International Journal on Emerging Technologies **8**(1): 433-442(2017)

ISSN No. (Print) : 0975-8364
ISSN No. (Online) : 2249-3255

Decision Tool to Define Choice of Microgeneration Retrofit for Indian Households: A Conceptual Framework

Siddhartha Koduru* and Dr. Madhumita Roy**
**Associate Professor, school of architecture and Design,*
Manipal university Jaipur, Rajasthan, INDIA
***Professor, Department of Architecture,*
Jadavpur University, Kolkata, West Bengal, INDIA

(Corresponding author: Siddhartha Koduru)
(Received 25 December, 2016 accepted 22 January, 2017)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: In India, housing sector is the second major consumer of electricity with the rate of demand increasing by 11.08% from 1984-85 to 2014-2015 in comparison to -16.92% by industries. around 97% of the electricity is generated using non-renewable energy sources. in contrast to this the government of India has promised to reduce the greenhouse gas emissions upto 33-35% by 2030 from 2005 levels. In 2010 the government of India also proposed the 'Jawaharlal Nehru national solar mission' to promote solar-based energy generation. in these 'solar cities' households and group housing societies are expected to install solar-based energy systems to satisfy the numbers without understanding their true potential and association with the built form parameters and user behavior. the consumer is not exposed to alternate renewable energy systems like wind based, heat pump, combined heat and power (chp). The paper defines the conceptual framework of a decision tool for homeowners to choose from different microgeneration retrofits. assessment includes analyzing existing consumption pattern of the household and its true energy demand to identify possible alternate measures. The output shall guide homeowner to make a decision based on the financial commitment and retrofitting required for the housing unit.

I. INTRODUCTION

India through its Intended Nationally Determined Contributions (INDCs) proposal in 2015 pledged at the United Nations Climate Secretariat that it would reduce carbon emissions by upto 33-35% relative of its GDP from 2005 levels by 2030. It also affirmed that out of the total electricity generated by 2030, 40% electricity shall be from non-renewable energy sources like solar and wind power (Neha, 2014).In 2014-15, industry sector was the highest consumer of electricity at 42.10% followed by the domestic sector at 23.53%. But if the historical values are compared from 1984-85 to 2014-15 the industrial sector has seen a decline of 16.92% in electricity consumption from 59.02% to 42.10%, whereas within the same duration the domestic sector has seen a growth of 11.08% in electricity consumption from 12.45% to 23.53%. In addition to the changing electricity scenario, India has the highest transmission and distribution losses in the world at 23.65% in 2012 (Central Statistics Office, 2016). Also, the per capita consumption of electricity in 2012 was 884 whereas the world average was 2,972 and countries like Brazil achieved a value of 2509.

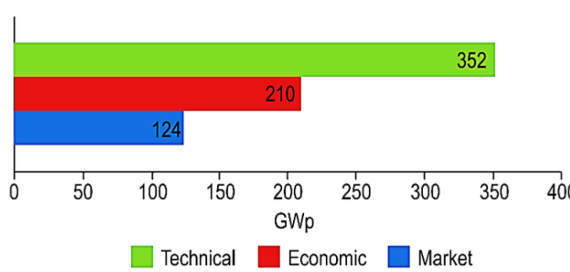

Fig. 1. India's Potential for Rooftop Solar Photo Voltaic Capacity. (Source: TERI, Reaching the Sun with Rooftop Solar Report, 2014).

The residential electricity use in India in expected to four-fold in 2030 and an average household shall consume upto five times electricity by 2020 in comparison to 2000 (Agency, 2007) (Ghosh, 2002).To meet this growing electricity demand there is a major momentum towards creation of energy infrastructure in different parts of India.

The present power generation configuration in India is mainly attributed to Coal (75.61%), Hydro (11.69%), Renewable Energy Sources (5.59%), Gas based sources (3.72%), Nuclear (3.27%) and Diesel (0.13%) based sources (Central Statistics Office, 2016). To increase the present renewableenergy based power generation from 5.59% to 40% within a span of 15 years it would require measures to enhance generation, control consumption and promote conservation. This would also require contribution from all the major consumer of electricity primarily the housing sector.

