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IMPLEMENTING INTELLIGENT PLANNING UNIT (IPU) CONCEPT FOR OPTIMIZED ELECTRICITY DEMAND MANAGEMENT IN THE COMPLEX BUILT ENVIRONMENT

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Abstract: Intelligent Planning Unit (IPU) is a recently developed novel concept that renders the complex built environment system to be more intelligent, helps to standardize the complex physical entities and processes at a modular scale as well as aids in the information collection at different levels of complexity for IPU refinement and control. Such a planning unit can be used to provide accurate and timely information to the responsible decision-makers for better decision-making. In this research, we propose an application to implement the IPU concept for optimizing an intelligent electricity demand management system in a built environment. The built environment related to electricity demand consists of four different categories of end-use consumers: residential, commercial, industrial and transportation. In this context, the individual components that constitute the energy systems in the built environment, e.g., the smart meters, sensors, electric appliances, energy storage equipment, water heating systems, transportation signals, etc., are considered as IPUs. These IPUs can be replicated as well as combined to have composite IPUs that will build up the upper hierarchy of the IPU network. Standardizing the energy system using the IPU strategy within the residential, commercial, industrial and transportation units will ultimately lead to several benefits such as, (a) reduced loss in energy use and optimum energy use; (b) accurate information and better understanding of electricity demand patterns; (c) better electricity adequacy planning; and (d) informed decision making at different levels of the complex built environment system.

1 INTRODUCTION

Our built environment constitutes of complex physical system, processes and stakeholders. Most of the construction projects in the built environment are also different in design, specifications, construction and operations which further adds complexity. Several research studies have identified the complexity of the construction projects, which is still an emerging area, incorporating complexity theory and institutional theory as the theoretical foundations (Hu et al. 2013; Naderpajouh and Hastak 2014). Jaafari (2007) proposed a comprehensive diagnostic methodology to assess the health of large projects at any point of their lifecycle compared to the desired targets. Ling and Lau (2002) analyzed the problems and the issues encountered in case of large projects which would provide lessons learned for application to future large-scale and complex projects. Due to such complexity in the built environment systems as well as the construction projects, it is extremely difficult to establish a streamlined flow in the entire process of the complex built environment system (Cui, Hastak, and Halpin 2010; Echeverry, Ibbs, and Kim 1991; Koo et al. 2013; Li, Love, and Gunasekaran 1999). Furthermore, for complex projects, it is also very difficult to optimize the adequate resources, e.g., labor, materials and machinery. Optimization of resources is an extremely important area of study and many research studies have tried to address this issue in the past. Hong and Hastak (2007) conducted a simulation study and process modeling to determine the productivity and cost per hour of installation in both the fiber reinforced plastic (FRP) bridge deck panel and partialdepth precast concrete deck construction. Koo, Hong, and Kim (2014) developed a decision support system leveraging the case-based reasoning approach to provide the historical data on existing expressway service areas (ESAs) as a reference to determining the optimal size of a new ESA. Koo, Hong, and Kim (2015) developed an integrated multi-objective optimization model to study the time-cost trade-off problems of the complex construction projects and provide optimal solutions based on the basic concept of Pareto front. Matthews et al. (2015) investigated the effectiveness of cloud-based building information modeling (BIM) for the real-time delivery of information to support progress monitoring and management of the construction of a reinforced concrete structure using action based research. The use of proposed cloud-based BIM during construction facilitated a new object oriented workflow and processes for progress management. Under such situations in a complex built environment, it is extremely challenging to meet the clients' expectations and requirements on the different project metrics such as time, cost, quality, and safety (Albogamy and Dawood 2015; Bayraktar and Hastak 2009).

Thus, to reduce the complexity of the built environment system, recently Hastak and Koo (2016) proposed a novel concept of Intelligent Planning Unit (IPU) to significantly reduce the complexity of the built environment system and standardize the complex physical entities at a modular scale. This would eventually help in the process of centralizing the valuable information from the ongoing as well as completed projects and help in better planning and decision making in the built environment system. In this paper, we present a proposed application of the IPU in developing a framework for optimized electricity demand management system in the complex built environment. The paper is organized in the following way: Section 2 provides an overview of an intelligent planning unit (IPU); Section 3 describes the framework for optimized electricity demand management in the complex built environment consisting of four electricity consumer sectors, namely, residential, commercial, industrial and transportation; Section 4 illustrates the different physical units that might be considered as IPUs in this particular problem and finally, in Section 5 we conclude the paper.

