A Smart Home Model Using JaCaMo Framework

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***Abstract*—Abstract. In order to address the challenges of greener energy generation, new techniques need to be developed both to generate electricity with lower emissions and to optimize energy distribution and consumption. Smart grid techniques have been developed specifically to tackle this latter challenge. This paper aims to contribute in improving the efficiency of energy use within a single household by modeling appliances within it as a multiagent system (MAS). We model this system as a virtual organization that seeks to minimize energy consumption while reaching a tradeoff between user comfort, energy cost and limiting peak energy usage.**

Keywords—Demand Side-Management, Smart Grid, Smart Home, JaCaMo

I. INTRODUCTION

Electricity is the most versatile and widely used form of energy, as such, global demand is growing continuously. However, electricity generation is currently the largest single source of greenhouse gas emissions, making a significant contribution to climate change. To mitigate the consequences of climate change, the current electrical system needs to undergo adjustments. The solution to these problems is not only to generate electricity more cleanly, but also to optimize the use of the available generating capacity. To achieve such optimization, the *Smart grid* comes into play.

A *Smart grid* is an electrical grid that uses information and communications technology to gather and act on information, such as information about the behaviors of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity [1]. Smart grid is capable to respond intelligently to changes in demand to help balance electrical consumption with supply, as well as the potential to integrate new technologies to enable energy storage devices and the large-scale use of electric vehicles.

Demand for electricity should be made more adaptive to supply conditions, avoiding peaks of demand, resulting in a more efficient grid with lower prices for consumers. As a result, the new electrical grid intends to achieve an economic balance and increase the efficiency of the current the electricity supply. Energy efficient technologies such as intelligent control systems that adjust the heating temperature, lighting can help with the management of consumption in buildings and houses. This intelligent control system can give consumers control over the amount of electricity they use. Controls in the household and appliances can be set up to respond to signals from the energy grid to minimize the energy use at times when the power grid is under stress from high demand, or even to shift some of their power use to times when power is available at a lower cost. Such an intelligent control system inside a household introduces the concept of *Smart home*.

Within the smart grid, a smart home is a household that has highly advanced automatic systems responsible for managing and controlling the smart appliances. A smart appliance is a device that allows access and operation through an automated management system. In this paper we improve substantially the model and experimentation presented in [2]. Our main contribution is an agent-based smart home model whereby individual autonomous agents are deployed to control each energy consuming device within a household, as well as an agent coordinating them all through the energy meter. This model should allow a smart home to become more collaborative with the electric grid by balancing energy demand, increasing the resilience of the household as well as optimizing user comfort. The rest of this paper is structured as follows: Section II reviews the background required for our definition of a smart home model; Section III presents the smart home model itself; Section IV evaluates the appliance management algorithms using the model proposed; and finally, Section V concludes this paper and presents future work.

II. BACKGROUND

In this section, we briefly explain the organization of the electric power industry and introduce key concepts relating to the smart grid, and some of its associated technologies.

A. Electric Power Industry

The electric power industry is divided into three major sectors: generation, transmission and distribution.

Electricity *generation* is the large-scale process of generating electric power generally in stationary plants designed for that purpose. A power station (also referred to as power plant) is an industrial facility for the generation of electric power [3].

Electric power *transmission* is the bulk transfer of electrical energy from power plants to electrical substations located near demand centers. Transmission lines when interconnected with each other become transmission networks [4].

Electricity *distribution* is the final stage in the delivery of electricity to end users. A distribution network carries electricity from the transmission system and delivers it to consumers. The distribution infrastructure is extensive since electricity has to be delivered to customers concentrated in cities, suburbs and very remote regions [5].

B. *Smart Grid*

Smart grid generally refers to a class of technologies using computer-based remote control and automation. These systems are made possible by two-way communication technology and computer processing that has been used for decades in other industries [1].

Murphy et al. [6] and Hamilton et al. [7] agree that smart grid is a modern electricity system that uses sensors, monitors, communication, automation and computers to improve the flexibility, security, efficiency, reliability, economy, and safety of the electricity system.

Ramchurn et al. [8] argue that the smart grid provides significant new challenges for research in AI since these technologies will require algorithms and mechanisms that can solve problems involving a large number of highly heterogeneous actors. Demand side management, electric vehicles, virtual power plants, energy prosumers and self-healing networks are some of the key components that deserve attention in smart grid research.

