Purdue University
Purdue e-Pubs

International High Performance Buildings Conference

School of Mechanical Engineering

2014

Performance analysis of an energy efficient building prototype by using TRNSYS

Kun Lai
Shanghai Jiao Tong University, China, People's Republic of, like304321@sjtu.edu.cn

Wen Wang
Shanghai Jiao Tong University, China, People's Republic of, wenwang@sjtu.edu.cn

Harry Giles
University of Michigan, USA, hgiles@umich.edu

Energy Performance Analysis of An Energy Efficient Building Prototype

KUN LAI[1], WEN WANG [2], HARRY GILES [3]

[1] Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai, 200240, China
like304321@sjtu.edu.cn

[2] Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai, 200240, China
wenwang@sjtu.edu.cn

[3] A. Alfred Taubman College of Architecture and Urban Planning, University of Michigan, Ann Arbor, MI 48109-2069 USA
hgiles@umich.edu

ABSTRACT

Buildings section accounts for a large part of the total primary energy consumption. This paper reports a simulative study on an energy efficient building prototype named MIDMOD. The prototype is a new genre of affordable medium density building concepts that are more adaptable, durable, and energy efficient as whole-life housing typologies than those currently available. The building envelope thermal insulation and air tightness are enhanced to reduce heat loss. Several technologies of indoor HVAC system are integrated, such as the hydronic radiant heating/cooling system (HRH/C), ventilation heat recovery (VHR), and heat pump water heater (HPWH), for better energy conservation and thermal comfort performance. A complex fenestration system (CFS) with fixed grid shading component is employed to reduce solar heat gain in summer and increase solar heat gain in winter. The building performance is rated based on the Energy Cost Budget (ECB) Method of ASHRAE. The result shows that the prototype can achieve better energy performance. HRH/C system decreases total energy consumption of building significantly. The energy consumption reduction reaches 36.17%. Double glazed window with grid shading component decreases the total energy consumption by 6.79% compared to common double glazed window.

Keywords: Building energy consumption; radiant heating/cooling; ventilation heat recovery; heat pump

1. INTRODUCTION

Energy consumption in building section plays an important role in total energy consumption of society. In developed countries, such as the U.S. and European Union countries, buildings (residential and commercial) accounted for approximately 40% of the total primary energy consumption (Ignacio *et al.*, 2010). In China, according to the data released by the former State Ministry of Construction, the ratio is about 27% (Cai *et al.*, 2009).

Pérez-Lombard *et al.* (2008) showed that among building services, HVAC systems energy consumption is particularly significant (50% of building consumption and 20% of total consumption in the USA) (Pérez-Lombard *et al.*, 2008). For an energy conservation building, there are two ways to improve the energy performance: Enhancing the building envelope design and optimizing the indoor thermal system. Olesen (2002) and Miriel (2002) showed that HRH/C system possesses the features of high thermal comfort level, energy saving potential, clean and quiet operation (Olesen, 2002) (Miriel, *et al.*, 2002). Chen (1990), Laouadi (2004), Feustel and Stetiu (1995) compared the performance of HRH/C system and conventional air-conditioning system, demonstrated that HRH/C system can offer quiet comfort and a level of energy efficiency (Chen, 1990) (Laouadi, 2002) (Feustel and Stetiu, 1995).

Ventilation heat recovery (VHR) technology is widely used in European Union. Tommerup (2006) showed that introducing mechanical ventilation with heat recovery together with the three insulation-related measures results an approximately 25% of the initial heating requirement (Tommerup, 2006). Other studies have analyzed the impacts of VHR on energy consumption of buildings. For example, Hekmat *et al.* (1986) compared different residential ventilation methods in different US climatic conditions (Hekmat *et al.*, 1986). Dodoo *et al.* (2011) analyzed the impact of VHR on the operation primary energy use in residential buildings (Dodoo *et al.*, 2011). They found that VHR systems can give substantial final energy reduction, but the primary energy benefit depends strongly on the type of heat supply system.

