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A Review of District-scale Energy Performance Analysis: Outlooks towards Holistic Urban Frameworks

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Abstract

Over the past few decades, the world has experienced a major population shift towards urban areas resulting in environmental degradation and increased energy consumption. To combat these challenges, energy efficiency measures are being deployed to improve the performance of different entities within urban built environments. However, effective implementation of such measures often requires a holistic approach to account for existing interrelated and complex relationships between entities at the urban scale. This paper presents a distillation of salient facts and approaches for energy performance evaluation of districts. The studies are reviewed in three sections; (1) concepts defining district energy performance, (2) approaches and methodologies for district energy performance evaluation and (3) system interactions between district entities. The state of the art review reveals that several challenges exist in the initial stages of energy performance assessment of districts. The suggested framework in this paper addresses this issue through pre-processing of data related to entities such as transportation systems and buildings. The framework classifies the available information under three potential categories, namely, 'Subject and Scope', 'Input Data Management' and 'Methods'. This categorisation results in easier integration of multidisciplinary aspects of entities involved in district energy performance assessment.

Keywords: Districts, Energy, Built environment, Planning Process, Performance

1 Introduction

Urban environments have grown at a remarkable rate and the world has experienced a major population shift from rural to urban areas. Cities account for approximately 75% and 80% of world's energy consumption and greenhouse gas emissions respectively, even though they occupy only 2% of the total world's surface [1]. Furthermore, the construction and operation of buildings contribute towards a large proportion of total energy end-use [2,3]. Fossil fuels are known as one of major contributors to greenhouse gas emissions, considerably affecting quality of life. To reduce the overall energy consumption and thereby greenhouse gas emissions, energy efficiency measures are being implemented worldwide. Alongside, existing energy systems are being transformed to increase the penetration of renewable energy sources [4–7].

Energy performance evaluation of buildings has experienced a major boost over the past decade as advanced techniques and methodologies are being developed. Since, the building sector accounts for a noticeable part of overall energy consumption and greenhouse gas emissions [8], many studies have developed approaches to evaluate the environmental impacts of existing buildings as well as new constructions. For instance, the “Nearly Zero Energy building (NZEB)” approach is becoming quite popular and generally implements scenarios for balancing the consumption and production of energy, especially through compensating energy use by renewable resources [9]. Alongside, new policy measures have come into practice to raise the existing energy standards of buildings [10].

In the current modelling domain, districts are usually modelled as consisting of one or two subsystems, often neglecting the interdependencies involved [10]. However, districts are composed of several subsystems where accurate and effective models need to consider the different subsystems together such as buildings and transportation systems [11]. Consequently, a comprehensive framework is required to use the district level models as an intermediary that would fill the gap between the modelling of entire city and individual elements and integrate all the components for energy performance analysis.

This study presents a literature review of key findings/research gaps, methodologies, results and further research suggestions in energy performance analysis of the built environments. Moreover, investigating upon academic literature and successful experiences, the paper reviews the role of different factors influencing the evaluation of energy performance at district/neighbourhood scale. The review reveals various challenges and constraints in different steps of the evaluation process with a critical role in the early stages of energy assessment process such as gathering required data for defining scope or determination of effective parameters in various methodologies. To address this gap, a framework is proposed to integrate the overall process through pre-processing of various categories of required information and actions related to relevant components of districts.

To entail a deeper understanding of the existing literature, section 2.1 discusses the concept definition of energy performance indicators employed at the district/neighbourhood scale. Section 2.2 discusses the significant approaches towards achieving the optimal solution in energy analysis with environmental, economic and social objectives. Effective components of energy performance in built environments are introduced in section 2.3. And finally, a theoretical framework is proposed in section 3 to address the difficulties which may occur in the early stage of analysis. This framework determines three main issues; first considering the precise and clear definition of subject and its scope, second, defining different types of input data which should be gathered and finally making decision towards the effective methods to handle the interactions and effects of these inputs.

2 Literature Review

2.1 Concept Definition

Energy performance analysis includes a wide spectrum of research areas in which different disciplines focus on the energy domain through specialised approaches and methodologies. Concepts such as “zero energy” have been applied in the existing literature to determine different aspects of energy performance in the built environment. In addition, the scale of the built environment also offers a stark separation between these definitions. Defining the metrics such as scale or approach is necessary to specify the subject and scope of energy performance studies. Considering these different dimensions, a short review of the zero energy building concept is presented in section 2.1.1. Section 2.1.2 highlights the issues related to scale evolution from buildings to districts. The key concepts of zero energy districts/neighbourhoods are discussed in Section 2.1.3.

2.1.1 *Zero Energy Building*

The most commonly articulated basis for zero energy definition is the compensation of the annual energy demand with renewable energy sources based on social and political characteristics of contexts and the availability of technology [12–17]. The European Energy Performance of Buildings Directive Recast (EPBD) has introduced “nearly zero-energy building” as a “building that has a very high energy performance where the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby” [18]. Torcellini and Crawley proposed four basic elements for balancing energy in buildings, namely, primary energy, site energy, cost and emissions [13]. Sartori et al. developed a systematic framework for “net zero-energy buildings” which considers the purposes and political targets that lay behind those purposes [12]. In this framework, the “net zero-energy buildings” are defined through the concept of import/export balance with emphasis on the exchanged energy flows between individual buildings and the grid to provide load match over different time steps [12].

2.1.2 *Scale Evolution*

Buildings as one of the lower level entities in the built environment are affected by the plans and frameworks of higher aggregated entities such as districts, cities and countries [19–21]. As buildings are the end-use entities in the energy flow process, they determine the energy usage patterns [22–24]. Although building assessment is considered as an essential stage in assessing the energy performance of built environment, focusing solely on such assessments may lead to unreliable results.

On the other hand, due to the cooperation at international level through policies and conferences such as “Rio de Janeiro Earth Summit” and “Our Common Future” [25], studies at mega-scales, world and country, have attracted more attention and budget in recent years [26,27]. These mega-scale studies integrate different data categories including building geometry, consumption patterns, generation profiles etc., which often result in conflict, ambiguity and uncertainty. Additionally, general findings from the mega-scale studies should be validated before the implementation at smaller scales. In this regard, an intermediate scale is required to handle the shortcomings of the modelling procedures at these two scales, i.e., building and mega-scales. Neighbourhood/district level is regarded as an appropriate scale, incorporating all the necessary components as well as providing means for the verification of results [28,29]. This scale facilitates the application of optimization tools with the goal to improve the energy performance and minimize the cost for energy infrastructure [30].

Figure 1- Number of papers published in Scopus database for the considered scales of buildings and districts with energy-related subjects.

The review of past literature demonstrates that although a limited number of studies exist at neighbourhood or district scale, the growing interest in this domain has been significant. Searching the databases can affirm this evolutionary trend. The Scopus database was chosen to perform an extensive search for the two scales, building and district, with similar keywords. To facilitate the search process, two categories were defined, first category (1) for buildings and second category (2) for a larger scale. Two criteria were applied to improve the results of the search attempts: first, filtering the results by excluding the irrelevant subject areas (for instance Biochemistry) and second, limiting the results to journal and review papers and omitting the conference papers. In the first run for category 1, by using keywords, *energy or zero and building*, 6031 papers were found published between 1954 and 2016. 66% of these papers were published after 2010, confirming the fact that interest in this study field is growing at a fast pace in this decade. For category 2, 1994 papers were found after applying the filters. The number of search results is significantly less than category 1. A similar pattern for both categories points out that the interest for studying energy performance in the built environment is growing and hence affirming that this field has a great potential for future research (Fig. 1). The important concepts to define energy performance at district scale are outlined in Section 2.1.3.

