significantly reduced and have acceptable values.

Furthermore, as illustrated in Fig. 2 and 3, as the average value of PCC in clusters increases in different scenarios, the collective operation cost of the MEEHs is decreased, respectively. This indicates that the proposed method also can result in more efficient energy management for MEEH economically.

V. CONCLUSIONS

From the energy system point of view, in the literature in addition to located buildings in the same areas, buildings owned by a single person or set of occupants although they are not located in the same area can be identified as a cluster. Further, market-related interconnection enables a common company or operator benefits from the energy flexibility of the buildings in the cluster by the management of the whole cluster. In this regard, in this paper, an optimization-based clustering approach is proposed to determine which type of buildings should form a cluster or a MEEH managerial framework. The proposed clustering algorithm divides

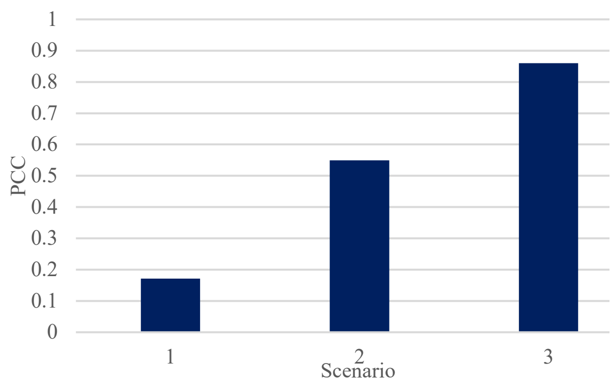

Fig. 2. PCC in different scenarios.

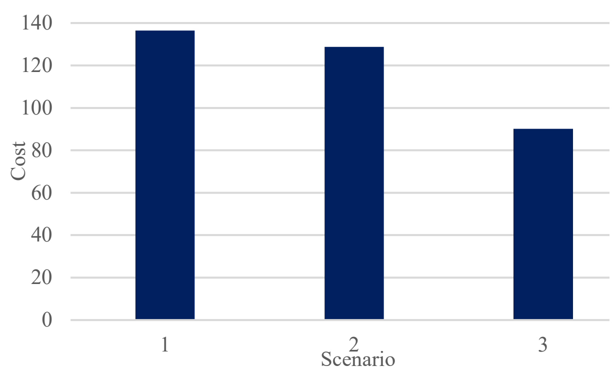

Fig. 3. Operation costs in different scenarios.

multiple buildings into different clusters based on building cluster PCC. The proposed approach aims to increase the PCC between the energy generations and demands of buildings that are divided into a building cluster MEEH. The numerical results show that the proposed approach implementation besides PCC has led to significant improvements in OER, OMR, MHS, and MHD as energy flexible building cluster indicators. The proposed method also can result in more efficient energy management for MEEH economically. In brief, the proposed approach can considerably facilitate the walking path towards NZECs.

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