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RESEARCH ARTICLE

ENERGY REDUCTION IN RESIDENTIAL HOUSING UNITS

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Abstract

Energy Management, being a pressing issue when energy crisis is considered, becomes a subject of study from a conservation perspective for residential housing units. Utilization of home energy management systems (HEMS) becomes viable when housing units continue to utilize solar photovoltaic systems for local power generation and add additional loads for electric vehicle charging. This paper identifies major areas of poor energy management at home for appliances such as televisions, wi-fi routers, etc., that contain small LED indicator lamps in unused condition when power-offed. Both reductions of energy demand by implementing steps such as restricted heating, ventilation, and air conditioning (HVAC) thermostats within permissible temperature settings and increasing the local power generation by solar photovoltaic systems becomes another viable solution. Additionally, an integrated home energy management system wherein the customers from different housing units communicate in an integrated manner to flatten the demand curve by shifting some of the loads during off-peak periods serves as a great tool in energy conservation. Some loads become essential loads, whereas many others are deemed non-essential depending on the time-of-day of usage. HEMS tends to select between essential vs non-essential loads for a given customer at a given time and instructs them on the feasibility of switching between grid and household battery energy storage systems or waiting until the grid is prepared to serve a given type of load.

Introduction:-

Residential housing units contribute to an average of 10,500 kWh of energy consumption annually [1]. To reduce the consumption of energy resources, there is a need to cut or restrict the usage of electricity. About 19% of overall energy is used for cooling and 12% for space heating [1]. Whereas a significant amount, 12% [1], goes to water heating. Some loads other than these three items comprise dishwashers, cooking units, lighting, small appliances, refrigerators, wi-fi routers, phone charging, and electric vehicle charging. Table 2 shows typical housing unit electrical loads in kW. Although electric vehicle home charging is a newer concept, many homes continue to add level 1 chargers at their homes.

Identifying energy conservation from its usage by type of load significantly reduces the load on grids. Transferring some of the loads, such as washing, drying, and electric vehicle charging, to home battery storage systems potentially benefits the generation companies as they are able to reduce the costs of power generation required to serve the given loads otherwise. Home energy management system, a recently developing concept for the

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management of power utilization for housing units, provides the integration of local power generation (by solar photovoltaics) with grid power and offers optimal management of home energy consumption. Thus, HEMS also has the potential for energy savings for homeowners. Sustainable practices, at times when energy crisis is impending, rise due to load addition from advanced heating and cooling systems and electric vehicles become crucial [2].
The existing profile of housing units per the Census Bureau is shown in Table 1.

Table 1:- Housing Units.

Region	Total Units [3]	Occupied Units
Northeast Region	25,107,871	22,496,652
Midwest Region	31,063,501	27,832,897
South Region	57,185,612	51,238,308
West Region	31,987,652	28,660,936

Several appliances at home include indicator LED lamps that add a small fraction of energy consumption. When the identification of unused elements of regular home appliances is studied, many doors are opened towards energy conservation from the reduction of energy usage from given appliances. Typically, an LED indicator lamp's wattage is 0.105 Watts [4], which contributes to 1.26kWh of energy consumption in a 12-hour of un-used period. Occupied Units (89.6% of Total Units [5]) were used for the calculation of energy lost from these indicator lamps. Using an average number of indicator lamps in occupied housing units across the United States, Fig. 1. shows the breakdown of energy consumption by each region (from Northeast to Midwest, South, and West regions).

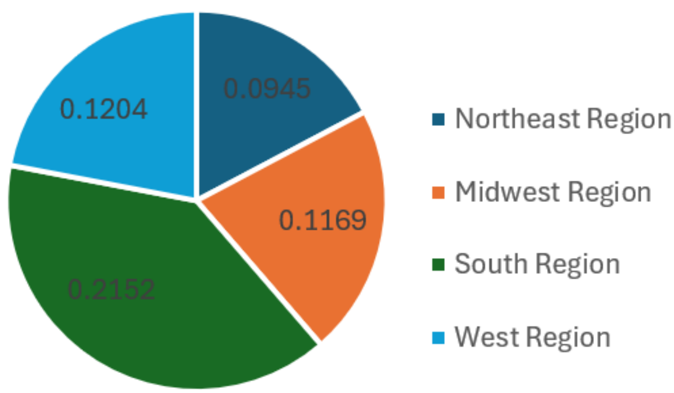

Fig. 1:- Energy Usage (in GWh) from Indicator LED Lamps.

