Finding Personalized Energy-Saving Behaviors Based on Questionnaire of User Preference
— Preliminary Study on Home Air-Conditioning —

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***Abstract*—This paper presents a method that finds the *personalized energy-saving behaviors* for the air-conditioning operations within the emerging home network system. We first conduct a preliminary questionnaire. The obtained preference of each user is then reduced to an optimization problem on preferred appliance operations and the power consumption. We finally derive a personalized energy-saving air-conditioning service.**

I. INTRODUCTION

Saving energy at home is a crucial problem. Houses are furnished with a variety of electric household appliances and equipments. The conventional system-centric approach (e.g., [1]) basically tries to save the energy of products or systems themselves. Hence, they sometimes decrease comfortability and quality of life of home users. To achieve more acceptable and sustainable energy-saving, we propose *personalized energy-saving behaviors*, which are user's energy-saving behaviors adapted to individual preferences and life styles.

In [2], we have previously proposed a method that recommends optimal energy-saving appliance operations for given user's requirement, using the emerging *home network system* (HNS, for short) [3]. In this method, we defined impacts of appliance operations to every environment property (e.g., temperature, humidity, power consumption). Representing user's requirements as constraints, we formulated a mathematical programming, finding an optimal solution that minimizes the power consumption. However, it is hard for general users to express personal preferences in mathematical formulas.

To cope with the problem, this paper proposes a pragmatic method that conducts a questionnaire to extract user's preferences in energy-saving. Especially focusing on the air-conditioning, we design a questionnaire. It asks each user his/her preference of energy-saving, warming, cooling, humidifying, drying, priorities among them, favorite and prohibited appliances. We then present a method to formulate an optimization problem based on the result of the questionnaire. We finally apply our previous method to derive the solution mathematically. Thus, we can obtain a personalized energy-saving air-conditioning service.

To demonstrate the effectiveness, we have conducted an experiment with fifteen subjects in an actual HNS. As a result, it was seen that all subjects had different preferences, which justifies the importance of the personalized energy-saving behaviors.

II. PERSONALIZED ENERGY-SAVING BEHAVIORS

To save energy consumption at home, many products and solutions have recently come onto the market. Most of these technologies are based on a system-centric approach, which tries to improve the energy efficiency of the system (object, device, appliance, etc.) itself [1]. Many guidelines are also published by various enterprises and organizations [4]. They include the way of installation of equipments, attitudes toward energy-saving, and usage of household appliances, encouraging individuals to perform the *energy-saving behaviors*.

Although many energy-saving products and guidelines exist, it is difficult to consider that all users can accept them as they are.This is because individual preference for the energy-saving varies from person to person. The above observation implies that we need to count individuals, in order to achieve sustainable and acceptable energy-saving. In this paper, we define a notion of *personalized energy-saving behaviors*, to represent energy-saving behaviors customized to individuals based on the user's preferences.

To derive the personalized energy-saving behaviors we extensively use the *home network system* (HNS)([3]). In the HNS, household appliances, sensors and equipments are connected to networks to provide various value-added services.

III. PREVIOUS METHOD

A. Finding Optimal Energy-Saving Operations by Solving Mathematical Programming

In [2], we proposed a method that recommends a set of energy-saving appliance operations for the given user's requirement using the HNS. Specifically, we defined an impact of every appliance operation to an environment property (e.g., temperature, humidity, power consumption, etc.) as an *appliance/environment effect* (called *A/E effect*). Then, for a set $\{o_1, o_2,.., o_n\}$ of appliance operations, we define a Boolean vector $X = (x_1, x_2, .., x_n) \in \{1, 0\}^n$ representing whether o_i should be chosen or not. Next, based on the A/E effect of each operation, we quantify each environment property e by the degree of contribution, represented by a polynomial formula $C_e(X)$. Finally, the problem is reduced to an optimization problem finding a solution $X_o = (x_{o_1}, x_{o_2},.., x_{o_n})$ minimizing the power consumption, subject to user's requirements and environmental constraints.

