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Identifying stakeholders and key performance indicators for district and building energy performance analysis

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Abstract

Integrated energy management at both the district and building scales can potentially improve multi-level energy efficiency, but such a solution requires the exchange and analysis of energy performance information from different stakeholders. With the complexities of energy management, there are numerous potential stakeholders and a considerable amount of information to consider. Therefore, a primary challenge is the development of a method that identifies the key stakeholders and extracts key information that supports their performance goals. In this paper, a systematic approach to identify stakeholders and key performance indicators (KPIs) is proposed to draw key information for multi-level energy performance analysis. Firstly, a three-task method for the identification and prioritization of stakeholders is suggested; secondly, a bi-index method to select the KPIs that underpin the stakeholders' performance goals is defined; finally, the proposed methodology is validated using a case study. The result demonstrates the feasibility of the methodology and illustrates that the selected KPIs contribute to the attainment of key information required to carry out a multi-level energy performance analysis.

Keywords: energy management; district; building; stakeholder; key performance indicator.

Abbreviations[1]

1 Introduction

Urban areas cover approximately 2% of the Earth's surface, but are responsible for almost 75% of overall resource consumption [1]. The current process of rapid urbanization exerts additional pressure on energy resource supplies and increases CO_2 emissions [2,3]. As a result, urban energy planning and management will be pivotal for the realization of sustainable cities [4]. Such smart cities and communities have the potential for large-scale energy management through adoption of approapriate new energy technologies and ICT (information and communication technologies) [5]. In addition, increased penetration of renewable energy resources in energy distribution networks requires energy management at a district scale, thus enabling opportunities for integration of energy supply and end use [6,7]. One example of which is demand-side management: this involves actions that can influence energy consumption patterns of end-users with upstream benefits for electricy distribution and transmission networks [8]. Such large scale benefits align with the Digital Agenda for Europe [9] as one of the seven pillars of the Europe 2020

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[1] SVI: Stakeholder Vote Index

SPI: Stakeholder Prioritization Index

CI: Comprehensive Index for stakeholder prioritization

Strategy. Therefore, a series of EU funded projects use ICTs to facilitate district-scale energy management [10]. These include DoF (District of the Future) [11] and COOPERATE (Control and Optimisation for Energy Positive Neighbourhoods) [12].

The built environment consumes significant levels of energy in cities, and accounts for approximately 40% of final energy consumption in EU countries [13]. However, a considerable proportion of the building stock is designed or operated inefficiently. For example, more than 50% of residential buildings in the EU were built before 1970, thus failing to complying with any energy regulations. Approximately 1/3 were built between 1970 and 1990 which corresponds with the initial implementation of energy policies [14]. By improving the energy efficiency of existing buildings, total energy consumption could be reduced by 5-6%, and CO_2 emissions by 5% [15].

Energy management is an important process that, when implemented correctly, should improve energy efficiency and reduce operating costs in buildings [16]. A lack of energy management during operation typically results in an overconsumption of energy when compared with design expectations [17]. Approaches that improve the energy efficiency of individual buildings with a view towards enhanced district scale performance is an ongoing socientical priority [18]. Solutions that consider the energy efficiency of buildings in the context of community or district level can significantly contribute towards sustainable and smart cities. However, multi-level energy management that aims to improve energy efficiency on both the district and building scales is a complex information-driven process that requires stakeholder interaction through exchange and analysis of energy-related information.

Stakeholder involvement is a prerequisite for exchanging this information and promotion of integrated energy management [20]. As a result, energy management is an interactive process between stakeholders and should realize their respective energy performance goals. Energy management in the context of this paper is a complex yet collaborative process, involving numerous potential stakeholders and enormous volumes of information. In order to manage this complexity, a method by which to identify the key stakeholders and extract the key information that addresses the stakeholders' performance goals is critical.

The stakeholder concept was initially introduced into the management discipline in 1984 [21]. Stakeholders can be defined as persons or groups whom are directly or indirectly affected by a project, as well as those who may have interests in a project and/or the ability to influence its outcome [22]. Although the importance of stakeholders for the success of a project is indisputable, there is a present shortage of studies that identify stakeholders related to energy management from building to district level. The most common means by which to identify stakeholders in the energy field is through the study of similar projects. In most cases, stakeholders are chosen without carrying out a detailed analysis [23,24].

The interanational industrial energy management standard, ISO 50001, specifies the requirements for establishing, implementing, maintaining, and improving an energy management system [25]. However, this standard fails to include stakeholders' engagement in energy management. The standard requires that organizations create energy objectives before implementing an energy management plan. The mechanism through which this is achieved is the identification of appropriate energy performance indicators (PIs) that track energy performance and ensure continuous improvement. Generally, the energy objectives should comply with relevant regulatory requirements yet represent stakeholders' goals. ISO 50001 provides guidance on the identification of energy PIs but fails to include guidelines relating to how indicators underpin stakeholders' goals. Additionally, numerous PIs can be identified, especially for district-scale energy management. Assigning a weighting to each indicator is essential when aiming to identify the key performance indicators (KPIs) that underpin overarching stakeholders' performance goals.

KPIs are useful for dealing with complex contexts such as districts and buildings. KPIs represent critical pieces of actionable information and help to evaluate and track the key aspects of performance within an organization [26]. KPIs are widely implemented in numerous disciplines such as construction and facility management. Currently, the identification of KPIs is commonly carried out using methods such as a literature review, stakeholder validation or discussion with industry players and experts [27,28]. However, these methods are predominantly qualitative. Although the method of stakeholder validation considers stakeholders' involvement, this method only takes place after the KPIs have been selected. KPIs validated by the stakeholders can support their performance goals to some extent. Nevertheless, a more favorable outcome should be attainable if stakeholders have the ability to select their specific KPIs at the beginning of the selection process.

This paper proposes a systematic approach to identify stakeholders and KPIs for multi-level energy management, at both the district and the building scales. Section 2 outlines the proposed methodology. Sections 3 and 4 elaborate the detailed methods that identify and prioritize stakeholders along with their corresponding KPIs. Section 5 demonstrates the proposed method via a case study while Section 6 discusses the main findings eminating from the results.

2 Methodology

The systematic approach adopted to identify the stakeholders and the KPIs for multi-level energy management comprises 11 tasks, as illustrated in Figure 1. Tasks 1 to 3 identify stakeholders and their respective priorities. In doing so, these tasks determine the relevant stakeholders and rank them in terms of their importance for the task at hand. The concept of intervention points [29] is introduced for identifying the stakeholders. Stakeholders become involved in energy management through these points. In order to identify a complete list of stakeholders, roles are identified, instead of highlighting the specific actors. Relevant stakeholders are therefore related to each role and are classified into internal and external stakeholders [30]. Not all stakeholders are equally important. Therefore, the performance goals of some stakeholders take precedence over others. For this reason, a prioritization analysis identifies the key stakeholders.

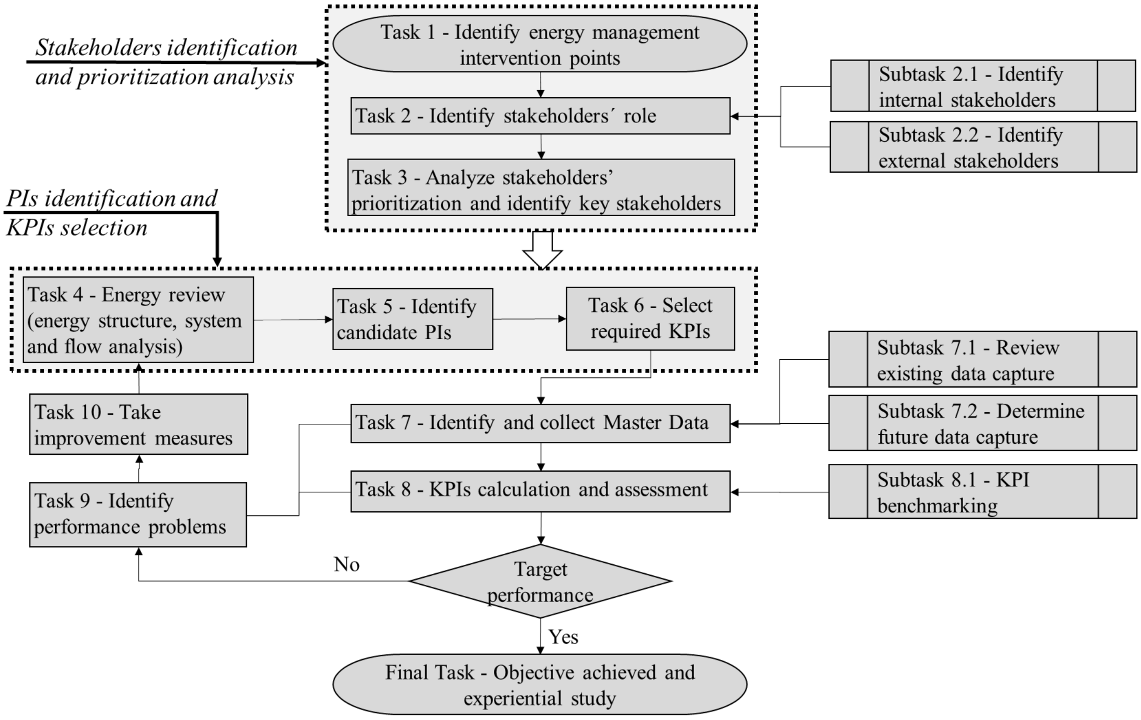


Figure 1: The systematic approach used to identify the stakeholders and the KPIs for multi-level energy management.