An average of 1-degree Fahrenheit adjustment of the thermostat for heating or cooling reduces the home energy consumption by 1-3% during an 8-hour period [6]. A strict enforcement of 78-degrees Fahrenheit for cooling and 68-degrees Fahrenheit for heating offers greater energy reduction. With 1-degree Fahrenheit adjustment, typically a total of 14,073 GWh of energy reduction is offered. Fig. 2 shows a breakdown by each region.

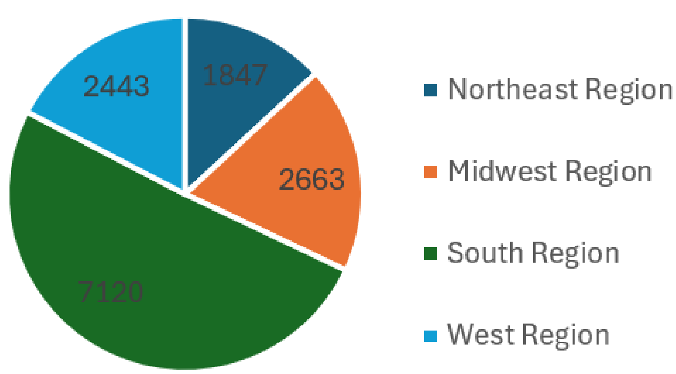

Fig. 2:- Energy Reduction (in GWh) from Cooling and Heating Loads.

Given the known areas of energy conservation, a home energy management system concept development is key for transforming residential energy usage. Currently, homeowners tend to own smart thermostats that can adjust with fixed settings. However, an integration with a larger system (consisting of interconnected housing units with the power grid and governing bodies) with HEMS enhances the governing bodies to override the thermostat settings to appropriate ones.

Methods:-

Home Energy Management System

The development of a home energy management system starts with calculating the loads connected to the system. Then, categorization into essential and non-essential loads. The essential loads always get priority to be powered either from grid power or local home power generation. Non-essential loads remain on a waitlist until the energy management system indicates availability from the grid. This lets users not only reduce their energy consumption and pay fewer bills but also reduces the overall demand on the grid. Mandating the requirements of housing units to incorporate roof-top solar photovoltaic systems boosts local generation, thereby reducing the dependence on grid power. A block diagram for the integration of HEMS with integrated intelligent control of lighting, thermostat, television, wi-fi, and other small appliances is presented in Fig. 3. Energy consumption for cooling reduces when natural ventilation is utilized based on outside temperature. Other methods to curb the HVAC loads are by improving the insulation levels of the walls and reducing air leakages from the windows and doors [7]. Intelligently sensing the occupancy of the house and, based on the same, raising the thermostat settings and turning off the unused loads is another methodology for reducing the burden on grid power.

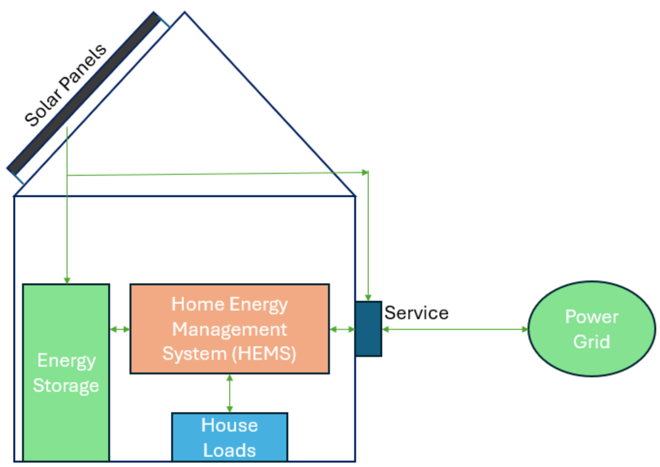

Fig. 3:- Home Energy Management System (HEMS) [8]

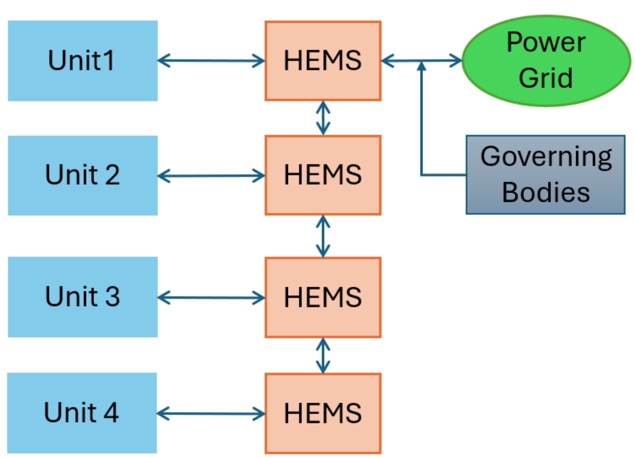

Fig. 4:- Integration of HEMS.