TABLE I
EXAMPLE OF A/E EFFECTS CALIBRATED FOR CS27-HNS

			Airconditioner(heating)			Airconditioner(cooling)				Humidifier		Curtain		Window		Fan	Heater	Carpet
			20°C	23°C	26°C	28°C	25°C	21°C	dry	humidify	dehumidify	open	close	open	close	on	on	on
		selection vector	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15	x16
A/E effects	direct	Temperature	8	10	12	-8	-10	-14	0	0	0	0	0	-3	3	0	14	4
		Humidity	-3	-4	-5	-3	-4	-5	-8	10	-7	0	0	-2	0	0	-6	0
		P.Consumption	350	450	600	400	500	650	500	300	300	0	0	0	0	60	650	150
	indirect	[delta]Temp	0	0	0	0	0	0	0	0	0	0	0.1	0	0.2	0.4	0	0

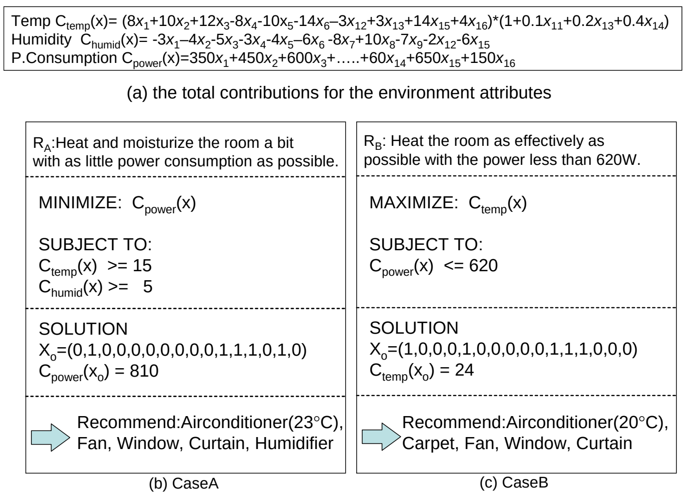

Fig. 1. Examples of problem formulation

Table I shows the A/E effects calibrated for our HNS (called CS27-HNS). The row "selection vector" defines a mapping between 16 appliance operations and variables $x_1, ..., x_{16}$. Every following row defines an impact of each operation to an environment property (temperature, humidity, or power consumption). As a result, the total impact to the three properties can be expressed by polynomials in Figure 1 (a). Figure 1(b) and (c) show examples of problem formulations for two different user requirements R_A and R_B.

In Case A in Figure 1(b), R_A represents a user requirement that "Heat and moisturize the room a bit with as little power consumption as possible". We encode this requirement using the total contributions of the A/E effects. In Case A, we specify a constraint condition $[C_{temp}(X) \geq 15]$ (the total contribution to temperature must be more than 15) AND $[C_{humid}(X) \geq 5]$ (the contribution to humidity must be more than 5). Under this constraint, we determine the object function as [MINIMIZE $C_{power}(X)$] (minimize the power consumption). By solving this problem, we obtain an optimal solution $X_o = [0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 0, 1, 0]$, which suggests to use the air-conditioner (with 28 degree), the fan, the window (close), the curtain (close), the humidifier to satisfy this requirement. In Case B in Figure 1(c), R_B represents a slightly different requirement for heating the same room, saying that "Heat the room as effectively as possible with the power less than 620W". As shown in the figure, the method recommends a different set of appliance operations.

B. Limitations of Previous Method

The previous method can compute an optimal combination of energy-saving operations for every different problem setting. Therefore, it can be used extensively to derive the personalized energy-saving behaviors. However, a major limitation is that it did not provide any concrete method of how to formulate an optimization problem from a given requirement. The method assumed that the problem is given by every user. In reality, however, it is quite difficult for home users to formulate the optimization problems (like the ones in Figure 1), consistently. Thus, we need a more user-friendly method to obtain the requirement according to user's preference.

