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Distributed Urban Energy Systems (Urban Form, Energy and Technology, Urban Hub)

A review study of the current research on energy hub for energy positive neighborhoods

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Abstract

Energy positive neighborhoods and cities are emerging concepts aimed at addressing the current energy and environmental sustainability challenges. In this paper, the concept and current research on energy hubs relating to energy positive neighborhoods are presented. In addition to discussing advantages and challenges of energy positive neighborhoods and energy hubs, opportunities for future research and development are also conversed.

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Keywords: Review; Buildings; Energy positive; Energy hub; Multi-energy carriers; Neighborhoods;

1. Introduction

With the depletion of fossil fuels and the issue of global warming, people try to integrate different forms of energy sources into the energy grids. The aim of doing so is to confront these problems and to move towards a sustainable future. These modifications change the currently centralized energy grids into distributed infrastructures. As a result of the use of different forms of energy sources, the future energy network will comprise of more intense integration of different energy carriers than electricity, gas and oil. In order to accommodate these changes, new

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research concepts try to integrate and hybridize different energy carriers (natural gas, oil, hot water, hydrogen, electricity etc.) to devise smart energy systems with the ability of interoperability.

Buildings are a major aspect that should be focused on, in terms of energy usage in the distributed energy grids. Buildings will play a vital role in the future smart energy grids with changing energy policies and targets. The "*International Energy Agency*" states that demand side activities should be a priority in energy policies and decisions regarding sustainable energy systems [1]. Apart from the collective sustainable energy targets, each country has their own building related energy goals. For example, according to the "*Energy Performance Building Directive*" all new buildings will be required to be nearly zero energy by 2021 for member states of the EU [2,3].

However, the energy dynamics of buildings cannot be fully analyzed when they are considered as isolated single units. They are always connected with several outside systems. Therefore, it is beneficial to consider the buildings with their connected systems as a collective unit at the neighborhood level [4] and achieve energy neutrality/positivity at the neighborhood level. With the distribution/decentralization of the energy grids, the neighborhood can be seen as a whole with local supply, demand and local energy management. The complexity of the local energy management systems increases with the number of energy sources, storage units integrated, and the demand requirements in the neighborhood. Therefore, optimal coordination of these separate systems is crucial.

Energy hub and smart building clusters are two research concepts that can be found in the literature for optimal coordination and energy management at the neighborhood level. Authors of [5] indicate that in the literature, the first attempt of a bi-level operation decision framework using the building cluster concept can be found in the year 2012 [6] while the energy hub was introduced in the year 2007 [7]. Yet, concepts which give attention to the energy management at the neighborhood level with a futuristic view on multi-carrier energy grids and achieving energy positivity at the neighborhood level are still lacking. Therefore, the aim of this paper is to review research papers on energy hubs and identify the potential of this concept to realize energy positive neighborhoods. The first section of the paper gives an introduction to energy hubs. This is followed by the review study. Finally, an approach to achieve energy positivity at the neighborhood level with this concept and the challenges hindering the practical realization of energy hub are discussed.

Nomenclature

BEMS	Building Energy Management System	IT	Italy
SW	Switzerland	CN	Canada
IR	Iran	NW	Norway
CH	China	US	United States of America
EPN	Energy Positive Neighborhood	GAMS	General Algebraic Modeling System
ICT	Information and Communication Technology	EU	European Union

1.1. Energy Hub

The concept of Energy Hub can be defined as a central point where multiple energy carriers meet each other and respective energy flows can be converted, conditioned, stored and finally distributed according to the demand requirements in an optimal manner [7,8]. The modeling concept of an energy hub describes the relation between input and output energy flows and can be used to optimize the energy consumption during planning and operation. Authors of [9] equate this to a flexible interface between different energy infrastructures.

It is a possibility that the energy carriers exist today will be diversified into different forms in the future. The energy hub concept could still be used even if the forms of energy carriers change over time. Fig. 1 illustrates an energy hub composite of different energy carriers. After an optimal coordination between supply and demand, it provides different demand requirements at the output.