2.1.3 Zero Energy Districts

Urban settlements spatially comprise smaller units, for instance, districts or neighbourhoods [31]. There are different definitions for concepts such as neighbourhoods and districts based on researchers' points of view and approaches. Hallman defines a "neighbourhood" as combinations of "geographical boundaries, ethnic or cultural characteristics of the inhabitants, psychological unity among people who feel that they belong together, or concentrated use of an area's facilities for shopping, leisure and learning" [32]. Barton with focus on spatial aspects, considers neighbourhood as "an area of distinctive identity, normally named, which may coincide with either a local catchment area or/and an environmental area, and is geared towards pedestrian/cyclist access" [33]. "Districts" are usually regarded as one of the fundamental organizing elements of new urban planning theories [34]. Urban districts might be formed of 4-5 neighbourhoods and their primary activity is supported by typically neighbourhood-scale uses [35].

Since the 21st century, planners and environmentalists have defined initiatives to pave the way for sustainability assessment at the neighbourhood scale [36–40]. Zero energy district is one of the important concepts in this domain and has been broadly researched. This section categorises the “zero energy district” concept based on three major features; scale, theoretical-practical, and finally benefits-constraints. The most cited references constitute a combination of all these three categories (Fig. 2). Sections 2.1.1 and 2.1.2 state the first feature, Scale, in details. The remaining two features are discussed in the following section.

A-Theoretical-Practical

The theoretical studies mainly concentrate on developing the framework definitions and thereby, casting a foundation for practical implementation [39,41,42]. In this regard, a significant body of literature such as review papers provide theoretical definitions of zero energy built environments based on the practical and theoretical orientations (Fig. 2). A study by Carlisle et al. (2009) summarises the different zero energy definitions for the individual buildings [43]. Sartori et al. applied the concept of zero energy to a cluster of buildings to present a possible framework for balance between weighted demand and supply based on the quantities that are of interest and available [12]. Another study by Kennedy and Sgouridis proposes a framework to define the carbon-neutral urban development using hierarchical emission categories including internal emissions depending on the geographical boundary, external emissions by core municipal activities, and internal-external emissions of non-core activities [44].

As far as practical implementation is concerned [45–53], the United States Department of energy (DOE) has classified the zero energy definitions based on the differences between end-use sectors and the function of the each place, for instance, function-specific definitions for residential communities or campuses [54]. Another definition for “zero energy community” (ZEC) by “National Renewable Energy Laboratory” [43], combines energy efficiency methodologies and renewable energy applications for thermal and electrical end-uses. The green district is one of the leading concepts with a focus on the environmental impacts of energy consumption [55]. A study by Bouton et al. has affirmed the growing opportunities and interests in green districts [56].

One of the prominent projects in this domain is Leadership in Energy and Environmental Design-Neighbourhood Development (LEED-ND) rating system, which comprehensively considers the sustainability concept [56]. In Europe, according to “European Performance of Buildings Directive” (EPBD), all new buildings have to meet the requirements of “nearly zero-energy” buildings (NZEB) by 2020 [57]. These attempts will result in CO₂ emission reduction by 50%, energy systems cost reduction by 15% and energy usage reduction by 30% [58]. Beddington Zero Energy Development (BedZED) for sustainable neighbourhood is considered to be the UK’s largest mixed-used zero-carbon community [59]. Also, the West Village in Davis, California is a working example of zero energy community in the US [60]. Previous and ongoing projects in this domain have been well documented by the International Energy Agency’s Energy in Buildings and Communities Programme (IEA-EBC) to increase the dissemination of information at a global level [61]. The European Commission has invested in an international research project, Ecocity, which aims to develop a sustainable framework for seven countries with specific legislative, socio-cultural, economic and climatic conditions [62].

B-Benefits-Constraints

Working at the neighbourhood scale involves significant benefits and poses numerous constraints as discussed briefly in this section (Fig. 2). Although studies have considered cities as an aggregation of disconnected energy consumer units, cities often consist of complex subsystems with varied energy performance metrics. A study by Choguill aptly concludes that “no single city can contribute to the overall sustainability if its own components are found not to be sustainable” [36]. In fact, neighbourhoods are regarded as an intermediate scale to fill the gap between the entire city and individual elements [63] and are often regarded as the backbone of cities [11]. Neighbourhood-scale studies add on to the results of individual building analysis, especially in the implementation of energy management [36] and to identify energy supply and demand patterns [64]. Additionally, problems at the micro scale arise due to poor planning at the macro scale, which deems it mandatory to define principles at the neighbourhood scale to prevent further inconsistencies and dilemmas at other scales [65]. Consequently to acknowledge these benefits, more focus is required to develop assessment frameworks and tools for this scale [66].

The benefits of working at district level incorporate various economic, social and environmental aspects of sustainability concept [10,64,66]. Zero energy districts result in economic growth especially through national policies in long term outlooks; for instance, governments can push national energy targets by district scale policies or intensify their optimal national outcomes by district scale interventions [67–70]. Furthermore, these practices enhance community participation in neighbourhood planning [67,71–73] and address the macro scale problems such as macroeconomic prospective, regional accessibility, low carbon cities and power and energy supply and generation [11,36,63,64,68,74]. Many studies, as presented in Fig. 2, have highlighted the benefits and constraints of analysis at district level.

Figure 2- Different aspects of energy analysis definitions of built environments based on their Scales, Types and Constraints and Benefits. Each circle shows a reference with focus on that specific aspect.

However, working at district scale involves difficulties due to the existence of varied sub-systems, their interdependencies and direct/indirect impacts on overall energy performance [75]. Site specific characteristics such as financial context, technological aspects, society, policy, and legal frameworks

and on-site conditions such as existing buildings, infrastructure and landscape can create constraints as well as opportunities for planning, which makes the neighbourhood scale more complex to work with. The most important constraints include financial limitations [76,77], implementation of theories and plans [66,71,76,78–80], different user patterns [81–84], and finally multiple goals and priorities, which may result in conflicting interests [30,42,85,86].

2.2 Performance Evaluation Approaches

Numerous approaches have been devised for energy performance evaluation of districts. Such approaches tend to identify optimal scenarios for energy usage based on their initial themes and objectives. However, due to the various kinds of available data relating to districts, it is necessary to specify a set of classification metrics to define the main theme and objectives of energy performance analysis. The following section reviews the predominant objectives of district energy performance approaches including social, economic and environmental aspects (Fig. 3).

Figure 3- Existing approaches for energy performance analysis of districts classified based on social, economic and environment factors

2.2.1 Environmental Aspect

Improper use of the existing resources and increased population rate has led to growing environmental concerns over the past century [87] resulting in increased CO₂ emissions from both the building and transportation systems [10,12]. Such environmental concerns have led to establishment of policy frameworks such as Strategic Environmental Assessment (SEA) and Sustainability Assessment (SA) for assessment of projects impacts in different countries [88]. After the introduction of National Environmental Policy Act (NEPA) in 1969 as the main United States environmental law, there was a growing interest for evaluating the consequences of projects through Environmental Impact Assessment (EIA) tools [89,90]. Initially, the EIA approach focussed on human impacts of the environment, which was further complemented with inclusion of social and economic factors. Most of these methods provide sets of criteria to assess the existing condition of the environment and further develop appropriate guidelines for planners and local stakeholders. Sharifi categorised the existing

EIA approaches into two groups based on the target scale: (1) buildings and (2) neighbourhoods [72]. The latest generation of impact assessment tools such as Neighbourhood Sustainability Assessment (NSA) do not just focus on “zero-energy” objectives but also cover the environmental, social and economic aspects of sustainability [91,92].