A major initiative towards promotion of renewable energy systems especially solar power based was the Jawaharlal Nehru National Solar Mission initiated in January 2010. The first stage goals of the mission is to deploy grid connected solar power of 20,000 MW by 2020 (Shrimali, 2012). Another simultaneous outcome of this mission was to create 'Solar Cities' across India. The main goal for these solar cities is to reduce their projected electricity demand met through conventional energy by 10% over a span of 5 years (TERI, 2014). The choice of renewable energy systems to be developed based on the availability of resources included solar, biomass, wind, waste to energy, small hydroetc. On the global scenario heat pump, combined heat and power (CHP) systems are also promoted as part of renewable energy systems.

The electricity sector is the major contributor of CO_2 and CO emission in India. In 2012, it contributed towards 35.5% of total emissions. Out of the total emission coal based power plants contributed towards 50.1% emission (Shrimali, 2012).With rapid urbanization and increasing ownership of electric appliances the contribution towards carbon emissions is expected to increase.

As per the World Bank Report 2014, out of the total electricity used in urban areas, 69% was utilized for heating and cooling, kitchen appliance and entertainment whereas 31% was used for lighting. With increasing power demand the frequency of outages owing to power shortage have increased, primarily during the summer season when the power consumption is the highest. Another major challenge is the vulnerability of our energy infrastructure as India is prone to various natural calamities like floods, drought, earthquake, tsunami and cyclones. As a result the whole electric grid fails resulting in loss ofemergency power to places affected by natural calamities or disasters at both urban and rural level, like the recent floods in Chennai and Uttarakhand. This calls in for decentralized and localized power generation initiatives that are primarily based on renewable energy systems, which have low distribution and transmission losses, easy maintenance and recovery, need less skilled manpower in comparison to conventional energy systems and understands the availability of local resources and their potential in energy generation.

To ensure that the goals set by the Government of India are met it is necessary to implement a range of initiatives, some of which are already underway like measures to conserve energy. Apart from these concrete measures towards developing a network of decentralized renewable energy based Microgeneration power systems are required. Another approach should aim to reduce wasteful consumption of energy through retrofit measures to the existing setup. In case of the housing sector the present rate of urban development demands for high rise high density development, resulting in such initiatives be initiated at the neighborhood level.

To accommodate the growing urban population various mega housing projects are being proposed all over the country thatare supported by high energy intensive service networks. To ensure effective implementation of any initiative and promote equal contribution from every household all proposal should be planned at the community level. Existing strategies adopted by various agencies are dictatorial in nature and aimed to meet the numbers rather than involve the community; as a result they are unable to meet the desired results. Heavy subsidies upto a tune of 40% (Bijli, 2016) on investment being offered on different renewable energy systems is the only reason behind their installation and there is no cross check mechanism to ensure their working condition or maintenance once there are installed.Instead of promoting these systems and awarding the subsidies on individual basis they should be awarded to communities based on their involvement and scale of implementing the Micro generation systems. The extent of subsidy offered to the community could be based on how the strategy adopted by them has ensured energy security, reduced carbon emissions and improved the living standards of all the community members.

To ensure a greater understanding towards various Micro generation systems there is a need to develop a decision making tool that would guide the community to make a decision regarding the choice, implementation and financial constraints of different systems. The other part of the tool would define the payback period and assured returns both financially and environmentally. The tool would predict potential interventions to achieve energy efficiency and possible renewable energy systems by taking into account the existing consumption patterns, climatic conditions ofthe place, possible energy saving through retrofit of housing unit, user behavior and actual energy demand.

