THE INFLUENCE OF RURAL BUILDING ENERGY SAVING DESIGN ON CLEAN ENERGY HEATING IN WINTER

by

Rao SHUN*

Jing De Zhen Ceramic Institute, JingDeZhen, China

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Taking a typical rural building as an example, the paper compares various factors that affect the heat load of the building, studies related literature and the living habits of rural residents, and suggests that the calculated temperature of the heating room in rural residential buildings in cold areas in winter is 14~17 ℃. Analyze and compare the initial investment and the investment pay-back period after the thermal insulation measures are adopted for each envelope structure. With the dual goals of energy conservation and economy, it is recommended that rural households with different economic conditions adopt different thermal insulation measures to provide clean heating in rural areas in the cold north. Provide strong technical guidance for energy conservation and emission reduction.

Key words: *heat load, rural housing, envelope structure, clean energy, heating, energy saving*

Introduction

With the continuous development of new rural construction and the improvement of people's living standards, residential buildings in rural areas are increasing rapidly, and the demand for heating in rural areas is also increasing. According to survey statistics, northern rural energy consumption accounts for 56% of the country's total rural energy consumption, and more than 80% of rural energy consumption is used for heating. Since most rural buildings do not take thermal insulation measures and generally use non-centralized heating, the heating equipment is relatively backward, so the energy consumption of rural heating remains high, and pollution is serious. The energy consumed for heating is closely related to the heat load of the building. Taking a typical rural building as an example, this article discusses the main factors affecting the building's heat load by comparing the heat load of the building under different interior design temperatures and different envelope structures. Energy conservation and economy are the dual goals [1]. Through energy conservation and economy analysis, it is recommended that rural households with different economic conditions adopt different insulation measures according to their economic conditions.

Introduction typical rural buildings in cold northern regions

By studying buildings' structural characteristics in the northern region and combining the actual situation, a typical rural building in the region is adopted. The main building plan is shown in fig. 1. It can be seen from the figure that the typical building is mainly composed

* Author's e-mail: 21605511@qq.com

of bedroom – 1, living room, and bedroom – 2. It consists of a building area of 70 m^2, a reinforced concrete flat roof, building height 3.5 m, window width 3 m, height 2 m, outer door width 2 m, height 2 m, inner door width 1 m, and height 2 m. Some scholars have found that the shape coefficient of rural buildings is between 0.58 and 0.88, which is importantly related to the fact that rural houses are independent households and the buildings are mostly one-story and two-story buildings. The figure coefficient of this typical building is calculated to be 0.83, which is higher than the limit of 0.52 (the number of floors ≤3) stipulated in the *Energy-saving Design Standard for Residential Buildings in Severe Cold and Cold Areas JGJ26-2010*, which shows the need for thermal insulation measures in rural buildings [2]. This building's window-to-wall ratio is 0.43, which is slightly lower than the limit of 0.50 (south) in cold areas. Table 1 shows the building parameters. This paper calculates buildings' thermal load by changing the building envelope's materials and properties, studying the factors that affect the thermal load of rural buildings, and provides effective guidance for constructing new rural areas.

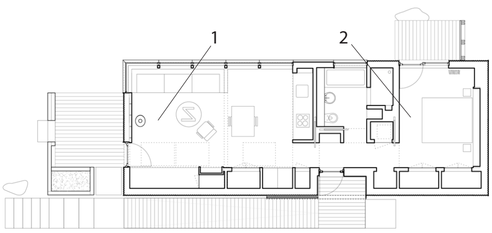

Figure 1. Lay-out plan of a typical rural residential building

Table 1. Outdoor calculation parameters

Heating calculation temperature [°C]	Air conditioning calculation temperature [°C]	Average wind speed in winter [ms^{-1}]	Relative humidity [%]	Atmospheric pressure [Pa]
–5.3	–7.7	2.9	53%	101910

Heat load calculation

Through the basic heat consumption calculation formula of the envelope structure:

$$Q_j = aKF\left(t_n - t_w\right) \tag{1}$$

where Q_j [W] is the basic heat consumption, K [$Wm^{-2}{}^\circ C^{-1}$] – the heat transfer coefficient of the envelope structure, F [m^2] – the heat transfer area of the envelope structure, t_n [°C] – the calculated indoor temperature in winter, and t_w [°C] – the calculated temperature outside the heating.

