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How the prioritization among different goals can affect consumers' energy-related decisions: A fuzzy logic approach with evidence from Asian households

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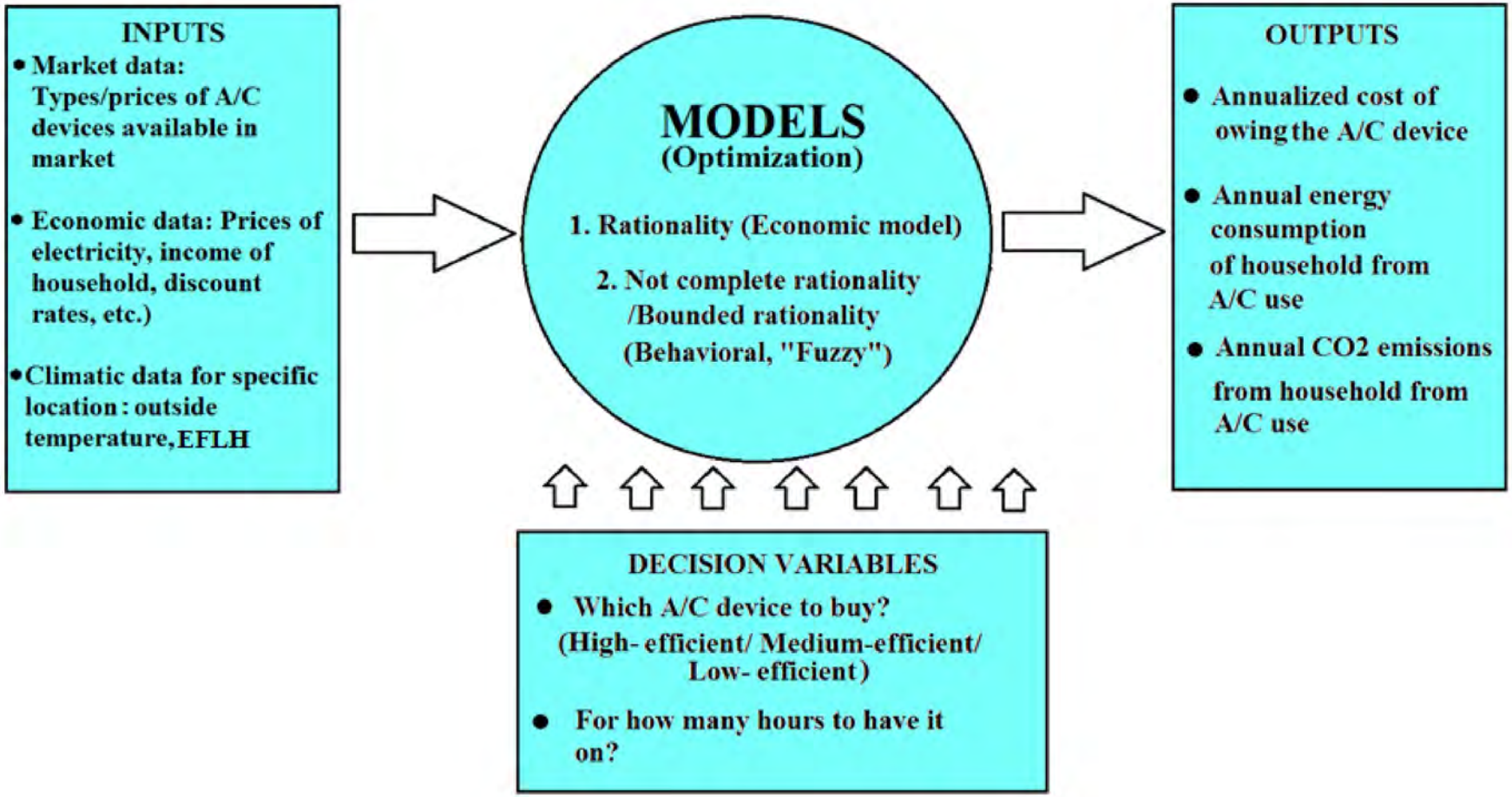
OUTLINE:

The problem: **"Energy efficiency gap".**
Bounded rationality is **not** taken into account

