A STOCHASTIC MODEL FOR BUILDING OCCUPANCY SIMULATION TO DETERMINING RURAL RESIDENTIAL HEATING DEMAND IN NORTHWEST CHINA

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In order to reduce the heating energy consumption of residential buildings in Northwest China, it is necessary to master the actual indoor heating demand of residents in winter. Reflect residential is established in this paper the main function room if anyone simplified markov chain state probability analysis of mathematical model, through large-scale survey for each main function room state transition probability matrix based data for the state probability of the room, and gets the northwest towns heating demand determine model building heating demand, the result show that the heating demand period is respectively all day in master bedroom, 7:00-22:00 in living room, 0:00-8:00 and 21:00-24:00 in second bedroom. The results can better reflect the residents' indoor heating demand of Northwest China, and can provide reference and basis for the application of temporal and spatial dimensions heating to reduce energy consumption in this type of building.

Keywords: *Stochastic model, Rural residential heating demand, Investigate, Northwest China*

1. INTRODUCTION

In the last 30 years, the Chinese economy has developed rapidly, living standard of urban and rural residents has been greatly improved, accompanied by the rapid increasing building energy consumption[1-2]. Rural building energy consumption has become one of the most important parts of the total energy consumption [3-4]. Currently, the amount of energy used for heating accounts for more than 50% of the total household energy consumption in this region [5].

The indoor personal activities in the buildings of villages and towns have certain randomness, but they also have certain similarity in Northwest China. The living habits and daily schedule of rural residents in Northwest China are different from other regions because of the differences in geographical and environmental characteristics. Therefore, to grasp the characteristics of indoor activity trajectory of residents can be used to analyze the status of the unstaffed rooms in each functional room of buildings in villages and towns, and further determine the heating demand of the room.

Occupancy in buildings is an important factor in estimating building energy consumption [6]. The determination of heating patents in such buildings as offices and schools can also be described by such means. The random schedule and rest method takes into account the randomness of room personnel in time [7], it is difficult to reflect the interaction between time and space. The time-autocorrelation stochastic process model can reasonably describe the work and rest situation of the personnel in a single room [8-10]. But still fails to reflect the interaction between Spaces.

Agent-based model [11-12] and activity-based model [13] can better reflect the interaction between time and space or personnel movement, but the former depends on a lot of research, while the latter needs to know the detailed schedule of personnel activities. The stochastic movement process model [14-15] based on the Markov chain solves the above problems well and can accurately calculate the indoor movement of people in buildings.

There are also studies used to determine the lighting demand of buildings [16] and electricity demand of buildings [17]. These studies all determined the number of people in the room, and the heating of the room depended on whether the room was occupied, this study focused more on whether there were people in the room, rather than how many people there were.

In this paper, a mathematical model of Markov chain room state probability analysis of residential buildings is established, and the calculation method of room state transition probability matrix is simplified in Northwest China. The room state transition probability matrix is determined by using a large number of survey data of residential buildings, and the state probability of each functional room is calculated by the model. Furthermore, the heating demand determination model of buildings in northwest villages and town is determined, which provides a basis for improving indoor thermal environment and reducing heating energy consumption of residential buildings in northwest villages and towns.

2. METHODS

2.1. Markov chain analysis of building room state probability

The movement of personnel in the building has not only certain regularity, but also obvious uncertainty and randomness. The state of each functional room of the building is predicted by the mathematical model of Markov chain.

The random sequence is represented as $\{X(\tau)\} = \{X(\tau), \tau = 0,1,2,\ldots\}$, where the value set S of $X(\tau)$ is called the state space. When there are a finite number of states in the set, non-negative integer numbering is carried out for each state.

In this article, there are two letters to represent the state of functional room: (a) vacant(absence) and (b) occupied(presence). The first (a) state means that there is on person in the room while (b) state means there is someone in the room, which are represented by the numbers 0 and 1, respectively. The functional rooms must occupy one of these two states in every discrete time step. This paper takes one day as the period, and the time step is 1h. Therefore, $\tau = 0,1,2,\ldots,23$.