Demand Side Management (DSM) and Demand Response (DR) are approaches to offer flexibility on the load side. DSM covers direct control of the energy consumption on the load side in order to increase or decrease the energy consumption over periods based on different criteria. In other words DSM can help the customers use electricity more efficiently. Existing approaches to reduce demand have been limited to either directly controlling the devices used by the consumers (e.g., automatically switching off high load devices such as air conditioners at peak times). DR covers the response of loads following an external signal, which can be based on markets as well as technical aspects (e.g performance of the supplying grid). Demand side integration (DSI) integrates both DSM and DR.

C. *Smart Home*

Smart home is the term commonly used to define a residence that has appliances capable of communicating with one another and can be operated remotely by a control system. Within a smart home, a smart meter is responsible for providing the information interface between household and the energy provider. Smart meters also provide utilities with more information about how much electricity is being used. Smart appliances can also respond to signals from the smart meter to avoid using energy during times of peak demand.

Current smart appliances and their communications technology are very heterogenous. In this scenario of heterogeneous devices and protocols, it is necessary to adopt an abstract, standards-based view of the new smart grid system as early as possible. In an ideal smart grid environment, all smart grid appliance functions, device connectivity, and device protocols are standardized in order to avoid multiplied maintenance effort and vendor lock-in for proprietary components [9].

The deployment of a smart home goes beyond the improvement of a household, for example, if a set of smart homes work together it is possible avoid peaks of demand in the whole power grid. For instance, a smart air conditioner might extend its work time slightly to reduce its load on the grid; while not noticeable to the user, millions of air conditioners acting the same way could significantly reduce the load on the power grid.

D. *JaCaMo*

JaCaMo is a framework for Multi-Agent Programming that combines three separate levels of abstraction. Each level of abstraction in JaCaMo has its own description language and programming model. A JaCaMo multi-agent system or, equivalently, a software system programmed in JaCaMo is defined by a **Moise** organization of autonomous BDI agents based on concepts as roles, groups, mission and schemes [10]; autonomous agents are implemented in **Jason** [11]; working in shared distributed artifact-based environments developed in CARTAGO [12]. The JaCaMo meta-model defines dependencies, connections and, more importantly, conceptual mappings and synergies between all the different abstractions available in the meta-models associated to each level of abstraction [13].

III. SMART HOME MODEL

A. *Domestic Appliances*

Within the domestic energy domain, it is common to characterize domestic appliances under specific categories: wet and cold appliances, water heating, space heating, cooking and lighting appliances, periodic load and miscellaneous appliances [14] [15].

The different categories imply different behaviors. Wet appliances typically involve set periods of time, programmed by the user or a device controller. Cold appliances have continuous demand. Conversely, temperature controllers have power consumption related to their usage and user routine, when there are users at home, temperature controllers and water heating have power consumption, otherwise when there is nobody at home they should be off or in a standby state. The other categories (lighting, cooking appliances, entertainment, periodic load and miscellaneous) are much more dependent on the user lifestyle and preferences.

B. *Appliances Description*

All devices considered in this model have only two possible states (On and Off), and switch between these states via their internal schedule or an external command. Future studies can consider additional states, such as a standby state. For this model we consider a domestic profile with fixed time intervals consisting of single days, divided in periods of half-hour. Each time slot $t \in$ T where T = 1,...,48 [16] [15].

Each appliance is responsible for requesting the power required for each cycle, and cannot demand more power than needed to operate in one cycle, even if there is energy left. An exception to this rule is related to the appliances that must operate continuously, such as a refrigerator. In this case the appliance must request all necessary power to operate in the operation window. Each appliance must execute within its predefined operation window.

The attributes defined for each appliance are: power, the number of cycles that the appliance needs to operate per day, category and operation window. Each appliance is described using the following notation:

$$appliance(Pow, Cycles, Categ, Window[Start, End])$$

Where **Pow** describes the energy required to operate in each cycle, **Cycles** are the number of cycles the appliance intends to operate per day, **Categ** defines the appliance category and **Window[Start, End]** informs which cycles the appliances may operate.