IV. FINDING PERSONALIZED ENERGY-SAVING BEHAVIORS BASED ON QUESTIONNAIRE

The proposed method consists of the following four steps.

A. Step1: Conduct Preliminary Questionnaire

To recommend personalized energy-saving behaviors, it is necessary to obtain every user's preference and characteristic, without enforcing technically difficult procedures. To do that, we conduct a preliminary questionnaire for every home user. Note that this paper experimentally focuses on the home air-conditioning. Hence, the questionnaire aims to obtain the user preference on the *room heating* and the *room cooling*.

Figure 2 shows the proposed questionnaire. It consists of 8 questions asking (Q1) attitude toward energy-saving, (Q2) tolerance of heat, (Q3) tolerance of cold, (Q4) tolerance of drying, (Q5) tolerance of moisture, (Q6) priority among the attributes, (Q7) favorite appliances, (Q8) prohibited appliances.

B. Step 2: Determine Energy-Saving Type

Here we propose a notion of *energy-saving type*, which is a personality type with respect to the home energy-saving. Based on the answer of the questionnaire, we try to classify every user into one of the following five energy-saving types.

Type1 (Highly Economy) Users who want to save energy (and money) at any cost are classified.

Type2 (Economy) Users who prefer energy-saving to being comfortable within an reasonable range are classified.

Type3 (Balanced) Users who like both energy-saving and comfortablity are classified.

Type4 (Wasteful) Users who prefer being comfortable than taking spontaneous energy-saving behaviors are classified.

Type5 (Highly Wasteful) User who want to be comfortable at all cost are classified.

Q1. Do you like saving energy and expenses at home?

1. I always encourage myself to save energy and expenses.
2. I like to do energy-saving behaviors as far as I can.
3. I like energy-saving behaviors but I want to be comfortable.
4. I like to be comfortable rather than doing energy-saving behaviors.
5. I don't like energy-saving behaviors at all as they are bothersome.

Q2. How well do you tolerate cold?

1. I can tolerate it whatever it would be.
2. I can accept it to a considerable extent.
3. It depends on the situation.
4. I am not good at it.
5. I cannot stand it any longer.

Q3. How well do you tolerate hot?

: (5 levels, same as Q2)

Q4. How well do you tolerate drying?

: (5 levels, same as Q2)

Q5. How well do you tolerate humid?

: (5 levels, same as Q2)

Q6. Please prioritize the following air-conditioning operations:

[Saving, Cooling, Heating, Humidify, Dehumidify]

Q7. Is there any appliance that you always use for heating or cooling a room?

Q8. Is there any appliance that you never want to use?

Fig. 2. Preliminary questionnaire for air-conditioning operations

The classification is performed for two different contexts: the room heating and the room cooling. For this, we use questions Q2 and Q3 as primary variables to determine the energy-saving type. In the context of the room heating, we basically take the answer of Q2 as his/her energy-saving type. On the other hand, we take the answer of Q3 to determine the energy-saving type for the room cooling. According to Q6, if a user prefers to energy-saving than air-conditioning, we take the answer of Q1 for his/her energy-saving type.

C. Step 3: Formulate Optimization Problem

This step formulates an optimization problem from the questionnaire and the energy-saving type.

1) Formulation Strategies: According to each energy-saving type, we decide primary strategies of problem formulation for personalized energy-saving behaviors.

Type1 (Highly Economy) We recommend appliance operations that consume as low energy as possible, as in the conventional energy-saving guideline.

Type2 (Economy) We recommend appliance operations that try to maximize user's comfortablity under a reasonable upper limit of power consumption.

Type3 (Balanced) We recommend appliance operations that can satisfy both user's requirement and power constraint with relatively mild settings.

Type4 (Wasteful) We recommend appliance operations that try to minimize power consumption with guaranteeing user's comfortability.

Type5 (Highly Wasteful) We recommend appliance operations which give priority to maximize the user's satisfaction anything else.