Window is an important part of building envelope. But its high heat transfer coefficient and light transmission allows too much solar radiation get into room which leads overheating in summer and in hence increases the cooling load. Double glazed window with air gap is commonly used for better thermal insulation of building. The air gap enhances the thermal insulation performance of window. When the air gap is employed in whole facade of building, it’s the so called double-skin facade. Gratiaand Herde (2004) showed that the use of a double-skin facade decreases the heating loads and increases the cooling loads (Gratiaand Herde, 2004). For the purpose of reducing solar heat gain through window in summer, the use of shading devices is more and more common. Almeida *et al.* (2011) studied free convection in a window with a heated between-panes blind (Almeida *et al.*, 2011). Sherif *et al.* (2012a) presented an external perforated window Solar Screens (Sherif *et al.*, 2012a). Sherif *et al.* (2012b) also studied the optimal size and depth of screen (Sherif *et al.*, 2012b).

Previous researchers have developed so many techniques for building energy conservation. But most of those research focused on commercial building since the investment of energy conservation building is too expensive to be employed by the holder of common residential building. How to apply affordable energy conservation technologies in residential building is an important issue for common people. In this paper, a simulative study on an energy efficient buildings prototype is conducted. A medium density residential building prototype integrated several techniques is presented. For better energy conservation performance, the enhancement of building facade and indoor HVAC system is the main problem which should be concerned.

2. PROTOTYPE BUILDING

2.1 Description of Midrise Modern Modular (MIDMOD)

MIDMOD is a medium density building concepts that are more energy efficient as whole-life housing typologies. The building consists of six different zones: two bedrooms, a bathroom, a kitchen, a dining room, and a living room. The floor plan is as follow:

Fig.1. The diagram of the MIDMOD apartment

2.1.1 Summary of Building Envelope Characteristics for MIDMOD

Table1 Data of the building envelope and the radiant panels

Building wall	Outside wall	Floor	Roof	Chilled ceiling	Radiant heating panel
Thickness (m)	0.17	0.08	0.141	0.35	0.13
U-value(Wm^2/K)	0.511	0.04	0.316	0.424	1.55

Table2 Zone parameters

Building zones	Bedroom1	Bathroom	Bedroom2	Kitchen	Dining & Living
Volume (m^3)	45.54	24.84	45.54	45.54	70.38
Fresh air ventilation (AC)	0.77	0	0.77	0.77	0.5
Infiltration (AC)	0.194	0.194	0.194	0.194	0.194

2.1.2 Inner heat gain

Table3 The inner heat gain of building

Item	unit	Value
Lighting Power Density (LPD)	W/m^2	17
TV	W	50
Occupants	W	100
Computer	W	50
Kitchen equipment	W	1000

2.1.3 Building Envelope Enhancements-double glazed window with grid shading component

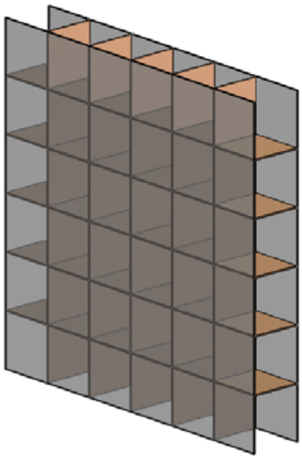

Fig.2. Double glazed window with grid shading component

As shown in Fig.2, the grid shading component is actually combination of horizontal and vertical blinds. The horizontal slats can adjust the solar heat gain with the change of zenith angle. As the zenith angle is higher, the shading component blocks more incline solar radiation, so it reduces solar heat gain in summer. The zenith angle is lower in winter. The shading component allows more solar radiation transmit the window. The vertical slats can adjust the solar heat gain with the change of azimuth angle of sun. In the diurnal time, the shading factor of morning and afternoon is better than that of noon. The size of grid shading component is designed for better shading performance in summer. Based on the research of Sherif *et al.* (2012b), a 80-% 90% perforated ration is the optimal configuration (Sherif *et al.*, 2012b). Here the depth of slats is 10cm while the spacing between slats is also 10cm, which is the optimization size for shading performance.