A washing machine, for instance, needs 600 watts to operate in one cycle, it needs 2 hours (4 cycles) to do the laundry, it is classified as a Wet appliance and the operating window has a size of 8 cycles, the washing machine operates between the cycles fourteen and twenty two. the notation below represents this example:

$$washing\_machine(600, 4, Wet, Window[14, 22])$$

C. Organization Model in JaCaMo

We implemented our model using the multiple abstraction layers from the JACAMO framework. The organization with the roles, objectives and schemes are implemented at the MOISE level. The environment artifacts that define he limit of power per day and limit of power per cycle are implemented at the CARTAGO level. Finally the implementation of agents is done at the JASON level.

The main roles defined at the MOISE level are: the **smart meter** and **appliances** that are divided according to the categories described in Section III-A We defined one scheme to coordinate the power consumption. This scheme covers four goals; each goal has one associated mission. The first goal is to control peaks of demand, this goal is achieved through mission **control demand**, this mission only can be adopted by an agent playing the smart meter role. The three other goals are demand energy, receive energy and execute in operation window; these three goals are achieved through the missions: **demand energy**, **receive energy** and **execute in operation window**; all agents playing an appliance role must commit to these three missions.

The JASON level includes the actual agent implementation, the agents can assume the roles defined at Moise level. Each agent can play just one role, however we allow some roles to be played by more than one agent; the air conditioner and the ceiling fan, for instance, can assume the role temperature controller. Each goal defined in the functional specification at Moise level is met by plans implemented in the agents. Each agent represents an appliance, and their individual behavior takes into consideration the appliance types from Section III-A.

We implemented two CARTAGO artifacts to simulate the virtual environment: the first artifact controls the cycles, providing perceptions to the agents, about: when the cycle starts, which is the current cycle and when a cycle finish. All agents in the simulation are aware of this first artifact. The second CARTAGO artifact controls the energy load and the appliances consumption. Through this artifact, it is possible to check the limit of energy that is available to be consumed per day and the limit of consumption per cycle. This artifact is known only to the agent playing the *SmartMeter* role.

D. Demand2Consume Allocation Protocol

The smart Meter has the responsibility of releasing load for each appliance; monitoring the set of appliances so they do not operate outside of their operating window; controlling the peak of demand per cycle; and controlling the limit of load per day. The appliances have to monitor their operating window, request the necessary load from the smart meter at the start of an operating window and in each cycle, negotiate with the smart meter if they can operate in the current cycle or should wait until next one.

Demand2Consume protocol begins when the smart meter and the appliances perceive from the environment that a new cycle has begun, then the Smart meter updates the belief in its belief base that monitors the cycles i.e. (***-+newCycle(C)***) [1], and wait for the appliances to demand power. As long as the power requests arrive, the smart meter must address them all.

Meanwhile, each appliance check if the current cycle is within its operating window, if that is the case, the appliance checks how much energy it needs and then sends a request to the smart meter informing its name, the daily shift it intends to operate on and how much energy it needs. The appliance accomplishes this by sending the literal ***.send(SmartMeter, tell, energy_request (Appliance, Shift, Energy))***, shown in Listing 1 line 8. Otherwise, if the current cycle is outside the appliance‘s operating window, the appliance simply waits until the next cycle.

```
1    +!demand_energy
2         :current_Cycle(Cycle) & operating_window(Begin,End) &
3         Begin <=Cycle & Cycle <=End &
4         lastCycleIdemandedEnergy(Last_cycle)&
5         Cycle > Last_Cycle & cycles_to_execute_remaining(R) & R>0
6    <-?.my_name(Me);
7         !energyNeeded(Energy);
8         .send(smartMeter,tell,energy_request(Me,Shift,Energy));
9         .wait(10);
10        !!energy_demanded.
```

Listing 1: demand energy plan

Listing 1 shows the plan ***demand energy***. With this plan the appliance verifies if the current cycle is inside the operating window, if the appliance has not demanded power in the current cycle yet and if the appliance still has the intention to operate; as a result if these three checks are true the appliance verifies how much energy needs and then send a request to the smart meter.

The plan ***!energyNeeded(Energy)*** in Listing 1 line 7 defines how much power the appliance intends to demand. The amount of power each appliance can demand is related to the category of the appliance, if an appliance needs to operate all day without interruption it means that this appliance can demand all energy necessary.

