

Cloud-based Home Energy Management (HEM) and Modeling ofConsumerDecisions

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Abstract
With the increasing number of smart home devices and the widespread availability ofbroadband communications, intelligent products built on the computational power andscalability of cloud, have the potential to reach beyond traditional markets. Cloud-basedHomeEnergyManagement(HEM)paradigmcanprovideintuitiveandautomatedservices that can not only save money and energy but also improve the quality of lives ofconsumers. This paper provides a detailed summary of the literature review of HEM andproposes (1) a conceptual smart home model with a special integration of solar powereddevices with the cloud, (2) a limited consumer survey, and (3) a Multi-Attribute Modeling(MAM) with an example application for consumer adoption of Home Energy ManagementSystem (HEMS) and allied devices. The results of literature research and an online surveypoint out that the surveyed consumers acknowledge the importance of energy efficiency intheir daily lives and lean towards adopting cloud-based smart home devices for theirneeds. The bottom line for adopting HEMS is the availability of secure, robust and cost-effectivesolutionscoupledwith considerablemoney-savingpotential.[2]

***Keywords**: Home Energy Management, Cloud-based Smart home, Residential Solar,Cost Savings,EnergyEfficiency, Smartdevices,Homeautomation*

1. Introduction

Smartdeviceshavefunctionalitiesthatcanhelpwiththemanagementandconservation of household energy, thereby, enabling residential consumers to take controlof their energy use and bills. Primary factors spurring end-user interest in Home EnergyManagement (HEM) can be attributed to cost, technical specifications of the device (size,features, and automation), technology, ease of installation and troubleshooting along withlong term energy and cost savings potential. These seemingly fuzzy features of HEMproducts have made home automation, a niche market. However, literature shows thatconsumers are increasingly attracted to the notion of managing homedevices via a fastand efficient mechanism that can save both time and money. There is an influx of devicesand technologies in the market that consolidate home energy information and facilitatedevice controlwith the touch of a button. Justin the lastdecade, a variety ofsmartdevices with different levels of configurations, ranging from simple energy meters andrenewable energy devices to sophisticated and highly customized multi-storey buildingenergy management systems have hit the market. Yet, (i) Do we, as consumers, haveenough knowledge to assess the utility of these devices? (ii) Does an HEMS have theability to catalyzeenergy conservationin ahome?An approachto HEMthat answersboththesequestionswouldbetoadopt,useandconnectsmartdevicesofahomeviathe internet to a single collaborative service in the cloud platform (sharing resources andstorage instead of local storage). The objective of this paper is to (1) highlight the conceptof HEMS, (2) present a model for integration of smart home devices - solar panels andelectric vehicles to a centralized cloud and (3) propose a simple multi-attribute model(MAM) for evaluating the –utility‖of choices for adoption of HEMS driven by key consumer preferences.

2. HomeEnergy ManagementSystem(HEMS)

HEMS can be defined as a system comprising of intelligent devices with hardware andsoftware layers that can monitor, control and provide feedback on a home‘s energy usage[1]. It encompasses components and principles of residential demand response programs(DR), home automation services, personal energy management, data analytics, energyauditing,visualizationofenergyusageandrelatedsecurityservices[2].HEMSfundamentallyrequiresaHomeAreaNetwork(HAN)-

―anetworkthatfacilitatesinteroperabilityamongdigitaldeviceswithinahomebyactingasacommunicationnetwork connecting all the components of HEMS‖ [1]. This network equips consumerswith accurate energy data and prompts them to modify their power usage in their smarthome. A ―smart home‖functions as a switchboard for digital information exchange among appliances for enhancing the quality of life of residents through enhanced comfort,convenience and connectivity [3]. It is an energy management system bolstered by thetechnologiesofthesmart grid andthepowerofconsumer electronics[4.].

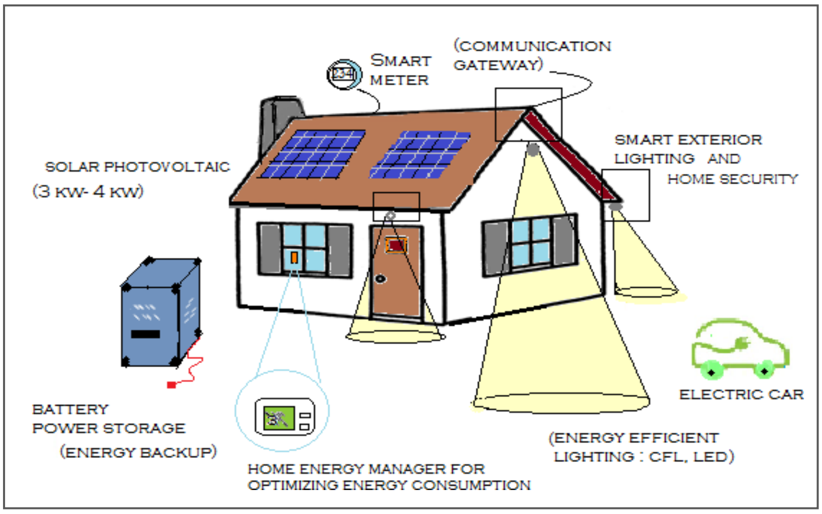


Figure1.ASmartHome

In a smart home (Figure 1) all components such as appliances, solar panels, electricvehicle*etc*.canbemanagedtooperateinanefficientpower-useenvironment.Byintelligently controlling them in a responsive and coordinated manner, these devices canprovide leverage for greater energy and cost savings [5]. This capability can benefit all thestakeholders–customers,utilities,andthirdpartyenergy/technologyfirms.Forinstance,a home-owner may not care about peak demand issues faced by a utility company but willbe concerned only about his/her electricity bills and supply reliability. Whereas, a utilitymaybeprimarilyconcernedonlywithmeetingtherequirementsofpublicutilitycommission. This disconnect in objectives could disrupt power sector businesses andconsumer satisfaction levels. A smart home connects the players and creates an intelligenttechnology-basedplatformtomeetcommongoals ofenergyconservation[4].

2.1. HEMAdoptionLevelsandConsumerOutlook

TheU.SEnergyInformationAdministration(EIA)hasestimatedthathouseholdsaccounted for approximately 21.4% of total energy consumption in the United States in2011[6].Withnewerandbiggerhomes,onanaverage,ahome-ownerspendsanestimated$2,020onHVAC,appliances,lighting*etc*.annually[7].Thisentailsanopportunity for households to make changes that can lead to savings on their energy bills(up to 30%)[7]. A common method for making simple home energy upgrades is thoughenergy audits. With the growing number of initiatives on the Smart Grid front in the U.S,an array of opportunities for smart home adoption can be spawned. End-users can assumean active role empowered with real time information and make favorable energy decisionsfor their homes and properties [8]. But there are challenges that need to be addressedbefore smart homes can become deployable to the masses,e.g. service adaptation todifferent households, dynamic home components, lifestyle, family size, interaction ofdevices,awarenessofbenefitsandsecurityissues,tonameafew[9].Literaturealsoshows that, in the last couple of years about 21% of Americans have remained unsure iftheywouldconsiderpurchasingHEMproducts.Thisisindicativeoftheexistingambiguity in this new market segment and the need for better marketing of smart hometechnologies[4].Ongoingresearchandmarketingeffortsareessentialtotransformconsumer motivations asbetterchoicesforoptimization[10].

