

Technical and Economic Analysis on Masonry Materials of Exterior Walls for Building Energy Conservation

Yanhong Wang*, Yonghe Yao, Yuping Wu, Xiaozhen Li

Jinhua polytechnic, Jinhua 321007, China

Corresponding Author Email: yyh527@163.com

<https://doi.org/10.18280/rcma.290302>

Received: 2 April 2019

Accepted: 1 June 2019

Keywords:

energy conservation, building envelope, masonry material, technical and economic analysis, ceramsite aerated concrete (CAC) blocks

ABSTRACT

In recent years, resource saving and energy conservation have attracted a growing attention across the globe, calling for technical and economic analysis of energy efficiency of exterior walls in buildings. Targeting an actual building project, this paper introduces the energy-efficient design software PKPM and the cost analysis software GBQ to the technical and economic analysis of the energy efficiency of exterior walls respectively made of three masonry materials: sintered porous bricks (SPBs), autoclaved aerated concrete (AAC) blocks and ceramsite aerated concrete (CAC) blocks. The analysis shows that the exterior walls made of the CAC blocks achieved the energy conservation requirements with the simplest structure, easiest construction and lowest cost. The application of the CAC blocks in exterior walls can save resources and reduce building energy consumption, achieve excellent technical, economic and social benefits, and should be promoted in building projects.

1. INTRODUCTION

With the gradual depletion of non-renewable energy resources, the energy issue has become a bottleneck of future development. Therefore, many countries are increasingly aware of the importance of energy conservation [1]. Statistics show that roughly 1/3 of world's energy is consumed by buildings. The building energy consumption mainly occurs as heat is dissipated via the exterior walls of building envelope and energy is consumed by the heating and cooling system [2]. In a building, 27.5 % of heat loss takes place at the exterior walls, while only 18.9 % happens at exterior windows and 7.9 % occurs on the roof. This means the exterior walls should be the focus to reduce building energy consumption [3-4].

According to the relevant literature, most countries are reducing building energy consumption from two aspects: enhancing the heat insulation of building envelope and improving the efficiency of heating and cooling system [5-6]. In China, the heat transfer coefficient (HTC) of building envelope is regarded as a key index for building energy conservation. The HTC of exterior walls must fall within 1.0~1.55W/(m²·K) in hot summer and cold winter regions, only 1/4~1/2 of that in places on similar latitudes in Northern Europe. Thus, it is of great significance to improve the heat insulation of exterior walls in China [7].

There are many software suites for energy-efficient design (e.g. DOE-2, EnergyPlus and PKPM) and cost analysis (e.g. STAT and GBQ) [8-9]. However, there is no comprehensive technical and economic analysis on the energy efficiency of exterior walls or their masonry materials. To make up for this gap, this paper selects suitable energy efficient design software and cost analysis software, and relies on them to analyze the energy efficiency of exterior walls and their masonry materials

from technical and economic perspectives. In this way, the optimal masonry material was identified for exterior walls, making a great contribution to the energy conservation of buildings.

2. TYPES AND PROPERTIES OF MASONRY MATERIALS

Currently, there are three types of masonry materials for the exterior walls of energy-efficient buildings: sintered porous bricks (SPBs), autoclaved aerated concrete (AAC) blocks and ceramsite aerated concrete (CAC) blocks [10-12]. The SPBs are produced by roasting clay, shale, coal gangue, fly ash, sludge and other solid wastes [13]. The AAC blocks are made of cement, lime, slag, sand and fly ash through mixing, pouring, foaming, autoclaving and cutting [14]. The preparation of CAC blocks is relatively complicated: the cementing materials (i.e. cement and fly ash) are mixed into a slurry with foaming agent and water; next, light ceramistes, whose volume ratio is equal to or greater than 40 %, are added into the slurry and stirred mechanically; the stirred mixture is then subjected to pouring, vibration, steam curing and cutting [15]. The technical properties of the three masonry materials are compared in Table 1 below.

The comparison shows that the CAC blocks are more suitable than the SPBs and the AAC blocks for exterior walls of buildings, thanks to their excellent technical properties, such as lightweight, high strength, ultralow shrinkage, strong impermeability, high self-insulation, sound insulation, high dimensional accuracy, good appearance, simple process, fast bricklaying and the elimination of the need for waterproof or crack-resistant layers [16].

