BUILDING ENERGY ANALYSIS AND SIMULATION OF CHANGSHA AREA

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ABSTRACT

In this paper, the potential of energy saving in residential building in Changsha area was studied with dynamic simulation approaches. As we know that cooling and heating are both required more or less in this climate zone considering the climate condition and solar radiation may be advantaged for winter but disadvantaged for summer. This simulation was made to analyze the effect on the air conditioning energy consumption from four aspects: the material of the exterior wall thermal insulation, the window glass type, exterior window shades, and the indoor lighting control. It is hoped that the work presented would enable architects and building designers to adopt optimal energy-efficiency design strategies according to the climate characters of some given zones.

KEYWORDS

Dynamic simulation; thermal insulation; exterior window shades; the indoor lighting control; the window glass type

INTRODUCTION

In order to generalizing the basic policy of the energy saving, Chinese National Building Department issued “The Residential Building Energy Saving Design Policy in hot summer and cold winter zone”(JGJ 134-2001)in 2001, and Hunan province of China published “The Residential Building Energy Saving Design Policy in Hunan province” (DBJ43/001-2004) in 2004. All these policys order building engineers and designers to use dynamic method to calculate the air-conditioning loads and to evaluate the energy-saving effect of design project. Choosing one residential building of Changsha city which belongs to the hot summer and cold winter zone as a research object, this paper uses dynamic simulation method to analyze its energy-saving effect.

PROJECT SUMMARY & AIR-CONDIONING DESIGN PARAMETERS

This residential building covers 5140.7 ㎡ inculding l4356.4 ㎡ living (conditioned) area and 784.3 ㎡ corridor (not conditioned) area. The meteorologic data employed in this dynamic simulation are collected from the typical meteorological year.

Air-conditioning design parameters

The parameters of indoor air design are listed in Tab.1, and the parameters of indoor personnel and equipments (contributing to space loads) are listed in Tab.2.

Table.1 Indoor air design parameters

Cooling T	Heating T	Min outdoor-air
26℃	18℃	20 m^3/(person·h)

The domestic central air conditioning system is air-source heat pump split all air system. In this paper, the heat-pump coefficient of performance (COP) is not discussed. Actually, the COP value is not invariable when heat pump system is running, and this alterable value may impact the energy saving effect. However, for contrasting expediently, the average COP value of cooling efficiency is set as 3.8, and the average EER value of heating efficiency is set as 3.0. These two values are generated automatically by the eQUEST simulation software, and this software can match appropriate HVAC system including unit capacity and system features to corresponding building basing on its characteristic, building operation schedule and the indoor air conditioning parameters.

The exterior envelope construction (shown in Tab.3)

In hot summer and cold winter zone of China, the Old-fashioned domestic architectures which are not energy-saving renovated have many general characters, such as, high exterior wall heat transfer coefficient, single clear glass window, high outer window heat transfer coefficient and shading coefficient. Further more, people's energy-saving awareness need to be improved. Anyway, the setting of the exterior envelope construction and indoor equipment running parameters for base building are representative of China's summer-hot and winter-cold area.

Table.2 Indoor equipment design paremeters

Design Max Occup	Lighting	Cooking/(W/㎡)	Miscellaneous equipment
32(㎡/per)	1.8(W/㎡)	10(80% sensible loads)	1.5 (W/㎡)

Table.3 The exterior envelope construction parameters

Envelope construction	Configuration material	U value(W/㎡·K)
Exterior wall	200mm HW concrete(without thermal insulation layer)	3.6398
Roof	200mm HW concrete+25mm polystyrene(thermal insulation layer)	0.8574
Floor	200mm HW concrete (marble finish)	4.0259
Exterior window	6mm single clear glass(without curtain or Venetian blind)	5.9054（S_C=0.85）
Window frame	35mm alum w/o fixed	2.4644
%Window (floor to ceiling, including frame): N-15%, W-28.8%, S-30.7%, E-36.2%, SE-40.3%		
The total area of exterior walls=1665.12m²		
Outside air infiltration rate: Air change/h=0.2		

All-year equipment running schedules

Generally speaking, Chinese office-goers go to work at about 7:00Am and return home at about 5:00Pm, many office workers eat lunch at the employee refectory near their company, however, they choose stay at home at most time of weekends and holidays. Conclusively, for simplifying simulation calculation, the running schedule of building interior equipments (including HVAC system) listed in Tab.4 is used.

