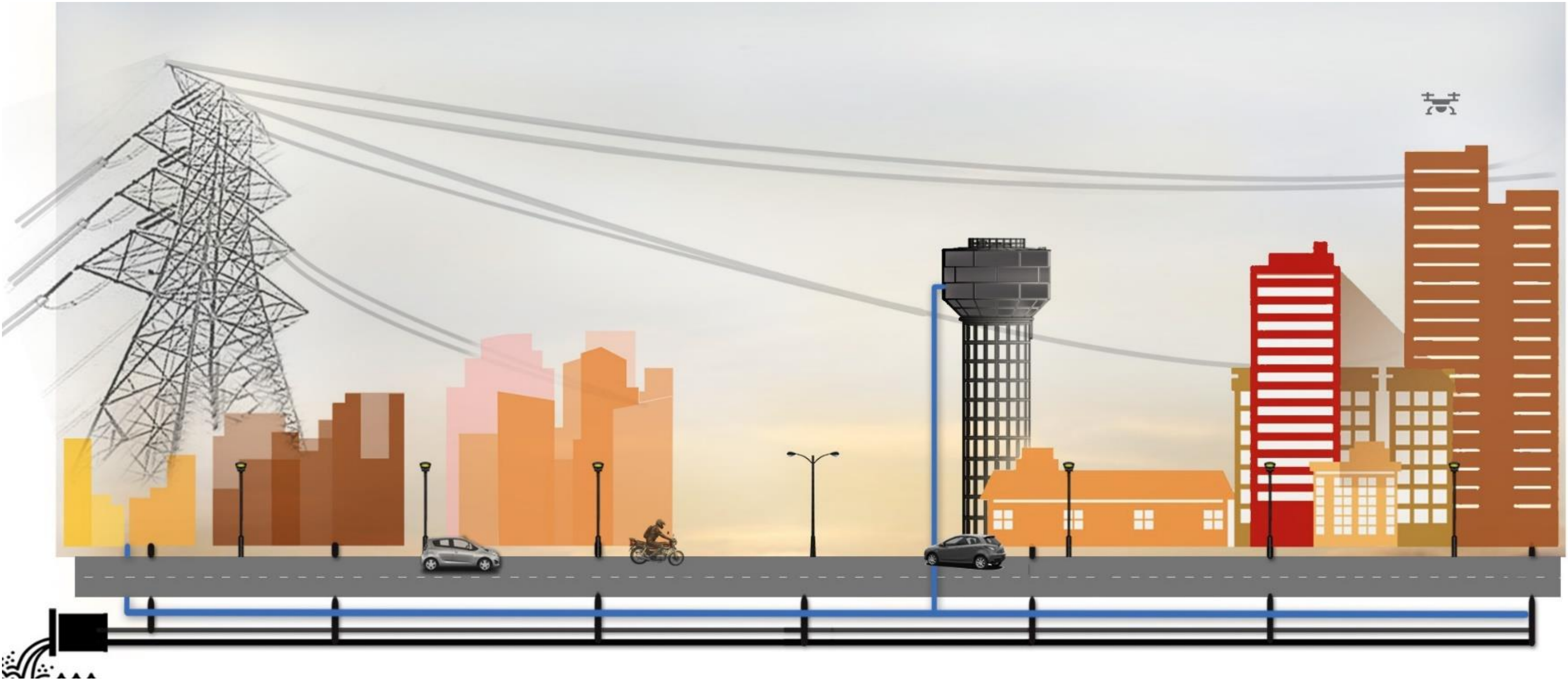

India-UK Joint

Integrated Urban Model for Built Environment Energy Research

(iNUMBER)

Residential Energy and Environment Monitoring: Improving Data Granularity

January 2019

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India-UK Joint Integrated Urban Model for Built Environment Energy Research (iNUMBER)

Work Package 3 (WP3): Improving Data Granularity

Residential Energy and Environment Monitoring: Improving Data Granularity

January 2019

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iNUMBER (iNtegrated Urban Model for Built Environment Energy Research) is a four-year (2017-2021) research project to help cities reduce their energy demand and improve their municipal services. This goal is led by CEPT University, Ahmedabad and supported in India by Indian Institute of Technology Bombay, Mumbai. It is led by University College London, London, and supported by the University of Oxford, Oxford.

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Acronyms

iNUMBER	Integrated Urban Model for Built Environment Energy Research
BIM	Building Information System
DISCOM	Distribution Company
AUDA	Ahmedabad Urban Development Authority
IMAC	Indian Model for Adaptive Comfort
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers

Abbreviations

EPSRC	Engineering and Physical Sciences Research Council
ESRC	Economic and Social Research Council
DST	Department of Science and Technology
WP	Work Package
AMC	Ahmedabad Municipal Corporation
PF	Power Factor
RH	Relative Humidity
ULB	Urban Local Body
Sq. km	Square Kilometer
PMAY	Pradhan Mantri Awas Yojna
BHK	Bed room, Hall and Kitchen
PPP	Public Private Partnership
FSI	Floor Space Index
CT	Current Transformers
WWR	Wall to Window Ratio
RNRH	Right Now Right Here
AP	Access Point
RTU	Remote Terminal Unit
PSU	Power Supply Unit

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Executive Summary:

iNUMBER is an Indo-UK collaborative research project that was co-created to address the Newton research topic: "Integration of information, communication and renewable energy technologies at building, community and city level interventions". The project aims to address this research topic by developing a data-driven Intelligent Urban Model for Built Environment and Energy Research (iNUMBER). The primary focus of this tool is to support the Indian Municipalities to understand the variations in energy demand and thereby assist in providing clean and sustainable energy services to its citizens. iNUMBER being a four-year collaborative research project (2017-2021), Ahmedabad has been selected as the primary case city for the research. Further, the project could be extended by considering other cities as well.

The key objective of the project is to develop a City Energy Model that includes the 3D building stock and the municipal services energy model. The project aims to achieve the same by linking the existing and new data sets and testing the validity of the developed model for a range of scenarios in accordance with different data availabilities. To achieve this overarching objective, the project has been sorted into 3 work packages (WP) as mentioned below,

1. WP1: Create 3D Building Stock Model
2. WP2: Incorporate Municipal Energy Services
3. WP3: Improving Data Granularity

This executive summary provides a brief account of the activities carried out under the WP3: Improving Data Granularity. This WP focusses on gathering intense datasets at dwelling unit level and common amenities at community level pertaining to the energy consumption, indoor environment parameters and thermal comfort conditions. There are two major outcomes under the WP3. First outcome is, 'Intensive Data Collection in Dwelling Units'. This includes capturing thermal comfort conditions, indoor environment parameters and energy consumption associated with the use of electrical appliances in 267 sample dwelling units in Ahmedabad city. The second outcome is, 'Extensive Data Collection at Community Level'. This includes gathering energy consumption data for common utilities using lower-tech participatory tools and methods in multi-storey buildings at community level in Ahmedabad city.

Under outcome-1, the report provides a detailed overview of energy and environment monitoring in dwelling units. Further, the report also demonstrates a detailed sampling methodology for the selection the dwelling units. The sample size has been divided into number of clusters with reference to building typology, population density and property count. Intensive data from WP3 becomes the source to build the city energy model which has been envisaged in WP1.

Under outcome-2, the report provides a brief overview of energy monitoring in multi-storey buildings. Further, the report mentions a pilot case study to measure energy consumed in common utilities at community level. The extensive data would feed building level energy consumption pertaining to municipal water services in WP2.

The integration of the outcomes from all 3 work packages will assist in understanding the energy demand of the entire city. Through a fourth work package, the activities under iNUMBER will further be integrated with other projects, related research in India, and across the world. Further, this integrated approach will develop new areas of inquiry related to future building stock and municipal services in India.

1. Introduction

Cities have often been described as the engines of economic growth (Colenbrander, 2016). Currently, 55% of the world's population is residing in the urban areas. This proportion is expected to stretch to 68% by 2050 (United Nations, 2018). As per new data sets launched by United Nations, it is observed that the overall shift in the human residences from rural to urban areas, combined with the overall growth of the world's population could add around 2.5 billion more people to urban areas by 2050. It is expected that, nearly 90% of this increase in the urban population would be accounted by Asian and African countries alone.

As the urban population increases, the demand for the basic amenities and living comforts will also increase. Thus, it is very important to plan and allow the urbanization to attain in a sustainable manner. In order to attain this, it becomes very necessary for the cities to develop and provide required amenities towards meeting the future demand of its citizens. One of the primary aspects that need to be accounted with the process of urbanization is the provision of the secure energy for the better health and comfort of the citizens.

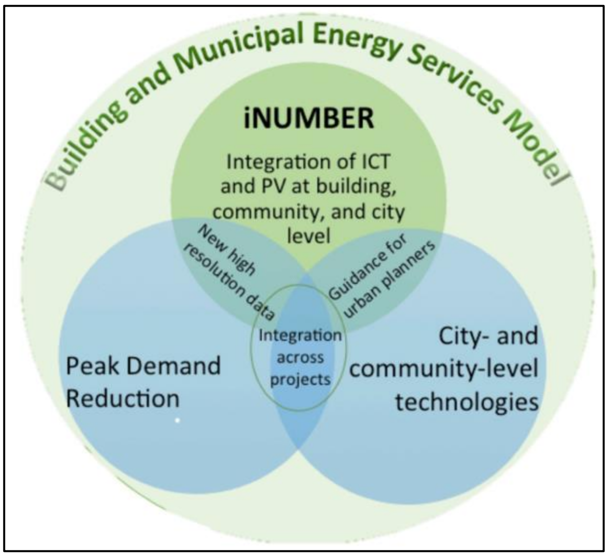
As the urban population increases, the city's demand for the clean energy will also increase. Thus, with the changing lifestyle and growing cities, it becomes very important to understand the energy demand of the city and identify more efficient methods of utilizing available resources in catering the demands. This can be achieved by assessing and understanding the variations incurring in the energy demands of the city. These variations can only be studied by constant observation and analyses of the data sets specific to the respective services. Thus, the tools capturing variations in the demand for the energy over the time and space will serve the greater cause in understanding the trends, rationalizing the energy demands and thereby assist in planning and attaining a sustainable energy services for the cities.

iNUMBER focusses on developing one such tool for assessing and understanding the variation in energy demand of the city over time and space. iNUMBER is an iNtegrated Urban Model for Built Environment Energy Research. The research program aims at developing a City Energy Model to help in planning a secure energy supply for the urban population. Further, the tool will support the urban energy management process and assist municipalities and local partners for developing a data driven intelligent urban model for assessing the built environment energy and the municipal planning.

1.1. About iNUMBER

'iNtegrated Urban Model for Built Environment Energy Research (iNUMBER)' is a four-year collaborative research project between India and United Kingdom to help cities reduce their energy demand and improve their electricity and water services. Funded by the Newton-Bhabha Fund, iNUMBER is jointly supported by the UK Engineering and Physical Sciences Research Council

(EPSRC), and Economic and Social Research Council (ESRC) in partnership with the Government of India's Department of Science and Technology (DST). The main objective of iNUMBER is to work towards reducing greenhouse gas emissions, stabilizing the electricity grid, and help the ULBs in rationalizing and planning the city's energy demands thereby, assisting in provision of secure and sustainable energy services. The tasks under the project are to develop a new model of building & municipal energy demand, grounded in appropriate empirical data and applicable to reducing energy



demand in a wide range of different contexts and with varying data availability.

Figure 1 Schematic representation of the iNUMBER project

iNUMBER was co-created from the India-UK workshop to address the India-UK Newton research topic, "Integration of information, communication and renewable energy technologies at building, community and city level interventions" by developing a data- driven intelligent urban model for built environment energy research and municipal planning. It supports Indian municipalities and local partners by diagnosing urban energy problems, testing solutions, verifying progress and improving policy through state of art monitoring, data science and analytics. It will also meet interrelated elements of the other two topics, "peak demand reduction" by contributing new high resolution data city and community technologies by providing guidance to urban planners.

The iNUMBER project is systematically sorted into 3 work packages (WP) and are classified as described below,

1. Work Package 1: Create a 3D Building Stock Model

The WP1 aims at identifying and analysing various approaches suitable for capturing the urban environment using advanced aerial survey technologies and develop a 3D Building stock model. WP1 incorporates existing geographical and administrative datasets available at the city level and integrates the information with the developed 3D Building Model. Finally, WP1 in association with partners investigates techniques to scale up Building Information Modelling (BIM) based energy simulations to develop a viable City Energy Model, thereby allowing municipalities to effectively optimize their current and future energy demands.

2. Work Package 2: Incorporate Municipal Energy Services

The WP2 primarily focusses on assessing the energy consumption in delivering the municipal services. The energy data sets obtained with regard to the municipal services feeds into the City Energy Model. Further, the work package also focusses on developing a framework for evaluating the municipal services with respect to their energy consumption.

3. Work Package 3: Improving Data Granularity

The WP3 primarily focusses on gathering intense datasets at dwelling unit level and common amenities at community level pertaining to the energy consumptions, indoor environment parameters and thermal comfort conditions. The data sets collected in this work package regarding the energy consumption will act as feeder for the City Energy Model, thereby assisting in improving the data granularity of the model.

The integration of the 3 work packages will assist in understanding the energy demand of the entire city. Through a fourth impact work package, the activities under iNUMBER will be integrated with other projects, related research in India, and across the world. Further, the integrated approaches incorporated in each of these work packages will help in answering additional questions and develop new areas of inquiry related to the future building stock and municipal services in India.

1.2. About Work Package 3: Improving Data Granularity

WP3 enriches the project with the data pertaining to the energy consumption and indoor environmental parameters in the dwelling units across the city of Ahmedabad. The energy consumption monitoring of dwelling units and the common utilities has been planned for the duration of one year to capture diverse trends in energy consumption and its impact on indoor thermal comfort. The data would also establish an important link to align the relationship of energy consumption and usage of electrical appliances in the dwelling units. The work package would also focus on the data collection from the common utilities at community level using lower tech participatory tools and methods for gathering energy consumption data.

1.2.1. Aim

The aim of the study is to enhance the understanding of energy use and related issues in the built environment to improve understanding about the residential building stock and derive energy demand reduction potential.

It supports India's deep decarbonisation pathway by mapping current and future energy demand reduction opportunities in the built environment. It will diagnose urban energy problems, test solutions, verify progress, and improve policy decisions utilising state of the art monitoring, data science and analytics.

1.2.2. Outcome of Work Package 3: Improving Data Granularity

The entire work of WP3 has been divided into two tasks with two different outcomes one focusing at dwelling level and another at community level.

Outcome 1: Intensive data collection in dwelling units

Outcome 1 focusses on capturing thermal comfort conditions and energy consumption associated with the use of electrical appliances in 267 dwelling units in Ahmedabad city.

Outcome 2: Extensive data collection at community level

Outcome 2 focusses on gathering energy consumption data for common utilities using lower-tech participatory tools and methods in multi-story buildings at community level in Ahmedabad city.

The sample of dwelling units to be monitored are divided into multiple clusters based on the building typology or combination of building typology to achieve outcome 1. These clusters have been planned to be monitored for the span of one year across the project timeline. Data pertaining to energy consumption of common utilities at community level has been planned to be monitored for the span of one year across the project timeline to achieve outcome 2.