2) Problem Formulation for Economy Users: For users classified as Types 1, 2 or 3, we specify a constraint condition with $C_{power}(X)$ and its upper limit. As an objective function, we take [MAXIMIZE $C_{temp}(X)$] for the room heating, or [MINIMIZE $C_{temp}(X)$] for the room cooling, respectively. This formulation guarantees a upper limit of power consumption, and tries to maximize the user's comfortability. The upper limit of $C_{power}(X)$ is specified according to the energy-saving type. For Type 1 users, we give a fixed minimum value independent of any environmental contexts. For Type 2 users, we determine the upper limit dynamically, considering the current environment contexts (temperature, humidity, etc). For Type 3 users, we relax the limit of Type 2 to balance the comfortablity and power consumption.

3) Problem Formulation for Wasteful Users: For users classified as Types 4 or 5, we specify a constraint condition with $C_{temp}(X)$, and an objective function [MINIMIZE $C_{power}(X)$]. This formulation guarantees a certain level of user's comfortablity on the temperature, and tries to minimize the power consumption. Hence, it is good for wasteful users. The constraint condition is determined according to the energy-saving type. For Type 4 users, we determine the constraint condition $C_{temp}(X)$ dynamically, counting the current environment contexts (temperature, humidity, etc). For Type 5 users, we give a fixed value for $C_{temp}(X)$ so as to conform to the user's comfortability.

4) Adding Supplementary Constraints: For those who give high priority to the moisture and the drying, we can specify an additional constraint with $C_{humid}(X)$. Also, if the user has an essential appliance operation o_i to be used (by Q7), we can add a constraint $x_i = 1$, which enforces o_i to be chosen. If the user has a prohibited appliance operation o_j (by Q8), we specify $x_j = 0$ so that o_j must be avoided.

D. Step 4: Derive Personal Energy-Saving Behaviors

We finally derive the personal energy-saving behaviors by solving the problem. Since the problem is the 0-1 integer programming with respect to a Boolean vector X, it can be solved by our previous method, or general linear programming tools. The derived solution X_o represents a set of operations reflecting the personal preference in the home energy-saving.

E. Running Example

To support understanding, we illustrate an example scenario deriving the personalized optimization problem from the questionnaire (from Step 1 to Step 3). We here suppose that a user A is a thrifty person, who does not like cold nor drying because of his sensitivity to cold.

Step 1: Suppose that the user A answers the questionnaire as shown in Figure 3.

Step 2: A is classified to be wasteful for the room heating, and economy for the room cooling. We see from Q4 that A wants to keep humidity high in the room heating. Also, Q8 prohibits the air conditioner for the room cooling.

Step 3: Figure 3 shows the personalized optimization problems derived for the user A.

TABLE II
RESULT OF QUESTIONNAIRE

Users	The answer of the questionnaire							Energy-saving types classified		Recommendation Results	Satisfaction Level
	Saving	Cold	Heat	Dry	Moisture	essential	prohibited	Room Heating	Room Cooling		
User1	4	3	4	1	4		Fan(in heating)	Balanced	Wasteful	A.C(23) Carpet Window Curtain	5
User2	3	4	3	2	4			Wasteful	Balanced	Heater Carpet Window Curtain	5
User3	2	2	5	4	5	Humidifier(in heating)		Economy	High Wasteful	Carpet Humidifier Window Curtian	4
User4	4	2	4	3	2			Economy	Wasteful	A.C(23) Fan Window Curtain	4
User5	3	2	4	2	4	Heater(in heating)	A.C(in heating)	Economy	Wasteful	Heater Fan Window Curtain	5
User6	3	5	1	4	2		A.C(in cooling)	High Wasteful	High Economy	A.C(26) Carpet Humidifier Fan Window Curtain	5
User7	2	1	2	2	2			High Economy	Economy	Carpet Window Curtian	4
User8	2	5	5	2	1	Fan(in cooling)		Wasteful	Wasteful	A.C(23) Carpet Fan Window Curtain	3
User9	3	2	4	4	5	Humidifier(in heating)		Economy	Wasteful	Carpet Humidifier Window Curtian	5
User10	4	4	4	2	3	AirConditioner		Wasteful	Wasteful	A.C(23) Carpet Fan Window Curtain	3
User11	3	3	5	5	3	Humidifier	Dehumidifier	Balanced	High Wasteful	A.C(20) Humidifier Fan Window Curtain	3
User12	3	3	4	2	3	Curtain		Balanced	Wasteful	A.C(23) Carpet Window Curtain	4
User13	3	2	4	2	4			Economy	Wasteful	A.C(23) Fan Window Curtain	3
User14	2	3	3	2	3	A.C(in heating)	Stove(in heating)	Balanced	Balanced	A.C(23) Carpet Fan Window Curtain	4
User15	3	5	3	2	2	Heater(in heating)		High Wasteful	Balanced	Heater Carpet Fan Window Curtain	4