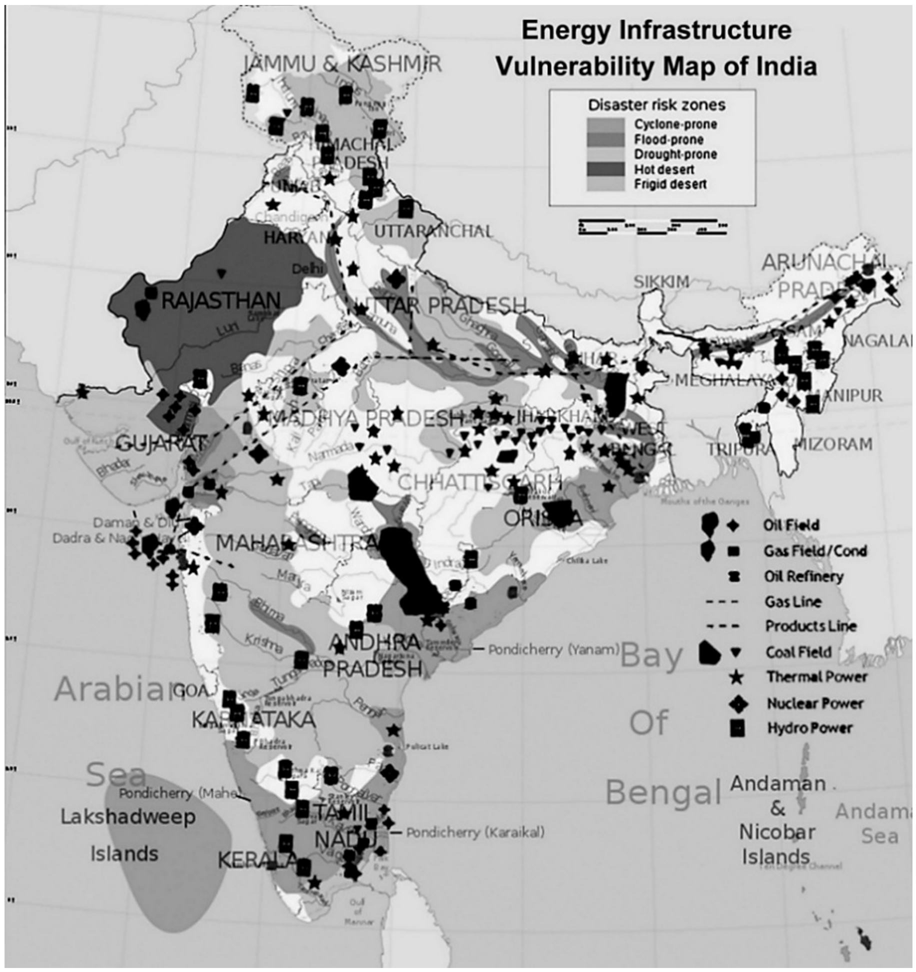

Fig. 2. Energy infrastructure vulnerability map of India.

It would guide the end users to make an evaluation based on financial and environmental benefits at household, building and neighborhood levels.

II. TOP DOWN AND BOTTOM UP VARIABLES

Energy modelling to define the energy consumption patterns at community level within the housing sector are guided by two approaches – 'Top-Down' and 'Bottom-Up' (Tuladhar et al. 2009). The Top-Down approach tries establish a relation between total energy supplied and actual energy demand in order to define measures of achieving balance. It includes collection of data for a series of variables that are based on a user, particular time period and the geographical location (Hourcade et al. 2006).

The top-down analysis relies on establishing the link between factors affecting energy consumption and total energy consumed by an individual household (Swan and Ugursal 2009). The advantage of top-down approach is that it can be analyzed using data collected through collected information like reports and processed information sets. It fails in modelling energy consumption at a larger scale and cannot model irregular changes in energy strategies or technologies (Swan and Ugursal 2009). The approach also tries to establish a relationship on basis of past data, but while modeling for scenarios related to environment, social and economic conditions and climate change it has been pointed out that the experience factor may not be the same or need not follow a trend (Kavgic et al. 2010). These limitations clearly indicate that the top-down approach cannot be the only option to identify key areas of trends in energy consumption and improving the demand side of energy at neighbourhood level (Swan and Ugursal 2009).

The Bottom-Up approach relies on data collected at household level andneighbourhood level. Based on the information collected, the energy consumption patterns identified are generalized for regional, city or national level.

The data can be analyzed at two levels – first processing involves the statistical methods and the second involving building assessment through physics based energy models.

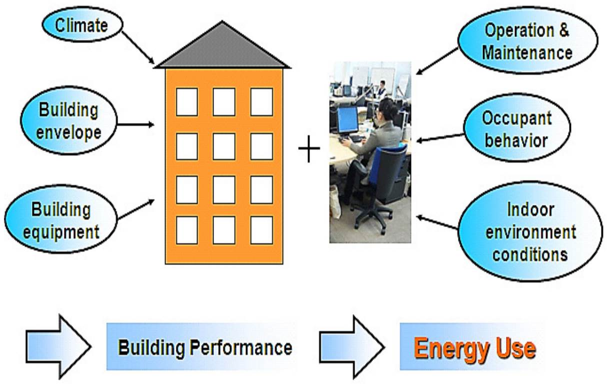

Fig. 3. Factors Influencing Total Energy Use in Buildings.