2 OVERVIEW OF INTELLIGENT PLANNING UNIT (IPU)

An intelligent planning unit (IPU) is a new thought process for intelligent planning in the complex built environment system. The purpose of the IPU theory is to (1) enhance the complex built environment to be more intelligent; (2) standardize the complex physical entities; (3) extend the concept to different levels of complexity through IPU refinement and control; and (4) provide better decision-making. Figure 1 illustrates the overview of the IPU concept with three-phase implementation process: (1) IPU planning, (2) IPU application, and (3) IPU network.

The first phase is IPU planning. The purpose is to clearly identify and define the necessary IPU design and IPU strategy. The IPU design consists of three components: objective and function (WHY), technology and methodology (HOW), and properties and specification (WHAT). For the IPU strategy, the other three aspects, i.e., WHERE, WHEN and WHO would ensure that the IPU is implemented at the right time and the right place (Hastak and Koo 2016). "WHERE" determines where the theory of an IPU can be applied with the defined objective, the level of physical entities at which the IPU would be implemented must be established. In general, an IPU can be applied at different levels of physical entities in the complex built environment system and in this paper we apply the concept of IPU at three different levels: equipment level, building unit level, and electricity grid level. Second, "WHEN" determines at what stage of the project life-cycle the theory of an IPU can be implemented while maximizing services to the decision-makers throughout the life cycle process. In general, an IPU can be implemented at any stage of the project life cycle (e.g., planning phase, design phase, construction phase, and the operation and maintenance phase) and with the defined objective, it is necessary to define the life cycle. Finally, "WHO" determines who will be the user of the IPU, i.e., it determines how an IPU should be planned and designed with the end user in mind. Finally, an IPU planning matrix with six elements in IPU design and application can be established (see Figure 4).

