The Study on Thermal Performance and Applicability of Energy-saving Wall Materials in Hot Summer and Cold Winter Zones

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Abstract: The **h**ot summer and cold winter zone is a transition zone between the cold zone and hot zone, sweltering in summer and chilly in winter, of which climate is worse. In recent years, with people's raised requirements on indoor living environments, the energy consumption of buildings in hot summer and cold winter zone has been greatly increased. However, the thermal performance of walls in this zone is worse, and thus a mass of energy is wasted. This paper thoroughly analyzes and compares some energy-saving wall materials and thermal insulation systems used in projects in general, according to the climate in the zone combined with the design standard for the walls of residential buildings in the hot summer and cold winter zone. The results indicate that reasonably selecting the applicable wall materials and thermal insulation systems according to the local energy consumption characteristics could optimize resource utilization and have a positive effect on energy efficiency.

Key words: hot summer and cold winter; wall materials; building energy efficiency

1. INTRODUCTION

Energy consumption of building has a very large proportion in total social energy consumption of China, reach to 30%-40%. Therefore, building energy efficiency was granted as an emphasis on the National 5^{11th} Plan, which strives for saving 101 million ton standard coal equivalent to 2010[1]. For a long time, energy consumption of building in China was attributed to the north heating consumption, thus the emphasis on building energy efficiency was put in the north heating zone. However, with the continuous improvement of people's living standards, the problem about energy consumption of building in non-heating zone is revealed gradually.

Hot summer and cold winter zone is transition zone between cold zone and hot zone, sweltering in summer and chilly in winter, of which climate is worse. In recent years, with people's raised requirements on indoor living environment, the energy consumption of building in hot summer and cold winter zone was increased greatly. However, the thermal performance of walls in this zone is worse widely, thus large amounts of energy were wasted. Therefore, "Design standard for energy efficiency of residential buildings in hot summer and cold winter zone" (JGJ 134-2001) (hereinafter referred as Standard) was implemented on October, 2001 and the application of new wall materials with well thermal performance was promoted greatly, all of which played an important role on decreasing the waste of building energy consumption.

Exterior wall is a main part for energy loss, thus the thermal performance of exterior wall has an important influence on the energy-saving effects of building. Heating and cooling consumption have different proportion among different areas of hot summer and cold winter zone by the different climate. As a result, wall materials and thermal insulation systems should be chosen according to the characteristics of climate and energy consumption, by which utilizing wall materials better, optimizing the performance of thermal insulation systems and having a good effect on energy efficiency.

2. COMMON WALL MATERIALS

With the prohibition of solid clay brick and the development of building energy efficiency, all kinds of new wall materials are gradually promoted and utilized everywhere. Presently, the wall materials used in hot summer and cold winter zone mainly include the following products.

2.1 KP1Sintered Perforated Brick

KP1 sintered perforated brick, as common clay brick, is mostly made of clay, set pore inside and shaped bearing block with definite voidage after roasting. It is one transition material because of the prohibition of common clay brick. KP1 sintered perforated brick has high compressive strength, good corrosion resistance and durability, and other advantages as low density and good thermal insulation performance, etc.

2.2 Autoclaved Sand-lime Brick

Autoclaved sand-lime brick is mostly made of quartz and fine sand, and shaped solid block material after billet preparation, press molding and autoclaved curing. It is characteristic with exact geometrical dimension, nice shape, high strength and glazed surface.

2.3 Fly Ash Ceramsite Concrete

Fly ash ceramsite is a kind of artificial lightweight aggregate with advantages of low density, high strength, sound insulation, thermal insulation, and making construction deadweight down. Lightweight aggregate concrete made by fly ash ceramsite can lighten 25% of structure deadweight, save 5% of cement, have a good effect on energy efficiency and can be applied widely to all buildings.

2.4 Hollow Concrete Block

Hollow concrete block is made of cement, fine sand and coarse sand, and shaped hollow and thin-wall block material with definite pore type. It is provided with advantages of high strength, low deadweight, facility for building, good wall planeness and high work efficiency. Besides, industrial waste residue can be utilized by simple technology. There are good effects on land-saving and energy-saving.

2.5 Aerated Concrete

Aerated concrete, which is made of siliceous (sand, fly ash or siliceous gangue) and calcareous (lime or cement) materials by adding appropriate air-entrained admixture and autoclaved curing, is a kind of perforated and light wall material with advantages of light weight, good thermal insulation and incombustibility. It is a new wall material with good performance and could be shaped different blocks, boards and insulation products, which are used to envelope or bearing structure of industrial and residential buildings diffusely.