Tasks 4 to 6 involve the identification of PIs and the selection of KPIs. By doing so, KPIs transform the stakeholders' performance goals in such a way that they can be measured and tracked to represent key performance information. KPIs are selected from an overarching set of PIs; and they include those that represent critical performance. The definitive set of PIs is identified through district and building energy reviews, including features such as energy structure, energy systems and energy flow analysis [25,31]. Therefore, these PIs reflect the basic performance concerns in the specific energy management context.

Tasks 7 and 8 focus on the identification and collection of master data, in addition to the calculation of the selected KPIs. The ever-increasing volume of monitored data relating to energy management is attributed to the accelerated adoption of ICTs. As a result, the concept of master data is introduced to represent the insightful core data that provides valuable information [32]. Precedents exist for the identification of key data using indicators and metrics [26,33], and such approaches are also applicable to master data collection. Master data include the key data for KPI calculation and performance analysis. It is sometimes necessary to review the existing data sources and to carry out further data collection. Additionally, KPI benchmarking against performance targets is especially important. If the performance targets are achieved, the final step would be to carry out an experiential study. Otherwise, tasks 9 and 10 need to be conducted in order to ascertain the performance problems and take measures to improve these. The approach proposed involves a process of continuous improvement until the final energy performance targets are achieved.

3 Stakeholder identification and prioritization analysis

This section presents a detailed method that identifies and analyzes stakeholders in the context of building to district scale energy management. Firstly, current practices for the identification and analysis of stakeholders are reviewed in Section 3.1. Thereafter, a newly developed three-task method (tasks 1-3 in Figure 1) for identifying and prioritizing stakeholders is illustrated in Section 3.2. The key components of which are the identification of intervention points for energy performance, the identification of stakeholders' roles and the prioritization of stakeholders.

3.1 Current practices for stakeholder identification and analysis

The current methods used for stakeholder identification and analysis usually focus on buisiness management, political science, development studies, project managment, and environment and natural resource management (ENRM). Mitchell et al. [34] proposed a theory of three relationship attriutes (i.e. power, legitimacy and urgency) for stakeholder identification and salience in a business context. Sharp et al. [35] developed an approach to identify the stakeholders involved in requirements engineering processes. Macaulay [36] identified four categories of stakeholders in relation to computer systems: 1) those who design and develop the system, 2) those who have a financial interest, 3) those who introduce and maintain the system and 4) those who are interested in using the system. In addition, Mok [37] studied stakeholder management in mega construction projects. Moreover, Colvin et al. [38] and Reed et al. [39] conducted a review of the current approaches to stakeholder identification in ENRM (Table 1).

Table 1 Common approaches to stakeholder identification and analysis in ENRM [38,39]

Approaches	Description
Geographical footprint	Through constructing a footprint of project impact, all individuals within that footprint are considered to be stakeholders.
Interests	Based on the interests triggered by a given issue (e.g. financial, lifestyle, sense of place, moral).
Influence	Involves analysis or brainstorming of all who may be able to influence the issue or project.
Intuition	Includes the use of tacit skills and understanding of the social dimension of the issues.
Key informants and snowballing	Individuals from initial stakeholder categories are interviewed, identifying new stakeholder categories and contacts.
Past experiences	It identifies stakeholders using reflection by the participants on their past experiences.
Stakeholder self-selection	Stakeholders can self-select for engagement in projects or issues of concern.
Focus group	A small group brainstorms stakeholders, their interests, influence and other attributes.
Semi-structured interviews	Uses interviews with a cross-section of stakeholders to check/supplement focus group data.
Social network analysis (SNA)	Uses structured interview/questionaire to identify the network of stakeholders.
Knowledge mapping	Identifies stakeholders who are particularly knowledgeable about a specific issue and determines how their knowledge is being used and by whom.
Q methodology	Stakeholders sort statements drawn from a concourse according to how much they agree with them.

Although there are different methods developed for stakeholder analysis in different disciplines, there is little information regarding how, when and why these methods are effective [39,40]. For example, the approaches of interests or influence usually involve a wide range of stakeholders, especially when applied to a project at a large scale. This undoubtedly increases the difficulty for stakeholder analysis and engagement, particularly when aiming to achieve a win-win situation. In addition, the methods of intuition and past experiences are predominantly subjective and depend greatly on practitioners' knowledge levels and partial opinions. Furthermore, commonly used techniques such as brainstorming, mind-mapping, generic stakeholder lists and studies of similar projects [41] usually contain stochastic processes for stakeholder identification. Given that some stakeholders are likely to be ignored, the list of identified stakeholders cannot be considered complete. Likewise, the methods mentioned above are all qualitative; a quantitative method by which to analyze and prioritize the stakeholders has not been addressed.

The importance of stakeholders has also been attracting growing interests and attention in the energy field. However, a common ground of the current studies in the energy field is that they only presented generic lists of stakeholders without addressing the method used to identify and analyze the stakeholders [42,43,44,45]. Stakeholder analysis and engagement are crucial to energy management as the complexity of energy operations at the district and building scales involves numerous actors. The present focus of energy managers is usually technical in nature and include specification of monitoring and control systems along with energy optimization techniques [46]. Although stakeholders are crucially important for successful implementations of energy management, it has been widely recognized that studies on stakeholder analysis in energy management are limited. Specifically, there is a lack of structured, well-functioning methods that can identify and prioritize stakeholders in the energy management context. In order to fill this gap, a structured three-task method will be developed in the following Section 3.2.

3.2 A three-task method for identifying and prioritizing stakeholders

Inspired by the study conducted by Macaulay [36], this work identified that potential stakeholders related to energy management are involved at different stages of the project's life cycle. The impact on energy performance occurs at various stages, most notably at the operation and maintenance stage by energy managers, but also during planning, design and construction stages by other stakeholders. The energy-related information can be gathered from the stakeholders at the different stages. Therefore, the life cycle is proposed as the time dimension used for the identification of stakeholders. Furthermore, due to the diversity of the energy operations at the district and building levels, integrated energy management involves multiple buildings, numerous systems, and equipment, all of which should be aligned spatially. Thus, the stakeholders, along with both the space and the time dimensions, are identified, resulting in a detailed method designed for identification and prioritization analysis, as illustrated in Figure 2.

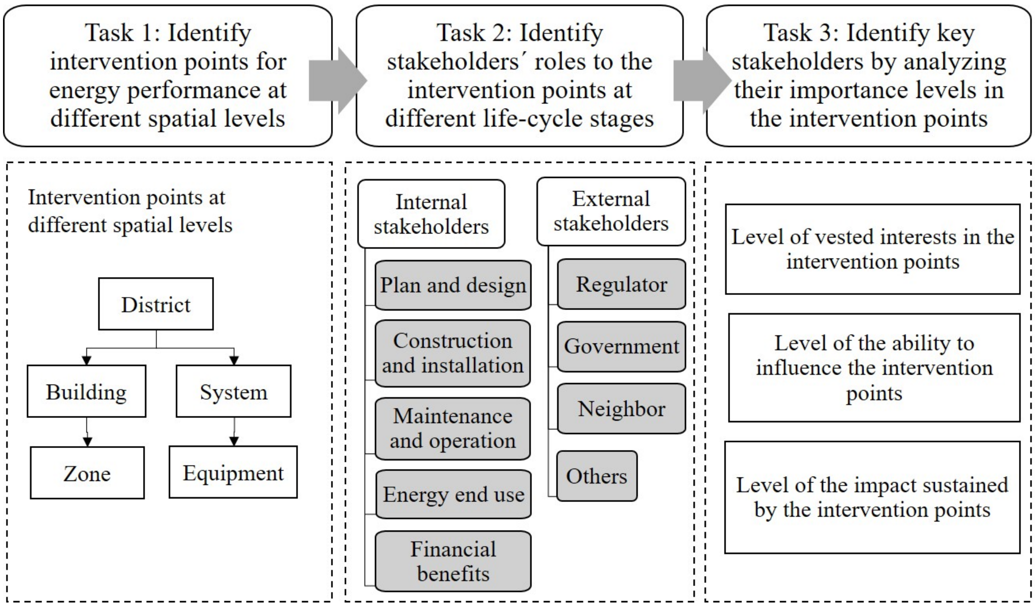


Figure 2: The three-task method to identify and prioritize stakeholders for enhanced multi-level energy management.

Task 1: Identify the intervention points for energy performance

Firstly, energy performance intervention points at the different spatial levels are identified as the entry points of the stakeholders. Intervention points were initially proposed by Bourdic and Salat [29] for modeling urban energy efficiency, emphasizing four points: urban morphology, building efficiency, system efficiency, and individual behavior. Although each of the points provides a different intervention mechanism for urban energy efficiency, they have limitations in terms of describing the complete aspects of energy management. For example, urban morphology omits the energy patterns in relation to district energy balance; building efficiency only accounts for passive designs [47] such as building envelopes, orientation and geometric parameters, excluding other aspects, such as the building’s function or indoor comfort. Therefore, energy managers are supposed to identify their own intervention points for energy performance.

The energy performance on the district scale can be described as a well-integrated structure of three levels, from top to bottom, namely the district level, the whole-building and system level, and the zone and equipment level (Figure 2). At each level, different intervention points can be identified, which influence various aspects of energy performance. As an example, Table 2 lists five typical intervention points at the three levels, and the performane aspects to which they relate.