2.2. UtilityModeling

The technology adoption model [11] shows that it can take about 10 years before newtechnologies are accepted and used in everyday life. Adoption of a new technology isgoverned by certain socio-economic factors determined in five stages viz. familiarity withthe technology, positive attitudes, peer discussions/ advertisements, hands on experienceand reinforcement of the decision. Early adopters are exposed to a combination of factorsin phases before the actual use of the product (Figure 2). It is rather a combination ofvariables in socio-economic and psychological paradigms. Perceived usefulness of theproduct can kindle behavioral intentions to adopt the product [11]. Research also showsthatconsumerattitudeisamoreaccuratepredictorofbehavioralintentthanothersubjectivenorms andiscapableofdirectlyimpactingtheadoptionlevelsofanytechnology[13].Itisnaturalforconsumerst obemotivatedtopurchasethemost –satisfying‖productsthatcanprovidecomfortorpotentiallyimprovetheiroverallliving standards.Thetheoreticalmodelofobtainingthehighestlevelsofutilityfromaproduct/service is called Utility Maximization. This is largely dependent on the totalincome of a household. Considering the various aspects involved in making a purchasedecisionofanewsmartdevice,amulti-attributemodel(MAM)ispresentedtodemonstrateitsapplicabilityfor HEMSin alatersection.

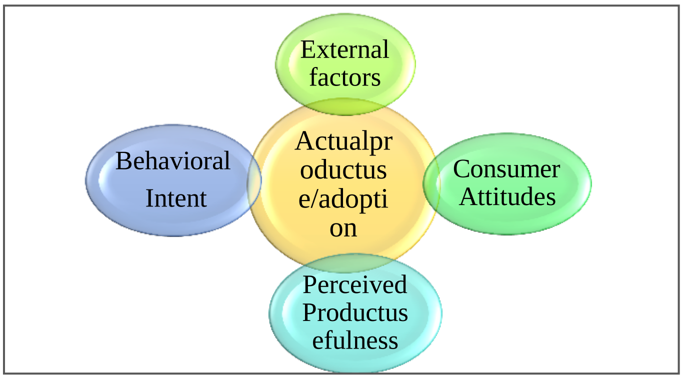


Figure2.TechnologyAcceptanceModel
Adaptedfromsource:[13]

2.3. DemandResponsePrograms

DR programs are an important dimension of HEM. The primary goal of DR programsis to reduce peak loads at consumer-end and accelerate energy efficiency. Changes in thelevels of energy consumption can be attained with the use of smart devices. Smart devicesare electronic in naturegenerally connected to other devices or networks. Most devicesareintheformofdeferrable,interruptible,non-deferrableandnon-interruptible,operational,PVbased,battery-assistedappliances[14].Furthermore,consumerscanbenefit from DR programs by allowing system operators to control some of the appliances(Heat Ventilating Air Conditioners load control) during peak hours. In addition to aidingconservation,DRprogramscansupportsupply-demandanalytics,infrastructureandtechnological upgrades.

2.4. HEMTechnologyFrameworks

The IBM vision of a –smarter‖home states that there are three characteristics that distinguish the new generation of –smarter‖homes from today‘s smart homes: *Instrumented, Inter-connected and Intelligent* devices [15]. Also, the report states that allisolated devices in a home can be connected to the cloud over the home gateway forintelligence data aggregation. Home gateway is an integrated infrastructure comprising ofnetworkaccesscontrol,middlewareandhomenetworktechnologies.Itperformsbridging/routingan daddresstranslationbetweenHANandtheexternalnetwork.Itpermits applications such as Voice/Video over IP and remote access to devices over theinternet[16].Muchoftheresearchisunderwaywithspecialfocusondevelopinginteroperabilitybetw een platforms forcloudintegration.

Following the overview of HEMS and its background theory, the internal componentsof an

HEMS unit are discussed in this section. The building blocks of this promisingtechnology can be broadly divided into digital interfaces, hardware, and software. Thecombination and unique assembly of these peripherals constitute various frameworks andproduct portfolio. An HEMS unit consists of appliance control units with wired/wirelesscommunication interface (e.g. Internet, ZigBee). Communication protocols can establishconnectivitybetweendevicesandtheutilitycompanyforaseamlessinformationexchange over the internet or alternatively viawireless LAN (Local Area Network),Bluetooth/Wi-Fi orcellularnetwork.
According to a Pacific Gas and Electric Company report [1], there are two kinds ofcapabilities in an HEMS unit - *Information and Control*. Figure 3 shows the differentcomponents and sub-components of an HEMS, classified based on their computationalcapabilities. An information-based system is aimed at offering feedback mechanisms thatcaptureand notifyanyanomaliesinthe home envelope.

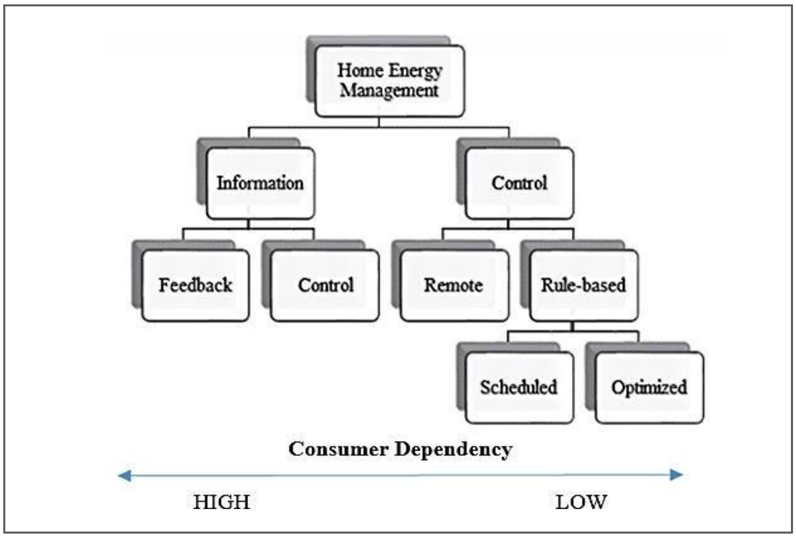


Figure3.HEMFunctionality

Adaptedfromsource:PG&E report [1]

The other category is control-based HEM which determines subsequent actions andcontrols in a device in response to notifications. All controls are carried out with theapplicationof–rules‖insidethesystemanddonotgenerallyrelyontheresidents‘input. A number of optimization and scheduling algorithms form the –rules‖that govern the HEMS. For instance, directing energy use, controlling the running time of devices andon/off status during peak hours*etc*. Scheduling algorithmsare deployedto dispatchsignals appropriately inside the system software. An HEMS acts as a demand-responsetool with capabilities of shifting the demand inside a home [17]. Some examples ofinformation-based HEM are load monitors, in-home display dashboard, data analyticsplatformandwebsite.Examplesofcontrol-basedHEMaresmartlighting,smartthermostats*etc*. [1].
External communication between end-user and the utility company can take placewirelessovertheAdvancedMeteringInfrastructure(AMI).Thiscanfacilitatethe —selection and implementation of strategies according to the energy use‖ [1].On theDemand-SideManagementfront,utilitiescanupgradeservicesbytakingcorrectiveactionswithoutdelaysandre mainwell-equippedforcontingencyplanning.Intheabsence of smart meters, receiving real-time information (via Wide-Area Measurement)from end-usercanbetime-consumingandinfeasiblesometimes.Tohandlesecurityissues, AMI systems that are resilient to attacks are paramount to this infrastructure. Thiscan be achieved with the deployment of management schemes and substation automationcoupledwiththeuseofcustomer-sideappliances[18].KeyelementsofHEMasidentified by Energy Innovation Project at the *MIT Industrial Performance Center* aresummarized inTable 1.

