The Impact of Appliance Efficiency on Building Energy Performance
-A Case Study for a Tianjin Eco-city in China

by

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Abstract

Buildings consume approximately 40% of the total energy use in the world. A building is a complex system whose annual energy use consists of many factors. The top five end-uses of building energy are space heating, space cooling, water heating, lighting and electrical appliances. Over fifty countries have developed efficiency standards and energy labels for residential appliances and commercial equipment to reduce energy consumption of those end-users. However, studies rarely consider the appliance efficiency in a whole building system. For this project, I used a computer-based simulation program to evaluate the impact of appliance efficiency in buildings on the heating, ventilation and air conditioning systems (HVAC). I studied the Chinese energy efficiency standards for refrigerators, washing machines, televisions, computers and rice cookers, and evaluated their impacts on two residential building prototypes being designed in an eco-city being planned and under construction in China. I found that improved efficiency of refrigerators and washing machines decreased peak load and the energy use for space cooling, but increased the energy use for space heating. The improved efficiency cut overall energy consumption and could lead to total annual energy savings of \$1.2 million in Tianjin eco-city. Although several limitations exist in this project, mechanical engineers may still consider the method and results to design more appropriately sized HVAC systems. Moreover, China may consider revising its building codes in order to better manage the energy consumption in its building sector.

Acknowledgements

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Table of Contents

List of Tables

List of Figures

Introduction

Buildings consume approximately 40% of total energy use in the world (WBCSD, 2009). A building is a complex system. The annual energy use of a building depends on many factors, including local climate, building orientation, insulation levels of the building envelope, heating, ventilation and air conditioning (HVAC) systems, lighting and appliance efficiency, operating schedules, and behaviors of the occupants. In addition, many stakeholders are involved in a building's value chain, including designers, developers, engineers, contractors and users (WBCSD, 2008). Therefore, it is vital to use a comprehensive approach in the design phase of a building's life cycle; and stakeholders in the early stages (i.e., designers, architect and engineers) should understand and/or inform stakeholders in the later stages (i.e., users) about the design of a building, because a building cannot be energy efficient without proper operation. Moreover, improving building energy efficiency is very important to demand-side management for utilities, because the reduction of peak load can cut the need for new power plant investments.

The top five end uses of energy consumption in buildings are space heating, space cooling, water heating, lighting and electrical appliances (DOE, 2009). Over 50 countries have developed efficiency standards and energy labels for residential appliances and commercial equipment to reduce energy consumption (Harrington & Damnics, 2004). Some researchers have studied the impact of appliance standards and voluntary labeling programs on a national scope (Fridley et al., 2007; Webber et al., 2000), but studies rarely consider the role of appliance efficiency in whole building systems. Appliances generate waste heat when they are in use, which will change the microclimate of a building. The heat gain from appliances can increase the cooling load in summer and reduce the heating load in winter. More energy efficient appliances are supposed to generate less heat, and can increase energy demand for space heating in winter. But on the other hand, less waste heat can help reduce energy use for space cooling in summer. So there is a tradeoff between energy use for heating and energy use for cooling, and my project is to evaluate the overall impact of appliance efficiency on building energy performance.

Studies which do not consider the interactions between appliances and HVAC systems may wrongly estimate the energy savings of implementing appliance efficiency programs. During the summer of 2009, I worked as an intern of the Rocky Mountain Institute's Built Environment Team where I conducted energy modeling for two residential building prototypes in a Tianjin eco-city in China. I used the Tianjin eco-city building models as a case study to evaluate the potential impact of appliance efficiency on whole building energy performance.

Tianjin Eco-City

Tianjin is one of the biggest industrial cities in China with over 1.18 million people as of 2008. The population density is 2,600 persons per square mile (NBSC, 2009). The eco-city site is located twenty-five miles from downtown Tianjin and ninety-three miles from Beijing (Fig. 1). The site is six miles from the core district of the Tianjin Binhai New Area, which is the current driving force behind Tianjin's economic growth.

The Sino-Singapore Tianjin Eco-city is a collaborative project between the Chinese and the Singaporean governments. This eco-city is a demonstration of a partnership between the two countries to deal with global climate change, to conserve energy and natural resources, to protect the ecosystem and to build a harmonious community. It aims to become a model for other cities in China as well as for other countries facing similar challenges. The groundbreaking ceremony of the project was in September 2008. The investment was about fifteen million US dollars in 2009 (Enorth, 2009), and is about 2.5 billion US dollars in 2010 (China Daily, 2010). By 2023, 350,000 people will move to this twelve- square mile eco-city (SSTEC, 2009). The first 500 apartments will be ready by the end of 2010 (People's Daily, 2010).

