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Prediction of energy saving policies effects reflecting decision making process of office building owners and tenants

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Abstract. Currently, energy savings in buildings are an urgent issue to be tackled in the world widely. In Japan, energy savings in buildings have been promoted through some policies such as energy saving standard compliance, Building-Housing Energy-efficiency Labeling System (BELS), and relevant subsidies. For more efficient policy making, it is important to estimate how those policies work and which of them should be considered to be important.Firstly, we developed agent-based simulation incorporating decision making model of building owners and tenants. Building owner agents apply energy retrofit based on energy saving policies and tenant agents move their offices to maximize profits based on a given circumstances such as energy efficiencies of buildings. Their decisions influence each other and we analyzed their behavior. Since the demonstration for all actual office buildings in target area is costly task, it was conducted in downscaled area while keeping statistical characteristics of office buildings in target area. The target was a business district in Tokyo, Japan. Then using the simulation, we demonstrated the effects of the policies. The results show that it is not easy to accelerate energy saving with only subsidies; appropriately combining subsidies and standard compliance obligations allows energy saving to be progressed.

1. Introduction

Recently, global warming becomes important issue. In 2016, Conference of Parties(COP21) adopted an agreement that the increase in the global average temperature rises below 2℃ above pre-industrial levels (Paris agreement)[1)]. In this agreement, Japanese government promised that they reduce 26% of CO_2 emission until 2030 compared to 2013. In this promise, building sector is desired to reduce 40% of CO_2. Therefore, urgent support from the government is needed in this industry.

Currently, these policies are enforced to energy saving of buildings[2)]; energy saving standard compliance, Building-Housing Energy-efficiency Labeling System (BELS), and relevant subsidies. For more efficient policy making, it is important to estimate how those policies work and which of them should be considered important This study aims to clarify these problems through a multi agent simulation.

2. Methodology

Agent-based simulation[3)] is a bottom-up simulation which describes a phenomenon based on an interaction of local elements. Diappi, L., & Bolchi, P use agent-based simulation in their thesis about real estate[4]. Silvia, C., & Krause, R. M investigate the impact of each policy to adopt plug-in electric vehicles using agent-based simulation[5]. From these previous studies, agent-based simulation is suitable to realize the goal of this study: clarify the impact of energy policies about building. saIn this research, we consider the phenomenon of tenant's moving in and out of a building as a complex system consisting of owners and tenants, and model it with agent-based simulation.

To describe moving in and out of lease buildings, we modeled the building owner agent (BA) and the tenant agent (TA). Figure 1 shows the flow of the model.

Firstly, we created a virtual space with 100 buildings and 1337 tenants for simulating a business district in Tokyo. In addition, we created another space as an outside of the target space for simulating TA moving in and out. The simulation period is 33 years (from 2018 to 2050), and one step of the calculation is 1 month.

