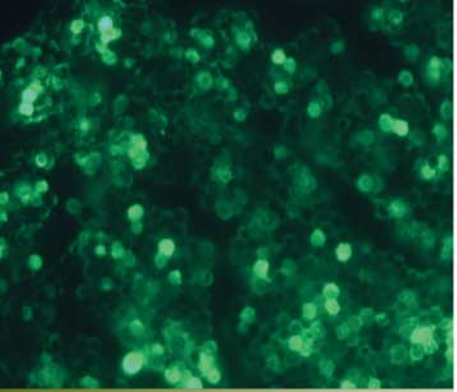

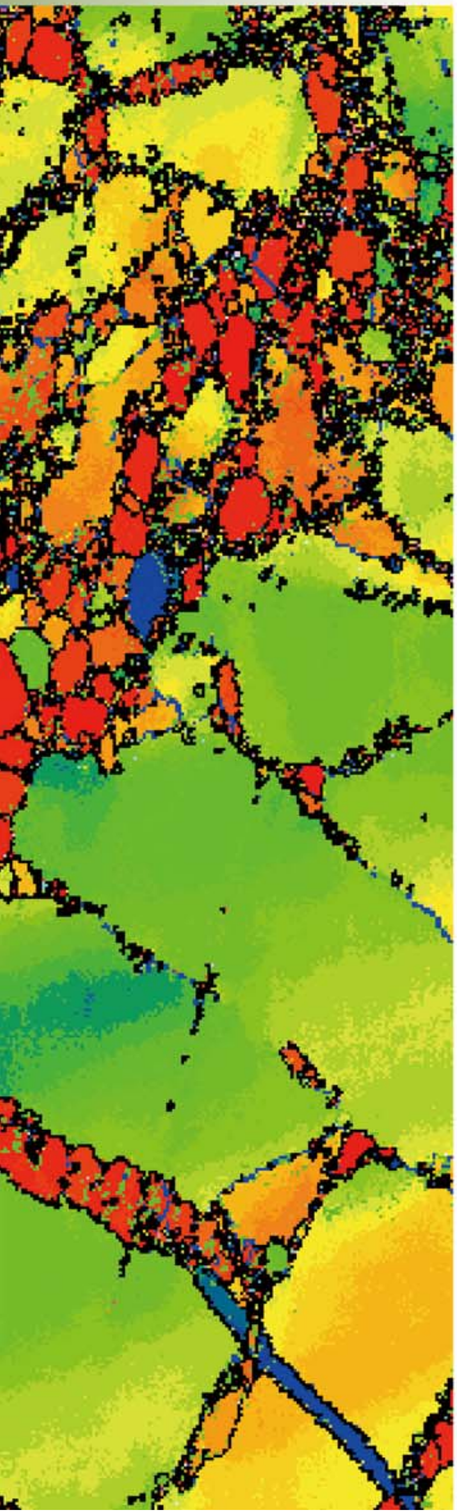

Vol.3 ,No.3,December 2016

Transactions on GIGAKU

Special issue of The 4th International Symposium on Engineering, Energy and Environment (ISEEE), 2015

GIGAKU Press
Nagaoka University of Technology

Transactions on GIGAKU: Scope and Policy

Nagaoka University of Technology publishes an online, open access journal titled “Transactions on GIGAKU”, which is focused on the science and technology related to GIGAKU*. The mission of this journal is to spread out the concept of GIGAKU and the fruits of GIGAKU to the global world and to be a strong network for innovations in science and technology and for development of next generations of high-level human resources. This journal, therefore, covers research and education activities related to GIGAKU in broad areas.

* See ‘What is GIGAKU?’ below.

‘What is GIGAKU?’

GIGAKU is a term composed of two Japanese word-roots; GI and GAKU. The word GI〔技〕literally stands for all kinds of arts and technology, and GAKU 〔学〕 stands for scientific disciplines in general when used as a suffix.

The term was originally coined to describe the fundamental philosophy of education and research of Nagaoka University of Technology (NUT) when it was established in 1976. Through this term the founders of NUT intended to express their recognition that all technical challenges in the real world require a scientific approach. And NUT has a relentlessly pursued GIGAKU since then.

Thirty-five years have passed and all surrounding conditions have changed dramatically during those years. We are witnessing rapidly globalizing economics and huge scale changes in demographic, industrial and employment structures. All those changes seem to necessitate the further evolution of GIGAKU. In response to this, NUT recently announced its new “Growth Plan” and a renewed definition of the term is given;

GIGAKU is a science of technologies, which gives us an angle to analyze and reinterpret diverse technical processes and objects and thus helps us to advance technologies forward. By employing a broad range of knowledge about science and engineering, management, safety, information technology and life sciences, GIGAKU provides us with workable solution and induces future innovations.

July 2012
Koichi Niihara, President of Nagaoka Univesrsity of Technology

Submission and Publishing

"Transactions on GIGAKU" publishes original papers focusing on education, science, and technology related to GIGAKU. Proposals for special issues aligned with conferences are strongly encouraged*, and guest editors are welcomed. Papers submitted are peer-reviewed before publication. Publication charge is free for all submitted papers.

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(Revised December 2016)

Preface of the special issue for the ISEEE2015

The 4th International Symposium on Engineering, Energy and Environment (ISEEE2015) was held at the Pattaya Campus of Thammasat University, Chonburi, Thailand from November 8 to 10, 2015. This International Conference was co-organized by Faculty of Engineering of Thammasat University, Tokyo Institute of Technology, Saitama University and Nagaoka University of Technology. This International Conference was also supported by Hiroshima University, Toyohashi University of Technology, Sirindhorn Instiute of Technology and Faculty of Science and Technology of Thammasat University.

In the Conference, there were 2 keynote speeches and more than 100 presentations in various sessions: Renewable energy and energy management, Environmental technology and management, Chemical processing, Material engineering, Manufacturing and design, Productivity improvement, Biomedical engineering and engineering in medicine, Diagnostic and monitoring system, Digital technology, Agricultural and food engineering, Transportation and logistics, Resilient engineering, Engineering and education and others. Among a large number of the presented papers, the selected and peer-reviewed 2 papers are included in this special issue. We hope you enjoy these interesting papers.