The opportunity:
Improving residential energy policies can bring
significant energy savings NOW
Integrated approach for explaining/predicting
energy-related **decisions and behavior** at home

Ongoing work on creating an
agent-based residential energy behavior model
that can incorporate **bounded rationality** and **social data**
into a mathematical framework. Using **Fuzzy logic.**

Optimization models



+ real empirical data (surveys)

MODEL 1: RATIONAL

MAXIMIZE SAVINGS $= (CC_{base} - CC_{standard}) + (OC_{base} - OC_{standard})$

Objective function F

SUBJECT TO :

$$\sum_{i=1}^{3} Y_{i,j} - \sum_{m=1}^{12} \text{EFLHm} \leq \Delta Hth_j$$

(Personal comfort constraint) S

$$\sum_{i=1}^{3} (CAP \times EFF_i \times e \times Y_{i,j}) \leq Eth_j$$

(Environmental constraint) E

and secondary constraints

$X_{1,j}$ *High-efficient device*

$X_{2,j}$ *Medium-efficient device*

$X_{3,j}$ *Low-efficient device*

where:

$CC_{base} = P_{base}$

$$CC_{standard} = \sum_{j=1}^{N} \sum_{i=1}^{3} \left[\frac{P_{i,j} \times r}{(1+r)^t - 1} \right] \times X_{i,j}$$

$$OC_{base} = \sum_{j=1}^{N} \sum_{i=1}^{3} \left[\left(\frac{CAP \times EFF_{base} \times Pelec_j \times r}{(1+r)^t - 1} \right) \times Y_{i,j} \right]$$

$$OC_{standard} = \sum_{j=1}^{N} \sum_{i=1}^{3} \left[\left(\frac{CAP \times EFF_i \times Pelec_j \times r}{(1+r)^t - 1} \right) \times Y_{i,j} \right]$$

MODEL 2: FUZZY

Fuzzy weighted aggegation (Kaymak and Sousa 2003)

Membership functions

$$G(S) = \begin{cases} 1 & S < \Delta Hth_j \\ \dfrac{\Delta Hth_j + R1 - S}{R1} & \Delta Hth_j \leq S \leq \Delta Hth_j + R1 \\ 0 & \Delta Hth_j + R1 < S \end{cases}$$

$$G(E) = \begin{cases} 1 & E < Eth_j \\ \dfrac{Eth_j + R2 - E}{R2} & Eth_j \leq E \leq Eth_j + R2 \\ 0 & Eth_j + R2 < E \end{cases}$$

$$G(F) = \begin{cases} 1 & zu < F \\ \dfrac{F - zl}{zu - zl} & zl \leq F \leq zu \\ 0 & F < zl \end{cases}$$

Weights

W1

W2

Wo

T-norms (product, Hamacher)

Real data

collected through web-based surveys

from households

- **Priorities** of people among
  1. **economic goals**
  2. **personal satisfaction** ⇒ **weights in**
  3. **environmental goals** **fuzzy aggregation**

- **Flexibility in satisfying goals** ⇒ **relaxation coefficients**

- **Influence from neighbors** ⇒ **change of weights**

- **Personal perceptions: planning horizon, prices, climate**

Hong Kong (population ~ 7 million)

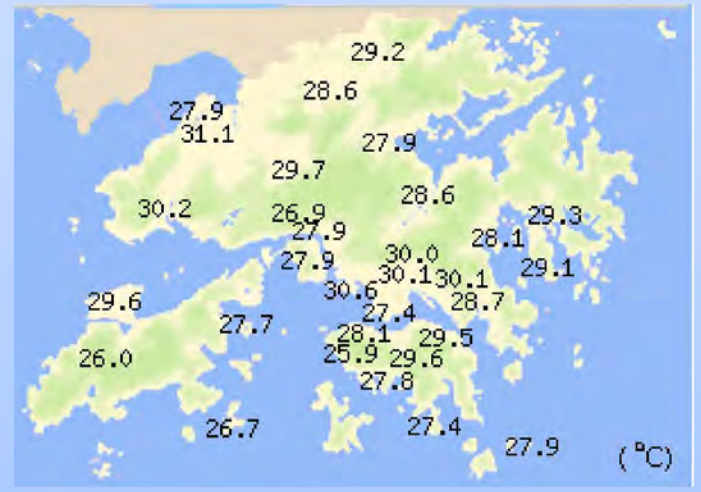
Climate of Hong Kong: sub-tropical, tending towards temperate

Electricity consumption has increased during the last decade

Buildings : 92% of electricity consumption

Space cooling: 23% of total energy used in residential buildings.