Table 2: The five typical intervention points and their related aspects of energy performance [29]

Level	Intervention point	Related energy performance aspects
District	District energy profile	District energy balance, energy generation/use, renewable energy use, CO_2 emissions
Building and system	Building performance	Building thermal load, energy use, building energy balance, building comfort (indoor air quality, thermal comfort, lighting comfort), building usage function, CO_2 emissions, energy cost
	System efficiency	Energy efficiency, energy use, energy loss, energy cost
Zone and equipment	Equipment efficiency	Energy efficiency, energy use, energy loss, energy cost
	Occupant/consumer behavior	Energy demand, energy balance, energy peak curtailing and shifting, energy cost, building comfort

Task 2: Identification of the stakeholders' roles

Stakeholders from the different life cycle stages become involved in energy management through the different intervention points. Generally, stakeholders can be classified into two groups, internal and external [30]. Here, internal stakeholders are defined as those who participate directly in energy-related processes and intervene in various aspects of energy performance, while external stakeholders are those who do not participate in the energy-related processes but have a specific interest in, and/or are affected by, the outcomes of energy management.

The roles of internal stakeholders can be classified into five groups in accordance with the timing of different life cycle stages. They are as follows:

1) roles relating to planning and design which have an impact on and/or an interest in various intervention points;
2) roles pertaining to construction and installation which have an impact on and/or an interest in the intervention points;
3) roles relating to operation and maintenance which have an impact on and/or an interest in different intervention points;
4) roles concerning energy end use;
5) roles related to financial benefits which potentially involve a profit from energy management.

The analysis of the stakeholders' roles is aimed at formulating a complete list of stakeholders. Table 3 lists some common stakeholder roles involved at different intervention points and life cycle stages. The stakeholders may play multiple roles simultaneously. In addition, the external stakeholders who act as regulators are particularly important, since the regulations and rules involve basic legal requirements that should be fulfilled. Meanwhile, efficient feedback provided to regulators can improve the further implementation of the related regulations.

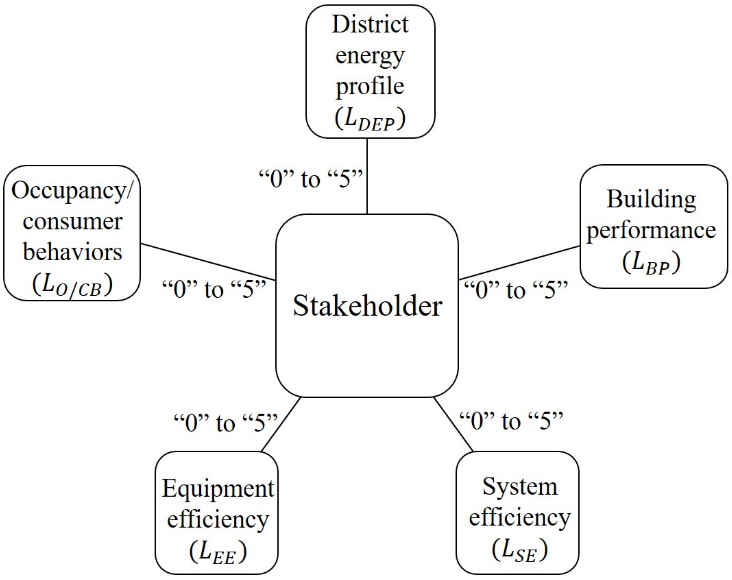
Table 3: A list of stakeholder roles involved in various intervention points

	Intervention Point / **Stage**	**District energy profile**	**Building performance and system efficiency**	**Equipment efficiency and occupant/ consumer behavior**
Internal	Planning and design	District planner, energy planner, energy engineer	Architect, electrical and mechanical engineer, energy engineer	Electrical and mechanical engineer, energy engineer
	Construction and installation		Construction company, equipment manufacturer, system installation company	Equipment manufacturer, equipment installation company
	Maintenance and operation	Distribution energy manager, asset manager	Building energy manager, facility manager, building solution provider, distribution energy manager, asset manager	Building energy manager, facility manager, asset manager
	Energy end use	Residential user, commercial user, office user, and institutional user	Occupant, building energy consumer/ prosumer	Occupant, building energy consumer/prosumer
	Financial benefits	Organization owner, energy supplier	Building owner/tenant, energy customer, organization owner	Building owner/tenant, energy customer, energy supplier
External		Central and local government, regulator, energy analyst, energy auditor		
		Environmental advocacy organization, local non-profit and community-based organization (environment/public health), neighbor		

Task 3: Prioritization analysis for the identification of key stakeholders

The stakeholders do not all have the same importance. Therefore, it is necessary to identify the key stakeholders who take precedence in terms of decision-making. By analyzing the importance of stakeholders at different intervention points, a prioritization analysis for the identification of the key stakeholders is performed.

To quantify the importance level, a 6-point Likert-type scale is used [48]. The rating scale varies from 0 to 5, where 0 represents the minimum importance, when the stakeholders have no relationship with the specific intervention point, and 5 represents the maximum importance. According to the definition of stakeholders [22], the importance level of a stakeholder regarding an intervention point is analyzed based on the level of his/her vested interests, the level of ability to influence, and the level of the impact sustained by the point. Thus, the more interest, influence, and/or impact a stakeholder has, the higher the rating is.



Legend:
"0" to "5" means the rating scale of a stakeholder's importance level for an intervention point.
L_{DEP}, L_{BP}, L_{SE}, L_{EE} *and* $L_{O/CB}$*, respectively, represent the importance level regarding district energy profile, building performance, system efficiency, equipment efficiency and occupancy/consumer behaviors.*

Figure 3: Analysis of a stakeholder's importance levels for the five typical intervention points.

For each intervention point, a rating value for each stakeholder can be obtained. As an example, Figure 3 depicts a stakeholder's importance levels for the five typical intervention points, where L_{DEP}, L_{BP}, L_{SE}, L_{EE} and $L_{O/CB}$, respectively represent the importance level regarding the district energy profile, building performance, system efficiency, equipment efficiency, and occupancy/consumer behaviors. Evaluating the sum of all rating points, as opposed to only using a single rating point, therefore identifies the overall importance of a stakeholder.

A summated rating scale [49] can be constructed to represent the comprehensive importance level of a stakeholder, the calculation of which is illustrated in equation (1). The value of the summated rating scale is defined as a Stakeholder Prioritization Index (SPI), since it determines the stakeholder's prioritization. The result of the SPI varies from 0 to 5. When the stakeholders have a value above the midpoint, they are identified as key stakeholders, taking precedence in relation to achieving their performance goals.

Equation: $SPI = (L_{DEP} + L_{BP} + L_{SE} + L_{EE} + L_{O/CB})/5$ *(1)*

4 KPI identification and selection

After identifying the stakeholders, the next step is to select the KPIs that underpin their performance goals. The current methods used for KPI identification are reviewed in Section 4.1. Afterwards, a KPI hierarchy for representing multi-level energy performance information is illustrated in Section 4.2. Finally, a bi-index method for weighting and selecting the KPIs that support stakeholders' performance goals is proposed in Section 4.3.

4.1 Current practices for KPI identification

Most of the current studies for KPI identification focus on formulating an ad-hoc list of KPIs, rather than developing a holistic method to identify KPIs [50,51,52,53]. Studies addressing different methods for KPI identification in different fields currently exist. For example, May et al. [54] proposed a 7-step methodology to develop firm-tailored energy-related KPIs for energy management in production and aim to measure energy efficiency performance of equipment, processes and factories. Xu et al. [27] used a three-step method to formulate a list of KPIs for the sustainability of building energy efficiency retrofit in hotel buildings. Such three steps include: (1) a literature review and in-depth interviews with industry experts and academic researchers for the filtration of KPIs; (2) a questionnaire based survey of various expert groups that analyzses the significance of selected indicators; and (3) fuzzy set theory for identification of the KPIs.

Literature reviews, interviews with industry experts and academic researchers, and questionnaire based surveys are the most commonly used methods for KPI identidication [55,56,57,58,59]. However, the experts' opinions are usually subjective, invoving fuzziness [27]. Fuzzy set theory can to some extent address this issue. In any case, involving all of the relevant stakeholders is essential for identification of the appropriate KPIs that represent the business objectives for a specific case. Therefore, stakeholders' consensus with further validation is also frequently used for KPI identification. The study of González-Gil [28] followed a consensus oriented process to develop KPIs for energy management of urban rail systems. Teixeira et al. [60] used the consensus between experts and stakeholders to select indicators for energy management in water services. The stakeholders' consensus and validation are qualitative means by which to select KPIs. A previous study by Chen et al. [61] proposed an energy-time consumption index (ETI) to select KPIs for intelligent building lifespan assessment; this involves a quantitative approach but fails to consider stakeholders' involvement.