Additional (correction) heat consumption of the enclosure structure:

$$Q = Q_j\left(1+\beta_{ch}+\beta_f+\beta_{lang}\right)\left(1+\beta_{fg}\right)\left(1+\beta_{jan}\right) \tag{2}$$

where Q [W] is the heat consumption of the enclosure structure after considering various additions, Q_j [W] – the basic heat consumption, β_{ch} – the orientation correction, β_f – the wind correction coefficient, β_{lang} – the two external wall correction, β_{fg} – the additional height coefficient, and β_{jan} – the intermittent additional rate.

The penetration of cold air consumes heat:

$$Q_2 = 0.28V\rho_w c_p(t_n - t_w) \tag{3}$$

where V [m^3h^{-1}] is the total amount of air that penetrates the room through the gaps between doors and windows, ρ_w [kgm^{-3}] – the air density at the calculated temperature outside the heating room, and c_p [$KJkg^{-1}{}^\circ C^{-1}$] – the specific heat of cold air at constant pressure.

The intrusion of cold air consumes heat:

$$Q_3 = 0.278 V_w c_p \rho_w \left(t_n - t_w\right) \tag{4}$$

where V_w [m^{3}h^{-1}] is the amount of cold air-flowing in.

Analysis of factors affecting heat load

The influence of indoor design temperature on building heat load

Due to the planar distribution of rural houses, and some additional rooms such as kitchens, toilets, and other auxiliary rooms are generally located in the courtyard, farmers often need to shuttle between the indoor living rooms and the extra rooms distributed in the courtyard. Besides, farmers often enter and exit. Indoor living rooms and courtyards generally wear thicker clothes in winter. If the interior design temperature is high, farmers will have to change clothes frequently. This is not only inconvenient but also easy to cause a cold [3]. Therefore, rural households' living habits and the distribution of rural houses determine that the interior design temperature in winter should not be too high. Some scholars found that the indoor temperature of rural houses in winter is 11.5 °C, which is seriously lower than the indoor design temperature of urban houses of 18 °C. Houses with an average indoor temperature below 12 °C accounted for 56% of all tested houses, and houses above 12 °C accounted for 48% of all tested houses. The *Technical Guidelines for Energy Conservation of Rural Residential Buildings in Severe Cold and Cold Areas* put into trial operation in 2009 put forward that *the calculated temperature of the winter heating interior design for the main rooms of rural houses is 14~18 °C*. The article stated that the main rooms of rural houses refer to bedrooms and living rooms, and this temperature is used as the calculated temperature for heating design. Many rural survey results show that due to the large difference between farmers' daily life and living habits and urban, the temperature requirements cannot be the same. Many farmers think that a comfortable heating temperature is 14~15 °C. Some scholars have researched the comfortable temperature of the indoor thermal environment in rural houses in severe cold areas in winter and suggested that the comfortable temperature range is 15~18 °C. Through the research of the literature, the thesis sets the indoor building design temperature as 14 °C, 15 °C, 16 °C, 17 °C, and 18 °C to calculate the indoor heat load for comparison. The performance parameters of the main envelope structure are shown in tab. 2.

Table 2. Performance table of the main enclosure structure

Name	Exterior wall	Outside window	Roof	Ground	Exterior doors
Bedroom 1	The plastered brick wall inside and outside surface, K = 1.53	Single-layer glass wooden frame window, K = 4.7	Cast-in-place reinforced concrete slab, K = 0.788	Non-insulated floor	–
Living room	A plastered brick wall inside and outside surface, K = 1.53	Single-layer glass wooden frame window, K = 4.7	Cast-in-place reinforced concrete slab, K = 0.788	Non-insulated floor	Double-layer wooden exterior door, K = 2.33
Bedroom 2	The plastered brick wall inside and outside surface, K = 1.53	Single-layer glass wooden frame window, K = 4.7	Cast-in-place reinforced concrete slab, K = 0.788	Non-insulated floor	–