Prapat Wangskarn
General Chair
Dean of Faculty of Engineering, Thammasat University

Masato AKETAGAWA
International Organizing Committee of ISEEE2015
Professor, Nagaoka University of Technology

Transactions on GIGAKU

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special issue for the ISEEE2015

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Experimental Optimization of Heat Input and Coolant Flow Rate of a Micro Heat Pipe with R134a as Working Fluid

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This research presents experimental optimization of heat input and coolant velocity based on the thermal performance of a micro heat pipe. The working fluid used is R134a. The coolant is water of 30 ºC and an inclination angle is set at zero. A micro heat pipe made from straight copper tube with an outer diameter of 6 mm and length of 200 mm. The heat pipe was divided into 3 parts, such as the evaporator section of 65 mm, adiabatic section of 70 mm and condenser section of 65 mm. The effect of operating temperature (40, 50 and 60 ºC) and flow rate of coolant (0.25, 0.50 and 1.00 L/min) on thermal performance of a heat pipe are studied. It was found that the heat input and the cooling air velocity have significant effect on the effective thermal conductivity. The results were optimized with the objective of maximizing the effective thermal conductivity; the highest thermal efficient is 54.18 % and maximum heat transfer rate is 34.83 W at the operating temperature of 40 ºC and flow rate of coolant as 1.00 L/min .

1. Introduction

The heat pipes have been widely applied to a variety of both simple and complex designs for space and terrestrial applications. Heat pipes are devices used for efficient transport of heat over large distances. Under typical operation, a metal container such as aluminum or copper contains a small amount working fluid pressurized to its saturation point. The heat transfer system is based on the continuous cycle of evaporation and condensation process. When heat is applied to the outer area of the tube, the liquid inside the tube boils and vaporizes into a gas that moves through the tube seeking a cooler location where it condenses, giving off its latent heat. Using capillary action, the wick transports the condensed liquid back to the evaporation section [1]. For gravity-assisted heat pipes, the liquid is condensed back to the evaporator section by means of gravity [2]. The appropriate choice of working fluid along with the inclination angle is therefore a major factor in heat transfer obtainable from heat pipes [3]. Heat pipes are energy-efficient passive devices and do not consume fossil fuels and other environmentally hazardous resources for carrying out its operation, thereby making itself extremely suitable for use in natural ventilation air streams. There are various heat pipe systems currently available which are applicable to operating temperatures associated with building energy applications [4].

Micro Heat Pipes (MHPs) are used in applications where small to medium heat transfer rates are desirable. The rate of cooling achieved from the MHP is significantly lower compared to forced convection systems. However, the capability to control temperatures in environments of varying heat loads along with its compact size allows it to be used in various applications [5]. Micro and miniature heat pipes are electronic component coolers. The interest stems from the possibility of achieving the extremely high heat fluxes near 1000 W/cm^2, needed for future generation electronics cooling application [6]. Effect of water-based Al_2O_3 nano-fluids as working fluid on the thermal performance of a flat micro-heat pipe with a rectangular grooved wick is investigated [7]. A novel design of micro heat pipe (MHP) with implanted arterial paths and an evaluation heat spreader are investigated. MHP implanted with

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arteries is supposed to effectively limit the propagation of the dry-out region. [8].Then, the effects of gravity, through the angle of inclination, on the heat transport capacity, the optimal charge level of the working fluid, the liquid volume fraction distribution, the circulation strength of working fluid and the solid wall temperature distribution are analyzed, to provide a better insight for the design of inclined micro heat pipes [9]. A theoretical analysis of transient fluid flow and heat transfer in a triangular micro heat pipes has been conducted to study the thermal response characteristics. By introducing the system identification theory, the quantitative evaluation of the MHP's transient thermal performance is realized [10]. The coupled effects of working fluid and solid wall on thermal performance of micro heat pipes; By incorporating the solid wall conduction, together with the continuity, momentum, and energy equations of the liquid and vapor phases, a mathematical model is developed based on the conservation laws and is solved to yield the heat and fluid flow characteristics of micro heat pipes [11].

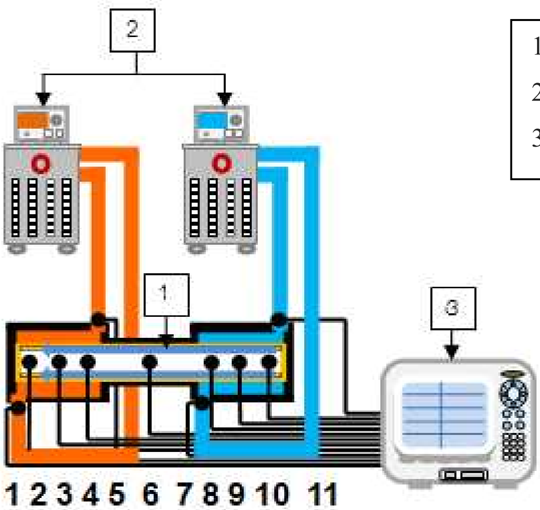
From the available literature review, it may observe that a limited number of working fluids had been used and some of them are rarely used, such as R134a. In addition to that, since most of the working engineering systems use micro heat pipe and the research work studying the optimization effect was also found to be very fields. Therefore, in order to study their effects on the performance of the micro heat pipe with R134a still need more work.

The objective of this work is to present the optimization of heat input and coolant velocity on the maximum thermal performance of micro heat pipe, with R134a as a working fluid.

2. Materials and methods

2.1 Experimental apparatus

Fig. 1 shows the experimental setup for testing heat pipes. Heat pipes made of copper pipe diameter 6 mm, length 200 mm with a porous structure sintered and refrigerant R-134a as the working. The heat pipe is divided in to three parts. It consists of the evaporator and the condenser, length of 70 mm bolt and the adiabatic section length of 60 mm. The tested the insulation to prevent heat loss in the system. The test set is connected to the water temperature and the condensation and evaporation. The experiment was controlled coolant temperature of 30 ºC were studied by changing the operating temperature was 40, 50 and 60 º C and the flow rates of the cooling water are 0.25, 0.50 and 1.00 L/min, respectively. Thermocouples K type are measuring the surface temperature of the heat pipe, the cooling water was circulated through the condenser jacket before the heat was supplied to the evaporator. In addition, the inlet and outlet temperatures of the cooling water were measured using two thermocouples. The adiabatic section of the heat pipe was completely insulated with the aero flex. The amount of heat loss from the evaporator and condenser surface was negligible. The thermocouples is connected the data logger (Yokokawa MW 2000) for record data. In order to analyzes the performance of heat pipe heat exchanger.



