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Climate adaptation research on the energy-saving design of gymnasiums in cold regions

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ABSTRACT

Energy-saving design must be based on regional climate conditions. This study takes the gymnasium in cold regions of northeast China as the research object, by analyzing the temperature, humidity, wind, rainfall and other climatic conditions of cold regions in China and combining with the characteristics of gymnasium, based on the field research, model simulation, data analysis result, and via study on mutual relationship of energy-saving strategies and construction techniques of gymnasium, proposes the envelope insulation, solar utilization, natural ventilation and other related strategies adopted by gymnasium in cold regions of northeast China to cope with local climatic conditions.

Keywords: Climatic adaptation; Cold region of northeast China ; Gymnasium; Energy-efficient design

1. Introduction

The building energy-saving issue has been increasingly focused, followed by increasingly diversified energy-saving technologies, how to make a best choice becomes a hard question, because an inappropriate choice for the energy-saving measure can not only cause a waste of resources, but even result in counterproductive result [1]. The research of this study is to solve this problem. Currently, the energy-saving technologies used for new buildings in cold regions are mainly considered from two aspects, the insulation of the envelope structure and the utilization of renewable energy [2–4]. We select the energy-saving technologies based on the climate condition and building energy-saving strategy simulated by the software. First, to establish a building model and then input the local climate parameters to stimulate the possible energy-saving measure, and choose the optimal energy-saving combination by the way of data comparison and finally, the feasibility of the plan was confirmed through energy consumption comparison.

2. Theoretical analysis of the building energy-saving adaptation to climate

2.1. Concept of the building energy-saving adaptation to climate

The adaptation of building energy-saving to climate originates from the adaptation of building to climate,

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which indicates that the building energy-saving shall adapt to the local climate condition, from which any measures of building energy-saving is constrained. Only when the measures of building energy-saving adapts to the local climate without producing side effect can the building energy-saving bring positive results. The essence of the adaptation of building energy-saving to climate exhibit in two aspects: One is the defensive force against atrocious weather: The ability to maintain a healthy and comfortable indoor environment under the atrocious outdoor condition, that is, reduce the adverse effect of the outdoor climate on the warm comfortable indoor environment by using applicable building means, and the other is the ability to utilize the climate resources, especially the renewable resources as the energy from solar, wind, water, and geothermy, to reduce the consumption of energy resources [5].

2.2. The effect of climate factors on the thermal environment of buildings in cold region

In geography, climatic zones are divided by latitude, and the region above 60 is prescribed as cold zone, but the latitude is not the only factor that affects climate, factors as form of ocean and land, gulf stream, etc. also have dramatic influence on the specific climate characters in every region on earth. According to the internationally prevailing summary, the winter climate of cities in cold region has five basic characters stated below: temperature is normally below 0℃; precipitation is usually in the form of snow; sunlight or daylight time is short; the above three stated characters last a long time; seasonal changes are obvious. The climate analyzing software called Weather Tool developed by Autodesk was utilized to simulate and analyze the climate condition of Harbin, which is typical city in the cold region of northeastern China. Fig. 1 shows the monthly degrees and days of heating and cooling in Harbin, reflecting the monthly building energy consumption of the building. From the comparative analysis in the figure, we see that the months of high-energy consumption in Harbin mainly concentrate in winter, which highlights the importance of thermal insulation for buildings, and Fig. 2 shows the daily temperature degrees and solar radiation, in which the horizontal axis represents the timeline, and the black zone (zone 1) represents the comfortable region of the building. From this figure we can see that the outdoor environment of the building in summer is relatively close to the comfortable region, whereas the great difference in winter indicates that buildings in cold region should strengthen the energy saving and insulation.

