Evaluating Commercial Building Retrofit Energy Saving by Using a Building Retrofit Tool – Case Studies in Shanghai

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ABSTRACT
Building energy efficiency is a very important government policy in China. Retrofitting existing commercial (or called public) buildings, especially large scale public or government office buildings, is one important issue. To better help practitioner assess retrofit energy saving and cost-effectiveness, a COMmercial Building Analysis Tool (COMBAT) for energy efficiency retrofit has been developed. This study applies the developed COMBAT tool to a couple of commercial shopping mall and hotel buildings in Shanghai, China. The energy conservation measures (ECMs) are analyzed in terms of their energy saving and cost effectiveness. Simulated energy savings are compared with buildings' actual measurement number. General conclusions and suggestions on building retrofit work for shopping mall and hotel in Shanghai.

KEYWORDS
building simulation, retrofit, COMBAT, energy conservation measures, payback

INTRODUCTION
Building consumes roughly 25% and 40% primary energy in China and United States respectively. Energy efficiency in buildings is very important issue. Among all building energy-efficient policies, existing building retrofit is particularly important in both China and the United States. In U.S., it is estimated that 14 billion m^2 of existing building will be renovated over the next 30 years which takes about 50% of the entire building stock. Renovating existing building takes about 86% of total building expenditure in U.S (Holness 2008).

China has become the world largest CO2 emitter. Because of fast urbanization process, more and more energy has been consumed in building sector. To target increasing building energy use, and improving building energy efficiency, Chinese central government has established several areas to improve buildings' energy performance. Those areas include: new construction energy efficiency, low energy and green building demonstration, North China residential building heating system metering and retrofit, large public (or commercial) building energy-efficient operations and retrofit, renewable energy building application and demonstration, rural buildings energy saving, new energy-efficient construction materials, and energy efficient policy system. To support existing building retrofit, the central and local government has created various incentive programs and subsidy.

One issue when doing commercial building retrofit in China is that, very few retrofit projects have good understanding on how much energy can be saved after retrofit, and what is the specific retrofit measures cost-effectiveness when applied to different building types. The current market-available tools are very generic which require detailed knowledge on building modeling and not specially targeted for retrofit (ORNL 2007, DOE 2011). In addition, the sophisticated energy modeling tools make it difficult for practitioners to do fast energy saving and cost-effective analysis. To better help commercial building retrofit work in China, a software retrofit tool called "COMBAT" has been developed(Levine, et al. 2012).

This paper will briefly review the functions of the retrofit tools. A couple of buildings in Shanghai are selected, and their retrofit energy savings are calculated by using the tool. The energy measurement data are collected and before and after energy savings are compared with the tool prediction data. In addition, the retrofit's cost data is used to analyze retrofit measures' cost-effectiveness. Finally, recommendations are given for conducting building retrofit in Shanghai in terms of how to select cost-effective measures in Shanghai climate.

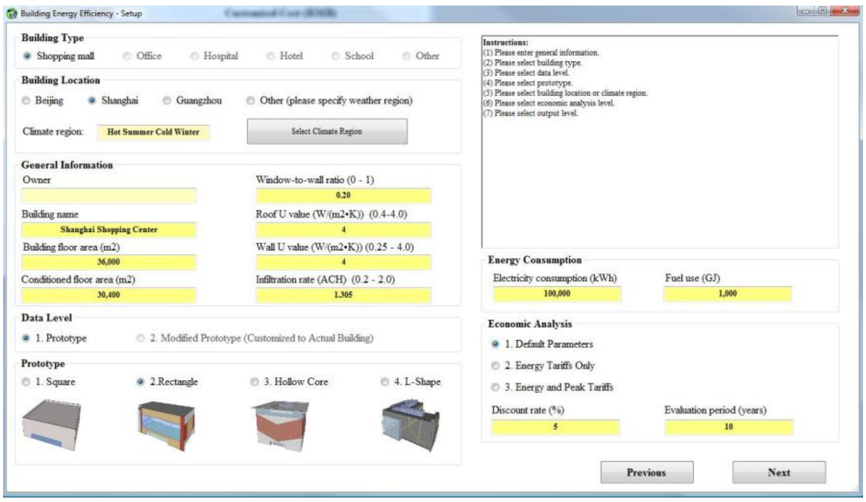

Figure 1. *COMBAT User-interface*

METHODOLOGIES

In COMBAT(LBNL n.d.), building retrofit measures are indentified and categorized in different systems such as envelope, lighting, HVAC, domestic hot water (DHW), and other building services. Reference buildings are obtained through surveys and building energy models are created in EnergyPlus.

