ENERGY SAVING TECHNOLOGY OF WALL INSULATION OF HARBOR BUILDING BASED ON ENERGY COST ANALYSIS

by

Xiangning WANG**, *Qing LIN, and Jing LI

Department of Civil Engineering, Hebei Vocational University of Technology and Engineering, Xingtai, China

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Seaport buildings have been affected by marine moisture for a long time, but most of the wall thermal insulation studies have not considered the moisture transfer effect of the wall structure. Therefore, considering the moisture transfer function of the wall structure and the energy consumption of solar radiation, based on the energy cost analysis, the paper puts forward the research on the wall thermal insulation and energy-saving technology of the harbor building based on the energy cost analysis. Grey clustering is used to analyze the project cost and environmental benefits to determine the index weight. By using two kinds of thermal insulation materials and three kinds of insulation positions, the thermal performance and condensation characteristics of the wall are analyzed. It is found that increasing the thickness of the insulation layer is conducive to reducing the heat loss of the wall. Extruded polystyrene foam (XPS) thermal insulation material is better than expandable polystyrene board (EPS) insulation material, while EPS is more economical and energy-saving than XPS.

Key words*: harbor building, wall structure, energy cost analysis, thermal insulation materials, humidity*

Introduction

The energy crisis in the world and the huge contradiction between China's energy demand and supply make the energy-saving problem get unprecedented attention. China is now in the peak period of urbanization construction. The rapid development of urban construction promotes the rapid development of building materials industry and construction industry. At the same time, the rapid increase of building energy consumption directly leads to more tense energy demand.

Building energy-saving is the most direct and cheapest measure to alleviate energy shortage contradiction, improve people's living and working conditions, reduce environmental pollution and promote sustainable economic development. It is also an important part of deepening economic system reform. Generally speaking, it is extremely difficult to improve the power generation energy-saving by 5% and the automobile energy-saving by 10%, while the building energy-saving can easily reach 50-60% [1, 2]. Domestic scholars pointed out:

*Corresponding author, e-mail: wangxiangning2021@163.com

According to the research and practice of the energy sector in the past 30 years, it is generally believed that building energy conservation is the most potential, most direct and effective way among various energy-saving ways, and is one of the most effective measures to alleviate energy tension and solve the contradiction between social and economic development and energy supply shortage [3, 4]. Therefore, to actively promote energy-saving buildings and reduce building energy consumption has become the focus of attention and research.

The port is a large energy consumer, and energy conservation and consumption reduction have great space and potential. It is necessary to actively respond to the call of the state, improve the energy structure of the port, and promote the transformation and upgrading of the port, from traditional loading and unloading to modernization, intelligent, safe and green direction, which is the basis for the green and low-carbon development of the port. The application of energy-saving technology in harbor construction mainly follows the relevant contents and policies of national environmental protection and energy conservation. Under the guidance of China's relevant building energy-saving standards and engineering construction specifications, the application of energy-saving technology is more and more widely [5]. In the northern port cities, the heating energy consumption of buildings accounts for a large proportion of the total energy consumption, causing great pollution to the social environment. In the process of building construction, the heat loss of the surrounding retaining structure is large, and the wall occupies a large proportion in the external enclosure structure. Therefore, the application of energy-saving and thermal insulation construction technology in the construction of building wall is more important, and it is also the core issue of current research [6]. At present, the economic benefit analysis of building energy conservation is becoming more and more specific [7, 8].

There are two main types of thermal insulation for exterior wall and interior wall. Most of the researches on wall thermal insulation only consider the heat transfer characteristics of the wall structure, without considering the moisture transfer effect of the wall structure and the influence of solar radiation on the heat and moisture transfer of the wall. Only consider the heating energy consumption in winter and ignore the influence of insulation on the cooling energy consumption in summer. Therefore, considering the solar radiation and the total energy consumption of heating and air conditioning, and based on the energy cost analysis, this paper puts forward the research on the wall insulation and energy-saving technology of harbor buildings.

Energy cost analysis method

This paper selects the grey clustering evaluation method to analyze and evaluate the cost-effectiveness of distributed energy. This paper analyzes the total cost of distributed energy from the perspective of project cost analysis and environmental benefit analysis, which lays the foundation for establishing the index system of building wall insulation that affects energy consumption.