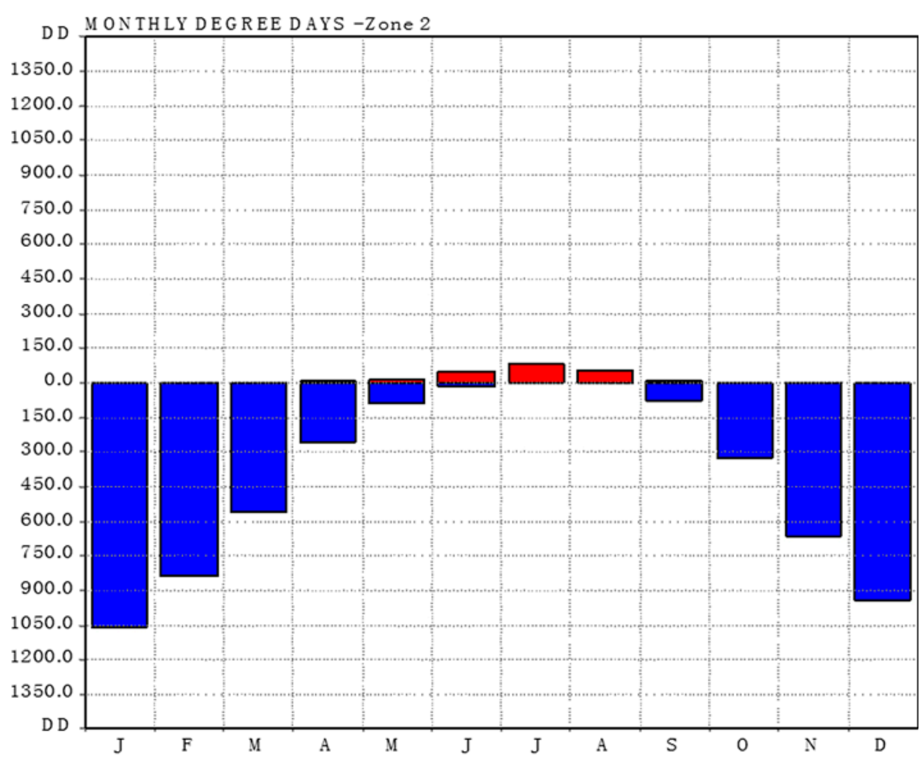

Fig. 1. Monthly degrees and days of heating and cooling in Harbin.

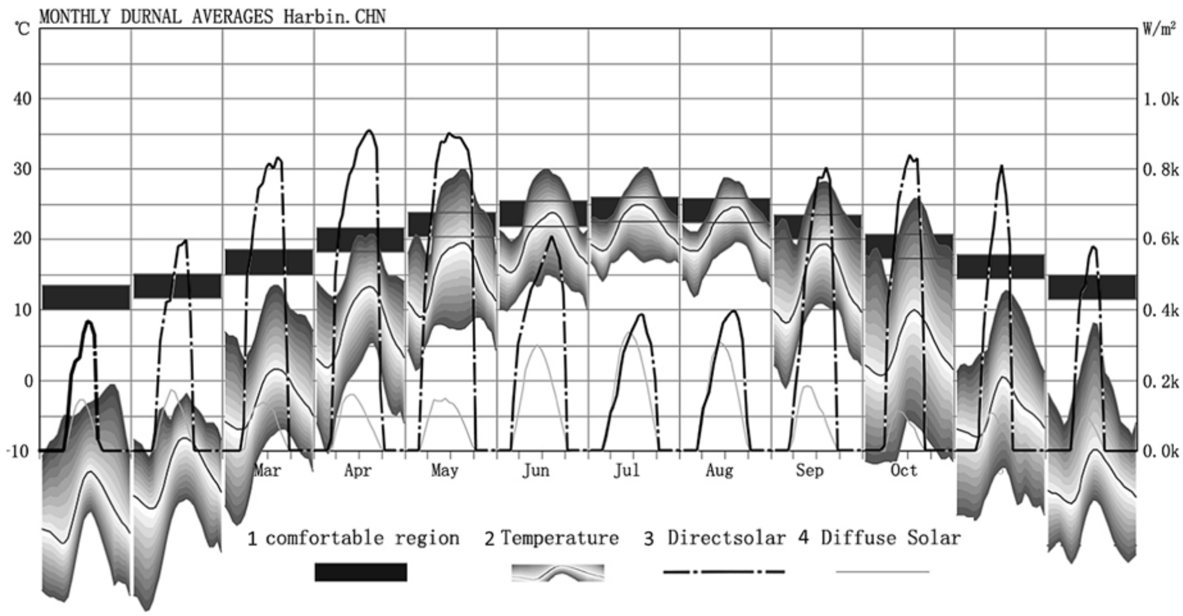

Fig. 2. Daily temperature degrees and solar radiation in Harbin.

3. Climate-based selection of the energy-saving strategy for gymnasiums in cold region

The software simulation was employed for the selection of energy-saving strategy. First, to determine all climatic parameters, then simulate all possibly utilized passive energy-saving strategy, compare the comfortability, thermal environmental performance, and energy consumption of the building under all kinds of conditions, and finally select the optimal strategy combination.

Examples and data in this paper are from the design of transformation for the Gymnasium in Harbin Institute of Technology, Harbin, Heilongjiang Province (Figs. 3 and 4). This gymnasium was built in the early 1990s of last century when the energy-saving measures used were limited, resulting in great energy consumption during its service after establishment.

Fig. 3. Harbin Institute of Technology gymnasium.

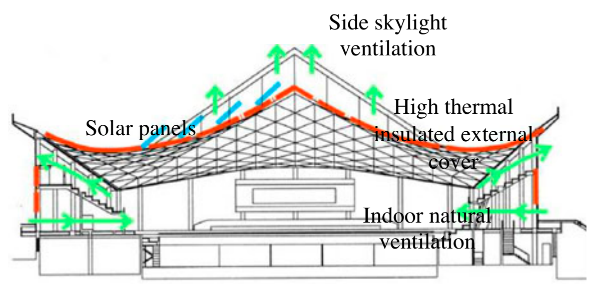

Fig. 4. Design strategy for energy-saving transformation of the gymnasium.