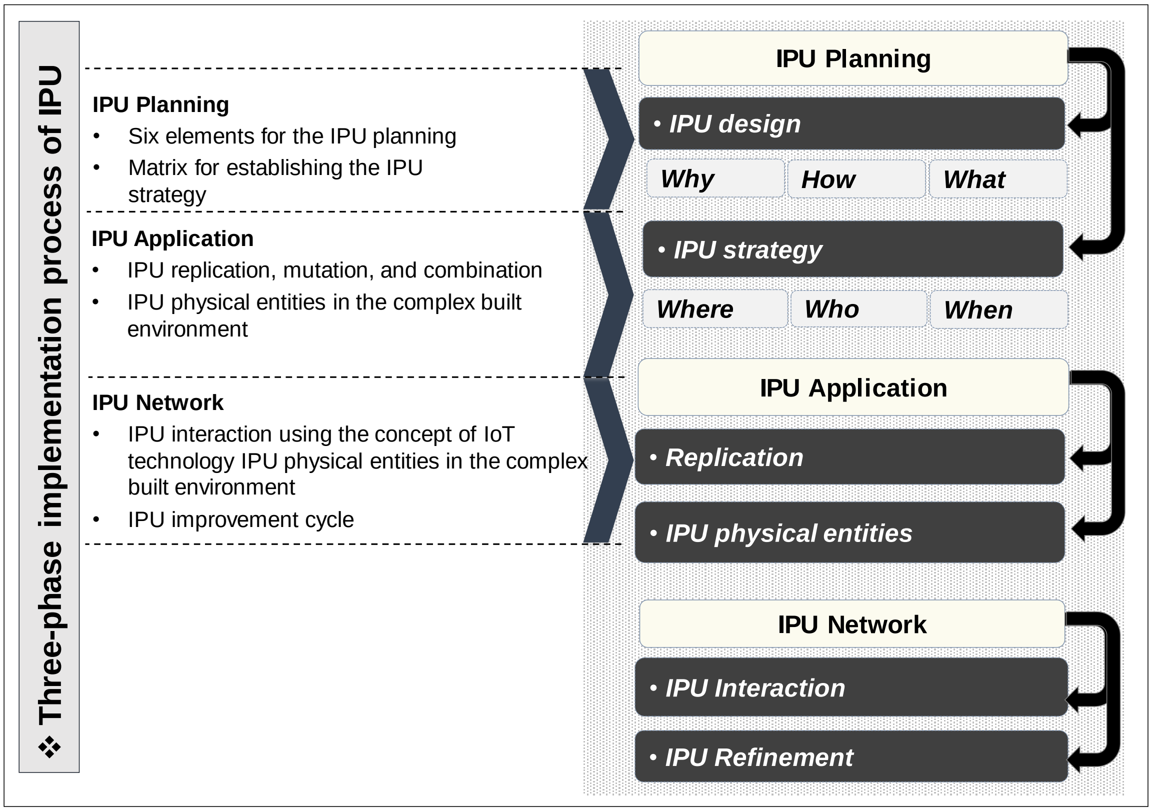

Figure 1. Overview of Intelligent Planning Unit (IPU)

Next phase is IPU application. Once the objective, the associated properties and specifications, and the advanced methodologies for IPUs are determined, the units can be extended through replication process. As can be seen from Figure1, the IPU application consists of replication and IPU physical entities. IPU Replication includes modification, mutation, and combination. Modification and mutation is the process of integration and transformation of properties of the IPUs. The combination indicates that new type of composite IPU can be produced at a different level. The replications can be implemented from a nanoscale level to a large-scale at the various physical entities in the complex built environment.

The last phase is IPU network including IPU interaction and refinement. The purpose of the IPU network are as follows: (i) IPUs should be able to interact with each other and be effectively integrated with the external environments at anytime and anywhere and, (ii) it should be implemented in the real world (or physical world) with a strategic intention. IPU interaction is to allow the defined IPUs to be sensed and controlled using Internet of things (stylized Internet of Things or IoT) which enables an IPU to be more intelligent in the real world. The IPU network is a computer-based system, resulting in improved efficiency, accuracy and economic benefit. Furthermore, IPU refinement provides feed-back process and refinement mechanism in the IPU improvement cycle shown in Figure 2. The four-step process in the IPU improvement cycle (i.e., data measurement (2), data collection (3), data analysis (4), and refinement and decision-making (5)) can minimize the gap between the as-planned and as-built performance as well as provide the as-planned (or better) performance.

The success of the three phase IPU implementation procedure is affected by several enablers during the design, procurement, construction, and, operation and maintenance phases of the project. Some of the major enablers include sustainability, cost, schedule, procurement, maintenance, retrofit and rehabilitation metrics. The nature of the project, i.e., green-field or brown-field often influence these enablers.