2.2 The thermal system

2.2.1 Hydronic heating and cooling (chilled ceiling and radiant heating panels)

Four 60×180cm radiant cooling panels constructed from copper coil have been installed on the ceiling. Four vertical radiant heating panel radiators were installed on different walls. Cooling water that flows to the cooling panel is supplied from a chilled water plant. Heating water is supplied from an electric water heater with a storage tank and is circulated by a pump.

2.2.2 VHR

A VHR system is employed to absorb waste heat or cool of the exhaust air. It can pre-heat or pre-cool fresh air drawn from environment. Then the fresh air flows to a dehumidifier to extract moisture. The fresh air from dehumidifier flows to the supply air loops under the floor.

2.3 Baseline model description

Baseline model is used for rating the energy efficiency of prototype. The building performance rating method bases on the Energy Cost Budget(ECB) Method of ASHRAE.

Table 4 Baseline model setting

Item	System setting

Building envelope	the same as the prototype
Operative schedule	the same as the prototype
Inner heat gain	the same as the prototype
HVAC system	Packaged terminal heat pump(PTHP)

3. TRNSYS MODEL

TRNSYS program (Transient System Simulation Program) is a transient systems simulation program with a modular structure. In this paper, the baseline model and prototype model are built by using TRNSYS. Three cases are took into account for energy performance rating. The baseline model is composed of a weather data reader module(type 15), a multi-zone building module(type 56) and a standard Packaged terminal heat pump module(type954).

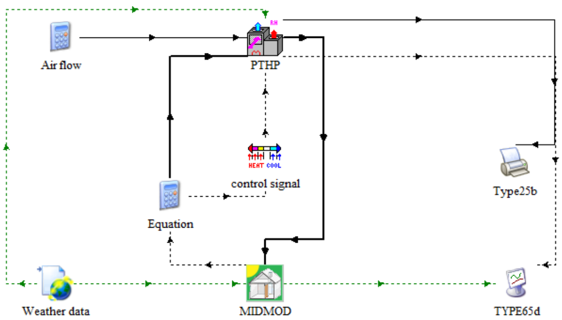

Fig.3. Case1 baseline model (PTHP)

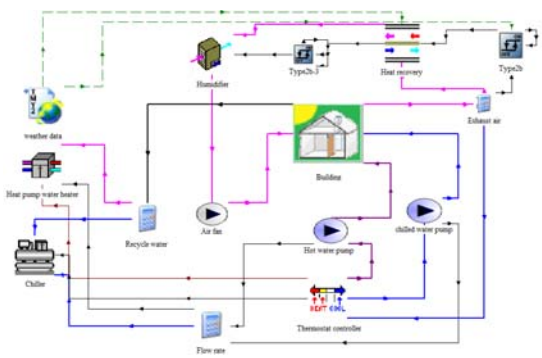

Fig.4. Case2 prototype model without CFS components

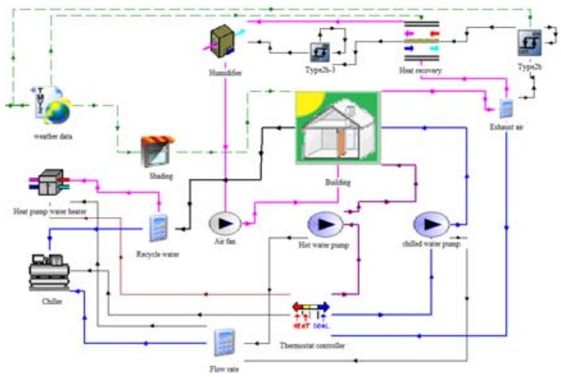

Fig.5. case3 prototype model with CFS components

Module type 56 of TRNSYS is capable of modeling an “active wall”(a wall with embedded pipes that carry hot fluid for radiant heating) and a “chilled ceiling”(a ceiling with embedded pipes that carry chilled water for radiant cooling), which is used to model the HRH/C system.
Typical meteorological year(TMY) weather data of Detroit is used for energy consumption calculation. The outdoor temperature varies from -25℃ in the winter to +32℃ in the summer.