This concept can be designed in different spatial scales according to the resources available and the level of complexity needed. In [10–12] authors have conducted their research for a residential energy hub model aimed at a smart home with residential combined heat and power (CHP) unit as a cogeneration technology and using plug-in hybrid electric vehicles. In [13] the authors discuss the importance of integrating and managing energy from renewables at the neighborhood level using a village in Switzerland as the study case. They have used the energy hub concept to optimize the energy flows between inputs and outputs and thereby reduce the energy consumption. Different scenarios have been applied by the authors for the village with a futuristic view on getting rid of the fossil fuel energy carriers. This explains the capability of the energy hub concept at different spatial levels.

The next important point to consider is the support of energy hubs for large scale renewable energy sources integration, reducing system losses and greenhouse gas emissions. Reduction of energy system losses is obtained by properly coordinating, optimizing and managing the different energy carriers [9,14]. Hierarchical optimization with distributed energy hubs used by the authors of [9] is a noteworthy approach for neighborhood energy management.

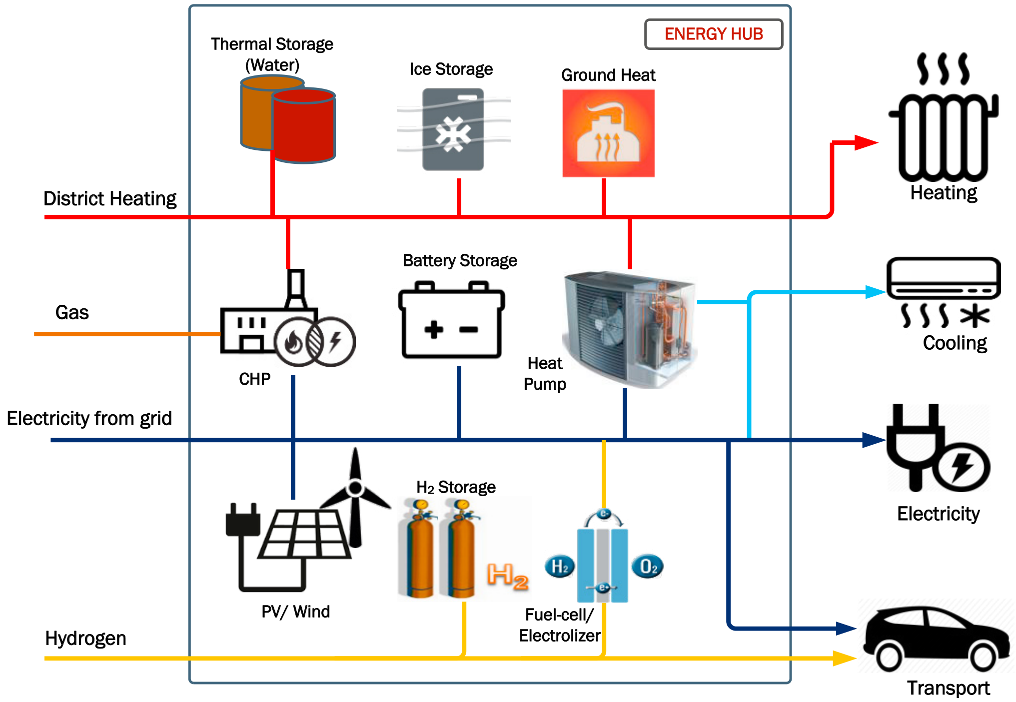

Fig. 1: A detailed illustration of an energy hub

2. Methodology

In the literature, more than 3000 research materials can be found for the keyword "*Energy Hub*" using the search engines Scopus and Web of Science. From these articles, in this paper, only the research materials that can be used to realize the concept energy positive neighborhoods are discussed. Out of the resulting 3000 papers, further filtering is undertaken using the keywords "*building OR neighborhood energy management*", the number of documents being reduced to a little above 150. From them, articles related to ICT infrastructures, electricity markets, only modeling and optimization and materials related to business management were removed. Finally, about 20 articles were chosen and those articles were found to be in line with the objective of this paper. In addition, other relevant publications by known authors or found through references were also reviewed. Table 1 shows the structure of article search.

