Practical Analysis of a New Type Radiant Heating Technology in a Large Space Building

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Abstract: Recently, building energy consumption and total social energy consumption has increased rapidly and non-renewable energy is becoming exhausted. How can we use energy efficiently to respond to rapid increases in building construction, especially in the fields of heating in large space and building energy conservation? In an attempt to conserve energy and reduce energy loss, it has become necessary to seek effective means of reducing heat loss in energy consumption. The development of improved means of heat transfer, especially using radiant heating, is thus a very important aspect of energy conservation in buildings.

Infrared radiant heating is a new kind of large space heating method. Based on a real heating system design, the initial investment, performance and energy conservation in radiant heating are analyzed. The building's thermal load was calculated by means of new methods and the results are compared with traditional calculation methods. The performance of radiant heating in a large space was simulated and the characteristics are introduced in this paper. The fundamental theory of radiant heating, and the advantages of performance and practical arrangement are introduced in the paper.

Key words: Energy conservation; Infrared rays; Radiant heating; Initial investment; Performance.

1. FOREWORDS

At present, some traditional heating ways such as radiator, air conditioner, heating machine are mainly used for large space heating in China. As is well known, it is irremissible that the traditional convection way and invalid heating loss on the uppers of buildings causes a serious waste of energy when heating in winter since there are wide windows and doors, ultrahigh space, broad span, as well as big heat conductivity when the ways are used in large space and all the uppers of large space buildings have almost an opening each in order to meet the need of ventilation and structure [1]. In addition, the big indoor temperature gradient and serious stratification brings about the phenomenon that indoor air is hot at the upper place and cold at the lower one due to big temperature differences between indoor and outdoor. The temperatures in working and living areas, however, are lower than those at any other place. Thus, it is unable to ensure the efficacy of heating. In regard to the way of hot-blast heating, which is also a kind of heat convection, its working process is just the same as that of a radiator system with the requirement that the working area temperature in the office achieves 16 . The space above 2 m high, however, will also become the target of heating. Hot air will rise because of the difference in density, which causes the vast majority of energy to be wasted. As we know from the references [2], when adopting radiant heating for these large space buildings like hall, airport lounge, exhibition room etc., the gradient in height indoor becomes very small; at the same time, We can not only build a more idealized environment but also decrease the consumption of energy about 15% compared with using convection heating, because of the comprehensive action of temperature and radiant illumination.

2. THERMAL CHARACTERISTICS OF RADIATION HEATING

The fundamental theory of infrared radiant heating system shows that the system imitates the sun to emit the radiation wave whose wavelength is between 2 to 12mm, and the wave propagates rectilinearly at the speed of thirty thousand kilometer per hour. Once it meets an object, a part of it will be

Tab. 1 Relationship between surrounding temperature and radiant Illumination needed by human body

Surrounding temperature（℃）	1 6	14	12	10	8	6	4	2	0	-2
Radiation illumination（W/m^3）	81	122	163	204	244	285	326	366	407	448
Surrounding temperature（℃）	-4	-6	-8	-10	-12	-14	-16	-18	-20	-22
Radiation illumination（W/m^3）	488	529	570	611	651	692	733	773	814	855