The largest energy consumer (16%) in the region, more than cooking, lighting, industrial processes, transportation.



No local fossil fuel resources

No strong energy policies

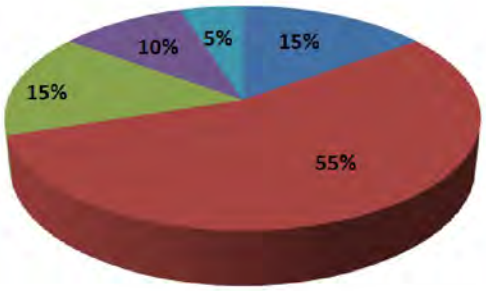
Source: The Government of Hong Kong SAR of the PRC

Priorities

WHEN I HAVE TO BUY A NEW A/C DEVICE,
I CHOOSE THE ONE THAT CAN HELP ME TO:

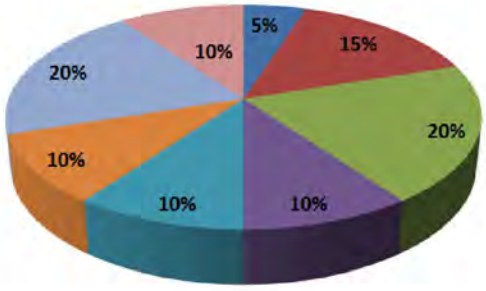
STRONGLY DISAGREE									STRONGLY AGREE
1	2	3	4	5	6	7	8	9	10