BRE Environmental Assessment Method (BREEAM) was introduced as a pioneer building assessment method in 1990s in the UK and provided an independent, third-party standard assessment certification for neighbourhoods [72]. LEED-ND introduced by Green Building Council is considered as one of the most reliable sustainability indices worldwide [93]. Sustainability Tools for Assessing and Rating (STAR) communities provide a broad range of socio-economic topics that define sustainability at the community level [94]. In addition, Comprehensive Assessment System for Built Environment Efficiency (CASBEE) and CASBEE- Urban Development (CASBEE-UD) rating systems have been developed by the Japan Sustainable Building Consortium (JSBC) to provide comprehensive assessment methods for assessing the built environment efficiency both for buildings and communities [95]. In addition to environmental concerns as the eminent focus of these studies, economic and social aspects of sustainability are also attracting more attention during these decades.

2.2.2 Economic Aspect

Economic approaches determine the optimum solution towards costs and benefits related to a specific project for a community or the private sector. The overall objective of the economic analysis should be to minimize total annual energy related costs, which involves the economic assessment (investment and operation costs) of different energy system components in the short, medium, or long term [96]. Numerous studies have established the important concepts for the energy economics domain. The economic aspects are crucial since they allow for feasibility and profitability assessments of projects. Economic concepts such as overall rate of return (ORR), net present value (NPV), internal rate of return (IRR), cost-benefit ratio (CBR), discounted payback period (DPP), simple payback period (SPP), amount of saving to investment ratio (SIR) and life-cycle cost methods have already been applied for economic assessment in the built environment [70,97–101]. Kaynakli used life-cycle cost assessment to determine the optimal thermal insulation required for a building envelop [102]. Goodacre et al. implemented a cost-benefit analysis to upgrade the existing heating system to an energy efficient one for the English building stock [103]. Furthermore, comparing the real estate market value before and after retrofitting is an important factor to assess the viability of a project [104].

2.2.3 Social Aspect

Social factors which involve comfort conditions, activity patterns, occupancy regimes, management, and maintenance methods play a significant role in the success of energy-related projects. Most of the literature in this area addresses the effects of occupants' behaviour in assessing the energy performance of the entire system. For instance, Owens and Wilhite have demonstrated that 10–20% of energy reductions can be achieved by changing the activity pattern of residents in the Nordic residential sector [105]. A study by Santin et al. affirms the role of occupant behaviour in energy consumption especially in hot water demand in Netherlands [83]. Yohanis argues about the relation between householders' awareness and domestic energy use [84]. He affirms that awareness of users for temperature control, energy saving and efficacy of systems and household appliances leads to significant energy savings. In addition to studies focusing on occupants' behaviours, Community Renewable Energy Network (CREN) has presented a holistic socio-energy method to handle the interdisciplinary challenges for a greenfield project [106].

The vast variety of research and practical projects with different methods incorporating social, economic and environmental variables affirms the complexity of analysis at district scale. Hence, it seems mandatory to dedicate considerable time and effort to review related methods to choose and implement the most effective one based on the specifications of a project.

2.3 System Interaction in Districts

For analysis of complex and interrelated systems, the performance of each element and its impact on other members should be addressed to enhance the accuracy results. A study by Haapio introduced the important components and indicators, which are used in well-known international assessment tools such as CASBE-UD, BREEAM and LEED-ND [66]. Infrastructure, transportation, ecology and location were considered as the most effective indicators in energy analysis of districts [66]. Another study investigated the interdependencies between the different system elements through system classification using four layers, namely, void layer, volume layer, functional layer and transportation layer [63]. Implementation of these four layers results in transforming cities to sustainable form by adaptive modification of each layer in addition to collaborative integration with other layers [63]. As proposed by Lund et al., transport energy operation is a key element in the coherent energy system analysis of scenarios at the district level [107]. C'osic' et al. have proposed a framework for achieving energy reduction considering an entire system involving buildings, industries, and transportation systems to implement a 100% renewable energy plan for Macedonia [27].

Community scenarios have been formulated to connect transportation systems, home energy systems and the electric grid [43]. A framework proposed by Boussauw and Witlox assesses the annual energy consumption for daily mobility (EDM) as an important indicator for sustainability of spatial structures [108]. In this research, they argue about the critical role of regional variations in the energy performance of the whole transport system such as the issue of proximity in home-to-work travels [108]. "Zero-energy neighbourhood" framework (nZEN) articulates the opportunities and challenges for the reduction in energy consumption and increment in on-site renewable energy production for both buildings and daily mobility sectors [37]. To clarify the role of different components, some peer-reviewed articles are introduced with a short summary of their key findings, implementation strategies and components considered in analysis (Table 1). The most important parameters are related to geometry and form of built environment and transportation system characteristics, which are discussed briefly in the following sections.

2.3.1 Design Metrics of Form

Urban morphology and building typology are considered as crucial parameters to evaluate the energy performance of the built environment [63,109] at different design stages for owners, engineers and planners. Hachem et al. investigated the effect of residential districts configurations and density on the electricity generation and consumption pattern [110]. Their results which have to be used in the early stages of design process, show that district configurations can compensate the increased energy consumption by more generation and improve the respond to the demand pattern in peak times [110]. Another study analysed the energy performance through parameters such as density, prominent function of the neighbourhood (mixed-use/residential) and location of the commercial centre relative to residential areas, in addition to the pattern of streets and the transportation system [10]. A similar study has investigated the positive impact of compactness of building distribution and their density on the energy performance of districts in modern developments [111]. Their results reveal that urban sprawl and suburban districts lead to significant energy consumption in both buildings and urban transportation sectors [111,112].

2.3.2 *Transportation*

To date, literature has addressed the individual role of transportation in energy performance assessment and has often neglected the interactions of transportation systems with the building sector or other components of districts [10]. Although transport and mobility systems are often neglected, these systems have aggravated the process of urban sprawl [113]. Boussauw and Witlox have developed a commute-energy performance index in Belgium to investigate the link between spatial structure and energy consumption for home-to-work travels at the regional scale [108]. They have considered buildings, transportation and public lighting systems as their effective components of energy assessment at the district scale [108]. Transport energy consumption is defined as a composite measure of travel distance, modal choice and journey frequency [113]. Vahabzade Manesh has defined the transportation system through parameters such as porosity, proximity, diversity, interface, accessibility and efficiency [63]. Although, the role of urban architecture in transportation energy usage has been well addressed, it is rarely considered as a component of the entire urban system in districts [86,113,114]. Steemers investigated the interaction link between buildings and transportation system for minimizing energy consumption and air pollution and moving towards compact and connected sustainable districts [115].

Reviewing the existing body of literature affirms this fact that most of the research analyse their case studies based on one or two of these components without considering their interactions [10]. These kinds of approaches result in failure to evaluate districts as a system of various components with internal interactions affecting the energy performance of upper and lower level systems [12,86]. Consequently, specific methods have to be determined based on the system interactions to become applicable in the districts.

Table 1- Summary of reviewed papers for energy analysis of built environment with focus on different effective components.