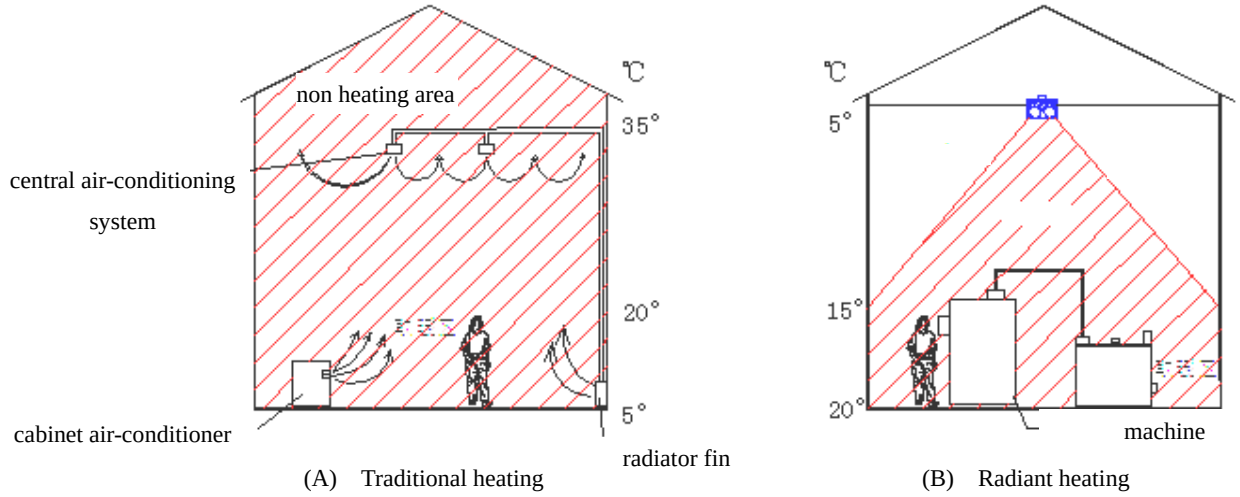
absorbed and transformed into heat, the rest of it willbe reflected. When the infrared radiant goes through the earth's atmosphere, it can be transmitted through the earth's atmosphere instead of being absorbed by the air, and then absorbed directly by objects and changes into heat at the same time. In addition, the infrared radiant can go into a fixed profundity through the surface of an object or a human body and to heat it inside.

Convection heating means mainly heat transmission by the motion in the air. Hence the temperature and the flow rate of the air have something to do with the indoor heating sanitary condition and heat effect. It depends on the indoor temperature when adopting natural convection heating way. Far infrared radiant heating dissipates heat mainly by radiant and also by convection so that we take the realistic induction temperature as the standard for far infrared radiant heating. (Convection heating takes the indoor air temperature as the standard)

The true felt temperature can be obtained through the black ball temperature; the black ball temperature thermograph can be also got from the black ball thermograph or calculated by experimentation. Actual result indicates that true feeling temperature under comprehensive radiation heating can be higher than the indoor ambient temperature by 2-3 when the human body in the comfortable scope. Namely under the same comfortable condition, the true feeling temperature in the room under comprehensive radiation heating can be lower 2-3 than that in the warm house where the convection heating is adopted. Radiation heating in the partial areas in the environment, the corresponding relationship between the surrounding temperature and radiant illumination can be seen in Table 1. As shown in Table 1, the surrounding temperature and radiant illumination can be supplementary in a certain scope. Namely when the ambient temperature is lower, people can also coordinate higher radiation and should pay attention to radiation intensity which a human body can be affected by is less than the allowable value. Therefore, it can be achieved that the person feels same comfortable.

3. COMFORTABLENESS OF INFRARED RADIATION HEATING

According to the research by the parties concerned, it is indicated that a human body's feeling comfortableness has something closely to do with various kinds of heat wet exchanges between the human body and its surrounding environment, e.g. convection, radiation and sweet evaporation and so on. When a total heat dissipated a human body is kept regular, reducing appropriately radiation heating for the human body and increasing correspondingly convention heating a little enables it to feel more comfortable. Upon the heat transfer study, we can also know that the heat radiation of human body depends on the ambient temperature and the flow rate of the air. When radiation heating produces higher temperature on the surface of a human body or/and an object than that produced by convection heating, the human body will reduce right away effective heat radiation outward. Although the surrounding air temperature is lower than the temperature produced when adopting convection heating, some physiological requirements of a human body can happen to be enlarged. Therefore it will feel more comfortable. useful objects by means of radiation



(A) Traditional heating (B) Radiant heating

Fig.1 The comparison between traditional heating and radiant heating

instead of heatir rement of air problems existing in heating for big space buildings, e.g. serious energy waste, low efficiency, high operating cost, huge covered area, arduous installation and maintenance, etc.