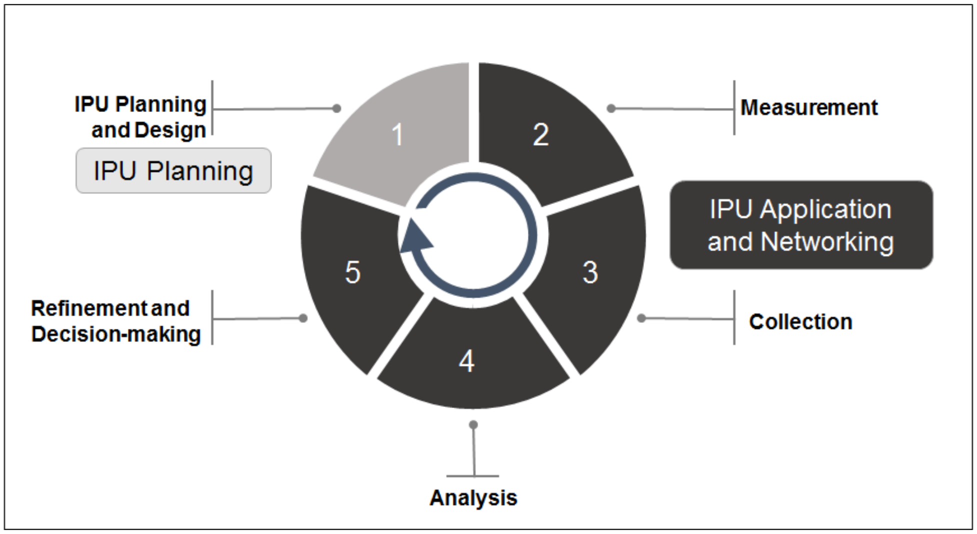

Figure 2. IPU Improvement Cycle

3 OPTIMIZED ELECTRICITY DEMAND MANAGEMENT

Electricity demand management is one of the important aspects of the smart grid that allows the different types of electricity consumers to make informed decisions about their energy consumption and helps the utility providers to better manage peak load demands and reshape the electricity load profiles. Such electricity demand management would aid in the sustainability enhancement of the smart grid (Logenthiran, Srinivasan, and Shun 2012). In this paper, we propose a method of optimized electricity demand management by adequate planning of the IPUs in the built environment. The built environment consists of four types of electricity sectors from the perspective of electricity consumption and the types of consumers, namely, residential, commercial, industrial and transportation. The U.S. Energy Information Administration (EIA) reported that in 2015, about 40% of total U.S. energy consumption was consumed by the residential and commercial buildings (EIA 2016). The residential electricity consumption includes the electricity requirement for household purposes while the commercial electricity consumption includes electricity consumption needed within the commercial buildings for normal performance of the commercial activities as well as electricity consumption for street and other outdoor lighting, and for water and sewage treatment. However, these energy uses are relatively small contributors to the commercial sector's total energy consumption (EIA 2016). The industrial sector mostly constitutes of the manufacturing industry and the major electricity consumption is attributed towards the manufacturing production processes. However, a part of the electricity consumption is also contributed towards the normal functioning of the industrial building such as indoor lighting, water pumps, space conditioning, etc. On the other hand, transportation sector's electricity demand is mostly attributed to the electricity driven vehicles, hybrid vehicles, signaling systems, etc.

In this paper, we will only focus on the electricity demand management needed for normal functioning of the buildings in the three sectors – residential, commercial and industrial. The paper establishes how the IPU concept can be used at different levels of granularity rendering simplicity to the complex built environment system. Figure 2 shows the different levels at which the IPU concept can be implemented for the electricity demand management system. Consider the electricity grid system for the state of Indiana which constitutes of five different utilities, namely, Northern Indiana Public Services Co. (NIPSCO), Vectren Corporation (VECTREN), Indiana Michigan Power (I&M), Duke Energy (DUKE) and Indianapolis Power and Light Company (IPL). Each of this companies provide electricity to the residential, commercial and industrial sector within their service territory. Further, each of these sectors consists of residential units, commercial units and industrial units. In this application, we consider that such individual units consist of different electrical/electronic equipment that are sufficient to render each of the units to be a smart system.

Examples of such electrical/electronic equipment include geothermal heat pumps, sensors, energy storage, smart meters, water filtration, smart appliance, efficient lighting systems, and demand response appliances.