Each power request is addressed individually by the smart meter. **Listing 2** summarizes how a power request is addressed by the smart meter. Before answering a power request the smart meter must check how much power is still available to be released in the current day; if the amount of power remaining is less than the amount demanded by the appliance the smart meter informs the appliance that it is not possible

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[1] We assume the user is familiar with AgentSpeak(L) [17]

```
@b1[atomic]
+energy_request(Appliance, Shift, Demand)
    :Shift = all & daily_load(Power_remaining) &
    Power_remaining >= Demand
<-!energy_sent_to_device(Appliance,Shift,Demand).

@b2[atomic]
+energy_request(Appliance, Shift, Demand)
    :not(Shift = all) &
    daily_load(Power_remaining)& Power_remaining  >= Demand &
    cycle_load(PCycle_remaining)& PCycle_remaining >= Demand
<-!energy_sent_to_device(Appliance,Shift,Demand).
```

Listing 2: energy request plan by Smart Meter

to provide energy because the daily limit has been reached. In that moment the appliance knows that it is useless to keep requesting power in the current day because there is not enough power for the appliance operate, as a result the appliance stops requesting energy and must wait until next day.

Otherwise, if there is enough energy available in the daily limit the smart meter checks the cycle limit, if there is not enough power or if the cycle limit has been reached the smart meter informs the appliance that no power will be released because the cycle limit can not be violated and the appliance needs to wait until the next cycle to try again. After these checks, if the smart meter concludes that the appliance can operate, the smart meter informs the requesting appliance that it can consume the energy requested. The plan ***energy_request*** must be atomic to prevent the smart meter from responding more than one request simultaneously and thus exceeding the limit of energy.

Finally, if the smart meter concludes that the appliance can consume energy, the smart meter informs the appliance that it is releasing a specific amount of power.

Listing 3 shows how the appliance handles the energy consumption. First of all, the appliance verifies if the quantity of energy received is enough to operate, if it has receiving energy within of its operating window and if it still has cycles to operate; if these checks are true the appliance removes the information sent by the smart meter from the belief base, updates the quantity of cycles to operate remaining and updates the consuming information using an internal action.

```
+releasingEnergy(consumeEnergy, Power):
  Power <=0 & demand_per_cycle(P) & Power >= P &
  current_cycle(Cycle)&  operating_window(Begin,End) &
  Begin <= Cycle & Cycle <= End &
  cycles_to_execute_remaining(R) & R > 0
<--releasingEnergy(consumeEnergy, Power);
  -cycles_to_execute_remaining(R);
  +cycles_to_execute_remaining(R - 1);
  ?.my_name(Me);
  update_LoadConsumed(Me, P, Power - P, R-1).
```

Listing 3: releasing Energy plan from Appliance

IV. EXPERIMENTS AND EVALUATION

In this section we describe the setup used in our experiments. This set up includes the environment used in the simulations which contains the daily shift configuration, the appliances profile and the group of appliances used in the simulation. We follow with a description of the implementation of our simulation, including the appliances setup, the local allocation protocol used to coordinate the simulation and three different scenarios used during the simulations.

A. *Experiment Setup*

Based on average household consumption in the South of Brazil [18], we assume that a household consumes 186 kwh per month during summer time or 6.2 kwh per day. Thus, each day has 48 cycles, the first cycle starts at 0:00 AM and ends at 00:29 AM.

Each appliance is classified according to its daily execution shift, there are 6 different options for which each appliance can be scheduled to operate: **Dawn** (from cycle 1 to 12); **Morning** (from cycle 13 to 24); **Afternoon** (from cycle 25 to 36); **Night** (from cycle 37 to 48), **All** (from cycle 1 to 48) or **Any**. In this simulation we define that just one option can be chosen and the appliance is now allowed to operate out of its daily execution shift [2].

If an appliance has “Morning” as its daily shift, it can only operate at any time between 6:00 AM to 11:59 AM. Moreover, if an appliance has “All” as its shift it must operate without interruption throughout all cycles, whereas if an appliance has “Any” as its shift, it can operate in any cycle. Finally, each appliance has an operating window, the interval of cycles in which the appliance must operate. The appliance is not allowed the operate outside its operating window.