Table 1. Benefits of Consumer Controlled and Utility

ControlledEnergyManagement

Adaptedfromsource:[19]

Feature	**UtilityEnd**	**ConsumerEnd**
Control	Loadcontrol,AMI	Consumerdecision/ data control
Pricingschemes	Time-based/dynamic/TimeofUse rates/ demandcharge/PPA/DRprograms	Incentives/rebates forparticipating in DRprogramsandpurchasing smartdevices
Home AreaNetwork/Gateway	Provided byutility/third partyvendors/telecomm.providers ;via proprietarysystems	Owned/purchased/rentedby consumers withpossible incentives fromutility;Via internet/ cellularnetwork*etc.*
Data	High data bandwidth. Twowaycommunication line betweenutilityandconsumer	Hourly/daily/monthlyfeedback, low databandwidth
Cost	More expensive;investments forlogistics and systemupgrades	Lessexpensive;financingoptions; flexibilitythroughDRprograms, longtermsavingsoffsetinvestments
Benefits/Impact	DR, supply-demandanalytics, energyefficiency, contingencyplanning,Demandshift.	Home scalability,resident comfort,Long term costsavings, Distributedgeneration, –go-green‖approach.

2.5. BarriersinCloudHEMDeployment

The *Association for Computing Machinery* article lists four significant challenges forHEMS adoption - cost of ownership, inflexible interoperability, poor manageability andsecurity [20].Some of the prevailing incompatibilities of smart devices may be due tolackofappropriatestandardsandprotocols.Thiscancausefragmentationintheelectronicsmarket.Literaturereinforcestheneedforstandardizationandacommonworking platform with collaboration of services, e.g. a centralized service platform orInternet of Technology (IoT), cloud service on-demand software delivery method [SaaS]or infrastructure as service (IaaS) [15]. In addition to the equipment costs and monthlyservicefees,systemupgradecostsandmaintenancecostsremainunquantifiableatpresent. Lack of awareness about energy efficiency programs among consumers is alsooneofthemainchallenges.Moreover,designchallengesintheformofproductcharacteristics, aesthetics, optimization algorithms, UI and emergency public notificationsystems also continue to exist [21]. These considerations emphasize that the choice ofenabling technology is essential for the successful implementation of HEMS [22]. A briefdiscussion of a couple of HEM prototypes found in the literature can be seen in the nextsection.

2.6. HEMModelsandAdaptations

There are cloud-based implementations in the industry pertaining to a specific purposeor device. For example, streaming media (camera, audio, video), email *etc*. A uniqueconceptofintegratingsolarpowereddeviceswithsmarthomedevicesalongwiththe capabilities of persisting data and exchanging information over cloud is proposed in thefollowingsection.

Accordingtothe*UniversalImplementationModelfortheSmartHome*[12],theCentralManagementUnit(CMU)handlesdevice-controlandrespondstochangingconditionsinsideahome.TheUserInterface[UI-viz.touchscreens,multimediainterfaces, smart phones *etc*.] is a salient component required for user-interaction throughcommands and icons. Application programming interfaces (APIs) execute a particularfunctionality as part of scenario management and allow device-use with built-in functionsandcommunicationprotocols[12].Eachfunctionoperatesindependentlyasrecognizedby the CMU. In order for this model to be generic, a user‘s access to each one of thesupported functions has to comply with at least one of these UI standards - lists, icons,scrolling selection list, 3D widget *etc*. The Database (DB) module is the main storageplaceforhomeenergydata.Wheneveranewdeviceisaddedtothesmarthomeenvironment, new records can be created in the DB with related privileges, operations andcontrols. Intelligence of a smart home can be attributed to the Artificial Intelligence (AI)engine that reacts to dynamic conditions of a home. Another framework called ZUMA(Zero- configuration, Universality, Multi-user optimality, and Adaptability) proposed inthe*InternationalConferenceonIntelligentEnvironments*articleclaimstoallowconsistentinter-operabilitybetweenvariousdevicesinauserfriendly,scalableandextendiblefashion [23].Itwouldbeinteresting to exploretheapplicability ofthesemodelsto upcomingsolarpowered devicesand new technologies.

Literature suggests that any cloud framework with different flavors such as public,private and hybrid must conform to the key specifications to collectively tackle one ormore challenges of powerful computing. The challenges are relating to data analysis,processing and event-logging abilities with methods such as context-aware functions, datamining andsemantic reasoning[24]. Modelmatching algorithmsincorporated in thesystem canpermitinteroperability fornew deviceadditions,thereby aiding scalability. Theresourcemanagementmoduleshouldbeable―talk‖withthecloudtoprovidebetter experiencefortheusers[25].SoftwareAPIscanbeprogrammedtoofferinstantnotifications to any unusual or life threatening scenarios. This is one of the reasons whytheyareincreasinglybecomingapartofgeriatricassistiveandwellnessdevices.Response actions such as surveillance or monitoring of the house via a centralized systemprovide access to shared resources among various stakeholders [21].Furthermore, theintent of adding more devices to the basic amenities of a smart home can be supported bycloud. Therefore, it is important not to overlook the roles and usefulness of a wide varietyof developing devices and actively include solar panels, battery storage, electric vehiclechargingstations*etc*. inthecontextof HEMSdiscussions andexperimentations [26].

3. ModelExtension:Cloud-basedHEMImplementation

Withthegoalofdesigningasmarthomethatiscapableofsupporting Solarintegration, the model described in the *Universal Implementation Model* [12] has beenchosen as the base on which certain adaptations applicable to a future smart home havebeen conceptualized. The principal assumption for this model improvisation is that allresidents implementing a PV system ought to have internet access. The utility can offercloud service that exposes an interface in the cloud to which residents can send devicedata,PVdeviceupdates,personalinformation*etc*.Figure4showsa―smarter‖homewith the addition of Electric Vehicle, PV panels, Solar battery/storage, energy-efficient LEDlighting system *etc*. (not limited to this list) to today‘s smart homes. In the future, with theimplementation of appropriate technologies, an effective net-zero energy living space canbe achieved. With the synchronization of devices, electricity consumption data will besaved to the cloud. This data can be accessed and downloaded at any point in time byresidentswhoareeitherathomeoroutsideviaamobileapporwebsite.Thiswaythe local storage of a device doesn‘t get over-used. The computational power of the cloud willenable data aggregation and time-to-time synchronization. The utility company can installsmartmetersinresidencesandthesamecanbemaintainedbythecompanytosupportdataaggregation.Thiscanprovideinsightsaboutconsumerenergypatternsandpredictionofdemandduringpeakhours .Improvementsandoptimizationscanbeperformed with this emerging technology. The experience of using this technology will besimilar to email/social media account/smart phone media. The simple power of cloudcomputing,service-orientedarchitecture(SOA)andstandardshavethepotentialtoprovideaplatformfor buildingthe nextgenerationofsmarterHEMS.