The calculation results of building heat load at different indoor design temperatures are shown in tab. 3. It can be seen from the calculation results in the previous table that as the interior design temperature increases, the heat load of the same building increases. From the calculation results, it can be seen that for the building, when the interior design temperature increases by one °C, the heat load increases by about 298 W. Since the various envelope structures in this calculation have not taken thermal insulation measures, the calculated heat load index is far greater than the value specified for building energy-saving [4]. Due to the lack of guidance from professional, knowledgeable personnel in construction in rural areas and the limitations of economic conditions, most of the enclosure structures of rural buildings have not adopted thermal insulation measures, which is the main reason for the large heating energy consumption in rural areas. This fully demonstrates the necessity of using thermal insulation measures for building envelopes in rural areas. Based on the calculation results and related literature investigations, the author believes that according to rural areas' living habits, the winter heating design temperature is set at 14~17 °C. This temperature can meet the heating needs of rural areas and meet the frequent needs of farmers. The need for access to courtyards and residential buildings.

Table 3. Heat load calculation table under different indoor design temperatures

Interior design temperature	14 °C	15 °C	16 °C	17 °C	18 °C
Total load [W]	6123.8	6440.9	6758.1	7075.2	7392.4
Thermal index [Wm^{-2}]	87.5	92	96.5	101.1	105.6

The influence of envelope structure on thermal load

From the aforementioned calculation results, each enclosure structure's load can be obtained under the condition of 16 °C. The external wall accounts for the largest proportion of the total load, reaching 54%, followed by the roof accounting for 17% of the total load, then the external window accounting for 15%, and the ground accounting for 15%, the minimum proportion of external doors is 2%. Due to rural families' living habits that require frequent opening and closing of doors to enter and exit residential buildings and courtyards, there was no discussion on the external doors. The following will analyze each enclosure structure except the door.

The influence of external wall structure on building heat load

The thesis sets the heating indoor design temperature of 16 °C in winter and calculates the influence of different envelope structures on the heat load of rural buildings. The exterior wall generally lacks thermal insulation measures in rural houses in cold regions. Even in newly built houses, the exterior wall still lacks thermal insulation [5]. On the one hand, due to the lack of professional and technical personnel to guide, review and supervise the design and construction of rural houses, farmers' self-built houses mostly adopt the common practices of most villagers, on the other hand, farmers' awareness of wall insulation and building energy conservation is weak and lacks professionals. Guidance and publicity, at the same time, economic conditions are also a key reason for the lack of insulation practices in farmers' housing construction.

In this section, three different brick walls with thermal insulation measures are set, namely solid clay bricks (cement polystyrene board), $K = 0.698$, solid clay bricks (polystyrene board), $K = 0.594$, solid brick walls (polystyrene board, Benzene board), $K = 0.441$, the performance of other enclosure structures is shown in tab. 4.

Table 4. Performance table of the enclosure structure

Name	Exterior wall	Roof	Ground	Exterior doors
Bedroom 1	Single-layer glass wooden frame window, $K = 4.7$	Cast-in-place reinforced concrete slab, $K = 0.788$	Non-insulated floor	–
Living room	Single-layer glass wooden frame window, $K = 4.7$	Cast-in-place reinforced concrete slab, $K = 0.788$	Non-insulated floor	Double-layer wooden exterior door, $K = 2.33$
Bedroom 2	Single-layer glass wooden frame window, $K = 4.7$	Cast-in-place reinforced concrete slab, $K = 0.788$	Non-insulated floor	–

It can be seen from the calculation results that when the other envelope structure parameters are kept constant, the thermal load of the building will be greatly reduced by adopting thermal insulation measures on the external wall. For example, the building's thermal load will be reduced by about 38.2%, after the solid brick wall (polystyrene board) is adopted. The heat load of the building of 6758.1 W (which was mainly caused by the large area of the building's outer wall), was reduced to 4181 W. Therefore, it is necessary to adopt thermal insulation measures for rural areas' outer walls in cold areas [6]. Table 5 shows the calculation table of building heat load under different external walls.

Table 5. Calculation table of building heat load under different external walls

Exterior wall materials	1 – Solid clay brick (cement polystyrene board), $K = 0.698$	2 – Solid clay brick (polystyrene board), $K = 0.594$	3 – Solid brick wall (polystyrene board), $K = 0.441$	4 – Ordinary 370 walls, $K = 1.53$
Total heat load [W]	4789.2	4107.6	4181	6758.1
Thermal index [Wm^{-2}]	68.4	64.9	59.7	96.5

The influence of exterior windows on building heat load

The window frame materials of rural houses in cold areas are mainly wood windows, aluminum alloys, and steel-plastics. The window glass forms are single-layer glass and double-layer glass. There are single-layer windows and open glass windows for aluminum alloy windows and steel-plastic windows. The performance and thermal load calculation results of various structural windows are shown in tab. 6.