The statistical modelling process involves collection of large data sets primarily involving the monthly electricity bills, economic base, fuel types used, hours of operation, etc. The reliability and information sharing of such data is always a challenge. The final coefficient of the input values derived through regression analysis is an indicator of energy consumption of households (Fung 2003). The end result is only an indicator of energy consumption within the household or neighborhood but cannot define the possible impact of measures taken up to reduce energy consumption through different scenarios (Fung 2003).

The short comings of the statistical methods could be answered by the building physics model which calculates the energy performance of a building or its components. This involves identifying the various physically measurable variables of a housing unit, its occupants and energy consuming infrastructure that would be required for quantitative assessment. The first and most predominant set of variables are linked to the area and dimensions of the housing unit and its various elements like floor, roof, walls, door and windows. The second set of variables includes the materials, components used in the construction of the unit and their corresponding thermal performance in form of U-values. The third set of variables are related to the occupants and their behaviour pattern listed in form of total number of occupants, heating and cooling needs, indoor and outdoor temperatures. The fourth set of variables are related to the configuration of energy consuming appliances in the household, their efficiency levels, period and duration of operation etc. (Johnston 2003).

The data sets for building physics modelling could be collected from surveys conducted both at household and neighborhood level, national, state or regional level information sets. The analysis will result in defining the existing energy consumption patterns and also estimate the future energy consumption of the households and neighbourhood (Larsen and Nesbakken 2004). In depth analysis would also aid in understanding the user behavior at household and neighborhood levels thereby making effective strategies aimed at reducing wasteful energy consumption and promoting energy conservation. Another major outcome would be the performance of electrical appliances and measures to enhance their efficiency.

The level and detail of information in the data sets defines the accuracy of the building physics model. The algorithm in the models being modular in nature, they could be modified to suit the needs and define the desired output (Kavgic *et al.* 2010). To check the accuracy and performance of the models, calibration could be done using historical data. Due to their diverse applicability and possible iterations building physics models have evolved to be the ideal method to estimate sector based energy consumption taking into view all possible impacts of any new technology, at the same not dependent on historical data for reference or identifying trends (Swan and Ugursal 2009).

III. MICROGENERATION CHOICES AND NEED FOR THE TOOL

The materials that are used in the construction of a housing unit account to 50% of total carbon footprint generated by the energy consumed by the unit in its lifetime. If the insulation of a unit is not taken care of then it becomes 25%. Interventions to minimize the carbon footprint of a housing unit through mitigation of its insulation and possible retrofitting should be promoted to reduce the overall energy demand.

Microgeneration infrastructure can be another set of measures to reduce dependence on fossil fuels as a result impacting the carbon footprint of the unit. Depending on the overall energy demand the type and configuration of the Microgeneration infrastructure can be defined. They could be standalone systems or a combination of two or more systems which are collectively called ‘co-generation’ or ‘tri-generation’ systems. These systems due to the close proximity between source and the point of use are more efficient than conventional grid based networks.

Fig. 4. Types of Microgeneration Infrastructure relevant to Housing Sector.

The various types of Microgeneration infrastructure (Fig. 4) that could be part of individual household and neighborhood are – solar water heating, photovoltaic, wind power, biomass, combined heat and power (CHP), heat pumps and hybrid technologies.

*A. Solar Water Heating and Solar Photo Voltaic (SPV)*Solar water heating systems are the simplest way to utilize sun's energy in heating water or air. The system is easy to adapt to various built form typologies. But the major challenge is its applicability in places that experience extreme cold conditions. The second major choice in Microgeneration infrastructure is the solar photovoltaic cells, which convert sun's energy into electrical energy and store it in batteries. Due to lack of moving parts they are the most easy to operate and maintain. The two major varieties that are commercially available are 'Mono Crystalline' and 'Poly Crystalline' modules.

The mono crystalline photovoltaic (PV) cells are costly due to highly refined circular solar cells but have higher efficiency of upto 45%, on the other hand poly crystalline PV cells have impurities as a result are less efficient and cheaper than mono crystalline cells. Apart from these a third generation of solar cells called Photo Electro Chemical (PEC) cells are being developed that can achieve an efficiency of 65%.

B. Wind Power: After solar, wind power is the next major renewable energy infrastructure being deployed at various part of the country. These wind farms are primarily located along the cost and open areas to take full advantage of the local resources.In the urban context, due to space constraints they are preferred to be installed on rooftops so that they are clear of any obstruction. To run the blades of the utility turbines, continuous air flow ranging over a speed of 6 m/s would be required.

