# Simulation Research on the Effect of Energy Saving Policy in Office Building based on Dynamic Game

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## ABSTRACT

Aiming at the difficulty of energy management in office building and the choice of energy saving policy, this paper used the Dynamic Game Theory to establish the game model between the manager and the user, which is focusing on the effect of energy saving policy in the micro level. Based on the actual situation of the certain office building, this paper makes use of the developed multi-agent simulation model to analyze the effect after the implementation of energy-saving policy. It provides a theoretical tool which has the practical value for the scientific decision-making of the energy-saving policy for the office building manager. The simulation results show that the user's willingness to cooperate with energy-saving policy is a crucial factor affecting the implementation of energy-saving policy and the reduction of energy consumption.

*Keywords--* Effect of energy-saving policy; Dynamic Game; Simulation Analysis; Office Building

# I. INTRODUCTION

At present, the research on energy-saving policy in building mainly focuses on the evaluation of policy effect and the game analysis of stakeholders[1-3]. Foreign scholars have realized the organic combination of normative research and empirical analysis to the energy-saving and emission-reduction policy of buildings, and the effect of policy implementation has been evaluated from various angles[4-7]. Domestic scholars will pay more attention to the analysis of stakeholders in the construction energy-saving policy. Xu Xiaolin [8]focuses on the various stakeholders and their behavior choices in the energy-saving of public buildings; Wang Sufeng[9] established two models which are the government construction enterprise group asymmetric game and construction enterprise-building user game, and focused on the design of government policy guarantee mechanism. The existing research methods mainly consider the game-player's complete rationality and analyze the game relation of stakeholders under energy-saving policy. However, considering that there are almost no real rational stakeholders in real life, the strategy is the result of continuous learning and adjustment. Therefore, it is more meaningful to discuss the game process of the limited rational stakeholder. In terms of research content, the existing research focuses on the macro stakeholder such as enterprise group and government, lacking the attention to the more micro stakeholder such as users and managers.

The game analysis of energy-saving strategies between users and managers in office buildings has guiding significance for explaining the mechanism of decision-making and making scientific decisions for strategies. Regarding the evaluation of policy implementation effects, public policy simulation is also one of the methods for studying policy effects. It can accurately represent and manipulate the variability, relevance and complexity of social systems, and also has been successfully applied in economic, social and other fields[10-13]. Therefore, based on the previous researches, this paper builds an evolutionary game model between managers and users based on dynamic game theory, and focuses on energy saving policy research at the micro level, applying multi-agent simulation method to the study of energy-saving policy implementation effects.

### Analysis of the Game Behavior of Users and Manageress in Office Building

In the energy consumption system of office

buildings, there is conflict and cooperation between users and managers, and users can freely control their own efforts in alternative behaviors. In this relationship, the final result depends on the game analysis of behavioral choice strategies between them. In this process, the decisions of stakeholders occur in a sequential order and are subject to dynamic changes. This paper chooses dynamic game theory to study the game behavior between users and managers. As a methodology, dynamic game theory mainly studies the dynamic behavior selection strategies between different stakeholders in the relationship between cooperation and conflict, and studies its equilibrium convergence problem according to the behavior characteristic and target pursuit of each participating subject. In the office building scenario, managers and users belong to the decision-making between the two groups when implementing energy-saving policies and incentives. The managers decide whether to implement energy-saving incentive policies, and the users decide whether to conduct energy-saving behaviors.

### 1.1 Basic assumptions of the game model

Assumption 1: The main stakeholders of the game are the office building energy managers and user groups. After the manager issues an energy saving policy, the user group has the option to cooperate with the choice of energy saving behavior, or not to cooperate. There is a process of mutual learning and mutual adjustment between the two groups.

Assumption 2: Managers not only focus on maximizing the own economic interests, but also focus on reducing energy consumption, increasing awareness of energy conservation, and sustainability of social resources. The user belongs to the bounded rational group, and the decision of each individual among the user groups is inevitably affected by the decisions and behaviors of other users. Therefore, the user adopts the strategy in the dynamic adjustment, the result is better than the average strategy will gradually be more players adopt. The proportion of players using a variety of strategies in the user community changes.