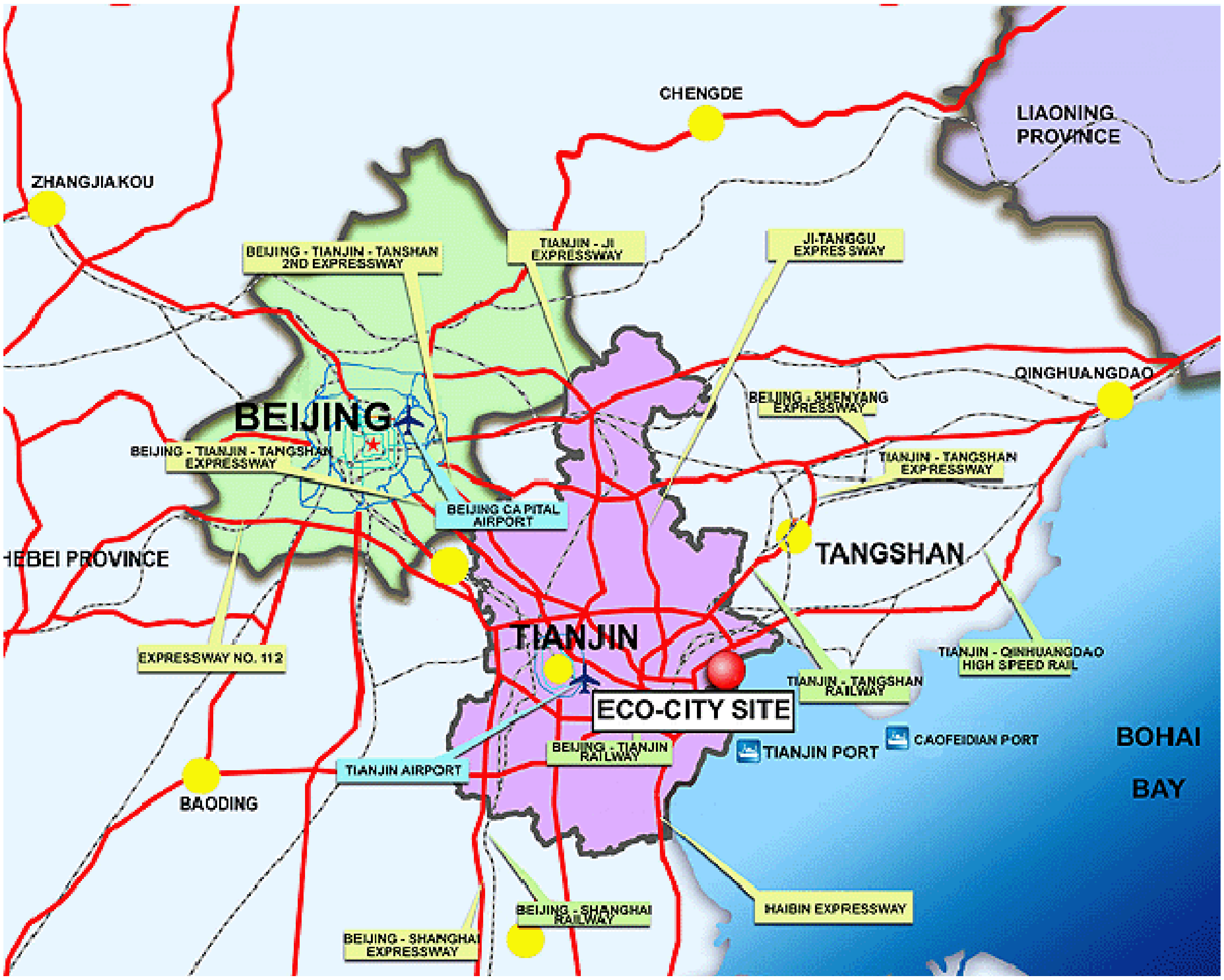

Figure 1. Location of the Tianjin eco-city site (SSTEC, 2010).

The major developer of Tianjin Eco-City is Keppel Land International Limited. Keppel Land consulted Rocky Mountain Institute (RMI) to provide recommendations for a master plan that utilizes whole system design strategies (RMI, 2008). My job was to utilize energy modeling to minimize energy consumption for individual residential building designs. In June 2009, Keppel Land provided RMI with floor plans for six building block types including 1784 apartment units. Among the six building block types, type A and type C had the most floors so I picked those two types as building prototypes for my analysis. All the eight type A buildings were high-rise so I chose type A as a sample for high-rise buildings; and then I chose type C buildings as a sample for mid-rise buildings. Additionally, some building blocks were semi-detached, where one building shadows at various hours throughout the day. Therefore, to further evaluate the effect of shading and building orientation, I picked two type A buildings side by side and with the most common building orientation according to the design by Keppel Land.