With a lot of obstructions, tree coverage and built mass it would be very difficult to achieve wind speeds that could run the turbines. To ensure better operation of the wind mill the turbine and blades should be at least 10 m above the highest obstruction. This possess a challenge for neighborhoods near airports due to height restrictions. The overall efficiency of wind mills range from 25% - 40% thereby the return period is longer than solar based systems.

C. Biomass: Biomass is a major source of energy in the rural parts of India. The most common form of biomass is agricultural waste, apart from that municipal waste converted into combustible pellets are also being considered as a form of biomass. Biomass is burnt in kilns to generate hot air or hot water that drive turbines to generate electricity.

The whole setup requires creation of large scale infrastructure that demands space and equipment to convert waste into combustible form and then burn the same to generate energy.

Storage of biomass as per the demand also requires a lot of space and most existing facilities have failed owing to problems related to storage and logistics of transporting municipal waste or agricultural waste to the biomass energy plants. The overall efficiency of biomass plant is about 22%-35% which is comparatively less than coal based power plants. Environmental concerns have also been raised towards disposal of ash generated by the biomass plants.

*D. Combined Heat and Power (CHP):*Combustion of any fuel to generate both heat and power thereby getting combined benefits is the working principle behind a Combined Heat and Power (CHP) energy systems. These systems also termed as 'Co-generation' and their variations like 'Tri-generation' or 'Quad-generation' are best suited for community level integration. The heat generated due to combustion of fuels can be used directly for heating needs of the communityand generation of power, alternatively generating steam using water canincrease the energy generation.

The primary fuel used for these CHP systems include all hydrocarbon based fuels like biomass, biogas, natural gas. Alternatively, petroleum based fuels like diesel and bio fuels like rapeseed oil could also be used. If such systems are integrated at neighborhood levels then there would be no more need for Diesel Generators for power backup and the diesel used in these DG sets could power the whole community. Gas based CHP units that could be powered by LPG or natural gas would enable more economical and environmental friendly option and with most community housing setups have piped LGP gas supply and storage facilities thereby facilitating easy integration of these systems in the housing sector.

CHP systems have a general efficiency of 80% - 85% varying on basis of choice of fuel used. In comparison conventional power generation systems using similar fuels have an efficiency of 49% - 56%. The CHP systems ideally have low investment costs, high rate of return and proven reliability, but the cost factor depends on the heat exchangers which are key to extract maximum energy out of fuel combustion. In case of excess heat is generated it could be stored either in specially designed thermal stores or converted into electrical energy and stored in batteries for future use.

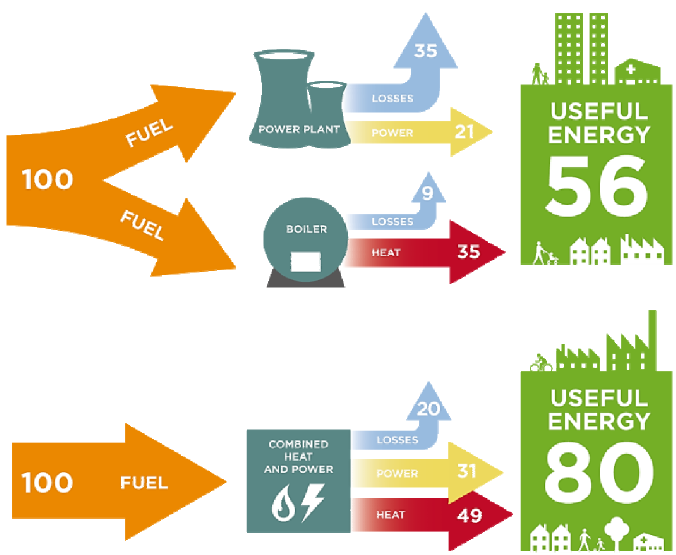

Fig. 5. Efficiency comparison of Conventional Power Generation and CHP Systems.

E. Heat Pumps: They are electrical energy driven systems that are ideal for space heating applications, but the added advantage of these systems is that their operation cycles are reversible. The heat pump transfers heat from one location to another. In winters, the heat pump captures heat from surroundings and concentrates it before delivering it to the occupants inside the building, alternatively in summers it could do the reverse by extracting heat from inside and dissipating it outside or storing it for other applications like water heating.

They are efficient for space heating rather than cooling, but if well planned during winters they could extract heat from the southern side of housing unit which are warm and deliver it to the cooler northern side spaces.