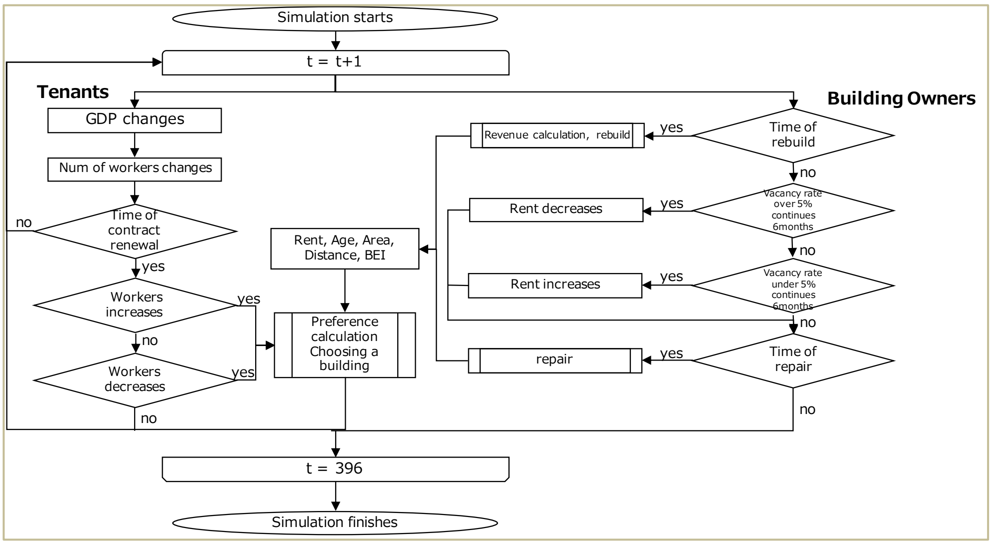

Figure 1. The simulation flow

2.1. *Setting of building owners*

According to the interview survey and references[6], BA decides to change their rent from the change in the vacancy rate, and they reconstruct and renovate based on the age of building as shown in Figure 1. Each buildings have features of total floor area (m^2), age of building (month), distance from the nearest station (m), and Building Energy-efficiency Index (BEI, ratio of the energy consumption of the building compared to the average one of Japan). They also have features which is related to transactions with tenants; rent and vacancy rate.

BA decides rebuilding in the 50th year of construction. It depends on net revenue from construction, operation, and rental business revenues and BA select a plan one with the highest net revenue.

From a statistic data about building lifecycle management[7], we investigated the timing of renovation which affects the buildings' energy consumption. If the vacancy rate is high when the period of renovation for each facility come, they introduce new energy-saving facilities. The amount of reduction of energy consumption when energy-saving facilities are introduced was set with reference to the past study[8].

2.2. *Setting of tenants*

As one of the reasons for relocation of tenants is the increase and decrease of businesses and personnel[9], TA relocates when the time of renewal of contract comes and the number of office workers has increased or decreased 2% more than the ones from the previous move (Figure 1). There is a correlation between the number of workers and GDP[10)], so we assumed that the number of office workers in each TA is proportional to the value of GDP in Tokyo.

We consider relocation selecting by TA as discrete selection problem described with a multinomial logit model. In the multinomial logit model, the selection probability of each BA is predicted under the assumption that the choice decision depends on the utility obtained by choosing an option. The utility value u_i which is obtained by relocation of TA is expressed by equation (1) consisting of the definite term v_i and the error term ε_i, which varies at random. i is the serial number of the BA in space. In this study, to calculate the office selection probability depending only on v_i (equation (2)), we processed ε_i as no effect. In particular, ε_i is set according to the Gumbel distribution and its scale parameter is 1.

Definite term v_i has 4 components; rent, distance from the nearest station, total floor area, and age (equation (3)). All these components can be influential to the choice of building and can research from actual data. Since these 4 components have different units, they were standardized for calculation. Parameters of the components (α in equation (3)) are adjusted as residual square sums of the actual value and the calculated value in average rent and average vacancy rate get minimum value. Figure 2 is the result of the adjustment of components. Both orders generally match though the details are not identical. Table 1 is the value of the parameters of the components.

$$u_i = v_i + \varepsilon_i \tag{1}$$

$$p_i = \frac{exp(v_i)}{\Sigma_j\, exp(v_j)} \tag{2}$$

$$v_i = \alpha_0 + \alpha_{Rent} Rent_i + \alpha_{Area} Area_i + \alpha_{Age} Age_i + \alpha_{Distance} Distance_i \tag{3}$$

Table 1. The preference of tenants

α_0	7.34
α_{Rent}	-0.29
α_{Area}	0.83
α_{Age}	-0.11
$\alpha_{Distance}$	-0.31

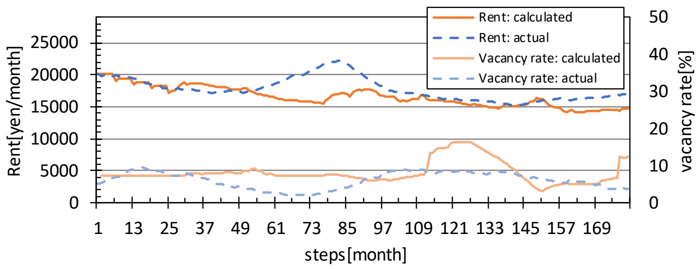

Figure 2. The comparison of rent and vacancy rate between actual and calculated value

2.3. *Initial settings and policy explanations*

Initial setting of BA is Table 2 Their value is determined by the calculation load. The number of building is 100 and features of each BA are determined to simulate the real statistic of building in office area in Tokyo. The number of TA is determined by statistics of the tenants' ratio to the number of buildings. Scale of each TA is determined according to the statistics of workers per tenant. In this study, the number of TA is 1337 and the whole workers are 39968.

