

Living Lab Concept for Sensor Based Energy Performance Assessment of Houses

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Abstract

All the social, economic and industrial development depends on the availability of energy. Since energy demand is increasing exponentially throughout the world, more and more CO₂ is being emitted out into the atmosphere, giving rise to global warming. Therefore, establishing a sustainable environment is becoming increasingly important. It has been found through research that domestic sector contributes a great deal to the rising energy consumption. Due to prevailing energy crisis, efforts are being made to reduce the increasing energy consumption and make efficient use of energy by making the buildings energy efficient. For this, realistic assessment of energy use patterns in existing houses and buildings is necessary to assure dataset accuracy. Living lab concept integrated with sensor technologies can be used for assessment of such patterns. This paper presents living lab concept for sensor-based energy performance assessment of Houses. First, detailed literature review to benchmark concepts of energy efficiency of buildings, living labs concept, sensor based assessment, energy audit, and application of living lab concept has been discussed. Thereafter, sensors based living lab assessment and living lab approach has been introduced as being utilized by the author in a research project for development of guidelines for energy efficient housing. The paper also highlights important parameters to be monitored that effect energy performance. The concept reflects usefulness of living lab concept for sensor-based energy performance assessment of houses that help in substantial reduction in the energy consumption. As such data can be utilized for both realistic energy simulations by improving level of development of models as well as better usage comparisons with modeled analysis, hence helping in identifying true and effective improvement measures

Keywords:

Energy Efficient, Energy Performance, Living Lab Concept, Sustainable Environment

1. Introduction

It has been discovered that around 40% of the global energy use is ascribed to the buildings, be it commercial, residential and office Friedman et al. (2014). Especially residential buildings are the significant consumers of energy in many countries. Pakistan has one of the highest domestic energy consumption rates in the world and is facing the severe energy crisis for decades. Therefore, it is extremely important to create an environment that is sustainable. In order to do so, reducing the energy consumption is one of the most important strategies. This is achieved through efficient use of energy by making the buildings energy efficient. An energy-efficient building is a high performing building with the least possible amount of energy consumption by maximizing the efficient use of resources. Alike constructing a new energy efficient building, retrofitting of existing buildings and houses also result in real-time cost-effective outcomes. For this, energy performance assessment of the existing houses is carried out through simulation software. In order to make such assessment realistic, users (habitants) of the houses are required to be involved through their use patterns. This involvement will result in realistic energy consumption patterns, increased level of development of simulation models, and hence accurate energy performance assessment. Living lab concept is a solution. Living lab concept is one of the emerging concepts that provides the opportunity to gather the real-time data using Information and Communication Technology (ICT) and Internet of Things (IoT). Using living labs base assessment, users can shape innovation in their daily real-life environments for better quality of life. Living lab is typically referred as a facility that operates in a real-life context with an experimental, user-centric approach having user involvement, collaborating and co-producing knowledge. Living lab seeks to support prototyping, validating and refining the guidelines made to improve and make the facility energy efficient. This paper provides details on concepts of energy efficiency in residential buildings and houses, concepts of living lab and sensors assisted energy performance assessments through comprehensive literature review. Thereafter, it presents a Living Lab Concept

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for Sensor Based Energy Performance Assessment of Houses. This is being utilized by the principal author for research project for development of guidelines for energy efficient housing. The idea of paper is to provide analytical review of sensor assisted living lab concept and introduce a concept in practice.

2. Literature Review

2.1. Energy Efficient Buildings

Energy efficient buildings are defined as the buildings that are designed or upgraded to require less energy for space and cooling regardless of the source of energy or equipment Isover and Gobain (2020). These buildings have relatively reduced energy demand, hence, more energy efficiency. Construction of energy efficient buildings and retrofitting of existing buildings for better energy performance, aids in the reduction of increasing energy consumption. There are two significant strategies adopted for making existing buildings energy efficient. These are active and passive strategies. Active strategies usually include altering parameters like; cooling and heating systems, while building orientation, insulation, windows and daylighting, air sealing and natural ventilation opportunities are included in passive design measures.

2.2. Energy Assessment of Buildings

Energy assessment of buildings helps in identifying how and where the most of energy is being consumed. This gives owners ideas to make buildings energy efficient.