Assumption 3: Two groups of office building energy managers and users have their own set of pure strategic choices. The manager's pure strategy selection set is {take energy saving policy, no energy saving policy}, and the user's pure strategy selection set is {select energy-saving behavior, not energy-saving behavior}. The proportion of managers adopting energy saving policy is Y, the proportion of non-energy saving policies is 1-Y; the proportion of users in the group is X, and the proportion of non-cooperation is 1-X.

Assumption 4: There are two types of means adopted by managers: (1) Positive incentive measures can be that managers set up energy-saving incentive funds to materially reward users with outstanding performance. (2) Punishment measures can be monetary punishment or verbal warnings, which directly affect the psychological comfort of energy users.

### 1.2 Game Model Construction

Based on the above hypothesis, a game model between the manager and the user is established, as shown in the table.

Table 1 The Game Model of Managers and Users' Benefits in the Scenario of Office Building Energy Consumption

| | | Manager Adopt energy saving policy（Y） | No energy saving policy（1-Y） |
|---|---|---|---|
| User | Choice energy saving behavior（X） | （$Q + U + S_1$，$P + P_2 - U$） | （$Q + S_1$，$P + P_1$） |
| | No energy saving behavior（1-X） | （$Q - C_1$，$P - U$） | （$Q$，$P$） |

1. When the manager does not adopt the energy saving policy and the user does not choose the energy saving behavior, the manager's income is P; the user's income is Q.

2. When the manager adopts the energy saving policy and the user does not choose the energy-saving behavior, the manager's income is P-U, and the user's income is $Q - C_1$. U is the cost of the energy saving policy for managers. Since there are negative penalties in the policy, when the user does not choose to cooperate, the manager will impose the penalty and the user's income will be affected. $C_1$ is the loss of user income.

3. When the manager does not adopt the energy saving policy and the user actively choose the energy saving behavior, the manager's income is $P + P_1$; the user's income is $Q + S_1$. P1 is the incremental energy saving benefit brought by the user's initiative to choose cooperation, such as the user's energy-saving awareness, saving energy consumption。

4. When the manager adopts the energy saving policy and the user actively choose the energy saving behavior, the manager's income is $P + P_2 - U$; the user's income is $Q + U + S_1$. P2 indicates that the manager implements the incentive policy, and

after the user cooperates, the incremental income of the energy saved by the manager, usually $P_2>P_1$。

For the user, the expected payoff of choosing cooperation in a group is $U_{M1}$, and the expected payoff from choosing not to cooperation is $U_{M2}$. The average expected benefit for the user group is $U_M$, then:

$$U_{M1} = Y*(Q+U+S_1)+(1-Y)*(Q+S_1)=Q+S_1+YU \quad (1)$$

$$U_{M2} = Y*(Q-C_1)+(1-Y)*Q=Q-YC_1 \quad (2)$$

$$U_M = X*(U_{M1})+(1-X)*U_{M2}=X*(S_1+YU+YC_1)+Q-YC_1 \quad (3)$$

$$U_M = X*U_{M1}+(1-X)*U_{M2}=X*(YC_1+S_1)+Q-YC_1 \quad (4)$$

The user belongs to the finite rational group, their optimal equilibrium stabilization strategy must be in the process of continuous learning and imitation. Low-income individuals imitate higher-earning individuals, constantly learning and adjusting their strategies. For users, the proportion of energy saving behaviors X will constantly change. This dynamic change can be expressed by replicated dynamic equation. On the basis of the above expected benefits, the replication dynamic equation for selecting energy saving behavior in the user group is:

$$F(X) = X*(U_{M1}-U_M)=X*(1-X)*(S_1+YU-YC_1) \quad (5)$$

Let $F(X)=0$, we can get the following three stable states:

（1）$X=0$

（2）$X=1$

（3）$Y=S_1/(C_1-U)$。 It means that whatever the value of X is, it remains stable.