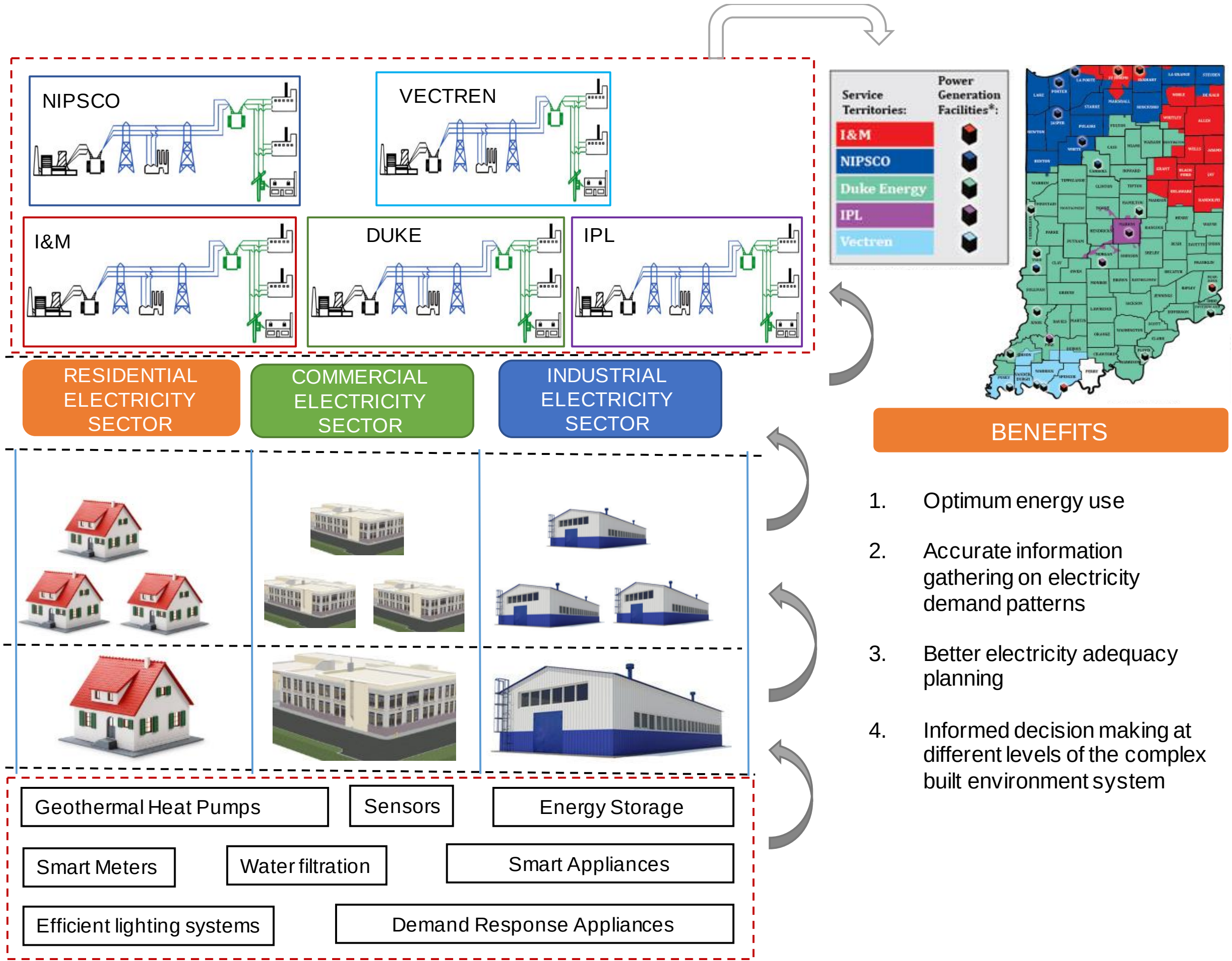

Figure 3: Efficient energy planning using Intelligent Planning Unit (IPU) concept: A hypothetical case for the state of Indiana

3.1 IPU Planning

As discussed in section 2, the IPU Planning stage consists of two phases, i.e., IPU Design and IPU Strategy. The IPU design phase needs to provide answers to the questions WHY-HOW-WHAT while the IPU strategy phase needs to be established from the perspective of WHERE-WHEN-WHO. These six elements of the IPU Planning phase constitute the IPU Matrix. Figure 4 shows the IPU Planning Matrix and we illustrate it using the example of the smart meter as an IPU. Smart meter is at the first level of physical entities and it is implemented in the design phase of the individual residential / commercial / industrial buildings.