There are important factors in order to determine building energy performance, which include: energy systems, climate, building envelop, building services, building operation and maintenance, indoor environmental quality, occupants' activities and behavior Wang et al.(2012). There are three methods for the quantification of energy consumption:

1. Calculation based method: It involves the simulation based energy assessment of building using simulation engines like Autodesk Revit, Green building studio etc.
2. Measurement based method: It involves measurement of the energy consumption by using different methods such as using energy bills or meters.
3. Hybrid method: This method is a combination of both calculations based and measurement-based methods.

The hybrid method is the one, whose needs and methods are in alignment with the use of IoT (sensor technology) and living lab concept in addition to need for an energy audit for parameters related to building envelop.

2.3. Sensors Based Energy Assessment of Buildings

Different strategies exist to obtain operational data of buildings like; sensors, in order to enhance the quality of building performance assessment and ultimately reducing the performance gap. Sensor based energy assessment is a measurement based method which involves the collection of the desired data through the use of sensors. Sensors can also be customized according to the data requirements. Sensors usually required include for parameters such as; temperature, light intensity, occupancy, voltage, current, humidity, pressure etc. These are minimum sensors that can help in collecting both operational and climatic data parameters.

2.4. Energy Audit

An energy audit is an assessment of a facility that provides insight into current energy consumption of the building and to spot what and where cost-effective energy efficiency measures could be applied. There are types of energy audit: 1) walk through audit, 2) Detailed - diagnostic energy audits. Energy audit checklist is made according to the data requirements. The type of energy audit depends on the following factors:

1. Industry used its function and types
2. Up to what extent depth of the study is required
3. The size of the audit and the desire of the study reached

The research conducts physical audits. Instruments are used to calculate energy variability in equipment and devices, identify electrical faults, locate energy losses in the building envelope, detect water damage and shape heat maps etc. The physical profiling of the house is conducted and technical data is collected that includes monitoring and measurement of the temperature and wind speed with the help of instruments.

2.5. Living Lab Concept

The term 'Living Lab' is in use for over 20 years that focuses on involving users in development and innovation Krogstie, J. et al. (2013). Living lab concept was first initiated by a European project named SusLabNWE (Sustainable Lab North West Europe) which helps in building Living Lab physical infrastructures, as well as approaches and strategies for user participation, across North West Europe Herrera (2017). Living Lab

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involves the co-creation and experimentation with the real users in the evolution of innovative solutions, services, products or innovative business models in real life environments Herrera (2017). In the context of energy efficiency, it can also help in investigating impact of ICT based user interface on behaviour change towards the energy efficiency.

2.6. Application of Living Lab Concept

The living lab concept has been in application for a decade. Many researches has been based on living lab. Some of the research studies are discussed below;

1. In 2013, middleware-based smart building living lab was deployed in 18 rooms of a three buildings in the university campus of Italy and an office building in research campus in Germany. The LinkSmart middleware was adopted and the living lab concept was applied in order to create building in research campus in Germany. The LinkSmart middleware was adopted and the living lab concept was applied in order to create the flexible software infrastructure for smart energy efficient buildings. It was created to be an open and extensible system that will develop into an energy management system of an integrated building, using user-centred and iterative living lab process. The interoperability between the technologies and system and the role of the end users that includes; occupants and building managers etc. are the real issues involved in such smart buildings. Altogether following technologies were adopted in the living lab (Jahn et al. 2013):
 - a. EnOcean technology is used to control lighting and heating as well as monitor presence, window states, temperature, and appliance and light energy consumption.
 - b. Monitoring devices
 - c. An Arduino-based experimental setup for detecting presence and window states.
 - d. Plugwise4 smart plugs for calculating appliance energy usage.
 - e. Hardware to control lighting and HVAC
 - f. Setup having a Siemens Desigo BMS is included.
 - g. Additional data regarding ambient conditions and device power usage is collected using TelosB WSNs and Plugwise smart plugs

By providing feedback, their aim was to increase the acceptance of smart buildings and foster research involving users and permitting transparency. Now they are validating sensor computations and modifying the control strategies to the quirks of deployed sensors.