Table.4 Running schedule

Mon.-Fri.	Weekend	Holiday
5pm-7am	Sat.11am-Sun.12pm	all day

Building Model

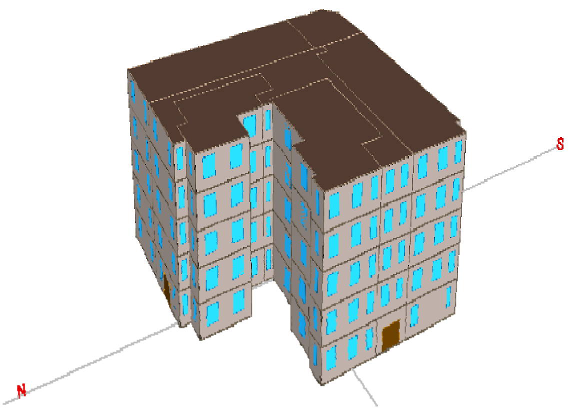


Figure.1 Basal building model

SIMULATION ANALYSIS

Analyzing Strategy

According to this basal building model, a series of energy-saving measures are proposed, such as adding exterior wall insulation, using window shades, lighting control, and so on. The energy saving effect of each measure will be simulated by eQUEST software. Finally, each measure will be fit together for the integrative optimizations of the exterior envelop construction.

1 Energy saving measure N0.1: Adding exterior wall thermal insulation

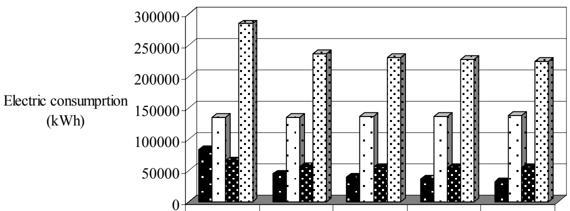
1.1 Energy consumption evaluation

It is known to all that adding thermal insulation to the surface of exterior or interior wall may prevent heat transmitting from outdoor to indoor availably. But thinking about the problem that the thermal bridge not only debases the local temperature of envelope construction, but also makes building energy consumption increasing, interior wall thermal insulation can not prevent the position which the exterior wall joints floor giving birth to being thermal bridge, however, the ext-wall thermal insulation have relative excellent heat-insulating capability (Jinliang Wang 2004). Therefore, this paper only simulated and analyzed the energy-saving effect of exterior thermal insulation. At present, polystyrene and polyurethane used as thermal insulation material are all-pervading, but the thickness of insulation material needs to be adjusted cautiously. The influences of different thickness of thermal insulation layer on the building energy consumption were simulated in the paper. The different ext-wall thermal insulation parameters are shown in Tab.5.

Table.5 Five kinds of exterior wall thermal insulation

Project	Thermal insulation layer	U value
No.1	Without	3.6398 W/㎡·K
No.2	25mm polystyrene	1.0 W/㎡·K
No.3	40mm polystyrene	0.7268 W/㎡·K
No.4	50mm polystyrene	0.5735 W/㎡·K
No.5	75mm polystyrene	0.4032 W/㎡·K

The simulation results of thermal insulation are shown in Fig.2. The Fig.2 shows that adding thermal insulation layer can reduce heating energy consumption remarkably, but can not reduce cooling energy consumption efficaciously, because the difference in outdoor-indoor temperature is very big in winter(outdoor design temperature for winter air conditioning is -3℃), but not the case in summer(outdoor design temperature for summer air conditioning is 35.8℃).