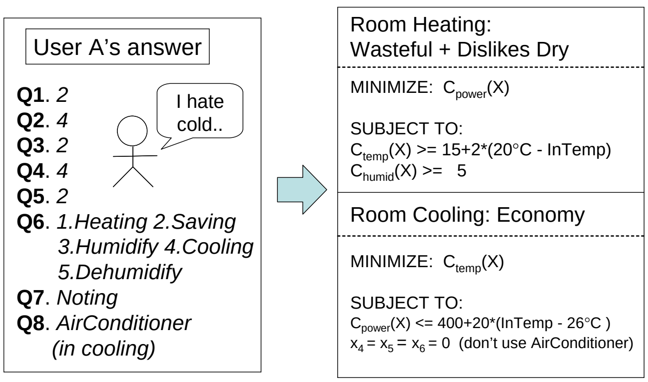

Fig. 3. Deriving optimization problem from questionnaire

V. EXPERIMENTAL EVALUATION

We conduct an experiment with fifteen subjects using our HNS. By applying the proposed method to every subject, we derive the personalized energy-saving behaviors optimized for the subject. The situation assumed in the experiment is:

- **Room:** Temperature: $12°C$, Humidity: 35%, Brightness: sufficiently bright.
- **Situation:** The user has just got back home, and wants to heat the room.

We used the questionnaire in Figure 2 and the A/E effects in Table I. We also conduct a subsequent questionnaire to gather feedback and comments from subjects.

Table II shows the result. We can see that all 15 subjects have different preferences from each other. Also, the same user is often classified into different energy-saving types for the room heating and cooling. The fourth column of Table II shows the energy-saving air-conditioning operations personalized for every subject. It can be seen that energy-expensive appliances (such as the air conditioner and the heater) are recommended for the wasteful users. On the other hand, energy-efficient appliances such as the warm carpet are recommended for the economy users. For the users who dislike drying, the humidifier is successfully recommended. Thus, we can see that the proposed method worked well for recommending personalized energy-saving behaviors.

In the subsequent questionnaire, we asked each subject to evaluate his satisfaction for the recommendation by the five-level scale, represented in the last column of Table II. The average value was as high as 4.01. The positive comments include "The appliance operations recommended were well suited to my preference.", and "It was pleasure that my favorite appliance was surely recommended.". But some of the subjects have dissatisfaction. The negative comments include "The warm carpet was not necessary to when using the air conditioner." and "I do not use these appliances usually." To improve the quality of service, we consider it necessary to have a feedback mechanism taking these comments for the future recommendation. This is left for our future work.

VI. CONCLUSION

In this paper, we have proposed a method that finds personalized energy-saving behaviors in the home air-conditioning services. To extract user's preference to energy-saving, the proposed method conducts a preliminary questionnaire. Based on the preference of each user, we then formulate an optimization problem. We finally derive a personalized energy-saving operations by solving the optimization problem. We have performed an experiment with fifteen subjects in an actual HNS. In our future work, we plan to develop a mechanism taking user's feedback to improve quality of recommendation.

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