Energy Sources

Keppel Land and another architecture and engineering firm, SOM Skidmore, Owings & Merrill LLP, provided RMI with a Green Building Evaluation Standard especially designed for the Tianjin Eco-city. This standard requires that residential buildings use 10% renewable energy for their total energy consumption; 40% of households use a geothermal pump for heating and air conditioning and solar hot water; and 60% of households use hot spring water (Keppel Land et al., 2009). The eco-city will also use waste heat from a major nearby power plant to provide heating (SSTEC, 2009).

Objectives

The goal of my master's project is to utilize energy modeling to evaluate the potential energy savings from improved appliance efficiency. As noted, the annual energy consumption of a building consists of many factors. Therefore the final proposed building designs should include energy efficiency measures in all aspects, e.g., daylighting design, the type of HVAC system, and building material choices. However, my master's project primarily focuses on the impact of appliance efficiency choices. I establish a baseline model using the least efficient appliances and evaluate the energy savings which result from using more efficient appliances--those in accordance with China’s latest appliance standards. I evaluate the interaction between appliance efficiency and HVAC system capacity. The final results included:

- annual energy savings for space heating and space cooling;
- peak load percentage saving; and
- estimation for the total energy cost saving in the eco-city.

Materials and Methods

To study the impact of using different energy efficient home appliances on a whole building system, I used a computer-based simulation program called eQUEST--“the Quick energy Simulation Tool” (eQUEST, 2009). It is an “hour by hour” simulation program which is capable of calculating the annual building energy use hour by hour (Energy Design Resources, 2002) based on observed annual weather data. eQUEST is one of the most commonly used energy analysis software programs in the building energy field (Crawley et al., 2008; Gowri, 2005; Zhu, 2006). Due to the flexibility of the program and its user-friendly interface, eQUEST is especially helpful to evaluate specific efficiency measures for individual buildings. The precursor of eQUEST is DOE-2 software. The Lawrence Berkeley National Laboratory and James J. Hirsch & Associates developed the DOE-2 software in the late 1970s (Fang & Chen, 2007; Feng, 2004; Richman et al., 2009). Building professionals have reviewed and validated DOE-2 for a few decades, and eQUEST “extends and expands DOE-2's capabilities” by adding graphics. eQUEST models the heat gain from electrical equipment, lighting and human occupants (Hirsch, 2004), which is critical to this project. I selected the latest version of the program as of June 2009, eQUEST version 3.63. Figure 2 illustrates the inputs and outputs of my building model.