The thermal physics parameters of the five wall materials above are listed in Tab.1:

Tab.1 The thermal physics parameters of wall materials [2]

Wall Materials	Density ρ (kg/m^3)	Heat conduction coefficient λ [W/(m·K)]	Heat accumulation coefficient S [W/(m^2·K)]	Specific heat C [kJ/(kg·K)]
KP1 sintered perforated brick	1400	0.60	7.92	1.05
Autoclaved sand-lime brick	1900	1.10	12.72	1.05
Fly ash ceramsite concrete	1700	0.95	11.4	1.05
Hollow concrete block	1200	0.68	7.21	1.05
Aerated concrete	500	0.24	3.51	1.05

Tab.2 The thermal physics parameters of insulation materials [2]

Insulation Materials	Density ρ (kg/m^3)	Heat conduction coefficient λ [W/(m·K)]	Heat accumulation coefficient S [W/(m^2·K)]	Specific heat C [kJ/(kg·K)]
Polystyrene Granule	200	0.600	0.95	1.05
EPS	30	0.042	0.36	1.38
XPS	32	0.030	0.32	1.38
PU	60	0.023	0.40	1.38

3. THE ANALYSIS OF THERMAL PERFORMANCE OF WALL MATERIALS

The thermal preservation and insulation of wall materials are two different concepts. The preservation means decreasing the winter heat loss caused by the different temperature between outdoors and indoors. The evaluating index is the average coefficient K_m of heat transfer of exterior wall. The lower value is, the less heat loses. However, the insulation means decreasing the summer cooling load caused by the solar radiant heat. The evaluating index is the index D of thermal inertia. The higher value is, the less cooling load is. Because of the special climate in hot summer and cold winter zone, both winter heating and summer cooling of buildings consume a mass of energy. Therefore, when carrying out the design for energy efficiency of exterior wall, the thermal preservation and insulation of wall materials should be considered for minimizing total building energy consumption of heating and cooling in one year. The average coefficient K_m and the index D of exterior walls are regulated compulsorily in Standard: as $D \geq 3.0$, $K_m \leq 1.5$; as $3.0 > D \geq 2.5$, $K_m \leq 1.0$.

For the sake of analyzing the thermal performance of the five wall materials above, four familiar thermal insulation materials listed in Tab.3 and Tab.4 (the thermal physics parameters listed in Tab.2) were selected as the reference objects, by which comparing the index of thermal inertia of the relevant insulation systems when the coefficient of heat transfer of the exterior insulation systems reach to the two limited value of Standard --- K_m=1.5 and K_m=1.0. (The data in brackets are the relative thickness of insulation materials as meeting the requirements, and unit is *mm*.)

Because of the various specs of wall materials, in order to compare easily, the thickness of all the selected wall materials in this paper is 200mm and the exterior insulation system was adopted, of which the structure from inside to outside in turn is: mixing mortar, wall material, cement mortar, insulation material and anti-crack mortar. The thickness of mixing mortar, cement mortar and anti-crack mortar is 20mm. Considering the influence on heat bridge, the actual coefficient of heat transfer of exterior wall is usually higher than the calculated coefficient. The influence on exterior insulation systems is almost 2%-5%[3]. As a result, the actual coefficient of heat transfer should be corrected by the calculated coefficient and the corrected factor is chosen to 1.05.

Tab.3 As K_m=1.5, the compare of the index of thermal inertia of different insulation systems

	Polystyrene Granule	EPS	XPS	PU
KP1 sintered perforated brick	3.51（9）	3.42（6）	3.42（4）	3.43（3）
Autoclaved sand-lime brick	3.33（18）	3.15（13）	3.14（9）	3.16（7）
Fly ash ceramsite concrete	3.39（16）	3.23（11）	3.22 （8）	3.24 （6）
Hollow concrete block	3.03（11）	2.92（8）	2.91（6）	2.93（4）

Aerated concrete	—	—	—	—

Tab.4 As Km=1.0, the compare of the index of thermal inertia of different insulation systems

	Polystyrene Granule	EPS	XPS	PU
KP1 sintered perforated brick	3.84（30）	3.55（21）	3.53（15）	3.57（11）
Autoclaved sand-lime brick	3.66（39）	3.28（27）	3.25（20）	3.30（15）
Fly ash ceramsite concrete	3.72（37）	3.35（26）	3.33 （19）	3.38 （14）
Hollow concrete block	3.36（32）	3.04（23）	3.02（16）	3.07（12）
Aerated concrete	3.42（0）	3.42（0）	3.42（0）	3.42（0）

Seen from Tab.3, as K_m=1.5 and the wall material is hollow concrete block, the index of thermal inertia of EPS, XPS and PU insulation systems less than 3.0, which couldn't meet the requirements of Standard. The index of thermal inertia of other insulation systems is more than 3.0 which could meet the requirements of Standard. Seen from Tab.4, as K_m=1.0, all insulation systems could meet the requirements of Standard and the index of thermal inertia more than 3.0 without exception. Compared Tab.3 with Tab.4, it is known that, when the average index K_m of heat transfer is degressive from 1.5 to 1.0, the thickness of insulation materials is increased to one times at least, but the index of thermal inertia is increased little. The main reason is the heat accumulation coefficient S of the insulation materials is too low, therefore the index of thermal inertia of insulation systems mainly lies on wall materials. The wall materials with low heat conduction coefficient and high heat accumulation coefficient have good thermal inertia. With the gradual degression of the average coefficient K_m of heat transfer, the index of thermal inertia of each insulation system is raised more or less. As K_m is lower, the index of thermal inertia of insulation systems could meet the requirements generally. As a result, when the design for energy efficiency of exterior wall is carried out, the average coefficient of heat transfer should be considered chiefly and check the index of thermal inertia. When the index of thermal inertia couldn't meet the requirement, it could be improved by decreasing the average index of heat transfer or using the wall materials with better thermal inertia according to the actual situations.