1. Heat pipe.
2. Hot bath and cold bath
3. Temperature recorder

1	Teo	Outlet temperature at evaporator section
2,3,4	Te	temperature at evaporator section
5	Tei	Inlet temperature at evaporator section
6	Ta	temperature at adiabatic section
7	Tco	Outlet temperature at condenser section
8,9,10	Tc	temperature at condenser section
11	Tci	Inlet temperature at condenser section

Fig. 1. Schematic diagram of experimental apparatus.

2.2 Experimental procedure

In this work, the effect of flow rates of the cooling water and working temperature were examined. The experiment runs were carried out according to the following steps:

1) The micro heat pipe was set up. One of these was filled with R134a. The inclination of pipe was controlled at 0^o.
2) The hot water was supplied to evaporator of the micro heat pipe until the desired working temperature level.
3) At the steady state after a time period of about 15 min, the surface temperatures were measured and recorded.
4) After finishing the above steps, cooling flow rates and working temperature are changed, the micro heat pipe and to make it ready for further experimental purpose.
5) The tested are repeated step 1-4 again.

2.3 Calculation procedure

The obtained temperature was used to calculate the heat rate and the total thermal resistance.

The output heat transfer rate from the condenser was computed by applying an energy balance to the condenser flow. Thus, the heat transfer rate of heat pipe was calculated using the equation.

$$\dot{Q} = \dot{m}c_p\left(T_{co} - T_{ci}\right) \tag{1}$$

The thermal resistance (R) was defined as

$$R = \frac{\left(T_e - T_c\right)}{\dot{Q}} \tag{2}$$

Thermal efficacy

$$\eta_{th} = \frac{Q_{act}}{Q_{th}} \tag{3}$$

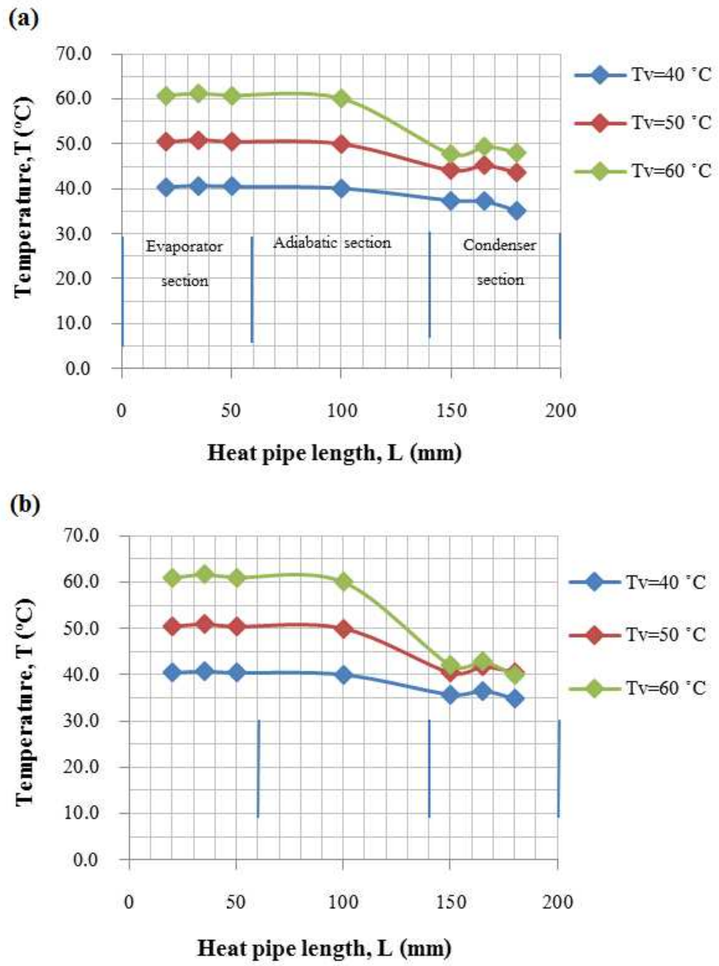
where T_e, T_c averaged values of temperatures at the evaporator and condenser were sections respectively and $\dot{Q}$ is the heat supplied to the system. $Q_{act,} Q_{th}$ are actual or measurement temperature and theory temperature, respectively.

3. Results and discussion

This experimental investigation and optimization of working temperature and cooling flow rates at condenser section on heat transfer rates of micro heat pipe, the results presented by the relationship of working temperature and cooling flow rates with other parameters.

Fig. 2. shows the relationship between the lengths of the heat pipe, the pipe surface temperature of heat pipe that used R134a as the working temperature was 40 °C under steady state operation. Temperature in the evaporator was 40.5, 40.5 and 40.7 °C and the temperature in the condensation of 36.6, 35.7 and 35.0 °C in is evident that the distribution of temperature along the length of the heat pipe, the same trend

in all cooling flow rates. The operating temperature is 50 °C and 60 °C, the evaporation and condensation has soared. The difference in temperature between the evaporator and the condenser will be higher. When supplied heat to evaporator section, the working fluid boils become to vapor and transfers heat from the evaporator to the condenser. After that the working fluid is condensed become to liquid and absorb to the porous material then flows back to the evaporator by capillary pump force. When supply heat increased to evaporator section. The working fluid boiled and evaporates rapidly, but cannot flow back to the evaporator and some area of the evaporator was dry. It can see that at operating temperature 60 ºC. The temperature of the evaporator fist point is higher than the others in the same section. This phenomenon is called capillary limit causes the limit based on the size of the capillary porosity and properties of substances. When the temperature raises the viscosity and surface tension decrease capillary pressure that occurs in porous materials porosity decreased.