Battery Storage Systems
Housing units with added roof-top solar photovoltaic systems for reducing their dependence on grid power or back-feeding the grid is another untapped application [9]. All other forms of energy storage within the residential homes may comprise of back feeding the grid. For instance, small UPS/ phone and large electric vehicle batteries become part of home energy storage systems.

Implementation of Home Energy Management System
Utility companies, through government-initiated orders, implement a typical control on house owners' energy consumption. Leveraging technology for intelligently switching off unused loads by HEMS and the coordinated manner of operation of the utility company promises a solution where the implementation of HEMS is seen as a major challenge. The level of intervention of governing bodies for enforcement of energy management within strict guidelines, such as the operation of HVAC systems at given thermostat settings, becomes a concerning subject for local jurisdiction to determine its feasibility and thus engage necessary tools and techniques for integration with HEMS. However, controlling aspects of the HEMS becomes a resource during the determination of right tools and techniques for governing bodies.

Cost of adding Home Energy Management
Per Statistica, around 24.7% of houses will have a HEMS by 2024 [9]. Each HEMS equipment cost ranges between $100-600 [11]. Thus, HEMS will add a $10.94 – 65.67B total cost when existing housing units upgrade with such energy management systems. This excludes any additional upgrades required for home appliances and smart energy metering. Heavy upfront costs for HEMS upgradation for existing housing units discourage widespread adoption, but energy conservation from HEMS promises a long-term benefit.

Practical Application:-
Let us visualize a single-family residential home of 2000 square feet area. Typical loads for the house start with lighting the interior and exterior space, water heaters, electric heaters, and compressor and air handling units for cooling to an electric cooking range, dishwasher, washer, dryer, small appliances such as television/ microwave, and outlets for phone charging/ computer stations. Table 2. summarized the loads and their equivalent electrical load in wattage. All loads were considered electric in line with government initiatives in utilizing fully electric equipment at residential homes and thus eliminating gas-power equipment [12]. EV charging load was based on level 1 charger [13]. Typically with a given total electrical load of 42,150 Watts, this residential unit gets a 200A at (120/240)V electrical service. HEMS classifies all these loads as essential and non-essential based on the time of the day. For example, the cooking range is categorized as a non-essential load other than regular lunchtime hours. Users may get notifications to use appliances in a coordinated manner so that the peaks in demand loads are minimized. The users get to use other critical loads, such as EV charging, as essential loads during nighttime for shaving the peak demand or re-distributing the demand amongst the neighboring homes. HEMS interface by a phone application updates the users on when to start using any non-essential load. So, users tend to communicate with each other, and depending on a user dropping the usage for one application, the next participant gets to use it. Using the methodology presented, an integrated system concept for a home energy management system was developed. Key elements in the storage were any or all kinds of batteries at home. Coordination between the housing unit holders on when to utilize the loads that were non-essential at a given time was emphasized. The HEMS selects the best case wherein the utility is not prepared to deliver a load at a given time and thus switches to a home battery storage system from solar PV.

Table 2:- Typical Residential Loads.

Appliances/ Equipment	Electrical Load (Watts)*
HVAC	12,000
Water Heating (Electric)	4,000
Illumination (Lights)	1,200
Refrigeration Units	1,500
Television Sets	800
Dryers	5,000
Ceiling Fans	500
Freezers	1,000
Cooking Range (Electric)	3,000

Dehumidification	1,000
Microwave	1,500
Pool Pump	2,000
Dishwashers	1,800
Washers	1,200
Hot Tub Heater	1,500
Hot Tub Pumps	1,500
EV Charging	2,400
Appliance charging & Miscellaneous	250

*Note: Exact value varies depending on the chosen equipment

Using NREL SAM output (in kWh by each month) of solar photovoltaic with available roof space of minimum 1000 sq feet for a house in Phoenix, Arizona was obtained and shown in Fig. 5. A total of 31,036 kWh of energy production is anticipated when panels of quantity forty (40) at 450 W were facilitated on a minimum roof size of 1000 sq feet. A battery storage system sized to support the generated energy from solar panels is required to ensure storage while there is not enough demand.

