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Simulating Lighting Energy Consumption in Office Buildings by Exploring the Relationship Between Environmental Psychological Factors and Occupant Behavior

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Presentation flow

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1. Introduction

Background

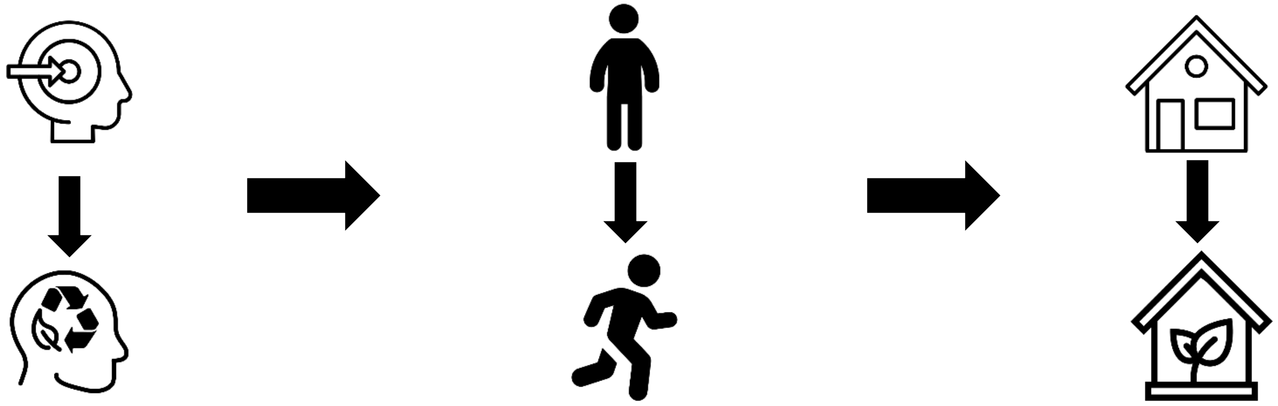
・Recent studies report that the **commercial and public sector** share of energy is **54 % in Japan** and **44 % in the United States** [1].

・ **Conservative working practices** can save up to **50% of energy** compared to **standard working practices**, while **wasteful working practices** can increase energy use by **89%** [2].

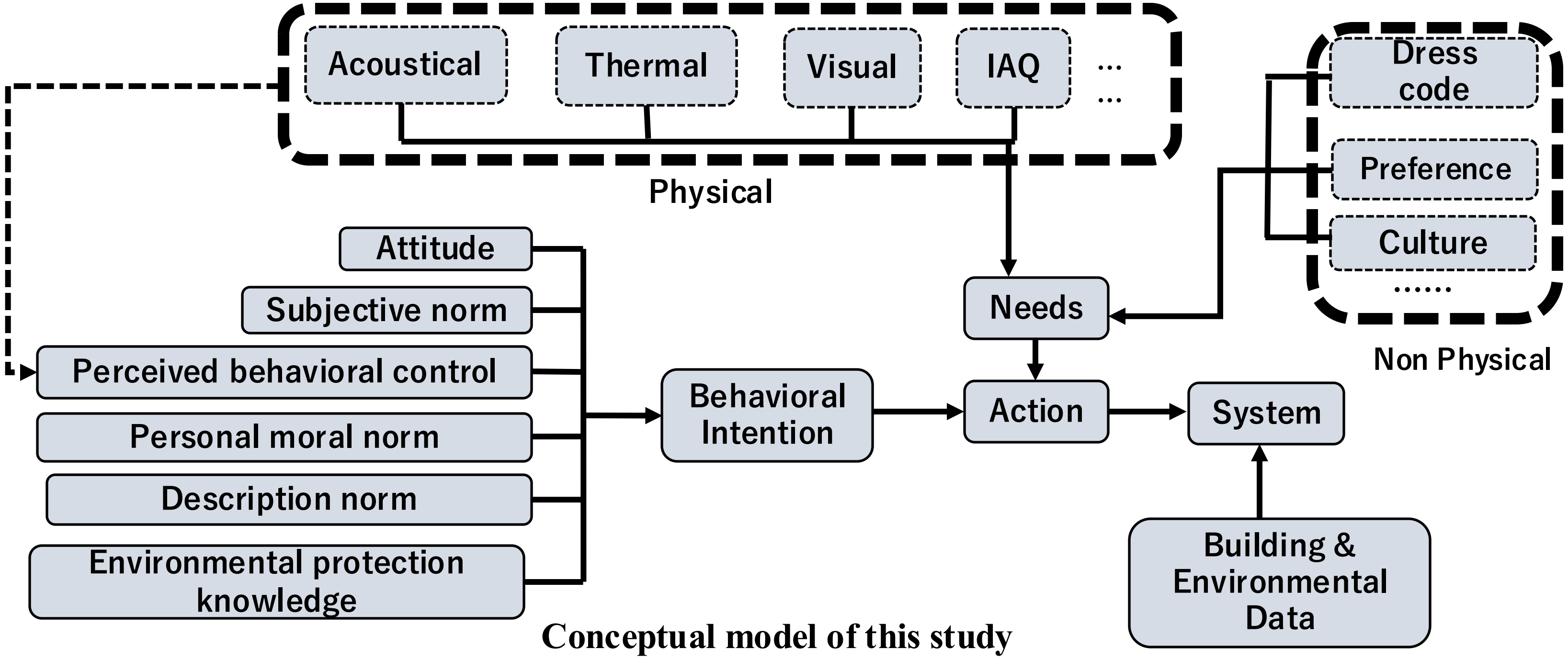
・ It is important to consider how **human behavior** can be changed to become environmentally friendly.