Table 1. Article search

Search Engine	Search Term	Search date	Number of articles
Scopus	Energy hub	20-03-2017 (All articles)	3269
	Energy hub and Building		417
	Energy hub and (Building or neighborhood)		203

	Limited to subject area Energy and Engineering		161
	Limited to keywords: Energy hub/ buildings/ office buildings/ commercial buildings/ energy management/ neighborhood		42
Web of Science	Energy hub	20-03-2017 (All articles)	1698
	Energy hub and Building		105
	Energy hub and Building and neighborhood		2

2.1. Assessment of the research articles

Table 2 shows the selected articles and the evaluation of the articles according to the scale, use of renewable energy sources, use of storage systems, tools used in each article to realize their objectives and the variety of case studies used. A comprehensive research on available tools for district level energy research can be found in [15].

Table 2. Assessment of the articles

Article	Country/year	Scale	Renewable Energy sources	Conversion technologies	Storage systems	Tools	Case Study
[10]	IR / 2015	Neighborhood	×	✓	×	-	Several residents
[11]	IR / 2014	Building	×	✓	✓	-	Smart home
[12]	IR / 2015	Building	✓	✓	✓	-	Smart home
[14]	IR-CN / 2015	Building cluster	×	✓	×	GAMS - CPLEX	School-shop-residential complex / Resident-food distribution center
[16]	IT / 2009	Building	✓	✓	×	DOE-2	Hotel
[17]	IT / 2009	Building	✓	✓	×	Energy Plus	Multi-family building
[18]	IT / 2011	Building	✓	✓	×	Excel tool/ MS solver Energy Plus	Large Commercial building
[19]	CN / 2012	Building	✓	✓	✓	AMPL-CPLEX 12.1/ GLPK 4.38	Resident
[13]	SW / 2014	Neighborhood	✓	✓	×	CitySim	Village
[20]	SW / 2014	Neighborhood	✓	✓	✓	Energy Plus	Village
[21]	SW / 2015	Building cluster	✓	✓	✓	Matlab/ CPLEX	Exhibition Center
[22]	IR / 2014	Building	✓	✓	✓	CPLEX	Resident
[23]	SW / 2015	Building cluster	✓	✓	×	CitySim	Campus
[24]	NW / 2015	Building	×	✓	×	FICO Xpress	University College building
[25]	IR / 2015	Building	✓	✓	✓	Matlab	Resident
[26]	CH / 2015	Neighborhood	-	-	-	-	Harbor industrial park
[27]	US / 2016	Neighborhood	×	✓	×	Matlab	University campus
[28]	IR -CN/ 2016	Building cluster	✓	✓	✓	GAMS - CPLEX	Residential complex-restaurant-office-commercial building
[29]	US / 2016	Building	✓	✓	✓	GAMS - CPLEX	Resident
[30]	SW / 2017	Neighborhood	✓	✓	✓	Energy Plus/ CPLEX	Residential community

3. Results

Results from the reviewed studies emphasized the importance of two major segments. First, it is vital to define a clear boundary for the neighborhood because it is treated as one unit with demand, local supply and storage. Treating demand and supply simultaneously is more important than handling them sequentially to have a better understanding of demand-supply matching. Modeling time interval is a major concern when using storage systems to impose some flexibility to the system. Second, when defining future scenarios for neighborhood energy systems, not only the infrastructure changes with different energy carriers, but also the improvements on buildings, (such as retrofitting of windows, walls, ceilings) need to be anticipated. Subsequently, an overall efficiency improvement in the selected neighborhood is attained.

4. Discussion

To realize energy positivity at neighborhood level the following approach could be taken.

1. Reduce consumption at dwelling level;
2. Increase local level supply options with renewable sources and increase efficiency of multicarrier energy systems;
3. Increase flexibility with storage and energy conversion possibilities at the neighborhood level;
4. Optimize supply energy flows and demand at the neighborhood level.

The mentioned approach is likely to be accomplished using the energy hub concept. A two-level optimization is recommended for the approach: at the building level and the neighborhood level interconnecting the residential level micro energy hubs and the higher (macro) level neighborhood energy hub. According to the reviewed papers, the hierarchical optimization with distributed energy hubs has the advantage of separately realizing the objectives of customers and utility providers. At micro hub level, the objective is to optimize energy consumption and to reduce energy bills to the customers. The target at the macro level is to optimize cumulative demand response of the cluster of buildings in the neighborhood and to reduce CO_2 emissions. This is the main objective of the utility providers. Incorporation of demand side management in the energy hub is also a possibility as outlined by authors in [31,32].