Among several researched wall materials, the thermal preservation and insulation performance of aerated concrete is obviously better than other wall materials by its rather low heat conduction coefficient. When the aerated concrete with 200mm thickness is used as single wall insulation, the average coefficient of heat transfer K_m<1.0 and the index of thermal inertia D>3.0, therefore it can meet the requirement of Standard without the exterior insulation and be feasible to promote and use in hot summer and cold winter zone. However, because of the worse impermeability and erosion resistance of aerated concrete, it should be paid attention in use. Generally, aerated concrete shouldn't be used in following parts of building:

(1) Beneath building ±0.000 (except for the inner non-bearing partition wall of basement)

(2) The place of immersion or alternation of drying and wetting frequently

(3) The environment of chemical erosion, such as strong acid, strong base or high concentration CO_2, etc

(4) The block surface which is always in the high temperature environment of over 80 degree Celsius

(5) The parapet on roof

4. THE APPLICABILITY ANALYSIS OF WALL MATERIALS

Excepted for aerated concrete, the thermal performances of other four wall materials have few differences, but each characteristic is different. For the general contrast and analysis of the thermal preservation and insulation performance further, Tab.5 shows the calculating data of the average coefficient of heat transfer and the index of thermal inertia of different insulation systems as the thickness of insulation materials is 20mm. (the index of thermal inertia is in brackets, and the structure of insulation systems is same as above)

Tab.5 The average coefficient of heat transfer and the index of thermal inertia of exterior wall used the insulation materials with 20mm thickness

	Polystyrene Granule	EPS	XPS	PU
KP1 sintered perforated brick	1.19（3.69）	1.02（3.54）	0.86（3.58）	0.74（3.72）
Autoclaved sand-lime brick	1.43（3.36）	1.20（3.21）	0.99（3.26）	0.83（3.39）
Fly ash ceramsite concrete	1.38（3.45）	1.16（3.30）	0.96（3.34）	0.81（3.48）
Hollow concrete block	1.24（3.17）	1.06（3.02）	0.89（3.06）	0.76（3.20）

Seen from Tab.5, as the thickness of insulation materials is 20mm, the index of thermal inertia of each insulation system is more than 3.0 and could meet the requirement of Standard. Hereinto, the average coefficient of heat transfer of the XPS and PU insulation systems is below 1.0.

As mentioned above, the average coefficient K_m of heat transfer mostly reflect the thermal preservation performance and have some effects on heating consumption in winter; while the index D of thermal inertia mostly reflect the thermal insulation performance and have some effects on cooling consumption in summer. As a result, by contrasting and analyzing the four selecting wall materials, it is discovered that, in the same insulation system, KP1 sintered perforated brick, of which the K_m value is low and the D value is high; both the thermal preservation and insulation performance are rather well, could be applicable in the areas of the high demand on heating and cooling; autoclaved lime-sand brick and fly ash ceramsite concrete, of which the K_m value of is high and the D value is high; the insulation performance is better than the preservation, could be applicable in the areas of the higher demand on cooling; hollow concrete block, of which the K_m value of is low and the D value is low; the preservation performance is better than the insulation, could be applicable in the areas of the higher demand on heating.

5. CONCLUSIONS

In this paper, by the analysis and contrast of some common wall materials and insulation systems in hot summer and cold winter zone, some references is provided for researchers and designers to reasonably select the wall materials and insulation systems.

□ The index D of thermal inertia of insulation systems mainly lies on wall materials. The wall materials with low heat conduction coefficient and high heat accumulation coefficient have a good thermal inertia.

□ With the gradual degression of the average coefficient K_m of heat transfer, the index of thermal inertia of each insulation system is raised more or less. As K_m is lower, the index of thermal inertia of insulation systems could meet the requirement generally.

□ As the thickness of insulation systems is 20mm, current insulation systems could meet the requirements of Standard.

□ The heat conduction coefficient of aerated concrete is quite low, in general, it can meet the requirements of Standard without the exterior insulation and be feasible to promote and use in hot summer and cold winter zone. However, because of the worse impermeability and erosion resistance of aerated concrete, it should be paid attention in use.

□ Comparatively, KP1 sintered perforated brick is applicable in the areas of the high demand on heating and cooling; autoclaved lime-sand brick and fly ash ceramsite concrete is applicable in the areas of the higher demand on cooling; hollow concrete block is applicable in the areas of the higher demand on heating.

This paper just simply analyzed the applicability of different wall materials in hot summer and cold winter zone from the effect of energy efficiency, and didn't consider economical factors. In practical projects, all kinds of influencing factors should be considered for the optimal effect of energy efficiency with lesser investment.

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