In order to describe the change of room state with time step, the transition probability is introduced:

$$P_{ij}(\tau) = P\{X(\tau+1)=j \mid X(\tau)=i\} \quad (1)$$

It indicates the probability that each functional room transition to state *j* after a time step under the condition that *τ* time is in state *i*. The size of this value is related not only to the current state of the functional room, but also to time. A schematic picture of the states and of the associated probabilities about one kind of room with various functions is given in **Fig. 1.**

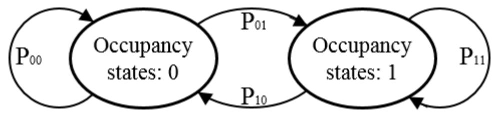

Fig. 1 States and transition probabilities in the Markov-chain occupancy model. Occupancy states: 0 = absent, 1 = present.

In order to improve the model and obtain the state probability of the functional room, the transition probability matrix needs to be given:

$$P(\tau) = \begin{bmatrix} P_{00}(\tau) & P_{01}(\tau) \\ P_{10}(\tau) & P_{11}(\tau) \end{bmatrix} \quad (2)$$

Where $P_{00}(\tau) + P_{01}(\tau) = P_{10}(\tau) + P_{11}(\tau) = 1$.

Then, the probability that the room is in the state 0 at time t+1 is expressed as:

$$P_0(\tau+1) = P_0(\tau)P_{00}(\tau) + P_1(\tau)P_{10}(\tau) \quad (3)$$

And, the probability that the room is in the state 1 at time t+1 is expressed as:

$$P_1(\tau+1) = 1 - P_0(\tau+1) \quad (4)$$

The state probability of the room at the time is expressed by the state probability at the initial time as:

（expressed by the probability at time t=0 and the transition probability matrix）

$$[P_0(\tau) \quad P_1(\tau)]=[P_0(1) \quad P_1(1)]\prod_{\tau=1}^{\tau-1}P(\tau) \quad (5)$$

With the determination of the initial state probability and transition probability matrix, the state probability of the room at any time in a day can be obtained.

Since it is easier to determine the state of the room at each time period than to determine the number of personnel the status of the room at each time period than to determine the number of personnel in the room before, the calculation of the transition probability matrix is determined by statistical analysis of survey data. The state transition probability between each moment can be expressed by the following formula:

$$P_{ij}(\tau)=\frac{N_{(s_i(\tau)\to s_j(\tau+1))}}{N_{s_i(\tau)}} \quad (6)$$

Where N represents the number of samples.

Therefore, the above model is used to calculate the probability of whether the building is occupied or not, which can be further used to analyze whether each functional room of the building needs heating in winter.

2.2. Model of determining residential heating demand

The occupancy-to-heating demand transition model assumes that the calculated room state probability is representative of the state of the whole heating season. The room is determined to be in a person means that the room needs heating, while an unmanned state means that the room does not need heating.

The following relationship exists for the probability of room occupancy:

$$P_0(\tau)+P_1(\tau)=1 \quad (7)$$

There is an interaction between the probability of occupancy and non-probability of each functional room. In the model, the value of the present state transition probability matrix of the body is given. Considering that the probability of occupancy of each functional room directly affects whether it needs heating or not, the need for heating is determined through the comparative analysis of the probability of occupancy of the room at the moment and the average probability of occupancy of the main functional room of the building.

$$\overline{P_1}=\frac{\sum_{1}^{n}\overline{P_{1,k}}}{n} \quad (8)$$

Where n is the number of rooms, k is the Kth room.