5. Conclusion

Even though there exist numerous studies on the Energy hub concept, a number of barriers block their practical realization. At the neighborhood level, the main difficulties are regulation and technical barriers. Most prominent are the regulation barriers which deal with the efficiency of the market. Not all the participants are interested in the EPN principal. Some participants have their own goals to reach, such as profit realization. Moreover, consumers are not willing to compromise and behavioral change is a huge problem. The fact that researchers do not have access to correct data and a lack of useful data are some of the main issues that can be categorized as technical barriers when realizing these concepts in general.

In future research, the concept of energy hub will be applied to a neighborhood including residential and commercial buildings and for a more complex situation like a hospital. The aim is to use the energy hub concept with a futuristic view on the changes of the energy grids and to achieve energy positivity at the neighborhood level.

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References

[1] IEA, Strategic Plan, (n.d.). http://www.ieadsm.org/wp/files/3.New_Strategy_2014-2019.pdf (accessed March 20, 2017).
[2] New buildings | BPIE - Buildings Performance Institute Europe, (n.d.). http://bpie.eu/focus-areas/new-buildings/ (accessed April 12, 2017).

[3] COMMISSION RECOMMENDATION (EU) 2016/ 1318 - of 29 July 2016 - on guidelines for the promotion of nearly zero-energy buildings and best practices to ensure that, by 2020, all new buildings are nearly zero-energy buildings, Comm. Recomm. (2016). http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016H1318&from=FR (accessed April 12, 2017).
[4] A. Monti, D. (Dirk) Pesch, K.A. Ellis, P. Mancarella, Energy positive neighborhoods and smart energy districts : methods, tools and experiences from the field, n.d.
[5] R. Dai, M. Hu, D. Yang, Y. Chen, A collaborative operation decision model for distributed building clusters, 84 (2015) 759–773. doi:10.1016/j.energy.2015.03.042.
[6] M. Hu, J.D. Weir, T. Wu, Decentralized operation strategies for an integrated building energy system using a memetic algorithm, 217 (2012) 185–197. doi:10.1016/j.ejor.2011.09.008.
[7] M. Geidl, G. Koeppel, P. Favre-Perrod, B. Klöckl, G. Andersson, K. Fröhlich, Energy hubs for the future, IEEE Power Energy Mag. 5 (2007). doi:10.1109/MPAE.2007.264850.
[8] M. Geidl, G. Andersson, Optimal coupling of energy infrastructures, in: 2007: pp. 1398–1403. doi:10.1109/PCT.2007.4538520.
[9] M. La Scala, A. Vaccaro, A.F. Zobaa, A goal programming methodology for multiobjective optimization of distributed energy hubs operation, Appl. Therm. Eng. 71 (2014) 658–666. doi:10.1016/j.applthermaleng.2013.10.031.
[10] M. Rastegar, M. Fotuhi-Firuzabad, H. Zareipour, Centralized home energy management in multi-carrier energy frameworks, in: Institute of Electrical and Electronics Engineers Inc., 2015: pp. 1562–1566. doi:10.1109/EEEIC.2015.7165404.
[11] M. Rastegar, M. Fotuhi-Firuzabad, M. Lehtonen, Home load management in a residential energy hub, Electr. Power Syst. Res. 119 (2015) 322–328. doi:10.1016/j.epsr.2014.10.011.
[12] M. Rastegar, M. Fotuhi-Firuzabad, Load management in a residential energy hub with renewable distributed energy resources, Energy Build. 107 (2015) 234–242. doi:10.1016/j.enbuild.2015.07.028.
[13] K. Orehounig, R. Evins, V. Dorer, J. Carmeliet, Assessment of Renewable Energy Integration for a Village Using the Energy Hub Concept, Energy Procedia. 57 (2014) 940–949. doi:10.1016/j.egypro.2014.10.076.
[14] A. Maroufmashat, A. Elkamel, M. Fowler, S. Sattari, R. Roshandel, A. Hajimiragha, S. Walker, E. Entchev, Modeling and optimization of a network of energy hubs to improve economic and emission considerations, Energy. 93 (2015) 2546–2558. doi:10.1016/j.energy.2015.10.079.