Project cost analysis

Energy project cost refers to the capital required to maintain the normal operation of an energy project, which mainly includes the following two parts: initial investment cost and operation and maintenance cost. The initial investment cost is the cost generated by the capital investment during the construction period of the project; The operation and maintenance cost is the maintenance cost to ensure the normal operation in the project operation life cycle. Therefore, the cost of distributed energy projects is calculated:

The calculation formula of project investment cost is:

$$C_v = C_1 + C_2 + C_3 + C_4 + C_5 \tag{1}$$

where C_v is the investment cost, C_1 – the equipment purchase cost of distributed energy project, C_2 – the infrastructure construction cost of distributed energy, C_3 – the installation cost of distributed energy equipment, C_4 – the land development requisition fee, and C_5 – the construction cost of distributed energy grid connection. The annual energy provided by the energy project is the product of the rated capacity of the equipment and the annual effective utilization hours:

$$Q_w = \gamma C_v \rho \tag{2}$$

where γ is the unit capacity factor of the project and ρ is the power of the project equipment.

The depreciation cost of fixed assets in the service life of distributed energy project equipment cannot be ignored. Assuming that the depreciation period is n years, the discount rate is r, and the depreciation cost is D, the annuity formula is:

$$D = \frac{r(1+r)^n}{(1+r)^n - 1} C_v \tag{3}$$

Then, the calculation formula of unit investment cost of distributed energy project is:

$$C_v^{'} = \frac{D}{Q_w} = \frac{\dfrac{r(1+r)^n}{(1+r)^n - 1} C_v}{\gamma C_r \rho} \tag{4}$$

Environmental benefit analysis

When evaluating the environmental benefits of distributed energy, the following related indicators can be set to see the energy utilization efficiency, pollutant emission intensity and environmental improvement degree, and quantitative analysis can be carried out through calculation.

- *Energy conversion efficiency*. Pefers to the ratio between the output W of the effective work of energy conversion and the utilization of primary energy H in the distributed energy system, which is usually expressed by θ:

$$\theta = \frac{W}{H} \tag{5}$$

- *Pollutant emission intensity index*. Pollutant emission intensity refers to the pollutant emission generated by energy consumption per unit of power generation, which is generally expressed in g/kWh, and the calculation formula is usually expressed as:

$$U = \frac{E_t}{W_E} \tag{6}$$

where E_t is the emission of pollutant t and W_E – the installed capacity of distributed energy system. For the energy system using solar energy, wind energy and ocean energy, because it does not produce air pollutants, it is considered that its pollution emission intensity is zero. For the distributed energy system using natural gas, biomass and other energy, due to its comprehensive utilization of energy, it has high energy utilization efficiency, so it produces less pollutant than traditional coal-fired power generation. The intensity of dye emission is also greatly reduced.

Degree of environmental improvement

Energy can improve the efficiency of energy utilization and realize the cascade utilization of energy. The use of distributed energy system in environmental improvement is reflected in two aspects: One is the reduction of pollutants generated by the distributed energy system itself and the other is the reduction of pollutant emission caused by the reduction of system line loss. According to the analysis, it is defined that the ratio of some pollutant emission data is the degree of environmental improvement when the distributed energy system is not connected or connected. The calculation formula is:

$$EIRI_{\mathrm{i}} = \frac{PE_{iw}}{PE_{iwo}} \tag{7}$$

where $EIRI_{\mathrm{i}}$ is the index of environmental improvement degree, PE_{iw} and PE_{iwo} are the emissions of the I pollution gas with and without the introduction of distributed energy system, respectively.

The values of $EIRI_{\mathrm{i}} = PE_{iw}/PE_{iwo}$ and PE_{iwo} can be obtained from:

$$PE_{iw} = \sum_{j=1}^{B} (EG)_j (AE)_j \tag{8}$$

where $(EG)_j$ denote that when the distributed energy supply system is connected and when the distributed energy supply system is not connected, the active power output of the j conventional generator, $(AE)_j$ – the amount of the I pollution gas emitted by the j conventional generator at unit output, and B – the number of distributed energy supply system.

Because the power plant emits a variety of pollutants into the atmosphere during the power generation process, the comprehensive index including all the pollutants is defined:

$$EIRI = \sum_{i=1}^{NP} \left(EI\right)_i \left(EIRI\right)_i \tag{9}$$

where $(EI)_j$ is the weight factor of the I pollutant gas and NP – the total type of the pollutant gas.