4. ENERGY PERFORMANCE ANALYSIS

4.1 Comparison of Baseline Model to Prototype Building model

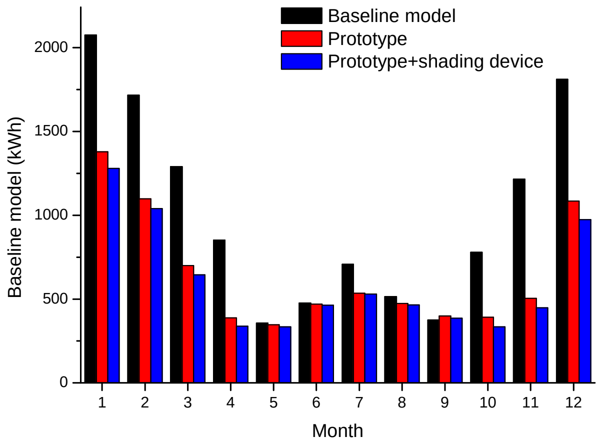

Fig.6. The annual energy consumption of building

For PTHP system, the total energy consumption includes the total energy input to the heat pump (compressor, indoor fan , outdoor fan and auxiliary heaters). For HRH/C system, the total energy consumption includes the energy use of water heater, water chiller, circulating water pump and ventilation fans. From Fig.4. we can see that the application of HRH/C system decreases total energy consumption of building significantly. The energy consumption reduction reaches 36.17%. In every month the energy consumption of HRH/C system is lower than that of PTHP system.
Double glazed window with grid shading component decreases the total energy consumption 6.79% compared common double glazed window. The impact of CFS is more obvious in winter. Because the building locates in a cold climate zone, which leads to a high heating load in winter and low cooling load in summer.

4.2 The energy consumption of ventilation and water circulation

The PTHP and HRH/C system is different in the way of fluid circulation. The fresh air of both system is supplied through fans. But in PTHP system indoor air cycles continuously through fans when the air conditioner is operating to maintain air temperature within setting range. In HRH/C system, the fluid medium for heating and cooling is water. Supply water is transferred by pumps.
The energy use for air ventilation of PTHP system is much higher than that of HRH/C system. The fresh air change rate of HRH/C system is only 0.77. So the energy consumption for ventilation can be as low as about 5.32% of PTHP system. But comparing to PTHP system, there is an extra energy consumption for water circulation. The total energy consumption for fluid circulation of two systems is nearly the same.

The energy consumption of ventilation accounts for 14.47% of total building energy consumption in PTHP while the energy consumption of water circulation accounts for 34.08% of total building energy consumption in HRH/C system. Through the employed of natural ventilation, the potential of energy conservation needs further studying.

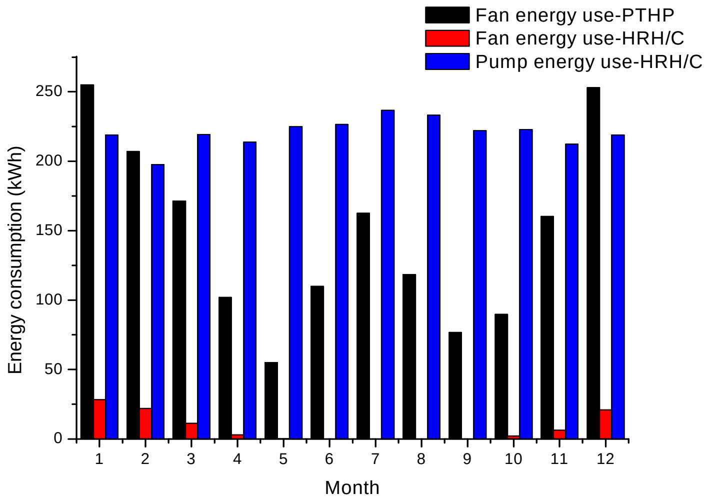

Fig.7. The energy consumption of fluid circulation

5. CONCLUSIONS

In this study an energy conservation building prototype is simulated using TRNSYS program in order to rate energy performance. The result shows that the prototype can achieve better energy performance. HRH/C system decreases total energy consumption of building significantly. The energy consumption reduction reaches 36.17%. Double glazed window with grid shading component decreases the total energy consumption by 6.79% compared to common double glazed window.