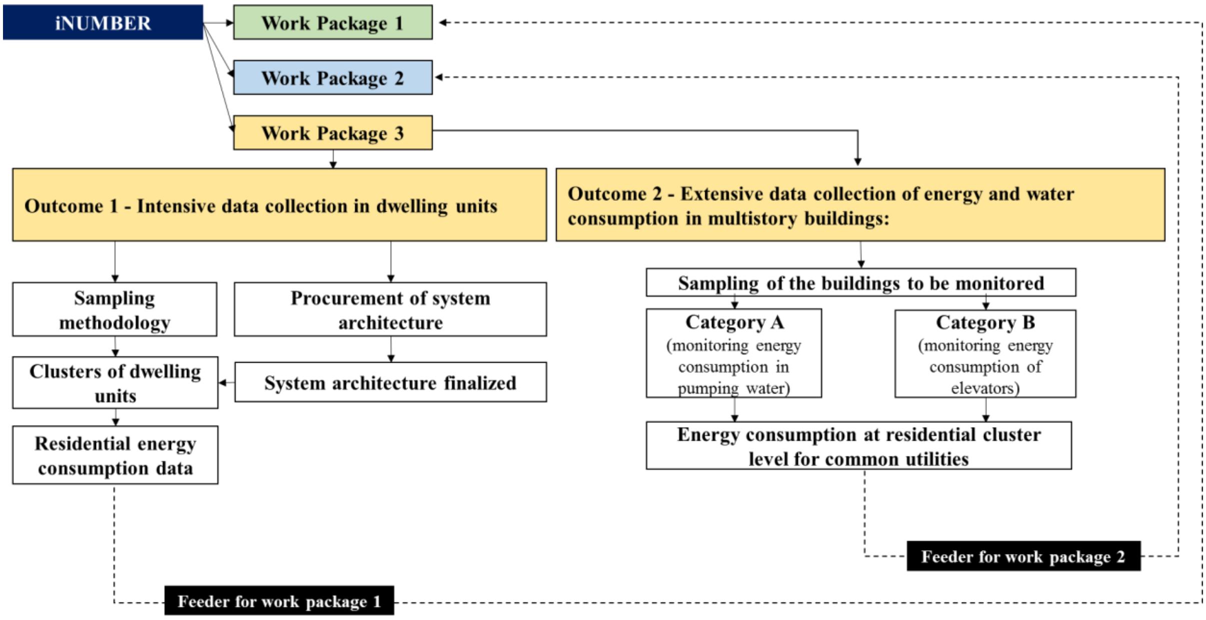


Figure 2 Overview of Work Package 3

Intensive data from WP3 becomes the source to build the city energy model which has been envisaged in WP1 as shown in figure2. The extensive data pertaining to the energy consumption of common utilities at community level would feed the database of WP2. This would also fill the data gap between WP3 and WP2 as shown in figure2.

1.3. Scope of Work Package 3: Improving Data Granularity

As mentioned above, WP3 focuses on the capturing data related to energy consumption and indoor environmental parameters at dwelling units and energy consumption with the reference to common utilities at community level in the city of Ahmedabad. Captured data would feed WP1 and WP2 which influences the scope of WP3. As the city of Ahmedabad represents the diversity in residential building typology, the study area has been limited to the city of Ahmedabad and within the Ahmedabad Municipal Corporation (AMC) Boundary. Outcome 1 of WP3 has been supported by availability of the database with reference to building typology, population density and property count for the city of Ahmedabad. Outcome 2 of WP3 which is the source of data for WP2 has been supported by the availability of the data pertaining to the water distribution network within AMC boundary. Additionally, the city energy model has been envisioned to prepare a model which would be fed with data collected from WP3. This limits the study to sample dwelling units and community level monitoring of energy consumption as the electricity distribution company (DISCOM) is different within AMC boundary and urban periphery which falls under Ahmedabad Urban Development Authority (AUDA).

Sampling of the dwelling units and common utilities of the community to be studied has been planned according to the administrative zones. The areas falling under cantonment are not included in the study.

2. Methodology

WP3, Improving Data Granularity envisions intensive data collection about the energy consumption and indoor environment in the residential scale as a part of Outcome 1. Outcome 2 is extensive data collection pertaining to energy consumption in providing common utilities (water pumping and elevators).

To capture the essential data across both the outcomes 1 and 2, a monitoring strategy has been designed with the ideal monitoring system for dwelling units, water pumping devices and elevators. It has also been envisaged to monitor indoor environmental parameters in sampled dwelling units. The desired system consists of a set of equipment which would monitor energy and indoor environmental parameters for the span of one year.

A sampling methodology has been prepared to ensure the homogenous representation of diverse typologies of dwelling units across the city of Ahmedabad. The methodology has been framed with the reference to literature for dwelling units and communities to be monitored under WP3.The sample has been distributed across the city by separating the sample into clusters of dwelling units and community based on the building typology and location in the city.

With the reference to the monitoring strategy, a guideline was prepared to procure desired monitoring system. These guidelines were circulated to the identified vendors in market. The proposals were received from different vendors and were revised based on the requirement. The proposals were analysed with the focus on technical specification of the equipment, financial specification, data communication channel, and installation process. A system has been finalized based on above mentioned selection criteria.

Instrumentation of the procured system involved designing system architecture at dwelling unit level and community level. A sample installation has been planned to check the operational efficiency of the system procured.

As mentioned earlier, the dwelling units to be monitored have been divided into different clusters. These clusters were identified with the number of dwelling units to be monitored along with common utilities at community level. Monitoring system has been customized for different building typologies with the reference to collected baseline data from the sampled cluster. On ground installation is planned which is followed by data collection at regular intervals.

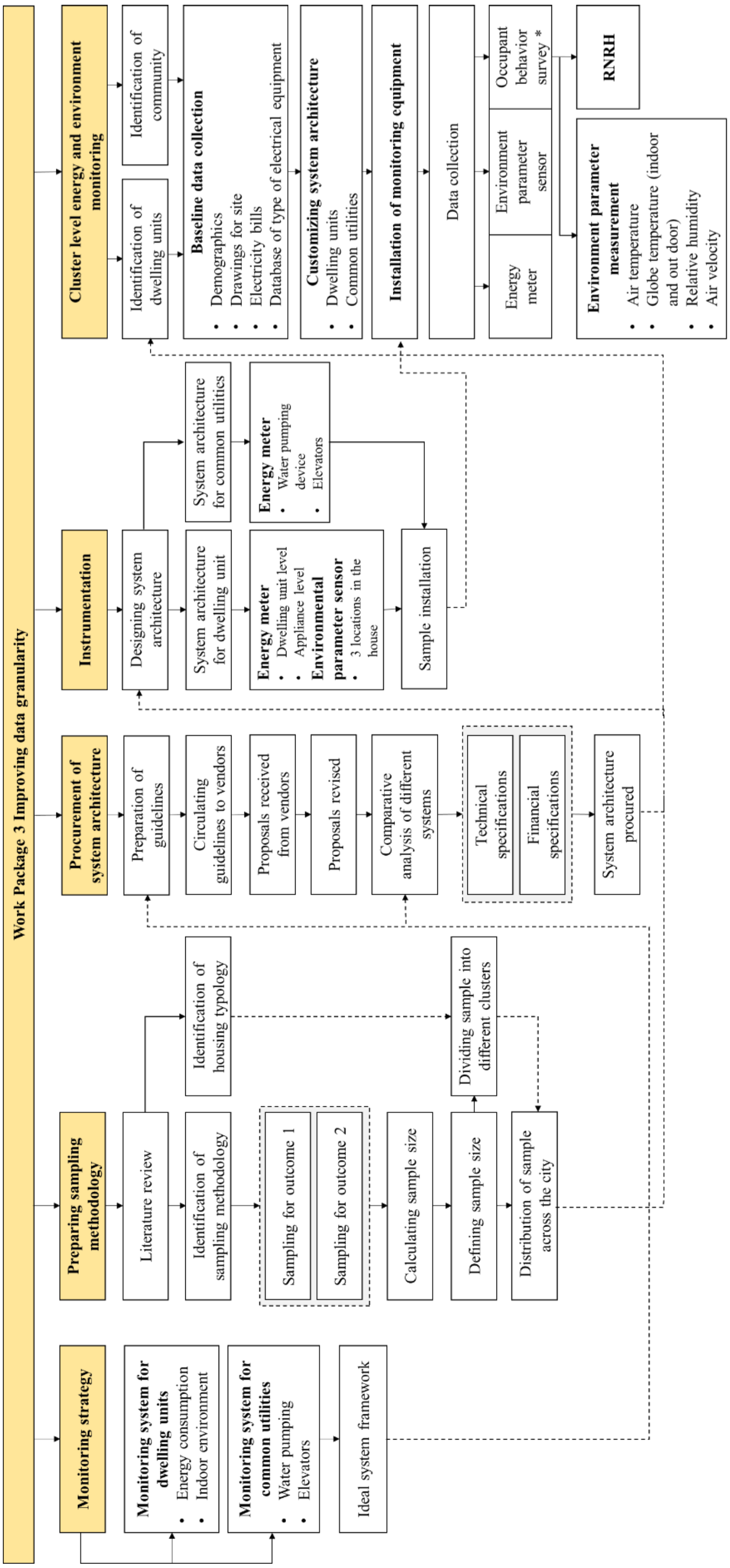


Figure 3 Methodology for work package 3 - Improving data granularity

3. Monitoring Strategy

Ideal monitoring strategy was designed based on the building typology to capture the granular data at dwelling unit level and community level. The strategy was envisaged to monitor energy consumption and indoor environment parameters remotely.

3.1. Energy and Environment Monitoring at Dwelling Unit Level

Monitoring and data recording of the dwelling units would be conducted with the help of installed meters in dwelling unit. The data recorded would further fed into a city energy model and estimate the increase in consumptions accurately. These devices would be planned to be installed in the dwelling units based on the energy consumption. The monitoring equipment is intended to commute the data within the system and then to the cloud server.

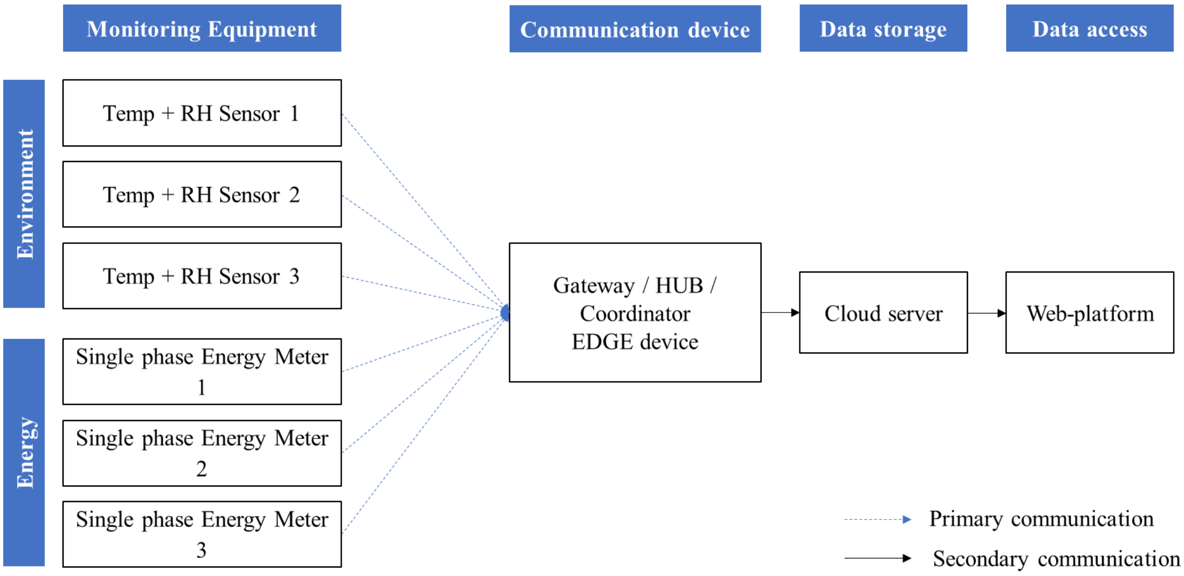


Figure 4 Ideal monitoring system architecture envisaged

Typically, three energy meters would be installed in a dwelling unit. Meter one will be installed with an appliance which is consuming energy continuously, i.e. refrigerator. Meter two will be installed at high energy consuming appliance having intermittent use, i.e. air conditioner. Meter three will be installed at dwelling level which will monitor total energy consumption of the dwelling unit. These energy monitoring meters would log Watts, Volts, Ampere and Power Factor (PF). The energy meters installed would be class-1 meters and would capture the energy consumption data every 1 minute. The monitoring of the energy consumption would be carried out for one year after the installation of meters. The research team would have full access to the data as well as visualization tool. Access to data visualization should be provided to owner/occupier of the residence as well.

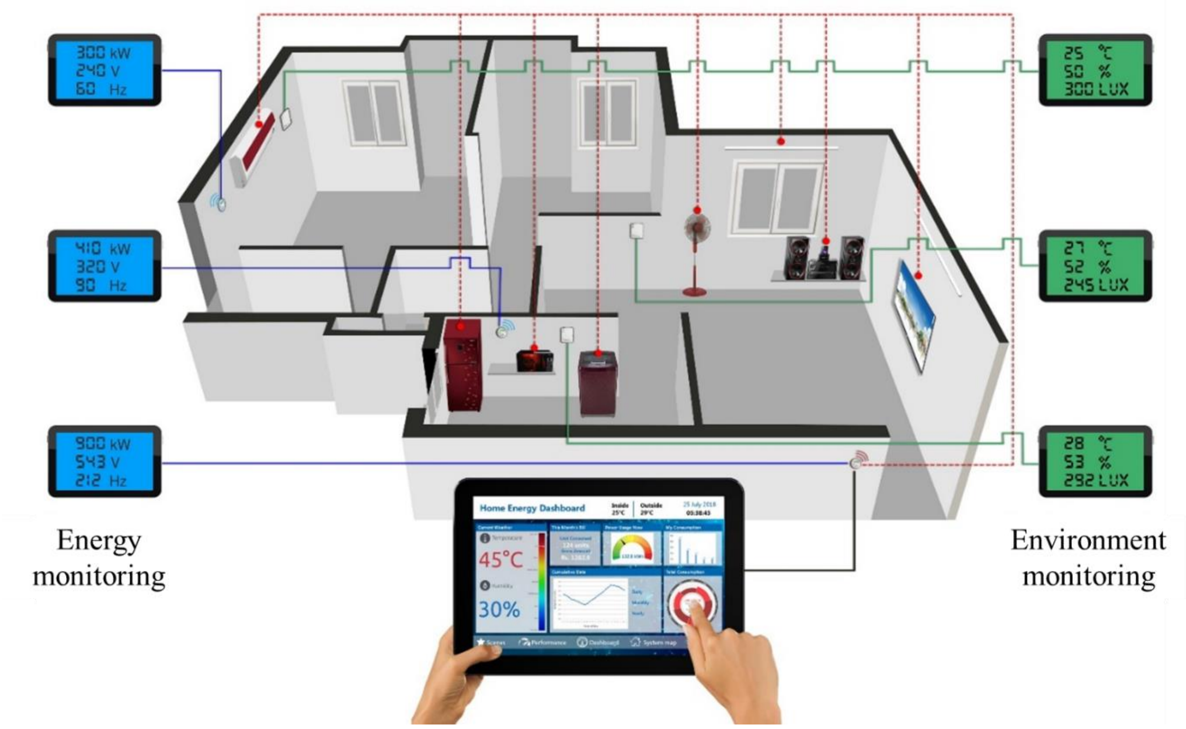


Figure 5 Ideal monitoring system envisaged for the dwelling unit

Environmental parameters like relative humidity and air temperature are associated with energy consumption of the residential unit. Indoor environmental parameters are factors influencing thermal comfort and hence influence the consumption of energy.