Because the gymnasium is mainly used for physical education, so we assume that there are 30 people in the gymnasium and the lighting equipment is open from 8:00 am–9:00 pm during five working days and 8:00 am–5:00 pm during weekends, and the gymnasium has natural ventilation in the summer. Under such conditions, we analyzed all possible energy-saving strategies for the gymnasium with the software Ecotect, the climate data used in the case was from the China Meteorological Administration Information Center [6] (Fig. 2). We can see the effective degree of all passive energy-saving strategies from the generated psychrometric chart shown in Fig. 4 and in which the horizontal ordinate represents the air dry-bulb temperature (DB, ℃), the vertical ordinate represents the air relative humidity (AH, g/kg), the curve represents the relative humidity (RH,%), the tilt curve represents the air wet-bulb temperature (EB, ℃), where the diagonal is the link between the maximum data and minimum data of every month, frame 7 represents the comfortable region of the internal space in the gymnasium without utilizing the passive energy-saving measures, frame 2 represents the comfortable range after heat storage of the wall body, the line 3 represents the comfortable region after the heat storage and night ventilation, the line 1 represents the comfortable region after natural ventilation, the purple color represents the comfortable region that is directly evaporated, while line 6 represents the comfortable range that is indirectly evaporated [7]. From the figure, we can see that the thermal performance of the wall body improved greatly after the passive energy-saving measures are employed individually, but the difference still exists between different measures. In comparison, the thermal performance of the building improves most obviously by strengthening the heat storage of wall body, utilizing solar radiation and natural ventilation. Based on the three measures, the transformation methods employed are as follows: (1) Strengthening the heat storage ability of the outside cover structure by utilizing highly thermal insulated wall body, roof, and employing double-layer glass curtain wall and low-E glass; (2) setting up solar panels on the slope roof exposed to sun for heating, cooling and lighting; (3) using the side high window and skylight for thermal natural ventilation to reduce energy consumption in summer (Fig. 5).

4. Climate adaptation-based design for the energy-saving for gymnasiums in cold region

4.1. Energy-saving design for the outside cover structure

4.1.1. TIM thermal-insulated external wall system

The TIM transparent highly thermal insulated external wall technology was employed in the transformation design for the gymnasium [8]. The TIM facade system is a new bionic technology, which originates from the simulation of the fur structure of polar bears. The entire external wall facade is composed of light tubes and heat storage wall body of which the light tubes are perpendicular to the wall body, and can transmit the radiative heat from the sun to the external wall which is used as the heat storage body and blocks the heat loss at the same time (Fig. 6(A)). For the purpose of strengthening the effect of heat absorption, the water cycle tube system is added, through which the heat from the light tubes can be better absorbed, and the absorption effect is also strengthened [9] (Fig. 6 (B)). Fig. 7 is the energy consumption comparison between ordinary and TIM external wall. This facade system can absorb heat effectively and is very suitable for urban buildings in cold regions.

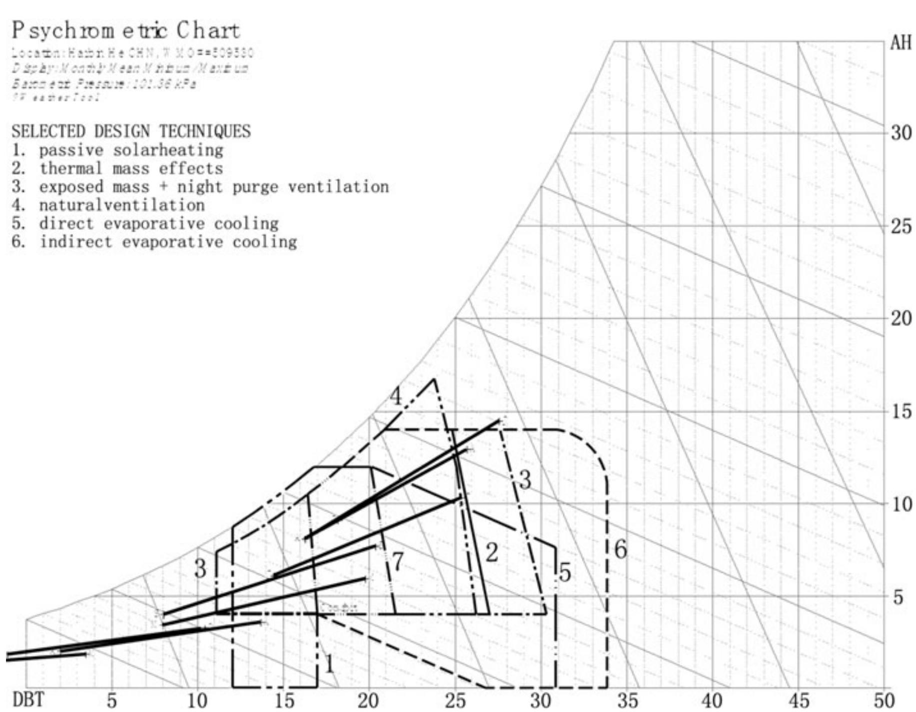

Fig. 5. Comparison of the psychrometric chart of internal space between different passive energy-saving strategies.