By linking the environmental improvement index and its environmental value in the previous formula, the environmental benefits of cogeneration system can be quantitatively analyzed from the perspective of total energy system, which has important guiding significance for the study of total pollution emission control from a global perspective, and provides an operational method for quantitative evaluation of environmental cost or benefit of energy utilization.

Determination of index weight

Considering the correlation between the indicators of the distributed energy project cost-benefit evaluation system, the analytic hierarchy process is finally selected to determine the weight of each index in the distributed energy project cost-benefit evaluation system. Through quantitative analysis and calculation, the influence of uncertainty factors on the system is reduced, and the weight is determined scientifically and effectively, which is suitable for the evaluation of multi-objective complex systems.

Sandwich system of composite wall insulation materials

The wall built by composite thermal insulation brick and block products basically blocks the thermal bridge of the wall mortar joint and reduces the heat transfer area. Compared with the traditional wall, its thermal insulation performance is excellent. Compared with other external wall insulation systems, it can be widely used in load-bearing walls and non-load-bearing walls. Polystyrene foam is used as a thermal insulation wall formed by thermoplastics in the blocks and hollow bricks. The structure layer and insulation layer are integrated to ensure the integrity, weather ability and waterproof performance of the building thermal insulation wall, so that the building thermal insulation system can be built. The service life of the system is consistent with the service life of the building. The wall made of composite thermal insulation brick and block has high bonding strength with mortar, and its external wall facing construction is simple and stable, which solves the problem that the external wall facing of other thermal insulation walls is easy to fall off. At the same time, the wall made of composite thermal insulation brick and block has the advantages of low cost, simple construction, high masonry efficiency, easy detection and quality control, and reduces the construction cost of the insulation system.

The influence of thermal insulation materials and location on the thermal and moisture properties of the wall

China's coastal areas are hot in summer and cold in winter. In order to explore the most suitable external wall insulation structure of a seaport building, this chapter takes the south facing red brick wall of a seaport building as an example. Based on the wall structure, physical properties, meteorological and economic parameters, the heat transfer load, optimal insulation layer thickness, indoor comfort and condensation characteristics of wall interface are studied the relevant research has been done.

Annual cooling and heating load of wall

Because of the high humidity outdoor environment in the hot summer and cold winter area, the moisture content is mainly transferred from the outside to the indoor. In the cooling season, the wet branch condenses and releases latent heat on the surface of the cold coil tube, while in the heating season, the moisture content does not condense and release heat. Therefore, the heat transfer load calculation only considers the latent heat load in summer and ignores the influence of latent heat load in winter.

The change of annual cooling and heating load of wall heat transfer with the thickness of insulation layer is shown in fig. 1.

Because the wall gets heat in summer and loses heat in winter, the corresponding cooling load and heat load are expressed by positive and negative values, respectively. It can be seen from fig. 1 that the heat load of the south facing wall in winter is far greater than that in summer. When the insulation position is different, the cooling load of the wall in summer is between 0.17 MJ/m^2, and the heat load in winter is between 5.5-20 MJ/m^2. With the increase of insulation layer thickness, the cooling load and heat load of three kinds of wall insulation structure are reduced, and the reduction range is more obvious when the thickness of insulation layer is small. This shows that increasing the thickness of the insulation layer is conducive to reducing the heat loss of the wall. Under the same thickness of insulation layer, when the insulation position is different, the cooling load of the wall in summer is basically the same, the heat load in winter is the smallest, the external insulation is the largest, and the middle insulation is in the middle, but the difference of heat load is not obvious. It shows that the position of insulation layer has little influence on the annual cooling and heating load of the wall. The variation of summer latent heat load, total heat load and winter sensible heat load of two different insulation materials with insulation layer thickness is shown in fig. 2.