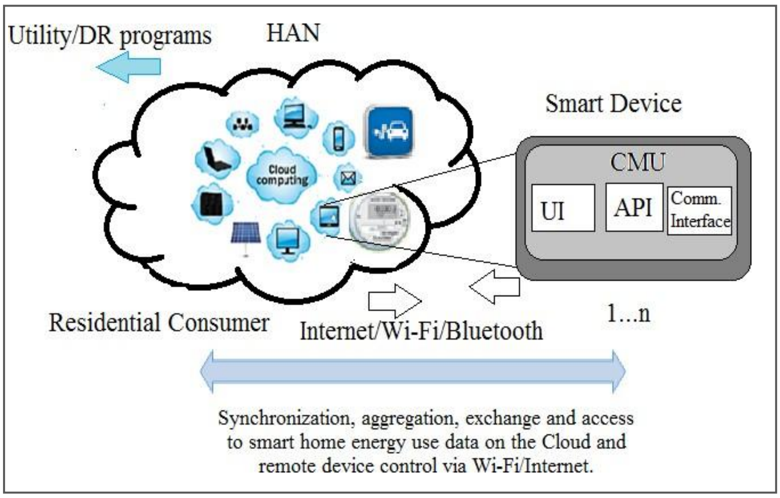


Figure4.Future SmartHomeEnvelope

The journal of *Open Cloud Networking* by Dell, points out a number of barriers in thedeployment of cloud technology. Cloud computing has not yet been realized to its fullestpotential due to obstacles such as behavioral barriers, industry fragmentation, ownershipissues, capital constraints, rebound effects, lack of energy efficient programs, lack ofawareness and information on Greenhouse Gas (GHG) emissions *etc*. According to thereport published by *Northeast Energy Efficiency Partnerships*, HEMS barriers can mostlybe attributed to ―Early Adopter Challenges‖ [1]. Complexity, security and elasticity ofdatastorage,qualityofservice,vendorviability,dataandapplicationmanagement,change control, transparency, portability, and disaster recovery, legacy and organizationalrisks require new integration methods for effective cloud deployment [27]. Encryption ofdataand highlevelsofmaskingarerequired to protecttheidentityofresidents [28].

4. Benefitsof CloudEnhancedHEMSIntegration

Table2.BenefitsofCloud-based HEMStoStakeholders

Adaptedand modifiedfrom[1]

Category	**Residents**	**Utility**	**Third-partyVendors**
EnergySavings	Automated systemsfor effective devicecontrol and energyconservation.	Advancedtechnologies for dataanalytics, clear insights on demand &supply	HEMS can be used asMeasurement &Verification tool

Safety &Convenience	Increased visibility,control, connectivityand instant access todevices andoperations, remoteaccess, enhancedsafetyand carefor residents	Real time demandresponse data (dataaccess can be eitherallowed or restrictedbased on residentpreferences)	Homemonitoring canfacilitate surveillancewith necessary supportfor installation andtroubleshooting
RenewableEnergy	Residential solargeneration can helpresidents for energystorage/backup. Consumer+producer ->_prosumer‘.	Power generation cansupplement additionalresources for the grid& offer efficientresourcemanagement	Platformforsavingswith collaborativepartnerships,innovations andmarketresearch
CostSavings	Energy optimizationresulting in moneysavingsforcustomers	Excess power can befed back into the gridto addressdeficit/shortage;in dependent of repairsorpower crisis. Operationalandtransportcostsavings	Revenue streams interms of monthly feefor servicemanagement, PPA,internet subscriptions,rentals and real timemonitoringand customerservice
Cloud-basedHEMS	Advanced ability tosense and monitordynamic aspects ofhome.Scalabilitywithreduced complexity ofsoftware,addition ofnewest devices,simplified troubleshooting	Utility can optimizepeak usage, customerengagement andsatisfaction byintegrating businessworkflows andprocesses, chargepowerratesaccording	Potential revenuestream formaintenance/service*etc*.

Some important benefits that integrated HEMS can provide to homeowners, utility andthird party vendors are discussed in Table 2. The table shows advantages such as cost andenergy savings, scalability for residents, revenue increase, data modeling *etc*. The tablealso provides an account of both energy and non-energy benefits (enhanced safety, health,security,environment,efficiency,processcontrol,wasteminimization,PeakLoadReduction *etc*.). A noteworthy result of anHEMS project, as discussed in the NEEPreport[1],showsthat8-22%Energy(Electricity&Gas)savingshavebeenachievedattheUnited IlluminatingUE3 Pricing, USAinthe year2011.

Consumers do not need to have the expertise to install or work with the aspects of thistechnology in order to reap the benefits. There is very little consumer-side effort in usingcloudtechnology.Cloudmakessmarthomeadoptionconvenientandhassle-free.Complexityofmanagingmultiplehomedevicesoftwareisbrokendowntoofferenhanceddeviceusability[25].Intheformof―softwareasaservice‖(SaaS)or ―infrastructure as a service‖ (IaaS), the service management module improves device lifecycleandreduces cost for servicemanagement.Residents canenjoy a one-stop servicefor information access and distribution of resources according to their home needs [29].User-centric applications such as storage for personal audio, pictures and video, multi-playeronlinegaming,featureinteractionbetweendevices,automatedmonitoring,security,healthand wellness,surveillance *etc*.are possiblewithcloud [30].

5. ChallengesandImplicationsofCloud-basedSmartHome

Despite the numerous benefits that cloud-based HEMS can offer, there is no denyingthatpurchaseofdevicescanbecapital-intensive.But,therehavebeenclaimsandcustomer testimonials that long term savings can eventually offset initial investments. Ontheotherhand,privacyisanotherissuethatcanconcernalotofresidentswhoarethinkingofadoptingacloudbasedsmarthome.Consideringthatcloudisoperatedby several data-centers, any minor component failure can result in connectivity issues orimproper back up or loss of data. There is no universal fault-tolerant system (yet) that isnot prone to failure. A temporary disconnection of internet can be surely problematic.Therefore, to accommodate a resilient system, a backup network subscription may berequired. But this could lead to increased network line, costs and additionalnetworktraffic for the home-owner. Finally, selecting a cloud vendor can be tedious to home-owner who does not have prior knowledge or experience about products and servicesofferedbythird partyvendors.

6. SmartDeviceandSolarTechnologyTrends–OpportunityAssessment

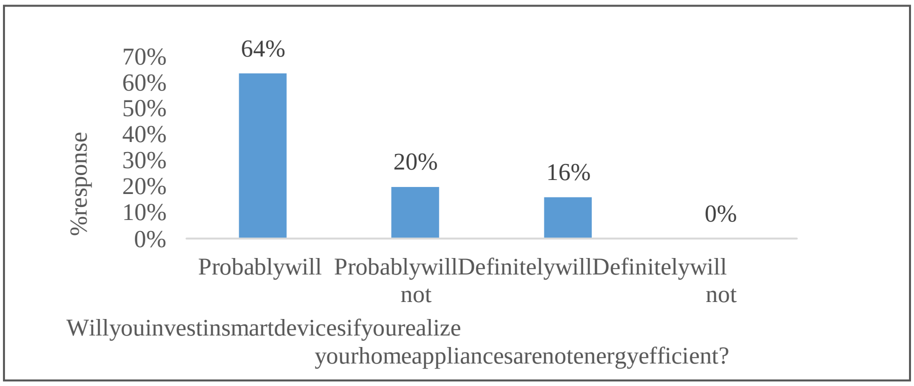
A systematic review of smart homes can create avenues for future research in the*Ubiquitous Home* domain [31]. Devices that can self-learn in a resident‗s spatial andbehavioral context can provide a multitude of benefits. Wearable, in-plant technology,assistivesensors(inwalls,floors*etc*.)and interactiveroboticshavethepotentialtorevolutionizetoday‗ssmarthomes.Wearablesensorgarmentscanmeasurebodytemperature using psycho-galvanic sensors to capture patient's heartbeat, Electro CardioGram (ECG) and other vital functions. The analog signals can be collected through a gridof conductive fiber sensors knitted into the fabric [32]. The device can be programmed tonotifyfamilyor physicianin case ofan emergency.