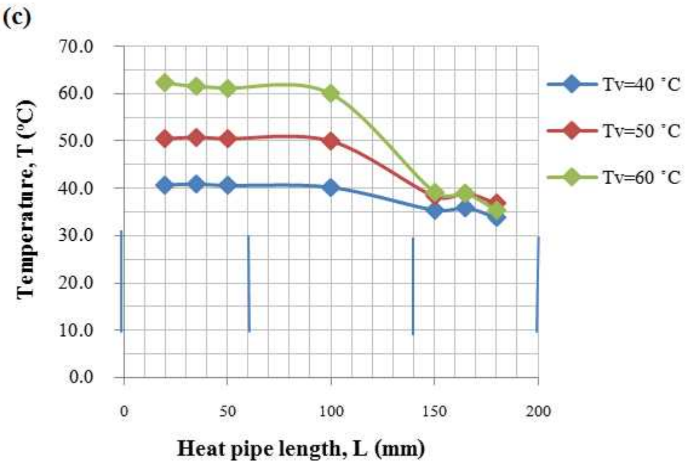


Fig. 2. Relationship between the lengths and the surface temperature of heat pipe (a) Flow rate 0.25 L/min; (b) Flow rate 0.50 L/min; (c) Flow rate 1.00 L/min

Fig. 3 shows the relationship between the working temperatures (Tv) and the heat transfer rate of heat pipe that uses R134a as the working fluid found at working temperature 40 °C the heat transfer rate is equal to 12.19. W, 24.38 W and 34.83 W at a flow rate of cooling water 0.25, 0.50 and 1.00 L/min, respectively; at working temperature 50 °C the heat transfer rates are equal to 24.38 W, 38.81 W and 41.8 W respectively; working temperature 60 °C the rate of heat transfer is equal to 33.09 W, 45.28 W and 48.77 W at a flow rate of cooling water 0.25, 0.50 and 1.00 L/min, respectively. It seen these trend found that when the working temperature increases affect the heat transfer rate increases too. Due to the higher temperature working fluid absorbs heat to change state to a vapor transfer from the evaporator to the condenser more than low temperatures.

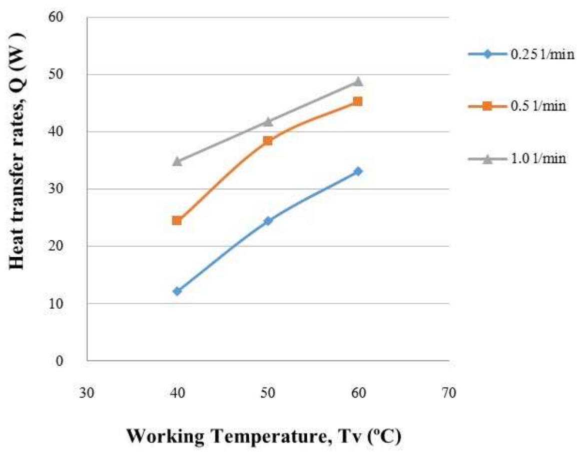


Fig. 3. Relationship between the working temperatures and heat transfer rate of heat pipe

Fig. 4 shows the relationship between the flow rate of cooling and the heat transfer rate of the heat pipe. It was found at when cooling flow rate increase from 0.25 to 10.25 L/min, the heat transfer rate increase from 12.19 W to 34.83 W at working temperature 40ºC.These trends are the same with working temperature 50 ºC and 60 ºC. This is because when the flow rate increases the cooling water can transfer heat from the surface of the heat pipe is higher than low flow rate. But at high flow rate and working temperature the heat transfers heat is very small, these because the heat pipe is nearly to heat transfer limit.

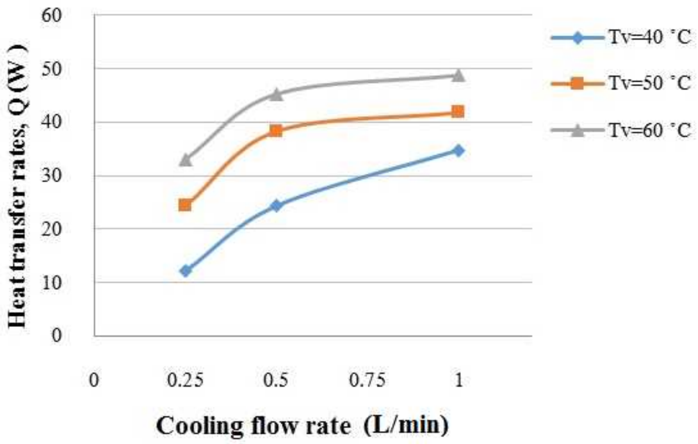


Fig. 4. Relationship between the flow rate of cooling and the heat transfer rate of the heat pipe

Fig. 5 shows the relationship between the working temperature and the thermal efficiency of heat pipe. At the cooling flow rate 0.25 L/min, when working temperature increases from 40 ºC to 50 ºC, the thermal efficiency increases from 27.16% to 33.1% but when working temperature increases to 60 ºC the thermal efficiency decrease to 21.79%. These because when the working temperature increases from 40 ºC to 50 ºC the heat pipe is still normal operated the thermal efficiency is increases. But when the operation of the heat pipe at working temperature 60 ºC , the point where it is unstable to work, due to the working fluid cannot flow back enough to received heat load from the evaporator section thus thermal efficiency decreases. At a flow rate of cooling water 0.50 L/min and 1.00 L/min when working temperature increases from 40 ºC to 60 ºC the thermal efficiency reduced from 45.27% to 18.97% and 54.18% to 16.77% respectively. These because at working temperature 50 ºC and 60 ºC the heat pipe is operated nearly heat transfer limited, thus the thermal efficiency continues reduced. At the same time, property of working fluid is changed especially viscosity that affect to reduced capillary force to return liquid condenses from condenser section evaporator section.

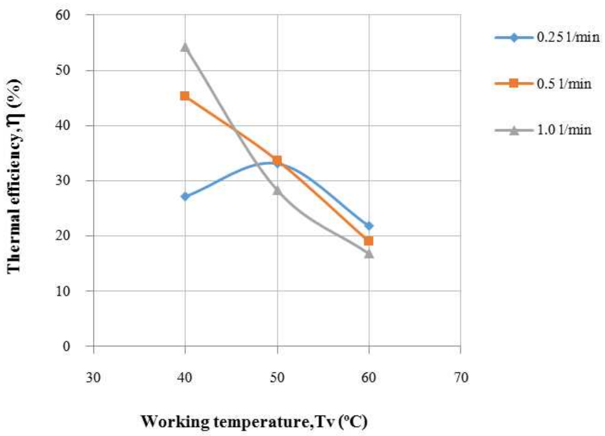


Fig. 5. Relationship between the working temperature and thermal efficiency of heat pipe

4. Conclusion

Experimental study of the thermal performance of a micro heat pipe with R134a as a working fluid is presented. This study is concerned to optimize the effect of heat input and coolant flow rate. The main results can be summarized as follows:

- The micro heat pipe wall temperature, the operating temperature, the temperature difference between the evaporator and condenser, and the overall heat transfer coefficient are increased corresponding to increasing heat input on over range of this work.
- The optimum heat input and coolant flow rate are found to be 40 °C and 1.0 L/min, respectively.
- The highest thermal efficiency of 54.18% and maximum heat transfer rate is 34.83 W.
- The obtained condition may be considered a helpful database tool.