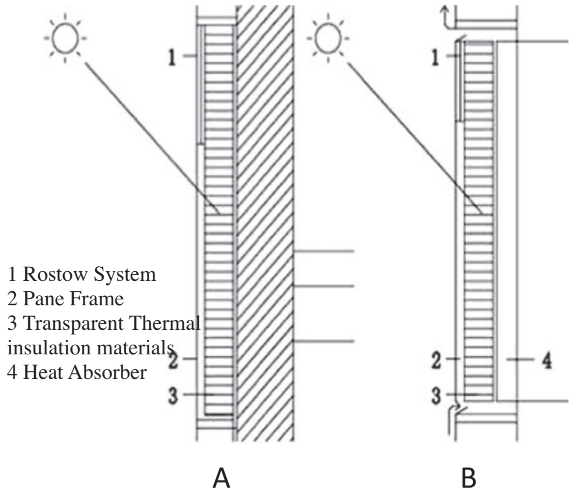

Fig. 6. Structural schematics of tim external wall [8].

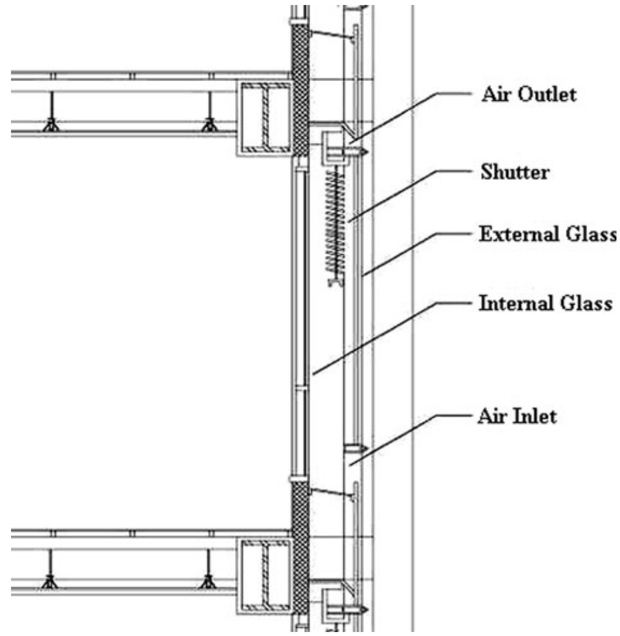

Fig. 8. Structural schematics of double-layer glass curtain wall.

4.1.2. Double glass curtain wall system

Curtain wall is also a kind of outside cover system extensively used in the building of gymnasium. Ordinary curtain wall has poor performance in the aspect of energy-saving but has improved a lot following the advancement of technology. This transformation design uses the double-layer curtain wall system, which is obviously a kind of new energy-saving curtain wall different from the traditional ones (Fig. 8). It is a double-layer structure system, in which there is a specified width of air layer between two layers of glass curtain wall, and the air inlet and outlet device is located at the top and bottom part of the air layer. When the ventilation valve is shut, the entire curtain wall system forms a reliable thermal insulation screen, which can reduce the indoor heat loss in winter, bring down the heating cost of the buildings, reduce the invasion of solar radiative heat in summer, and weaken the effect of the outdoor heat on the indoor environment, thus the air conditioner load is reduced. Compared with the ordinary single layer glass curtain wall, the double-layer curtain wall can save 40–50% of energy while heating, save 35–60% of energy while cooling and get a very obvious energy-saving effect. The low-E glass in the curtain wall greatly enhances the energy-saving performance of the curtain wall. With the heat transfer coefficient of 1.5–0.5 $W/(m^2 K)$, the low-E glass possesses a better thermal insulation effect compared with the ordinary single-layer window with heat transfer coefficient of 5.5 $W/(m^2 K)$ and the ordinary double-layer window with heat transfer coefficient of 2.8 $W/(m^2 K)$, and it can save more than 70% of energy in winter, and more than 6% of energy in summer, thus dramatically enhances the thermal insulation performance of the entire outside cover structure, Fig. 9 is the energy

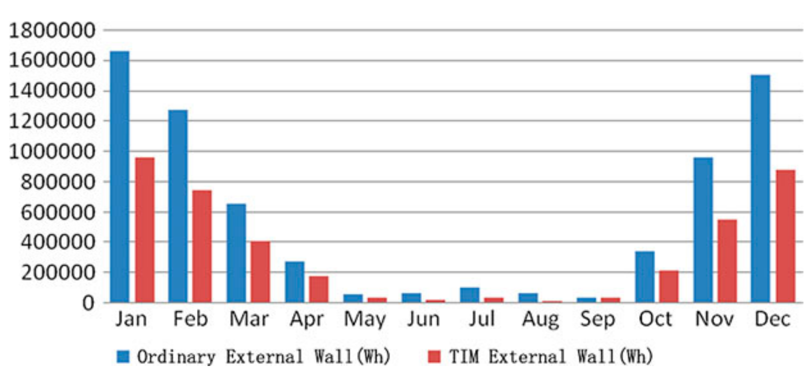

Fig. 7. Energy consumption comparison between ordinary and TIM external wall.