The evolutionary stability strategy must not only satisfy $F(X)=0$, but also satisfy $F'(X)<0$.

Therefore, let $F'(X)<0$,we can get:

$$(1-2X)*(S_1+YU-YC_1)<0 \quad (6)$$

①If $Y=S_1/(C_1-U)$, $F'(X)$ is equal to 0, not an evolutionary stability strategy.

② If $Y<S_1/(C_1-U)$, when $(1-2X)<0$, $F'(X)>0$; when $(1-2X)>0$, $F'(X)<0$。

Therefore, X*=0 is an evolutionary stabilization strategy. In other words, users do not actively choose to cooperate.

③ If $Y>S_1/(C_1-U)$, when $(1-2X)>0$, $F'(X)>0$; when $(1-2X)<0$, $F'(X)<0$

Therefore, X*=0 is an evolutionary stabilization strategy. In other words, users will actively choose to cooperate.

For managers, the expected benefit on the choice of adopting an energy saving policy is UN1, and the expected benefit for choosing not to adopt an energy saving policy is UN2. The average expected benefit of the manager is UN, then：

$$U_{N1} = X*(P+P_2-U)+(1-X)*(P-U)=P+XP_2-U \quad (7)$$

$$U_{N2} = X*(P+P_1)+(1-X)*P=XP_1+P \quad (8)$$

$$U_N = Y*U_{N1}+(1-Y)*U_{N2}=Y*(P_2-U-XP_1)+XP_1+P \quad (9)$$

The dynamic equation for replication is:

$$F(Y) = Y*(U_{N1}-U_N)=Y*(1-Y)*(XP_2-U-XP_1) \quad (10)$$

Let $F(Y)=0$，we can get the following three stable states:

（1）$Y=0$

（2）$Y=1$

（3）$X = U/(P_2 - P_1)$。 It means that whatever the value of Y is, it remains stable.

In the same way，let $F'(Y) < 0$

$$(1-2Y)*(XP_2 - U - XP_1) < 0 （11）$$

① If $X = U/(P_2 - P_1)$， $F'(Y)$ is equal to 0, not an evolutionary stability strategy ② If $X < U/(P_2 - P_1)$, when $(1-2Y) > 0$， $F'(Y) < 0$；when $(1-2Y) < 0$， $F'(Y) > 0$。

Therefore, Y*=0 is an evolutionary stabilization strategy. In other words, managers will eventually choose not to engage in energy-saving incentives.

③ If $X > U/(P_2 - P_1)$， 当$(1-2Y) > 0$， $F'(Y) > 0$；当$(1-2Y) < 0$， $F'(Y) < 0$. Therefore, Y*=1 is an evolutionary stabilization strategy. In other words, managers will eventually choose to engage in energy-saving incentives.

### 1.3 Game Result Analysis

Through the analysis of the game between the above managers and user groups, we can use the coordinate axis to draw the evolution trend of the evolutionary game, as shown in the diagram below.
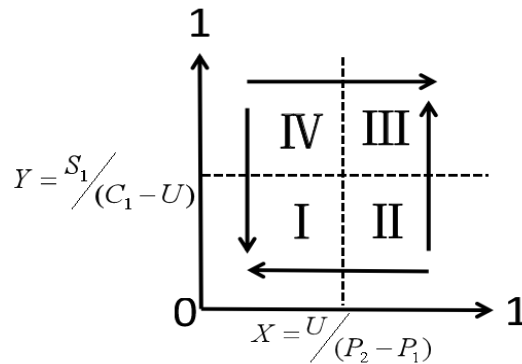


Figure 1 The evolution trend of dynamic game

As you can see in the graph above, there are two evolutionarily stable strategy (ESS) in evolutionary game analysis for both managers and users: (No energy-saving policy, no active cooperation), (energy-saving policy, active cooperation). The difference in the initial state, that is, the difference between the initial ratio of the manager and the user selection decision, the final game model will converge to different evolutionary stability strategies. Detailed analysis is as follows:

① When the initial proportion of the incentive policy adopted by the manager is less than $S_1/(C_1 - U)$, and the initial proportion of the user's cooperation is less than $U/(P_2 - P_1)$, that is, when the initial state is in the I region，the game model will eventually converge to (0, 0)，which means the manager chooses not to take Incentive policy, users choose not to cooperate actively

② When the initial proportion of the incentive policy adopted by the manager is less than $S_1/(C_1 - U)$ and the initial proportion of the user's cooperation is more than $U/(P_2 - P_1)$; or when the initial proportion of the incentive policy adopted by the manager is more than $S_1/(C_1 - U)$, and the initial proportion of the user's cooperation is less than $U/(P_2 - P_1)$, which means when the initial state is in the II region or the IV region, the final convergence state of the game model is not necessarily determined, depending on the learning adjustment speed of the user and the manager.

③ when the initial proportion of the incentive policy adopted by the manager is more than $S_1/(C_1 - U)$, and the initial proportion of the user's cooperation is more than $U/(P_2 - P_1)$, that is, when the initial state is in the III region, the final convergence state of the game model is (1, 1), which means the manager chooses to adopt an energy saving policy, and the user chooses to actively cooperate.

According to the result of the dynamic game evolution trend between the user and the manager, the final convergence result in the game model depends largely on the initial state of both the user and the manager. At

present, the current situation of energy saving for users in office buildings in China is still not obvious, and the proportion of managers adopting energy-saving incentive policies is also small. The two sides in the game model have not entered the III region and cannot converge to (1,1) state. It will be necessary to step up our advocacy efforts, introduce energy-saving incentive policies, increase energy-saving awareness, and increase the ratio of X and Y to promote the game system to enter the III region ,which will be what we need to do.

# II. DYNAMIC GAME SIMULATION MODEL BETWEEN MANAGER AND USER BASED ON MULTI-AGENT

### 2.1 Simulation model agent and research method

According to the analysis of the game model, there are two types of agents in the dynamic game simulation model: the manager agent and the user agent. This paper will adopt the multi-agent simulation modeling method, and use AnyLogic tool to simulate the dynamic game decision-making process between the user groups and the managers.

### 2.2 The attribute and behavior of the simulation agent

The main attributes of managers are: income, incentives for policy.

The main attribute of users are: income, the probability of cooperation in energy-saving behavior. There are three types of user behavior: decision behavior, coordination behavior, and comparative behavior. Decision-making behavior means that each time the user makes independent decisions about energy-using behavior, such as turn on lights. Coordination behavior refers to whether the user decides to implement the energy-saving behavior by cooperating with the manager's appeal. Comparative behavior means before users make a decision, he compares his current earnings with the average income of other users. If the income is higher than the average income, the user tends to maintain the original

decision. If the income is lower than the average income, the user tends to change the decision.

In the model, public variables such as incentives for policy are defined as public information.

**Step 1：** Initialize the attributes of the user and the manager

**Step 2：** Giving users' decision-making behavior

**Step 3：** Giving the user the cooperation behavior when the manager implements the energy-saving policy. The user will choose cooperation behavior with a certain probability.

**Step 4：** Giving the users' comparative behavior。After comparing their income and their average income, user agents decide the choice tendency of the next decision-making behavior.

Step 5： Return to the step2.

### 2.3 Simulation experiment and result analysis of the change of User's Cooperative Will

In the model parameters setting, the incentive of the manager is set as the global parameter, the initial setting is 5. In the model, the initial income of each user is set to 100, and the probability of the user choosing to cooperate is set to 0.5. The decision-making behavior of the user not only brings the benefit to the user, if it cooperates, the income increases, if does not cooperate, the income is reduced. At the same time, the user's decision-making actions lead to the energy consumption of the office building, which is initially set to 0, and the energy consumption of the office building is observed once a day.