Therefore, whether the functional room needs heating at any time.

$$\begin{cases}\text{if } P_1(\tau)\geq\overline{P_1}, & \text{with heating demand}\\ \text{if } P_1(\tau)<\overline{P_1}, & \text{without heating demand}\end{cases} \quad (9)$$

2.3. Simulation calculation process

Through calculation and simulation of the probability of staff in each functional room in a day, then determine whether the functional room needs heating. Given the initial value of the assumed probability of whether a room is occupied or not, the state transition probability matrix of 24 hours in a day is determined according to the survey, and the new initial value of the probability of whether the room is occupied at t=24 is obtained. After repeated calculation until the initial value converges, the corresponding result is the final value of the initial value, as shown in **Fig. 2**. Furthermore, the hourly probability of the occupancy of each functional room of the building is obtained. As shown in **Fig. 3**, according to the hourly probability of occupancy in each functional room, the average value of the probability of occupancy in the building room is obtained, and whether the room needs heating at that time is determined by comparing the hourly probability value with the average value.

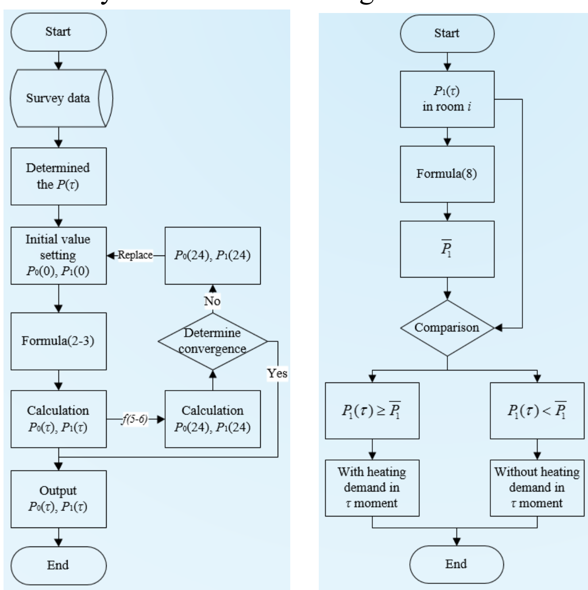

Fig. 2 Flow Chart of Determining Room Occupancy

Fig. 3 Flow Chart of Determining Room State Probability

The markov chain state probability analysis model is not complicated. It is an iterative continuous multiplication calculation. The relative error is less than 0.1% to stop the calculation.

According to the hourly probability of occupants in each functional room, the average value of the probability of occupants in the building room is obtained, and whether the room needs heating at that time is determined by comparing the hourly probability value with the average value.

3. DATA COLLECTION AND ANALYSIS

3.1 Research overview

Questionnaire survey was conducted on the village households in the main regions of the five northwest provinces (Shaanxi, Gansu, Ningxia, Qinghai and Xinjiang) in winter for four years, and the test area of this survey covered the main villages and towns in the five northwest provinces. In the early stage, the total number of villages and towns in Northwest China and the confidence degree of sampling survey were analyzed, and the number of villages and towns for sampling survey was determined based on factors such as climate type, town size, population density, etc. During the survey, a total of 966 questionnaires were sent out successively, and 722 valid questionnaires were taken back.

It is found that the main functional rooms in this kind of buildings include the master bedroom, the second bedroom, the living room and the kitchen. Therefore, four types of functional rooms are taken as the research objects to determine their heating requirements. In the investigation process, the room was taken as the object of observation, and the hourly presence of personnel in each functional room was recorded in the questionnaire.

3.2. The state transition probability matrix

Because it takes a lot of time to observe and record the single-family residential buildings for a long time, and there are some differences among different residential users, the single-family long-term survey cannot fully represent the residential buildings in the northwest villages and towns. Based on the survey records of a random day in the heating season of several residential buildings in northwest villages and towns, this paper calculates the state transition probability according to the survey data, and takes it as the average level of the whole heating season of residential buildings in northwest villages and towns.

The state transition probabilities of the four functional rooms are obtained as shown in **Fig. 4** and **Fig. 5**. It can be seen that the indoor state transition probability of residents' changes grammatically over time, and there is a big difference between different state transition probability parameters of the same functional rooms, and there are also significant differences between different functional rooms.