Air temperature and relative humidity are the Environmental parameters which would be monitored by a set of devices installed in different areas of a residential unit. These meters would be installed in kitchen or dining area, bedroom with air conditioning equipment and the living room. The installed environmental parameter monitoring devices would capture data every 15 minutes with the accuracy of air temperature (with accuracy ± 1ºC) and relative humidity (with accuracy ± 5% RH).

3.2. Energy Monitoring of Common Utilities at Community Level

The energy consumed at the community level includes pumping water to overhead tank from the common community level reservoir and in the elevators in the multi-storeyed buildings. The data collected by monitoring the energy consumption of common utilities at community level will be an essential link between the two larger database, (i) energy consumption at dwelling unit and (ii) energy consumed by the municipal utility. The energy utilized in these common utilities will vary based on the location of the building with the reference to the water distribution network of the city, height of the building, occupancy and the economic section of the residents.

The energy monitoring devices are envisaged to be installed at the water pump level which is used to elevate water to overhead tank and elevators at the community level. Monitoring of energy consumption at water pump level has been planned to install for a period of one year to capture seasonal variation. In case of elevators, one week of monitoring in multi-storey apartments at community level is foreseen. This data from common utilities will fill in the data gap between energy consumption in dwelling units and energy consumption in providing services like water from Urban Local Body (ULB) to last mile user connectivity.

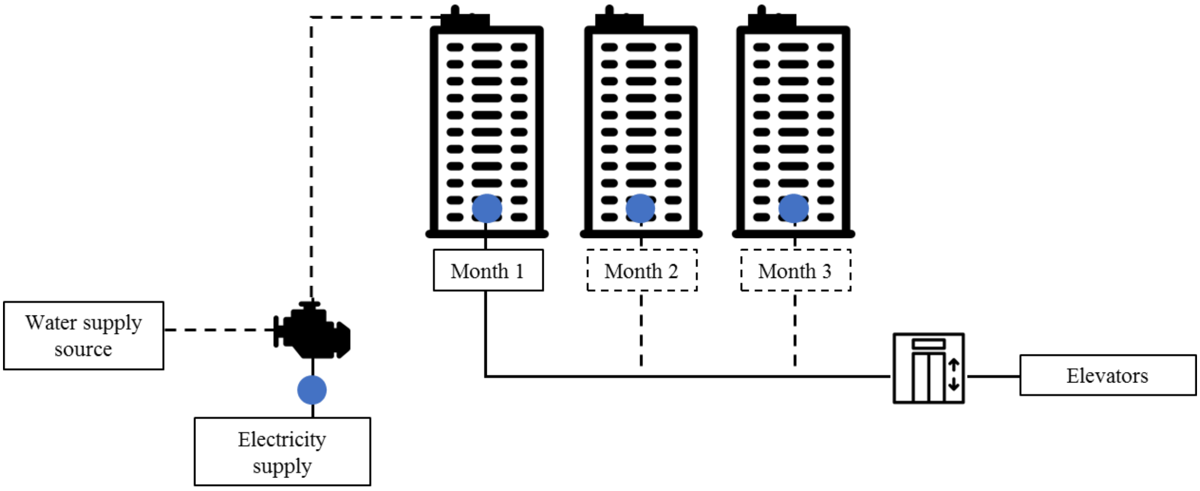


Figure 6 Ideal monitoring system envisaged for community level monitoring

3.3. System Prerequisite

A market study was carried out with the intention to procure the most accurate and reliable monitoring system. Diverse proposals from the vendors were received with the reference to below mentioned guidelines/prerequisites:

System architecture guidelines/prerequisites:

1. The study has been envisaged to capture the data of energy consumption and indoor environmental parameters from 267 dwelling units in three phases with equal number of dwelling units in each phase.

2. Total duration of monitoring has been planned for one year for a dwelling unit. System would be reinstalled to another dwelling unit (in phase two) after monitoring of phase one is completed. The study will cover multiple residences over three years. A unit of system will be deployed at three dwelling unit over three years, having a tenure of one year at each dwelling unit.

3. Typically, three energy meters are foreseen to be installed in a dwelling unit. The energy meters should monitor Watts, Volts, Ampere and PF.

    - Meter one will be installed with an appliance which is running continuously, i.e. Refrigerator.
    - Meter two will be installed at high energy consuming appliance having intermittent use. i.e. air conditioner

- Meter three will be installed at dwelling level which will monitor total energy consumption of the dwelling unit.

4. The environmental parameter sensor is strategized to be installed at three locations in a dwelling unit one near location of air conditioner, one in living or dining space and one near kitchen area.it is desirable for these sensors to log air temperature with the accuracy ± 1 °C and relative humidity with of accuracy ± 5% RH.
5. The timestamp of these monitoring equipment (environmental parameter sensor and energy meter) should vary between one minute and one hour. The system should be accessible for research team to change timestamps remotely as and when needed with or without help from service provider.
6. The monitoring equipment can be power or battery based. The communication between monitoring equipment should be preferably wireless.
7. Data logged should be accessible for research team along with data visualisation tool of all the dwelling units being monitored. Data visualisation should be accessible to the resident of the dwelling unit for that dwelling unit.
8. The system architecture should notify the research team in case of any technical malfunctions and connectivity loss.

4. Sampling Methodology

The sampling methodology for energy and environment monitoring at dwelling unit level has been defined based on the diversity in building typology in the Ahmedabad city. The energy consumption of common utilities at community level has been planned to monitor at three multi-storey apartments as part of the pilot study.

4.1. Introduction to Ahmedabad city

Ahmedabad is the city with approximately 25% area under residential cover on developed land (predominantly under AMC) with the diversity in building typologies (Iii, Development, & Regulations, 2015). The dominating building typology ranges from Bungalows, Row houses, Tenements, Traditional houses (pol houses), Kachha house/Squatter settlements (slum or slum-like settlements), Affordable housing units, and Apartments (low rise and high rise).

4.2. Sampling Strategy at Dwelling Level in Ahmedabad city

A definite plan of obtaining the representative sample unit/s that represents the whole city with the focus on the dwelling units within the municipal corporation boundary has been envisaged. As the city of Ahmedabad is divided into six administrative zones and represents diversity in residential building typology in each of these zones. The sample strata has been divided into six zones (east, west, north, south, central and new-west).

Following are the most frequently used sampling methodologies used for studies with larger population size or more variables in the study scope. The methodology of stratified sampling has been followed to capture the archetypal sample.

Table 1 Sampling Methodology

Probability Sampling	Simple random sampling		An adhoc sampling of the items based on convenience
	Complex random sampling	Cluster sampling	Unit/s of the population/study area is/are sampled after dividing the study area/population into multiple equal parts
		Systematic sampling	An item or individual in the population is sampled based on the pre-decided arithmetic number
		Stratified sampling	The methodology used when to be studied cluster is not homogenous or consists of the diverse typology of the strata to be studied Representation of each typology based on the density is possible
Non - Probability Sampling	Haphazard sampling or convenience sampling		The probability of representation of each typology is not certain Selection of the items to be studied depending on the convenience or the judgment in the research process

(Kothari, 2004)

4.2.1. Stratified Sampling

'If population from which a sample is to be drawn does not constitute a homogeneous group, stratified sampling technique is generally applied to obtain a representative sample.' (Kothari, 2004)

As the scope of the study, the urban area of Ahmedabad city is a dynamic and heterogeneous stratum which require stratification to be a representative sample. The individual stratified areas of the city are comparatively homogenous than the city. Formation of the strata is proportional to the homogenous distribution of the variables to be sampled (here, dwelling units). The process of strata formation is to ensure that the elements or items to be sampled are most homogenous within the stratum and heterogeneous between different strata.

4.2.2. Calculation of Total Sample Size

In this study, the population size comprises of the residential property count within the AMC boundary to calculate sample size. The property count nearly has been reported to be 10,94,930 residential properties across various building typology in AMC boundary (Centre for Advanced Research in Building Science and Energy, 2015). The residential cover in the city is diverse and scattered heterogeneously in the city, because of which the city is divided in the six-major administrative zones which is comparatively homogenous strata for sampling.

Table 2 Sampling calculation across zones of Ahmedabad city

Zones in AMC boundary	Total residential property units	Total sample size	No. of dwelling units to be sampled	No. of dwelling units (rounded off)
Central zone	104477	25.48	267	25
East zone	194160	47.35		47
West zone	189340	46.17		46
South zone	171048	41.71		42
North zone	140400	34.24		34
New west zone	295505	72.06		72
	1094930	**267**		**267**

Following formula has been used to calculate the sample size of 267 dwelling units for energy and environmental parameters monitoring.

$$\text{Sample size} = \frac{\dfrac{Z^2 \text{X } p(1-p)}{e^2}}{1 + \left(\dfrac{Z^2 \text{X } p(1-p)}{e^2 N}\right)}$$

Where,

- N = Population size – Total number of individuals or items represented in the scope of the area in the study. The total area covered (in sq. km) within the municipal corporation boundary under the residential land use has been considered as a population size.
- e = Margin of Error – a percentage that represents the deviation in the data gathered and which have a lesser effect on the results envisaged in the study.
- Sample size – Number of the individuals or items that are homogenous and represent the entire population under the scope of the study.
- Confidence level – A confidence level is the percentage value for representation of all possible samples that can be expected to present in the true population size which is represented by z-score in the formula.

The sample size is directly proportional to the accuracy of the data envisaged. To get the smaller margin of error, the larger sample size has been selected from the given population. Higher Percentage of confidence level or the z-score reduces the errors in the sample calculation. Also, the sample size increases with a higher confidence level. Following table explains the relationships between the desired confidence level and z-score.

Table 3 Relationship between confidence level and z-score

Desired confidence level	**z-score**
80%	1.28
85%	1.44
90%	1.65
95%	1.96
99%	2.58

4.2.3. Residential Building Typologies

Residential sector in the city of Ahmedabad covers diverse typology with the reference to the construction type, heritage, income group, and building height. The city of Ahmedabad is geographically divided into two halves by the river Sabarmati, the eastern part of the city comprises of the old/walled city and has vernacular residential buildings dominated over the multi-storey apartments, row houses or bungalows. The western part of the city developed later and is dominated by multi-storey apartments on the transit corridors and peripheries of the city, bungalows and row houses. Affordable housing units in the city of Ahmedabad are concentrated in the peripheral belt of the city and in the areas where the in-situ slum redevelopment has taken place in the internal pockets of the city. Following are the building typologies considered for the study:

- **Bungalows –** Large detached houses with one or more story and peripheral open space in the gated or non-gated neighbourhood.
- **Row houses -** A Residential neighbourhood with dwelling units constructed in a linear pattern where two buildings share a common wall. These dwelling units have similar architecture and plot area.
- **Traditional houses –** Traditional houses in Ahmedabad are also known as 'pol houses' which are houses in narrow streets of the walled city of Ahmedabad. These are the cluster of houses constructed in a way where two houses share a common wall and structure consists of wooden posts and beams with infill wall of bricks. These houses have plastered interiors and exteriors.
- **Kachha houses** (**Squatter settlements**) – Temporary settlements
- **Affordable housing units –** Affordable housing units are the multi-storeyed buildings constructed under the aid or national program Pradhan Mantri Awas Yojna (PMAY) which is a financial aid from Prime minister's affordable housing scheme for urban poor and lower income group in the urban areas. These houses are generally 1 bed room, hall and kitchen (BHK) and are constructed by Public Private Partnership (PPP) of ULB and private developers.
- **Apartments** (**high rise and low rise apartments**) **–** Multi-storied residential building with multiple dwelling units on each floor. This category of residential building is further divided into two sub-categories high and low rise based on the local floor space index (FSI).

4.2.4. Sampling across the Building Typologies and Administrative Zones

It becomes essential to sample dwelling across different zones from all categories in way where every single category has representation in most of the zones depending on the availability. Traditional houses are predominantly located in east zone of the city. High rise buildings are concentrated in comparatively newly developed (west and new west zone) areas of the city hence the sample size vary accordingly in these areas.

Table 4 Sampling of dwelling units to be monitored across various typologies and administrative zones

AMC Zones / Building Typologies	Central zone	East zone	West zone	South zone	North zone	New west zone	Total per building typologies
Bungalows	3	2	4	4	6	7	26
Row houses	3	4	4	5	2	8	26
Tenements	3	3	4	5	3	8	26
Traditional houses		26					26
Kachha houses	3	3	4	6	3	7	26
Affordable houses			10		10		20
Apartments - 2-bhk (low rise)	3	3	5	6	2	11	30
Apartments - 2-bhk (high rise)	3	2	5	5	3	11	29
Apartments - 3-bhk (low rise)	3	2	5	6	2	11	29
Apartments - 3-bhk (high rise)	4	2	5	5	3	10	29
Total per zone	25	47	46	42	34	73	**267**

5. System Architecture

The monitoring strategy described an ideal system to monitor energy and environment parameters that is required for the study. System architecture defines a conceptual model and steps to procure the monitoring equipment.

The study has been designed to focus on the data collection for energy consumption and indoor environmental parameters in the dwelling units and communities across diverse typologies across the larger geographical area. Deployment of monitoring equipment will be done as the building typologies sampled across the city boundary after the procurement of the system.

5.1. System Architecture Proposals Review

After circulating the guidelines to the vendors, proposals were received. A comparative analysis was done among different proposals based on technical specifications, financial specification, data communication and installation process as explained in Appendix A.

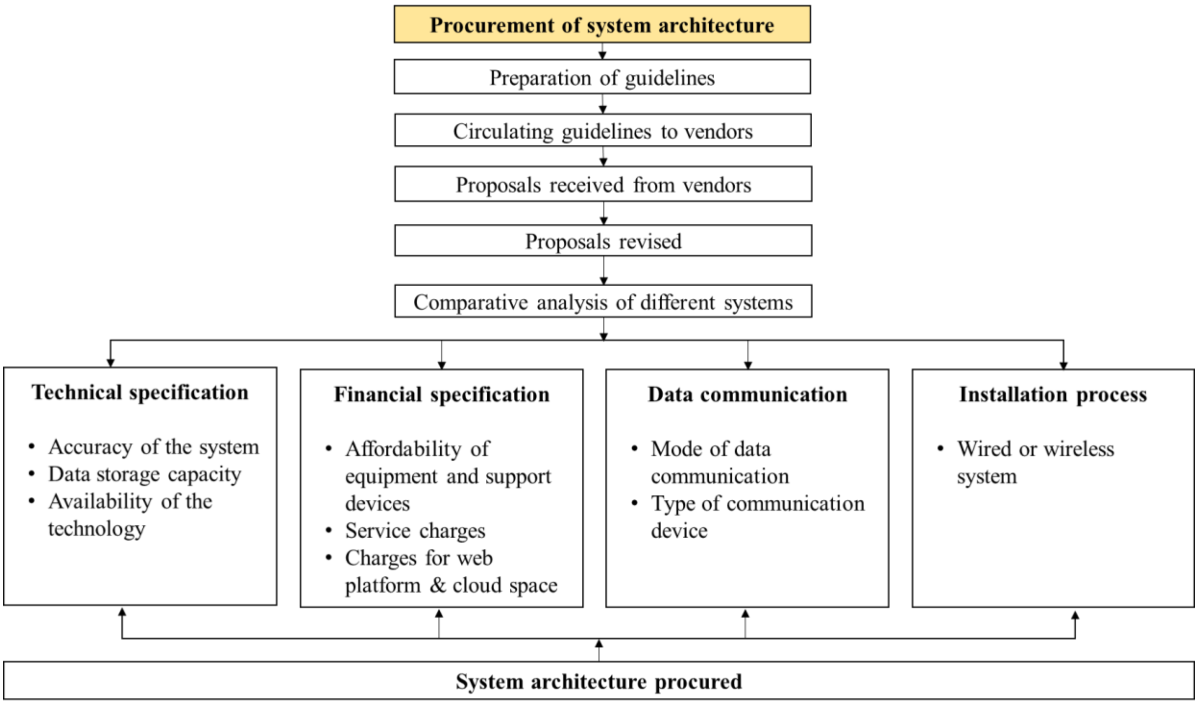


Figure 7 Methodology for system architecture procurement

5.2. Procured Monitoring Equipment

This system procured consists of two types of monitoring devices which are secure elite 440, the energy monitoring device and HOBO U12-012, the indoor environmental parameter sensor. The technical specification and system architecture is mentioned in Case 8 of Appendix A.