Table 1. Technical properties of the three masonry materials [17-19]

Indices	Types of masonry materials		
	SPBs	AAC blocks	CAC blocks
Dry density kg/m ³	About 1,500; heavy deadload; high steel consumption in foundation and structure	About 750; light deadload; low steel consumption in foundation and structure	About 750; light deadload; low steel consumption in foundation and structure
Thermal conductivity W/(m ² ·K)	≤0.58; no self-insulation	≤0.18; self-insulation	≤0.18; self-insulation
Strength MPa	≥10; high strength	≥3.5; low strength	≥5.0; moderate strength
Water absorption %	30-40; low impermeability	50-60; no impermeability	15-20; strong impermeability
Dry shrinkage mm/m	About 0.3; not prone to shrinkage crack	About 0.8; prone to shrinkage crack	About 0.2; no shrinkage crack
Sound insulation	Poor sound insulation	General sound insulation	Sound insulation and absorption
Workability	Small single block, slow bricklaying	Complex process, requiring waterproof and crack-resistant layers	Large single block, simple process, fast bricklayer, requiring no waterproof or crack-resistant layers

3. TECHNICAL AND ECONOMIC ANALYSIS

3.1 Energy-efficient design analysis

The most popular energy-efficient design software, PKPM, was selected to analyze the energy efficiency of the masonry materials for exterior walls. In the light of the relevant codes and engineering building parameters [8], three envelope models were set up based on the exterior walls made of the SPBs, the AAC blocks and the CAC blocks, respectively. The software modules were executed according to the following sequence: File management, Open project, Envelope energy, Material editing, Index calculation, Weighting and Export report. The structural layers were adjusted continuously to achieve the required energy-efficiency indices of walls and the optimal structural effect with the fewest exterior insulation layers, the thinnest material and the simplest construction process.

3.2 Cost analysis

Based on the relevant data determined in PKPM energy-efficient design, the GBQ software [9], the most widely used building cost analysis software in China, was employed to compute the cost of exterior walls made of the SPBs, the AAC blocks and the CAC blocks, respectively. The software modules were executed according to the following sequence: New project, New section, Project management, New unit work, Project overview, List and bid price, Measures, Other items, 3M (manpower, materials and machines) summary, cost summary, and export report.

4. PROJECT APPLICATION

4.1 Project overview

The SPBs, the AAC blocks and the CAC blocks were separately used to build the exterior walls of a residential building in Jinhua, eastern China's Zhejiang province. The project site (E: 119°65'; N: 29°12') belongs to the subtropical monsoon climate. The 23.20m-tall building covers an area of 2,348.90m². There are eight floors above ground and a basement floor. The total volume of the building is 9,178.36m³, of which 6,811.81m³ is aboveground. The surface area of the building is 2,994.13m². With a shear wall structure, the building has a shape coefficient of 0.44. In the building envelope, the exterior walls (excluding windows) cover an area of 1,010.638m², the thermal bridge columns 695.130m², the thermal bridge beams 267.540m² and the thermal bridge floors 67.920m².

4.2 Energy-efficient designs

With the aid of PKPM software, the limit HTC of each masonry material was calculated statically according to the local climate, shape coefficient and thermal inertia indices. Next, the thermal properties of building envelope with each masonry material was computed dynamically through comparative assessment and comprehensive weighting. The optimal designs for exterior walls made of the SPBs, the AAC blocks and the CAC blocks that ensure building energy efficiency are listed in Tables 2~4, respectively.

Table 2. Structural design for the exterior walls made of the SPBs

Exterior wall	Wall structure	Thermal bridge structure
		Cement mortar (20.0mm) SPBs (200.0mm) Interface agent Inorganic lightweight aggregate thermal insulation mortar, type I (35.0mm) Crack-resistant mortar fiberglass mesh (5.0mm)
Weighted HTC	K=1.27W/(m ² ·k), falling within the required interval of 1.0~1.5W/(m ² ·K); The designed annual energy consumption is 24.95kWh/m ² , below that (25.17kWh/m ²) of the reference building.	

Table 3. Structural design for the exterior walls made of the AAC blocks

Exterior wall	Wall structure	Thermal bridge structure
	Crack-resistant mortar fiberglass mesh (5.0mm) Cement mortar (10.0mm) Interface agent AAC blocks (B07) (200.0mm) Interface agent Inorganic lightweight aggregate thermal insulation mortar, type I (30.0mm) Crack-resistant mortar fiberglass mesh (5.0mm)	Crack-resistant mortar fiberglass mesh (5.0mm) Cement mortar (10.0mm) Reinforced concrete (200.0mm) Interface agent Inorganic lightweight aggregate thermal insulation mortar, type I (30.0mm) Crack-resistant mortar fiberglass mesh (5.0mm)
Weighted HTC	K=1.15W/(m ² ·k), falling within the required interval of 1.0~1.5W/(m ² ·K); The designed annual energy consumption is 24.84kWh/m ² , below that (25.17kWh/m ²) of the reference building.	