Furthermore, a solar standalone system with load profile for a Plug-in Hybrid electricvehicle can be one of the vital additions to today‗s homes. Electric vehicles with advancedcascadedpowerconvertersaresupportedbyrenewableenergyintegration.Theyareparticularly aimed at reducing stress on the power grid.Allied product developmentisstill in its nascent stage and is open for much research, development and validation. It isnecessary to combine technical advancements with the right marketing tools to appeal tothe present-day tech-savvy consumers. Virtualization of wireless sensor network (VSN)containing heterogeneous and sophisticated nodes such as temperature, humidity, sound,and video can be an opportunity for capturing customer base, (e.g. millennials) in a cost-effective way. In this regard, virtualization in sensor network can be a propitious futureresearch topic for large-scale commercial sensor network and smart homes. Smart Homein the future will be an intelligent ecosystem - interactive and adaptive to residents‗lifestylepatternse.g.vision-basedsensorsviaacentralizedcomputersystem[33].According to a report by Continental Automated Buildings Association 2013, efforts havebeenmaximizedtowardsinnovativeservicestoimprovethescalabilityofcloudtosupport more energy efficient devices. Studies show that 13% of all U.S households areexpectedtohaveHEMSinstalledby2020andnearly20%areexpectedtohavesurveillanceorsecurity systemswithinthenexttwoyears.Thistrendispromisingasfaraswide-spreadadoptionisconcerned[34].HEMScanalsooffereasyenergydisaggregation. It is a set of statistical approaches for extracting appliance-level data froma building without any plug-level sensors. This will be a leap in the energy managementarena [35]. Last but not least, on the solar energy generation front, California EnergyCommission defines _net metering‗ as an approach by which utilities can measure the netamount of electricity consumed by residents using solar (Photo-voltaic panels). In orderfor this arrangement between home-owners and utilities to work, smart meters must be inplace. Net metering merits include credits to customer at full retail rates and accuratecapturingofenergyinformation.Utilitiesareengaginginsolarpowerpurchaseagreements (PPA) to earn the benefits of clean electricity generation [36]. Literaturesuggeststhatcurrentresearchisfocusedonassessing newmaterialsandfabricationprocessesforimprovingtheefficacyoforganicandinorganicsolarcells,feasibilityoflow cost rooftop applications and battery storage. New technologies of HEMS such assolarpoweredwindows,3-dimensionalsolarcelltechnologyandsolarpoweredcarpaint arecapturingtheattentionofentrepreneurs.Oneoftherecentgroundbreakingtechnological innovations is PV spray-painting on surfaces and paintable batteries [37].This disruptive technology can transform any painted surface to a rechargeable solarbattery. It is encouraging to note that solar industry is migrating towards neighborhood-scale programs such as Aggregated Net Metering as well as Community Solar. With theuse of smart meter technology, community net metering can allow aggregation of powerload from multiple meters to a centralized solar panel system with a shared subscriptionmechanism.

7. OnlineSurveyResultsofConsumerKnowledgeandPreferences

Consumerstendtogravitatetowardssmartdevicesforanumberofreasons.Tounderstandtheperceptions,anonlinesurvey(Tool:QualtricsResearchSuite)wasconducted among 80 people between the age group of 20-60 years. The results of thesurvey have helped us gain a leap of understanding of consumer preferences, savings-expectation and the adoption potential of solar and cloud based HEMS. Roughly 35% aremoderately familiar with the HEMS concept. About 50% of the respondents spend moneyon new devices once in every 2 years. Importantly, none of them responded that they willnever invest in smart home devices. There is a possibility that even respondents who donot have any familiarity with smart devices, could consider exploring HEMS options. Awhopping majority of respondents, i.e. 91% agree that they would like to save money ontheir electricity bills and 80% are willing to invest in smart devices (Figure 5). Thisuniversal motivation among consumers can pave ways for innovative measures to saveenergy and money. With regard to cloud technology, 78% rated ‗Security' as a crucialfactor for cloud-based HEM and 66% rated ‗Performance' (Figure 6). About 68% preferDIY without any third party assistance and about 45% prefer a simple mobile app fordevice control and monitoring. The survey also created an opportunity to understand whatwill be a critical factor for smart home adoption. Clearly, a less expensive cloud-basedsmart home technology solution is the ultimate factor driving adoption. About 35% ofrespondentsalsoprefertechnologiesthatcanyieldsavingsofUSD500annuallyonelectricitybillsforalargehousehold.About19%supporttheenergyconservationobjective (Figure 7).

Figure5.LikelihoodofInvestinginSmartDevices



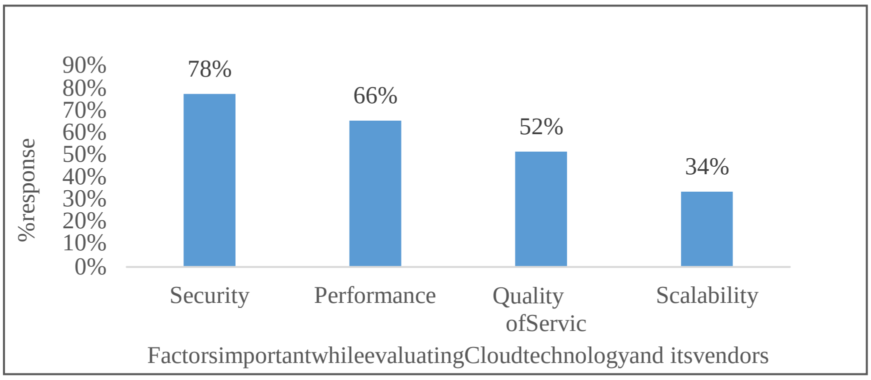


Figure6.KeyCharacteristicsof CloudTechnology

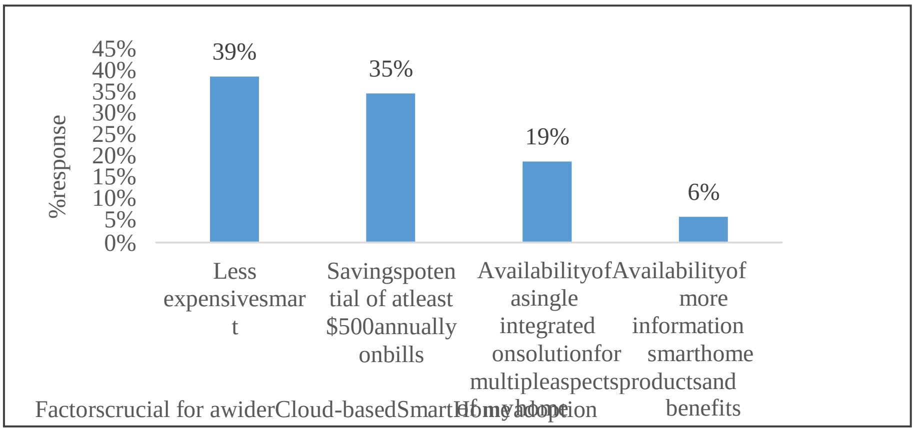


Figure7. Crucial FactorGoverningthe AdoptionofCloud-basedHEM

Regarding the likelihood of HEM expansion, about 72% agreed that they will includemore devices such as solar panels or electric vehicle in the future to their present homeenvironment (Figure 8). Consumer perceptions towards devices revealed that 75% wouldlike to own general appliances that are energy efficient, whereas 66% prefer smart LEDlighting and 20% want to have senior/disability or wellness devices (Figure 9). More thanhalf, i.e. 60% are interested in residential solar and about 25% are very likely to installsolar panels in their homes in the next 5 years (Figure 10). On the contrary, about 16%responded that they are very unlikely to adopt solar panels for a number of reasons whichmay include: apartment living, lack of roof space, inflexibility in payment options, lack ofawarenessandnon-cooperationfrom HomeOwnersAssociation*etc*.However,about70% are willing to participate in Solar net metering schemes by which excess power canbefedbacktothepowergrid.Thisshowsthatthereisopportunityforlaunchingcommunitysolargardeninitiatives.