Ref	Year	Component	Implementation Strategy	Key Findings	City/ Country
[115]	2003	<ul style="list-style-type: none"> • Building • Urban form: density • Transportation (Car travel) • Function 	<ul style="list-style-type: none"> • Modifying density • Changing compactness 	<ul style="list-style-type: none"> • Energy efficacy • Link between transport and building energy • Quality of urban environment 	London
[114]	2008	<ul style="list-style-type: none"> • Buildings operation • Food • Transportation 	<ul style="list-style-type: none"> • Material flow analysis • Metabolism approach 	<ul style="list-style-type: none"> • Metabolism of components • Urban context as a live creature 	Toronto
[43]	2009	<ul style="list-style-type: none"> • Building's function • Transportation • Community-based infrastructure 	<ul style="list-style-type: none"> • Community as intermediate tool • Multi-year and long-term implementation strategies 	<ul style="list-style-type: none"> • Cost effective balance • Using renewable on three sites: Onsite or brownfield in community; Green space within the within the region; Purchase of new sources 	–
[108]	2009	<ul style="list-style-type: none"> • Infrastructure • Commuting behaviour • Spatial-economic structure 	<ul style="list-style-type: none"> • Home-to-work travel pattern 	<ul style="list-style-type: none"> • A commute-energy performance (CEP) index • Residential density • Role of context characteristics 	Flanders
[113]	2012	<ul style="list-style-type: none"> • Buildings • Transport • Public lighting 	<ul style="list-style-type: none"> • Sensitivity analysis scenarios • Interactive decision-making tool 	<ul style="list-style-type: none"> • Developing a tool on the web 	Belgium
[27]	2012	<ul style="list-style-type: none"> • Industry • Transport • Residential • Public services • Commercial sector 	<ul style="list-style-type: none"> • EnergyPLAN • Defining special set of input and output data 	<ul style="list-style-type: none"> • A 100% renewable energy scenario in Macedonia • Integrating renewable energies • Applying storage technologies 	Macedonia
[116]	2013	<ul style="list-style-type: none"> • Built-up mass layer • Open spaces, streets • Land use layer • Transportation layer 	<ul style="list-style-type: none"> • IMM (Integrated Modification Methodology) • Modification and collaborative integration 	<ul style="list-style-type: none"> • Distinguishing principle and secondary layers • Modification horizontal relation • Collaborative integration vertical layer 	Barcelona
[37]	2014	<ul style="list-style-type: none"> • Buildings: space heating space cooling, ventilation, appliances, cooking and domestic hot water • Daily mobility 	<ul style="list-style-type: none"> • Simplified net “zero-energy neighbourhood” • “Energy mutualisation” for energy production and energy consumption 	<ul style="list-style-type: none"> • Energy efficiency • Maximize on-site renewable energy production • Using off-site renewable energy production • Balancing on-site production and load by grid application (send and receive) 	Belgium

3 Discussion and Results

The growing interest in low and zero energy concepts has increased the number of district studies over the past few decades. This confirms the necessity for performing energy analysis in districts; however, based on the literature reviewed in the section 2, various challenges and constraints exist in the entire process of energy performance assessment [10,66]. Few of the reviewed studies investigated the challenges in the initial stages of designing different steps of energy performance analysis in districts. Moreover, the multidisciplinary and numerous effective parameters of district scale studies have resulted in the ambiguity of defining methodologies. Since, inaccurate or imprecise assumptions in the basic steps of energy performance analysis may lead to irreparable consequences such as wastage of project resources or unreliable results and solutions; significant attention has to be paid to this issue. Implementation of techniques such as data mining and gathering is required and transformation of inputs to more standard outputs via specific metrics is important to establish the initial stages of data gathering process for energy performance analysis (Fig. 4).

Fig. 4- Initial stages in the data gathering process of energy performance assessment. The effective issues are extracted from the main concepts of literature review and transformed via classification metrics to form the conceptual framework's objectives.

The most important concepts of existing literature for applying in the district energy performance were reviewed and summarised in three sections including; (1) defining concepts relating to the district energy performance, (2) main themes of approaches for district energy performance evaluation and (3) system interactions between district entities. However, there are challenges and issues in each of these three groups which have to be considered before carrying out the analysis. The input data for each group should be categorised based on the related classification metrics and transformed as standard outputs which are necessary to be considered in energy performance analysis. These outputs form the basis of the conceptual framework of this study (Fig. 4).

This framework involves three main steps; “*Subject and Scope*”, “*Input Data Management*” and “*Methods*”. In this regard, further discussion on the reviewed studies and recommendations for combating the identified challenges are presented in three sections as below: 1) defining the effective components as the subject and scope of research, 2) categorising the input data Management by target group, required resolution and specific type and 3) determining methods to handle the interactions of variables. In this section, a preliminary framework is proposed to address these difficulties, which need to be determined in the early stages of the project (Fig. 5).

Fig. 5- The conceptual framework to identify the challenges in the early stages of design process in energy performance analysis.

3.1 Subject and Scope

Over the past decade, the research focus has shifted from performance analysis of individual building level to performance analysis at larger scales. As mentioned in section 2.1, 73% of studies have been conducted after 2000 emphasizing the growing interest for district level studies (Fig. 1). Based on the sections 2.1 and 2.2, approaches utilised at the district scale consider the district as a cluster of buildings and neglects numerous other components (Fig. 2). Buildings have received more attention since they are the most tangible and accessible test objects [22]. Working in larger scales involves considering a wide variety of effective parameters that makes the analysis process more complex. Although transportation, public spaces and green fields play paramount role in the energy performance of districts, the integrated effect of these entities has often been overlooked. Neglecting these components leads to inaccurate results and further impedes the objective for achieving zero energy districts [10]; since, energy optimization and efficiency scenarios need to be implemented for the whole district and not just for buildings [43]. Consequently, describing the subject and scope is a basic step to pave the way in determining the other aspects of the framework such as gathering the relevant data and solving system interactions.

3.2 Input Data Management

In the data gathering process, three principal challenges should be resolved: the first challenge concerns the type of data to be gathered. The second challenge describes the mandatory level of details required to ensure the validity and reliability of the research, and finally, the third challenge concerns the stakeholders who would benefit from this data. Sections 3.2.1- 3.2.3 lay out the platform to address the challenges related to the data gathering process.

3.2.1 Type

Owing to the multidisciplinary nature of energy performance in the built environment, different kinds of data are available. Hence, the most challenging part is often to establish a set of criteria for relevant

data selection. The amount of input data can be reduced through defining a set of relevant goals. Moreover, goals and approaches have evolved during the past few decades. With the advent of sustainability in projects, initial goals were mainly directed towards reducing CO₂ emissions and other pollutants and conserving fossil fuel reserves. However, end-users and implementation methods are now being considered in defining the goals to account for social and economic aspects respectively. Economic aspects should be thoroughly addressed to avoid conflicts and delays during the project and deliver the initial targets within the specified time. Social features demand special attention and efforts since these features add external variables into the project making it more complicated and time consuming.

3.2.2 *Resolution:*

Because of the inter dependencies in the parameters involved and the complex measurement methods, district level studies are often quite challenging. Such studies are usually based on information-driven process to deal with different scales and domains [117]. The parameters deal with quantitative and qualitative variables including different types of data such as social behaviour, energy consumption of mechanical systems etc. The level of detail varies from material specifications such as U-value to district configurations and layouts, for instance, the location of public spaces and street patterns. Coupling with such huge diversity makes the procedure of data gathering, analysis and modelling more problematic [118].

These difficulties force planners to organize a balanced scenario based on their time, budget and resources. In other words, although decreasing the level of details will reduce the accuracy and validity of results [23]; focusing on a lot of those details renders the quantitative and qualitative analysis methods inefficient [119]. Another approach is to link information from different scales to provide a balanced view of required resolution such as considering interaction between the demand-side of buildings (lower scale) and the supply-side of districts (upper scale) [119–121]. Such links improve the energy assessment of both scales [122]. Consequently, defining the required level of resolution is mandatory at the early stage of project, which can be considered as the grounded criteria covering the whole process.