Acknowledgements

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Electricity-Saving Behavior in Households after the Great East Japan Earthquake

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The paper presents the result of an internet-based questionnaire survey conducted on electricity-saving behavior in households in the summer after the Great East Japan Earthquake in March 2011. A total of 60 households residing in metropolitan Kanto region where electricity is provided by Tokyo Electric Power Company was surveyed based on the 3 groups, A, B, and C, depending on their level of electricity-saving behavior declared by each respondent. Electricity consumption data was obtained from the electricity bills. A comparison of electricity data showed that the total electricity consumed from April to November in 2010, i.e. before the Earthquake, accounted for 2,113 kWh for Group A whereas it added up to over 3,000kWh for Group B and C, reflecting active electricity-saving behaviors taken by people in Group A. In addition, Group B showed the greatest electricity-saving rate in June and July of 2011, as declared to have engaged in electricity-saving behavior triggered by the Earthquake. However, a great deal of "rebound" was also confirmed in the months soon after the lift of the electricity saving edict in group B, indicating the difficulty of sustaining the electricity-saving behavior and its effect driven by a top-down approach. The attributes identified via factor analysis could be interpreted as those proposed in the widely used theory of planned behavior. Different weight of these factors in leading to electricity-saving behavior for each group implies the importance of fostering sensibility for general environmental issues for sustained electricity-saving practices and its effects.

1. Introduction

Promotion of energy-saving, including electricity-saving, behavior in households is becoming increasingly important from the viewpoint of climate change measures in the recent years. It is also considered difficult, however, as it happens in private spheres where social norms tend to be weak [1]. In response to the serious energy crisis caused by the Great East Japan Earthquake (the Earthquake) and the subsequent disastrous accident at the Fukushima Daiichi Nuclear Power Plant (the Fukushima Accident) of Tokyo Electric Power Company (TEPCO) in March 2011, the household sector contributed to the nation-wide electricity-saving effort by achieving 11% reduction rate from the previous year based on a non-binding voluntary reduction target[2]. This paper explores psychological mechanisms behind electricity-saving behavior among people by looking at the results of a questionnaire survey conducted after the Fukushima Accident in 2011, with the aim of finding implications for promoting, and more importantly sustaining, energy-saving behaviors in households.

2. Research Method

An internet-based questionnaire survey was conducted in December 2011 targeting families (a couple with 1-2 children) residing in metropolitan Kanto region where electricity is served by TEPCO. A total of 60 households participated in the survey, after a pre-screening process where conditions such as having access to the electricity bills for the period relevant to the study and not undergoing any renovation work or moving since April 2010 were confirmed. Households were separated into three groups, A, B, and C, with 20 households in each group, depending on the level of electricity-saving behavior taken at home as declared by each respondent. People in Group A claim to have been active electricity-savers even before the energy crisis; Group B consists of those who began taking electricity-saving behaviors after the energy crisis, and people in Group C claim that they have never engaged in electricity-saving behavior either before or after the energy crisis. The survey consisted of five parts: 1) 14 questions constructed on the psychological determinant factors of their electricity-saving behaviors on a 7-point scale; 2) actual electricity-saving behaviors conducted on a 3-point scale; 3) electricity consumption data, in the form of total kWh written on the electricity bills from April to November in 2010 and 2011; and 4) other questions related to the Earthquake and the Fukushima Accident, such as experience of rolling blackout, feelings towards these incidents, as well as sustainability of electricity-saving intention; and lastly 5) demographic facts such as age, age of children, occupation, and household income. The survey answers were analyzed by statistical analyses, such as analysis of variance and factor analysis, to evaluate the determinant attributes of electricity-saving behavior for each group.

The demographic features of the respondents are summarized as follows. Age groups of the respondents were: among in their 30s (30%), 40s (43%) and 50s (27%). The number of children were divided into one (57%) and two (43%) as specified in the pre-screening condition. The age of the first child ranged “over 18” being the largest (42%), followed by “between 6 and 18 (33%)” and “under 6 (25%).” The household income ranged: 20% in the lower income (less than 4 million yen) group; 43% in the middle range (income between 4 to 8 million yen); and 36% in the higher income (8 million yen or more) group. All respondents were female, perhaps due to our request that the main person in charge of daily housework in each house to fill the survey; and 70% of them were housewives with no paid jobs whereas only 15% are working on a full-time basis. A majority (63%) of the respondents did not undergo actual rolling blackouts, as the metropolitan Tokyo wards where 42% of the respondents reside and areas where high-level of emergency functions, such as hospitals and fire stations, were excluded from the rolling turns.

3. Results and Discussion

3.1 Electricity Consumption

A comparison of electricity consumption data, in the form of total kWh written on the electricity bills from April to November in 2010 and 2011, is shown in Table 1. The total electricity consumed from April to November in 2010, i.e. before the energy crisis, accounted for 2,113 kWh for group A whereas it added up to over 3,000 kWh for group B and C. A more detailed comparison of the monthly average consumption figures for 2010 and 2011 within each group (“t”-values under the “Electricity saved” heading in Table 1) reveals differences between these two years are of statistical significance for all months for Group A. By contrast, differences in April and May for Group B and April for Group C were not statistically significant. This means that the people in Group A had even begun to take more electricity-saving measures on a voluntary basis already in April, reflecting active electricity-saving behaviors as claimed by them. In addition, the analysis of variance for electricity consumption across the groups in the same months, shown in “F”-values and corresponding “p”-values in Table 1, indicates significant statistical differences for most of the months, except September 2011. Similar trends are apparent in the amount of electricity saved, i.e. electricity-saving rates. In general, Group B showed the greatest saving rate in June and July of 2011, as declared to have engaged in electricity-saving behavior since the energy crisis. However, a great deal of “rebound” was also confirmed in the months soon after the lift of the electricity saving edict in early September in Group B, implying a difficulty of sustaining the electricity-saving behavior and its effect driven by a top-down approach. It should also be noted that there is not much statistical differences between Group B and C in terms of electricity consumption and saving data, although their perception of their own electricity-saving behavior, whether they perceive themselves to be engaged in electricity-saving or otherwise, is different.