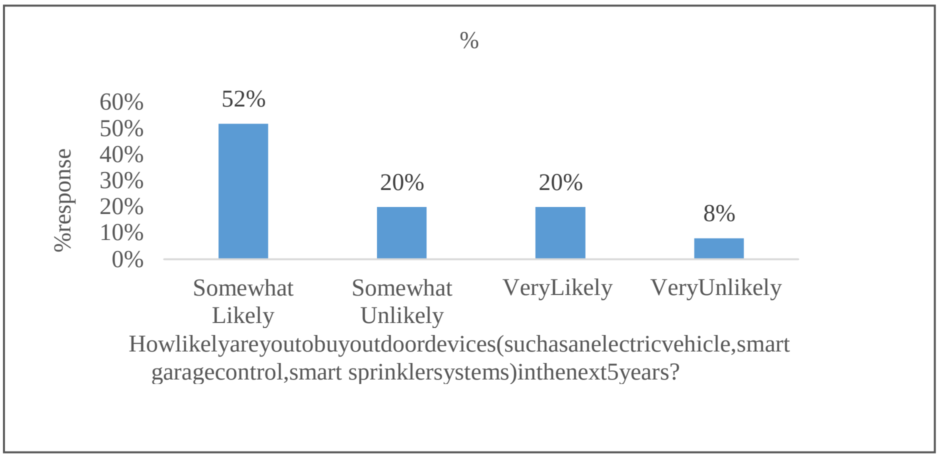


Figure8.LikelihoodforAddingMoreDevicestoaSmartHome

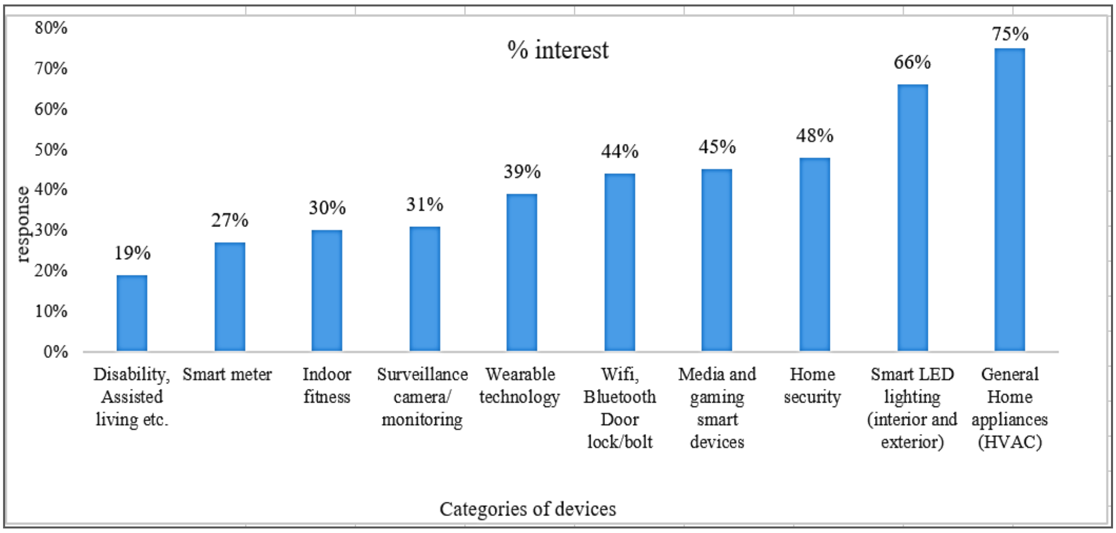


Figure9.VariousCategoriesofSmartDevices

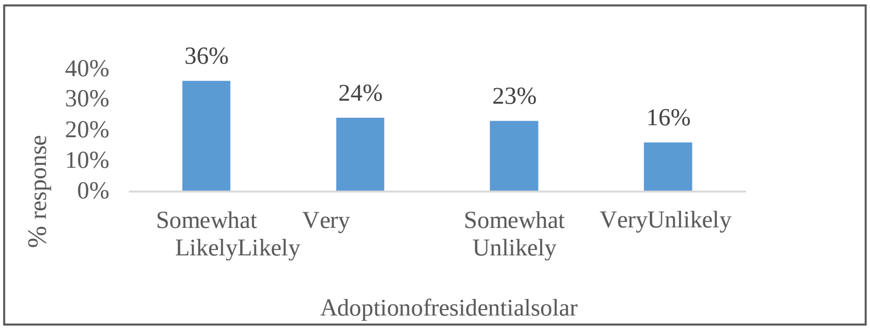


Figure10.AdoptionLikelihoodforResidentialSolarPanels

Overall, the survey results suggest that consumers show interest towards adoptingenergy efficient appliances and will purchase PV panels and electric vehicles within thenext 5 years. This notion is further strengthened by the findings that more than 50% of therespondents have experienced savings on bills in the past with the use of one or moresmart devices (Smart thermostat, energy efficient washer/dryer *etc*.). With an abundanceof opportunities in this domain, utilities and consumer electronics companies can devisemeasuressuchasfinancialincentivesorrebatestohelpconsumerstakecomplete advantage of energy programs. Telecommunications companies should invest in solutionsthat ensure security in the Cloud services to prevent data loss/breach, traffic hijacking,insecure interfaces or APIs, threats/malicious attacks/hacking, denial of service, and othertechnologyvulnerabilitiesasidentifiedbythe*CloudSecurityAlliance*.Ubiquitousconnectivity, limitless resources, user-friendly mobile apps and context awareness shouldbe some of the main considerations while interfacing with cloud-based smart devices. Theresults denote that integrating devices inside and outside a home can be a welcome factorfortech-savvyresidents withprogressive home/energyneeds.

8. An Example Application of Multi-Attribute Modeling for ConsumerAdoptionofHEMS

The overall problem is to choose an integrated HEMS, including devices and featuresthat can maximize the consumer's utility within the multi-criteria decision environment.AnHEM―package‖,inthisexamplecase,isdefinedasaprofessionallyselectedintegrated set of energy saving appliances and devices, in different price and efficiency(energy use) ranges, different acquisition and maintenance cost categories, offered tohome-owners for their particular situation or need. The modeling approach also allowsconsumersto createtheir own customized package.