The tool pre-simulated the combination of building inputs and different retrofit measures based on different building types. The large number of sensitivity runs created a retrofit database. In addition, building retrofit measure cost data is surveyed in China and also store in the database.

Based on the reference building models, users can modify building inputs such as building floor areas, internal energy load density, and various selections for retrofit measures (Figure 1). The tool can query the pre-simulated database to get buildings' before and after retrofit energy consumption and calculate energy saving, retrofit cost and payback period. To help users understand the effects of each selected measure, the tool can also report the cost-effectiveness of each measure when it is applied alone.

Based on the developed retrofit tool, this study selects a couple of retrofit cases. The purpose is to test the retrofit tool and understand how the tool can help users in their actual retrofit work.

CASE STUDY

1. Building introduction

In 1990s, Shanghai witnessed a rapid development. High-rise buildings, large shopping malls and modern hotels are built dramatically during this period. However, the development and implementation of building energy-efficient technologies were lagged behind. In this study, six buildings (4 shopping malls and 2 hotels) were investigated in Shanghai. The retrofit measures range from building envelope to HVAC systems. Table 1 lists buildings' basic characteristics, and retrofit measures taken for each building.

Table 1. *Outlines of Retrofit Building Information*

	Shopping Mall				Hotel	
Building	A	B	C	D	E	F
Gross Floor Area (m^2)	127,262	108,000	250,000	32,000	55,842	26,000
Built time	1999	1995	2006	1992	1988	2002
Retrofit time	2007-2011	2008	2008	2008	2006-2010	2011
Retrofit system						
Case A	Lighting system: Replace interior lights with T5 lamps; Replace floodlights with high frequency electronic discharge lamps; Replace landscape lights with LEDs					
	HVAC air system: Add outside-air economizer on CAV system; Replace DX air conditioners with FCU&AHU supplied by heat pump; Add VFD on exhaust fans in garage					
	HVAC water system: Replace air-cooled heat pump with water-cooled heat pump; Replace cooling towers' fill; Add VFD on pumps and replaced the motor by high efficiency devices					

Case B	HVAC air system: Add outside-air economizer on CAV system
Case C	Equipment: Use VFD to control escalators
	HVAC air system: Add VFD on HVAC system fans
	HVAC water system: Add VFD on pumps
Case D	Equipment: Use VFD to control escalators
	HVAC water system: Add VFD auto control on pumps
Case E	Building Envelope: Add insulating layer on walls, roofs and windows; Walls' U-factor: from 1.72W/m^2.K to 0.4 W/m^2.K; Roofs' U-factor: from 0.8 W/m^2.K to 0.6 W/m^2.K; Windows: from Single-Glass(6.4 W/m^2.K) to Low-E in air(2.1 W/m^2.K)
	Lighting System: Guest Rooms: Replace cold light lamp with LED; Dining Room &Public Area: Replace filament lamps with LED; Floodlight: Replace traditional lamps with LED
	Equipment: Replace traditional cookers with energy efficient ones
	DHW system: Add heat recovery on laundry-used oil-fired boiler; Add card water system on staff shower rooms
	HVAC air system: Add VFD on exhaust fans in kitchens
	HVAC water system: Replace CW pumps and CHW pumps
	Refrigeration: Use water saving cooling towers
	Renewable energy: Add solar water heater
Case F	DHW system & HVAC water system: Replace oil-fired plants with heat pumps and heat recovery chiller. Therefore, the DHW is heated by the recover heat from double-effect heat recovery chillers.