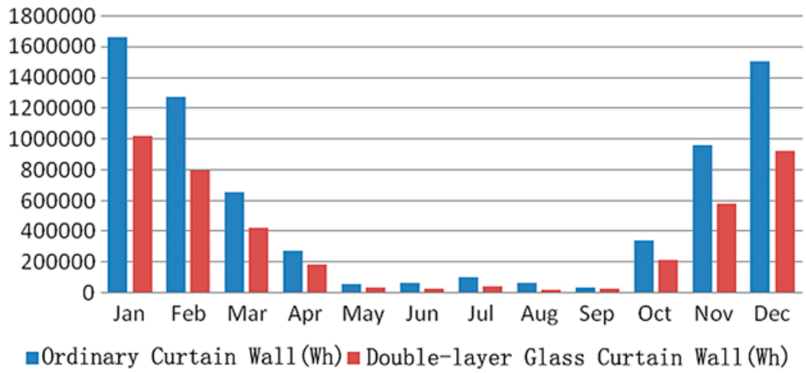

Fig. 9. Energy consumption comparison between ordinary and double-layer glass curtain wall.

consumption comparison between ordinary and double-layer glass curtain wall.

4.1.3. Lightweight composite thermal insulation roof

The principle of the roof energy-saving in cold region is basically the same as the wall body, which mainly improves the thermal performance of the roof to prevent heat transfer. Grass roof, heat storage roof, and double-layer roof are all efficient energy-saving and heat insulation measures but are restricted in the application of large span sports buildings due to their large roof load. The application of lightweight composite materials is focused on in the thermal insulation design of large span roof. In this design, the integrated technology of thermal insulation and waterproofing with stiff polyurethane foam (SPUF), and spray of polyurea elastomer (SPUA) is employed [10]. The SPUF used as the integrated materials with function of thermal insulation, and waterproofing has both the excellent performance of thermal insulation and waterproofing, and the SPUF used as the waterproof decorative material possesses extremely excellent waterproofing performance, so the SPUF–SPUA roof can achieve the integration of heat preservation, thermal insulation, and water proofing, reducing the structural level of the roof and being lighter and more efficient.

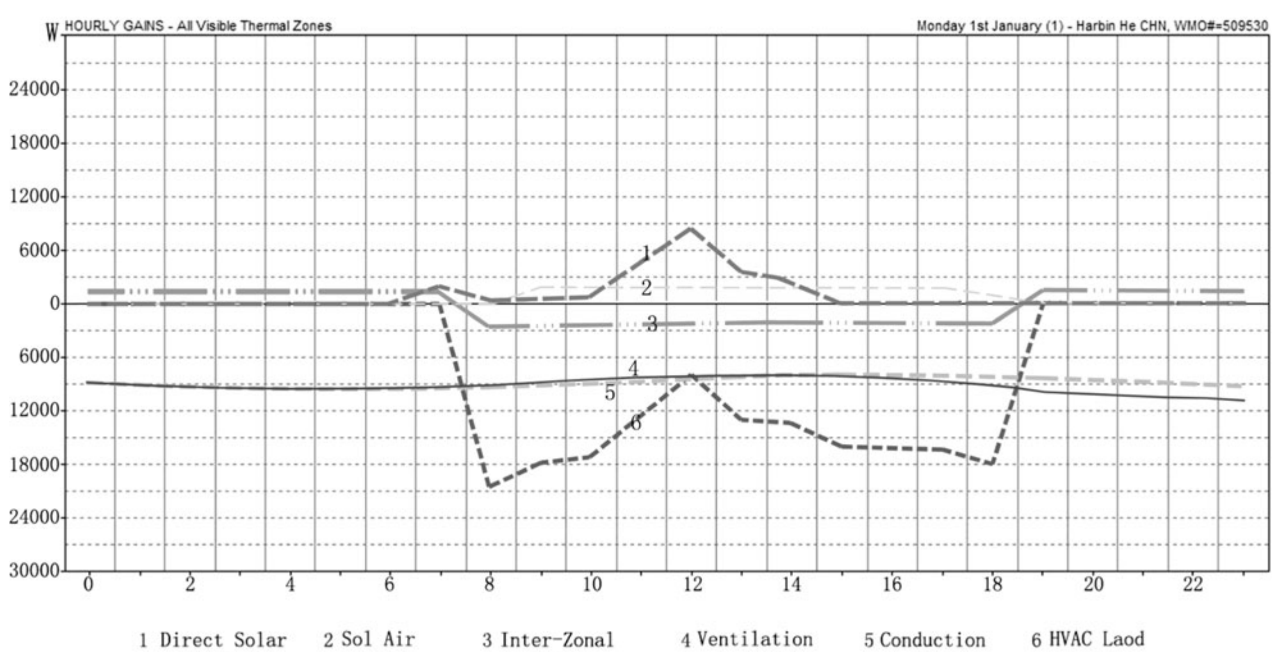

Fig. 10. Analysis of hourly heat gained on winter solstice before transformation.