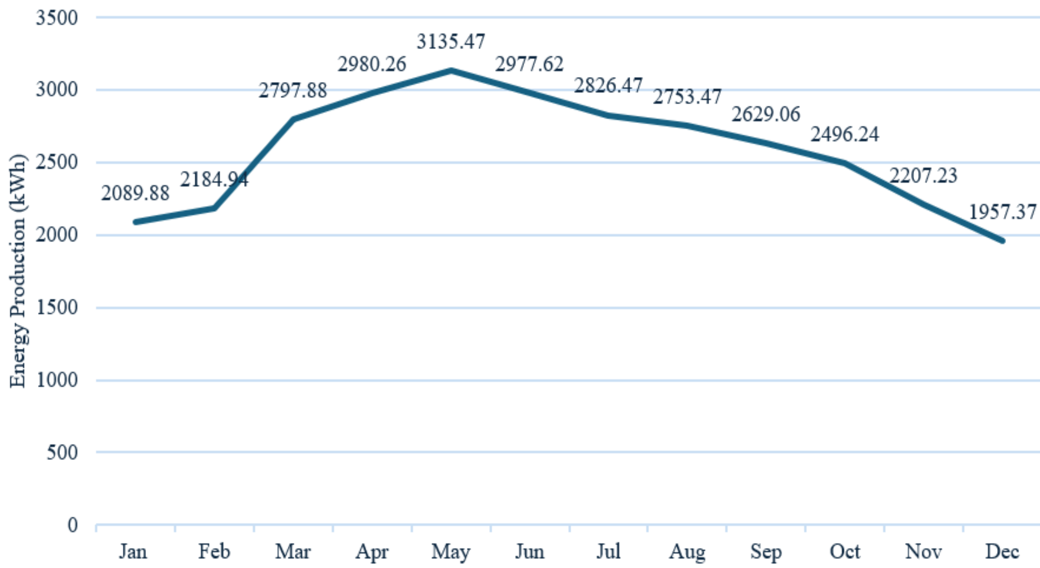

Fig. 5:- Energy Production from Solar PV.

Results and Discussion:-

HEMS was conceptualized with the need to improve the integration of the individual HEMSs with each other, utility companies, and governing bodies. Challenges to such integration were related to high costs for upgrades and the preparedness of the governing bodies for large-scale implementation and integration. Typical housing unit loads were summarized, and energy generation from roof-top solar photovoltaics was quantified. Sources of energy dissipation in housing units, such as loss of energy from LED indicator lamps when appliances were in a switched-off position, were quantified. With rising technology in communication, there are promising solutions to how a HEMS be implemented at a large scale in a coordinated manner. There are issues around the security of data that pose a threat when it gets exposed to cyber-attacks. Developing an interface that readily interacts with the customer by phone applications and, at the same time, with the household appliance/ equipment involves the upgradation of existing equipment to support integration with HEMS. For example, smart thermostats and sensors attached to each of the major appliances/ equipment play a positive role in HEMS implementation. Utility companies must come together and make a uniform platform for transparency on demand curve sharing. They must become less profit-centric when seeing the move of energy conservation potentially reduce their business due to diminishing energy demand. And, thus, offer full support to the governing bodies to allow control of the energy usage by the consumers.

Renewable energy use and its penetration into housing unit owners depend on how much-regulating bodies emphasize going green. Support from local government bodies in terms of education and funding programs not only ensures a reduction in energy demand but also makes them responsible citizens. The selection of renewable energy generation is not limited to solar photovoltaics but also wind power. Some concepts of residential homes with both solar and wind power become a foundation for large-scale local power generation.

Most housing unit owners tend to rely on some type of notification by which they limit their energy consumption. For example, utility bills indicate how well they compare with neighbors who were more energy efficient during a current billing period. Additional instructions on recommended thermostat settings act as a decision-making tool. HEMS becomes a key resource in interacting with customers in real-time for energy management. Simple instructions on switching off loads or suggesting a time-of-day to utilize some of the heavy loads become a foundation for an integrated manner of operation. The impact of how the HEMS holistic model operates with other commercial buildings' energy management systems is another aspect that requires analysis. Certainly, many promising solutions to energy savings are offered from optimal selection of the appliance (such as energy star rated), HEMS is one additional step towards going green.

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