Energy saving standard compliance is conducted in Japan from 2017. It prohibits to build new buildings exceeding the standard BEI (Building Energy-efficiency Index). In this model, the BA avoids reconstructing the building exceeding the line. BELS is a labeling system in order to evaluate excellent buildings about energy saving. It evaluates the energy saving performance of buildings in 5 levels. If BELS becomes popular, people can easily check the energy saving performance and purchase better one. In this model, we expressed BELS by incorporating BEI into tenant's preference (vi) and changed its weight; α_{BEI} in equation (4). Subsidies help the building renovation for introducing energy saving facilities by paying a part of the initial cost. BA tends to make a revenue easier by using a subsidy.

$$v_i = \alpha_0 + \alpha_{Rent}Rent_i + \alpha_{Area}Area_i + \alpha_{Age}Age_i \\ + \alpha_{Distance}Distance_i + \boldsymbol{\alpha_{BEI}BEI_i} \tag{4}$$

Table 2. The average value of building initial information

Area(m2)	Age(month)	BEI(-)	Distance(m)
1583	337	0.904	181
11612	666	1.339	458
631	9	0.848	92

3. Results and discussion

Using the constructed model, we conducted case studies of each policies; energy saving standard compliance, BELS, and relevant subsidies. The conducted simulation patterns are in the Table 3. We conducted 72 patterns of the combinations of the policies.

As the Figure 3 shows, the more severe the standard is, the more energy saving proceeds. For cases except BEI 1.0 and 0.9, the BEI in 2050 almost agrees with the standard. This is because near the standard BEI can get the best revenue for BA when the standard get severe. If the standard is generous, randomness of the model become stronger and the average BEI varies widely.

From the Figure 4, it can be confirmed that energy conservation progresses as tenants' preference for low-BEI buildings increases. However, order is reversed between α_{BEI} 0.9 and α_{BEI} 0.6. In the case of α_{BEI} 0.9, as the preference is strong, the vacancy rate of buildings with high BEI increases. Therefore, BA choose lowering rents rather than conducting energy conservation.As shown in Figure 5, energy conservation almost does not proceed with subsidies only. It is because it is difficult for the subsidy to cover the construction cost of energy saving facility and energy conservation does not lead to tenants' preference.Next, from Figure 6, we state the effect of combination of policies. Although subsidy only is ineffective, its effect increases (BEI decreases) as the tenants' environmental awareness improves. It is considered that this is because in the case where α_{BEI} is not 0, since TA prefers an energy-saving office building, the profits of energy-efficient office buildings are likely to rise, and in addition, the net profit of the building is likely to increase due to the subsidies. Also, as the obligation standard gets stricter, the effect of grant subsidies will increase. Especially when Subsidy is 2/3 of initial cost, energy conservation progresses greatly.

On the other hand, regarding α_{BEI}, when the BEI standard is 0.7 or less and subsidy is other than 2/3 of the initial cost, it hardly contributes to energy conservation. This is because most of the initial building have BEI from 1.0 to 0.7, and if the standard is enforced at 0.7 or less, it is built in the building of obligation standards regardless the tenants' preference.

Table 3. *The examined patterns of simulation*

							The number of patterns
standard	1	0.9	0.8	0.7	0.6	0.5	6
BELS	0	0.3	0.6	0.9	-	-	4
subsidy	0	1/3	2/3	-	-	-	3

All set of simulations; 6*4*3 = 72 patterns

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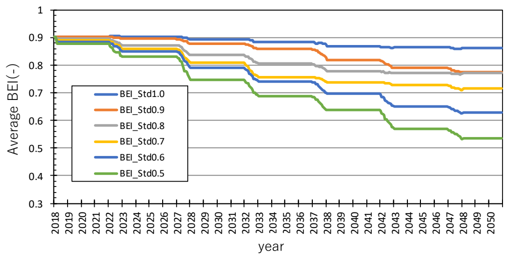