Purpose

The purpose of this study is to explore the relationship between **consciousness, behavior and energy consumption** by investigating the relationship between consciousness and behavior and creating a simulation tool that can model the effect of consciousness on building energy consumption behavior.



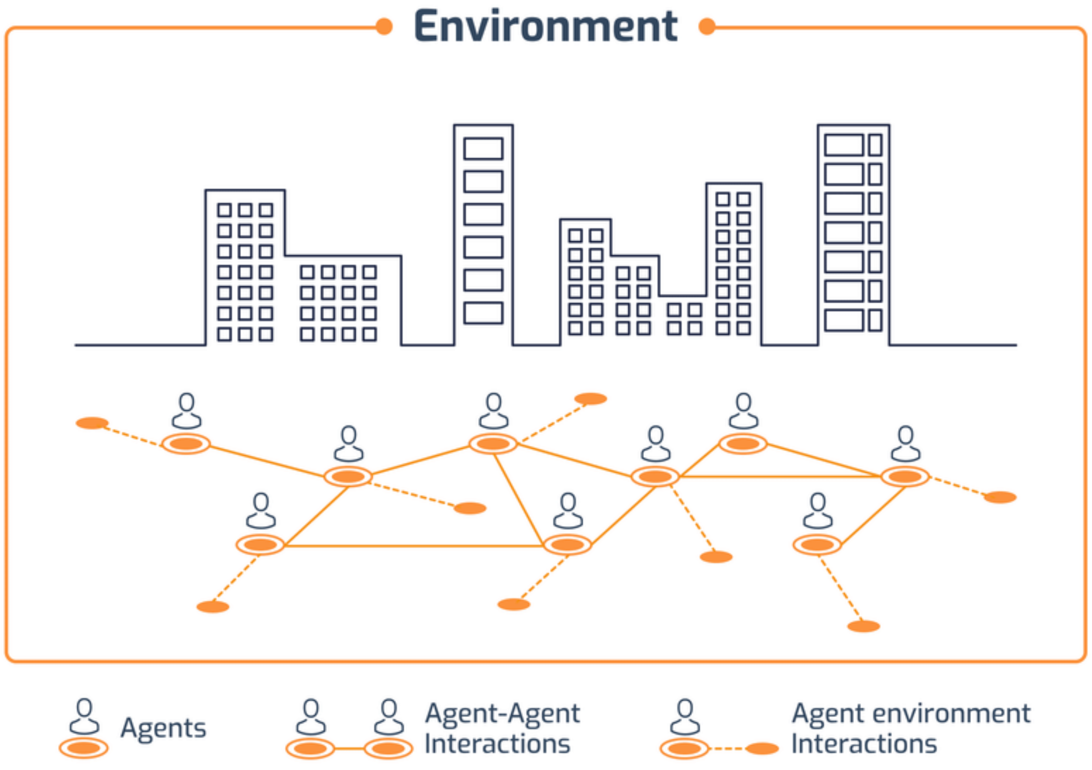
2. Literature review and conceptual model