It is found from Table 1 that retrofitting building HVAC system is widely adopted. There are four cases installed VFD on pumps. Installing VFD on AHU fans is also adopted in two cases. Three cases replaced chillers and boilers with higher efficiency devices. Outside air economizer is applied in two shopping malls' HVAC system retrofit. Previous study has shown that outside air economizer is very energy-efficient and cost-effective for buildings, such as shopping malls, with large internal heat gain (Levine, et al. 2012). Domestic hot water system retrofit is commonly adopted in hotel renovation. The retrofit measures took in hotel DHW system include hot water equipments used in guest rooms, laundry rooms and staff shower rooms. The improvement of building domestic hot water central plant is also commonly adopted in hotel. Lighting system and internal equipments are also popular retrofit measures. One case used LED lamps to renovate exterior lighting system. High energy-efficient lamps like T5 fluorescent lamps are used when retrofitting interior general lighting system. Two shopping malls (Case C and D) installed VFD to control escalators to reduce energy used in unoccupied mode.

2. Retrofit analysis

In order to estimate the retrofit benefits, the energy consumptions before retrofit and after retrofit are measured. As the final energy types are different based on end use equipments, all the energy usage results are converted to electricity final energy.[1](Shanghai Urban Construction and Communications Commission.2012) In

1 DGJ08-107-2012/J12068-2012:Design standard for energy efficiency in public buildings, P72: 1kg Standard Coal=3.691kWh electric energy;

theory, it is good to take a certain period (e.g. three years) energy data and calculate annual energy usage value for before and after retrofit analysis. Unfortunately, only limited energy use data is accessible prior to retrofit and most buildings are only retrofitted in recent years. In this study, we only present one year's measurement data for before and after retrofit conditions.

The economic benefit for the retrofit tool is calculated based on Shanghai's electricity time of use (TOU) tariff. (SMEPC) The retrofit assumes that the fuel energy is supplied by natural gas, and a constant rate for natural rate is assumed in the retrofit tool. In future development, the tool will make energy price and types editable by users.

Table 2. *Summary of Retrofit Information*

	Shopping Mall				Hotel	
Building	A	B	C	D	E	F
Gross Floor Area (m2)	127,262	108,000	250,000	32,000	55,842	26,000
Num. of Retrofit Measures	3	1	3	2	8	2
Energy Consumptions: (electric equivalent)						
Before Retrofit (kWh)	38,846,823	33,512,000	73,044,000	8,287,000	14,228,805	3,719,348
Before Retrofit: Energy Use Intensity (EUI) [kWh/m2]	305.25	310.30	292.18	258.97	254.80	143.05
Energy Savings (kWh)	5,736,905	1,363,985	5,032,395	794,628	3,723,340	1,405,648
EUI saving[kWh/m2]	45.08	12.63	20.13	24.83	66.68	54.06
Investment (RMB)	14,860,000	1,772,497	5,002,900	1,328,800		
Economic Benefits(RMB/Year)	24,214,735	9,186,470	33,966,315	5,276,200	3,350,700	

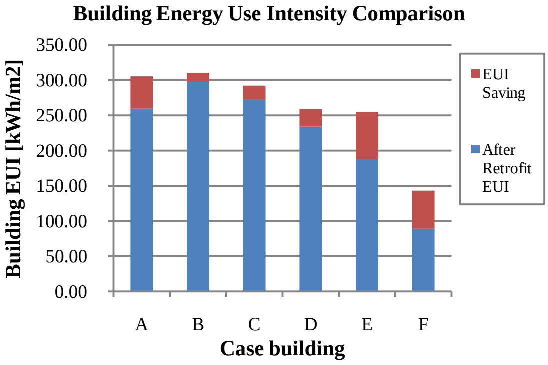

Figure 2. *Building retrofit Energy Use Intensity (EUI) Comparison*

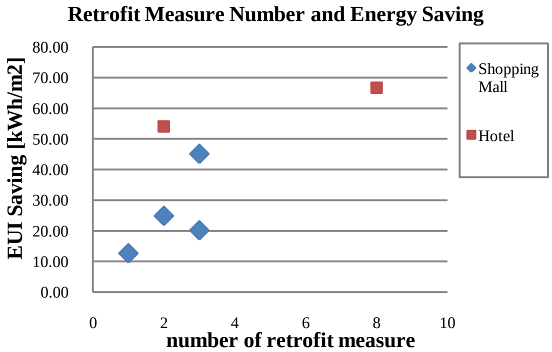

Figure 3. *Energy Saving and Retrofit Measure Number*

In Figure 2 and 3, it is found that retrofit can produce good energy saving for each of our case buildings. Building E generated the largest energy saving. One reason for the significant amount of energy saving in building E is contributed to the large number of retrofit taken by the building.