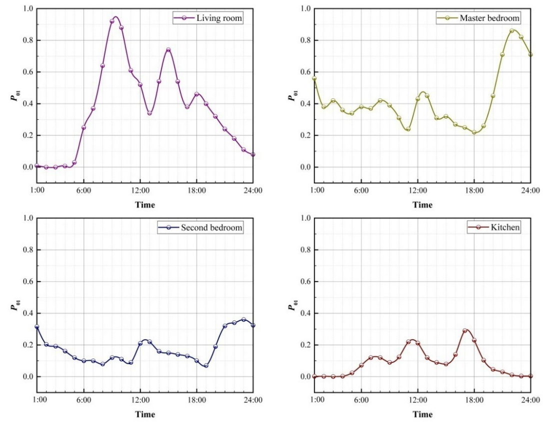

Fig. 4 Probability changes over time form state 0 to state 1 of each functional room

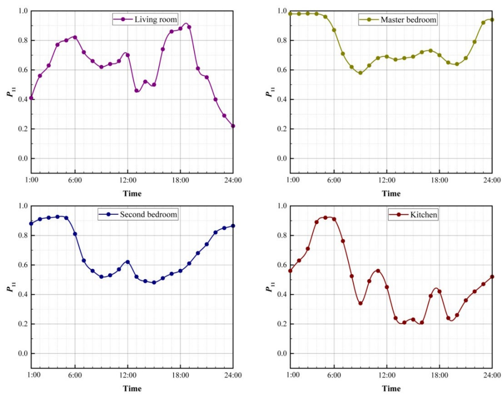

Fig. 5 Probability changes over time from state 1 to state 0 for each functional room

4. RESULTS AND DISCUSSION

According to the calculation flow chart 2 of room state probability, and combined with the survey results of room state transition probability, the state probability results of four functional rooms with personnel distribution can be obtained, as shown in Fig. 6.