The integration of heat pumps and being completely dependent on them to achieve balance between heating and cooling needs is a great challenge. To meet both heating and cooling needs simultaneously independent heat pump need to be installed as the sizing of a single unit becomes difficult owing to their full efficient in heating but while dealing with cooling needs their efficiency is reduced to half. In view of all these observations, heat pumps ideally have a major role to play in winters like water and space heating as solar based systems fail during similar conditions and integrating the heat pump with a thermal store where heat energy could be collected all over the year and used during winters will enhance their viability and efficiency.

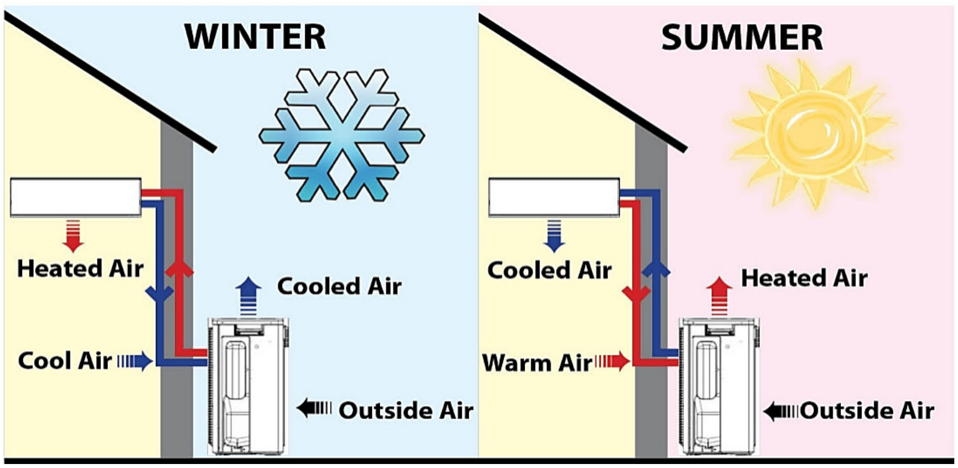

Fig. 6. Working Cycle of Heat Pump in Winter and Summer.

In view of varied options in Micro generation based infrastructure, it becomes a major challenge for the end user to understand and identify the ideal solution. The decision tool is expected to ease the challenges faced by the user by understanding their existing built-form characteristics, household power consumption, user behavior, expected demand versus actual consumption analysis, financial constraints and integration within the built environment and define possible interventions at household, built-form and neighborhood level.

All the systems listed above have their own inherent benefits and challenges, but no consumer would prefer to be part of a housing community that relies only on Microgeneration energy based infrastructure. Grid connected communities would have the added advantage of being dependent on the grid as and when the demand arises, primarily due to shortage of fuel, shutting down of the facility for maintenance and repairs, occasional increase in energy demand due to festivals or extreme seasonal variations etc. This demands for installation of net meters that monitor inflow of grid power as per need and excess power generated by the community that could be shared with the grid in return. Based on such scenarios the decision tool should not only limit itself to plan and choose the type of infrastructure but also indicate the expected expenditure gained or incurred by the community in case of power exchange with the grid.

IV. DECISIONTOOL METHODOLOGY AND ITS ASSEMBLY

There have been various building energy modelling engines developed specifically for the domestic sector, most of them are based on the BREDEM (Building Research Establishment Domestic Energy Model). On basis of the BREDEM model other models have been developed like The Community Domestic Energy Model (CDEM) (Firth *et al.* 2010). The Domestic Energy Carbon Counting and Carbon Reduction Model (DECoRuM) (Gupta 2009). The DECarb Model (Natarajan and Levermore 2007). The Energy and Environmental Prediction (EEP) Tool (Jones et al. 2007). Each of these models has been modified to varying degree based on their data structure and expected future deployment of the model. The major problem with most of these models was in the implementation of their policy or interventions as they lacked the ability to be developed as a user or stakeholder level interface (Mhalas *et al.* 2013).

The key aspect in the development of a decision tool based on building energy modelling engine is identifying the various architectural types or archetypes possible and integrating them into the model. This also highlights that the initial application of such a model would be restricted to those neighborhoods where the archetypes are limited and continue to the same without any major modifications to the built form. The challenge would arise in those neighborhoods where there is no defined or uniformity in development of households or there have been major changes to the architectural character of built form. To encounter these challenges alternative visualization techniques and database generation tools need to be employed which are not within the scope of this study.