5.2.1. Energy meter

The energy monitoring meters would log Watts, Volts, Ampere and PF. The devices installed would be class-1 meters and would capture the energy consumption data every 15 minutes. The energy meters are designed to be installed in an enclosure box along with Current Transformers (CT).

Figure 8 Energy meter - secure elite 440

5.2.2. Environmental parameter sensor

Air temperature and relative humidity are the Environmental parameters which would be monitored by a device, HOBO U12-012 installed in different areas of a dwelling unit. These sensors would be installed in (i) kitchen or dining area, (ii) bedroom with air conditioning and (iii) living room or common area. The installed environmental parameter monitoring device would capture data every 15 minutes with the accuracy of air temp (with accuracy ± 1ºC) and relative humidity (with accuracy ± 5% RH). This equipment is battery based with battery life of 1 year and are wall mount type.

Figure 9 Indoor environmental parameter sensor (Data logger) - HOBO U12-012

5.3. Instrumentation

5.3.1. Installation of Monitoring Equipment at Dwelling level

The energy meter in the system is wired equipment and the environmental parameter sensor is a wireless monitoring device. Both the equipment are wall mount type, where the energy meter is in the enclosure box along with CT (if required) and mounted on wall.

Typically, three power based energy meters would be installed in a dwelling unit. Meter one will be installed at high energy consuming appliance having intermittent use, i.e. air conditioner (appliance level or circuit level installation based on the wiring system of the appliance). Meter two will be installed at dwelling unit level which would monitor the net energy consumption of the dwelling unit. Meter three will be installed with an appliance which is consuming energy continuously, i.e. refrigerator.

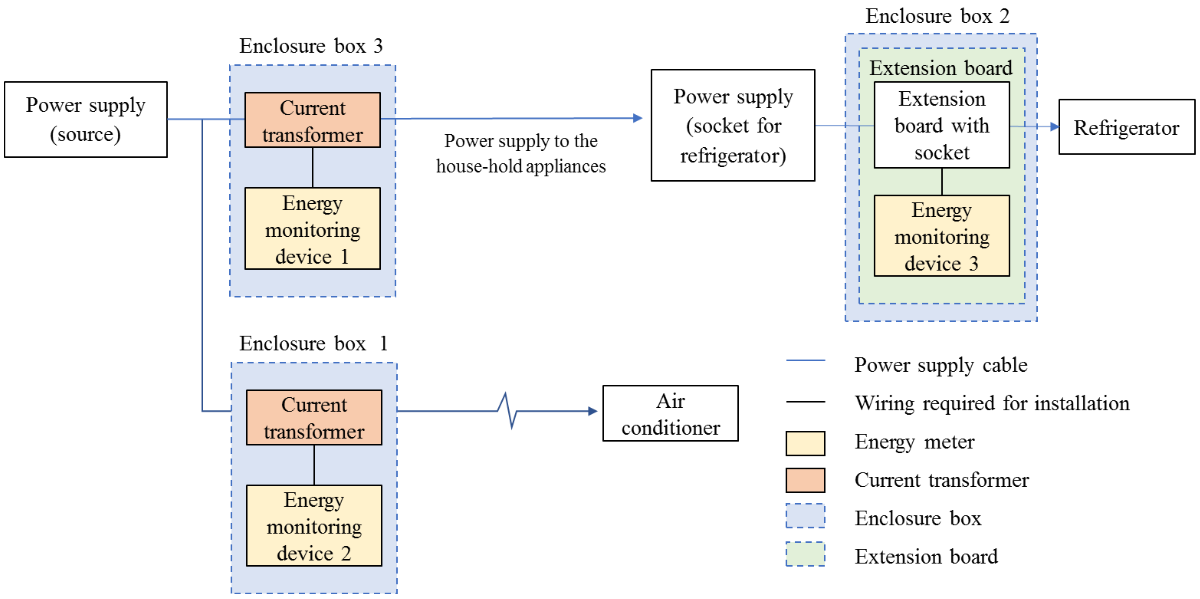


Figure 10 System architecture at dwelling level with three energy meters

5.3.1.1. Monitoring of Energy Consumption at Dwelling Level

A single energy meter has been planned to monitor the energy consumption of the entire dwelling unit which would be installed next to the distribution board through which the energy is supplied by DISCOM. This meter will capture the energy consumption data for all the appliances consuming electricity in the dwelling unit.

Figure 11 Installed energy meter at dwelling level

5.3.1.2. Monitoring of Energy Consumption at Appliance Level

Two meters at the appliance level has been envisaged out of which one meter would be installed next to the main meter at circuit level through which the energy is supplied by DISCOM which would capture energy consumption of the room with the air conditioner as the appliance is high energy consumption device. The second appliance to be monitored is refrigerator which is a continuously running device. The meter capturing energy consumption of refrigerator is connected to extension board which would be a connection between appliance and power supply.

Figure 12 Desired installation of energy meter at appliance level

5.3.1.3. Monitoring of Environment Parameters at Dwelling Level

The environment monitoring sensors, HOBO U12-012, would be installed in different areas of a dwelling unit. These sensors would be installed in (i) kitchen or dining area, (ii) bedroom with air conditioning and (iii) living room or common area base on the building typology. The installed environmental parameter monitoring devices are wireless and wall mount type.

Figure 13 Installed environment sensor at dwelling level

5.3.2. Installation of Monitoring Equipment at Community level

The energy meter in the system is wired equipment. The equipment is wall mount type, where the energy meter is in the enclosure box along with CT (if required) and mounted on wall.

Typically, two power based energy meters would be installed to monitor energy consumption of the common amenities at community level. Meter one will be installed to monitor energy consumed by water pump to elevate water coming through municipal water service lines to overhead tank. Meter two will be installed at to monitor the energy consumed by the use of elevators.

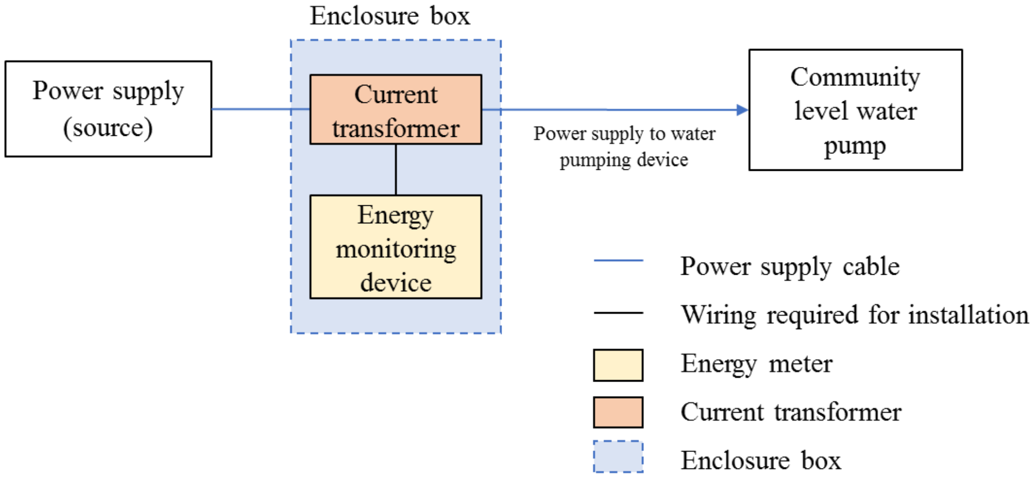


Figure 14 System architecture at community level with one energy meter for water pump

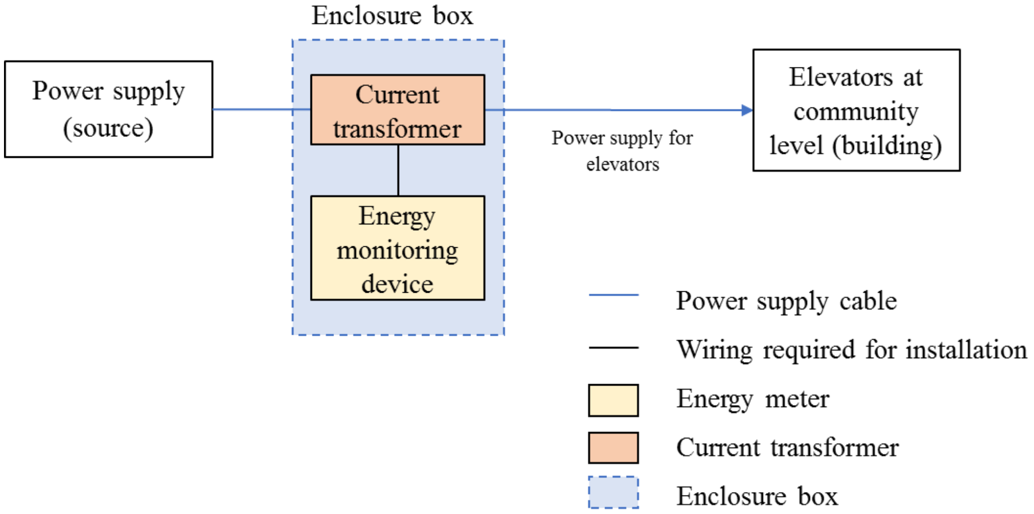


Figure 15 System architecture at community level with one energy meter for elevator

Figure 16 Installation of community level monitoring

6. Energy and Environment Monitoring at Dwelling level

Monitoring of the sampled dwelling units has been divided into multiple clusters which are as per the categories quantified in the sampling methodology or a combination of different categories. The process of installation of the monitoring devices have been planned according to the clusters of the dwelling units. The monitoring timeline of a single unit has been strategized for one year to capture the data related to indoor environmental parameters and the respective energy consumption across all the seasons.

6.1. Cluster I - Affordable Housing Units

PMAY, the national scheme launched in 2015 has targeted 20 million dwelling units for urban poor by 2022. "Affordable housing refers to any housing that meets some form of affordability criterion, which could be income level of the family, size of the dwelling unit or affordability in terms of EMI size or ratio of house price to annual income" (Gopalan & Venkataraman, 2015) .

6.1.1. Site Selection for Cluster I

20 dwelling units were selected which are spread across three different affordable housing schemes as part of Cluster I (Appendix B).

- Site 1 - 5 dwelling units
- Site 2 - 8 dwelling units
- Site 3 - 7 dwelling units

The sampled dwelling units which are scattered in three different affordable housing schemes are based at three different locations in the city of Ahmedabad. These buildings are constructed under the national scheme of PMAY for in-situ rehabilitation of the urban slum population. The dwelling units constructed are generally 30 to 60 sq. m which are allotted to beneficiaries or urban poor by in situ slum rehabilitation program. (MoHUPA, 2015).

6.1.2. Baseline Data Collection for Cluster I

As part of the study, demographics related data is collected. These dwelling units have single phase electricity supply from DISCOM. Electricity bills are collected to verify the same based on which the type of the energy meters were selected. Number and types of equipment in the dwelling unit has been noted. Construction type and wall to window ratio (WWR) has been noted. After collecting the site plans and floor plans, number of monitoring equipment and location have been selected.

6.1.3. Designing System Architecture for Cluster I

The typical dwelling unit constructed under PMAY scheme consists of 1BHK dwelling units where monitoring of energy consumption and environmental parameter has been envisaged. The dwelling unit has been installed with one dwelling unit level energy meter and two environmental parameter logging sensors. The energy meter is connected between DISCOM supply and the main distribution circuit (dwelling unit level) and has been mounted on wall. Environmental parameter sensors have been mounted on the common wall of kitchen and living area. The data logged in the monitoring devices is extracted fortnightly along with Right Now Right Here (RNRH) survey.

This system consists of two types of monitoring devices which are Secure elite 440, the energy monitoring device and HOBO U12-012 is the indoor environmental parameter sensor.

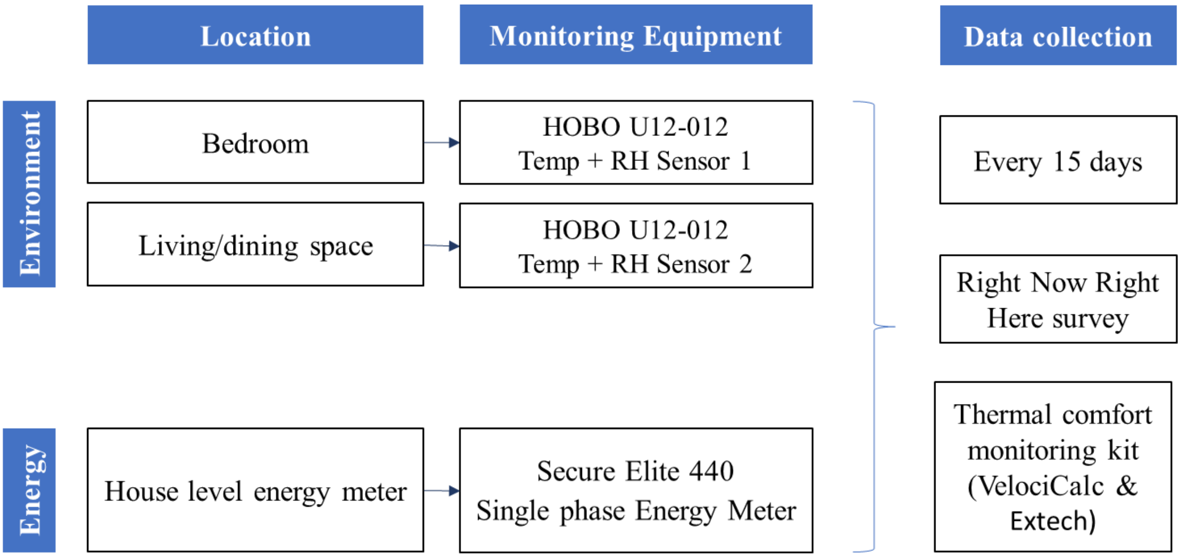


Figure 17 System architecture at dwelling level for cluster I

6.1.4. Installation of Monitoring Equipment for Cluster I

An energy meter has been installed in each dwelling unit as the dwelling unit showed single-phase power supply. The energy meter has been calibrated to capture hourly data. The meter has been installed inside the dwelling unit for the safety of the equipment and beside the main power supply fuse near the entrance. The energy meter is power based wall mount type and in an enclosure box.