An HEM package consists of, for example, major appliances (refrigerator, freezer,stove, washer and dryer, *etc*.), solar energy generating devices and systems (appliances,panels, surfaces), lighting systems (both interior and exterior), home heating and cooling(HVAC)systems,electricaltools,computers,laptops,entertainmentsystems,smallappliances, vehicle charging station, *etc*. Any energy consuming devices and appliancesthatcanbeintegratedintothehomecanbeconsideredforanHEMpackage.Thedevelopment and use of multi-attribute modeling (MAM) for home-energy managementcanbedescribed usingthe followingsteps:

1. Develop a suitable set of attributes by decomposing the HEM problem into sub-problems.Thesub-problemshavetobemeaningful,well-defined,measurable,non-overlapping,and orthogonal.
2. Developatree(orhierarchy)ofattributes(aggregateandbasicattributes).
3. Developtheutilityfunctions(qualitativeand/orquantitative).
4. Assignweights(basedonpreferencesofindividual consumers)toattributes.
5. DevelopHEMpackages.
6. EvaluateHEMpackagesviatheattributesandtheutilityfunctionstodeterminetheaggregateutilityof a package.
7. Comparecumulativeutilities,andchoosetheHEMpackagewithhighestutility.

A consumer selects a customized HEM package, or customizes his/her own package.UsingtheMAMmodel,theutilityofeachselectedHEMpackageisevaluatedbycomparingaggregate(cumulative)utilitiesofalternativepackages.Additionally,aconsumer will have the ability to adjust the weights (importance) of attributes to test andevaluate personalpreferences ofdifferentcustomized, orself-createdoption packages.Theconsumercanalsoconduct―what-if‖analysiswithdifferentpreferencesandweights,different package contents to compare costs (acquisition and maintenance) and energysavings.

Themulti-attributeutilityfunction,assumingalinearadditiveform,canbepresentedasfollows:

$$U[x_1,x_2 \ldots x_n]=w_1U[x_1]+w_2U[x_2]+w_3U[x_3]+\ldots+w_nU[x_n]=\sum_{i=1}^{n} w(i)U[x(i)]$$

Where,

- $U[x_1, x_2, \ldots, x_n]$ is the aggregate [cumulative] utility, the sum of weighted utilitiesofattributes

- $U[x_i]$istheutilityofattribute$x_i$for $n$attributes$i$ =1ton
- $w_i$istheweight $i$appliedtoutility$U$ ofattribute $x_i$suchthat $\sum^n_{i=1}(i)=1$
- attributes $x_i$areindependent for all$i$=1to n
- Theutilityfunctionislinearandadditive.

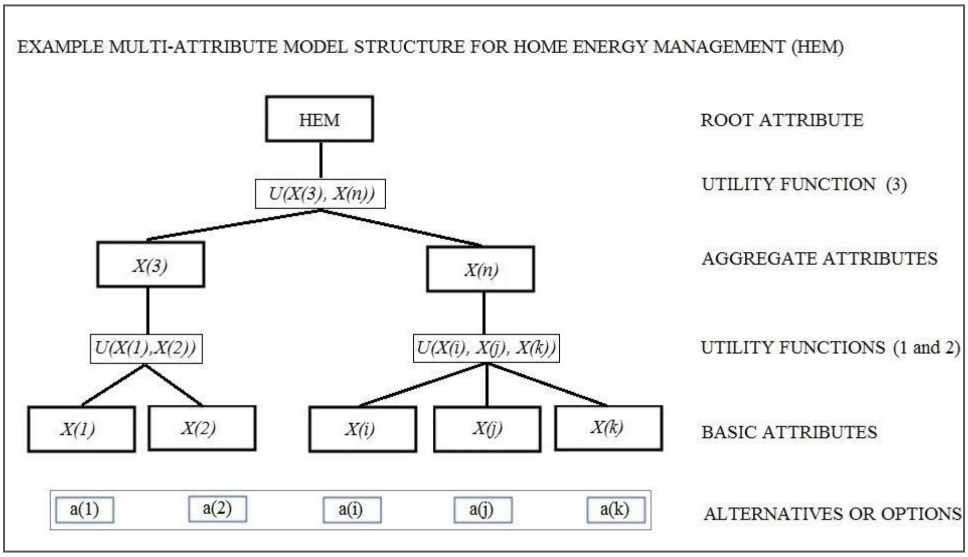


Figure 11. Multi-Attribute Model Structure for Home Energy Management(HEM)

Figure 11 shows a typical structure of the multi-attribute model for an HEM packageselection. In figure 11, a (1), a (2), a (i), a (j), a (k) represent alternative packages, x(1),x(2),x(i),x(j),x(k)representbasic–leaf‖attributes,U(x(1),x(2))andU(x(i),x(j),x(k)) represents utility functions,x(3)and x(n)represent aggregateattributes,U(x(3),x(n))represents a utility function, and HEM represents the root attribute aggregate utility of theevaluated package. To provide more specific context, we will next develop a simple,qualitative, multi-attribute model for the HEM package selection. Consider the followingattributesfor HEM:

1. TotalcostofanHEMpackage
a. Purchaseprice
b. Installationcost
c. Annualmaintenancecost
d. Annual operatingcost

2. Basic(necessary)featuresandcharacteristics
a. Majorappliances
b. Heatingandcooling(HVAC)
c. Smallappliances(includingcomputers,TVs,entertainmentsystems,phones,smallkitchenappliances)
d. Lightingsystems (interior,exterior)

3. Options–electricitygeneratingand-consumingdevicesandappliances
a. Energygeneratingdevicesandinstallations(solar-,wind-, geothermal-,…)
b. Energystoragesystems (batteries,backupsystems,…)
c. Electricvehiclecharging
d. Electricpowertools,equipmentanddevices
e. Pools,hot-tubs,andotherexteriorappliancesanddevices.

Each one of the attributes represents decision sub-problems. As can be seen from theabove list, the three main categories (1. Total cost; 2. Basic features; 3. Options) representaggregate attributes. Each of these aggregate attributes is further sub-divided into(basicoraggregate)attributes identified above.

Theaggregateattribute–Totalcost‖isdividedintofourbasicattributes:a)Purchase price (PRICE); b) Installation cost (INST); c)Annual maintenance cost (MAIN); and d)Annual operating cost [OPER].In this example, and in order to simplify, each basicattributePRICE,INST,MAIN,OPERcanassumethreevaluesonly,respectively:―high‖, ―medium‖,―low‖.The values for the basic attributes are provided by experts, and includedinthe HEM package.

The aggregate attribute –Basic features‖ consists offour attributes:a)Major appliances (M APPL); b) HVAC; c) Small appliances (SM APPL); and d) Lighting (LIGHT) systemsboth interior and exterior. These attributes can be aggregate attributes or basic attributesdepending on the desired level of model detail. In this example, and in order to simplify,theattributesareconsideredbasicattributes.Eachofthefourbasicattributesgovernsthe ―package‖ created by an expert, and can assume three values only, respectively: ―high‖(highendappliancesandsystems;ahigh-end―package‖createdbyanexpert),–medium‖ (mediumlevelappliancesandsystems,partialsystems;amedium-level―package‖createdby an expert), ―low‖(low end appliances and systems; a low-level, basic, ―package‖ createdbyan expert).Thevaluesforthebasic attributes areprovided byexperts.

The aggregate attribute –Options‖consists of five attributes: a) Energy generating devicesandinstallations(includingsolar-,wind-,geothermal-)(EGEN);b)Energystoragesystems(ESTO);c)Electricvehiclecharging(ECHA);d)Electricpowertools(ETOOL);e)Pools,hot-tubs,*etc*.[POOL].Asdescribed,theseattributescanbeaggregate attributes or basic attributes depending on the desired level of model detail. Inthis example, and in order to simplify, the attributes are considered basic attributes. Eachof the five basic attributes governs the ―package‖ created by an expert, and can assumefourvaluesonly,respectively:―high‖(highendsystemswithhigh-endcharacteristicsandfeatures;a―package‖createdbyanexpert),―medium‖(mediumlevelsystemswithsome butnotallcharacteristicsandfeatures;a―package‖createdbyanexpert),–low‖(lowend systems, basic systems; a ―package‖ created by an expert), and the ―no‖ options chosenalternative.Thevalues forthe basic attributesare providedbyexperts.