Table 4. Structural design for the exterior walls made of the CAC blocks

Exterior wall	Wall structure	Thermal bridge structure
	Cement mortar (20.0mm) CAC blocks (B07) (200.0mm) Cement mortar (30.0mm)	Cement mortar (20.0mm) Reinforced concrete (200.0mm) Interface agent Inorganic lightweight aggregate thermal insulation mortar, type I (25.0mm) Crack-resistant mortar fiberglass mesh (5.0mm)
Weighted HTC	K=1.31W/(m ² ·k), falling within the required interval of 1.0~1.5W/(m ² ·K); The designed annual energy consumption is 24.84kWh/m ² , below that (25.17kWh/m ²) of the reference building.	

As shown in Tables 2~4, the exterior walls made of the SPBs, the AAC blocks and the CAC blocks, following the optimal structural designs, all reached the required energy efficiency for buildings. The exterior walls of the CAC blocks, which contain no exterior insulation layer or crack-resistant layer, were constructed with the fewest steps. The simple construction method saves materials and manpower, shortens the construction period and improves construction efficiency.

4.3 Cost analysis

The unit work costs (e.g. divisional work and item work

costs, additional costs, regulatory costs and taxes) of exterior walls made of the SPBs, the AAC blocks and the CAC blocks were computed by GBQ cost analysis software [20]. The computation was carried out by the comprehensive unit price method according to the bid price model of construction and installation projects and the items listed in the *Composition of Cost Items in Construction and Installation Projects* (Jian/Biao (2013) No. 44). The labor and material costs were converted based on the quota of 2013 Budget of Zhejiang province and the market prices of that province in December, 2018. The computation results are listed in Tables 5~7.

Table 5. Unit work costs of the exterior walls made of the SPBs

No.	Cost items	Amount (RMB yuan)
1	Divisional work and item work costs	307,676
	Including 1.Labor cost + machinery cost	57,261
2	Additional costs	5,113
	(II) Construction Organization costs	5,113
	Including 3.Safe and civilized construction cost	5,113
3	Regulatory costs	5,955
	13.Pollution charge, social insurance fee, housing provident fund	5,955
4	Taxes	31,874
5	Construction cost	350,618

Table 6. Unit work costs of the exterior walls made of the AAC blocks

No.	Cost items	Amount (RMB yuan)
1	Divisional work and item work costs	341,858
	Including 1.Labor cost + machinery cost	59,479
2	Additional costs	5,113
	(II) Construction Organization costs	5,113
	Including 3.Safe and civilized construction cost	5,311
3	Regulatory costs	5,955
	13.Pollution charge, social insurance fee, housing provident fund	5,955
4	Taxes	31,874
5	Construction cost	350,618

Table 7. Unit work costs of the exterior walls made of the CAC blocks

No.	Cost items	Amount (RMB yuan)
1	Divisional work and item work costs	297,876
	Including 1.Labor cost + machinery cost	42,735
2	Additional costs	5,113
	(II) Construction Organization costs	5,113
	Including 3.Safe and civilized construction cost	3,816
3	Regulatory costs	5,955
	13.Pollution charge, social insurance fee, housing provident fund	5,955
4	Taxes	31,874
5	Construction cost	350,618

The comparison between Tables 5~7 shows that the exterior walls of CAC blocks incurred much less construction cost than those of the SPBs and the AAC blocks. In terms of unit work cost, the exterior walls of CAC blocks costed RMB 13,900-yuan fewer than those of the SPBs, and RMB 51,900-yuan fewer than those of the AAC blocks. In terms of the cost per unit area, the exterior walls of CAC blocks costed RMB 5.91 yuan/m² fewer than those of the SPBs, and RMB 22.12 yuan/m² fewer than those of the AAC blocks.

5. CONCLUSIONS

Taking a residential building in Jinhua, China as example, this paper carries out technical and economic analysis on the exterior walls made of the SPBs, the AAC blocks and the CAC blocks, using the energy-efficient design software PKPM and the cost analysis software GBQ. It is learned that the CAC blocks satisfy the requirements of the current national code for building energy conservation, and have excellent technical features, such as lightweight, high strength, thermal insulation, ultralow shrinkage, strong impermeability and sound insulation [21]; the exterior walls made of the CAC blocks contain two fewer layers than those of the other masonry materials, consume relatively few materials and manpower, and are easy and fast to build; the exterior walls made of the CAC blocks have a per unit area cost of only RMB 143.36 yuan/m², 3.96 % lower than that of the exterior walls made of the SPBs and 13.37 % lower than that of the exterior walls made of the AAC blocks. These results show that the application of the CAC blocks in exterior walls can save resources and reduce building energy consumption, achieve excellent technical, economic and social benefits, and should be promoted in building projects. The proposed structural design and cost analysis methods for exterior walls of energy-efficient buildings provide a good reference for energy-efficient design, material selection and cost analysis in other projects.

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