Table 6. Heat load under different exterior windows

Window frame material	Window type	Heat transfer coefficient [Wm^{-2}k^{-1}]	Heat load [W]
Wood	Single glazing	4.7	6758.1
	Double-glazed windows	2.3	6267.3
	Single window	6.4	7105.7
Aluminum alloy	Hollow glass (air 6 mm)	3.7	6553.6
	Hollow glass (air 12 mm)	3.4	6492.3
	Single window	4.7	6758.1
Steel plastic	Hollow glass (air 6 mm)	2.6	6328.7
	Hollow glass (air 12 mm)	2.4	6287.8

It can be seen from the previous table that the thermal insulation performance of wooden frame double-layer windows is higher than that of wooden frame single-layer windows, and the thermal insulation performance of insulating glass for aluminum alloy windows and steel-plastic windows is higher than single-layer windows and the greater the thickness of the air layer, the greater the thermal insulation performance. Good, so it is recommended to use double-layer wooden windows for windows in cold areas. However, with the development of the economy, more and more aluminum windows and steel-plastic windows are used to construct new rural areas [7]. Therefore, when using aluminum alloy windows and steel-plastic windows, insulating glass windows must be selected within the economic range to minimize heat loss and achieve energy saving and emission reduction. It can also be seen from the table that the effect of different types of windows on the thermal load is smaller than that of the external wall structure. This is mainly because the window area of the model selected in this article is smaller than that of the external wall. The orientation is in the same direction.

The influence of the house on the heat load of the building

The roofs of rural houses in the cold northern areas mainly consist of concrete roofs and wooden roofs, and the main forms of roofs are flat roofs and sloped roofs. Among them, concrete roofs are mostly used in new buildings, and wooden roofs are mostly in old houses. The concrete roofs are in the form of flat roofs used for drying food, and the wooden roofs are in the form of sloped roofs. Concrete roofs are more expensive, while wooden roofs are relatively cheaper. Farmers choose the roof form according to their economic conditions and preferences. The roof selected in this section has cast-in-place reinforced concrete panels, $K = 0.788$, a flat roof (rigid polyurethane foam), $K = 0.578$, a flat roof (EPS board), $K = 0.463$, and the ground is non-insulated. The other envelope structure parameters remain the same, and the calculated building heat load results are shown in fig. 2.

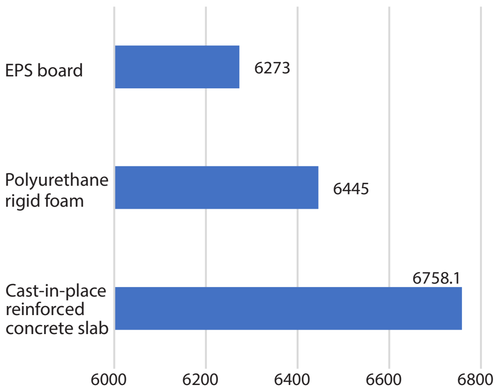

Figure 2. Building heat load diagrams under different roofs

It can be seen from the figure that the better the insulation measures adopted for the roof, the smaller the heat load of the building. After the roof insulation measures adopted EPS board insulation, the building heat load decreased from 6758.1-6273.5 W, and the heat load was reduced by about 7.2%. The decline is much smaller than the decline of the outer wall, mainly caused by the roof area being much smaller than the outer wall.

The influence of ground on building heat load

The indoor floors of rural houses in the cold northern regions mainly include three types: compacted soil, cement floor, and brick-paved floor, basically without insulation measures and thermal resistance is far from meeting the requirements of ground insulation. With the development of the rural economy and the improvement of farmers' living standards, farmers have increasingly higher requirements for the living environment's comfort. Human feet are in contact with the ground most of the time [8]. If the ground temperature is low, it will increase discomfort, make people vulnerable to diseases such as rheumatism and arthritis, and increase the energy consumption of heating. Therefore, it is of practical significance to take thermal insulation measures on the ground. Moisture-proof and thermal insulation measures for the ground are fine stone concrete + environmentally friendly waterproof coating + extruded polystyrene board (K = 1.567).