The MAM model for HEM package selection is shown in Figure 12. The model shownisaqualitative MAMmodelwithfour qualitativeutilityfunctions.

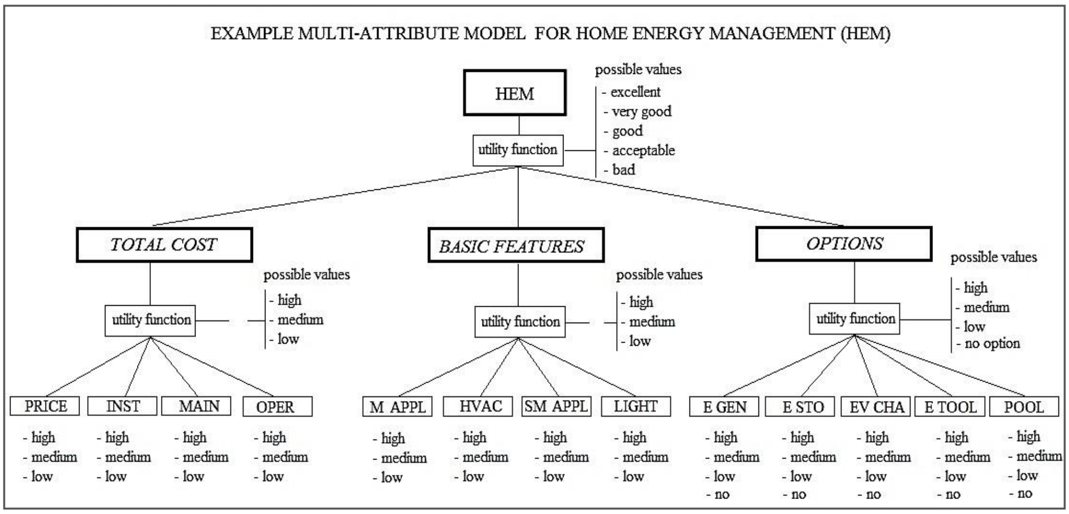


Figure 12. Qualitative Multi-Attribute Model Example for Home EnergyManagement(HEM)

Forexample,thequalitativeutilityfunctionfor–TOTALCOST‖receivesinput from PRICE, INST, MAIN and OPER. As stated before, the initial values of the basicattributes are set by experts. Each of the basic attributes can assume three values [high,medium, low]. Therefore, there are 81 (= 3^4) different input combinations as PRICE canassume any of the three values [high, medium, low], and for that INST, MAIN and OPERcan independently assume any of their respective basic attribute values. Now to developthecompleteutilityfunctionfortheaggregateattributeTOTALCOST,onehastoconsider each of the 81 combinations, and assign each combination separately a value thattheutilityfunctioncanassume,inthiscase–high‖,–medium‖,or–low‖.Ifnow,asan example,thebasicattributesPRICE,INST,MAIN,andOPERareallclassifiedas―high‖,then the expert could consider this combination to translate to ―high‖ TOTAL COSTusingtheutilityfunction.Ontheotherhand,acombinationofPRICE―high‖,INST ―medium‖,MAIN –medium‖and OPER –low‖,might lead the expert to consider the utility of that combination to TOTAL COST as ―medium‖, and so on. The expert wouldthen consider each of the 81 combinations, and assign a value for the combination for theaggregateutilityTOTALCOSTusingtheutilityfunction.Thesameprocessisusedforallbasicattributesofallbranchesofthetree,andallcombinationsfor―BASICFEATURES‖,and―OPTIONS‖. Atthenextlevel, theaggregateattributesTOTAL COST(canassumethreepossiblevalues],BASICFEATURES(threepossiblevalues)andOPTIONS(fourpossible values) are considered in a similar way as above. There are 36 combinations,coming from these aggregate attributes, to be considered for the HEM utility function.Considertwoofthosecombinations:TOTALCOSTat―high‖,BASICFEATURESat ―high‖andOPTIONSat–high‖mightbeconsidered–good‖bytheHEMutilityfunction, whereasTOTALCOST–low‖,BASICFEATURESandOPTIONSbothat–high‖might be considered–excellent‖bythe expertfor HEM levelutility.

9.Conclusions

Thispaperhasproposedanextensiontoexisting HEMprototypesbytakingsomeoftheimportantsolardeviceoptionsintoaccountandamulti-attributemodeling(MAM) approach to smart home adoption. Firstly, in order to increase and expand the number ofsmart devices in a home, the proposed model add-on has been discussed by drawingconclusions from consumer perceptions captured in an online survey. The goal of thisstudy is to offer a comprehensive account of synthesis–generated insights about HEMSalong with the implications of a cloud-based smart home. An integrated HEMS offers adata-driven approach to energy efficiency with the help of programmable devices that canmeasuretheamountofelectricity anapplianceuses(including phantom loads).Themethodologies discussed in the report can help consumers make wellinformed decisionsregardingHEMS.Secondly,thisstudycallsattentiontotheprincipalbarriersandchallenges in HEMS and cloud technology‘s reach in today's power landscape. Smarthomeswith cutting edgetechnologiesmakeessentialactivities and tasksin ahomeenvironment possible, both manually and remotely. With growing electricity charges andimpending powercrises, there is a sense of urgency for effective energy efficiencythatcan save money as well. All of the above can be achieved by using cloud integrateddevices because they can provide prudent homeowners with real time information onenergyconsumptionindynamicscenarios.Thirdly,themostcrucialfactorofcloudtechnology determined from the survey results is ‗Security‘. This information can supportConsumer Electronics and Tele-communications companies to tighten security measuresin the administration of their cloud computing services. New fault-tolerant platforms tomitigate conformance slips and infrastructure vulnerabilities must be made available tocustomers.Thesurveyresultsalsosignalthatthereisconsumerinclinationandenthusiasm towards solar adoption as well as different categories of devices viz. LEDlighting, surveillance cameras, and media and gaming devices. Affordability and possiblesavings potential of such devices can result in a wider adoption of cloud-based HEMS.Thirdly,intheproposedpragmaticconceptofHEMsystemmodeling,thecriticalnatureof"functionalities"or"tasks"expectedoutofadevice,asrequiredbyaparticularconsumerinaparticularsituation(withorwithoutconditions)areselectedtoforman ―HEM package‖.With this contextual information and other tier-based attribute selections, the aggregate utility function can be formulated. The proposed qualitativemethodology to purchasing smart devices has been illustrated with an example. Thisinventive technique in consumerbehavior can be provento beuseful for anyHEMpackage using real-time data. The model can render a purchase option that has the highestutility and lowest cost for the expected feature/functionality in a device. Last but not least,this study emphasizes the benefits of DR programs. Identifying changes in consumerbehavior with the introduction of financial incentives and rebates relating to Smart Homesunderscores the need for utility companies to offer cash rebates or credit to help end userstake advantage of these programs. This will have cumulative effects on both the utilitiesandconsumers.Inconclusion,anextensive,robustandacost-effectivecloud-basedHEMS with the capabilities of energy data exchange can be a powerful mechanism forhandlingenergyissues acrosscities.

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