4.1.4. Evaluation on the thermal performance of the outside cover structure

Following the design of the energy-saving for the outside cover structure, the model was built to simulate the thermal performance. Figs. 10–12 are the generated analyses of building energy consumption, of which, Fig. 10 is the hourly gained heat analysis for the gymnasium without utilizing the thermal insulation structure on winter solstice. Fig. 11 is the analysis of hourly heat gained on winter solstice after transformation of the outside cover, in which the longitudinal axis represents the energy consumption (W), the horizontal axis represents the time (h), and the curve represents the energy consumption of the building in one day. In accordance with the legend for the color, the green curve represents HVAV Load, the red curve represents the heat conduction (conduction) of the outside cover structure, the red dash line represents the heat from solar radiation (direct solar), The dark green curve represents the cold air infiltration (ventilation), the blue curve represents the heat from internal people and equipment (internal), the light blue curve represents the heat between zones (inter-zonal). From the comparison, we can see that the thermal

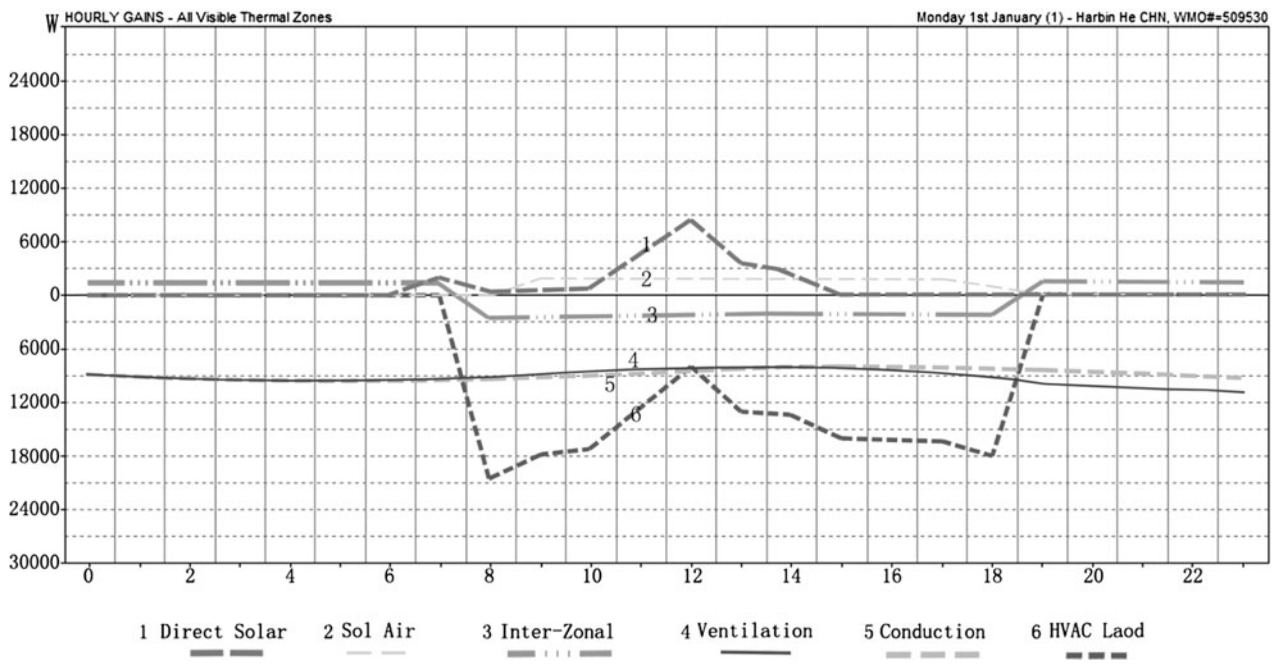

Fig. 11. Analysis of hourly heat gained on winter solstice after transformation of the outside cover.