2. In another research, in 2013, the FormIT Living Lab methodology was applied having three iterative phases to the buildings in the partner countries including Norway, Sweden, Denmark, Lithuania, and Iceland. The objective of this research was to establish general requirements across several countries to information systems that supports reduced energy consumption in houses by describing a living lab approach. The first phase in FormIT was finding a need finding and generating an idea of energy efficient solutions that included user, public authorities and developers of energy saving solutions, second was development of concept and testing, and third was development and test of final system. In third phase, private businesses deliberated development of solutions by deciding on which solutions they could incorporate into their own current energy saving service. The co-partners then developed solutions and tested them in real life situations with user-groups in different partner countries. The user experience was then assessed and documented and questionnaire was made which concentrated on feedback from the users about the impact of the final solution on the energy usage and the solutions' effectiveness The results were then compiled which included, ICT usage, current situation, actions, and future solutions. Actions to save energy included; low energy light bulbs, triple-glazed windows, heat pumps, motion detectors for light, doors that automatically open and close and, sensors which work on quantifying needed heating and cooling. Depending on the number of people present in the building and dishwashers to energy graded ones. Through the developed solutions users were (Krogstie, J. et al. 2013):
 - a. Able to control some specific devices in their houses and see the results immediately on their smart phones by using existing Wi-Fi as transport for AMS meter readings.
 - b. Use an app, which shows real-time energy consumption and other power statistics.
 - c. Smart house technology that enabled user to control over power devices through the mobile app.
3. Another research, in which smart building "GreEn-ER" is used as living lab. It is a new building in eco-city in Grenoble, France, supporting teaching and research in the discipline of sustainability. This paper presented energy key factors and the capability of the building structures to improve sustainability. GreEn-ER is a 6 floors building comprising a space area of 4500 m² per floor for teaching / research platforms (Delinchant et al. 2016). Its design included application of a number of sustainable ideas. These sustainable measures in experiment comprised of energy improvement measures, cooling strategies that

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use natural convection, data server room releasing calories were reused to heat a facility, and forced convection in offices, low temperature supply and dual flow ventilation having high efficiency recovery, automated HVAC, lighting and blinding dependent on local sensors of CO₂, temperature, illuminance, and inhabitancy, moderate energy use i.e. restricted cooling, no boiling water in restrooms, switching of power supply, moderate water use for example two-fifth of the water utilization is from rainwater and green rooftop. It predicted the total primary energy usage to be less than 2200 MWh / year that corresponds to 110 kWh/m² (Delinchant et al. 2016). In GreEn-ER lab, PREDIS-MHI platform is an energy system with an area of a 600 m², specifically designed to reach zero energy buildings. Further measures were taken to make it a zero energy building. Installed photovoltaic panels on vehicles roof and building roof having a capacity of 20kW, combined heat & power (CHP) that may also heat the platform, electrical productions such as a fuel cell, storage capabilities, 50kWh stationary battery and optimal control solutions based on predictive models for both electrical and thermal equipment were tested in the living lab (Delinchant et al. 2016). Dimmable lighting, HVAC, blind, electric plug load efficiency, blind and switch were some of hundred measuring points and control that had been taken. These communication protocol measures were web service based that enabled interoperability. Co-simulation and predictive control were carried out and optimization techniques were also adopted. In the living lab, automation of energy management and users were integrated and occupants were able to define set points such as temperature, CO₂ concentration, luminosity, heating mode. Users were provided with several defined workshops for developing ideas, innovative products, and solutions. The workshops were end-user side view and helped integrating smart grid essentials like; decentralized renewable energy integration, energy peak reduction, and end-user needs like comfort, sustainability, and economy. The results were based on energy consumption aligned with occupant comfort criteria, and peak power. This helped in identifying scientific results such as; energy autonomy of building or micro-grid, real-time energy management, multi-flow energy optimization.

4. Sensor Based Living Lab Assessment

Living labs can be described in a variety of ways and serve a variety of goals. The concept of living lab surrounds in the same fashion as Figure 1 depicts.