3.2. Psychological factors determining electricity-saving behavior

Fourteen questions rated by the degree of agreement on a 7-point scale (1: do not agree at all to

Table 1 Comparison of electricity consumption in 2010 and 2011 by group

		Electricity Consumption 2010					Electricity Consumption 2011					Electricity saved (2010-2011)						
		Average	S.D.	F	p	Tukey	Average	S.D.	F	p	Tukey	Average	S.D.	t	p	F	p	Tukey
April	C	392.4	174.2	4.512	0.015**	A-B**	381.0	179.7	5.764	0.005***	A-B***	11.4	99.4	.513	.614	1.681	.195	
	B	386.8	171.6			A-C**	411.3	249.1			A-C**	-24.5	149.5	-.731	.474			
	A	267.1	82.9				228.8	71.9				38.3	55.5	3.083	0.006**			
May	C	432.6	190.6	6.659	0.003***	A-B***	378.5	184.6	5.163	0.009***	A-B***	54.1	92.7	2.607	0.017**	.173	.842	
	B	495.9	210.2			A-C**	450.5	241.7				45.4	117.8	1.723	.101			
	A	302.2	85.8				265.1	95.1				37.1	50.0	3.321	0.004***			
June	C	410.2	200.9	6.605	0.003***	A-B***	312.8	167.4	3.502	0.037**	A-C**	97.4	92.8	4.695	0.000***	7.357	0.001***	A-B***
	B	443.2	186.5			A-C**	294.7	118.9				148.5	86.0	7.720	0.000***			
	A	266.7	69.2				215.2	63.0				51.5	56.5	4.074	0.001***			
July	C	453.2	195.0	7.375	0.001***	A-B***	352.2	201.2	3.436	0.039**	A-B*	101.0	92.9	4.863	0.000***	9.905	0.000***	A-B***
	B	562.6	228.4				362.8	161.0			A-C*	199.9	92.7	9.637	0.000***			A-C***
	A	339.5	105.1				245.3	85.5				94.2	62.9	6.702	0.000***			
Aug.	C	332.9	181.2	3.358	0.042**	A-C**	295.9	173.2	2.760	0.072*	A-C*	37.0	59.1	2.795	0.012**	2.226	.117	
	B	300.8	150.6				252.4	110.4				48.5	50.4	4.300	0.000***			
	A	221.5	57.1				205.0	52.7				16.5	32.4	2.273	0.034**			
Sept.	C	348.3	187.7	3.195	0.048**	A-B*	299.2	177.2	2.115	.130		49.2	65.9	3.334	0.003***	2.410	0.099*	A-B*
	B	360.2	159.0				282.5	121.6				77.8	82.1	4.233	0.000***			
	A	251.6	78.1				219.1	66.5				32.5	44.2	3.291	0.004***			
Oct.	C	324.5	182.6	3.111	0.052*	A-C**	365.9	186.3	5.630	0.006***	A-B***	-41.4	63.5	-2.912	0.009***	4.576	0.014**	A-B**
	B	293.3	113.4				378.0	152.8			A-C**	-84.7	99.5	-3.807	0.001***			
	A	224.7	63.8				241.1	56.6				-16.4	41.8	-1.748	0.097*			
Nov.	C	329.9	164.8	3.360	0.042**	A-B*	361.6	185.0	5.016	0.010***	A-B***	-31.7	56.4	-2.510	0.021**	3.974	0.024**	A-B**
	B	331.1	130.4			A-C*	403.7	154.1			A-C*	-72.6	77.6	-4.182	0.001***			B-C*
	A	239.6	71.4				262.0	72.9				-22.5	39.2	-2.559	0.019**			
Total	C	3023.8	1409.9	5.000	0.010***	A-B**	2746.9	1397.2	4.498	0.015**	A-B**	277.0	251.1	4.933	0.000***	1.007	.372	
	B	3173.8	1283.9			A-C**	2835.6	1212.8			A-C**	338.3	270.2	5.598	0.000***			
	A	2112.7	566.4				1881.5	532.0				231.2	189.4	5.460	0.000***			

Units for average and S.D. are in kWh; *p<0.1; **p<0.05; ***p<0.01

7: completely agree) were asked to measure psychological factors determining electricity-saving behavior among people. Items specifically related to the Earthquake and Fukushima Accident were also included. The wording of each question was made in the past tense, as this study looked back at the electricity-savings done in the past. The results are presented in Table 2. Degrees of agreement on 8 measures on awareness of problems and sense of responsibility, economic factors, perceived behavior control, and subjective norm, altruistic/egoism value are generally low, indicating the low level of awareness among the respondents. This is especially true for the issues of general environmental problems such as global warming. The result of analysis of variance then identified 6 items with statistically significant differences among groups: two measures on social responsibility, one perceived behavior control, one economic factor, and one egoism value.

A Principal Factor Analysis (PFA) with promax rotation was then conducted to find potential determinant factors for electricity-saving behavior among people. The result of PFA revealed four factors explaining 77.6% of the variance. The factor loadings of each variable and reliability of scale are shown in Table 3. Of the fourteen questions, the measures on intention to buy energy-efficient

Table 2 Rating of psychological factors determining electricity-saving behavior

	Total sample		Group mean			ANOVA	
Measurement	Mean	S.D.	A	B	C	F	p
I felt that there was a risk of energy shortage in the summer after the Earthquake.	5.5	1.28	5.8	5.5	5.2	.920	.404
I felt threatened by the issues of radioactive contamination by Fukushima accident.	5.5	1.37	5.6	5.6	5.3	.312	.733
Global warming and depletion of fossil fuel has been a problem even before the Earthquake.	4.9	1.02	5.1	4.8	4.7	1.005	.372
I felt responsbile to save electricity when considering the victims of/those affected by the Earthquake.	5.5	1.24	6.1	5.4	5.0	4.099	0.022**
I have been feeling joint responsibility for electricity saving considering the global warming, etc.	4.7	1.05	5.1	4.7	4.3	3.078	0.054*
I felt that I could contribute to solve energy shortage issue by engaging in electricity saving.	4.8	1.38	5.1	4.9	4.5	.840	.437
I was able to engage in things which were of burden to me.	4.8	1.22	5.5	4.6	4.3	5.485	0.007***
I was able to engage in things which could made me less comfortable.	4.5	1.14	5.0	4.4	4.2	2.823	0.068*
I intented to buy more energy-efficient products, even it's more expensive than others.	3.6	1.34	3.7	3.8	3.4	.574	.567
I have been concious about my utility bills even before the Earthquake.	5.1	1.48	6.0	4.8	4.4	7.170	0.002***
I felt pressued to reduce the use of electricity by people around me.	3.7	1.46	3.6	3.6	3.8	.160	.853
I felt obliged to reduce the use of electricity due to the government edict.	4.5	1.43	4.5	4.8	4.2	.733	.485
I felt satisfied that I could contribute to solve energy-shortage in the society.	4.4	1.27	4.8	4.3	4.0	2.355	.104
I felt satisfied that I could save electricity bills from electricity savings.	4.7	1.26	5.3	4.8	4.0	6.546	0.003***

*p<0.1; **p<0.05; ***p<0.01

products and egoistic value were excluded from further analysis as they did not fit well into any of the four factors. The fourth factor with eigenvalue of less than 1 was adopted based on the judgement on the scree plot and the account of explained variance.