The calculation results show that the thermal load is reduced from 6758.1-6371.8 W after thermal insulation measures are taken on the ground, a decrease of 386.3 W, a decrease of about 5.72%. The reduction in thermal load after thermal insulation measures is much smaller than the reduction in external walls after thermal insulation measures, as shown in tab. 7.

Table 7. Heat load under different ground

Floor material	Non-insulated floor	Thermal insulation floor (environmental protection waterproof coating + extruded polystyrene board)
Total heat load [W]	6758.1	6371.8
Thermal index [Wm^{-2}]	96.5	91

Energy-saving and economic analysis

After analyzing various factors that affect the building's thermal load, the paper compares the building's thermal load with insulation measures the building's thermal load without any insulation measures. The interior design temperature of the building is set to 16 °C. The calculated result, as shown in tab. 8.

Table 8. Heat load table of each enclosure structure before and after heat preservation

Envelope structure	Area [m^2]	Material	Envelope thermal load L_{otus} [W]	Heat load per unit area H_e [Wm^{-2}]
Exterior wall	117	Ordinary 370 wall	3620.64	30.94
		Solid brick wall + polystyrene board	1043.59	8.92
Outside window	12	Wooden frame single glass	982.12	81.84
		Wooden frame double glazing	491.36	40.94
Roof	70	Cast-in-place reinforced concrete slab	1174.91	16.78
		Cement mortar + EPS board	690.34	9.86
Ground	70	Ordinary non-insulated floor	812.82	11.61
		Environmental protection waterproof coating + extruded polystyrene board	426.58	6.09

It can be seen from tab. 9 that when heat preservation and energy-saving measures are taken for each envelope structure, the building heat load of this typical residential building is reduced by 6758.1 – 2819.5 = 3938.6 W, calculated according to 120 days in the heating season, and the operating time is 12 hours. Save 20.2 GJ, equivalent to 696 kg of standard coal (standard coal calorific value 29307 kJ). However, the initial investment will inevitably increase after adopting thermal insulation measures, so it is not enough to consider only energy conservation [9]. The initial investment of the envelope structure and the investment's payback period must be discussed to obtain thermal insulation measures suitable for rural areas to achieve energy conservation and economy.

Table 9. Heat load table without and without insulation measures

Name	Heat load without heat preservation [W]	Heat load after heat preservation [W]
Total heat load [W]	6758.1	2819.5
Thermal index [Wm^{-2}]	96.5	40.3

The heating in rural areas in the cold northern areas is mainly coal. The coal types are mainly bituminous coal and anthracite. The burning of coal will cause serious air pollution. The heat load of a building is directly related to the amount of coal burned, so the building's heat load is discussion and research on influencing factors is of great significance. Most of the coal used for rural heating is bituminous coal, which has a calorific value of 6000 kcal/kg and a price of 695 CNY per ton. In rural areas, scattered coal heating stoves are diverse, and the measured thermal efficiency varies greatly, with an average of less than 40%, so the thermal heating efficiency is 0.4. According to the villagers' living habits, the heating time is 120 days, and the daily operating time is 12 hours. The economic comparison of various enclosure structures and the pay-back period of investment are shown in tab. 10.

Table 10. Economic analysis of different envelope structures

Building envelope	Exterior wall	Outside window	Roof	Ground	Exterior wall + exterior window
Insulation materials	Polystyrene board	Wooden frame double glazing	EPS board	Environmental protection waterproof coating + etruded polystyrene board	Polystyrene board + double glass
Load after heat preservation [W]	4181	6267.3	6273.5	6371.8	3690.3
Load difference before and after heat preservation [W]	2577.1	490.8	484.6	386.3	3067.8
Insulation material price [CNY per m^2]	60-80	80-90	60-80	80-110	Polystyrene board 80-110, double glass 80-90
The cost of heat preservation [CNY]	7020-9360	960-1080	4200-5600	5600-7700	7980-10440
Energy saving equivalent to bituminous coal [kg]	1330	254	251	200	1584
Pay-back period [year]	8-10	5-6	24-32	40-55	8-10