	No.1(base)	No.2	No.3	No.4	No.5
Space Heating	83540	44779	39239	35807	31725
Space Cooling	135021	135124	135920	136806	137858
Fan&Pump&Aux	65717	56249	55383	54911	54362
Total	284278	236152	230542	227524	223945

Figure.2 HVAC System Energy Consumption of different "thermal insulation" measures

From Fig.3 it can be seen that an interesting phenomenon that ext-wall thermal insulation reduces the energy consumption in July & August, but increases the energy consumption in May & June & Sep. It may be concluded that the average outdoor dry-bulb temperature is low in May & June & Sep, and at night the building interior equipments run so frequent that much space cooling loads occur, however, ext-wall thermal insulation makes against building heat dissipating. Consequently, in hot summer and cold winter zone, using thermal insulation to reducing the cooling loads caused by the difference in outdoor-indoor temperature may not be effectual. However, it may make a contrary effect on building heat dissipating.

To sum up, adding ext-wall thermal insulation is in favor of building energy saving, and the different thickness like 25mm, 40mm, 50mm, 75mm, result in different building HVAC system energy efficient rate, 17.69%, 19.86%, 21.02%, 22.41%, respectively.

1.2 Economic evaluation

It is known that exterior walls area is 1665.12 ㎡, the price of Polystyrene Foam Plate is 102dollars/m³(Jinghua Tang 2005)and the electricity price is 0.075(dollar/KWh) in Changsha. The first cost about exterior wall insulation material and the whole building annual electricity bills of each project are shown in Tab.6.

In this paper, time value of capital is not taken into account, the researches for valuation of external-wall exterior insulation are based on the evaluation method of investment-return. The means of static payoff period is the time that the net income of project using to return all the investment. The static payoff period may be calculated as following (Weiding Long 2005):

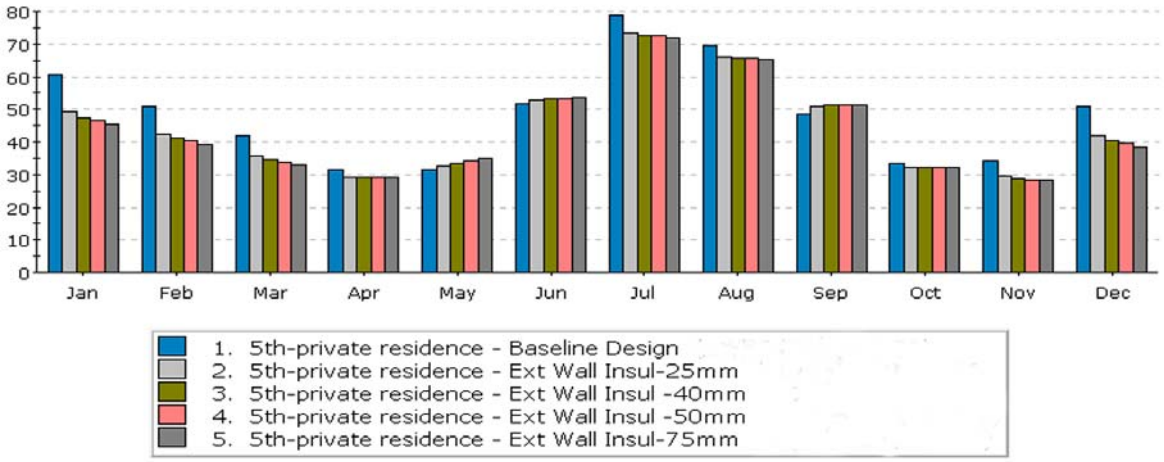


Figure.3 Monthly Total Energy Consumption(KWh)

Table.6 Five kinds of exterior wall thermal insulation

Project	No.1	No.2	No.3	No.4	No.5
Insulation Layer Thickness	0mm	25mm	40mm	50mm	75mm
the first cost of thermal insulation	$0	$4246.06	$6793.69	$8492.11	$12738.37
Total electricity fee	$21320.9	$17711.4	$17290.65	$17064.3	$16795.88

$$\sum_{t=0}^{T_\varphi} NB_t = \sum_{t=0}^{T_\varphi} (B - C)_t = K$$

Annotation:

K—— aggregate investment;

B_t—— the income in No."t" year;

C_t—— the expenditure in No."t" year;

NB_t ——the net income in No."t" year, $NB_t = B_t - C_t$;

T_φ—— the investment payback period.

Tab.7 shows that the project of "25mm ext-wall thermal insulation" is economical correspondingly.