For the building in cold climate zone, the improvement of indoor HVAC system can reduce the energy consumption significantly. The impact of enhancement in window shading component is not as better as expected. The study about best application condition of CFS system and further improvement of indoor thermal system and building envelope is the next step researcher work.

ACKNOWLEGEMENT

This work was financially supported by The University of Michigan – Shanghai Jiao Tong University collaboration on renewable energy science and technology, official vice president research fund (U029504). Also authors would like to thank Assoc. Prof. Mojtaba Navvab (The University of Michigan), Assoc. Prof. Lars Junghans (The University of Michigan).

REFERENCES

Ignacio Z. B., Antonio V. C., Alfonso A. U., 2010, Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential. *Building and Environment*, vol.46, no. 5:p. 1133-1140

Cai, W.G., et al., 2009, China building energy consumption: Situation, challenges and corresponding measures. *Energy Policy*, vol.37, no. 6: p. 2054-2059.

Pérez-Lombard, L., J. Ortiz, and C. Pout, 2008, A review on buildings energy consumption information. *Energy and Buildings,* vol.40, no. 3: p. 394-398.

Olesen B., 2002, Radiant floor heating in theory and practice. ASHRAE Journal,vol.44, no.7:p. 19-24.

Miriel, J., L. Serres, and A. Trombe, 2002, Radiant ceiling panel heating–cooling systems experimental and simulated study of the performances thermal comfort and energy consumptions. *Applied Thermal Engineering*, vol.22: p. 1861–1873.

Chen Q., 1990, Comfort and energy consumption analysis in buildings with radiant panels. *Energy and Buildings*, vol.14, no.2:p. 87-97.

Laouadi A.,2004, Development of a radiant heating and cooling model for building energy simulation software,*Building and Environment*, vol.39, no.4:p. 21-31.

H.E. Feustel, C. Stetiu,1995, Hydronic radiant cooling-preliminary assessment, *Energy and Buildings*, vol.22 :p. 193-205.

H. Tommerup, S. Svendsen, 2006, Energy savings in Danish residential building stock, *Energy and Buildings*, vol.38, no.6:p. 618–626.

D. Hekmat, H.E. Feustel, M.P. Modera, 1986, Impacts of ventilation strategies on energy consumption and indoor air quality in single-family residences, *Energy and Buildings*, vol.9, no. 3:p. 239–251.

Dodoo, A., L. Gustavsson, and R. Sathre, 2011, Primary energy implications of ventilation heat recovery in residential buildings, *Energy and Buildings*, vol.43, no.7: p. 1566-1572.

Gratia, E. and A. De Herde, 2004, Optimal operation of a south double-skin facade, *Energy and Buildings*,vol.36, no.1: p. 41-60.

Almeida, F. and D. Naylor, Experimental study of free convection in a window with a heated between-panes blind,*Energy and Buildings,* 2011. 43(10): p. 2647-2655.

Sherif, A., H. Sabry, and T. Rakha, 2012, External perforated Solar Screens for daylighting in residential desert buildings: Identification of minimum perforation percentages, *Solar Energy*, vol. 86, no.6: p. 1929-1940.

Sherif, A., A. El-Zafarany, and R. Arafa, 2012, External perforated window Solar Screens: The effect of screen depth and perforation ratio on energy performance in extreme desert environments. *Energy and Buildings*, vol.52: p. 1-10.

NOMENCLATURE

LPD Lighting Power Density W/m^2

AC Air change rate