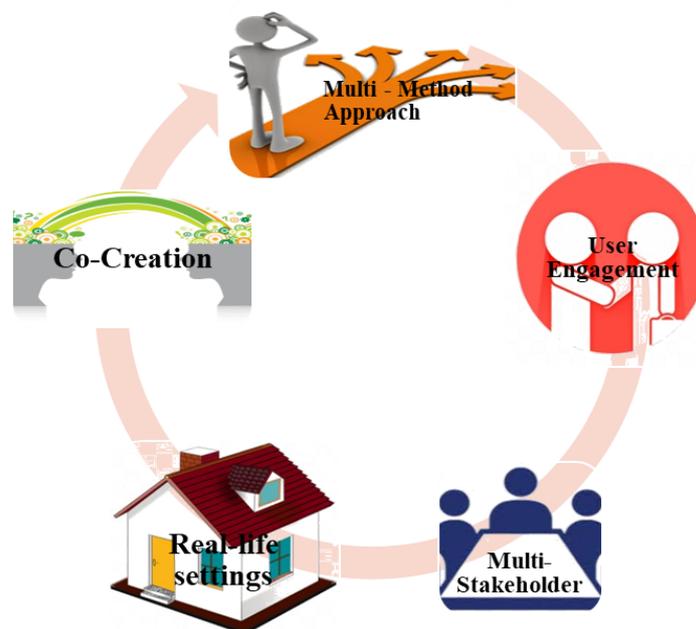


Figure 7 Living Lab Concept (adapted Aversano, P., Baccarne, B., Schuurman 2019)

4.1. Multi-Method Approaches

There is no single living lab technique; instead, every living labs mix and personalize several user-centered, co-creation methodologies to best suit their needs.

4.2. User Engagement

It is the essence of living lab concept. Without the involvement of user the purpose of living lab is dead. It distinguishes the experiments with those which have been done in closed desired controlled environment.

4.3. Multi-Stakeholder Participation

The main actor that plays vital role is user, but the participation of other stakeholders, public and private sector, academia and people is also crucial to handle.

4.4. Real Life Setting

This is the core characteristic of the utilization of living lab as it give the real time knowledge and data to gain a thorough overview of the real time scenarios.

4.5. Co-Creation

The living lab concept aims for mutually beneficial outcomes as a result of all stakeholders participating actively in the process from the very beginning stage of the projects.

Method to establish a living lab depends upon the nature of experience types, namely: cultural, economic, emotional, empathically, social and technological (Pallot and Pawar 2012). Then they are further segregated into different information rich small packets. Herrera in 2017(Herrera 2017), explained the concept of living lab in detail with the help of following Figure 2.

Figure 2 depicts the three levels of integration suggested by Herrera in 2017 (Herrera 2017), using a three-ring metaphor of a funnel's top view, beginning with an extended surface representing the context under study's complexity, moving deeper into more specific and narrow areas of practices, and finally touching on specific sustainability and human aspects of strategies

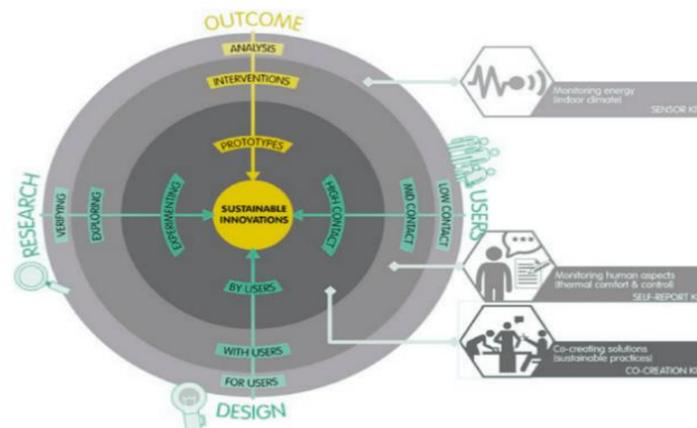


Figure 8. Mixed Approach for Sustainability Lab (Krogstie, J. et al. 2013)

Four axes show the different sort of user involvement as USERS, design strategies for as DESIGN, research targets as RESEARCH and innovation and solutions as OUTCOMES. To characterize each level of integration, these axes constitute quartets of [User, Design, Research, and Outcome] configurations. Consider the following scenario:

4.6. Outer Ring

In this scenario there is intermittent or no user involvement in the data collection that represent the basic needs of the client. Sensor systems are used to collect continuous data and cloud-based database is generated. The knowledge generated describes the long-term resilience of present behaviors, and creation is facilitated by the identification of new possibilities and their potential impact. The outcome is a strong analysis typically more useful for research and development in addition to interventions for client.