Table.7 The value of investment payback period

Project	No.2	No.3	No.4	No.5
T_φ	1.18	1.69	2	2.82

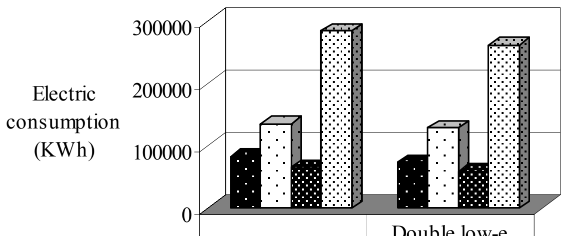
2 Energy saving measure N0.2: Adopting double Low-e coating window glass

Comparing to single clear window glass, double low-e coating window glass has better heat insulating and sun-shading capability, the simulation parameters are shown in Tab.8.

Table.8 The simulation parameters of window glass

Window glass type	U value	SC
single clear	5.9(W/㎡·K)	0.85
double low-e coating	3(W/㎡·K)	0.7

The simulation results of window type are shown in Fig.4.



	Single Clear(base)	Double low-e coating
■ Space Heating	83540	73753
□ Space Cooling	135021	129203
■ Fan&Pump&Aux	65717	59887
□ Total	284278	262843

Figure.4 HVAC System Energy Consumption of different "window glass type" measures

Solar radiation may be advantaged for energy saving in winter but disadvantaged in summer (Kefeng Xu 2003)， so reducing solar shading coefficient (SC) value may cut down indoor solar heat gain, which may occur dual effects which are decreasing space cooling loads and increasing space heating loads (Qisen Yan 1986）. So SC value must be set carefully, 0.7 is proved to be appropriate in this simulation. In addition, when U value is decreased from 5.9 to 3.0, inside and outside heat convection is restrained effectively. The measure of adopting double Low-e coating window glass results in 4.58% energy efficient rate. If it is only contrasted to the HVAC system heating and cooling electric consumption of the baseline design, the corresponding energy efficient rates are 11.72% and 4.31%, respectively. Fig.4 visualizes the energy saving effect described above.

3 Energy saving measure N0.3: Adding exterior window shades & Lighting control

When solar altitude is higher in summer, ext-window shading keeps out much solar radiation, which would benefit reducing HVAC system energy consumption and lessening solar firing feeling. When ext-window shading keeps out a little solar radiation in winter, space heating loads may increase simultaneously, because solar radiation may be conducive to indoor thermal environment of building in winter. However, when wind blow through the ext-window shading, vortex come into being hereabout which will reduce the wind rate seriously and then decrease the infiltration air volume, so a part of HVAC system consumption could be economized (The Building Technology Physics Lab of Building Engineering Department 1965). To sum up, exterior window shading makes little effect on building energy consumption in winter, but redounds to thermal insulation in summer. Shading dimension parameters are as following: 210mm for the distance from window, 700mm for depth.

Adding ext-window shading reduces solar heat gain, simultaneity, the indoor lighting time will be prolonged, and cooling loads from lighting may increase, especially in cloudy weather (Xiangzhao Fu 2002). Therefore, installing light-inducing control

Table.9 The exterior window shades & Lighting control simulation projects

Project	Horizontal baffles	Vertical baffles	Lighting control
No.1	-	-	-
No.2	√	-	-
No.3	-	√	-
No.4	√	√	-
No.5	√	√	√

Table.10 The electric Use of different simulation measures about exterior window shades & Lighting control (KWh)

Project	Lighting	Miscellaneous equipment	Space Heating	Space Cooling	Fan &Pump &Aux	Total	Energy saving rate

No.1	33454	150049	83540	135021	65717	467781	0%
No.2	33454	150049	82963	126903	62190	455559	2.61%
No.3	33454	150049	83330	126413	62364	455610	2.60%
No.4	33454	150049	82733	118938	58860	444034	5.08%
No.5	27485	150049	82827	116076	57503	433940	7.23%

Table.11 The simulation project

Project	**25mm ext-wall insulation**	**Double Low-e**	**Ext-window integrative shading**	**Lighting-control**
No.1（baseline）	×	×	×	×
No.2	√	×	×	×
No.3	×	√	×	×
No.4	×	×	√	×
No.5	×	×	√	√
No.6	√	√	√	√

equipment in residential room is necessary when ext-window shades are added. The simulation projects are shown in Tab.9. Remark: In this simulation, the lighting power lowering limit that can be adjusted is the 30% of the max power.