In addition, Peral et al. [62] used data mining techniques to obtain specific KPIs for business objectives in a semi-automated manner. This approach requires existing data sources as opposed to existing KPI lists or test candidate KPIs over a cycle. Furthermore, Analytic Hierarchy Process (AHP) or Analytic Network

Process (ANP) which is a multi-criteria decision-making method is also used for identifying KPIs and defining their importance. For example, Shah et al. [63] and Alwaer et al. [64] used the method of AHP to evaluate the importance of KPIs for sustainable intelligent buildings. Khalil et al. [65] adopoted the AHP to rank indicators of building performance. Carlucci [66] proposed an ANP-based model for driving managers in the selection of KPIs. Kucukaltan et al. [67] proposed a decision support model based on the ANP for identification and prioritization of KPIs in the logistics industry. The pillars of AHP for selecting and ranking KPIs are the selected criteria for decision-making. However, such criteria are usually identified based on a literature review or the judgement of the experts. Therefore, the priority levels for a selected criterion is largely dependent on the experience and knowledge of the experts. Furthermore, even though the decision-makers are all experts, results can sometimes be very subjective. To avoid this, an effort must be made during the process of selecting KPIs to be more objective whilst including all relevant stakeholders.

Therefore, a bi-index method will be developed in order to select the KPIs that underpin and balance stakeholders' performance goals in energy management. The proposed method aims to provide a quantitative and more objective means by which to weight and validate the KPIs.

4.2 A multi-level KPI hierarchy

In order to track multi-level energy performance, the KPIs are illustrated on three levels. According to the principles of facility management [68], the hierarchy of KPIs can be presented as strategic, tactical, and operational; each of these refers to different decision levels. Similarly, the KPIs related to energy management can also follow these levels. In addition, different decision levels can relate to different aggregation levels and scales [69], as shown in Figure 4. The strategic KPI is aggregated and designed for the district level. The tactical KPI can be disaggregated from the strategic equivalent and associated with the building and system level. The operational KPIs represent the operational performance of basic energy units such as equipment and zones. This hierarchy has the advantage of distributing the different KPIs at different levels, but in an interrelated form and maintaining their interdependences.

Decisional level	**Aggregation level**	**Scale**
Strategic	Aggregated	District
Tactical	Disaggregated	Building and System
Operational	Appliance	Zone and Equipment unit

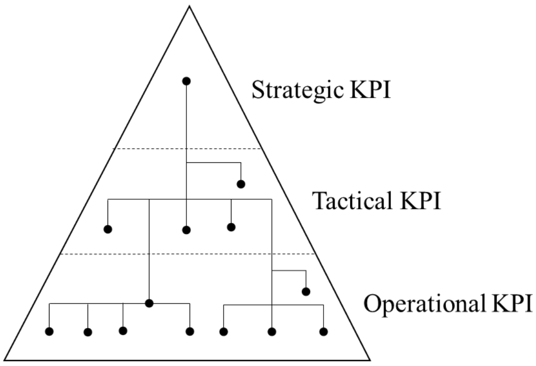


Figure 4: The three dimensions of strategic, tactical, and operational KPIs [68,69]

4.3 A bi-index method for KPI identification and selection

Prior to the selection of the KPIs, a pre-list of PIs should be devised. The PIs should represent the basic performance concerns in the energy management context. Therefore, the guidance of ISO 50001 [25] is used. The PIs are defined through an energy review, which includes the analysis of the energy structure (e.g. electricity, gas), the energy systems (e.g. generation and consumption systems), and the energy flow (e.g. energy distribution and end use) [31]. Since a considerable amount of energy PIs already exist, a literature review of the previous indicators can assist in identifying those that can be reused. When necessary, new PIs can also be developed; a PI can be a simple measurement value, a metric or a complex model.

Since the KPIs are the key indicators that measure the key performance goals, this implies that only the most critical PIs should be selected as KPIs. A bi-index method is proposed in order to identify the KPIs that underpin the stakeholders' goals. The two indexes are the Stakeholder Prioritization Index (SPI), as proposed in Section 3.2, and a Stakeholder Vote Index (SVI).

The SVI is determined via interviews with stakeholders. The stakeholders grade the PIs from 0 to 5 based on a 6-point Likert-type scale, where 0 means that the PIs are not related to the stakeholders, while 5 means that the PIs are of the most importance to them. The issue of whether a PI is selected as a KPI depends on the summated rating scale decided by the votes from all of the stakeholders. Therefore, a comprehensive index (CI) is defined to represent the value of this summated rating scale. The calculation of CI follows equation (2), where SVI_{Si} represents the vote of stakeholder i, and w_i represents the weighting factor of the vote of stakeholder i. The purpose of the weighting factor is to prevent the stakeholders from maximizing their own benefits at the expense of others. The sum of w_i is designed to be 1, which ensures that the rating value also varies from 0 to 5. To decide the value of each weighting factor, the SPI that represents the prioritization of the specific stakeholder is used. The calculation of the weighting factor follows equation (3), where SPI_{Si} represents the SPI of stakeholder i.

Equation: $CI = \sum_{i=1}^{n}(w_i * SVI_{Si})$, where $\sum_{i=1}^{n} w_i = 1$. *(2)*

Equation: $w_i = SPI_{Si} / \sum_{i=1}^{n} SPI_{Si}$ *(3)*

Considering both the stakeholders' votes and their prioritization, the CI can guarantee that the selected KPIs not only support the stakeholders' performance goals, but also balance their benefits. The value of the CI determines whether the PI will be chosen as a KPI or not. If it is higher than the average rating value of 2.5, the PI will be considered a KPI. The final list of the selected KPIs should be validated again by the stakeholders [28].

5 Case study

In order to demonstrate the feasibility of the proposed method, a case study was performed, based on the competition site of Solar Decathlon Europe (SDE) 2012,[2] located in Madrid, Spain. SDE is a global competition involving high-efficiency solar houses equipped with photovoltaic (PV) panels, aimed at creating zero-energy buildings. There were 18 solar houses, together with several public service buildings, connected using a microgrid. Thus, a small district, called the Villa Solar, was formed. All of the solar houses in the Villa Solar have energy management systems. They were monitored from September 17th to 28th, 2012, as was the microgrid.

In order to extract the key performance information that underpin the stakeholders' goals, the following Sections 5.1 and 5.2 elaborate, respectively, the identification of key stakeholders using the three-task method and the selection of KPIs using the bi-index method. Section 5.3 illustrates the analysis of three representative KPIs in order to validate the benefits of the proposed method for supporting multi-level energy performance analysis.

5.1 Stakeholder identification and prioritization analysis

Task 1: Identify intervention points for energy performance

As proposed in Section 3.2, the identification of intervention points is conducted at different spatial levels. In this case, the points at the district level are identified as a district energy profile, which comprises both the building stock form and the district energy system form. As the buildings of the district have different

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[2] Solar Decathlon Europe 2012, (2012). http://www.sdeurope.org/

functions, the building stock form indicates their functional type, density and construction year. The district energy system form represents the energy types and features of energy generation, delivery and consumption systems. Then, at the whole building and system level, the building performance depends on the aspects of passive building design as well as the realization of the building's comfort and function during the post-occupancy period. The systems' efficiency can be divided into district energy and building energy systems' efficiency. Furthermlore, since inefficient equipment and the inappropriate operation of the equipment will have an impact on the level of energy use in the buildings, at the zone and equipment level, the equipment efficiency has also been considered as an intervention point. Lastly, the occupants' behavior is one of the most important factors, since it significantly impacts upon the energy demand, and has an impact on the energy balance in the solar houses.

The overall intervention points used in the Villa Solar are as follows:

- the district energy profile (building stock form and district energy system form);
- the building performance (passive efficiency, indoor comfort, and building function);
- the systems' efficiency (district energy systems' efficiency and building energy systems' efficiency);
- the equipment efficiency and the occupants' behavior.

Task 2: Identification of the stakeholders' roles

Subsequently, the internal stakeholders from different life cycle stages are identified in the context of each intervention point.

At the district scale, the stakeholder that plays the role of the district planner is a planning group that allocates the construction site and plot area of each building. The stakeholders who act as energy planners are the district energy engineers. Such energy engineers also serve as district energy managers during the operation and maintenance stage. A microgrid system company typically sells and installs the components of the microgrid and also plays the role of asset manager. The buildings are the energy consumers or prosumers which produce electricity through installed PV systems. The energy supplier receives surplus energy from the solar houses.

At the building scale, individual buildings have a number of internal stakeholders across the building life cycle. Each building has its own architects for building design and its own electrical and mechanical engineers for energy system design. Additionally, each building has a technical construction company for building construction and system installation and commissioning. The systems and equipment are supplied by various manufacturers. During operation stage, a building energy manager operates each solar house. Such energy managers also act as facility managers. The occupants in each building are also the energy consumers, whose behavior has a direct effect on energy usage.

To align the identified internal stakeholders with their involved intervation points, Figure 5 illustrates the stakeholders in a two-dimensional map according to the life cycle stages and the intervention points at different spatial leves. For example, the district planning group, energy supplier and district energy engineers determines in the district energy profile (building stock form or district energy system form); the building owners influence building performance and the efficiency of the building systems and equipment; building energy managers are key for indoor comfort and the building function (subpoints of building performance), in addition to the efficiency of systems and equipment; the occupants decide the energy use behaviors and influence the overall building performance.

When considering external stakeholders, the organizing committee of the competition is the most important. This committee creates the competition rules that each solar house should follow and such rules should be implemented for both building design and operation.