3.2.3 *Target Group*

Target groups such as planners, designers and practitioners who use the findings of research need the information suited to their needs in a specific format [73]. They can be external or internal individuals or organizations that can influence or have interest in the project. Consequently, coupling the requirements of all these groups is a difficult procedure, which affirms the need for a management system for the survival of energy efficient districts [123]. Management systems usually monitor the whole process and handle all upcoming challenges in identifying the key stakeholders through special methods such as Information and Communication Technologies (ICT) [23]. ICT has paved the way for integration of different disciplines and approaches towards optimization of energy generation and consumption in districts and buildings [124].

Energy performance evaluation methods using ICTs provide a better platform for large scale energy management [125]. Some projects such as the Digital Agenda for Europe [126] under EU Horizon 2020 [123], have dedicated special focus on this concept by developing programs to accelerate the process of handling all different groups of stakeholders. Other projects such as RESILIENT [127] and Energy management and decision support systems for Energy Positive (EEPOS) [128] have also worked on the implementation of ICTs towards low carbon and intelligent management of districts spanning different groups of stakeholders. In this regard, smart grids and central hubs are emerging as new concepts to deal with the real-time input data, assigning the appropriate energy resource to

consumers, send/receive extra or required energy by connecting to other grids and finally predicting errors and reporting unexpected crashes to find the best solutions [118,119,129–131].

Data handling and management is crucial in energy performance evaluation to verify the validity of the research principles and results which in turn bolsters the importance of choosing the most fitted and applicable methods.

3.3 Methods

As discussed in sections 2.1 and 2.2, the vast range of effective parameters incorporate different kinds of social, economic and environmental variables and hence, complex sets of equations are required to achieve accurate results (Fig. 3). The complexity of the calculations involved deems it mandatory to implement the most effective method for performing these calculations. Parametric methods such as “sensitivity analysis” [85] identify the value of each parameter individually as well as in relation to other parameters. Based on the multi-objective nature of energy issue in districts, there usually exists no single optimal solution [132] or in other words, when a large number of solutions are available, the required evaluation and selection process is more difficult [3].

Problems faced by the existence of multiple and competing objectives and wide variety of solutions require special methods such as Multi-Criteria (MC) analysis or Analytic Hierarchy Process (AHP) [133]. These methods ensure a balance by assigning a proper weight to each parameter based on its priority. Multi-criteria analysis presents the most appropriate solution through defining the appropriate decision variables, targets and constraints for implementation [3]. Linear Program (LP) and Non-Linear Program (NLP) algorithms deal with inputs and goals to achieve approximate results while maintaining the desired level of accuracy [134].

Optimization is another method, which guides the planners and managers to one or more optimised scenarios representing the fittest condition based on the priorities, goals, limitations and delimitations. Optimization methods need a powerful system processor or access to cloud based servers to run huge amount of calculations [85]. Significant studies have developed multi-objective optimization algorithms for district energy systems, such as Multi objective Neighbourhood Field Optimization (MONFO), which deal with the diverse set of solutions based on stakeholder preferences [132]. Multi-criteria analysis utilises mathematical methods such as Pareto analysis to obtain the most fitting solution for the optimum and feasible condition [132]. The multidisciplinary parameters, affecting the energy performance of districts, confirm the necessity of studying the role of each parameter in choosing the whole methodology. The characteristics of energy-oriented problems suggest appropriate methods including single or mixed methods. Different statistical, mathematical or graphical assessment methods have to be distinguished by the process, purposes and type of indices and parameters [135] and then be implemented in the systems with significant number of interactions such as in districts.

4 Conclusions

The drastic rate of urban development and population growth affirms the importance of urban areas in the context of overall energy consumption and greenhouse gas emissions. Energy performance analysis spans different research areas through specialised approaches and methodologies. Concepts such as “zero energy” or “low energy” spotlight different aspects of energy performance in the built environments especially at the district scale which is reviewed in this paper. District level plays a crucial role in the energy analysis as an intermediate level between individual components such as

buildings and mega scales such as cities and countries. Analysis at the district scale includes all the necessary components such as transportation system, form and geometry metrics of buildings and district patterns. However, the absence of a comprehensive framework for district studies casts doubt on the delivery of goals. The multidisciplinary and numerous effective parameters of district scale studies make the process of energy performance analysis more challenging. Due to the inter dependencies involved, it often becomes challenging for planners and policy makers to select the best approach for their projects corresponding to the special characteristics of each district. The state of the art methodology presented here addresses the challenges existing in the initial steps of energy performance through highlighting set of criteria for relevant data selection.

The various groups of data which have to be considered in the energy performance analysis are extracted from the literature and reviewed in three groups of basic concepts and definitions, main approaches and themes and finally the interactions between different components. The main concepts of literature are categorised based on the related classification metrics and transformed to three aspects; “Subject and Scope”, “Input Data Management” and “Methods” (Fig. 4). In “subject and scope”, extents of the case and exact horizons of the study are determined by defining the role of each component in the energy performance of districts. Districts as the subject of the study are considered as the intermediate scale between individual components and cities for carrying out the energy analysis. In the second step, classification metrics such as type of required data, level of details and the target group are applied for data gathering process. There are important points which need to be addressed in this step including (1) the type of data which mostly concerns the objective and theme of the research, (2) the mandatory level of details required to ensure the validity and reliability of results and (3) the impact and role of the stakeholders who would benefit from this data. In the third step, the vast range of effective parameters affirms the need for selection of appropriate analytic methods to be used based on complexity of variables, their interactions and the required level of details. The selection of single or mixed methods depends on the number of determined components and their interactions in districts.

Future research has to investigate more details about early stages of energy performance analysis such as data gathering or definition of subjects and scope. Moreover, it is necessary to determine holistic frameworks possessing the ability to handle the complicated interactions of district variables through an appropriate weighting process. These frameworks can focus on the next steps of energy analysis including modelling, simulation and analysing methods. Implementation of these frameworks in case studies to validate and improve the possibility for generalization is another crucial point which should be addressed in the future works.

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6 References:

- [1] Ash C, Jasny BR, Roberts L, Stone R, Sugden AM. Reimagining cities. *Science* (80-) 2008;319:739–739.
- [2] United Nations. World urbanization prospects: The 2007 revision. New York UN 2008.
- [3] Asadi E, Da Silva MG, Antunes CH, Dias L. Multi-objective optimization for building retrofit strategies: a model and an application. *Energy Build* 2012;44:81–7.
- [4] Saidur R, Atabani AE, Mekhilef S. A review on electrical and thermal energy for industries. *Renew Sustain Energy Rev* 2011;15:2073–86.
- [5] Husnawan M, Masjuki HH, Mahlia TMI, Saifullah MG. Thermal analysis of cylinder head carbon deposits from single cylinder diesel engine fueled by palm oil--diesel fuel emulsions. *Appl Energy* 2009;86:2107–13.
- [6] Ong HC, Mahlia TMI, Masjuki HH. A review on energy scenario and sustainable energy in Malaysia. *Renew Sustain Energy Rev* 2011;15:639–47. doi:10.1016/j.rser.2010.09.043.
- [7] Jayed MH, Masjuki HH, Saidur R, Kalam MA, Jahirul MI. Environmental aspects and challenges of oilseed produced biodiesel in Southeast Asia. *Renew Sustain Energy Rev* 2009;13:2452–62.
- [8] UNEP. District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy 2015:137. http://www.unep.org/energy/portals/50177/DES_District_Energy_Report_full_02_d.pdf.
- [9] Voss K, Musall E, Lichtmeß M. From Low-Energy to Net Zero-Energy Buildings: Status and Perspectives. *J Green Build* 2011;6:46–57. doi:10.3992/jgb.6.1.46.
- [10] Hachem C. Impact of neighborhood design on energy performance and GHG emissions. *Appl Energy* 2016;177:422–34. doi:10.1016/j.apenergy.2016.05.117.
- [11] Engel-Yan J, Kennedy C, Saiz S, Pressnail K. Toward sustainable neighbourhoods: the need to consider infrastructure interactions. *Can J Civ Eng* 2005;32:45–57.
- [12] Sartori I, Napolitano A, Voss K. Net zero energy buildings: A consistent definition framework. *Energy Build* 2012;48:220–32. doi:10.1016/j.enbuild.2012.01.032.
- [13] Torcellini PA, Crawley DB. Understanding zero-energy buildings. *ASHRAE J* 2006;48:62.
- [14] Marszal AJ, Heiselberg P, Bourrelle JS, Musall E, Voss K, Sartori I, et al. Zero Energy Building - A review of definitions and calculation methodologies. *Energy Build* 2011;43:971–9. doi:10.1016/j.enbuild.2010.12.022.
- [15] Pless SD, Torcellini PA. Net-zero energy buildings: A classification system based on renewable energy supply options. National Renewable Energy Laboratory; 2010.
- [16] Ma Z, Cooper P, Daly D, Ledo L. Existing building retrofits: Methodology and state-of-the-art. *Energy Build* 2012;55:889–902. doi:10.1016/j.enbuild.2012.08.018.
- [17] Malatji EM, Zhang J, Xia X. A multiple objective optimisation model for building energy efficiency investment decision. *Energy Build* 2013;61:81–7.
- [18] Jamieson M, Brajterman O, Verstraeten Y, Arbon J. Energy Performance of Buildings Directive (EPBD) Compliance Study. 2015.
- [19] Fleming PDD, Webber PHDF and PH, P. D. Fleming and P. H. Webber, Fleming PDD, Webber PHDF and PH. Local and regional greenhouse gas management. *Energy Policy* 2004;32:761–71.
- [20] Liu C-M, Liou M-L, Yeh S-C, Shang N-C. Target-aimed versus wishful-thinking in designing efficient GHG reduction strategies for a metropolitan city: Taipei. *Energy Policy* 2009;37:400–6. doi:10.1016/j.enpol.2008.09.055.
- [21] Jos Sarralde J, James Quinn D, Wiesmann D, Steemers K, Sarralde JJJ, Quinn DJ, et al. Solar energy and urban morphology: Scenarios for increasing the renewable energy potential of neighbourhoods in London. *Renew Energy* 2015;73:10–7. doi:10.1016/j.renene.2014.06.028.
- [22] Anderson JE, Wulfhorst G, Lang W. Energy analysis of the built environment — A review and outlook. *Renew Sustain Energy Rev* 2015;44:149–58. doi:10.1016/j.rser.2014.12.027.
- [23] Reinhart CF, Cerezo Davila C. Urban building energy modeling - A review of a nascent field. *Build Environ* 2016;97:196–202. doi:10.1016/j.buildenv.2015.12.001.
- [24] Torcellini P, Pless S, Deru M, Crawley D. Zero Energy Buildings: A Critical Look at the Definition; Preprint 2006.
- [25] Brundtland G. Report of the World Commission on environment and development: "our common future." 1987.
- [26] Bagsii B. Towards a Zero Energy Island. *Renew Energy* 2008;34:784–9. doi:10.1016/j.renene.2008.04.027.
- [27] Cosic B, Krajačić G, Duić N. A 100% renewable energy system in the year 2050: The case of Macedonia. *Energy* 2012;48:80–7. doi:10.1016/j.energy.2012.06.078.
- [28] Amado M, Poggi F. Towards solar urban planning: A new step for better energy performance. *Energy*

- Procedia 2012;30:1261–73. doi:10.1016/j.egypro.2012.11.139.
- [29] Orehounig K, Evins R, Dorer V. Integration of decentralized energy systems in neighbourhoods using the energy hub approach. *Appl Energy* 2015;154:277–89. doi:10.1016/j.apenergy.2015.04.114.
 - [30] Eicker U, Monien D, Duminil É, Nouvel R. Energy performance assessment in urban planning competitions. *Appl Energy* 2015;155:323–33. doi:10.1016/j.apenergy.2015.05.094.
 - [31] Searfoss L. Local perspectives on HUD's neighborhood stabilization program. MUP Capstone 2011.
 - [32] Jenks M, Dempsey N. Defining the neighbourhood: Challenges for empirical research. *Town Plan Rev* 2007;78:153–77. doi:10.3828/tpr.78.2.4.
 - [33] Barton H, Grant M, Guise R. *Shaping neighbourhoods : a guide for health, sustainability and vitality*. Spon; 2003.
 - [34] Orehounig K, Mavromatidis G, Evins R, Dorer V, Carmeliet J. Towards an energy sustainable community: An energy system analysis for a village in Switzerland. *Energy Build* 2014;84:277–86. doi:10.1016/j.enbuild.2014.08.012.
 - [35] Cowan R. *The dictionary of urbanism*. Streetwise Press; 2005.
 - [36] Choguill CL. Developing sustainable neighbourhoods. *Habitat Int* 2008;32:41–8.
 - [37] Reiter S, Oise Marique A-F, Reiter S. A simplified framework to assess the feasibility of zero-energy at the neighbourhood/community scale. *Energy Build* 2014;82:114–22. doi:10.1016/j.enbuild.2014.07.006.
 - [38] Blum A. HQE2R—research and demonstration for assessing sustainable neighborhood development. *Sustain Urban Dev* 2007;2:412–28.
 - [39] Huang Z, Yu H, Peng Z, Zhao M. Methods and tools for community energy planning : A review. *Renew Sustain Energy Rev* 2015;42:1335–48. doi:10.1016/j.rser.2014.11.042.
 - [40] Amado M, Poggi F. Solar energy integration in urban planning: GUUD model. *Energy Procedia* 2014;50:277–84. doi:10.1016/j.egypro.2014.06.034.
 - [41] Sheppard E. The spaces and times of globalization: place, scale, networks, and positionality. *Econ Geogr* 2002;78:307–30.
 - [42] Haughton G. Developing sustainable urban development models. *Cities* 1997;14:189–95.
 - [43] Carlisle N, Geet O Van, Pless S. Definition of a Zero Net Energy Community. 2009.
 - [44] Kennedy S, Sgouridis S. Rigorous classification and carbon accounting principles for low and Zero Carbon Cities. *Energy Policy* 2011;39:5259–68. doi:10.1016/j.enpol.2011.05.038.
 - [45] Robinson D, Scartezzini J-L, Montavon M, Compagnon R. *Solar Utilisation Potential of Urban Sites* 2005.
 - [46] Steemers K, Baker N, Crowther D, Nikolopoulou M. Project ZED, Modelling environmental characteristics of urban forms,'. *Sol Energy Archit* 1996.
 - [47] Compagnon R. PRECis: Assessing the Potential for Renewable Energy in Cities Solar and Daylight availability in urban areas Final Technical Report 1998.
 - [48] D 'agostino D, Zangheri P. Development of the NZEBs concept in Member States Towards Nearly Zero Energy Buildings in Europe Title: Development of the NZEBs concept in Member States 2016. doi:10.2788/278314.
 - [49] EPBD Building platform: REHVA 2017. <http://www.rehva.eu/eu-projects/completed-projects/epbd-building-platform.html> (accessed April 27, 2017).
 - [50] Federation of European Heating Associations Ventilation and Air Conditioning. Nearly Zero Energy Hotels 2017. <http://www.rehva.eu/eu-projects/completed-projects/nezeh.html> (accessed April 27, 2017).
 - [51] Federal Energy Management Program | Department of Energy 2017. <https://energy.gov/eere/femp/federal-energy-management-program> (accessed April 27, 2017).
 - [52] Green Building Council 2017. <http://www.ukgbc.org/research-and-innovation> (accessed April 27, 2017).
 - [53] Energy performance of buildings — Overall energy use, CO2 emissions and definition of energy ratings. 2006.
 - [54] DOE. DOE Releases Common Definition for Zero Energy Buildings, Campuses, and Communities | Department of Energy 2017. <https://energy.gov/eere/buildings/articles/doe-releases-common-definition-zero-energy-buildings-campuses-and> (accessed April 19, 2017).
 - [55] BuildingGreen 2017. <https://www.buildinggreen.com/> (accessed April 19, 2017).
 - [56] Bouton S, Newsome D, Woetzel J. Building the cities of the future with green districts | 2015. <http://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/building-the-cities-of-the-future-with-green-districts> (accessed April 19, 2017).
 - [57] Pacheco M, Lamberts R. Assessment of technical and economical viability for large-scale conversion of single family residential buildings into zero energy buildings in Brazil: Climatic and cultural considerations. *Energy Policy* 2013;63:716–25. doi:10.1016/j.enpol.2013.07.133.
 - [58] Lund H, Connolly D, Thellufsen JZ, Van Mathiesen B, Østergaard PA, Lund RS, et al. *EnergyPLAN documentation*. *Appl Energy* 2015;154:0–15. doi:10.1016/j.apenergy.2015.05.086.