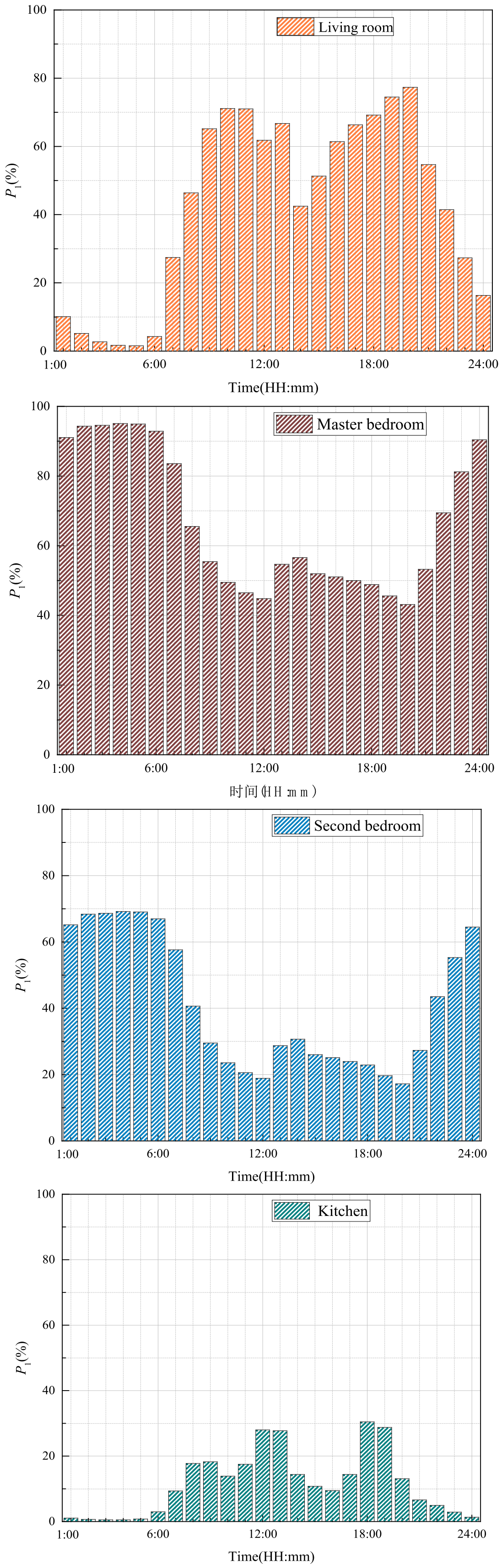

Fig. 6 Personnel distribution probability in each functional room

It can be seen from the figure that there is a big difference in the distribution of personnel in each functional room, and there is a day-night difference over time. From the mean status probability of each functional room in a day. It can be found that the probability of personnel distribution in the master bedroom is the highest, followed by the living room and the second bedroom, and the kitchen is the lowest. Among them, the distribution ratio of master bedroom and secondary bedroom was higher and decreased in day. The sitting room is contrary, which is anastomotic with the law of resident work and rest.

The probability of personnel activities in the master bedroom remained at a high level throughout the day, because the main activities of local residents were in the master bedroom, which has exceeded its regular use functions in the survey. It was found that more households also transferred daily activities such as dining and leisure to the master bedroom, so that the master bedroom maintained a higher probability of personnel activities in the day. There are three obvious peaks in the probability of kitchen personnel distribution, and the maximum rate of personnel activity is only about 30%. Because the time of cooking in the northwest villages is relatively scattered, and some residents transfer cooking activities to other functional rooms

According to the above model hypothesis, if the room is occupied, it means that the room needs heating, and if the room is unmanned, it means that the room is not heated. The probability analysis model of the room state and the calculation model of whether the room is staffed or not can be used to determine whether the four functional rooms need heating. The results are shown in **Fig. 7**. As can be seen form Fig. 7, heating is required for the master bedroom, the living room from 7:00 to 22:00, and the second bedroom from 9:00 to 8:00 and 21:00 to 24:00 in winter in the northwest villages and towns, heating is not required for the kitchen, the living room from 0:00 to 7:00 and 22:00 to 24:00, and the second bedroom from 8:00 to 21:00. It can be seen that there is a great difference between heating and not heating in different functional rooms of buildings in northwest villages and towns. Therefore, it is helpful for residents to supply energy to the space in need of heating and reduce energy consumption of building heating by mastering the rule of whether the functional rooms need heating or not.

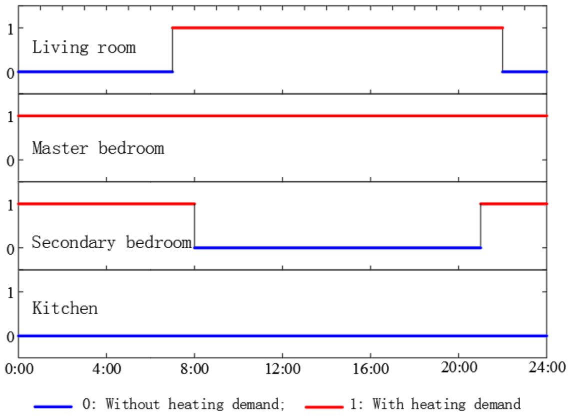

Fig. 7 Heating demand results for each functional room

5. CONCLUSION

In this paper, a large number of field research on residential buildings in northwest villages and towns is carried out, and a Markov chain state transfer analysis mathematical model is introduced to characterize the indoor activity trajectory of residents. Through simplified calculation, the hourly variation rule of the status probability of each functional room with or without personnel was obtained. Furthermore, the actual heating demand period of each functional room was obtained through the residential building heating demand determination model. The results showed that the main bedroom was heated all day long, the living room was heated form 7:00to 22:00, and the secondary bedroom was heated from 0:00 to 8:00 and 21:00 to 24:00, while the other time periods were not heated.

The calculation results of a large number of survey data can reflect the general law of actual heating demand of rural buildings in Northwest China. The research results can provide a basis for the application of time-sharing zoning heating mode to reduce building heating energy consumption in such buildings.

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