SAVE MONEY



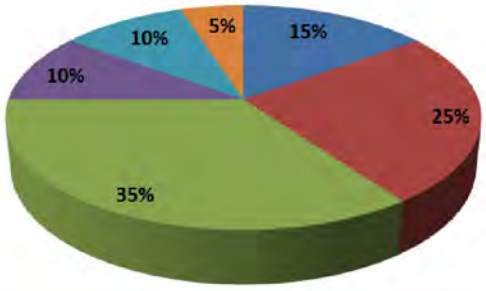
Answers
10
9
8
7
6

PROTECT THE ENVIRONMENT



Answers
10
9
8
7
6
5
4
3

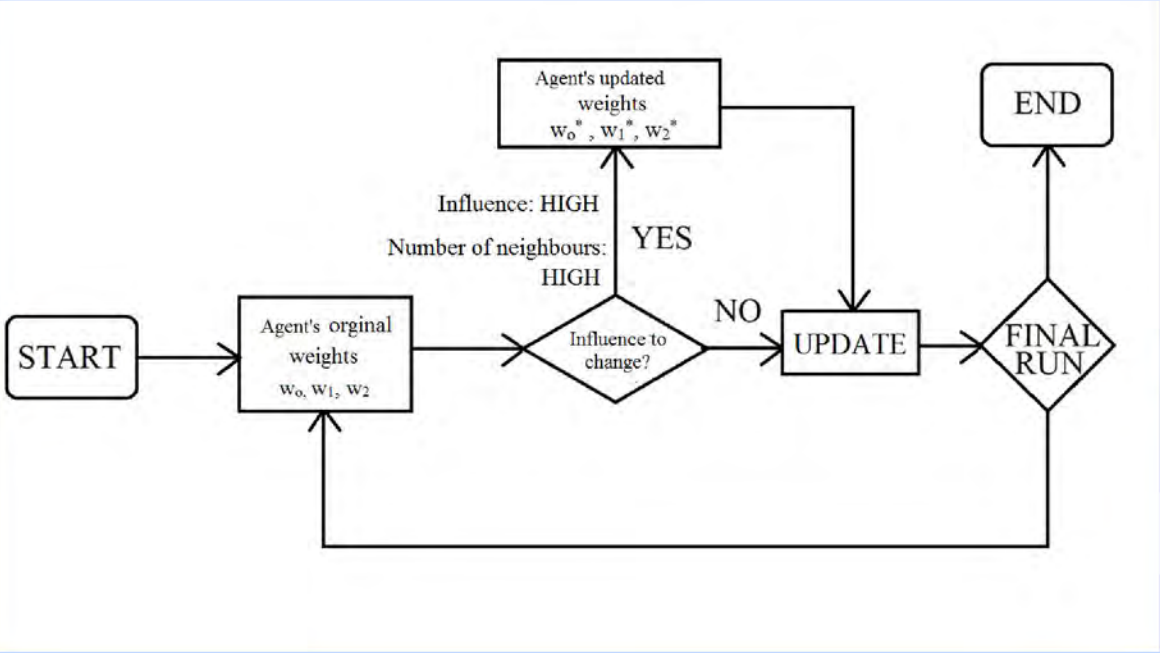
IMPROVE MY COMFORT



Answers
10
9
8
7
6
5

SAVE MONEY > 5	**100%**
PROTECT ENVIRONMENT > 5	**60%**
IMPROVE COMFORT > 5	**95%**

Influence from neighbors



High number of interactions

WHEN MY NEIGHBORS SWITCH TO AN A/C MODEL OF DIFFERENT EFFICIENCY TYPE OR CHANGE THE NUMBER OF HOURS OF OPERATION IN ORDER TO PROTECT THE ENVIRONMENT , I WILL ALSO DO THE SAME

strongly disagree	1	2	3	4	5	6	7	8	9	10	strongly agree
						+0.1	+ 0.2	+0.3	+ 0.4	+ 0.5	

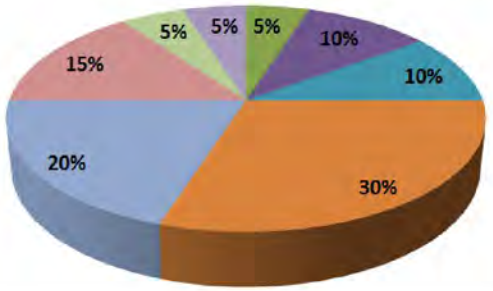
new weight

Influence from neighbors (2)

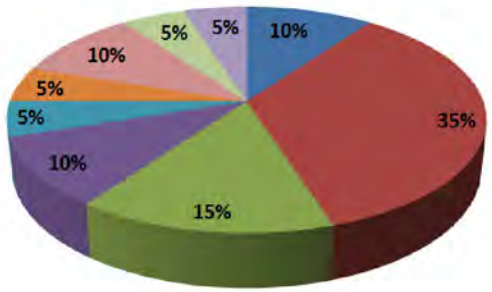
WHEN MY NEIGHBORS SWITCH TO AN A/C MODEL OF DIFFERENT EFFICIENCY TYPE OR CHANGE THE NUMBER OF HOURS OF OPERATION IN ORDER TO ....., I WILL ALSO DO THE SAME

STRONGLY DISAGREE									STRONGLY AGREE
1	2	3	4	5	6	7	8	9	10

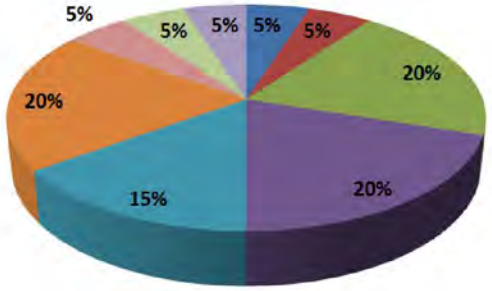
SAVE MONEY



PROTECT THE ENVIRONMENT



IMPROVE THEIR COMFORT



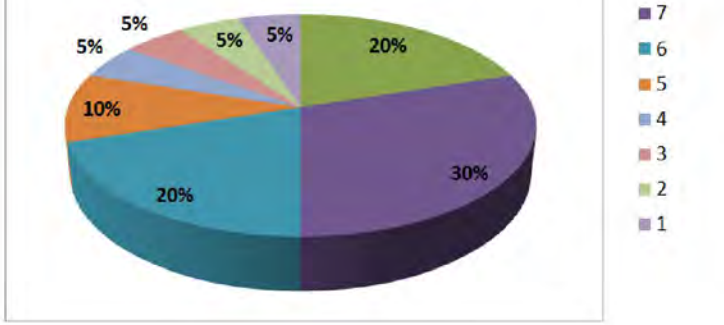
SAVE MONEY > 5	**55 %**
PROTECT ENVIRONMENT > 5	**75 %**
IMPROVE COMFORT > 5	**65 %**