Conceptual model of this study

The **<u>conceptual model</u>** for this study is based on the Theory of Planned Behavior (TPB) model[3] by Icek Ajzen et al. and the DNAs framework[4] by Tianzhen Hong et al. <u>Based on the extended theoretical model of TPB and the theoretical model developed from the DNAs framework,</u> **<u>the questionnaire was designed</u>.** Through the questionnaire, this study collected various data on people's environmental awareness and lighting usage habits. The study then analyzed the relationships between these factors, providing insights into how psychological awareness influences energy-saving behaviors.

2. Literature review and conceptual model



Schematic representation of an agent-based model (ABM).

Agent-based models (ABM) are computer simulations used to study the interactions between people, things, places, and time. They are stochastic models built from the bottom up meaning individual are assigned certain attributes.

3. Questionnaire design and results

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Table1 Constructs and measurement items in questionnaire

Constructs	Items
Attitude (ATT)	ATT1. The continuously increasing energy demand is a serious issue for society.
	ATT2. I also bear some responsibility for issues such as global warming and the depletion of fossil fuels.
	ATT3. I believe that energy conservation in daily life is useful for environmental preservation.
Subjective Norm (SN)	SN1. The managers (executives, officers, etc.) of your company are considering the request to turn off the office lighting and air conditioning when not in use.
	SN2. People who are significant in my life think that I should conserve energy wherever possible.
	SN3. I value the opinion of people who are significant in my life when it comes to making decision on energy conservation.
Perceived Behavioral Control (PBC)	PBC1. I have knowledge and know-how to implement energy-saving practices in my daily life.
	PBC2. Convenience without compromising energy efficiency is also an important factor for me when promoting energy conservation.
	PBC3. Whether or not saving energy is completely up to me.
Personal Moral Norm (PMN)	PMN1. There is a moral responsibility to engage in energy-saving practices in everyday life.
	PMN2. I use electricity, gas, and other forms of energy in my daily life, and I feel that my actions have an impact on climate change.
	PMN3. Save energy in my daily life is depending on my own moral obligation.
Descriptive Norm (DN)	DN1. A number of employees in my company I know have participated in energy saving behavior.
	DN2. Others who are important to me have participated in energy saving behavior.
	DN3. My manager and the high-level management team have participated in energy saving behavior.
Environmental Protection Knowledge (EPK)	EPK1. Greenhouse gases have the effect of suppressing the thermal radiation emitted by the Earth.
	EPK2. The increase in greenhouse gases in the atmosphere over the past 150 years is primarily attributed to human activities.
	EPK3. I know much about the energy-saving tips of daily life.
Behavioral Intention (INT)	INT1. I will pay more attention and accumulate energy-saving knowledge and tips in the future.
	INT2. I am going to behave pro-environmentally in the coming month to reduce my impact on the environment (e.g. by turning off the computer, printing less, using a mug etc.)
	INT3. I intend to engage in energy-saving activities in the future.
Behavior (B)	B1. I turn off the lights when leaving the room
	B2. I select the areas that will be illuminated based on the number of people in the room.

Choices:
5: Strongly agree;
4: Somewhat agree;
3: Neither agree nor disagree;
2: Somewhat disagree;
1: Strongly disagree

Choices:
5: Always do it;
4: Often do it;
3: Sometimes do it;
2: Rarely do it;
1: Hardly ever do it

3. Questionnaire design and results

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3.2 Results of questionnaire

In March 2023, the questionnaire distribution was completed, yielding a total of 1069 valid responses. Respondent profiles are shown in Table2.