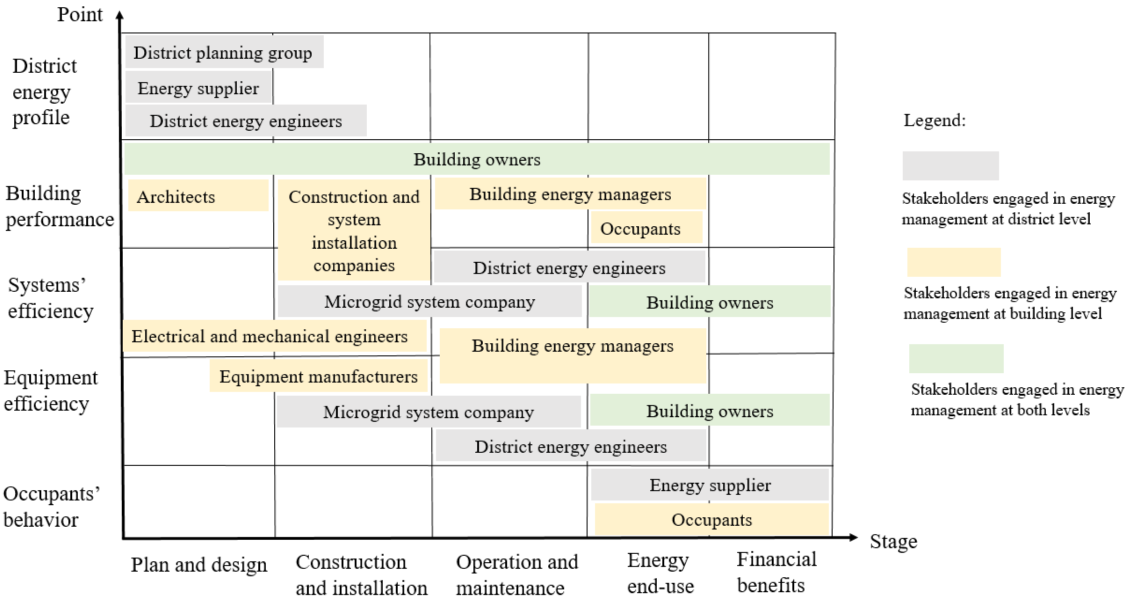

Figure 5: The internal stakeholders identified for energy management in Villa Solar.

Task 3: Analysis of key stakeholders

After identification of the stakeholders, the next step is to rate their importance levels at the identified intervention points. An impact/interest matrix [70] analyzes and presents the rating value concerning stakeholders' importance for each intervention point, for example, stakeholders' importance levels in the district energy profile (Figure 6). The district planning group and the district energy engineers are key players at this intervention point as they directly influence and have a high level of interest in building stock form and district energy system form. Thereby, they have a rating value of 5. In addition, the energy supplier and the microgrid system company have a high level of interest in the district energy profile but have a low level of impact at this point; thus, they are assigned a rating value of 3. Finally, the building owners need to know the district energy profile in order to fulfill the building's requirements but their interest or influence in the overall district energy profile is not as high as the energy supplier or the microgrid system company. Moreover, building owners have a low impact at this intervention point. Thus, they are considered to have the least importance, and are assigned a rating value of 2. The organizing committee of the competition makes the rules for the Villa Solar and the solar houses; therefore, it has a high level of interest in and a high impact at this intervention point.

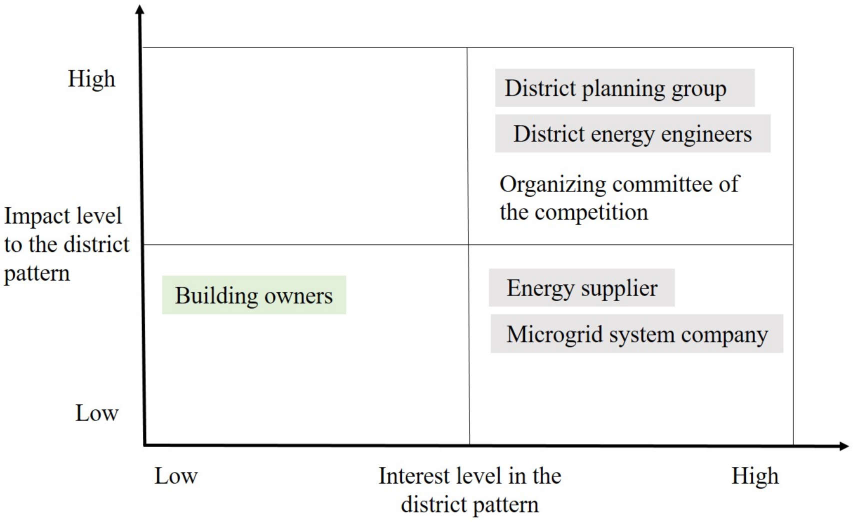

Figure 6: Levels of stakeholders' importance in regard to the district energy profile (L_{DEP}).

With a similar analysis, the levels of stakeholders' importance at the other four intervention points have also been identified, and are summarized in Table 4. The SPI is calculated using equation (1). The result of the SPI indicates that the stakeholders who only undertake the design and construction stages have a lower priority, while the stakeholders who are maintenance and operations staff, end-users and financial beneficiaries are of more importance in energy management. Six groups of stakeholders have SPI values which are higher than the average; therefore, they are identified as key stakeholders (namely, the district energy engineers, the microgrid system company, the building owners, the building energy managers, the occupants, and the organizing committee of the competition).

Table 4: Prioritization analysis for the identification of key stakeholders.

Scale	**Stakeholder**	**Degree of concern in relation to the intervention points**					**SPI**
		L_{DP}	L_{BP}	L_{SE}	L_{EE}	$L_{O/CB}$	
District	District planning group	5	2	0	0	0	1.4
	District energy engineers	5	2	5	4	3	3.8
	Microgrid system company	3	2	5	5	0	3
	Energy supplier of the main grid	3	0	3	2	3	2.2
	Building owners	2	5	4	3	4	3.6
Building	Architects	0	5	0	0	0	1.0
	Electrical and mechanical engineers	0	4	5	5	0	2.8
	Construction and system installation companies	0	3	4	3	0	2.0
	Equipment manufacturers	0	4	3	4	0	2.2
	Building energy managers	0	5	5	5	4	3.8
	Occupants	0	5	4	4	5	3.6
	Organizing committee of the competition	5	5	5	5	0	4.0

5.2 KPI identification and selection

This step is aimed at identifying the KPIs that underpin the stakeholders' performance goals. Firstly, a preliminary review of the district's energy structure, flow, and systems is conducted in order to formulate a pre-list of PIs for the selection of KPIs. Through the preliminary energy review, together with a literature review of previous studies addressing KPIs in the smart grid [50,71] and individual buildings [33,72,73,74], a list of 35 PIs is proposed for the candidate KPIs. The description and calculation of each PI are listed in Appendix A.

To select the KPIs among the proposed PIs, the CI is calculated using the SPI and SVI. The value of the SPI for each stakeholder has been indicated in Section 5.1. Therefore, the SVI should be decided through interviews involving the participation of stakeholders. Since the case scenario originated in 2012, many of the stakeholders could not complete this task. Therefore, only the representatives of the key stakeholders participated in the vote on the PIs.

Table 5 reveals the values of the SVI from the key stakeholders. The weighting factors for the SVI of each stakeholder is determined by equation (3). As a result, the weighting factors for the relevant stakeholders are as follows: district energy engineers (S1=0.174), microgrid system company (S2=0.138), building owners (S3=0.165), building energy managers (S4=0.174), occupants (S5=0.165), the organizing committee (S6=0.183). The values of the CI are calculated using equation (2). The result indicates that 23 indicators have a higher value than the average of the rating scale and are therefore chosen as the KPIs. Remaining PIs are treated as supporting indicators.

Table 5: The values of the SVI from key stakeholders and the CI for weighting the KPIs

Tag	Performance Indicators (PIs)	SVI						CI
		S1	S2	S3	S4	S5	S6	
I01	Reduction in CO_2 emissions	5	2	4	5	3	5	4.1
I02	Energy cost saving	4	5	5	5	5	5	4.8
I03	District energy balance	5	4	1	3	1	5	3.2
I04	Overall energy use reduction	5	4	5	5	5	5	4.9
I05	Individual building energy balance	1	3	5	5	1	5	3.4
I06	Inter-building energy balance	3	3	2	3	1	2	2.3
I07	Time correlation between energy generation and use	5	3	5	5	5	5	4.7
I08	Peak demand reduction	5	3	1	3	1	2	2.5
I09	Renewable energy share	5	2	5	5	4	5	4.4
I10	System performance	4	5	4	5	4	4	4.3
I11	Energy loss reduction	5	4	3	4	2	1	3.1
I12	Generation system efficiency	4	5	3	5	3	3	3.8
I13	Storage system efficiency	4	5	2	2	1	1	2.4
I14	Distribution system efficiency	5	5	1	1	1	1	2.2
I15	Consumption system efficiency	3	2	4	4	4	4	3.6
I16	Single-building energy use reduction	2	1	5	5	5	5	3.9
I17	Significant energy use reduction	3	1	5	5	5	3	3.7
I18	Building functionality	3	3	5	5	5	5	4.4
I19	Building comfort	1	1	4	5	5	5	3.6
I20	Purchased energy use reduction	4	4	5	5	5	1	4.0
I21	Purchased energy at a lower price	1	1	1	1	1	1	1.0
I22	Influence of energy storage on cutting peak demand	4	3	1	2	1	1	2.0
I23	Influence of TOU energy price on cutting peak demand	1	1	1	1	1	1	1.0
I24	Accuracy of the prediction of the energy supply and demand	5	1	1	3	1	1	2.0
I25	Capacity factor	4	5	1	1	1	1	2.1
I26	Equipment energy efficiency	4	5	4	5	5	4	4.5
I27	Operational schedule and occupancy consistency	3	1	2	5	3	1	2.5
I28	Occupancy stability indicator	3	1	2	4	1	1	2.0
I29	Thermal load reduction	3	1	5	5	5	5	4.1
I30	Thermal comfort	1	1	3	5	5	5	3.4
I31	Light comfort	1	1	3	5	5	5	3.4
I32	Appropriate temperature	1	1	3	5	5	5	3.4
I33	Appropriate humidity	1	1	3	5	5	5	3.4
I34	Appropriate amount of fresh air	1	1	3	5	5	5	3.4
I35	Consumers' participation	5	2	1	5	1	1	2.5

Note: S1: district energy engineers; S2: microgrid system company; S3: building owners; S4: building energy managers; S5: occupants; S6: organizing committee of the competition.