Policies- willingness to change

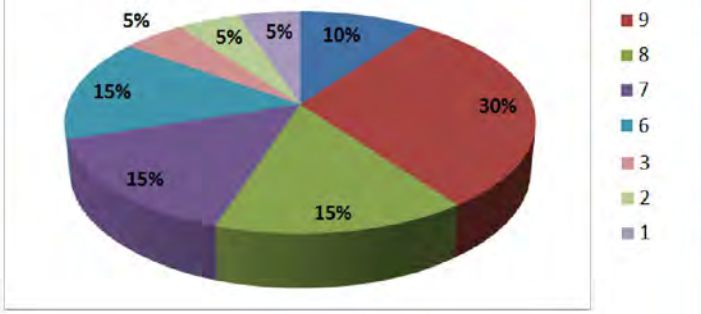
I AM WILLING TO REDUCE MY ENERGY CONSUMPTION IF.....

STRONGLY DISAGREE									STRONGLY AGREE
1	2	3	4	5	6	7	8	9	10

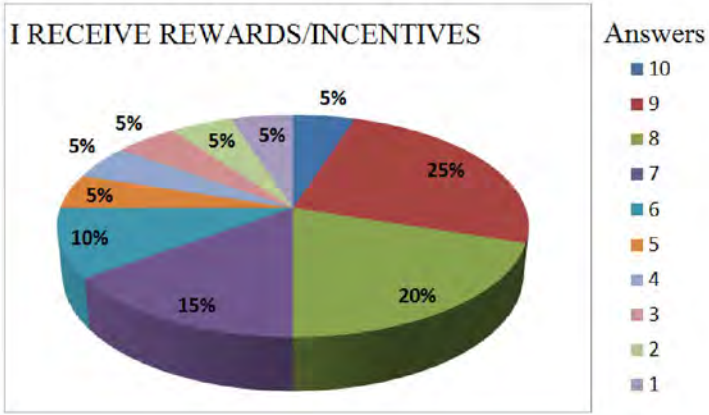
THE PRICE OF ELECTRICITY INCREASES



I RECEIVE A PENATLTY FOR OVERCONSUMPTION



I RECEIVE REWARDS/INCENTIVES



ELECTRICITY PRICE INCREASE > 5	**70 %**
PENALTY > 5	**85 %**
REWARD/INCENTIVES > 5	**75 %**

Rational vs. Fuzzy

Table 1: Optimal solutions for different aggregations and combinations of weights, foreseeing 1 year in the future

Agent foresees **1 year** in the future	weights			Choice of A/C device efficiency type	Number of hours per year when the device is ON (h)	CO2 emissions per year (m.t. CO2)	Total savings from owning and operating the A/C device ($)
	W_o	W_1	W_2				
Non-fuzzy model	-	-	-	**LOW**	**1954.5 (h per day: 10.85)**	**0.80**	**-16.51**
Fuzzy model, product t-norm	**1**	**1**	**1**	**LOW**	**2180 (h per day: 12.11)**	**0.892**	**-15.53**
	1	**0.2**	**1**	**LOW**	**2181.9 (h per day: 12.12)**	**0.893**	**-15.52**
	1	**0.2**	**0.2**	**LOW**	**2340 (h per day: 13.11)**	**0.95**	**-14.73**
Fuzzy model, Hamacher t-norm	**1**	**1**	**1**	**LOW**	**2180 (h per day: 12.11)**	**0.892**	**-15.53**
	1	**0.2**	**1**	**LOW**	**2192 (h per day: 12.17)**	**0.897**	**-15.47**
	1	**0.2**	**0.2**	**LOW**	**2282 (h per day: 12.67)**	**0.934**	**-15.08**

Capacity: 6000 Btu/h (small), ΔHthresh= 0, Emmthresh= 0.8, R1=500, R2=0.2

Rational vs. Fuzzy (2)