Table.2 Profile of the respondents participating in the survey

Characteristics		Frequency	Percent (%)
Gender	Male	537	50
	Female	532	50
Age group	20~29	93	9
	30~39	231	22
	40~49	308	29
	50~59	265	25
	60~	172	16
Region	Hokkaido	52	5
	Tohoku region	53	5
	Kanto region	429	40
	Chubu region	145	14
	Kinki region	223	21
	Chugoku region	60	6
	Shikoku region	32	3
	Kyushu region	75	7
Total		1069	100

3. Questionnaire design and results

3.2 Results of questionnaire

Table 3 correlation of environmental awareness and lighting behaviors

	ATT	SN	PBC	PMN	DN	EPK	INT	B1	B2
ATT	1								
SN	.768**	1							
PBC	.689**	.752**	1						
PMN	.795**	.776**	.707**	1					
DN	.541**	.688**	.618**	.674**	1				
EPK	.716**	.718**	.721**	.780**	.687**	1			
INT	.798**	.780**	.709**	.806**	.657**	.791**	1		
B1	.403**	.396**	.370**	.332**	.266**	.335**	.390**	1	
B2	.344**	.407**	.327**	.299**	.321**	.329**	.365**	.522**	1
**. Correlation is significant at the 0.01 level (2-tailed).									

4.1 Decision-making frameworks for agent and behavior

Probabilistic calculations for Lighting behavior:
The regression formula was chosen to establish a mathematical model predicting the relationship between awareness and behavior, as shown in formulas (1) and (2) on the right.
In the formula, P_{B1} and P_{B2} represent, respectively:

P_{B1} : probability of turning off the lights when leaving the room
P_{B2} : probability of selecting the areas that will be illuminated based on the number of people in the room.

$$P_{B1} = \beta_1 + a_1X_{ATT} + b_1X_{SN} + c_1X_{PBC} + d_1X_{PMN} + e_1X_{INT} \quad (1)$$

$$P_{B2} = \beta_2 + a_2X_{SN} + b_2X_{PMN} + c_2X_{DN} + d_2X_{INT} \quad (2)$$

Table 4 Values of constants and coefficients of equations (1) and (2)

β1	1.5728	β2	0.7848
a1	0.2773	a2	0.4583
b1	0.2361	b2	-0.3235
c1	0.1950	c2	0.1332
d1	-0.2005	d2	0.1855
e1	0.2027		

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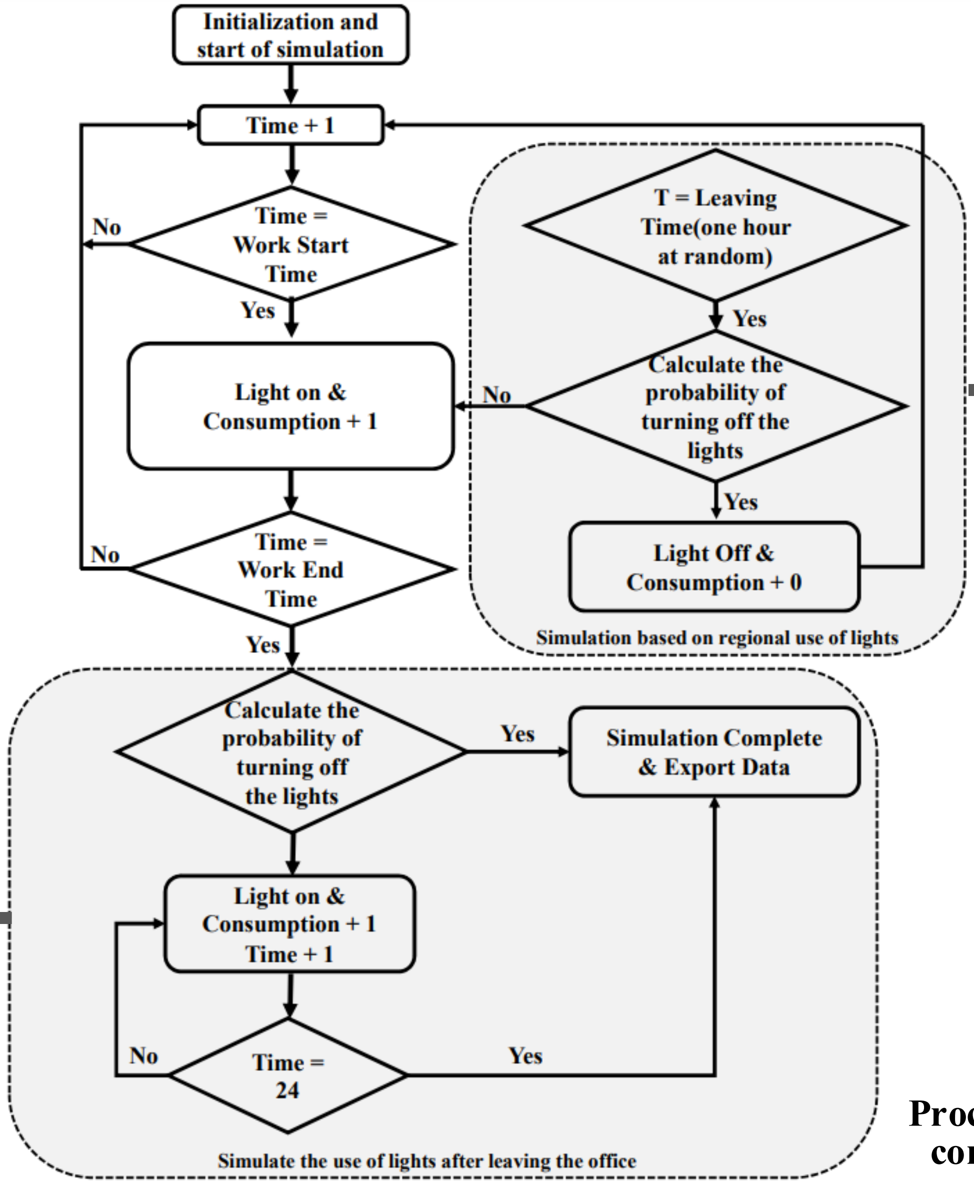
4.1 Decision-making frameworks for agent and behavior