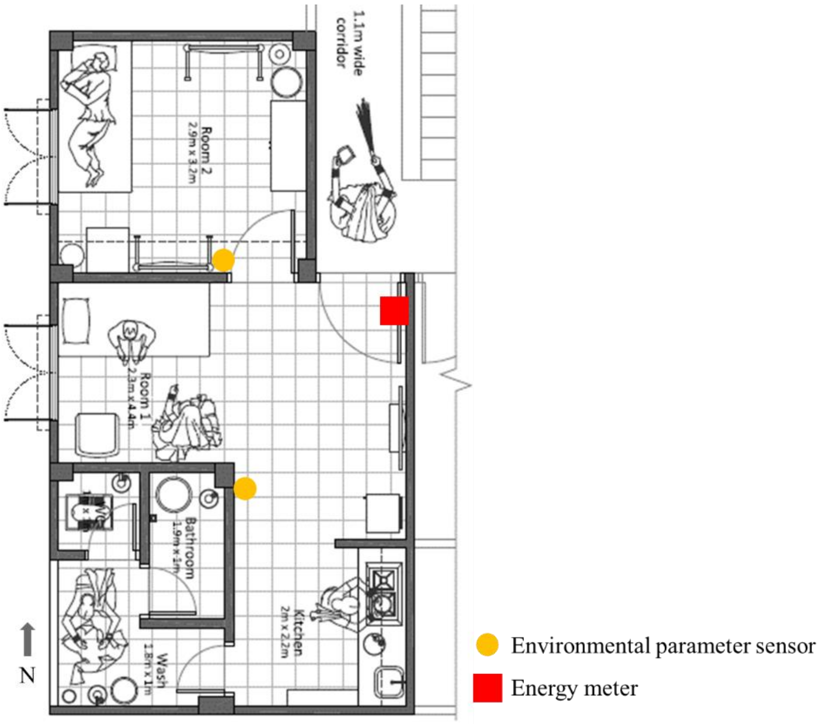


Figure 18 Monitoring equipment installation location on typical floor plan of affordable dwelling unit

Two Environmental parameter sensor (HOBO U-12 data loggers) are installed in each dwelling unit, in two different orientations. These are wall mounted, one in the living room and another in the bedroom away from direct sources of heat radiation such as windows, refrigerator, gas stove etc.

The logging interval for both energy meters and data loggers is set at 15 minutes. The logging start time is kept same for both to ensure similar date and time stamps for the data.

7. Monitoring of Energy Consumption of Common Utilities at Community level

Monitoring of energy consumption of common amenities at community level for one of the site from the three pilot sites has been implemented.

7.1. Site I - Multi-Storey Apartment

The monitoring timeline of the selected site has been strategized for one year to capture the data related to energy consumption of water pump and elevator across all the seasons. As there is only one multi-storey apartment at the selected site, the monitoring of energy consumed by the use of elevator is planned for a period of one year.

The selected site has 4 floors and 8 dwelling units. There are two monitoring devices which are Secure elite 440 for energy consumption for both the common utility. The logging interval for both energy meters and data loggers is set at 15 minutes.

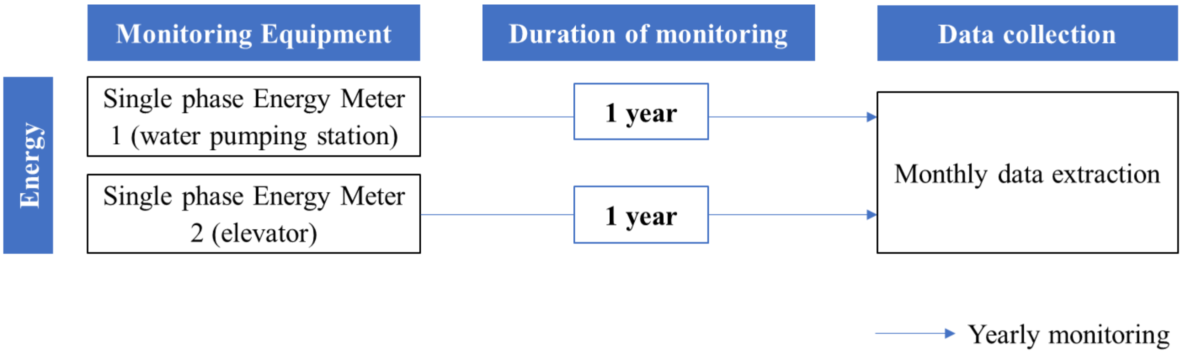


Figure 19 System architecture at community level for site I

8. Data Collection

8.1. Data Collection at Dwelling Unit Level - Cluster 1

The process of data extraction is done by visiting the site twice every month. The monitoring equipment is supported by the software to capture and store data in the specific format (Appendix C). Occupant behaviour survey is the component of the data collection only in case of cluster 1 which is affordable housing units (Appendix D).

8.1.1. Data extraction

The data collection process for the dwelling units installed with the monitoring equipment consists of three stages; data extraction from energy meter, Environmental parameter sensor and conducting occupant behaviour survey. Data collection activity has been planned every 15 days and cumulative database for energy consumption and indoor environmental parameters has been maintained. The activity of conducting thermal comfort survey has been planned based on the convenient time suggested by residents to capture maximum response.

The monitoring equipment are supported by a software to capture data in the desired format. The energy meter (secure elite 440) is calibrated to store data for 19 days after which ConfigView software is used to extract the data every 15 days. The environmental parameter sensor is a battery based device which can store data for one year but data is extracted every 15 days along with energy meter with the help of HOBOware software. The captured data is stored under the unique device code assigned to it.

8.1.2. Occupant behavior survey

The questions in the occupant behaviour survey are the part of a master question bank of RNRH survey tool referred from Indian Model for Adaptive Comfort (IMAC) and responses are based from American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) RP884 standards. The votes are recorded by researcher as a unique response every 15 day.

The data collected in the occupant behaviour survey would be integrated with the consumption of the energy and the indoor environmental parameters in the residential unit. Subjective on-field inputs from the occupants is another focus which is an addition to the data source and is relatable to both energy consumption and existing environmental parameters in the residential unit. To collect the on-field responses of the occupants' survey has been designed. This is a digital tool to collect subjective responses for the occupants about the thermal comfort. The survey has been envisaged to be conducted twice every month (fortnightly) for one year in all 20 sampled residential units under affordable housing category. The respondents this survey would be the residents of the sampled dwelling unit and every response for the survey has been a unique response for the indoor thermal comfort.

The questions in Survey is subcategorized into four types which are air temperature, Air movement, Air Quality and General comfort. These questions would be responded with the focus on sensations, acceptance and preferences for thermal comfort of the occupants in the sampled residential units.

8.2. Data Collection at Community Level - Site I

The process of data extraction is done by visiting the site once every month. The monitoring equipment is supported by the software to capture and store data in the specific format (Appendix C).

The data collection process for the site I installed with the monitoring equipment consists of data extraction from energy meter. Data collection activity has been planned every 30 days and cumulative database for energy consumption has been maintained.

9. Data Analysis

Data analysis would be attempted on below mentioned areas -

- Identifying determinants of energy use in low-cost dwelling units
- Co-relating the energy use to indoor and outdoor weather conditions, occupant number, appliance ownership, occupant behavioural characteristics
- Hourly, daily and seasonal load profiles of dwelling units
- Co-relating occupant thermal comfort sensation to occupant age, gender, clothing, metabolic activity, controls, measured environmental variables (air temperature, relative humidity, and air speed) and establish the strength of relationship of each independent variable on the dependent variable

10. Way Forward

The timeline will be prepared to achieve the tasks within planned duration. Ongoing site visits for data collection and thermal comfort surveys will continue for a period of one year. Data management and analysis will be attempted for the data collected. Further, more clusters for dwelling units and multistorey buildings will be identified in order to monitor energy and environment parameters.

References

Centre for Advanced Research in Building Science and Energy. (2015). *Advancing Buildings Energy Efficiency in India*.

Colenbrander, S. (2016). *Cities as engines of economic growth: The case for providing basic infrastructure and services in urban areas*. Retrieved from http://pubs.iied.org/pdfs/10801IIED.pdf

Gopalan, K., & Venkataraman, M. (2015). Affordable housing: Policy and practice in India. *IIMB Management Review*, *27*(2), 129–140. https://doi.org/10.1016/j.iimb.2015.03.003

Iii, P., Development, G., & Regulations, C. (2015). Comprehensive Development Plan 2021 (Second Revised), *2021*(JANUARY).

Kothari, C. R. (2004). *Research Methodology: Methods & Techniques*. *New Age International (P) Ltd*. https://doi.org/10.1017/CBO9781107415324.004

MoHUPA. (2015). Pradhan Mantri Awas Yojana - Housing for All (Urban) - Scheme Guidelines 2015, 1–62. Retrieved from http://mhupa.gov.in/pmay/repository/01_PMAY_Guidelines_English.pdf

United Nations. (2018). 68% of the world population projected to live in urban areas by 2050. Retrieved from https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html

Appendix A System Architecture Study

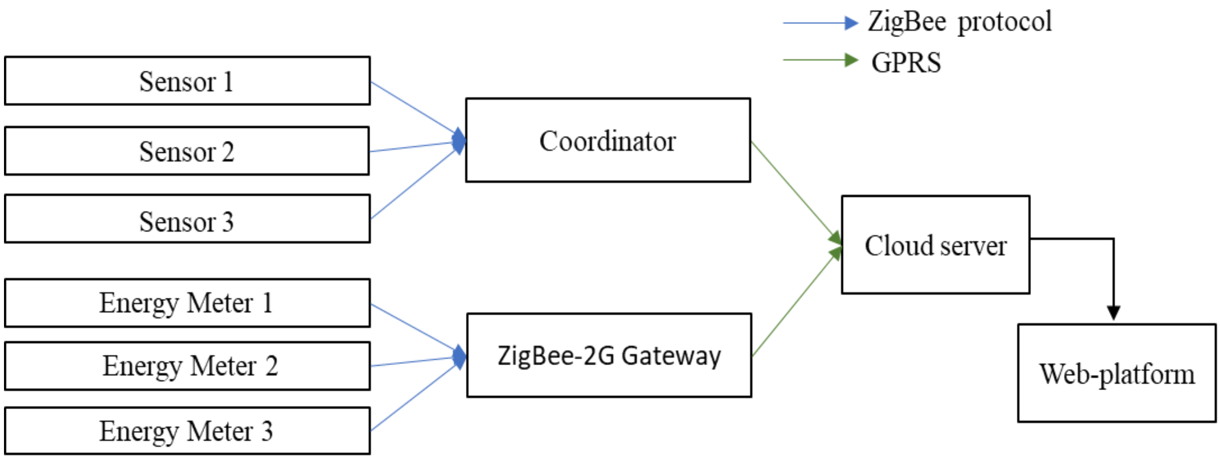
Case 1

Proposal A

This is a wireless system with three energy meters communicating to a common coordinator and three environmental parameter sensors communicating to a gateway. The secondary communication devices which are gateway and a coordinator transfers the data to cloud by 2G GPRS. The energy meters and environmental parameter sensors are to be installed in three locations of the dwelling unit; bedroom, kitchen and in the common area or living room next to the main meter box of the dwelling unit.

This system architecture utilizes two different communication protocols; primary communication between the monitoring devices and coordinator or gateway occurs through ZigBee protocol and secondary communication occurs through 2G GPRS protocol between coordinator or gateway to cloud survey.

System architecture



Technical specification

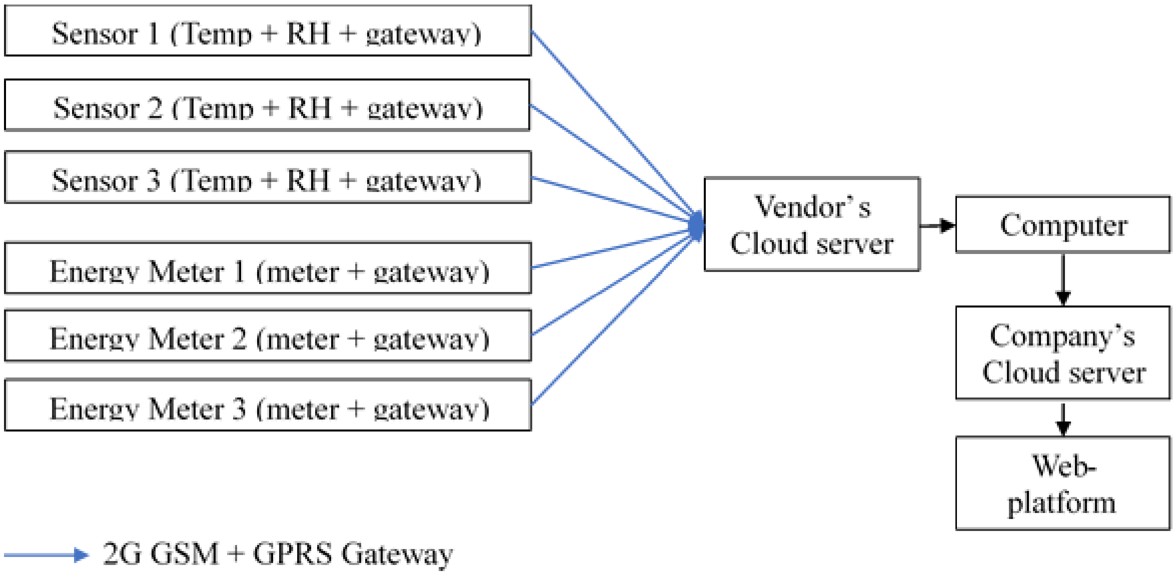
The system is a wired solution with the reference to monitoring equipment and its installation. The energy monitoring equipment are class one energy meters.

Case 2

Proposal A

This is a completely a wireless system with three energy meters and three environmental parameter sensors with inbuilt gateway which sends the data periodically to the cloud server. The energy meter and environmental parameter sensors are to be installed in bedroom, kitchen and living room or common area in the dwelling unit. The data from the monitoring devices is transferred to the vender's system and then to computer which is at CARBSE with uninterrupted power supply and internet connectivity from which finally to the company's cloud server.

System architecture



Technical specification

1	**Energy meter**	Accuracy	Class 1.0 as per IEC 62053 - 21
2	**Environmental parameters sensor**	Temperature	Range = 5°C - 50°C Accuracy = +/- 0.5 °C
		Relative Humidity	Range = 0 -100 % Accuracy = +/-4.5 %
3	**Gateway**	Connectivity	2G
		IP rating	IP20
		Power supply	24 V Power consumption 2W
		Communication (Protocol / frequency)	RS-485
		Expandable memory	8GB

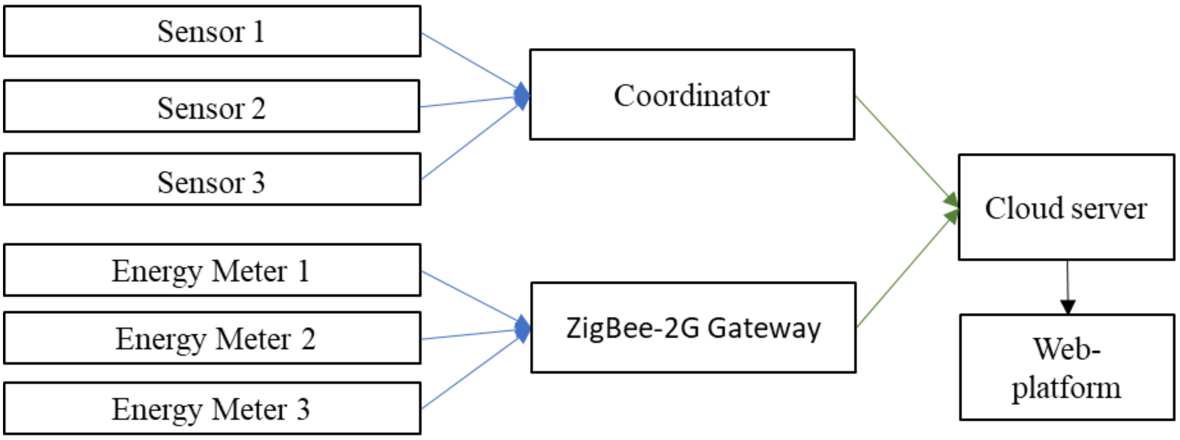
<u>Case 3</u>

Proposal 1

This is plug-n-play with the feature of data backup of the captured energy consumption and indoor environmental parameters in the sampled dwelling unit. The monitoring equipment to be installed which are energy meter and environmental parameter sensor are intended to be programmed by an App. Energy meters in this system are of the two types; one set of meters which are plug based, monitors and analyses the power consumption of the individual device load connected to it (i.e. – refrigerator and air conditioner) another energy meter monitors and analyses power consumption for the entire dwelling unit. In typical dwelling unit three environmental parameter monitoring sensors are designed to be installed which would be in bedroom, kitchen and living room or common area. The data management system has a feature of email alerts in case of malfunction of the monitoring equipment or in case of battery upgrade requirement. In the system energy meters are power based and environmental parameter sensor is battery based.