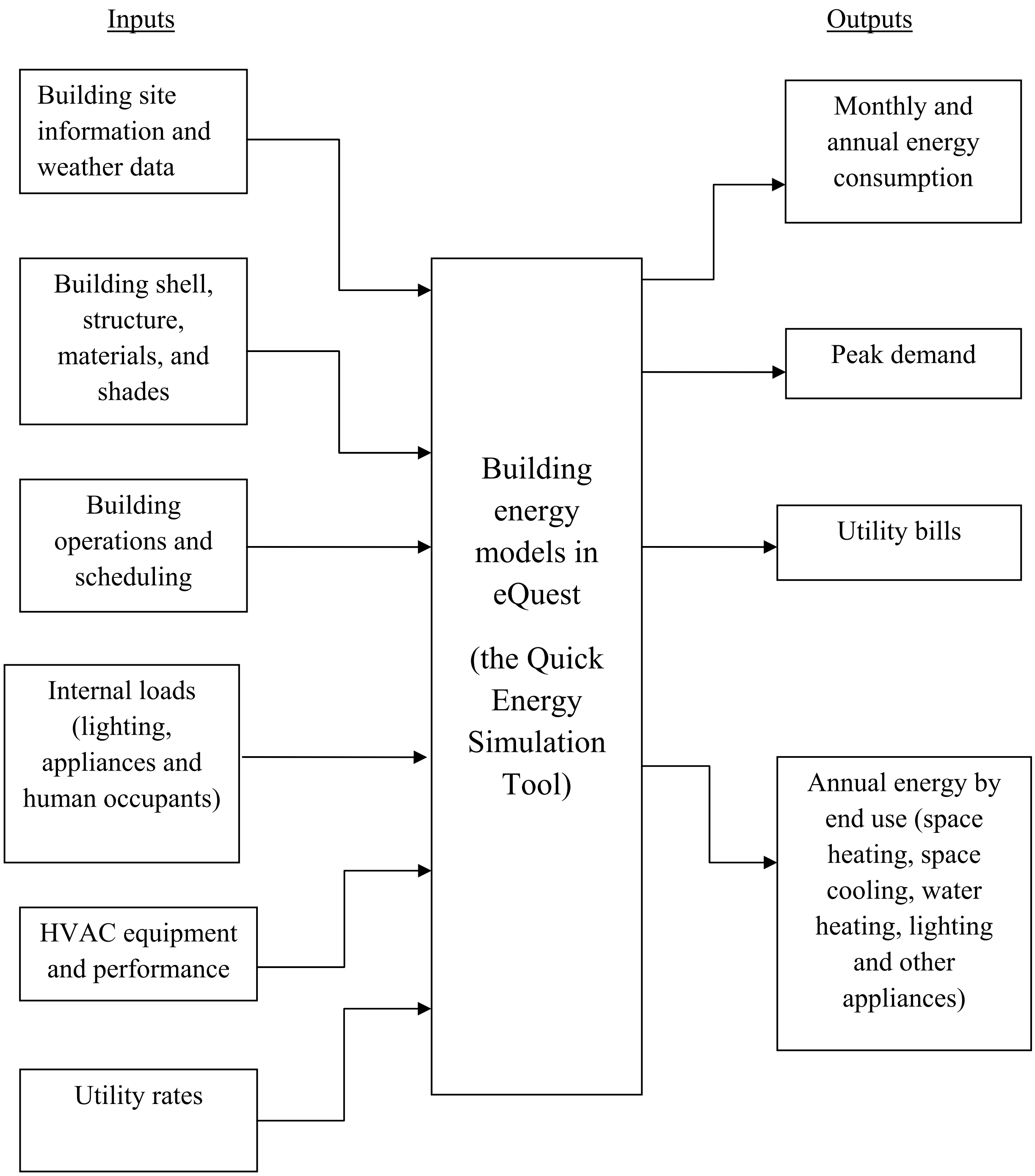

Figure 2. Flow chart of eQUEST modeling process (adapted from Hirsch, 2004).

Basic building description

Before I modeled the impact of appliance efficiency on the two building prototypes, I needed to describe the characteristics of the buildings. Firstly, I put into the model the information that Keppel Land, the developer, provided about building type and other general project information. Then I imported Keppel Land's architectural drawings into eQUEST of the floor plans of the mid-rise and high-rise building prototypes. eQUEST allows modelers to import computer aided design (AutoCAD) into the program to define building geometry including footprints, floor to floor distances and zoning patterns (Hirsch, 2004). Figures 3 and 4 show the output of 3-D building footprints. I imported weather data for Tianjin from the DOE2.com website (DOE2, 2009).