The first factor consists of all the questions specifically related to the Earthquake and Fukushima Accident, whereas the second factor reflects more general pro-environmental attitude. The third factor was identified as "perceived seriousness of the risk/problem" when it actually occurs arising from the experiences of the Earthquake/Fukushima Accident, noted to be a different scale from the general "perception of probability of the risk occurring[3]. Finally, the forth factor is reflecting personal subjective norm. Three far-right columns in Table 3 indicate the contribution of each factor in percentage by Group, of which interpretation will follow in section 3.5. below.

3.3. Electricity-saving behavior

Specific electricity-saving behaviors engaged by the respondents were rated by a 3-point scale extending from "I have been engaging in this behavior since before the Earthquake;" "I have engaged in this behavior since the Earthquake;" and "I have never conducted this activity either before or after the Earthquake." The results are presented in Table 4. Performance rates are generally high in Group A, followed by Group B then C, but a good proportion of people in Group B and C also engaged in many of the activities even before the Earthquake, resulting in only 5 behaviors with statistically significant differences among the groups shown with asterisks in Table 4.

Table 3 Factor loadings of the determinants for electricity-saving

	Factor (overall)**				α	Contribution by Group		
Measurement*	1	2	3	4		A	B	C
Engaged in things which were of burden	**.94**	.03	.06	.22				
Engaged in things which could made me less comfort.	**.88**	.17	-.23	.06				
Felt satisfied contributing to solve energy-shortage.	**.79**	-.23	-.02	.40	0.89	17%	65%	20%
Felt responsbile to save electricity for those affected by Earthquake.	**.71**	.06	.28	.21				
Felt contributing to solve energy shortage issue by electricity saving.	**.71**	.04	.03	.16				
Feel joint responsibiity for electricity saving against global warming, etc.	.06	**.88**	-.15	-.15				
Concious about one's utility bills even before the Earthquake.	-.02	**.79**	.00	.13	0.75	32%		16%
Global warming etc. has been a problem even before the Earthquake.	.05	**.71**	.23	-.01				
Felt threatened by radioactive contamination by Fukushima Accident.	-.10	-.04	**.92**	.18	0.83	10%		
Felt a risk of energy shortage in the summer after the Earthquake.	.10	.01	**.89**	-.06				39%
Felt pressued to reduce the use of electricity by people around me.	-.11	.04	.01	**.92**	0.72	16%	11%	
Felt obliged to reduce the use of electricity due to government edict.	.08	.10	.10	**.77**				
Eigenvalue:	5.58	1.65	1.17	.91		75%	76%	75%
Explained variance (%):	46.5	13.7	9.7	7.5				

* measurement are shown with abbreviated expression. **Estimation method by Principal Factor Analysis with promax rotation

Table 4 Comparison of electricity-saving measures conducted by each group

		Rates (%) conducted				
Elecrtricity-saving behavior		Before	Since	never	F	p
Air-conditioner at 28 degrees celcius	A	95	5	0	6.27	0.003***
	B	45	35	20		
	C	60	25	15		
Use of sunshade/curtains to avoide direct solor radiation	A	40	20	40	0.06	.945
	B	45	20	35		
	C	50	5	45		
Use of fans insteard of air-conditioner	A	75	15	10	2.87	.065
	B	40	45	15		
	C	40	30	30		
Use of energy-saving lighting (LED tubes etc.)	A	30	20	50	0.09	.918
	B	30	20	50		
	C	25	20	55		
Partial use/removal of lighting tubes, etc.	A	65	25	10	1.96	.150
	B	35	55	10		
	C	40	30	30		
Lowering brightness of TV screen as much as possible.	A	40	5	55	0.13	.876
	B	30	20	50		
	C	30	10	60		
Turning off the TV when not watching	A	75	10	15	5.43	0.007***
	B	40	30	30		
	C	25	25	50		
Avoid unnecessary/prolonged oening of refrigerators	A	50	15	35	.58	.564
	B	35	25	40		
	C	30	25	45		
Lowering of the refregeration temperature	A	75	10	15	3.02	0.057*
	B	35	25	40		
	C	55	20	25		
Avoid using "keep warm" function	A	75	20	5	2.89	.064
	B	75	15	10		
	C	50	20	30		
Frequently switch-off electric appliances	A	80	20	0	2.46	.094
	B	70	25	5		
	C	60	15	25		
Reduce standby power by unpluging from the outlet	A	70	20	10	4.07	0.022**
	B	40	45	15		
	C	35	20	45		
Be an early-bird to utilze the sunlight	A	60	5	35	1.98	.147
	B	45	10	45		
	C	30	5	65		
Dressing light	A	100	0	0	6.40	0.003***
	B	85	10	5		
	C	60	15	25		

*=p<0.1; **=p<0.05; ***=p<0.001

The results of a PFA with promax rotation then identified three factors explaining 54% of the variance (Table 5). Three variables (reducing standby power by unplugging, avoiding unnecessary opening of refrigerator, and partial use/removal of lighting tubes) were excluded from further analysis as they did not fit well into any of the three factors. Each factor is named “Change in habit,” “setting change (small cost but with some endurance),” and “setting change (little endurance but with some cost),” respectively. Three far-right columns in Table 5 indicate the performance rates conducted for each factor by Group as declared by the respondents in the survey. The differences in performance rates among groups give an interesting implication: especially of that people in Group B, who claim that they actively engaged in electricity-saving since the Earthquake, changed in a number of habits, but activities requiring certain level of endurance, such as setting air-conditioning at 28 degrees celcius, remained indifferent from Group C.