Moreover, air transfers weakly with few dust in it and without distribution by the air temperature in warm houses. It's benefit to improve the working condition and environmental sanitation and to do maintenance.

A more comfortable and sanitary air environment can be also provided by heat radiation instead of convection heating. And it is indicated in Reference [3] that the radiation wave can go through a human body skin below 2-3mm, the staff in the office feel not merely the surrounding air temperature but two kinds of functions, i.e. air temperature and radiation heating enable it to feel well and comfortable either at the low temperature.

4. ENERGY CONSUMPTION AND ENERGY-SAVING EFFECT

In radiant heating system, the most attractive advantage is the high energy consumption efficient with excellent heating performance, especially in present energy shortage period.

Because radiation heating creates enough radiation heat intensity in a certain space to maintain heating effect by the form of radiation mainly, the temperature per 1m height of the air in the working area of a building) is less than that of the convection heating so that heat loss in the upper region of a building can be reduced greatly. At the same time, the corresponding cold wind infiltration capacity also reduces because the thermo-compression reduces. And also the actually felt temperature in the building can be lower about 2-3 when using radiation heating than that when using heat convection,(when high temperature radiating, lower 5-10) reducing the heat consumption in the building[4,5]. Therefore, the performance of radiant heating can be considered the most efficient way to heating large space. In the following picture the energy saving percentages is the function of the building height is illustrated.

As shown in Fig. 2, the energy-saving effect is only 20% when a building is only 5 meters high; the energy-saving effect of radiation heating, however, can achieve 68% when the building is up to 25 meters high. It means that the energy-saving effect of radiation heating can be remarkable gradually with the development of radiation heating compared with those of traditional heating ways.