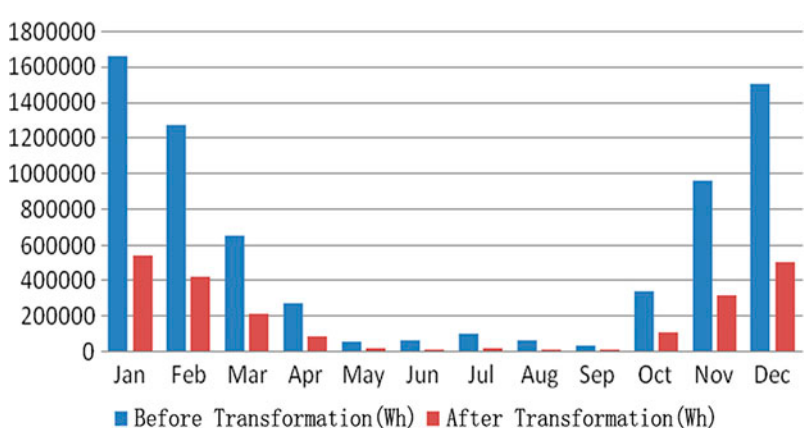

Fig. 12. Energy consumption comparison before and after the transformation of the gymnasium.

performance improves dramatically after the transformation of the building. Fig. 12 is the total energy consumption comparison before and after the design for the transformation of the building, in which the horizontal axis represents month, the longitudinal axis represents the energy consumption, the curve is the link of the energy consumption value between each month, the blue curve represents the modern building, the red curve represents the energy consumption after transformation, the current building consumes a yearly energy of 7005548 Wh, while for the design after transformation, 2295635 Wh.

4.2. Efficient utilization of the climate resources in cold regions

4.2.1. The technology of solar energy utilization

The solar energy can be efficiently utilized by installing PV modules and solar collectors on the outside cover structure of the building. In this design, we use the combination of solar panels and solar collectors, of which solar panel units are installed directly on the Porous corrugated metal plate, where the air is heated and transferred while flowing in the hollow space, and the collector panels utilize the wasted heat from PV panels for the heating and ventilation system of the building with thermal efficiency of up to 50–60%, meanwhile, because of the flowing air, the roof temperature decreased, assisting the PV panels to increase efficiency at lower temperature [11]. Experiments show that installing the PV panels on the collector panels can increase power output efficiency by about 10%. In order to better determine the location for PV panels, the software is simulated. Fig. 13 is the software simulated distribution of solar radiation on the sunny roof of the gymnasium. The warmer the color the stronger the solar radiation, and more appropriate for placing PV panels. Fig. 14 is the expected yearly power generation for this region. The total generation is 1818564 Wh and mainly in the season of spring and autumn.

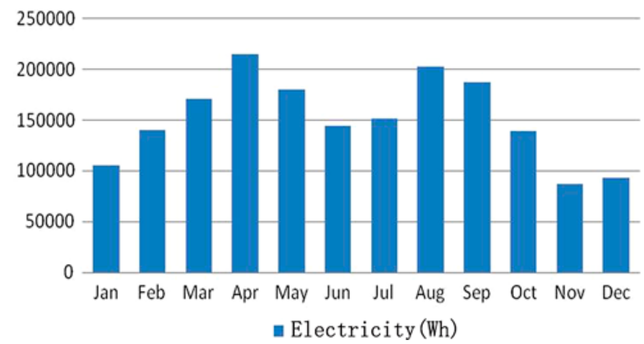

Fig. 14. Yearly power generation of solar pv panels on runny roof of the gymnasium.

4.2.2. Natural ventilation

Natural ventilation possesses the advantages of energy-saving, improving the indoor thermal comfortability and enhancing the indoor air quality.

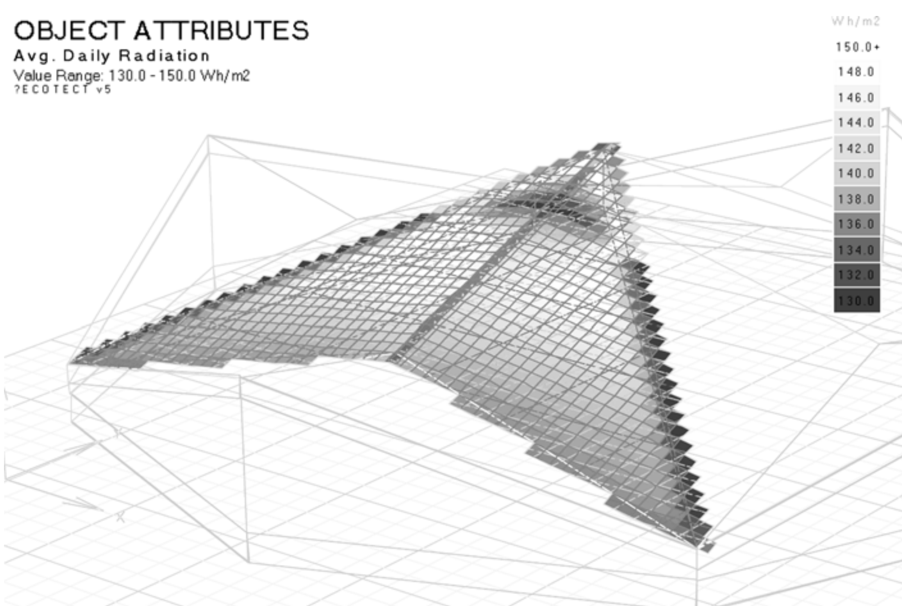

Fig. 13. Distribution of solar radiation on sunny roof of the gymnasium.