- [59] Zedfactory | BedZED 2017. <http://www.zedfactory.com/bedzed> (accessed April 22, 2017).
- [60] Gaiser K, Stroeve P. The impact of scheduling appliances and rate structure on bill savings for net-zero energy communities: Application to West Village. *Appl Energy* 2014;113:1586–95.
- [61] IEA-EBC. Energy in Buildings and Communities Program 2017. <http://www.iea-ebc.org/projects/ongoing-projects/> (accessed April 22, 2017).
- [62] Coplák J, Raksanyi P. Planning sustainable settlements. Bratislava Slavak Univ Technol 2003.
- [63] Vahabzadeh Manesh S, Tadi M, Zanni F. Integrated sustainable urban design: Neighbourhood design proceeded by sustainable urban morphology emergence. *WIT Trans Ecol Environ* 2011;155:631–42. doi:10.2495/SC120532.
- [64] Koch A, Girard S, Mckoen K. Towards a neighbourhood scale for low- or zero-carbon building projects. *Build Res Inf* 2012;40:527–37. doi:10.1080/09613218.2012.683241.
- [65] Farreny R, Solà JO, Montlleó M, Escribà E, Gabarrell X, Rieradevall J. Transition towards sustainable cities: Opportunities, constraints, and strategies in planning. A neighbourhood ecodesign case study in Barcelona. *Environ Plan A* 2011;43:1118–34. doi:10.1068/a43551.
- [66] Haapio A. Towards sustainable urban communities. *Environ Impact Assess Rev* 2012;32:165–9. doi:10.1016/j.eiar.2011.08.002.
- [67] Rey E, Lufkin S, Renaud P, Perret L. The influence of centrality on the global energy consumption in Swiss neighborhoods. *Energy Build* 2013;60:75–82. doi:10.1016/j.enbuild.2013.01.002.
- [68] Sweatman P, Managan K. Financing Energy Efficiency Building Retrofits. *Clim Strateg Partners* 2010.
- [69] Zavadskas E, Raslanas S. The selection of effective retrofit scenarios for panel houses in urban neighborhoods based on expected energy savings and increase in market value: The Vilnius case 2008;40:573–87. doi:10.1016/j.enbuild.2007.04.015.
- [70] Nikolaidis Y, Pilavachi PA, Chletsis A. Economic evaluation of energy saving measures in a common type of Greek building. *Appl Energy* 2009;86:2550–9. doi:10.1016/j.apenergy.2009.04.029.
- [71] Komeily A, Srinivasan RS, Rinker ME. A need for balanced approach to neighborhood sustainability assessments: A critical review and analysis. *Sustain Cities Soc* 2015;18:32–43. doi:10.1016/j.scs.2015.05.004.
- [72] Sharifi A, Murayama A. A critical review of seven selected neighborhood sustainability assessment tools. *Environ Impact Assess Rev* 2013;38:73–87.
- [73] Lippard LR. The lure of the local: Senses of place in a multicentered society. New Press New York; 1997.
- [74] Rey E. Quartiers durables. Défis et opportunités pour le développement urbain. 2011.
- [75] Kaklauskas A, Zavadskas EK, Raslanas S. Multivariant design and multiple criteria analysis of building refurbishments. *Energy Build* 2005;37:361–72.
- [76] Tobias L, Vavaroutsos G, others. Retrofitting Office Buildings to Be Green and Energy-Efficient: Optimizing Building Performance, Tenant Satisfaction, and Financial Return. Urban Land Institute Washington, DC; 2009.
- [77] Popescu D, Bienert S, Schützenhofer C, Boazu R. Impact of energy efficiency measures on the economic value of buildings. *Appl Energy* 2012;89:454–63.
- [78] Mills G. Progress toward sustainable settlements: a role for urban climatology. *Theor Appl Climatol* 2006;84:69–76.
- [79] Cole RJ. Regenerative design and development: current theory and practice 2012.
- [80] Luederitz C, Lang DJ, Von Wehrden H, Wehrden H Von. A systematic review of guiding principles for sustainable urban neighborhood development. *Landsc Urban Plan* 2013;118:40–52. doi:10.1016/j.landurbplan.2013.06.002.
- [81] Fedoruk LE, Cole RJ, Robinson JB, Cayuela A. Learning from failure: understanding the anticipated--achieved building energy performance gap. *Build Res Inf* 2015;43:750–63.
- [82] Westerhoff LM. Emerging Narratives of a Sustainable Urban Neighbourhood: The Case of Vancouver's Olympic Village. *Articul Urban Res* 2016:1–23.
- [83] Santin O, Itard L, Visscher H. The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. *Energy Build* 2009.
- [84] Yohanis Y. Domestic energy use and householders' energy behaviour. *Energy Policy* 2012.
- [85] Keirstead J, Jennings M, Sivakumar A. A review of urban energy system models: Approaches, challenges and opportunities. *Renew Sustain Energy Rev* 2012;16:3847–66. doi:10.1016/j.rser.2012.02.047.
- [86] Reiter S, Marique A-F. Toward low energy cities. *J Ind Ecol* 2012;16:829–38.
- [87] Costanza R, Graumlich L, Steffen WL. Sustainability or collapse?: An integrated history and future of people on Earth. Mit Press; 2007.
- [88] Pope J, Dalal-Clayton B. From SEA to sustainability assessment. *Handb Strateg Environ Assess* 2011:547–65.