The decision-making framework for behavioral simulation in this study was established based on the regression model.

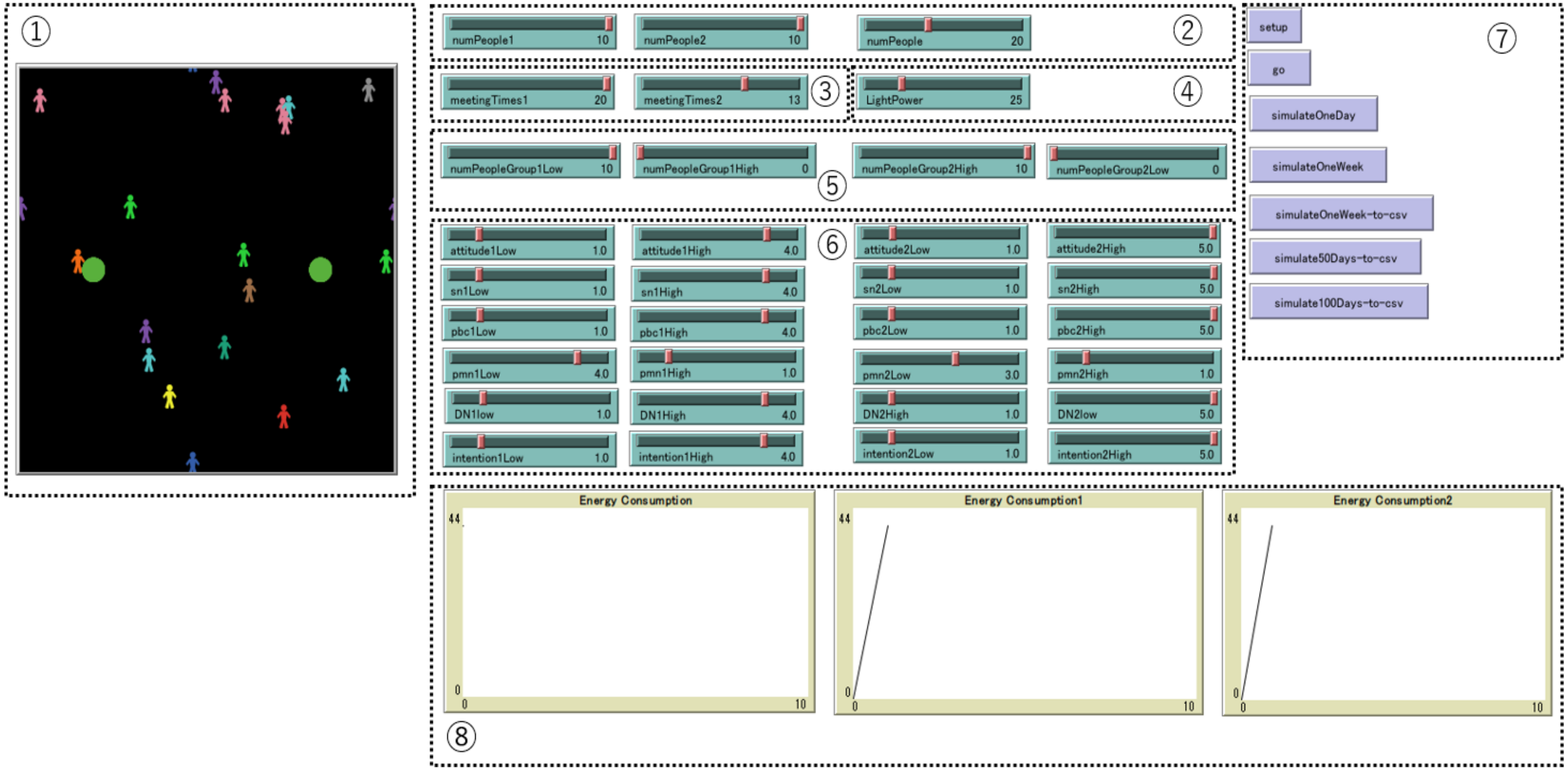


B2：select the areas that will be illuminated based on the number of people in the room.

B1：probability of turning off the lights when leaving the room

Process of simulating people's air conditioning decision behavior