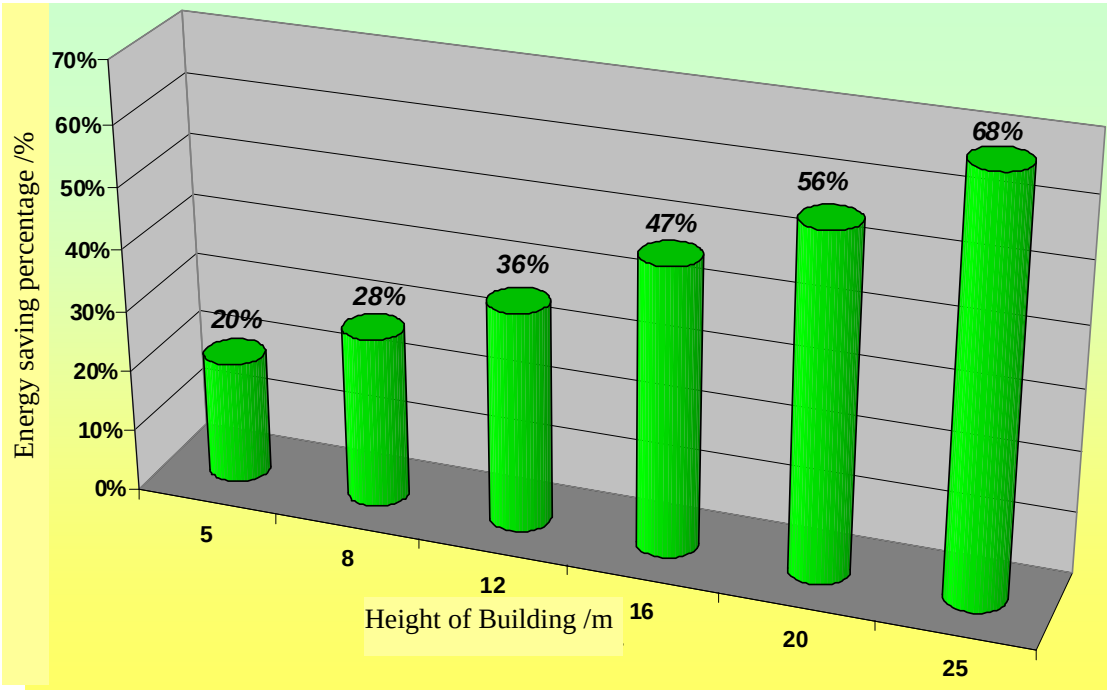


Fig.2 Relationship between high radiation and energy-saving effect

5. ANALYSIS ON RADIATION HEATING TEMPERATURE FIELD

In general, heat convection cannot satisfy with t he requirements of partial heating in a large space and on some special occasions. The radiation heating can send radiated heat directly to a working area; on some special occasions and open-air places, the radiation heating can achieve the effect of convection heating, which is realized with difficulty. However, it depends on mainly the appropriate radiation illumination to maintain this kind of heating effect. For the building with comprehensive heating by radiation, the internal surface of guard structure can be avoided being moist due to the lengthened service life of the building because the internal surface temperature of guard structure is higher than indoor air dew-point temperature.

As shown in Fig. 3 and Fig. 4, heat radiates directly downward when using radiation heating; partial quantity of heat can be saved on the ground. Therefore, indoor air temperature gradient is small and heat loss is also very little in the corresponding building. As shown in Fig. 3 either, there can be the superimposition of radiating heat between two sets of the systems as a result of the radiation-heating characteristics.

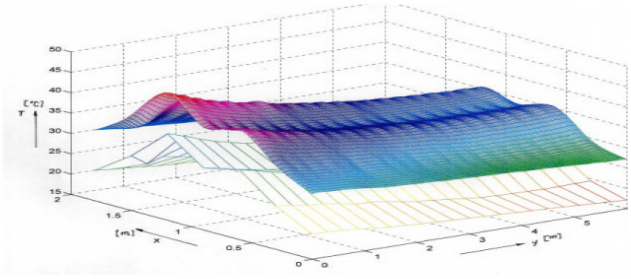


Fig.3 Temperature distribution by means of radiant

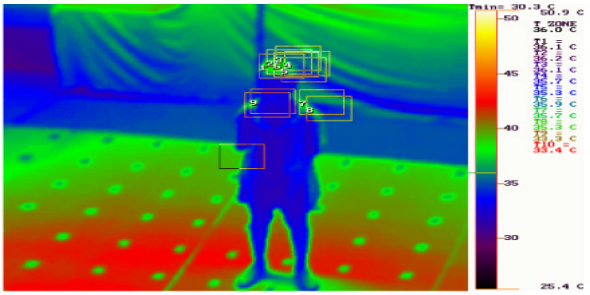


Fig.4 Heat analysis of radiation flux on human body Surface

6. ANALYSIS ON THE SELECTION OF HEATING PLANS FOR SOME BIG BUILDINGS

6.1 Analysis on Heating Effect

The radiation heating system is compared

Tab. 2 Comprehensive comparison of radiation heating system with conventional methods

Type of heating system		High power radiant heating system	Low power radiant heating system	Hot water radiator heating
Application	System structure height limit	Host and radiant tube 8~35m(crane optional)	Burner, fan and heat pipe 5-12m	Boiler + radiator fin 4m
	Heat load ratio of heating way	1.0	1.1~1.4	2.5~3.0
	High temperature retention layer	Within 3m on the ground	Lower space and upper	Heat upper space at first, and then heat lower space
	Use automatic temperature control system	Better, easy to realize	Convenient for small system; complex for large system	Poorer, not good effect
	Operating time	Easy to realize intermittent heating, shorter operating time	Easy to realize intermittent heating, shorter operating time	Low temperature hot water operates continuously, longer time limited
	Space selection of system layout	Very well	general	limited
Influence	On working space	Non	There is no dust, maybe there is smoke	Temperature lamination exists
	On human body	Better comfortableness	There is influence of smoke	Obvious uncomfortableness
Energy	Energy consumption ratio	1.00	1.1~1.50	1.5~2.50
	Preheat time	Shorter	General	Longer
Maintenance	Pipe line and wire in the space	Less	Morn	Very much
	Maintenance and repair	Simple, burner only	A lot, burner only	Burner, boiler and fan

comprehensively with conventional heating ones in Table 2.