The group of appliances used in the simulation is described in Table I. For each appliance we have: the power required for operation, the number of cycles they intend to operate per day, the category and the operating window.

B. *Runs*

Three different scenarios were considered in order to compare the results. The first one focuses on the average consumption throughout the day, we assumed that the peak of demand allowed in each cycle should be 10% of the daily load. The second scenario prioritizes energy saving and focuses on the user economy, the peak of demand per cycle allowed is 3.33% of the daily load (one third of the peak allowed in the first scenario). In this scenario the user comfort steps aside, some appliances may fail to operate because the competition for energy is high. In the third scenario the user comfort is top priority, this scenario allows a peak of demand per cycle of 60% of the daily load, the appliances operating window are distributed in the 48 cycles because we assume that the group of appliances defined here does not operate together, however the peak of demand defined in this scenario allows all appliances to operate at the same time.

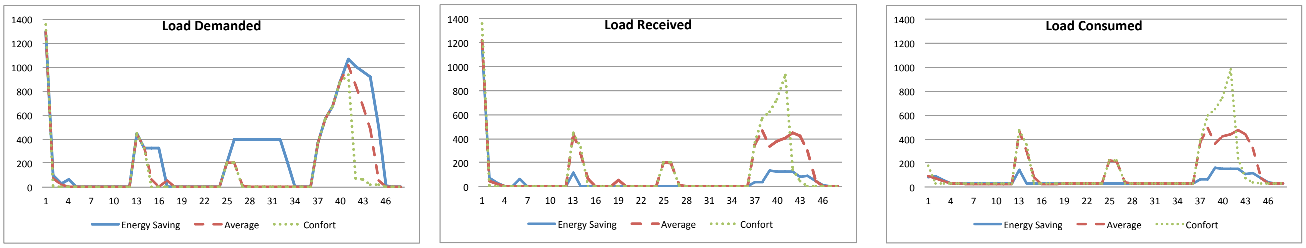
C. *Results*

We empirically evaluate these scenarios by executing them and comparing the total load demanded in each cycle, the total load received in each cycle and the total load consumed in each cycle.

Fist chart from **Figure 1a** shows a chart of the load demanded in each of three scenario, it illustrates that there is a peak of demand in the first cycle, as the refrigerator must operate in all cycles, this appliance is allowed to demand all

Appliance	Power(W)	Cicles/day	Daily Demand	Category	Operating Window
Air conditioner	1000	5	1650	Temperature Controller	37 to 44
Air conditioner	1000	2	660	Temperature Controller	13 to 16
Washing machines	600	0.5	150	Wet	1 to 15
Coffee maker	500	0.2	50	Cooking	13 to 14
Toaster	700	0.2	70	Cooking	13 to 14
microwave	1000	0.5	250	Cooking	41 to 45
Refrigerator	50	48	1200	Cold	1 to 48
Television System	420	4	840	Entertainment	38 to 45
Computer	200	3	300	Entertainment	39 to 44
Cellphone charger	6	4	12	Periodic Load	1 to 13
NoteBook charger	60	4	120	Periodic Load	40 to 48
Hair dryer	600	0.5	150	Personal Care	40 to 46
Clothes Iron	800	1	300	Miscellaneous	25 to 32
Vacuum	800	0.5	200	Miscellaneous	26 to 33
2 Living room Fluourescent light bulbs	40	4	80	Lighting	37 to 42
Bathroon Fluorescent light bulbs	20	4	40	Lighting	40 to 44
Kitchen Fluorescent light bulbs	20	4	40	Lighting	37 to 42
Bedroom Fluorescent light bulbs	20	4	40	Lighting	40 to 48
Living roon LED bulbs	18	6	54	Lighting	37 to 42
3 Dining roon LED bulbs	18	2	18	Lighting	39 to 43

TABLE I: Appliances used in the simulation



(a) Load demanded

(b) Load received

(c) Load consumed

Fig. 1: Load demanded, received and consumed in each scenario

necessary energy in the first cycle resulting in a virtual reserve of energy for the refrigerator. Second chart from **Figure 1b** shows a chart of the load received in each of three scenario, it illustrates that the refrigerator received energy during the same cycle that demanded in almost 95% of the cases and received in the next cycle in 2% of the cases. Third chart from **Figure 1c** shows a chart of the load consumed in each of three scenario, it shows that all cycles have consumption, even the cycles when there is no appliance demanding energy because the refrigerator has its reserve of energy and consumes it through all cycles.