4.2 Introduction of NetLogo system setting



NetLogo is a programming language and integrated development environment (IDE) for agent-based modeling.

4.Simulation system and results

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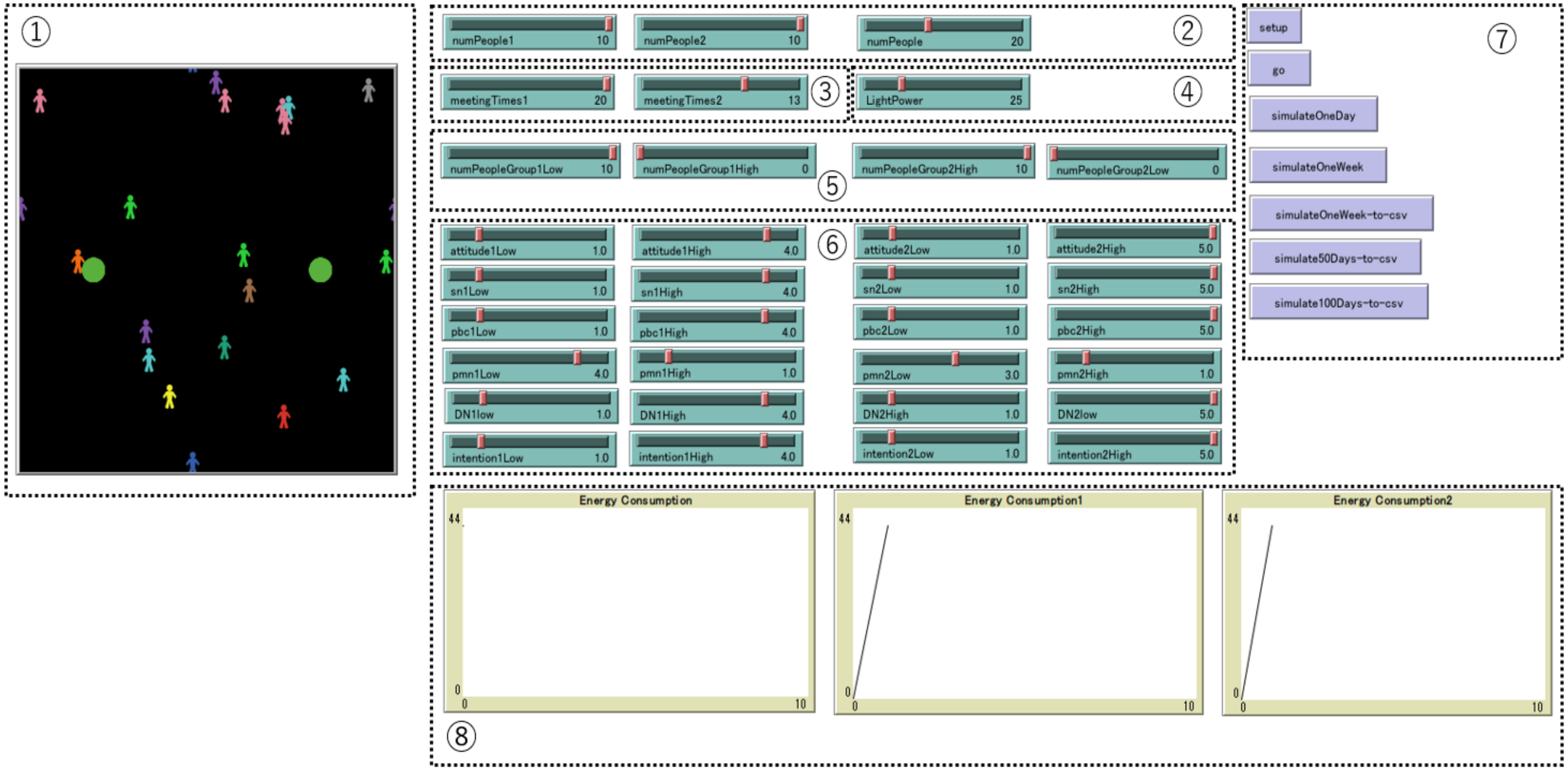
4.2 Introduction of NetLogo system setting