The selected KPIs and the supporting indicators can be represented in the three-level hierarchy, including interrelationships, where KPIs are highlighted in yellow (Figure 7). The strategic KPIs I01 to I04 are hyper-aggregated at the district level. These KPIs represent the four main energy performance aspects in energy management, namely: CO_2 emissions reduction, energy cost saving, energy balance, and energy use reduction. Meanwhile, I05 to I21 are disaggregated from the strategic KPIs at the building and system level, and I22 to I35 are the underlying PIs at the operational level.

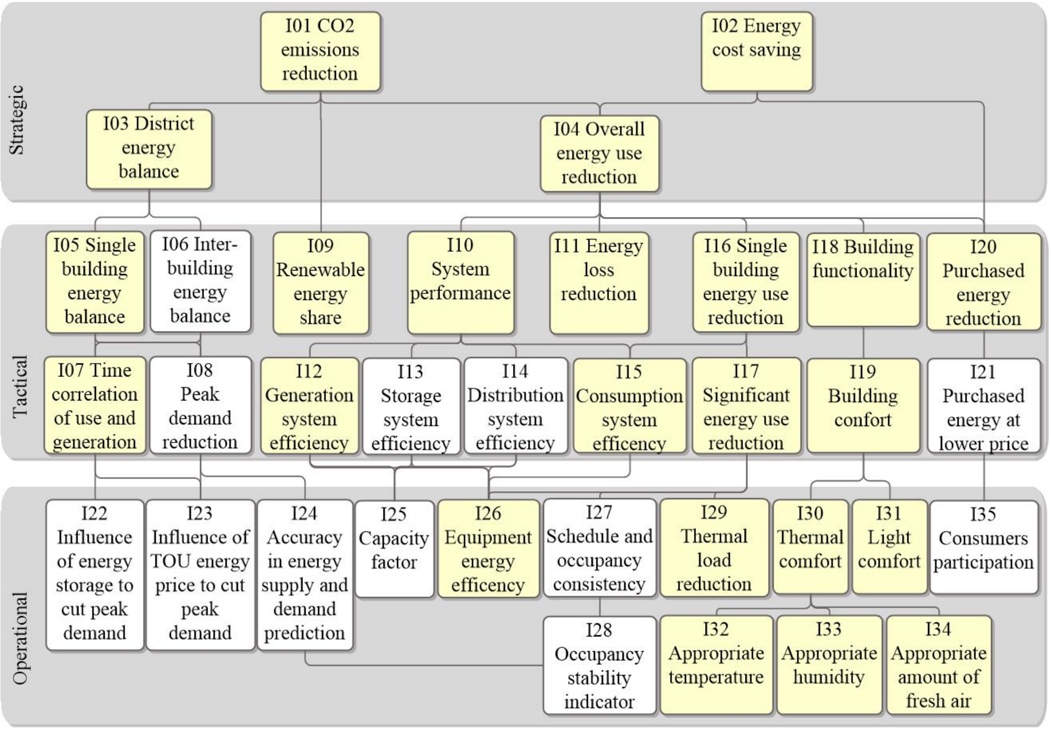

Figure 7: The hierarchy of the KPIs (highlighted in yellow) and their relationship with the supporting PIs.

In addition to the KPI hierarchy, new KPIs are also defined. One example is I02 (energy cost saving), which calculates the energy cost by considering both the energy purchase from the external grid and the energy sale to the external grid (equation (4)). The total energy cost is the difference between the cost of purchasing energy and the benefits of selling energy, which are, respectively, determined by the energy cost tariff and the feed-in tariff. When the value is negative, it means that economic profits have been obtained from the surplus energy.

Equation:

$$I02 = E_{Purchase} \times Tariff_{Energy\_cost} - E_{Sale} \times Tariff_{Feed\_in} \qquad (4)$$

Another new KPI is I07 (time correlation between energy generation and use) where T represents the time interval in which the power generated behind the meter did not cover the demand (equation (5)). I07 measures the total amount of unidirectional energy imported from the external grid. When its value is 0, no external power is imported, thereby achieving the targeted level of performance.

$$\text{Equation: } I07 = \int_0^T P_{Demand\_uncovered\_by\_site\_generation}\, dt \qquad (5)$$

5.3 Multi-level energy performance analysis

The selected KPIs aim at supporting the multi-level energy performance analysis for achieving stakeholders' goals. Three representative KPIs in relation to energy balance (I03, I05 and I07) were analyzed.

I03 (district energy balance) measures the difference between the total amount of energy generation and consumption in the district during a time step. If the result is 0, the district's energy balance is achieved. If the result is positive, the surplus energy will be exported to the external grid. Finally, if the result is negative, the performance target is considered to be unfulfilled. Figure 8 reveals the results of I03 and the supporting indicator I06 (inter-building energy balance), taking the evaluation time step as one day. This result implies that the district energy balance has not been achieved during the monitored days. The reason is that the energy generated by the solar houses did not suffice to cover the demand in the public service buildings. The solar houses always generated surplus energy, with the exception of two days: September 27th and 28th.

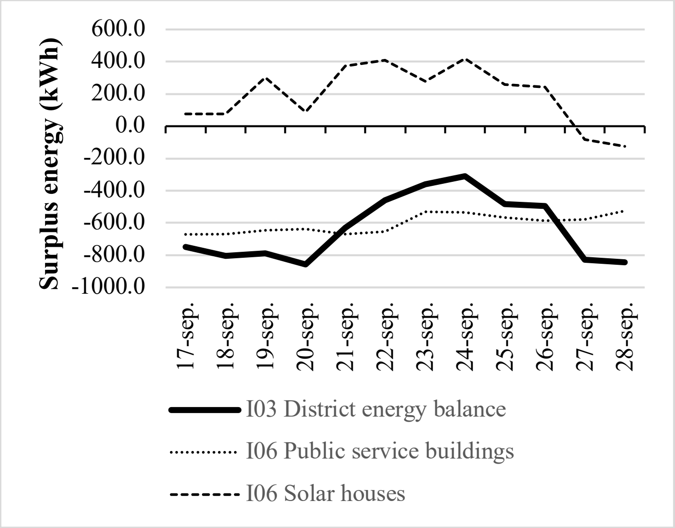

Figure 8: The results of I03 (district energy balance) and I06 (inter-building energy balance).

In order to evaluate and compare the performance of each solar house, the disaggregated indicator I05 (individual building energy balance) has also been calculated. Figure 9 presents the results of I05. The color gradient shows the amount of surplus energy generated. It indicates that, on September 27th and 28th, almost all of the solar houses did not achieve the required energy balance. Since solar energy generation depends heavily on weather conditions, the global horizontal and inclined 41° (best angel in Madrid) solar radiation have been examined, as shown in Figure 10. It shows that the solar radiation on September 27th and 28th was much lower than the other days, which is the reason for the energy imbalance on these days.

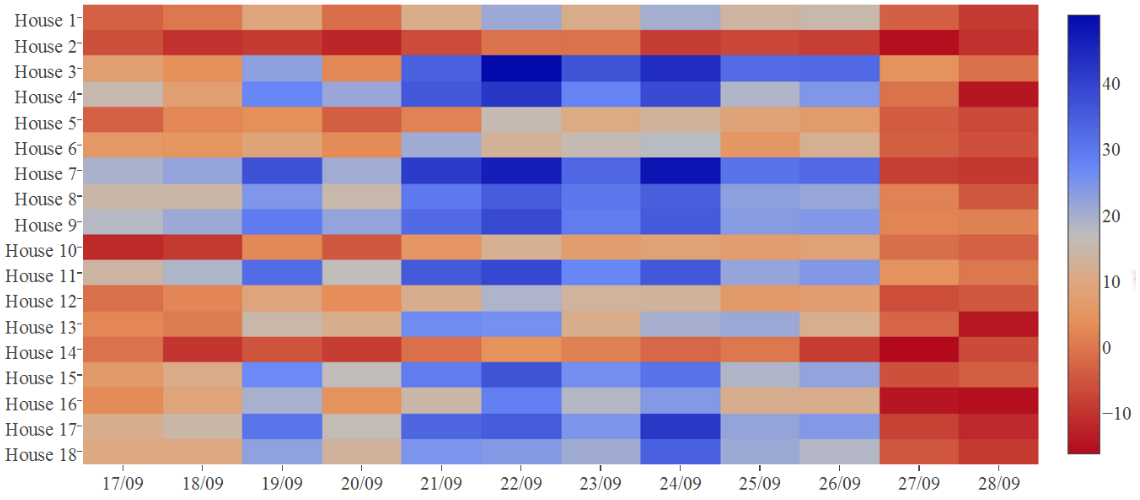

Figure 9: The results of I05 (individual building energy balance) (unit: kWh)

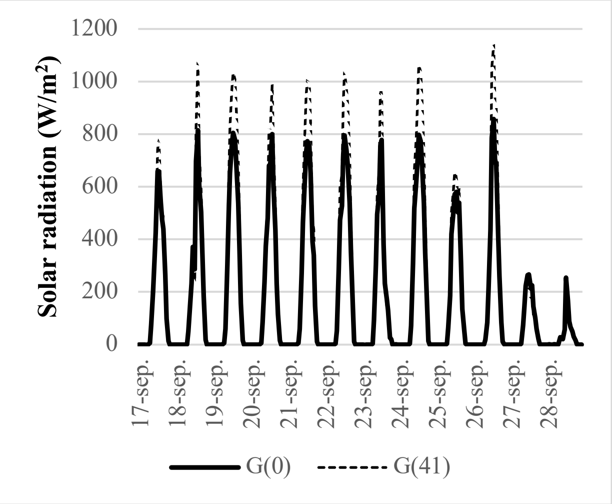

Figure 10: Global horizontal solar radiation (G(0)) and global inclined 41° solar radiation (G(41)).