1kg Diesel Oil=7.831kWh electric energy

The retrofit tool firstly calculates the case buildings' before and after retrofit energy use difference to get energy saving for electricity and fuel. Then, time of use (TOU) energy tariff is applied to calculate the economic savings. It is noticed that for commercial buildings such as shopping malls, they are generally operated in peak and intermediate tariff. The calculated economic savings from the COMBAT model will be slightly higher than using flat electricity price.

The retrofit tool can also evaluate when individual retrofit is applied, the energy saving and cost-effectiveness of each measure. We take Case C as an example. Three retrofit measures were chosen in Case C: using VFD on HVAC system's fans, VFD to control pumps and VFD to control escalators unoccupied speed. COMBAT calculated case C's energy saving when each measure is applied based on Table 1. The measures' energy saving and cost-effectiveness are in shown in Figure 4 and Table 3. It is found that installing VFD on HVAC system's fans, pumps and building escalators are all cost-effective. However, the detailed energy saving and period varied from measure to measure. This function can better help users compare different measures when multiple retrofit options are available and assist them to prioritize retrofit strategies.

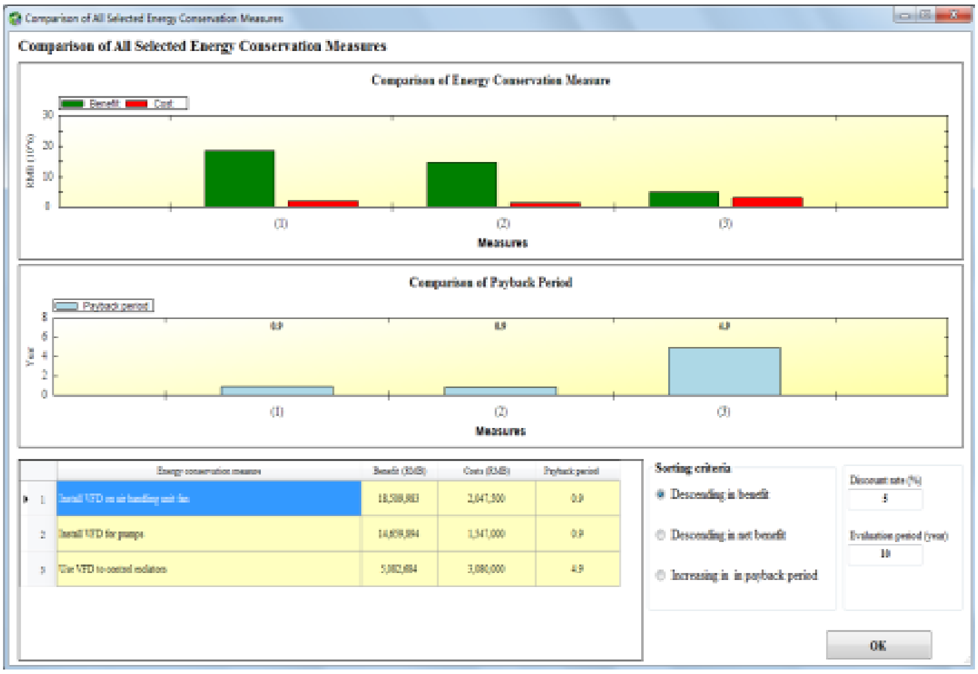

Figure 4. *Measures' Cost-effectiveness Analysis on Case C*

Table 3. *The Benefit, Cost and Payback Period of Each Measure in Case C*

	Energy Conservation Measure	Benefit (RMB)	Cost (RMB)	Payback Period
1	Install VFD on air handling unit fan	18,509,983	2,047,500	0.9
2	Install VFD for pumps	14,659,894	1,547,000	0.9
3	Use VFD to control escalators	5,082,684	3,080,000	4.9

3. Comparison of simulation and measurement results

To analyze the calculation accuracy of the retrofit tool, five retrofit cases are taken as test examples. Tool calculated energy saving is compared with the measured energy saving. The results are summarized in Table 4. Relative and absolute error factors, defined blow, are calculated to assess the accuracy of tool's calculation.