From the perspective of the **IPU Design stage**, at first, in terms of WHY, we need to clearly define the objective and functions of an IPU. This would establish the reason for which the decision-makers would like to implement the theory of an IPU in the real world (or physical world). In our example, the need to implement the smart meter by the utility service providers is to monitor accurate electricity consumption and electricity billing. Second, in terms of WHAT, specific properties that should be incorporated, measured and managed in the IPU for achieving the defined objective and functions must be explored. In case of the smart meters, the property of recording electric energy consumption is the most important. Different specifications of the smart meters that are available in the market should also be investigated. Finally, from the perspective of HOW, advanced methodologies and emerging technologies should be considered to realize the required specifications for each of the properties. The smart meters are advanced technologies equipped with real-time or near real-time sensors and are used in the smart grids for accurate monitoring of the electricity consumption.

In the **IPU Strategy phase**, from the perspective of "WHERE", an IPU can be established at each of the hierarchical levels (X-axis: "Physical entities"). In this context, as per the definition of an IPU, each of the physical equipment can be considered as an IPU. When these IPUs will be strategically placed within each of the units with an objective to minimize the electricity consumption, each of the units within the three different sectors will become an IPU. Aggregation of such IPU units will form the sector IPU which when further aggregated will form the grid IPU. Now, from the WHEN perspective, these IPUs can be implemented during the planning stage of the project life-cycle. This will be an important starting point for planning the smart grid systems. This entire IPU framework will be designed from the perspective of the utility providers as the goal is to minimize the electricity demand providing maximum efficiency of electricity usage. Thus, in this case, from the perspective of WHO, the stakeholders and decision makers are the utility providers.