With the results of I05, the energy balance performance of each solar house can be compared. It has been found that Solar House 2 and Solar House 14 had the worst performance in terms of energy balance. In order to ascertain the reason for this, the generated and consumed power in these two houses were analyzed, as shown in Figure 11 (a) and (b). This implies that Solar House 2 had problems with its PV system, as its energy generation was so low that it could almost be ignored. The PV system of Solar House 14 ran very inefficiently, since the power output was less than 2.5 kW, although the capacity of the PV system was 8.8 kW.

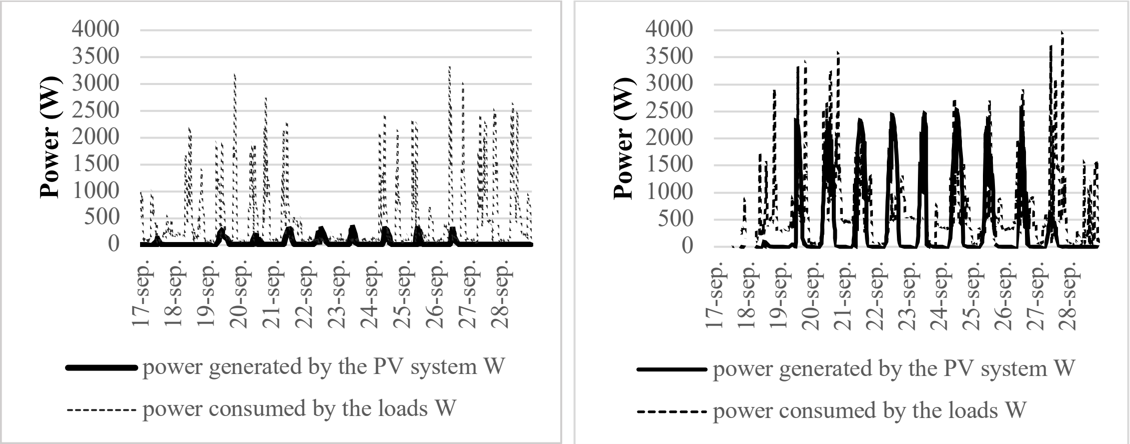

Figure 11: Power generated and consumed in Solar House 2 and Solar House 14: (a) power generated and consumed in Solar House 2; (b) power generated and consumed in Solar House 14

Finally, I07 (time correlation between energy generation and use) was analyzed. Figure 12 illustrates the results of I07. It implies that most of the solar houses needed to import energy from the external grid, although they generated surplus energy during the day, because they did not achieve the required time correlation between energy generation and use. Time correlation is one of the most difficult challenges.

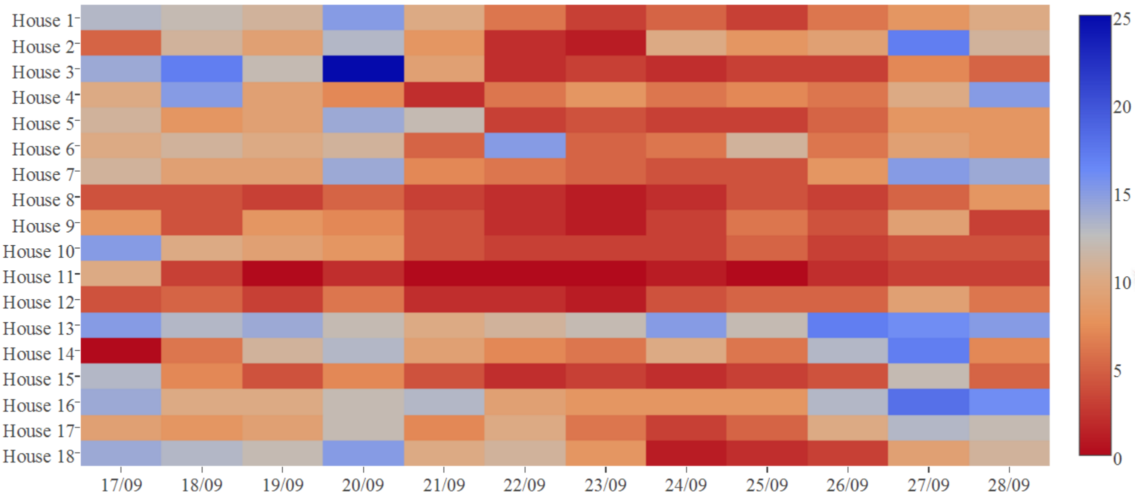

Figure 12: The results of I07 (time correlation between energy generation and use) (unit: kWh)

Taking Solar House 13 as an example, it imported 162 kWh in total during the days monitored, while, according to I05, it had 123.4 kWh of surplus energy. Figure 13 presents the generated and consumed power in Solar House 13 from September 21st to 25th. It reveals that the power generated was much higher than the power consumed. However, most of the energy consumption occurred during times that involved no energy generation. To improve the performance in this case, adjustments in the occupants' behavior or the utilization of energy storage are possible solutions.

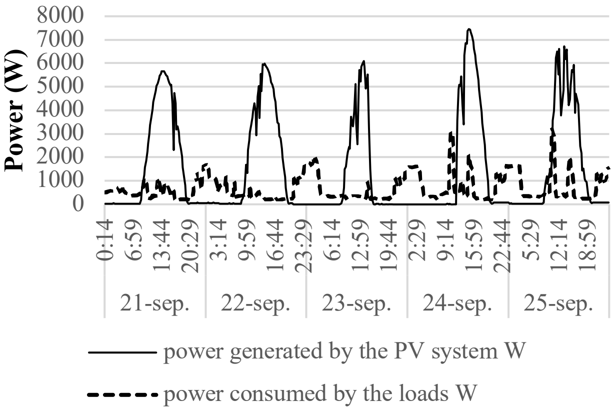

Figure 13: Power generated and consumed in Solar House 13 from 21st September to 25th September.

6 Discussion

This work demonstrates the feasibility of the proposed methodology for identifying key stakeholders and selecting KPIs that support multi-level performance analysis. Using the three-task method, 12 groups of stakeholders were identified, among which six groups were considered to be key stakeholders. Compared to current practice, which usually identifies stakeholders arbitrarily and presents them in a simple list, the proposed method provides an explicit evidence-based means to analyze stakeholders in accordance with different intervention points and various life cycle stages. Furthermore, the proposed approach illustrates identified stakeholders in a two-dimensional stakeholders' map. Analysis of stakeholders confirms that the use of intervention points facilitates identification of stakeholders' roles. Moreover, the definition of the SPI offers a quantitative means for stakeholder prioritization. The calculation of the SPI is based on the levels of stakeholders' importance in relation to different intervention points as determined through analyzing the impact/interest matrix. Considering that the impact/interest matrix is only an approximate means by which to analyze the importance of stakeholders, a further study will consider the introduction of a stage impact factor for the prioritization analysis as stakeholders influence the intervention points to different extents at different life-cycle stages. Furthermore, the current analysis considers different intervention points as having the same importance. An improvement could be made in relation to weighting different intervention points based on their significance for energy management.

Subsequently, using the bi-index method, 23 KPIs were selected among the pre-list of 35 PIs proposed in the case study. The PIs identified by the energy review confirmed that different energy performance information concerning the energy management context is represented by the indicators. The SVI for each PI is weighted by the SPI of the associated stakeholder; this validates the advantage of the proposed method to balance the stakeholders' benefits in accordance with their importance. Instead, the current practices for KPI selection always involves only stakeholders' consensus or validation, without any consideration of stakeholders' prioritization. Furthermore, the comprehensive index calculated by the SVI and the SPI provides a quantitative means by which to weight each indicator and select the KPIs. The KPIs are structured according to the three-level hierarchy and show their ability to underpin multi-level key performance information. Furthermore, new KPIs were also defined, such as I02 (energy cost saving) and I07 (time correlation between energy generation and use).

Finally, the analysis of I03, I05, and I07 validates the benefits of the proposed methodology to support multi-level energy performance analysis. The results reveal that the performance goal of I03 (district energy balance) was not achieved but most solar houses achieved their individual building energy balance. Furthermore, although I05 (individual building energy balance) had a desirable level of performance, the solar houses had an unsatisfactory performance in relation to I07 (time correlation between energy generation and use). The results of the three indicators demonstrate the interrelationship between high-level aggregated KPIs and low-level disaggregated KPIs. These indicators also illustrate the advantages of addressing performance problems at different levels in order to achieve stakeholders' performance goals.