- [89] Shepard RB. Quantifying environmental impact assessments using fuzzy logic. Springer Science & Business Media; 2006.
- [90] Turner T. Landscape planning and environmental impact design. Routledge; 2004.
- [91] European Commission. HQE2R Project 2004. <http://www.suden.org/en/european-projects/the-hqe2r-project/> (accessed April 23, 2017).
- [92] STAR. STAR Communities | Sustainability Tools for Assessing and Rating Communities 2017. <http://www.starcommunities.org/> (accessed May 1, 2017).
- [93] LEED. Getting to know LEED: Neighborhood Development | U.S. Green Building Council 2017. <http://www.usgbc.org/articles/getting-know-leed-neighborhood-development> (accessed May 1, 2017).
- [94] BREEAM. Building Research Establishment Environmental Assessment Method 2017. <http://www.breeam.com/> (accessed May 1, 2017).
- [95] CASBEE. Comprehensive Assessment System for Built Environment Efficiency 2017. <http://www.ibec.or.jp/CASBEE/english/> (accessed April 23, 2017).
- [96] Sanaei SM, Nakata T. Optimum design of district heating: Application of a novel methodology for improved design of community scale integrated energy systems. *Energy* 2012;38:190–204. doi:10.1016/j.energy.2011.12.016.
- [97] Krarti M. Energy audit of building systems : an engineering approach. CRC Press; 2011.
- [98] Verbeeck G, Hens H. Energy savings in retrofitted dwellings: economically viable? *Energy Build* 2005;37:747–54. doi:10.1016/j.enbuild.2004.10.003.
- [99] Petersen S, Svendsen S. Method for component-based economical optimisation for use in design of new low-energy buildings. *Renew Energy* 2012;38:173–80. doi:10.1016/j.renene.2011.07.019.
- [100] Gorgolewski M. Optimising renovation strategies for energy conservation in housing. *Build Environ* 1995;30:583–9.
- [101] Huber A, Mayer I, Beillan V, Goater A, Trotignon R. Refurbishing residential buildings: A socio-economic analysis of retrofitting projects in five European countries. *World Sustain Energy* 2011.
- [102] Kaynakli O. A review of the economical and optimum thermal insulation thickness for building applications. *Renew Sustain Energy Rev* 2012;16:415–25. doi:10.1016/j.rser.2011.08.006.
- [103] Goodacre C, Sharples S, Smith P. Integrating energy efficiency with the social agenda in sustainability. *Energy Build* 2002;34:53–61.
- [104] Zavadskas EK, Kaklauskas A, Gulbinas A. Multiple criteria decision support web-based system for building refurbishment. *J Civ Eng Manag* 2004;10:77–85.
- [105] Owens J, Wilhite H. Household energy behavior in Nordic countries—an unrealized energy saving potential. *Energy* 1988.
- [106] Tomc, E., Vassallo, A. Community Renewable Energy Networks in urban contexts: the need for a holistic approach. *Int J Sustain Energy Plan Manag* (in Press 2015;8:31–42. doi:10.5278/IJSEPM.2015.8.4.
- [107] Lund H, Möller B, Mathiesen BV, Dyrelund A. The role of district heating in future renewable energy systems. *Energy* 2010;35:1381–90. doi:10.1016/j.energy.2009.11.023.
- [108] Boussauw K, Witlox F. Introducing a commute-energy performance index for Flanders 2009;43:580–91. doi:10.1016/j.tra.2009.02.005.
- [109] Dascalaki EG, Droutsas KG, Balaras CA, Kontoyiannidis S. Building typologies as a tool for assessing the energy performance of residential buildings--A case study for the Hellenic building stock. *Energy Build* 2011;43:3400–9.
- [110] Hachem C, Athienitis A, Fazio P. Evaluation of energy supply and demand in solar neighborhood. *Energy Build* 2012;49:335–47. doi:10.1016/j.enbuild.2012.02.021.
- [111] Marique A, Reiter S. A method to evaluate the energy consumption of suburban neighborhoods. *HVAC&R Res* 2012.
- [112] Onat NC, Egilmez G, Tatari O. Towards greening the US residential building stock: a system dynamics approach. *Build Environ* 2014;78:68–80. doi:10.1016/j.buildenv.2014.03.030.
- [113] Marique A-F, Reiter S. A method for evaluating transport energy consumption in suburban areas. *Environ Impact Assess Rev* 2012;33:1–6. doi:10.1016/j.eiar.2011.09.001.
- [114] Codoban N, Kennedy CA. Metabolism of neighborhoods. *J Urban Plan Dev* 2008;134:21–31.
- [115] Steemers K. Energy and the city: density, buildings and transport. *Energy Build* 2003;35:3–14. doi:10.1016/S0378-7788(02)00075-0.
- [116] Behfar A, Alam MMR, Shahmoradi R, Tadi M, Vahabzadeh S. Optimizing energy performance of a neighborhood via IMM ® methodology : Case Study of Barcelona. *J Energy* 2013;7:74–85.
- [117] Aman S, Simmhan Y. Energy management systems: state of the art and emerging trends. *IEEE Commun* 2013.
- [118] Allegrini J, Orehounig K, Mavromatidis G, Ruesch F, Dorer V, Evins R. A review of modelling approaches and tools for the simulation of district-scale energy systems. *Renew Sustain Energy Rev*

- 2015;52:1391–404. doi:10.1016/j.rser.2015.07.123.
- [119] Karnouskos S. Demand side management via prosumer interactions in a smart city energy marketplace. *Innov Smart Grid Technol ISGT Eur 2nd IEEE PES Int Conf Exhib* 2011;1–7.
 - [120] Palensky P, Dietrich D. Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads. *IEEE Trans Ind Informatics* 2011;7:381–8. doi:10.1109/TII.2011.2158841.
 - [121] Strbac G. Demand side management: Benefits and challenges. *Energy Policy* 2008;36:4419–26. doi:10.1016/j.enpol.2008.09.030.
 - [122] Manfren M, Caputo P, Costa G. Paradigm shift in urban energy systems through distributed generation: Methods and models. *Appl Energy* 2011.
 - [123] The European Innovation Partnership on Smart Cities and Communities - European Commission 2017. <http://ec.europa.eu/eip/smartcities/> (accessed August 2, 2017).
 - [124] Batić M, Tomašević N, Vraneš S. ICT Platform for Holistic Energy Management of Neighbourhoods 2016:112–7.
 - [125] Madlener R, Sunak Y. Impacts of urbanization on urban structures and energy demand: What can we learn for urban energy planning and urbanization management? *Sustain Cities Soc* 2011;1:45–53.
 - [126] European Commission. Digital Agenda for Europe 2016. <https://ec.europa.eu/digital-single-market/> (accessed August 2, 2017).
 - [127] European Commission. RESILIENT Project 2016. <http://www.resilience-project.eu/> (accessed August 2, 2017).
 - [128] EEPOS Consortium. An EEPOS Neighbourhood 2015. <http://eepos-project.eu/eepos/eepos-project/an-eepos-neighbourhood/> (accessed August 2, 2017).
 - [129] Geidl M, Andersson G. Operational and structural optimization of multi-carrier energy systems. *Eur Trans Electr Power* 2006;16:463–77. doi:10.1002/etep.112.
 - [130] Geidl M, Graz T. Integrated Modeling and Optimization of Multi-Carrier Energy Systems 1977.
 - [131] O ’connor P, Macsweeney R, Dunphy N. NewTrend 2017. http://newtrend-project.eu/wp-content/uploads/2015/11/NewTREND_WP1_D1.1_An_Analysis_of_the_Value_Chains.pdf (accessed July 24, 2017).
 - [132] Wu Z, Xia X, Wang B. Improving building energy efficiency by multiobjective neighborhood field optimization. *Energy Build* 2015;87:45–56. doi:10.1016/j.enbuild.2014.10.079.
 - [133] Wang B, Xia X, Zhang J. A multi-objective optimization model for the life-cycle cost analysis and retrofitting planning of buildings. *Energy Build* 2014;77:227–35.
 - [134] Sedghi M, Aliakbar-Golkar M, Haghifam M-R. Distribution network expansion considering distributed generation and storage units using modified PSO algorithm. *Int J Electr Power Energy Syst* 2013;52:221–30. doi:10.1016/j.ijepes.2013.03.041.
 - [135] Nguyen A, Reiter S. A performance comparison of sensitivity analysis methods for building energy models. *Build Simul An Int J* 2015.