[15] J. Allegrini, K. Orehounig, G. Mavromatidis, F. Ruesch, V. Dorer, R. Evins, A review of modelling approaches and tools for the simulation of district-scale energy systems, 52 (2015) 1391–1404. doi:10.1016/j.rser.2015.07.123.
[16] E. Fabrizio, M. Filippi, J. Virgone, An hourly modelling framework for the assessment of energy sources exploitation and energy converters selection and sizing in buildings, Energy Build. 41 (2009) 1037–1050. doi:10.1016/j.enbuild.2009.05.005.
[17] E. Fabrizio, V. Corrado, M. Filippi, A model to design and optimize multi-energy systems in buildings at the design concept stage, 35 (2010) 644–655. doi:10.1016/j.renene.2009.08.012.
[18] M. Bayraktar, E. Fabrizio, M. Perino, The extended building energy hub: A new method for the simultaneous optimization of energy demand and energy supply in buildings, in: 2012: pp. 67–87. doi:10.1080/10789669.2011.588300.
[19] M.C. Bozchalui, S.A. Hashmi, H. Hassen, C.A. Canizares, K. Bhattacharya, Optimal Operation of Residential Energy Hubs in Smart Grids, IEEE Trans. Smart Grid. 3 (2012) 1755–1766. doi:10.1109/TSG.2012.2212032.
[20] K. Orehounig, G. Mavromatidis, R. Evins, V. Dorer, J. Carmeliet, Towards an energy sustainable community: An energy system analysis for a village in Switzerland, 84 (2014) 277–286. doi:10.1016/j.enbuild.2014.08.012.
[21] G. Beccuti, T. Demiray, M. Batic, N. Tomasevic, S. Vranes, Energy hub modelling and optimisation: an analytical case-study, in: 2015 IEEE Eindhoven PowerTech, IEEE, 2015: pp. 1–6. doi:10.1109/PTC.2015.7232413.
[22] F. Brahman, M. Honarmand, S. Jadid, Optimal electrical and thermal energy management of a residential energy hub, integrating demand response and energy storage system, 90 (2015) 65–75. doi:10.1016/j.enbuild.2014.12.039.
[23] S. Coccolo, J. Kaempf, J.-L. Scartezzini, The EPFL Campus in Lausanne: New Energy Strategies for 2050, Energy Procedia. 78 (2015) 3174–3179. doi:10.1016/j.egypro.2015.11.776.
[24] S.O. Ottesen, A. Tomasgard, A stochastic model for scheduling energy flexibility in buildings, 88 (2015) 364–376. doi:10.1016/j.energy.2015.05.049.
[25] M. Rayati, A. Sheikhi, A.M. Ranjbar, Optimising operational cost of a smart energy hub, the reinforcement learning approach, 30 (2015) 325–341. doi:10.1080/17445760.2014.974600.
[26] X. Tian, R. Zhao, Energy network flow model and optimization based on energy hub for big harbor industrial park, (2015) 298–303. doi:10.2112/SI73-052.1.
[27] M.R. Almassalkhi, A. Towle, Enabling city-scale multi-energy optimal dispatch with energy hubs, in: Institute of Electrical and Electronics Engineers Inc., 2016. doi:10.1109/PSCC.2016.7540981.
[28] T. Falke, S. Krengel, A.-K. Meinerzhagen, A. Schnettler, Multi-objective optimization and simulation model for the design of distributed energy systems, Appl. Energy. (2016). doi:10.1016/j.apenergy.2016.03.044.
[29] I. Sharma, J. Dong, A.A. Malikopoulos, M. Street, J. Ostrowski, T. Kuruganti, R. Jackson, A modeling framework for optimal energy management of a residential building, Energy Build. 130 (2016) 55–63. doi:10.1016/j.enbuild.2016.08.009.
[30] R. Wu, G. Mavromatidis, K. Orehounig, J. Carmeliet, Multiobjective optimisation of energy systems and building envelope retrofit in a residential community, Appl. Energy. 190 (2017) 634–649. doi:10.1016/j.apenergy.2016.12.161.
[31] I. Sharma, C. Canizares, K. Bhattacharya, Residential micro-hub load model using neural network, in: Institute of Electrical and Electronics Engineers Inc., 2015. doi:10.1109/NAPS.2015.7335091.
[32] M. Batí, N. Tomaševí, G. Beccuti, T. Demiray, S. Vraneš, Combined energy hub optimisation and demand side management for buildings, Energy Build. 127 (2016) 229–241. doi:10.1016/j.enbuild.2016.05.087.