①View

②Slider ： numbers of people in the room

③ Slider： frequency of leaving the office during working hours

④ Slider： Power of lighting

⑤ Slider：Number of people with different levels of consciousness

⑥ Slider： different awareness level

⑦Simulation setup and start button

⑧Plot：energy consumption

4.Simulation system and results

4.2 Introduction of NetLogo system setting

Table 5 Setting of simulation

Input	Setting
Environmental awareness	High awareness: 5; Medium awareness: 3; Low awareness:1
Working time	9:00~12:00; 13:00~18:00
Number of groups	3 groups (high awareness, medium awareness, and low awareness) Each group 10 people
Length and frequency of temporary absence (meetings)	1 hour at a time, once a day

4.Simulation system and results

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4.2 Introduction of NetLogo system setting

Table 6 The simulation results of B1

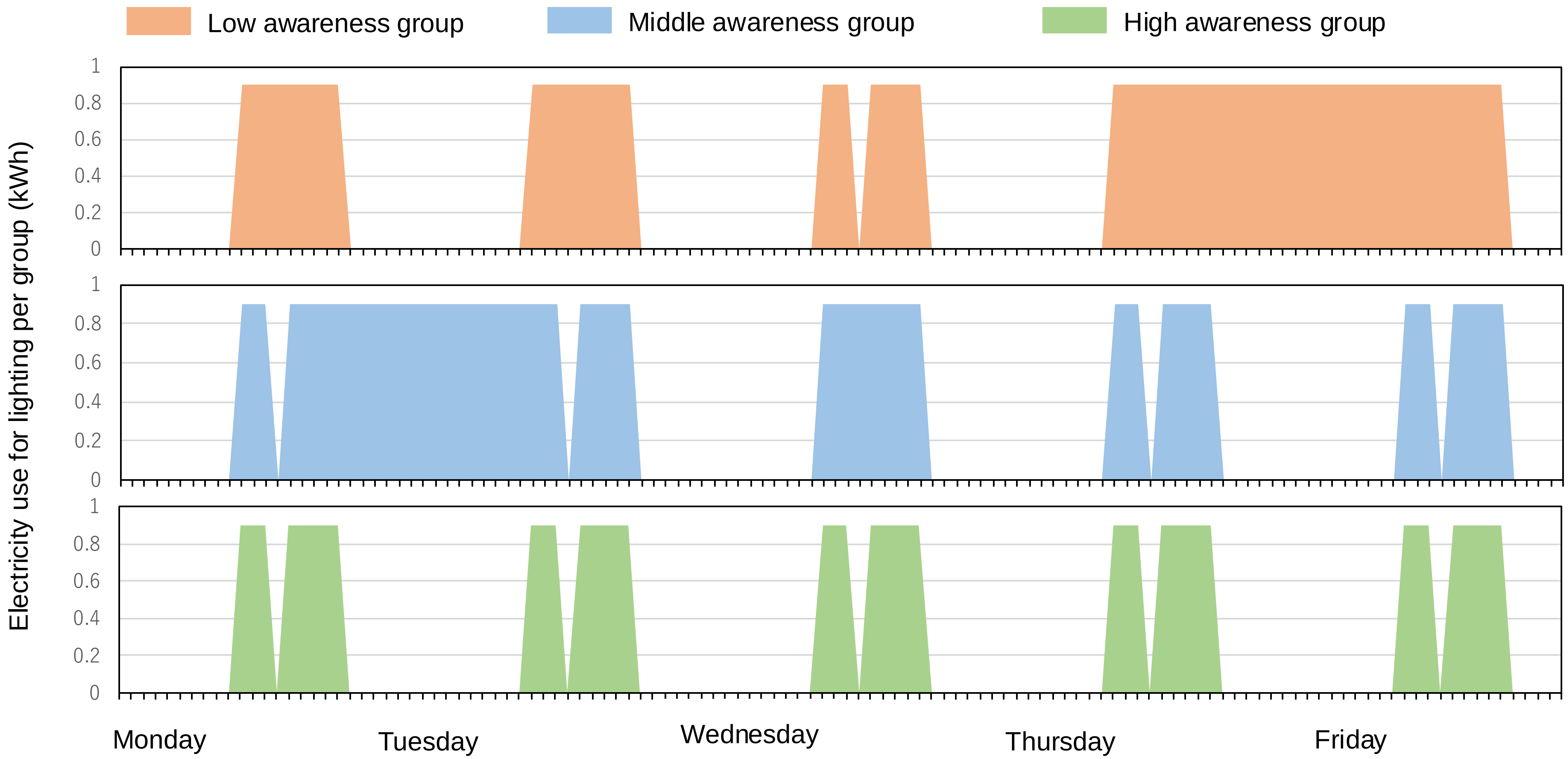
	Average daily electricity consumption on a working day (kWh)	The average number of times the lights are left on when leaving on a working day
Low awareness group	14.94	0.96
Middle awareness group	10.98	0.54
High awareness group	7.20	0.13

Table 7 The simulation results of B2

	Average daily electricity consumption on a working day (kWh)	The average number of times the lights are left on when leaving on a working day
Low awareness group	7.08	0.87
Middle awareness group	6.99	0.77
High awareness group	6.93	0.69

4.Simulation system and results

4.3 Results of simulation



Schematic of lighting use in a random week

5.Discussion and Conclusion

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Based on the results of the questionnaire and simulation, the following conclusions can be drawn from this study:

○ A tool was developed to analyze office **lighting usage by linking awareness and behavior**.

○ Higher environmental awareness correlates with more energy-saving lighting behaviors.

○ In **B1**(turning off the lights when leaving the room), low awareness **doubles** energy use and increases the chances of not turning off lights by seven times; in B2(select the areas that will be illuminated based on the number of people in the room), low awareness groups are **1.26 times** more likely to leave lights on.

○ Different psychological factors affect behaviors, and strategies like education and enhancing norms can improve energy-saving actions.

5.Discussion and Conclusion

Limitations:

◯The study only simulates the impact of awareness on lighting behavior, without considering other factors like illumination, working hours, and job nature.

Future Research:

◯ Validate findings through experiments in real office buildings.

◯ Expand simulations to include various behaviors to further reduce energy consumption and improve occupant comfort.

References

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Thank You!

Thank you for your attention!

I am happy to answer any questions.

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