7 Conclusions and future work

Integrated energy management at both the district and building levels is a multi-stakeholder, cross-domain issue. There are many potential stakeholders and a vast amount of information involved. This paper proposed a systematic approach for determining the key stakeholders and extracting the key information for multi-level energy performance analysis. In doing so, a three-task method defines a novel, structured means by which to identify and prioritize stakeholders. Meanwhile, a bi-index method provides a quantitative approach to weigh and select the KPIs that represent the key performance information and underpin the stakeholders' key performance goals.

The selected KPIs facilitate multi-level energy performance analysis for identifying energy performance problems at different levels. This is demonstrated through the case study, which illustrates how to leverage the proposed three-task method for stakeholder analysis, and how to use the bi-index method for weighing and selecting KPIs. Analysis of three representative KPIs proves the multi-level relationship between the KPIs and the benefits of the proposed methodology in terms of identifying performance problems and helping stakeholders to achieve their goals.

Stakeholders' engagement is of the utmost importance for enhanced energy management at district and building levels, since the distributed energy and information sources usually belong to different actors. The identification of stakeholders and the determination of their prioritization will contribute to devise an appropriate, effective engagement mechnisim among stakeholders for optimal decision-making in terms of energy performance improvement. To represent stakeholders' performance goals in a way that can be measured and tracked, multi-level KPIs are selected. The sharing of multi-level key performance information between the identified stakeholders can enable a more thorough performance analysis and helps to identify more profound energy performance problems. In a context which contains various building prosumers as the case study, the involvement of stakeholders and their exchange of key performance information will further facilitate energy sharing between various buildings in order to benefit from available surplus energy. The prioritization of stakeholders identifies the key stakeholders who take precedence in decision-making, which further determines the KPIs that underpin the key performance goals. The priority order in decision-making can effectively manage and obtain a trade-off between the needs of various stakeholders. This helps to rank the tasks for energy performance improvement according to their significance to the stakeholders.

Future work will focus on improving the proposed method in terms of stakeholders' prioritization and developing an ontology to describe the interrelationship between different stakeholders, KPIs, and master data in order to facilitate the sharing and exploitation of the key performance information and master data gathered from various stakeholders.

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Appendix A: Definition and calculation of the proposed PIs

Tag	**Performance Indicator (PI)**	**Description**	**Calculation**	**Unit**
I01	CO_2 emissions reduction	Reduction of CO_2 emissions by energy savings and renewable energy use	$E_{Fossil\_fuel\_replaced\_by\_renewables} * Conversion\_factor_{CO_2}$	kg
I02	Energy cost saving	Total energy cost saving caused by reducing purchased energy and/or selling surplus energy	$(E_{Purchase} \times Tariff_{Energy\_cost}) - (E_{Sale} \times Tariff_{Feed\_in})$	€
I03	District energy balance	The balance between enery generation and consumption at the district level during given time step (TS)	$E_{District\_generation} - E_{District\_consumption}$	kWh

I04	Overall energy use reduction	Total site energy use reduction due to global energy efficiency improvement	$E_{District\_consumption}$ (site energy use measurement)	kWh
I05	Individual building energy balance	Energy balance between building integrated energy generation and consumption in given TS	$E_{Building\_generation} - E_{Building\_consumption}$	kWh
I06	Inter-building energy balance	Energy balance between generation and consumption among several buildings	$\sum_{1}^{n} E_{Building\_generation} - \sum_{1}^{n} E_{Building\_consumption}$	kWh
I07	Time correlation between energy generation and use	Time correlation between energy generation and use for instantaneous energy balance	$\int_{0}^{T} P_{Demand\_uncovered\_by\_site\_generation}$	kWh
I08	Peak demand reduction	Curtailment of peak demand by adjusting energy demand	$\frac{P_{Average\_demand}}{P_{Peak\_demand}}$	kW/kW
I09	Renewable energy share	The deployment level of renewable energy in districts and buildings	$\frac{E_{Total\_renewable\_generation}}{E_{Total\_consumption}} * 100\%$	%
I10	System performance	A summary indicator measuring the global efficiency of the energy system	$\frac{E_{Desired\_output}}{E_{Input}} * 100\%$	%
I11	Energy loss reduction	Level of losses in the storage and distribution system in a given TS	$\frac{E_{Supply} - E_{Consumption}}{E_{Consumption}}$	kWh/kWh
I12	Generation system efficiency	Energy efficiency of energy generation system at a given time	$\frac{P_{Generation}}{P_{Solar\_radiation}} * 100\%$	%
I13	Storage system efficiency	System efficiency accounting for energy losses in the storage system in a given TS	$\frac{E_{Storage\_output}}{E_{Storage\_input}} * 100\%$	%
I14	Distribution system efficiency	System efficiency accounting for energy losses incurred in transporting energy at a given time	$\frac{P_{Distribution\_output}}{P_{Distribution\_input}} * 100\%$	%
I15	Consumption system efficiency	Energy efficiency of energy consumption systems at a given time	$\frac{P_{System\_output}}{P_{System\_input}} * 100\%$ (or COP)	%
I16	Single-building energy use reduction	Energy use reduction in a building within a given TS. A lower value means more energy saving or efficiency	$\frac{E_{Building\_consumption}}{V_{Air\_conditioned\_volume}}$	kWh/m^3
I17	Significant energy use reduction	The reduction of significant energy use, such as HVAC, lighting system, etc.	$\frac{E_{Significant\_energy\_use}}{E_{Building\_consumption}}$	kWh/kWh
I18	Building functionality	A summary indicator assessing the overall function in a building	$Vote_{Building\_consumer/occupant}$	-
I19	Building comfort	A summary indicator assessing the overall comfort in a building	$Vote_{Building\_occupant}$	-
I20	Purchased energy use reduction	The amount of energy purchased from the external grid in a given TS	$\frac{E_{Purchased\_from\_main\_grid}}{E_{Total\_consumption}}$	kWh/kWh
I21	Purchased energy at lower price	The deployment level of TOU (time of use) energy prices for energy cost saving	$\frac{E_{Purchased\_at\_trough\_energy\_price}}{E_{Total\_consumption}}$	kWh/kWh
I22	Influence of energy storage on cutting peak demand	The effect of an energy storage system on curtailing peak demand at a given time	$\frac{P_{Covered\_by\_storage\_system}}{P_{Peak\_demand}}$	kW/kW
I23	Influence of the TOU energy price on cutting peak demand	The effect of the TOU (time of use) energy price on curtailing peak demand within a given TS	$\frac{E_{Valley\_energy\_price}}{E_{Peak\_energy\_price}}$	kWh/kWh
I24	Accuracy of energy supply and	The gap between predicted and actual energy demand at a given time	$\frac{P_{Predicted\_supply/demand}}{P_{Actual\_supply/demand}}$	kW/kW

	demand prediction			
I25	Capacity factor	The fraction of actual energy generated or delivered in the power system compared to the capacity that could be generated/delivered	$\frac{P_{Actual\_generated\_or\_delivered\_energy}}{P_{Generation\_or\_distribution\_capacity}}$	kW/kW
I26	Equipment energy efficiency	Energy efficiency of specific equipment	$\frac{P_{Equipment\_output}}{P_{Equipment\_input}} * 100\%$	%
I27	Operational schedule and occupancy consistency	Evaluates whether the system's operational schedule is aligned with occupancy, in order to avoid energy wastage through off-occupancy consumption	$N_{Hours\_schedule\_inconsistent\_with\_occupanc}$	hour
I28	Occupancy stability indicator	The stability level of occupancy in a building or zone, which affects energy demand and its prediction	$N_{Occupant\_in\_zone\_or\_building}$	-
I29	Thermal load reduction	Reduction of heating/cooling load caused by envelope insulation in specific thermal zone	$\text{Uvalue}_{Envelope} \times Area_{Envelope} \times (Tp_{Indoor} - Tp_{Outdoor})$	W
I30	Thermal comfort	Provides comprehensive thermal comfort in a zone	$PMV = (0.303e^{-0.036M} + 0.028)L$	-
I31	Light comfort	Measures whether the illuminance intensity meets the specific requirements in a zone	$Measurement_{Illuminance\_intensity}$	lux
I32	Appropriate temperature	Assesses whether the temperature meets the specific requirements in a zone	$Measurement_{Temperature}$	^{O}C
I33	Appropriate humidity	Gauges whether the humidity meets the specific requirements in a zone	$Measurement_{Humidity}$	%
I34	Appropriate amount of fresh air	Measures if the air quality meets the specific requirements in a zone	$Measurement_{CO_2\_concentration}$	ppm
I35	Consumers' participation	The amount of load participating in demand-side management at a given time	$\frac{P_{Interruptible\_tariffs\_and\_direct\_load}}{P_{Total\_demand}}$	kW/kW

Note: In calculation equations, "E" means energy, with a unit of kWh; "P" means power, with a unit of kW; "t" means time; "E" can also be presented as the integral of "P" based on time; "V" means volume, with a unit of "m^3*"; "N" means number; "Tp" means temperature; "PMV" means predicted mean vote index for thermal comfort; "M" means occupants' metabolic rate; "L" means thermal load for a person at a comfortable skin temperature and evaporative heat loss by sweating at the actual activity level.*