The environmental parameter sensors communicate to the coordinator and the energy meters to the 2G gateway by the 2G GPRS and ZigBee protocol respectively in the installed dwelling unit. These secondary communication devices (coordinator and 2G gateway) transfers data to the cloud server.

System architecture



Technical specification

1	**Energy meter**	Accuracy	1.0 category
		Dimension	13.5 cm x 5.5 cm x 10.1 cm (Single Phase Meter) 19.5 cm x 15 cm x 7.5 cm (Three Phase Meter)
		Power supply	Power based
		Communication	ZigBee protocol
2	**Environmental parameters sensor**	Power supply	Battery based
		Temperature	accuracy of ±1°C
		Relative Humidity	accuracy of ±5% RH

Case 4

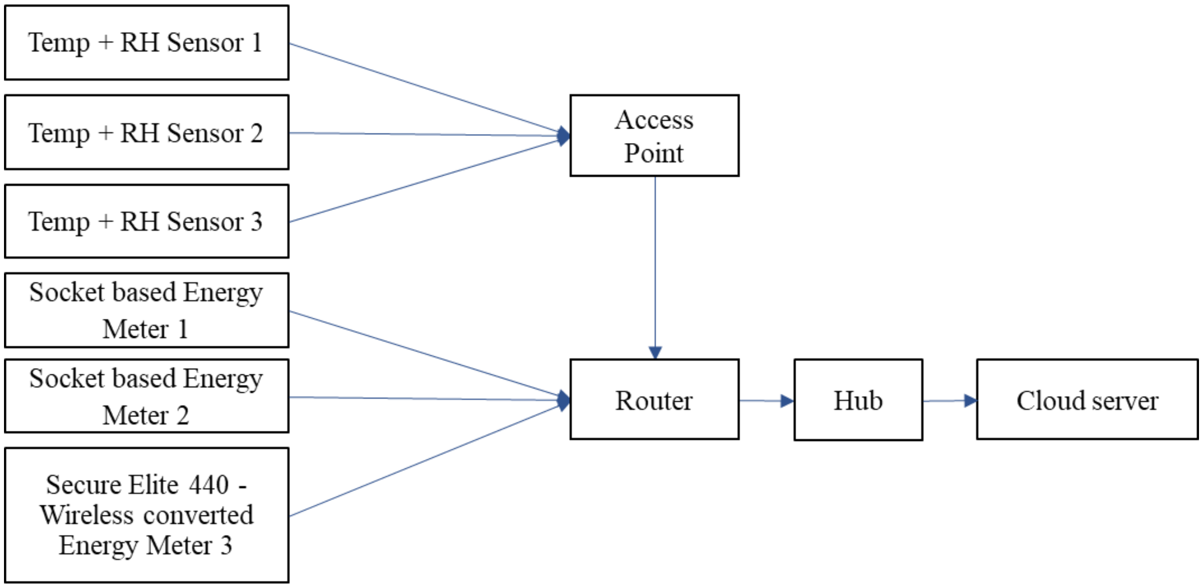
Proposal A

This is a customised system where the available energy monitoring equipment in the market has been proposed to be retrofitted to make it wireless with is originally available as wired device in the market.

The energy meter would be designed to communicate to hub wirelessly with the help of additional device which would be a communication channel between energy meter and HUB. For appliance level monitoring a plug based monitoring device has been proposed.

Similar customised proposal for environmental parameter sensor has been received, where wireless or wired monitoring equipment are to be procured from market (wired sensors has been proposed to be converted into wireless). These sensors will monitor environment data at three locations and will wirelessly send data to Access Point (AP). This data further will be wirelessly transferred from AP to Router, Router to Hub and Hub to Cloud Server. The communication from HUB to cloud would be through 2G GPRS.

System architecture



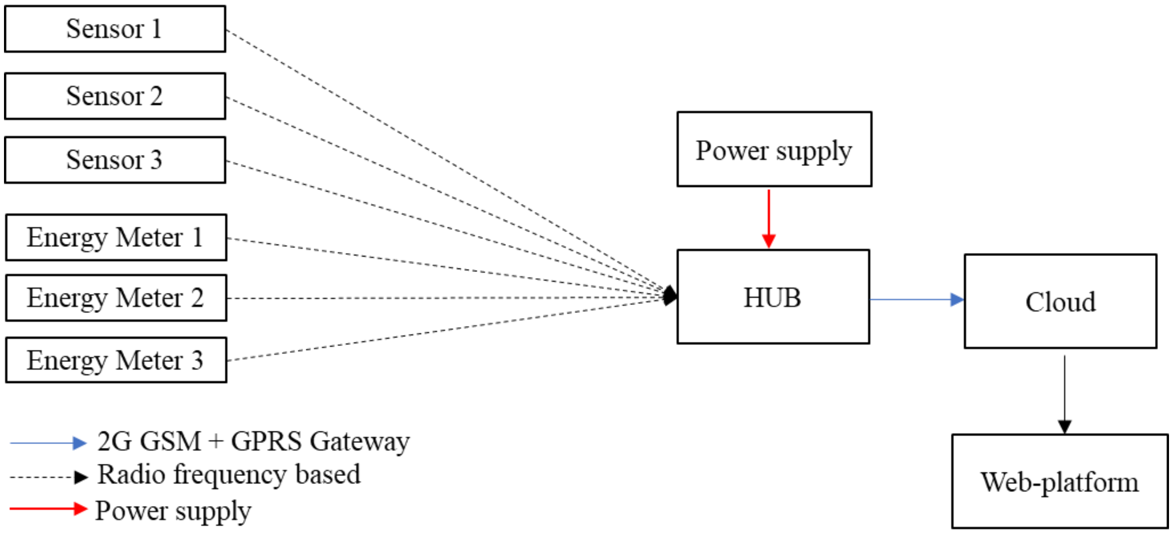
Case 5

Proposal A

This is system is a wireless system with the classical energy meter; three phase IOT energy meter or single phase IOR energy meter along with environmental parameter sensors. The installed energy monitoring devices are power based in this system and based on the communication protocol of radio frequency which transfers data to HUB (secondary communication device). The environmental parameter sensors are the devices communicating wirelessly with the HUB through radio frequency protocol.

Energy meter in the system are power based and the environmental parameter sensors are battery based. The installed energy monitoring equipment consumes <1 MB of the data monthly for communication. The secondary communication device uses 2G GPRS signals to transfer the data to the cloud server.

System architecture



Technical specification

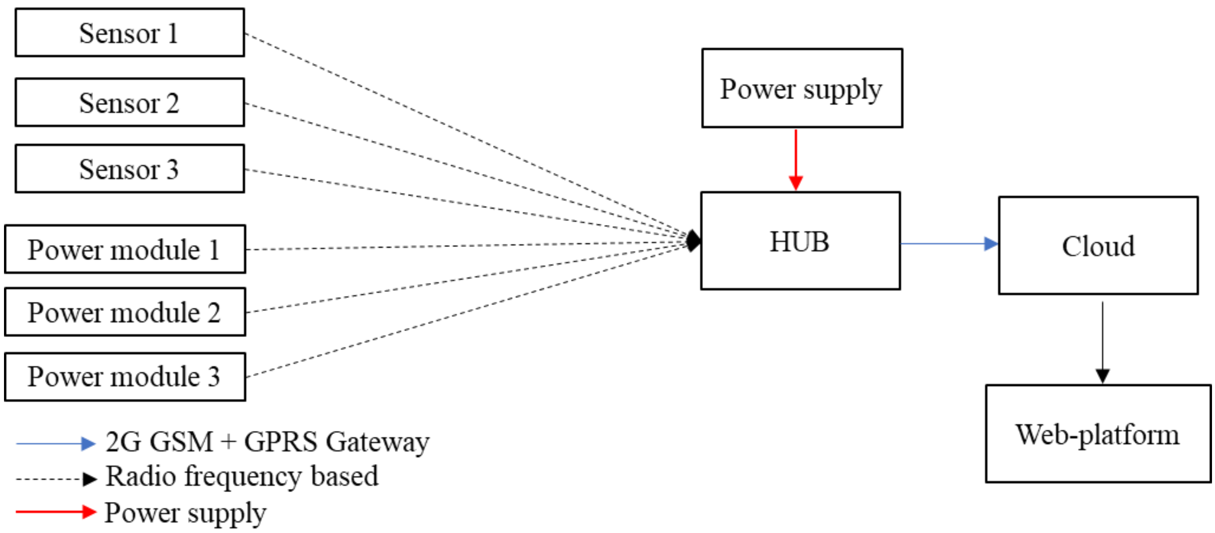
1	**Energy meter**	Accuracy	Class 1
		Dimension	Three phase:200*100*100 mm Single phase:100*75*75 mm
		Power supply	Three phase: Rated Voltage: 3 x 230/400 V Single phase: 240 V L + N
		Communication	Radio frequency based
2	**Environmental parameters sensor**	Dimension	55*55 mm
		Power supply	Battery based - consumes <5W
		Temperature	Accuracy: ± 1 °C Range: -10 °C to 85 °C
		Relative Humidity	Accuracy: ± 5 %RH Range: 0 to 90 %RH
		Communication (Protocol / frequency)	Radio frequency based
3	**H.F. HUB**	Power supply	Power based
		Communication protocol	SIM card Based

Proposal B

This is system is a wireless system with power module along with environmental parameter sensors locates at three locations in a typical dwelling unit (Bedroom, Kitchen and living room or common area). The installed power modules are the devices which record energy only with reference to KWh are power based in this system that communicates through radio frequency signals with HUB (secondary communication device). The environmental parameter sensors are the devices communicating wirelessly with the HUB through radio frequency protocol.

The installed energy monitoring equipment consumes <1 MB of the data monthly for communication. The secondary communication device uses 2 G GPRS signals to transfer the data to the cloud server.

System architecture



Technical specification

1	**Environmental parameters sensor**	Dimension	55*55 mm
		Power supply	Battery based - consumes <5W
		Temperature	Accuracy: ± 1 °C Range: -10 °C to 85 °C
		Relative Humidity	Accuracy: ± 5 %RH Range: 0 to 90 %RH
		Communication (Protocol / frequency)	Radio frequency based
2	**Power module**	Power supply	Input Voltage: 110 to 240 V Power Consumption: < 5 W
		Parameters Measured:	KVA
		Dimensions:	53*50*20 mm
3	**H.F. HUB**	Power supply	Power based
		Communication protocol	SIM Card Based

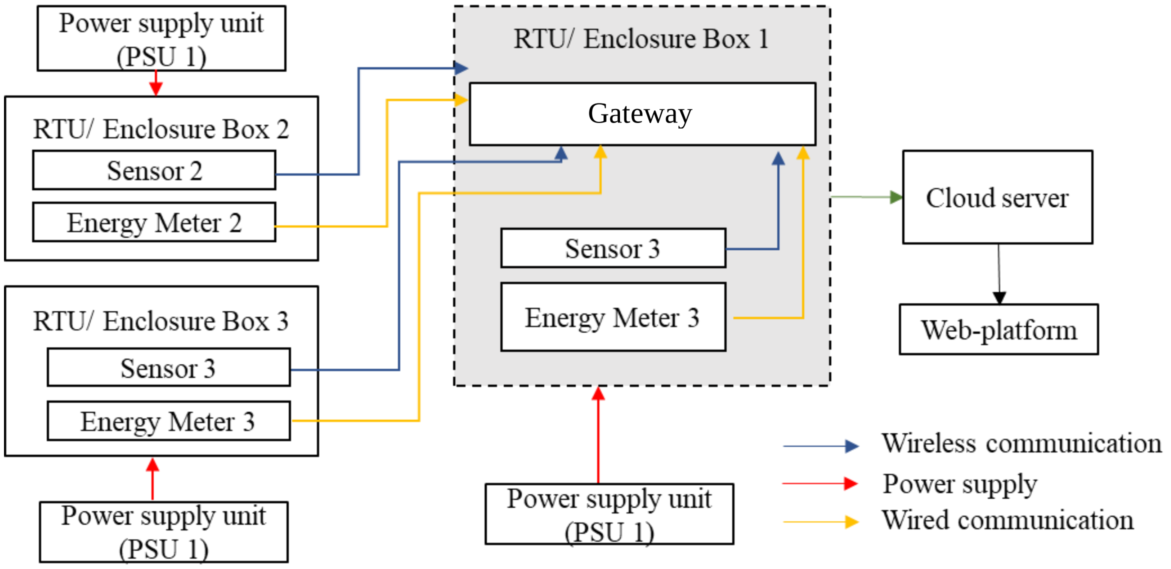
Case 6

Proposal 1

Solution 1 proposed is with three Enclosure boxes along with the Remote Terminal Unit (RTU) installed at a dwelling unit which is to be monitored. A set of monitoring unit which includes 1 energy meter and 1 environment sensor with a power supply which is a wall mount type, inside an enclosure box. One such set of monitoring devices is to be installed in the bedroom and kitchen. The third set of monitoring devices set would include a gateway additionally which is to be installed at main power supply of the dwelling in the living room or common area of the dwelling unit. In this system where the energy meters involved wired communication with the gateway and the environmental parameters sensor involved wireless communication with gateway. Power supply unit (PSU) supplies power to the energy meter in the enclosure box and to the gateway (only in enclosure box 3).

The system involves wired communication of energy meters with the gateway and wireless communication of environmental parameters with gateway occurs through WiS-122 protocol which uses Wi-Fi as a communication channel. The monitoring devices installed communicate to a gateway which is a secondary communication device which transfers data to cloud. The gateway installed in enclosure box 3 is 300 x 300 mm dimension and connected with cloud by 2G GPRS as a channel of communication.