Table 5 Factor loadings of the electricity-saving behaviors actually taken

	Factors (overall)*			α	Rates (%) by Group**		
	1	2	3		A	B	C
Frequently switch-off electric appliances	**.70**	-.08	.04	0.70	89%	81%	61%
Be an early-bird to utilze the sunlight	**.59**	-.02	-.04				
Dressing light	**.56**	.08	-.08				
Avoid using the "keep warm" function	**.52**	-.04	.17				
Turning off the TV when not watching	**.50**	.16	-.07				
Air-conditioner at 28 degrees celcius	.02	**.64**	.14	0.65	80%	69%	68%
Lowering of the refregeration temperature	.02	**.61**	-.13				
Use of fans insteard of air-conditioner	-.03	**.57**	.00				
Lowering brightness of TV screen	.08	**.45**	.03				
Use of sunshade/curtains to avoide direct solor radiation	-.12	.12	**.73**	0.64	55%	58%	50%
Use of energy-saving lighting (LED tubes etc.)	.10	-.10	**.68**				
Eigenvalue:	2.84	1.75	1.36		n/a	n/a	n/a
Expained variance (%):	25.8	15.8	12.4				

* Estimation method by Principal Factor analysis with promax rotation.
** Average combined rates of "before" and "since" in Table 4 as declared by respondents.

3.4. Other factors

Demographic variables, such as income, age of the respondents, and experience of rolling blackouts, were considered for its interaction effects. Overall, interaction effects were minimal both in psychological determinants of electricity-saving behavior and actual behaviors taken by people. This could presumably be due to the physical and mental proximity of the respondents to the experience of the rolling blackouts actually happening in the nearby areas. The severity of the shock of the incidents also could have worked to foster a moral norm when considering the victims and those affected by the Earthquake and Fukushima Accident.

3.5. Implication

A closer look at the factors identified in 3.2 and 3.3 gives some implications for how different factors determined electricity-saving behaviors taken by people in each group. Although the small sample size of the study, especially when analyzed by group, hindered an application of structural equation modelling, retrofitting the psychological factors determining the electricity-saving behavior identified in this study could be related to the factors proposed in the widely well accepted theory of planned behavior (TPB) by Ajzen[1] namely attitude, personal norm, perceived behavioral control which lead to form the behavioral intention, which consequently reaches to actual behavior (Fig.1). In particular, the most powerful factor by far, namely “Earthquake-driven attitude” identified in this study could be equated with the “perceived behavioral control” of the TPB. If so, when perceived behavioral control is so powerful and almost become a moral norm, behavioral intention and actual behavior occurs almost simultaneously, leading to immediate action on electricity-saving as seen in the case of Group A and B (Fig. 2 and 3). Without a more general “attitudinal drivers,” however, the action does not sustain and showed a significant rebound as soon as the top-down electricity-saving edict was lifted as in Group B. From the sustainability point of view, the role of more general pro-environmental attitude become critical as in the case of Group A, suggesting a

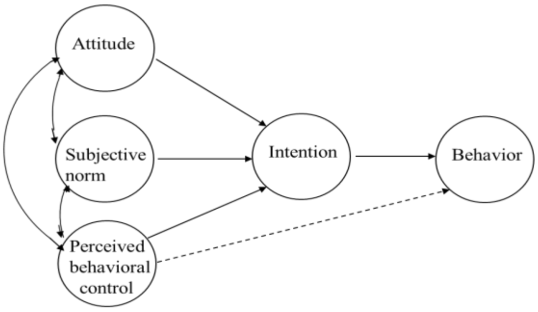

Fig. 1 Theory of planned behavior (TPB) by Ajzen [1]

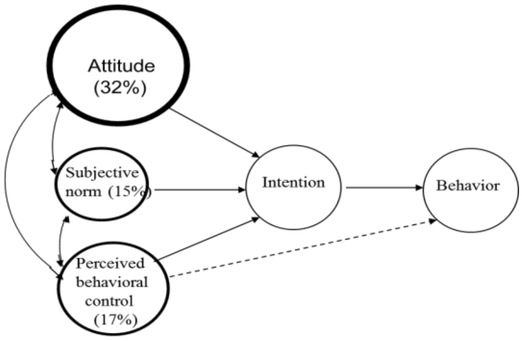

Fig. 2 Notational image of psychological path using Theory of Planned Behavior for Group A

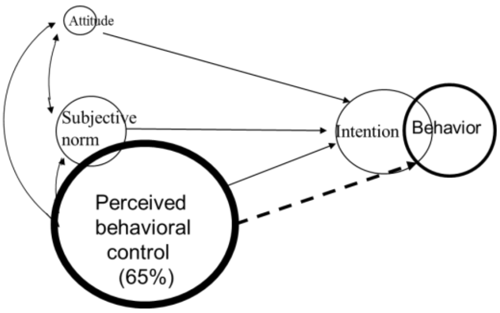

Fig. 3 Notational image of psychological path using Theory of Planned Behavior for Group B

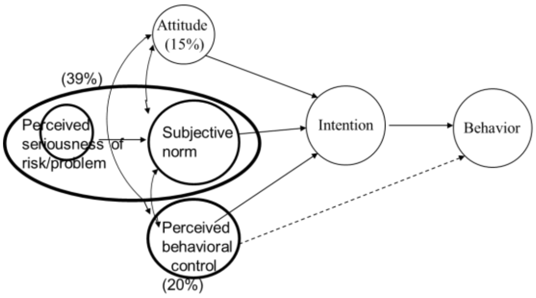

Fig. 4 Notational image of psychological path using Theory of Planned Behavior for Group C

continued need for environmental and moral education. It is also interesting that people in Group C, claimed as non-active electricity savers, share a more similar psychological traits with Group A than those in Group B, except that they were more influenced by external drivers, i.e. subjective norms, than by their internal, i.e. attitudinal, drivers (Fig 4).

4. Conclusion

In evaluation of the factors determining electricity-saving behavior in households in the summer after the Great East Japan Earthquake, it was suggested that four factors, closely related to the theory of planned behavior, differently influenced the structure of electricity-saving behavior for each group. The "Earthquake-driven," perceived behavioral control had the greatest influence by far, but fostering a sensibility and attitude for general environmental problems is more crucial for sustained electricity-saving practices and its effects. It should be noted, however, that the small sample size of the study puts a certain limitation on generalizing the conclusion found in this study. In addition, rather than taking an approach where grouping by self-declared perception of engagement in electricity-saving behavior and their psychological determinants as a central focus of the analysis, a more detailed consideration of grouping by demographic characteristics such household income and age of the children as well as by the actual electricity consumption/saving could add further implications for promotion of energy-saving, including electricity-saving, behavior in households.

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