4.7. Middle Ring

In this scenario, relatively more rigorous and active participation of user is required in data collection due to which the deeper insights of the user needs can be gathered. The knowledge generated provide the ways to different alternative resilience behaviors. The outcome is more suitable for potential interventions by users, and are at just exploratory level for researchers.

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4.8. Inner Ring

In this scenario the user collaborates as the most active participant in data collection. The outcomes help in developing prototypes with some validated impact on sustainable practices, hence, can serve as mere as experiments for researchers.

5. Proposed Concept in Practice

The proposed concept in practice i.e. living lab concept for sensor-based energy performance assessment of houses is aligned with outer ring (Figure 2) in which the intermittent user involvement is required, designs are for users, verification is done as research and analysis can be provided as outcome.

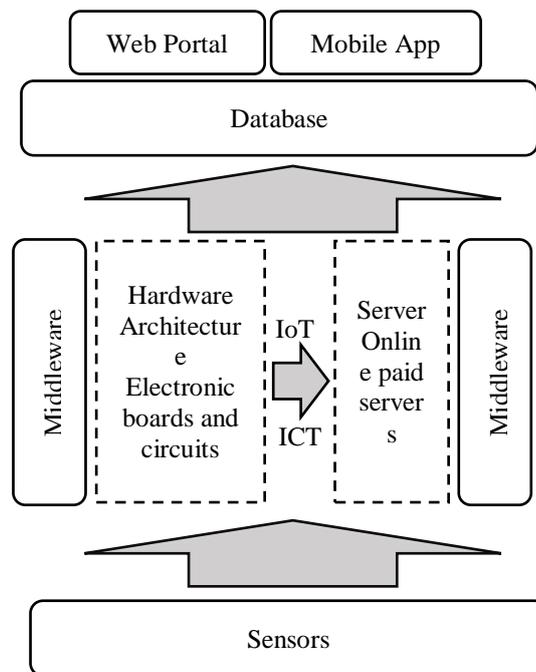


Figure 9. Living Lab Concept using Sensors

Above presented schemes (Figure 3) is a bottom-up approach. Three sets sensor-based system that include; temperature, pressure, humidity, light intensity sensors for indoor measurement, and weather station at top of house/building providing same parameters externally is used. Additionally, weather station also provides wind speed. And watts per square meter that can be used to measure solar and wind energy generation potential of a roof top. Data collected from sensors that give the internal climatic condition in the form of temperature, humidity, atmospheric pressure etc. to depict the real time scenario of the house. This information is recorded through the sensors then send to hardware architecture. Now, it transferred to online paid server using Internet of Things (IoT). After transferring to the server, data is displayed on web-portal or mobile app and data base is generated.

A web-based dashboard is designed to collect data feeds from sensor, the frequency of which can be adjusted by the user from 20 seconds to 30 minutes interval. A snapshot of results from dashboard is shown in Figure 4. After creating the database through this approach Energy performance assessment of a house has been done which shows that the real time data gathered created the most accurate results.

6. Conclusions

1. IoT provide immense help in furnishing the requirements of living lab.
2. The living lab concept provide the real insights of energy performance of houses as compare to the energy performance analysis provided by modeling software.
3. ICT and IoT plays major role in completing the living lab concept.
4. Data collected using living lab approach give the chance to model the houses more accurately. It offers the provision of increasing the information in Level of Development (LOD). LOD500 is the highest level of information that can be provided in modeling software which requires the as-built conditions and scenarios. Light intensity, power density and occupancy schedule are the key factors. When these key factors were incorporated in the modeling of house, results of energy analysis vary 70% approximately

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from the previous results without the information collected through living lab. It can be concluded that the data collected through living lab increases the LOD which ultimately improves the results of the energy analysis through modeling.



Figure 10 Dashboard for Sensors

7. Acknowledgment

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