System architecture



Technical specification

1	**Energy meter**	Dimension	**Plug based:** 96X63X49 **DIN rail Energy meter:** 35 mm width

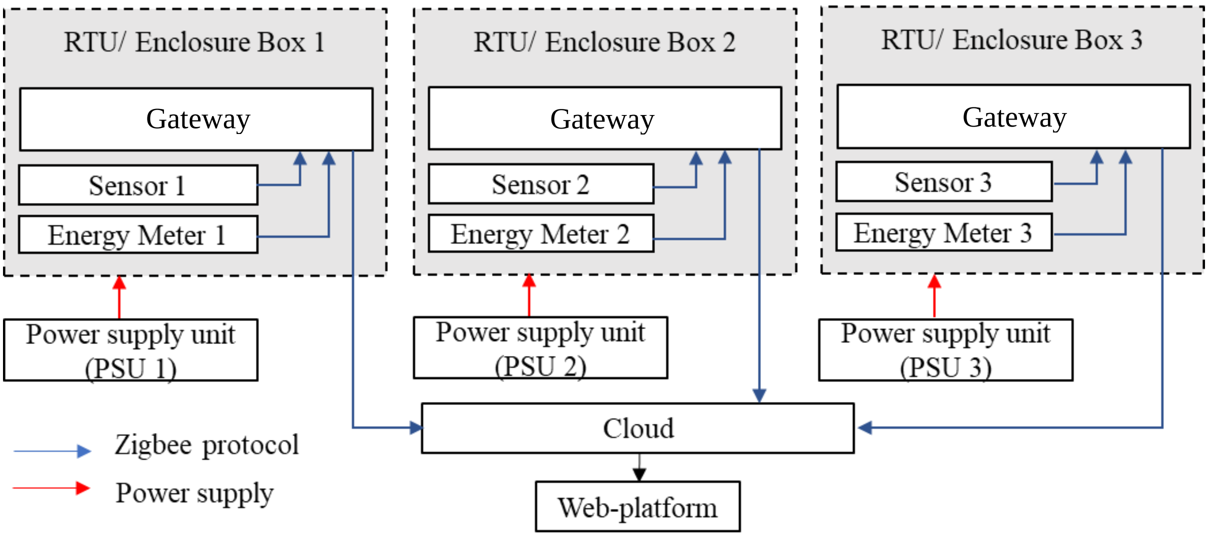
		Power supply	Plug based: External voltage (supply from main to equipment): 90 - 250 VAC Typ. Power consumption (of energy meter): <0.5 W DIN rail Energy meter: External voltage (supply from main to equipment): 90 - 250 VAC Typ. Power consumption (of energy meter): <0.5 KW
		Interface / sensors	**Plug based:** Capacity: 10A-15A **DIN rail Energy meter:** Capacity: 10A-15A
		Communication	**Plug based / DIN rail Energy meter:** wireless M-bus 868 MHz
2	**Environmental parameters sensor Multi sensor for Temperature, Relative Humidity, Motion detection, Air pressure, Brightness, CO2**	Dimension	107 x 52 x 15.5 mm with or without flange (LxWxH)
		Material	PC-V0, white
		IP rating	IP20
		Power supply	Battery configuration up to 3 x 3.6 V Lithium in parallel approx. 9000mAh and battery lifetime up to 10 years
		Temperature	**Range** = -40°C. +120°C **Accuracy** +5°C. +60°C: max. +/-0.4°C, typ.+/- 0.3 °C -40..+5°C: max. +/-1.2°C, typ. +/- 0.7 °C +60°C.+120°C: max. +/-1.6°C, typ.+/- 0.8 °C
		Relative Humidity	**Range** = 0. 100% **Accuracy** 0..20%RH: max.+/-5%,typ.+/-3% 20..80% RH: max.+/-4%, typ. +/-2% 80..100% RH: max,+/-5%, typ.+/-3%
		Communication (Protocol / frequency)	OMS/Wireless M-Bus 868 MHz

Plug based meters are proposed at appliance level and DIN rail Energy meter is proposed at dwelling unit level. The feature of 'low battery' alerts in the environmental sensor to prevent connection loss and ensure reliable operation.

Proposal B

This is a wireless system with three enclosure boxes which is to be installed at three locations; Kitchen, Bedroom and living room or common area with the main meter box. Each enclosure box consists of an energy meter, environmental parameter sensor, a gateway and a PSU for gateway and energy meter. The primary communication of energy meter with gateway is wired and environmental sensor is wireless. The secondary communication involves data transfer from gateway to the cloud through Wi-Fi which is WiS-122 protocol (Broadband Router). The gateway installed in enclosure box 3 is 300 x 300 mm dimension and connected with cloud by 2G GPRS as a channel of communication.

System architecture



Technical specification

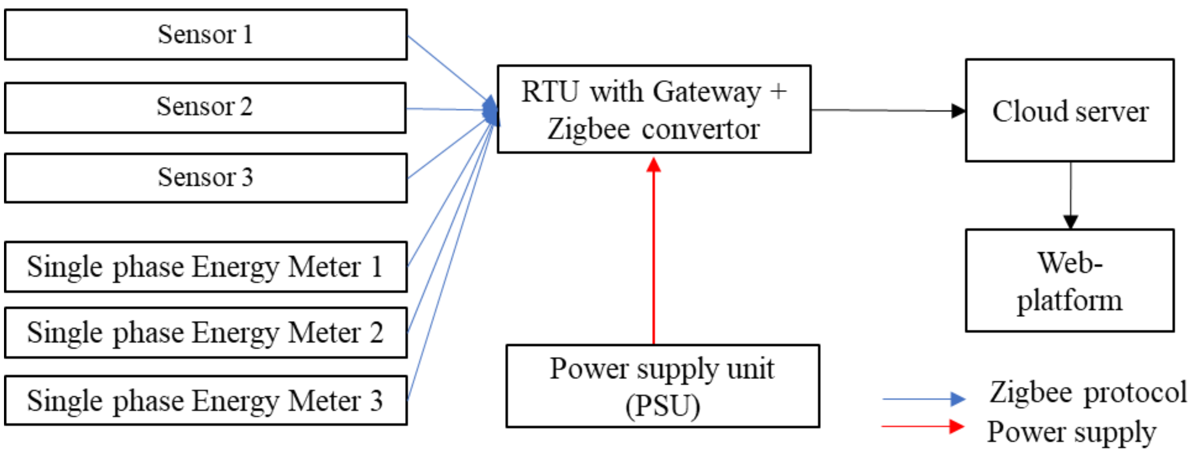
1	**Energy meter**	Dimension	**Plug based:** 96X63X49 **DIN rail Energy meter:** 35 mm width
		Power supply	Plug based: External voltage (supply from main to equipment): 90 - 250 VAC Typ. Power consumption (of energy meter): <0.5 W DIN rail Energy meter: External voltage (supply from main to equipment): 90 - 250 VAC Typ. Power consumption (of energy meter): <0.5 KW

		Interface / sensors	**Plug based:** Capacity: 10A-15A **DIN rail Energy meter:** Capacity: 10A-15A
		Communication	**Plug based / DIN rail Energy meter:** wireless M-bus 868 MHz
2	**Environmental parameters sensor** **Multi sensor for Temperature, Relative Humidity, Motion detection, Air pressure, Brightness, CO2**	Dimension	107 x 52 x 15.5 mm with or without flange (LxWxH)
		Material	PC-V0, white
		IP rating	IP20
		Power supply	Battery configuration up to 3 x 3.6 V Lithium in parallel approx. 9000mAh and battery lifetime up to 10 years
		Temperature	**Range** = -40°C. +120°C **Accuracy** +5°C. +60°C: max. +/-0.4°C, typ.+/- 0.3 °C -40..+5°C: max. +/-1.2°C, typ. +/- 0.7 °C +60°C.+120°C: max. +/-1.6°C, typ.+/- 0.8 °C
		Relative Humidity	**Range** = 0. 100% **Accuracy** 0..20%RH: max.+/-5%,typ.+/-3% 20..80% RH: max.+/-4%, typ. +/-2% 80..100% RH: max,+/-5%, typ.+/-3%
		Communication (Protocol / frequency)	IEEE 802.11b/g/n

Proposal C

This is a wireless system where the energy meters are plug based at appliance level which is at refrigerator and AC and main meter box consists of DIN rail Energy meter. The system also involves three environmental sensors at three different locations of a dwelling unit which are at Kitchen, Bedroom and Living room. An enclosure box is proposed in this system which comprises of a common gateway and a ZigBee converter in the Common area. The installed devices communicate to the common gateway installed with a ZigBee converter wirelessly and through ZigBee protocol. The whole system includes 6 monitoring devices (3 energy meters and 3 environmental sensors) and an enclosure box with gateway and a ZigBee converter which is supplied with a power by PSU. The gateway installed in enclosure box is 300 x 300 mm dimension and connected with cloud by 2G GPRS as a channel of communication.

System architecture



Technical specification

1	**Energy meter**	Dimension	**Plug based:** 96X63X49 **DIN rail Energy meter:** 35 mm width
		Power supply	Plug based: External voltage (supply from main to equipment): 90 - 250 VAC Typ. Power consumption (of energy meter): <0.5 W DIN rail Energy meter: External voltage (supply from main to equipment): 90 - 250 VAC Typ. Power consumption (of energy meter): <0.5 KW
		Interface / sensors	**Plug based:** Capacity: 10A-15A **DIN rail Energy meter:** Capacity: 10A-15A
		Communication	**Plug based / DIN rail Energy meter:** wireless M-bus 868 MHz **Plug based / DIN rail Energy meter:** Wireless LAN
2	**Environmental parameters sensor**	Dimension	107 x 52 x 15.5 mm with or without flange (LxWxH)
		Material	PC-V0, white
		IP rating	IP20

	Multi sensor for Temperature, Relative Humidity, Motion detection, Air pressure, Brightness, CO2	Power supply	Battery configuration up to 3 x 3.6 V Lithium in parallel approx. 9000mAh and battery lifetime up to 10 years
		Temperature	**Range** = -40°C. +120°C **Accuracy** +5°C. +60°C: max. +/-0.4°C, typ.+/- 0.3 °C -40..+5°C: max. +/-1.2°C, typ. +/- 0.7 °C +60°C.+120°C: max. +/-1.6°C, typ.+/- 0.8 °C
		Relative Humidity	**Range** = 0. 100% **Accuracy** 0..20%RH: max.+/-5%,typ.+/-3% 20..80% RH: max.+/-4%, typ. +/-2% 80..100% RH: max,+/-5%, typ.+/-3%
		Communication (Protocol / frequency)	IEEE 802.15.4 ZigBee, max. 250 Kbit/s, ISM 2.4 GHz
3	**Zigbee converter**	Dimensions	69.5 x 110 x48.4
		Material	PC-V0, white
		IP rating	IP20
		Power supply	External voltage 100-240 VAC 50-60Hz Max.20W Euro plug, opt. US/UK
		Operating system	Linux 2.6
		CPU	Marvell Kirkwood, Sheeva-Core, ARMv5TE compliant, 800 MHz - 1.2 FHz L1 Cache: 16K Instruction,16K L2 Cache: 256 KB
		Memory	512 MB DDR2 400 MHz, 16-Bit Bus 512 MB NAND Flash
		Communication (Protocol / frequency)	IEEE 802.15.4 ZigBee, max. 250 Kbit/s,ISM 2.4 GHz
		Data export	Temporary storage as CSV files. CSV files can get transferred vis.SSH,SCP or HTTP

Case 7

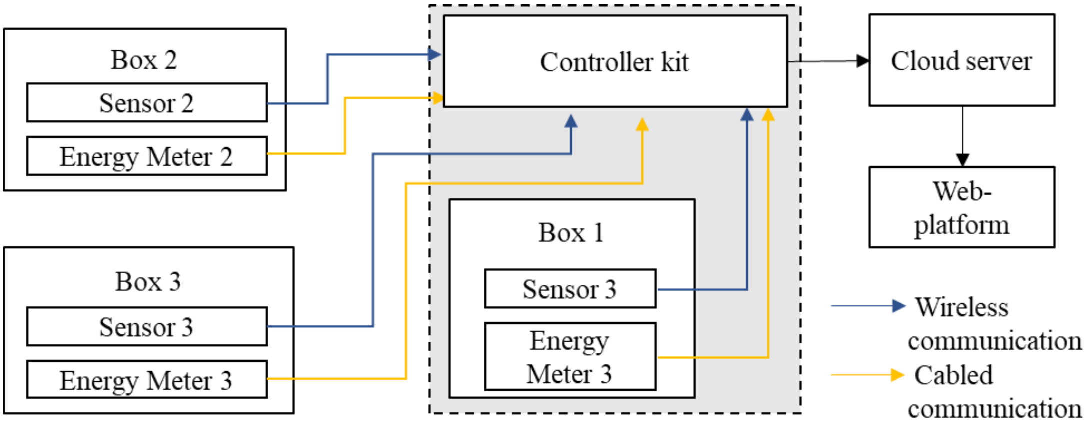
Proposal A

This is system is the combination of the wired and wireless systems. The energy meters at three locations, a set of meters at appliance level (i.e. – refrigerator and Air conditioner) to monitor the load of the power consumption of individual device load connected to it, another energy meter monitors the power consumption of the of the entire dwelling unit. The energy meters installed are power based and transfers data to the common controller kit by wired communication.

In typical dwelling unit three environmental parameter monitoring sensors are designed to be installed which would be in bedroom, kitchen and living room or common area. The environmental parameter sensors are battery based and communicate to controller kit wirelessly.

Controllers collects the data from Energy Meters/Environmental Sensors and pushes this data to the cloud via a GSM connection. The controller also has the capability to store data for longer duration of time in case of connectivity loss to ensure minimal data loss. It creates a local Wi-Fi network for temperature and humidity sensors to communicate wirelessly with it. Additional controller maybe required for the sensors when they are away from the energy meter (for e.g. basement of the dwelling unit).

<u>System architecture</u>



<u>**Case 8**</u>

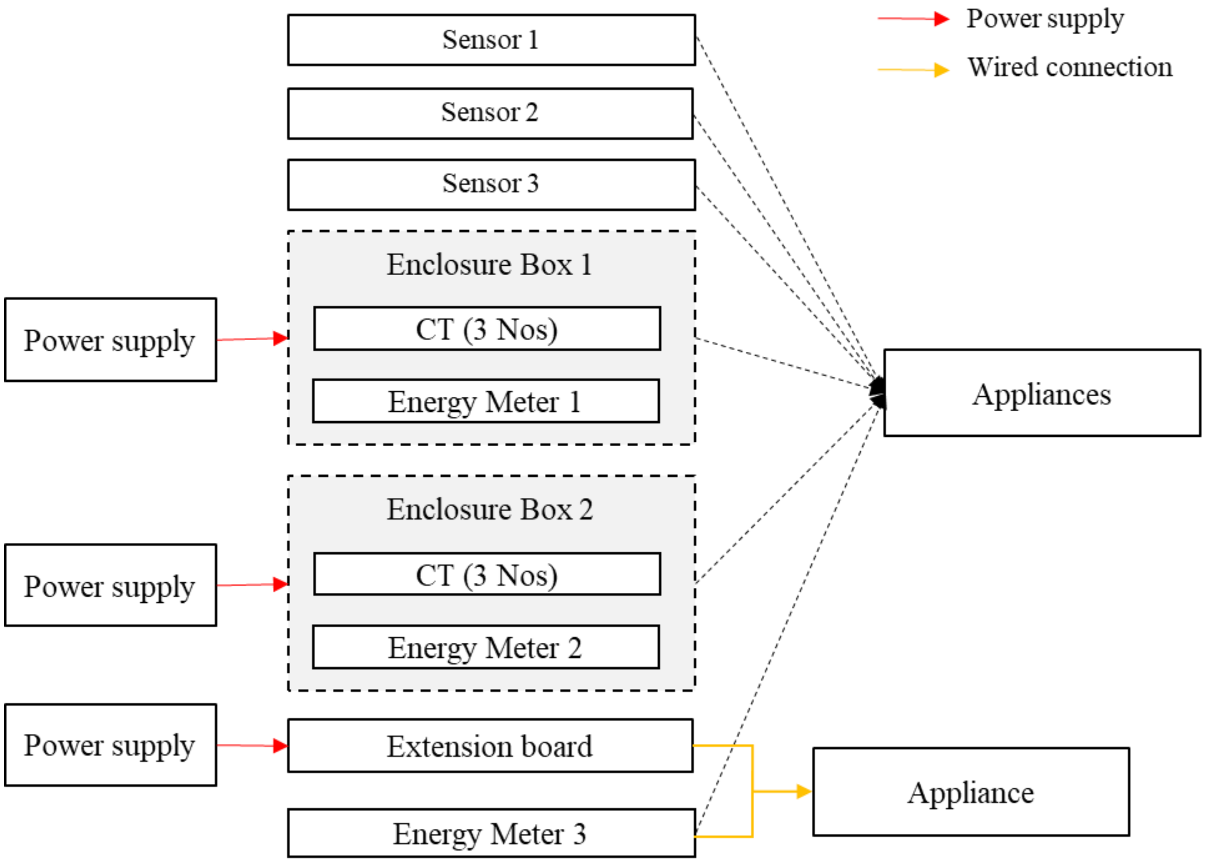
Proposal A

This the system consists of two types of monitoring devices which are Secure elite 440, the energy monitoring device and HOBO U12-012 is the indoor environmental parameter sensor.