Tab.10 indicates that it is suitable to install shutter shades to the eastern & western side ext-window, and install integrative shades to the southeast & southwest side ext-window (The Building Technology Physics Lab of Building Engineering Department 1965), so setting ext-window shades blindly is not advocated. It is advisable to adopt right protecting from the sunlight to the building according to ext-window orientation. As the Tab.10 depicts, the amount of the building electric consumption decreased from 467781(KWh) in Project-1 to 433940(KWh) in Project-4. Compared with Project-1, the energy saving rate of Project-4 is 5.08%.

In my view, on one hand, indoor lighting heat counteracts a part of space heating loads in system heating season; on the other hand, indoor lighting heat increases space cooling loads in system cooling season. And the simulation results are well accordant to the above analysis. According to the statistics shown in Tab.10, compared with Project-4, the lighting electric consumption energy-saving rate of Project-5 is 17.84%. The electric consumption for space heating has increased by 94KWh, and the electric using for space cooling has decreased by 2862KWh. Obviously, Project5 is the best for energy-saving.

The comparison of the different energy saving measures

The four kinds of project (project-2 in measure.1, project-2 in measure-2, project-4 in measure-3 and project-5 in measure-3), which are selected from the above energy saving measures No.1-No.3 are chose to compare with each other. It is shown in Tab.11.

As shown in the Fig.5, Project-5 has the strongest energy-saving capability in cooling season, and the energy saving capability of Project-2 is the highest in heating season. Synthetically, the all-year energy-saving effect of Project-2 is the most obvious.

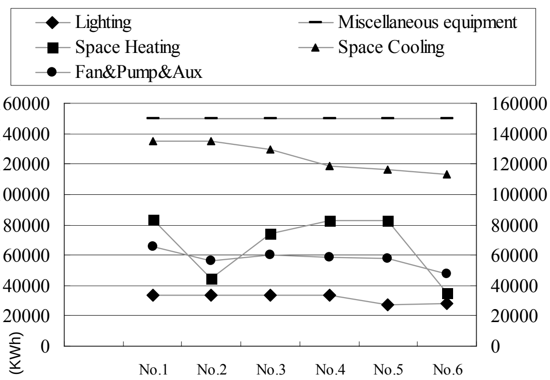


Figure.5 Building Energy Consumption of different simulation measures

Subsequently, Project-6 reconstructed baseline building by adding four kinds of energy-saving measure described above simultaneously. Fig.6 shows that compared with Project-1 (base design), the all-year building energy saving rate of Project-6 is 20.12%. Definitely, the energy-saving effect is striking.

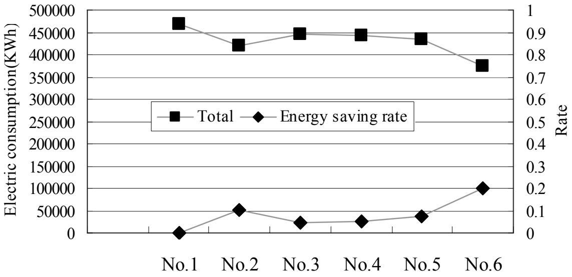


Figure.6 Building Energy Consumption & Energy Saving Rate

CONCLUSION

The research on building energy-saving measures of Changsha area provides some valuable and instructive experiences to building energy-saving study of all Yangtze River area even all hot summer and cold winter zone.

In hot summer and cold winter zone, besides of the demand of meeting the indoor thermal comfort standard, there is a huge energy-saving potential in the energy saving reconstruction of civil architecture by ameliorating the thermal characteristics of the exterior envelope construction and using indoor lighting control.

In the whole simulation and analysis course, the energy consumption simulation software-eQUEST which is based on the advanced edition of DOE-2, acted a remarkable effect, quantifies the various simulation results, so that this paper can find energy-saving gist and optimize the energy-saving measure.

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