Comparing the radiation heating system with other systems, it is indicated that the radiation heating can widely apply in big space buildings, i.e. factory building, sports facility, large-scale demonstration hall, airplane hangar, warehouse, train outfit storehouse, exhibition hall, automobile exhibition hall, greenhouse and so on. Low power radiation heating equipment (46 ~ 60kW) is suited for buildings 5-12 meters high. High power radiation heating equipment (150 ~ 600kW) is suited for buildings 8-35 meters high and also applies in the places with a guard structure and temperature difference and without smoke emission, e.g. exhibition hall, factory building and hangar. In addition, people can divide heating areas, set time, perform temperature control and make intellectualized control plan so as to able to switch on and shut out the equipment at all times and all places and reduce heat loss.

Along with the increase of construction height, traditional heating ways could not already satisfy with the requirements of big space heating. It is obvious that, however, the superiority of radiation heating is appearing suddenly. As shown in table 3,

Tab. 3 Analysis on operating cost comparison between radiant heating and traditional heating

	Plan 1	Plan 2	Remark
Expenses of other power equipment	6 kW/set×14×0.72RMB/kW=60.48RMB/h	Induced draft fan, blower, water pump, etc. =200kW×0.72RNB/kW=144RMB/h	simultaneous serviceability index 80%
Annual electricity cost for system operation	60.48RMB/h×5×0.7×150=36,000RMB	144RMB/h×8×150=172.8RMB	Industrial electricity cost: 0.72RMB/kW
Total cost of fuel, manpower and water for system operation	696,000RMB	1.311 Million RMB	
Total	732,000RMB/a	1.4838 Million RMB /a	
Construction cost/m^2	39.1RMB/㎡	79.3RMB/㎡	

regardless of its limitations, the heating way is characterized by high heat load in the heating, district heating possibility, effect to heat up working area, simple system layout, in to the working space influence, low energy consumption, short preheat interval, easy maintenance, repair and installation as well as long service life. Efficient radiation heating is the best heating way for big space buildings. In summary, the efficient radiation heating can be used as the best heating way in regard to the construction characteristics of this project.

6.2 Economic Analysis of Heating Systems

Economic analysis and computation of several plans is limited only to the comparison of equipment, main engine, pipe network and terminal radiation equipment, initial investment as well as operating cost.The analysis on Plan 1 and 2 in Table 3 are based upon a heating season of 150 days, with systems working approximately 8 hours per day. The total operating time is 1,500 hours. Propane is used as fuel in Plan 1, service factor is 0.7 and fuel price is computed in terms of 4,000 RMB/ton.

7. CONCLUSION

In Europe, people have already been applied far infrared ray radiation heating. It has started to be applied this kind of heating way at home in recent years and it was applied at first in a sports facility. Through Heating directly a radiant tube by burning natural gas and after it is heated up, the tube releases far infrared rays which are benefit to human body health. Although the energy-saving effect of radiation heating is affected on by the internal surface radiation absorption factor of outside guard structure as well as indoor heating temperature [6], this kind of heating way changes the traditional ones that the air in an entire space is heated up completely, directly heats up human bodies and reduces heat losses due to convection, some other heat changes and pipeline. Therefore, its thermal efficiency can achieve above 95%. Since not heating up indoor air, it is specially suited for heating of factory buildings where the conditions of heat preservation and sealing are poor and their gates are opened frequently. The off-on of radiation heating system is controlled completely by a computer. It is able to be achieved that a few radiant tubes are switched on only for working overtime on individual work stations, the others are shutoff automatically, i.e. regional and periodical heating. Nowadays, the far infrared radiation heating becomes a kind of advanced way used for big spatial heating and energy-saving and more popular in the world.

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