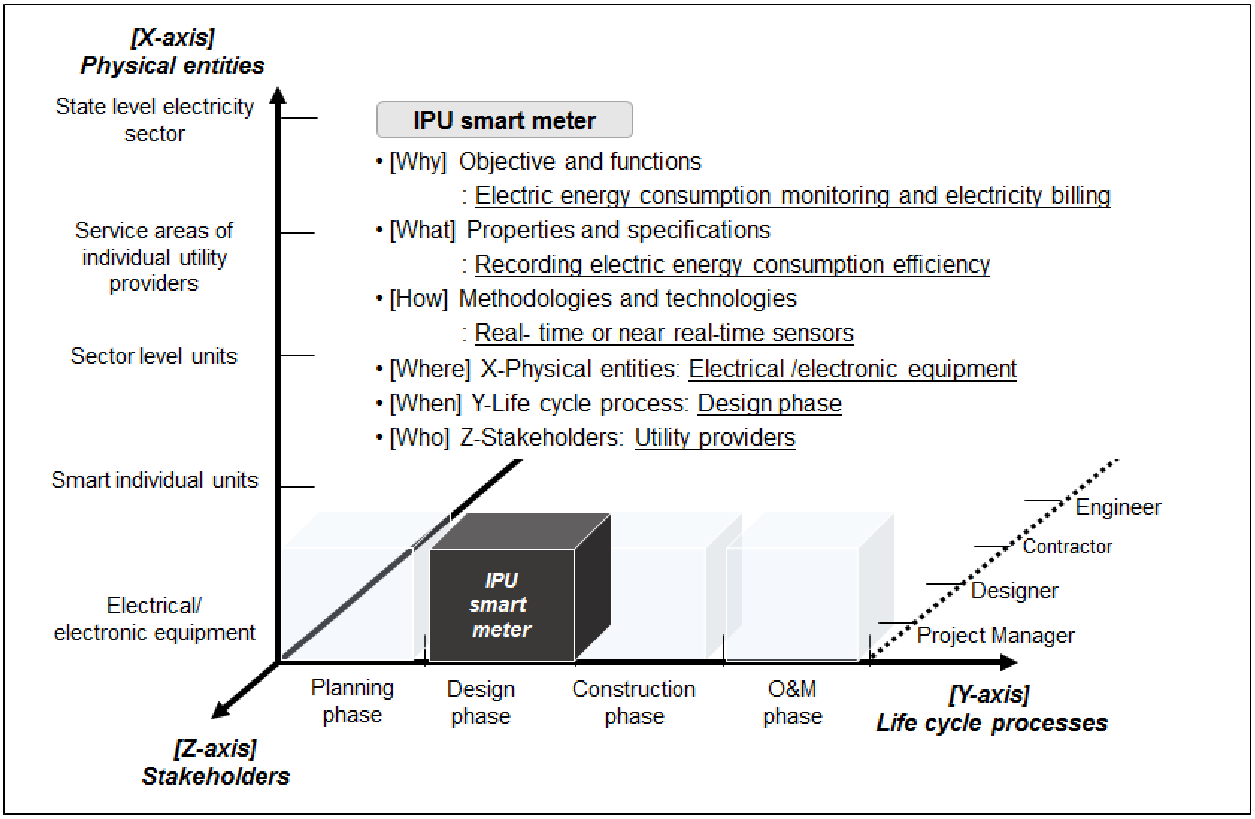

Figure 4: IPU Planning Matrix

3.2 IPU Application

The IPU application phase is the second phase in the IPU framework which consists of two aspects: (i) IPU replication and (ii) IPU physical entities. The proposed IPU concept illustrates that a well-defined IPU can be replicated with its principle or can be modified with the enhanced performance (Hastak and Koo 2016). Furthermore, integrating several types of IPUs form a composite IPU that can be developed to realize a higher-level objective. When it scales up, an IPU or a composite IPU can be applied to different levels of physical entities, e.g., from electric / electronic equipment through state-level electricity sector or beyond.

Thus, each of the electric /electronic equipment is an IPU and such strategically placed IPUs within the individual residential / commercial / industrial units will form the composite IPU. As it goes up in the level (Figure 3), smart individual unit IPUs will form sector level unit IPUs (i.e., residential sector, commercial sector, industrial sector) and such sector level unit IPUs will render electricity service areas IPUs. Similarly, it can be extended to state-level electricity sector IPU and even beyond.

3.3 IPU Network

The IPU network can be established by incorporating intelligence and smart features into each of the electrical equipment units (e.g., geothermal heat pumps, sensors, energy storage systems, etc.). The information of the electricity consumption can be continuously collected and stored in the cloud based data systems. Thus, such a system will aid in collecting adequate and accurate information that can be analyzed to obtain accurate information about electricity demand patterns and thus optimize the electricity demand management from the perspective of the utility providers.

3.4 Benefits of using the IPU framework in electricity demand management

There are multiple benefits of using the IPU framework in electricity demand management. Strategically designed IPUs can offer the following benefits:

- **Optimum use of energy**: Strategically designed IPUs can help in optimizing the use of energy. For example, different combinations of the electrical / electronic level IPUs in the planning and design phase will lead to different patterns of energy consumption. This would help in the selection of the composite IPU at smart individual unit level or sector level that requires least amount of energy, providing adequate efficiency at the same time.

- **Reduced loss of energy**: IPUs will adequately be able to monitor energy consumption patterns and thus will be able to provide enough information to track the loss of energy. IPUs will thus help the decision makers to take adequate actions to reduce the loss of energy.

- **Accurate information collection on various electricity demand patterns**: The IPU network will record and collect data through the cloud-based data systems using real time or near-real time monitoring systems which would yield accurate information for future energy analytics. Accurate information will also help in electricity adequacy planning.

- **Aid in informed decision making at different levels in the complex built environment**: The individual and composite IPUs can capture the complexity of the built environment system at different levels. Thus, as the information is collected at different levels, it helps in the informed decision making process for the various stakeholders.

4 CONCLUSION AND FUTURE WORK

The research study presented a framework for optimum electricity demand management using the novel approach of Intelligent Planning Units (IPUs). An IPU can be developed by breaking down the physical entities and processes in the complex built environment system into carefully planned units at recognizable level. Another property of an IPU is that it can also be replicated and implemented at different levels of complexity (i.e., any level of the physical entities in the complex built environment system). Based on the intelligent feature of communication, it is possible to improve the performance of an IPU through a refinement process. The research proposed that strategically placed smart individual IPUs as well as the composite IPUs can help in better real-time monitoring and data collection and most importantly, such IPUs can be replicated as per the need which helps to reduce the complexity for the built environment. However, it is noteworthy that this paper presents a partial implementation of the IPU theory as a proof of concept. In future, this concept can be extended to real life complex built environment applications and the data obtained from the IPU network can be analyzed to develop data-driven decision making tools.

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