Figure 3. average BEI from2018 to 2050 in each standard compliance BEI

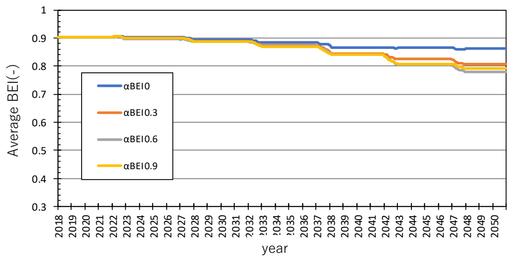

Figure 4. average BEI from2018 to 2050 in each preference to BEI

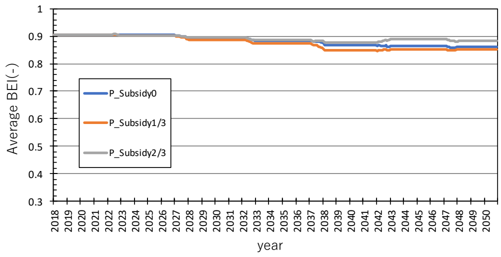

Figure 5. average BEI from2018 to 2050 in each subsidies

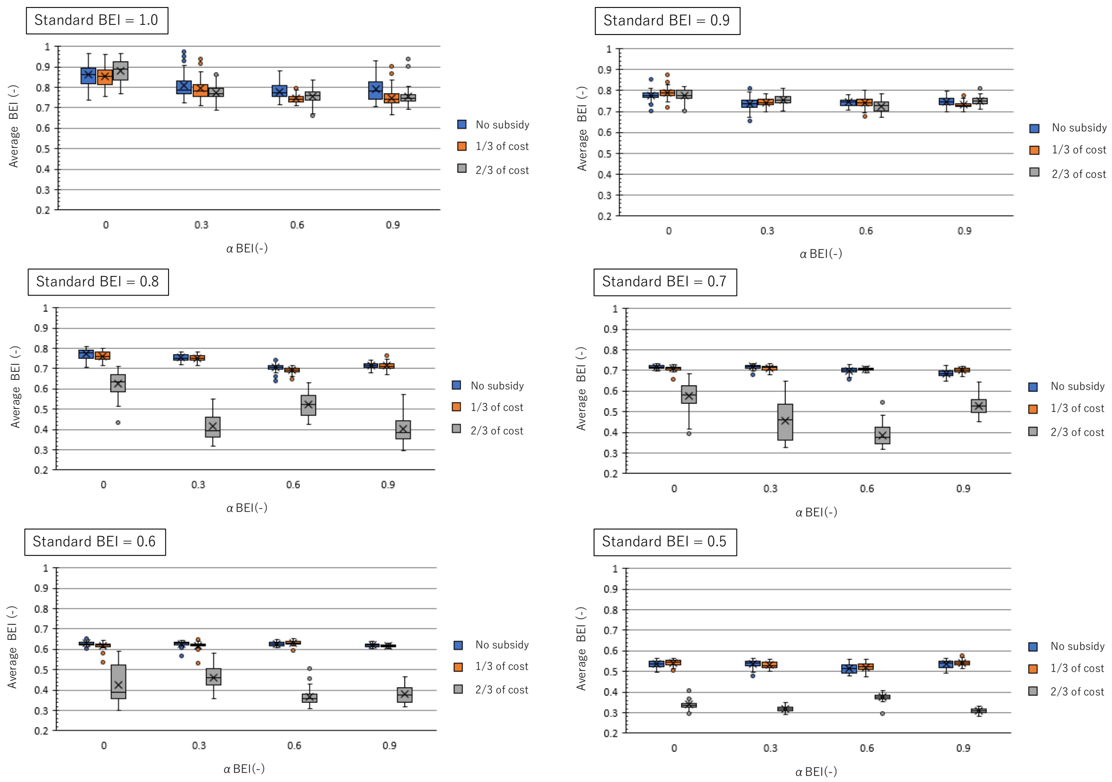

Figure 6. average BEI at 2050 in each policy

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4. Conclusion and implications

In this study, using the agent-based model, we construct a virtual space made of building owners and tenants. Then using it, we analyzed the effect of each energy saving measures and their combinations. We found that it is difficult for energy conservation to proceed with subsidies alone, but with the standard obligation it progresses energy conservation greatly. We also found that the effect of tenants' preference will decrease when the obligation standard becomes strict.

However, since this research includes many simplifications and assumptions, the problem remains with the accuracy of the predicted value. For the further investigations and analyzes, we consider that more detailed and large-scale simulation is desirable.

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