The operating window between cycles 13 and 16 in the energy saving scenario, where the air conditioner, the coffee maker and the toaster intend to operate. As the air conditioner demands more energy than the cycle limit, it creates a peak of demand and fails to operate in all cycle of its operating window. Otherwise, the toaster and the coffee maker intend to operate just for few minutes, as a result they receive the energy necessary to operate. In the average and comfort scenarios there is a peak in the 13th cycle but it does not violate the cycle limit, all three appliances are able to operate inside their operating window.

Likewise in the operating window between cycles 25 and 33 in the energy saving scenario as well, which has the vacuum and the clothes iron scheduled to operate. Both of than need 200 watts to operate, the cycle limit in the energy saving scenario is 205 watts, it means that they demand less energy than the cycle limit, however the refrigerator has its virtual reserve of energy and the smart meter prioritize this appliance. Consequently, none of them can operate in the energy saving scenario. Besides, in the other two scenarios the vacuum and the clothes iron are allowed to operate.

Further in the operating window between the cycles 37 and 45. The air conditioner is programed to begin over the 37th cycle, the television system operating window begins at 38th cycle, the computer is set to operate in three cycles between 39th cycle and 44th cycle and the hair dryer has intention to operate just fifth teen minutes (0.5 cycle) between 40th cycle and 46th. Together these four appliances need more than 900 watts to operate, this causes a peak of demand between cycles 38 and 44. In the energy saving scenario, the air conditioner and the television system demand more power than the limit allowed per cycle, the cycle limit is 205 watts that represent 3.3% from the available daily load and the air conditioner and television system demand 330 watts and 210 watts per cycle respectively. As a result, there is a peak of demand between

38th and 44th cycles (**Figure 1a**), however the smart meter does not release energy to them. The computer and the hair dryer have permission to operate in this scenario because their need is inferior to the cycle limit, 100 watts and 150 watts respectively. Although, they can not operate in the same cycle because the sum of their demand it is higher than the cycle limit, wherefore in cycles that the hair dryer and the computer demand energy together sometimes one receives energy and the other does not and sometimes the opposite.

Meanwhile in the average scenario the behavior of the air conditioner, the television system and the computer are quite different. The cycle limit allows just two of them to receive energy per cycle resulting that the power usage is distributed along the cycles, avoiding peaks of demand in cycles that these three appliances demand power together (between cycles 39 and 44) sometimes the air conditioner and the television system receive energy and the computer does not, other times the computer and the air conditioner are allowed to operate and the television system does not and in some occasions the air conditioner fails to operate and the other two appliances does not.

Finally, in the comfort scenario we can see that the air conditioner, the television system, the computer and the hair dryer get energy in the firsts cycles of their operating window, it is possible because the cycle limit is higher than their demand. As a result there is a significant peak of demand and peak of consumption beginning in the cycles 36 and reaching its top in the cycle 41

V. CONCLUSIONS AND FUTURE WORK

The electrical power system is now one of the most critical components of the infrastructure on which modern society depends. To satisfy both the increasing demand for power and the need to reduce carbon emissions, we need an electric system that can handle these challenges in a sustainable, reliable and economic way.

In this work we developed a smart home model designing a multi agent system to strike a balance in optimizing comfort, electrical efficiency and increasing the resilience of a household. The smart home model is composed by a control systems that is responsible for avoiding peak of demand by controlling the appliances power consuming. This control system forbids the household to consume more than the limit of power available, as a result the household became more collaborative with the power grid.

As future work we will further develop the model presented in this paper by aggregating to the smart home model the micro generation system and the evolve the control system and the communication protocol between smart entities. The daily execution shift will be explored in future work, in a reward and penalty approach the appliance can be encouraged to operate in the daily execution shift in exchange of some kind of reward, otherwise, the appliance can be free to operate in another daily shift while accepting some kind of penalty. We intend to study the different users' profiles to understand the kind of customization that the smart system should perform to balance the demand considering the energy variation in the grid, also study the household configuration profiles (cost versus comfort) to enable the users to configure their houses balancing cost and comfort in different levels.

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