On the basis of the setting of the scenario parameters, the user's willingness to cooperate is taken as 0.4, 0.5, 0.6, 0.7, 0.8, and the simulation experiment is carried out to observe the daily energy consumption changes in the office building, and the average of the five groups of experiments is averaged. This experiment is used to explore the form of influence of the user's willingness to change the energy consumption of office buildings. The simulation experiment results are shown in the figure：
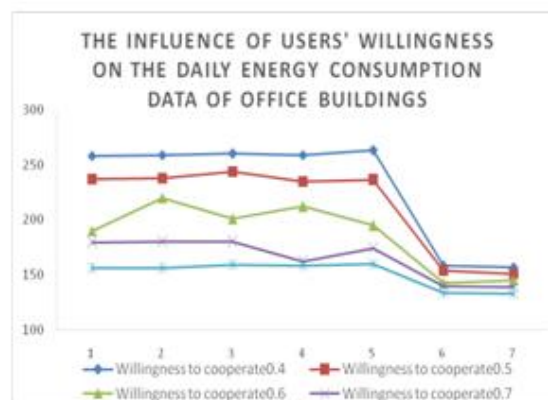


Figure 2 The influence of users' willingness on the daily energy consumption data of office buildings
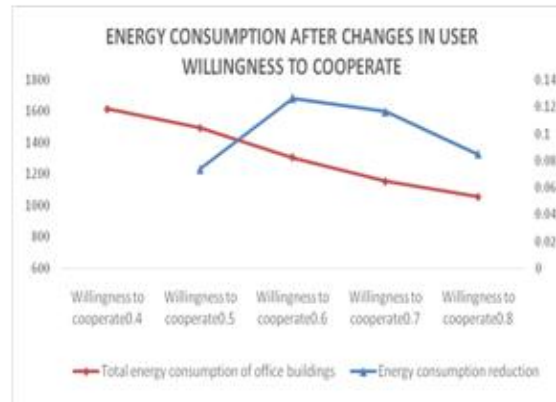
Figure 3 Energy consumption after changes in user willingness to cooperate

It can be clearly seen from the above figure that as the willingness of users to cooperate increases, the amount of energy consumed in office buildings begins to decline. It shows that we can correctly guide the user's cooperation behavior, or carry out appropriate means to improve the user's willingness to cooperate. However, by observing the reduction of energy consumption, we can find that with the increase of users' willingness to cooperate (0.4 to 0.7 in the figure), the increase of users' willingness to cooperate has gradually affected the reduction of energy consumption of office buildings, and the change has gradually increased. When the user's willingness to cooperate gradually increases to 0.8, the marginal contribution of the user's willingness to reduce energy consumption begins to decline and the reduction in energy consumption of office buildings begins to converge. This shows that the marginal contribution of the user's willingness to reduce the energy consumption of office buildings is not a blind increase. In the reality that the user's energy-saving awareness is generally not high, managers can improve the user's willingness to cooperate through the implementation of energy-saving policies, and indirectly improve the energy efficiency within the office building; however, for the user's energy-saving awareness is generally higher, technical improvement And the choice of management strategy may be the main way to improve the efficiency of building energy consumption.

## III.    CONCLUSION

In the scenario of the implementation of energy-saving policies in office buildings, there is conflict and cooperation between users and managers, and users can freely control their own efforts in alternative behaviors. In this relationship, the final result depends on the game analysis of the behavior selection strategy of both users and managers. This paper establishes a dynamic evolutionary game model of the interests of both stakeholders by studying the behavior selection strategies of managers and users in the energy consumption of office

buildings, and carries out simulation analysis through Multi-Agent modeling and simulation methods. The paper concludes with the following conclusions: (1) Through the analysis of the game convergence results, it is found that the initial state of the user and the manager in the evolutionary game model has a great influence on the final game convergence result. (2) The user's willingness to cooperate with energy-saving policies has a crucial impact on reducing the energy consumption of office buildings. Managers should guide energy-saving users from energy and energy, and implement energy-saving policies through the combination of soft and hard means. User's willingness to cooperate, thus reducing the artificial waste in office buildings. (3) Increasing the willingness of users to cooperate has not continued to increase the marginal contribution to reducing energy consumption in office buildings. Managers need to grasp the actual situation of the user's current energy-saving awareness and willingness to cooperate, and "approve according to their aptitude" and take appropriate measures to guide users.

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