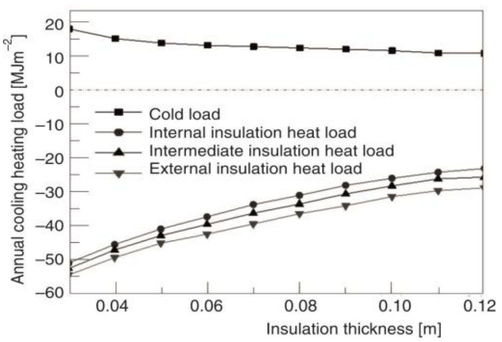

Figure 1. Annual cooling and heating load of walls with different insulation positions

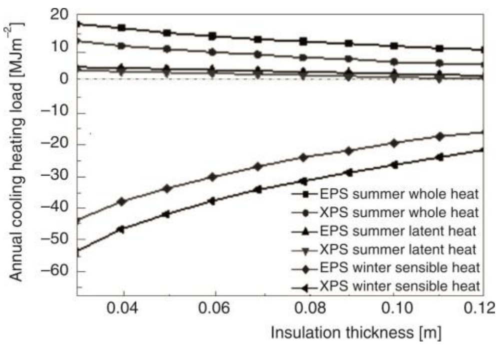

Figure 2. Annual cooling and heating load of walls with different insulation materials

It can be seen from fig. 2 that with the increase of insulation layer thickness, the total heat load in summer and sensible heat load in winter decrease with different insulation materials, while the latent heat load changes little in summer, indicating that the sensible heat load decreases with the increase of thickness in summer. Under the same insulation layer thickness, the total heat load difference between XPS and EPS in summer is about 5 MJ per square meter, and the difference gradually decreases with the increase of insulation layer thickness, and the difference is not obvious. In winter, the sensible heat load of EPS is about 10 MJ higher than that of XPS per unit area of wall every year, and the difference decreases with the increase of insulation thickness. In other words, the type of thermal insulation material has an impact on the annual cooling and heat load of the wall. Under the same insulation thickness, the insulation effect of XPS is better than that of EPS.

Optimum insulation thickness of wall

With the increase of insulation thickness, the heat transfer through the wall will be reduced, the energy conservation of the wall will be enhanced, and the energy consumption cost of heating and air conditioning will be reduced, while the cost of thermal insulation materials will gradually increase. This is related to the annual cooling and heating load of the wall. When the insulation position is different, the cooling load in summer and heat load in winter are basically the same, and the unit price of energy consumption and thermal insulation material are the same. Therefore, the optimal thickness of insulation layer, the minimum investment present value and the maximum earned present value of the wall are the same. It shows that the optimum thickness of insulation layer has nothing to do with the position of insulation layer.

Indoor surface temperature and humidity of wall with different insulation positions

The thermal insulation wall has a very obvious regulating effect on the temperature and humidity of the indoor surface, which can reduce the change range of the temperature and humidity of the internal surface. The change of inner surface temperature will change the indoor average radiation temperature and directly affect the comfort of human body. From the perspective of human comfort, the annual average relative humidity of indoor air is 40-60% [9]. The humidity fluctuation of the inner surface of the wall will affect the amount of moisture released from the wall to the room or absorbed from the room, which will change the indoor relative humidity, and then affect the human skin's sense of moisture, the sense of touch on clothing and indoor air quality, and indirectly affect the comfort of human body.

Conclusion

Based on the analysis of energy cost, based on the theoretical understanding of wall thermal insulation location, thermal insulation materials and their advantages and disadvantages, this paper analyzes the thermal performance and condensation characteristics of the wall when two kinds of insulation materials and three kinds of insulation positions are used. The following conclusions are obtained:

- Increasing the thickness of insulation layer is conducive to reducing the heat loss of the wall, but the location of the insulation layer has an impact on the annual cooling and heat load of the wall. The results show that the time delay and attenuation effect of the wall on the peak temperature is the most obvious when the external wall external insulation structure is used, and the temperature and humidity fluctuation of the inner surface of the wall is the smallest, and the indoor comfort is the highest.
- When the insulation position is different, the best insulation layer thickness of the wall is the same.
- The insulation performance of XPS insulation material is better than that of EPS insulation material under the same insulation thickness and location.

However, EPS is more economical and energy-saving than XPS when the same heat preservation effect is achieved. Among the various structural measures to achieve building energy conservation, external thermal insulation of building exterior wall is the most common and most effective energy-saving structural measures, and expanded polystyrene is the most economical thermal insulation material. This study does not consider the influence of wind in coastal windy areas, which has some limitations. In the future research, we will further study the influence of wind on the thermal insulation performance of building walls.

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