- Relative error,

  Relative error= (Measured saving - Simulation saving) / (Measured saving) (1)
- Absolute error,

  Absolute error=Energy saving ratio$_{measued}$ - Energy saving ratio$_{simulated}$ (2)

  Energy saving ratio = (Energy savings) / (Total energy use before retrofit) (3)

The relative error is a useful indicator to represent how accurate the simulated saving compared with measured one. However, when measured saving value is small, a small difference between simulation and measurement can give a big relative error number. In our case, the relative error of energy saving is approximately within +/- 40% range. This is a reasonable number based on existing experience of comparing simulated with measured energy performance (NBI 2008). Figure 5 and Figure 6 show the difference between calculated and measured savings. The energy saving difference between simulation and measurement results in Case A is slightly higher. More detail investigation is needed to find the discrepancy.

Table 4. *Energy Savings Result Summary*

		Building A	Building B	Building C	Building D	Building E
Energy Consumption Before Retrofit		38847	33512	73044	8287	14229
Energy Savings (MWh/Year)	Simulation	7902	1950	4952	419	3337
	Actual	5737	1364	5033	795	3723
	Relative Error	-37.7%	-43.0%	1.6%	47.3%	10.4%
Energy Saving Rates	Simulation	20.3%	5.8%	6.8%	5.1%	23.5%
	Actual	14.8%	4.1%	6.9%	9.6%	26.2%
	Absolute Error	-5.6%	-1.7%	0.1%	4.5%	2.7%
Economic Benefits (RMB/Year)	Simulation	6299256	1506165	3825256	323361.4	3461041
	Actual	5378438	1278750	4718438	745312.5	3350700
	Relative Error	-17.1%	-17.8%	18.9%	56.6%	-3.3%

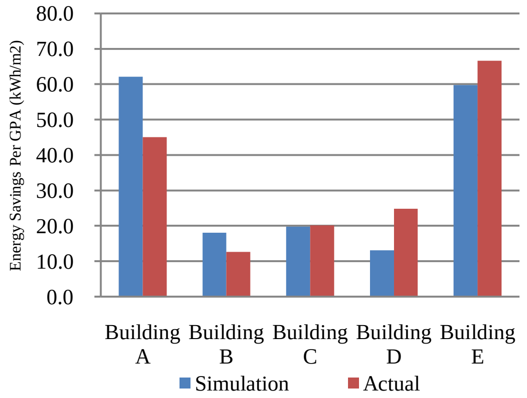

Figure 5. *Simulated and Measured EUI Saving Comparison*

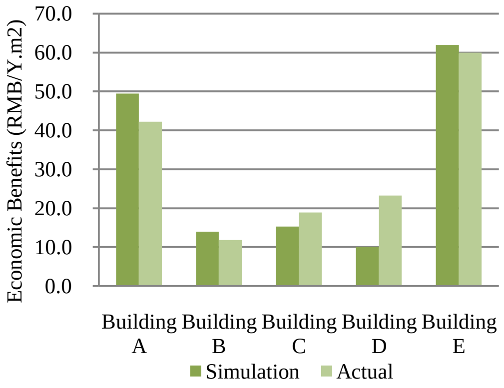

Figure 6. *Economic Benefits of Simulation Result and Actual Value*

CONCLUSIONS

In Summary, the commercial building retrofit tool – COMBAT demonstrates an effective way to perform building retrofit analysis. It can calculate building energy saving and retrofit measures' cost-effectiveness in a fast manner. This study shows a few retrofit cases in Shanghai and document the retrofit measures taken by those buildings. Case buildings' energy monitoring data are collected, and the measured energy savings are compared with COMBAT simulated results. The comparison shows that COMBAT can provide reasonable energy saving prediction. Furthermore, the tool can calculate the energy saving and cost-effectiveness of individual measures, and help users select the suitable measures for their application. The on-going development for this tool includes more building types and flexible energy cost and fuel types inputs. These features will be in included in future release.

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