Table 2: Optimal solutions for different aggregations and combinations of weights, foreseeing 2 years in the future

Agent foresees **2 years** in the future	weights W_o	W_1	W_2	Choice of A/C device efficiency type	Number of hours per year when the device is ON (h)	CO2 emissions per year (m.t. CO2)	Total savings from owning and operating the A/C device ($)	Savings per year ($)
Non-fuzzy model	-	-	-	**MEDIUM**	**2148 (h per day: 11.93)**	**0.80**	**-39.65**	**-19.82**
Fuzzy model, product t-norm	**1**	**1**	**1**	**MEDIUM**	**2180 (h per day: 12.11)**	**0.811**	**-39.12**	**-19.56**
	1	**0.2**	**1**	**MEDIUM**	**2180 (h per day: 12.11)**	**0.811**	**-39.12**	**-19.56**
	1	**0.2**	**0.2**	**MEDIUM**	**year 1: 2680 (h per day: 14.88)**	**year 1: 0.998**	**-33.74**	**-16.87**
					year 2: 2180 (h per day: 12.1)	**year 2: 0.811**		
Fuzzy model, Hamacher t-norm	**1**	**1**	**1**	**MEDIUM**	**year 1: 2460 (h per day: 13.66)**	**year 1: 0.916**	**-35.14**	**-17.57**
					year 2: 2350 (h per day: 13.05)	**year 2: 0.875**		
	1	**0.2**	**1**	**MEDIUM**	**year 1: 2500 (h per day: 13.88)**	**year 1: 0.931**	**-34.54**	**-17.27**
					year 2: 2380 (h per day: 13.22)	**year 2: 0.886**		
	1	**0.2**	**0.2**	**MEDIUM**	**year 1: 2580 (h per day: 14.33)**	**year 1: 0.96**	**-33.23**	**-16.61**
					year 2: 2460 (h per day: 13.66)	**year 2: 0.916**		
Capacity: 6000 Btu/h (small), ΔHthresh= 0 , R1=500, Emmthresh= 0.8 , R2=0.2								

Worldwide


CANADA
CALIFORNIA
MILAN
ATHENS
BEIJING
TOKYO
ASIA
HONG KONG
SOUTH AFRICA
AUSTRALIA & NEW ZEALAND

Why Fuzzy logic for bounded rationality ?

•Deciding under bounded rationality, **does not mean** deciding irrationally.

•Instead, bounded rationality can be considered as a **degree of decline from the "optimal" rational behavior**, or a partial version of it.

•The **"degree of decline from the optimal behaviour"** concept can be seen as an analogus to the **"degree of membership"** concept, on which fuzzy set theory is largely based.

•**Bounded rationality theory and fuzzy sets theory** can be **connected**:
the latter can be able to provide a platform for the representation of
the former

Inputs: rational vs. fuzzy

Models	Perceptions				Priorities among goals	Flexibility in satisfaction levels
	Planning horizon (years)	changing prices ($P_{i,j}$, $Pelec_j$)	changing climate (*EFLHj*)	Discount rates (r)	Weighted factors (w_0,w_1,w_2)	Relaxation coefficients (R1,R2)
"Rational"	Agent-defined	Projections	Projections	Projections	_	_
"Fuzzy"	Agent-defined	Agent-defined	Agent-defined	Agent-defined	Agent-defined	Agent-defined

Thank you

For your comments and questions:

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Questionnaire

40 questions: Residence characteristics- Lifestyle priorities – A/C use – Influence from neighbors – Willingness to change

Sample questions:

•How much you agree with the following statements?

❑"When I choose which A/C model to buy, I choose the one that can allow me to **save more money** from my **electricity bill**."

❑"When I choose which A/C model to buy, I choose the one that can allow me to **improve** my **personal satisfaction** and **comfort**."

❑"When I choose which A/C model to buy, I choose the one that can allow me to **protect the environment."**

You are now need to use your A/C device for LESS HOURS per day. Every HOUR that you use it LESS, HELPS THE ENVIRONMENT, but at the same time it makes you feel hotter and more UNCOMFORTABLE. For how many LESS HOURS are you WILLING TO USE your A/C?