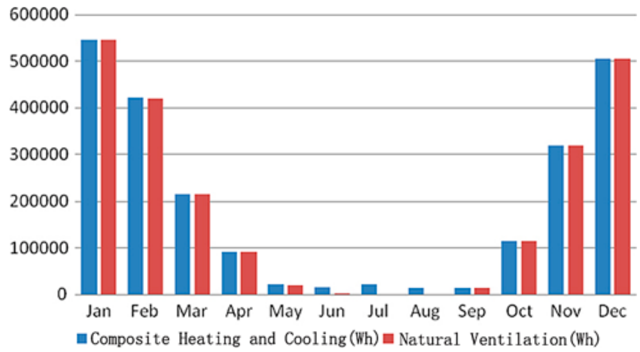

Fig. 15. Energy consumption comparison between natural ventilation in summer and composite heating and cooling.

The main natural ventilation methods for the gymnasium buildings are wind pressure ventilation and heat pressure ventilation. The method adopted in this design is the latter and is also called the Chimney Effect, which produces an indoor and outdoor temperature difference, further produces a density difference, and finally creates the natural ventilation driving force to make air flow [12]. In the design of energy-saving transformation for the HIT gymnasium, the air outlet is designed as the skylight by utilizing the height difference between shell roofs, and the air inlet is designed in the seat region, efficiently decreasing the temperature of the seat region by organizing heat pressure ventilation. Fig. 15 is the energy consumption comparison between AC cooling and natural ventilation in summer, in which the red histogram represents the natural ventilation, and the blue histogram represents the AC regulation. The composite heating and cooling method consumes the energy of 2295635 Wh a year, while for the natural ventilation method, it is 2247822 Wh, so natural ventilation reduces the cooling energy consumption efficiently in summer.

5. Conclusion

Based on the energy efficiency renovation design of the Gymnasium of Harbin Institute of Technology, the selection and application of technical means for building energy conservation in cold regions are explored. Data comparison shows that the increase in the heat storage of walls, utilization of solar radiation and use of natural ventilation are three most powerful measures for improving the thermal performance. The application of TIM curtain walls, double-glass curtain walls and light composite thermal insulation roofing has realized cumulative energy conservation of 2295635 Wh every year and becomes the most effective energy-saving measure. The annual generating capacity of photovoltaic panels is 1818564 Wh, which can provide renewable energy for the gymnasium. The role that natural ventilation plays in the reduction of energy efficiency of public buildings in cold regions is not very noticeable, and it is still an effective measure for reducing the air-conditioning load of buildings in summer. Technical measures for building energy conservation are demonstrated through the data comparison of the actual case, since the gymnasium is special large space public building, the technical measures for the energy conservation of other different space types in cold regions still require further studies.

References

[1] S. Schiavon, A.K. Melikov, Energy-saving strategies with personalized ventilation in cold climates, Energy Build. 41 (2009) 543–550.
[2] T. Olofsson, T.M.I. Mahlia, Modeling and simulation of the energy use in an occupied residential building in cold climate, Appl. Energy 91 (2012) 432–438.
[3] K.K.W. Wan, D.H.W. Li, D. Liu, J.C. Lam, Future trends of building heating and cooling loads and energy consumption in different climates, Build. Environ. 46 (2011) 223–234.
[4] K. Bakirci, B. Yuksel, Experimental thermal performance of a solar source heat-pump system for residential heating in cold climate region, Appl. Therm. Eng. 31 (2011) 1508–1518.
[5] B. Givoni, Climate Consideration in Building and Urban Design, John Wiley, New York, NY, 1998.
[6] China Meteorological Administration Information Center, China Building Thermal Environment Dedicated Meteorological Data, China Building Industry Press, Beijing, 2005.
[7] C. Filippin, S. Flores Larsen, V. Mercado, Winter energy behaviour in multi-family block buildings in a temperate-cold climate in Argentina, Renew. Sustain. Energy Rev. 15 (2011) 203–219.
[8] Q. Zhao, The research of design countermeasure on the sustainable development of the residences in winter cities, Harbin Institute of Technology, Doctoral dissertation, 2007, pp. 68–69.
[9] L. Jing, System optimization-based research on natural lighting and ventilation energy saving for gymnasiums in colleges and universities, Harbin Institute of Technology, Doctoral dissertation, 2010, pp. 45–47.
[10] U. Teoman Aksoy, A numerical analysis for energy savings of different oriented and insulated walls in the cold climate of Turkey—simulation-based study, Energy Build. 50 (2012) 243–250.
[11] Z. Yang, Y. Zhao, X. Xu, B. Zhai, Analysis and comparison of building energy saving reconstruction in hot summer and warm winter regions of South China and cold regions of North China, Energy Build. 54 (2012) 192–195.
[12] J. Wang, X. Xu, Bio-climatic condition-based research on ecological strategy for urban design, Archit. J. 3 (2011) 128–132.