From the aforementioned table, it can be seen that the initial investment in thermal insulation measures for external windows is the lowest, and the pay-back period is the shortest. Therefore, rural households with poor economic conditions can give priority to thermal insulation for external windows. Due to the large area of the external wall, the initial investment is the largest after the thermal insulation measures are taken, and the economic pay-back period is 8-10 years. Therefore, it is recommended that farmers with better economic conditions can take thermal insulation measures on the external wall, which can reduce the building's heat load to a greater extent. The initial investment of roof and ground insulation is between the initial investment of external windows and the initial investment of external walls, but the investment pay-back period is more than 20 years, so it is not recommended for farmers to heat the roof and ground. For farmers with good economic conditions, it is recommended to take thermal insulation measures for external walls and external windows at the same time so that the building's heat load is minimal, and the investment pay-back period is 8-10 years, which can minimize coal combustion.

Conclusions

This article analyzes the reasons for the large energy consumption of rural buildings in the cold northern regions. Taking a typical rural house as an example, through analysis and calculation of various factors affecting the heat load of rural residential buildings, the dual goals of energy-saving and economic efficiency are adopted. Comparing the energy conservation of the envelope structure, the initial investment, and the investment pay-back period after the use of thermal insulation measures, it is found that the initial investment for external window insulation is the lowest and the pay-back period is the shortest. The initial investment for the exterior wall is the highest, and the pay-back period is 8-10 years. The initial investment in a roof and ground insulation is between the outer window and the outer wall, but the investment pay-back period is more than 20 years. Therefore, heat preservation and energy-saving measures suitable for farmers with different economic conditions are proposed. It is recommended that farmers with poor economic conditions can give priority to the outer window. Carry out heat preservation, such as covering the external windows with plastic film*, etc.* Farmers with better economic conditions can take heat preservation measures for the external walls or external walls and external windows according to their economic conditions. The external windows can be double-layered or triple-layered glass. Polystyrene board or cement polystyrene board can be used. It is not recommended that farmers unilaterally take thermal insulation measures on the roof and ground. By adopting thermal insulation measures for the envelope structure, the building's heat load can be reduced, and significant energy-saving effects can be achieved during the whole life of the building. This kind of insulation measures for the envelope structure cannot be achieved by other energy-saving and emission-reduction methods (such as clean energy for heating*, etc.*). Therefore, residential buildings in cold rural areas in the north should adopt necessary thermal insulation measures for the building envelope within the economically allowable range to reduce heat loss, reducing heating energy consumption, and realizing that the country advocates energy-saving and reduction. The goal of emission and environmental protection.

References

[1] Murshed, M., An Empirical Analysis of the Non-Linear Impacts of ICT-Trade Openness on Renewable Energy Transition, Energy Efficiency, Clean Cooking Fuel Access and Environmental Sustainability in South Asia, *Environmental Science and Pollution Research*, *7* (2020), 29, pp. 36254-36281
[2] Gillingham, K. T., *et al*., The Short-Run and Long-run Effects of Covid-19 on Energy and the Environment, *Joule*, *4* (2020), 7, pp. 1337-1341
[3] Wu, S., Study and Evaluation of Clustering Algorithm for Solubility and Thermodynamic Data of Glycerol Derivatives, *Thermal Science*, *23* (2019), 5, pp. 2867-2875
[4] Dobbins, A., *et al*., Strengthening the EU Response to Energy Poverty, *Nature Energy*, *4* (2019), 1, pp. 2-5
[5] Fawcett, T., *et al*., Energy Efficiency Obligation Schemes: Their Future in the EU, *Energy Efficiency*, *12* (2019), 1, pp. 57-71
[6] Reuter, M., *et al*., Applying ex Post Index Decomposition Analysis to Final Energy Consumption for Evaluating European Energy Efficiency Policies and Targets, *Energy Efficiency*, *12* (2019), 5, pp. 1329-1357
[7] Pollin, R., Advancing a Viable Global Climate Stabilization Project: Degrowth *vs*. the Green New Deal, *Review of Radical Political Economics*, *51* (2019), 2, pp. 311-319

[8] Khasawneh, H., *et al*., Utilization of Hydrogen as Clean Energy Resource in Chlor-Alkali Process, *Energy Exploration & Exploitation*, *37* (2019), 3, pp. 1053-1072
[9] Wu, S., Construction of Visual 3-D Fabric Reinforced Composite Thermal Perfomance Prediction System, *Thermal Science*, *23* (2019), 5, pp. 2857-2865

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