The decision tool is expected to take into consideration the various stakeholders at household level or at community level in case of multistoried housing units and define various scenarios along with their possible impact on the existing energy consumption pattern, retrofitting required within the housing unit to further reduce energy consumption, renewable energy infrastructure and their configuration to promote energy generation and finally the financial component to guide the household in terms of investment required, quantifying possible benefits into financial variables and payback duration. The tool should employ multi-criteria analysis and decision technique to define the possible benefits divided into social, environmental, technical and economic criteria (Mhalas *et al.* 2013). A key aspect of the decision tool would be understand the complexity in estimating energy savings from combined initiatives like in case of a well-insulated house the payback returns from a heat pump would require more time as the energy required for the operation of the heat pump would be reduced. So, special consideration should be given when calculating the payback period in case of households that involve combined interventions (Mhalas *et al.* 2013).

In Table 1, the various segments of the decision tool and their data inputs are detailed out – the first segment of information details out the physical geometry of the housing unit, the second segment defines the impact of climate, wind and sun on the overall energy performance of the unit as a result the role of artificial light and ventilation is being analyzed, the third segment defines the performance and utility of all household electrical equipment, their usage pattern and user behavior.

Table 1: List of Data Sets and their corresponding Variables.

Physical Geometry of Housing Unit	
• Site Area	• Floor Area and Perimeter of Unit
• Height of Roof	• Total Number of Storeys
• Area of Roof	• Area of Doors and Windows
Heating Cooling and Ventilation of Housing Unit	
• Geographical Location of Unit	• Solar Irradiation Value for the Location
• Wind Speed and Direction	• Architectural Typology of Housing Unit
• Material for Walls and Windows (U-Value)	• Material for Floor and Roof (U-Value)
• Types of Doors and Windows	• Orientation of Doors and Windows
• Overhangs / Chhajas	• Balconies / Verandahs
• Types of Mechanical Ventilation	• Efficiency of Mechanical Ventilation
• Type of Cooling System	• Efficiency of Cooling Systems
• Type of Heating System	• Efficiency of Heating Systems
Energy Consumption of Housing Unit	
• Number of Occupants	• Operating Hours of Electrical Equipment
• Type of Household Appliances	• Efficiency of Household Appliances
• Type of Cooling System	• Efficiency of Cooling Systems
• Type of Heating System	• Efficiency of Heating Systems
• Type of Lighting System	• Efficiency of Lighting Systems

The information sets collected under Physical Geometry of Housing Unit shall aid in developing a physical dwelling model of different housing typologies varying on basis of their shape, material of construction and height. Incorporation of Heating Cooling and Ventilation data sets with the physical model shall define the actual energy demand in maintaining habitable living conditions. Comparison of the actual energy demand in relation with existing energy consumption based on data sets under Energy Consumption of Housing Unit shall assess the performance of the housing unit under three categories – High, Moderate and Balanced.

The high categories indicates that the actual energy demand is less than existing consumption. This demands that interventions related to building retrofitting and energy conservancy need to be initiated before integration of Microgeneration infrastructure. In case of moderate scenario the energy demand is marginally higher than the energy consumption, this shall require initiation of interventions related to energy conservancy only. In case of balanced scenario, energy demand and energy consumption are nearly equal and act as the perfect platform to meet the energy demand through incorporation of Microgeneration infrastructure.

The choice of infrastructure and its incorporation within the housing unit or neighborhood shall be based on the building form, peak energy demand, installation feasibility, initial cost, maintenance cost, expected savings and payback period.

V. CONCLUSION

There is a greater need for the housing sector to reduce its dependence on grid power and search for alternative Microgeneration options. Avenues to strengthen the end user through development of a decision support tool shall aid in promotion of logical and informed decision making leading to development of sustainable neighborhoods. The implementation of the tool right at the early stage of designing housing units could further ensure development of near zero energy based housing. The conceptual framework is only an insight into the actual tool, but with further research and findings it is expected that the tool would undergo changes to enhance its accuracy. With inflow of more efficient and varied Microgeneration infrastructure options, the database and choices of energy saving interventions shall increase. The tool in its existing form is limited to regular archetypes and further research is needed to identify and incorporate the diverse housing typologies in the Indian housing sector. The financial component of the tool needs working as energy pricing and subsidy on Microgeneration infrastructure vary from state to state.

If developed fully with an interactive interface that enables user groups and decision makers to make key decisions right at the start of any housing project or define the possible interventions required in existing housing stock, the tool can ensure sustainable energy generation and total energy security at neighborhood level.