Typically, three energy meters would be installed in a residence which are power based. Meter one will be installed at high energy consuming appliance having intermittent use, i.e. room air conditioner (appliance level or circuit level installation based on the cabling of the appliance). Meter two will be installed at dwelling unit level which would monitor the net electricity consumption of the dwelling unit. Meter three will be installed with an appliance which is consuming electricity continuously. i.e. Refrigerator. These energy monitoring meters would log Watts, Volts, Ampere and PF. The devices installed would be class - 1 meters and would capture the energy consumption data every 15 min. The energy meters are designed to be installed in an enclosure box along with CTs in case of meter one and three. Meter three which is installed at the appliance level may or may not require the CT.

Air temperature and relative humidity are the Environmental parameters which would be monitored by devices, HOBO U12-012 installed in different areas of a residential unit. These sensors would be installed in kitchen or dining area, bedroom with air conditioning equipment and the living room or common area. The installed environmental parameter monitoring devise would capture data every 15 minutes with the accuracy of air temp (with accuracy ± 1ºC) and relative humidity (with accuracy ± 5% RH). This equipment is battery based with battery life of 1 year and are wall mount type.

System architecture



Technical specification

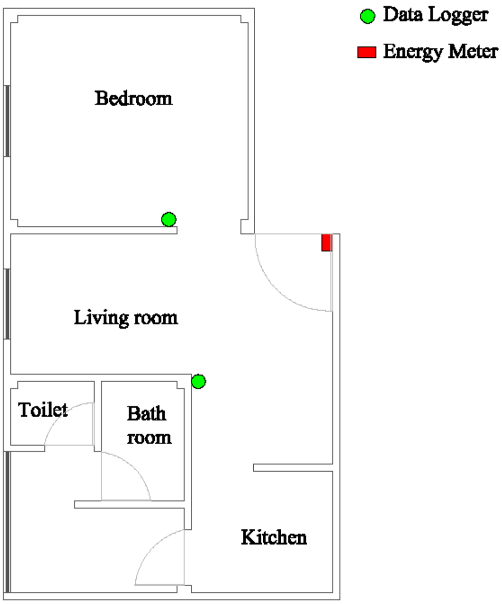
1	**Energy meter Secure Elite 440**	Accuracy	Class 1
		Dimension	96 x 96 x 65 mm (w/o module) 96 x 96 x 110 mm (with module) Cut out size 92 x 92 mm 0.5 kg (approx.)
		Power supply	Power based

		Communication	Wired - RS485 Modbus half duplex (Default) and data will be available in floating point format (IEEE754)
2	**Environmental parameters sensor HOBO U12-012**	Accuracy	Temperature: ± 0.35°C from 0° to 50°C (± 0.63°F from 32° to 122°F) Relative Humidity: 5% to 95% RH (non-condensing)
		Dimension	58 x 74 x 22 mm
		Power supply	Battery based, 1year battery life
		Relative Humidity	±2.5% from 10%RH to 90%RH typical to a maximum of ±3.5% including hysteresis at 25˚C (77˚F) below 10%RH and above 90%RH ±5% typical 0.05%RH
		Memory	64K bytes (43,000 12-bit measurements)
		Sampling rate	1 second to 18 hours, user-selectable
		Operating temperature Logging:	-20° to 70°C (-4° to 158°F); 0 to 95% RH (non-condensing)

Measurement range of the environmental parameter sensor is -20° to 70°C (-4° to 158°F). The sampling rate of the sensor ranges from 1 second to 18 hours which can be designated based on the requirement.

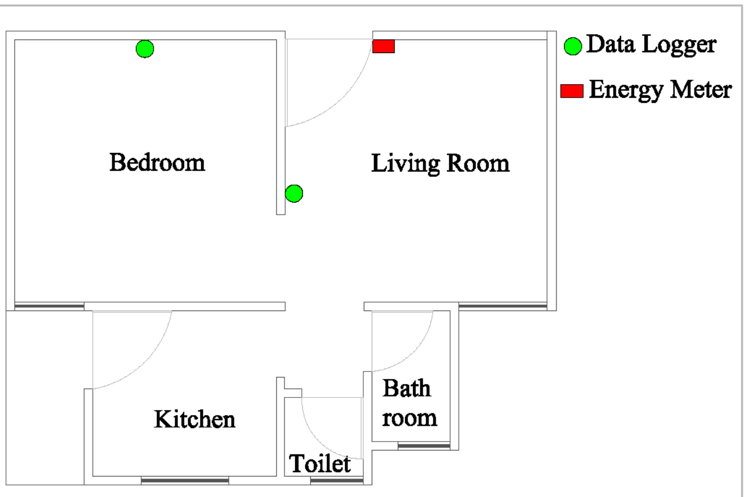
Appendix B Typical Floor Plan - Cluster I

Typical floor plan of site 1



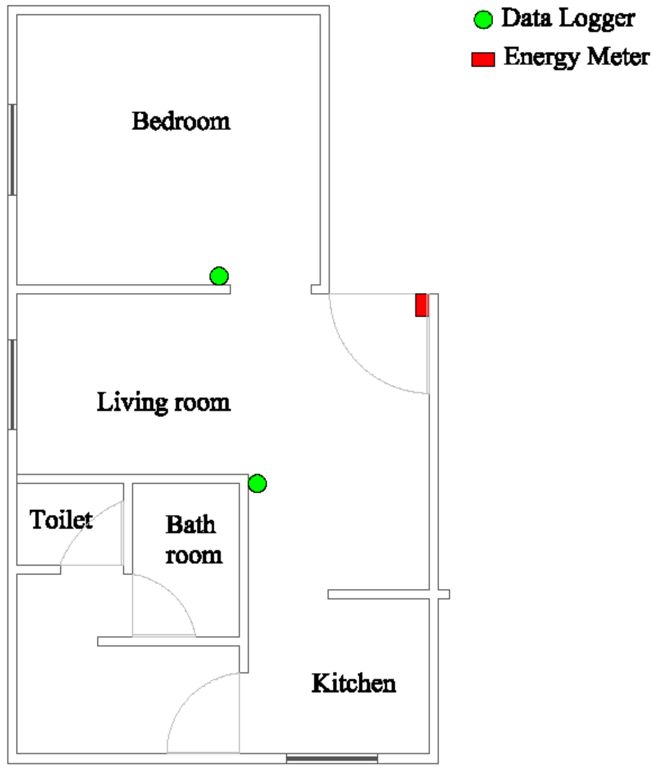
Typical Floor Plan Shantadeep Cooperative Housing Society

Typical floor plan of site 2



Typical Floor Plan Shree Ram Nagar Cooperative Housing Society

Typical floor plan of site three



Typical Floor Plan Gokuldham Cooperative Housing Society

Appendix C Data Collection Protocol

Pre- installation

Sampling

Sampling of the dwelling units to be monitored has been carried out referring literature followed by calculation of sample size, distribution of the sample across the study area. Identification of the residential typology has been carried out parallel with sampling methodology.

Site selection

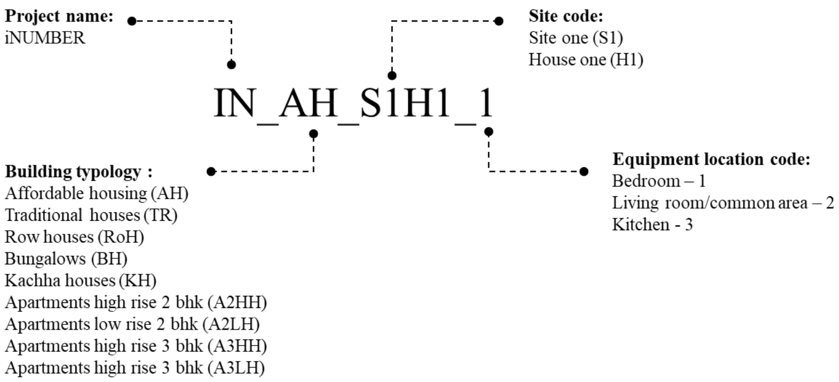
Based on the sampling methodology dwelling units has been decided to be monitored across various identified residential typologies. After selection of the probable site, an equipment demonstration is planned for the residents of the sampled dwelling unit. This activity focused to receive consent from the residents for installation of monitoring.

Baseline data collection

Data related demographics, drawings of site, electricity bills, database of type of electrical equipment is collected which would be reference for designing system architecture. The activity of collecting baseline data has been carried out with the equipment demonstration for residents of the dwelling unit.

Designing system architecture for monitoring devices

A unique system architecture is designed for different dwelling unit typology by referring baseline data collected. The equipment to be installed has been given unique number before installation. Record of the equipment to be installed is kept which includes residential typology, location of the site, dwelling unit code and location of equipment in the dwelling unit as shown below. The energy



meter which requires wired installation is kept ready with primary wiring.

Installation of monitoring equipment

The energy meter is mounted on wall in an enclosure box at three locations in a dwelling unit. The meter is set to measure and store data related to Watts, Volts, Ampere and PF at regular intervals of 15-minutes. The environmental parameter sensor is also mounted on wall and is wireless. These devices are given unique number based on the location inside the dwelling unit. The environmental parameter sensor is launched to capture new data before installation with the settings to capture data every 15-minutes pertaining to relative humidity and air temperature.

Post installation

Scheduling site visit for data extraction and occupant behaviour survey/RNRH

Site visit for data extraction and occupant behaviour survey is to be scheduled every 15 days for all dwelling units being monitored. The process of scheduling site visit for data extraction and occupant behaviour survey is done by granting permission from the residents for the same. The thermal comfort survey kit comprising of Velocicalc Multi-Function Ventilation Meter 9565 and Thermoanemometer Straight Probe 960 along with Extech HT30 meter is taken along for the surveys for simultaneous measurements of indoor dry bulb temperature, relative humidity, air velocity along x (longitudinal)

and y (lateral) directions and globe temperature.

Velocicalc Multi-Function Ventilation Meter 9565 and Thermoanemometer Straight Probe 960 as shown in first figure below.	For instantaneous measurement of air velocity, temperature and relative humidity in a thermal comfort survey close to subject.
Extech HT30: Heat Stress WBGT (Wet Bulb Globe Temperature) Meter in second figure.	For measurement of indoor and outdoor globe temperatures in a thermal comfort survey.

The process of data collection begins with measurement of indoor globe temperature in the dwelling unit close to the subject responding to RNRH survey with the help of Extech HT30.

Data extraction process for monitoring equipment is executed with the help of a software for energy meter (Secure Elite 440) and environmental parameter sensor (HOBOU12-012) which is ConfigView and HOBOware respectively. These software are installed in a laptop which is carried onsite to extract data from monitoring equipment and store the same. A data cable connects the monitoring equipment to laptop with software installed.

As the environmental parameter sensor (HOBOU12-012) is a battery based device, battery usage is verified and record is kept for the same. The batteries are replaced if required. It is verified if the equipment is logging the parameters which should be monitored, the equipment is replaced with extra equipment carried on site in case of malfunction.

The air velocity close to the subject is measured in both orientation (horizontal and vertical) with the help of Velocicalc Multi-Function Ventilation Meter 9565 and Thermoanemometer Straight Probe 960.

The survey response is recoded with the help of digital tool which is referred by the researcher on site, the questions in the survey form is explained to the respondent and the response is recorded in digital survey tool. Every survey is recorded as a unique response with the dwelling unit code and response number such as 17th survey response for dwelling unit 2 at site 3 is recorded as S3H2r17. The clothing value of the respondent is recorded based on observation by the researcher.

Appendix D Occupant Behaviour Survey Questionnaire

Thermal comfort survey (Right Now Right Here Survey)

1. **Response number**

   ____

2. **What age group do you belong to?**
   - ☐ Below 20
   - ☐ 20-30
   - ☐ 30-40
   - ☐ 40-50
   - ☐ Above 50

3. **What is your gender?**
   - ☐ Male
   - ☐ Female

4. **What is your approximate weight?**

   ____

5. **What is your approximate height?**

   ____

6. **Since how long have you occupied this house?**

   ____

7. **How do you feel about the thermal environment right now? (Check the one that is most appropriate)**
   - ☐ Cold (-3)
   - ☐ Cool (-2)
   - ☐ Slightly Cool (-1)
   - ☐ Neutral (0)
   - ☐ Slightly Warm (+1)
   - ☐ Warm (+2)
   - ☐ Hot (+3)
8. **How acceptable is the thermal environment? (Check the one that is most appropriate)**
   - ☐ Very Acceptable

☐ Unacceptable
☐ Neutral
☐ Acceptable
☐ Very acceptable

9. What change would you want in your thermal environment?

☐ No change
☐ Want cooler
☐ Want warmer

10. How do you feel about the air velocity in this room right now?

☐ Very low (-3)
☐ Low (-2)
☐ Slightly low (-1)
☐ Neutral (0)
☐ Slightly high (+1)
☐ High (+2)
☐ Very High (+3)

11. Right now, how do you feel?

☐ Comfortable
☐ Uncomfortable

12. What would you mention, is the source for your discomfort? *

	High	Low
Temperature	☐	☐
Relative Humidity	☐	☐
Air Velocity	☐	☐
Light Levels	☐	☐

13. Using the list below, please check each item of clothing that you are wearing right now. (Check all that apply)*

	Light Weight	Medium Weight	Heavy Weight
Hijab	☐	☐	☐
Scarf/ Dupatta	☐	☐	☐

Shawl	☐	☐	☐
Bra	☐	☐	☐
Blouse (for sari)	☐	☐	☐
Sari	☐	☐	☐
Short sleeved shirt/kurta	☐	☐	☐
Long sleeved shirt/kurta	☐	☐	☐
Long sleeved flannel shirt	☐	☐	☐
Panties	☐	☐	☐
Petticoat	☐	☐	☐
Skirt	☐	☐	☐
Dress	☐	☐	☐
Pajama / Salwar / churidar	☐	☐	☐
Shorts	☐	☐	☐
Pants	☐	☐	☐
Jeans	☐	☐	☐
Pajama	☐	☐	☐
Socks	☐	☐	☐
Stockings	☐	☐	☐
Shoes	☐	☐	☐
Chappals / Sandals	☐	☐	☐
Long sleeved sweater	☐	☐	☐
Vest / Waistcoat / sleeveless sweater	☐	☐	☐
Jacket	☐	☐	☐
Thermal underwear-Upper	☐	☐	☐
Thermal underwear-Lower	☐	☐	☐
Turban	☐	☐	☐
Tie	☐	☐	☐
Men’s briefs	☐	☐	☐
Dhoti	☐	☐	☐

14. Using the list below, please check the type of chair you are occupying right now.

☐ Upholstered

☐ Not Upholstered

15. What has been your activity level in past one hour? (Check the one that is most appropriate)

- ☐ Seated, quiet
- ☐ Seated, working
- ☐ Standing, relaxed
- ☐ Sleeping
- ☐ Walking
- ☐ Driving
- ☐ Cooking
- ☐ House cleaning

16. Which of the following do you personally adjust or control in your space? (Check all that apply)

- ☐ Ceiling fan
- ☐ Operable windows
- ☐ Window blinds/ curtains
- ☐ Door to exterior space
- ☐ Door to interior space
- ☐ Add/ Remove clothing
- ☐ Room air conditioning
- ☐ Portable heater
- ☐ Portable fan/cooler
- ☐ Move out of the house

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