REFERENCES

[1]Agency, I.E. (2007) ‘World energy outlook 2007: China and India insights’. Paris: Organization for Economic Co-operation and Development (OECD).

[2]Bijli, B. Team (2016) ‘Procedure to get subsidy on Solar PV Systems through NABARD in India’. Available at https://www.bijlibachao.com/solar/procedure-to-get-subsidy-on-solar-pv-systems-through-nabard-in-india.html

[3]Central Statistics Office (2016) ‘Energy Statistics 2016’, Central Statistics Office, Government of India.

[4] Cheng, V. and Steemers, K. (2011) ‘Modelling domestic energy consumption at district scale: A tool to support national and local energy policies’, *Environmental Modelling & Software,* **26**(10), pp. 1186–1198. doi: 10.1016/j.envsoft.2011.04.005.

[5]Firth, S. K., Lomas, K. J., & Wright, A. J. (2010). Targeting household energy-efficiency measures using sensitivity analysis. *Building Research and Information*, **38**(1), 24–41.

[6] Fung, A. S. (2003). Modeling of National and regional energy consumption and associated greenhouse gas emissions. PhD Thesis.Dalhousie University.

[7] Ghosh, S. (2002) ‘Electricity consumption and economic growth in India’, *Energy Policy,* **30**(2), pp. 125–129. doi: 10.1016/s0301-4215(01)00078-7.

[8] Hourcade, J. C., Jaccard, M., Bataille, C., &Gershi, F. (2006). Hybrid modeling: new answers to old challenges. *Energy Journal*(Special Issue), 1–12.

[9] Johnston, D. (2003). A physically based energy and carbon dioxide emission model of the UK housing stock. Leeds, UK: Leeds Metropolitan University.

[10] Jones, P., Patterson, J., & Lannon, S. (2007). Modelling the built environment at an urban scale - energy and health impacts in relation to housing. *Landscape and Urban Planning,* **83**, 39–49.

[11] Kavgic, M., Mavrogianni, A., Mumovic, D., Summerfield, A., Stevanovic, Z., & Djurovic-Petrovic, M. (2010). A review of bottom-up building stock models for energy consumption in the residential sector. *Building and Environment,* **45**, 1683–1697.

[12] Larsen, B. M., &Nesbakken, R. (2004). Household electricity end-use consumption: results from econometric and engineering models. *Energy Economics,* **26**(2), 179–200.

[13] Mhalas, A., Kassem, M., Crosbie, T. and Dawood, N. (2013) ‘A visual energy performance assessment and decision support tool for dwellings’, *Visualization in Engineering,* **1**(1), p. 7. doi: 10.1186/2213-7459-1-7.

[14] Natarajan, S., & Levermore, G. J. (2007). Domestic futures-Which way to a low carbon housing stock? *Energy Policy,* **35**(11), 5728–5736.

[15] Neha Pahuja, Nimisha Pandey, Koyel Mandal & Chayan Bandhopadhyay (2014). 'GHG Mitigation in India: An Overview of the Current Policy Landscape', Working Paper, World Resource Institute, pp. 1-32

[16] NITI Aayog (2015). Report of the Expert Group on 175 GW RE by 2022.

[17] Shrimali Gireesh and Rohra Sunali (2012). India's solar mission: A review, *Renewable and Sustainable Energy Reviews,* Vol. **16**, pp. 6317–6332

[18] Swan, L. G., & Ugursal, V. I. (2009). Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. *Renewable and Sustainable Energy Reviews,* **13**, 1819–1835.

[19] TERI (2014). Reaching the sun with rooftop solar. New Delhi: The Energy and Resources Institute. Available at: http://shaktifoundation.in/wp-content/uploads/2014/02/Reaching-the-sun-with-rooftop-solar_web.pdf

[20] Tuladhar, S. D., Yuan, M., Bernstein, P., Montgomery, W. D., & Smith, A. (2009). A top-down bottom up modelling approach to climate change policy analysis. *Energy Economics*, **31**(Supp. 2), S223–S234.

[21] Wang, J. J., Jing, Y. Y., Zhang, C. F., & Zhao, J. H. (2009). Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renewable and Sustainable Energy Reviews*, **13**, 2263–2278.

[22] Wright, A. (2008). What is the relationship between built form and energy use in dwellings? *Energy Policy*, **36**, 4544–4547