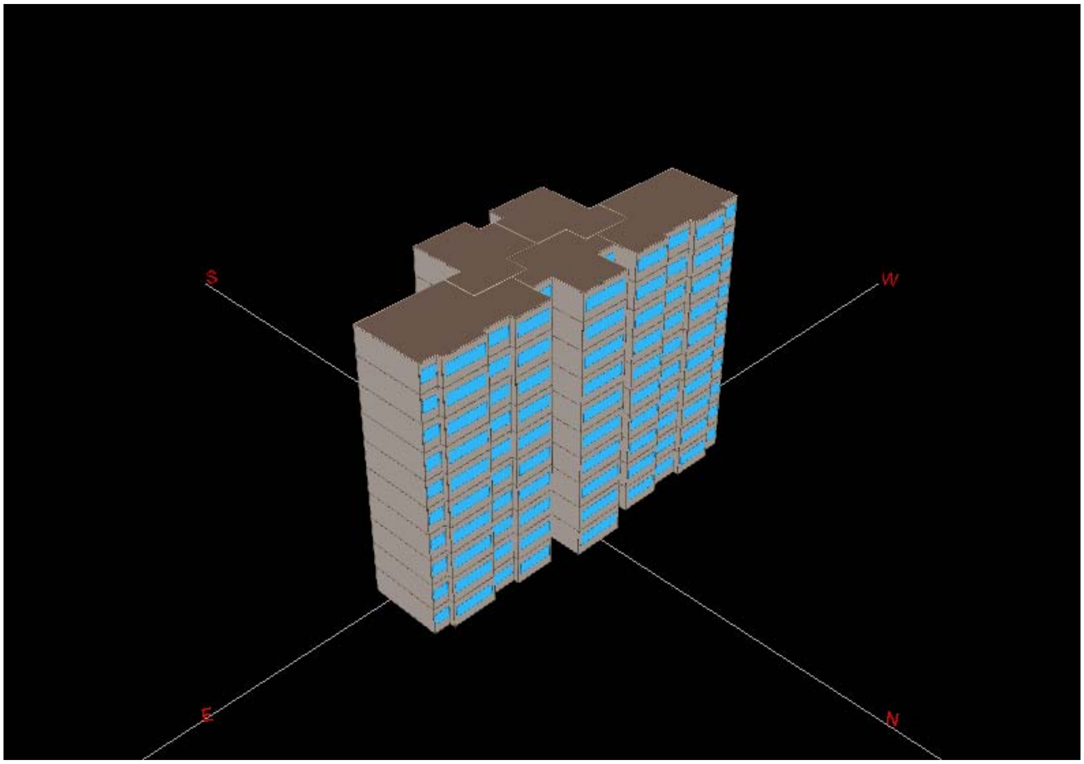

Figure 3. eQuest 3-D geometry for the Tianjin mid-rise building model.

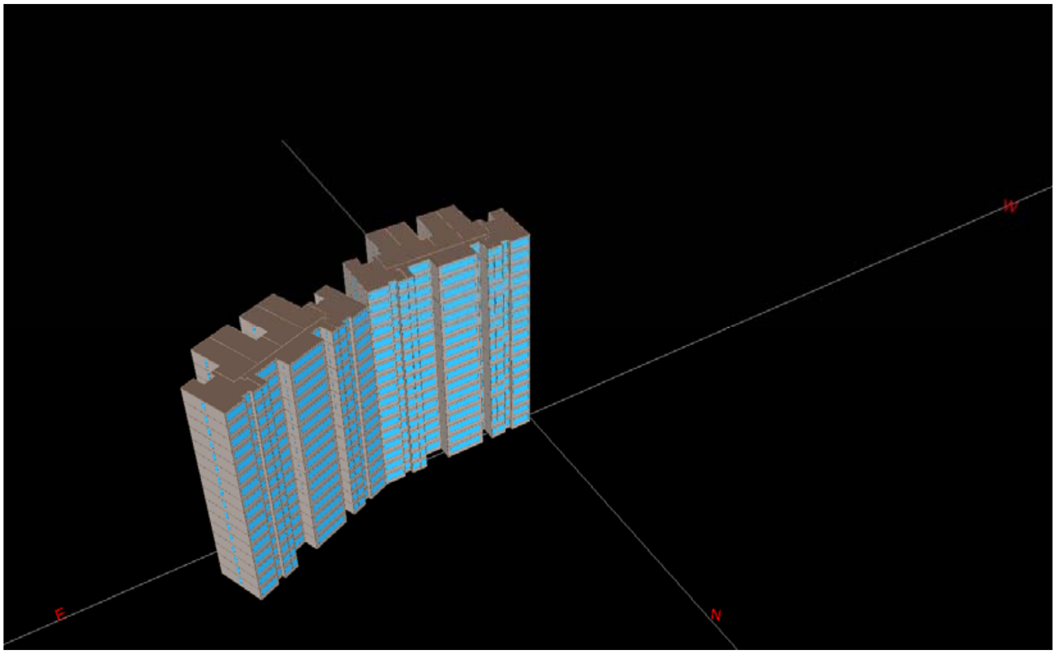

Figure 4. eQuest 3-D geometry for the Tianjin mid-rise building model.

Building the energy modeling baseline

In order to model the effects of various efficiency measures, it is necessary to define an energy consumption baseline. Tianjin local building energy code (TCMC, 2007) requires a 65% energy reduction from the energy consumption of the same kinds of buildings designed in 1980. However, there is no detailed description of the 1980 standards and thus it is impossible to assess energy performance improvement from this baseline. Based on my literature research on China's 1980 building standards, only a 1993 retrospective article mentioned an "80-Residential-2" building with six stories designed for the Beijing area (Siwei & Huang, 1993). Because the buildings designed for Tianjin Eco-city are very different from this "80-Residential-2" building in terms of size and building materials, and because information such as equipment and lighting power density, human occupants and the HVAC system is missing, the two building types are not comparable. I also tried to compile data from the Tianjin eco-city Green Building Evaluation

Standard and other relevant Chinese building codes, but still much of the information was missing or inconsistent. Therefore, using the 1980 standards as my energy modeling baseline is not feasible for this project. Thus I set the baseline energy performance using the Performance Rating Method in Appendix G of the *Energy Standard for Buildings Except Low-Rise Residential Buildings* (ASHRAE, 2007a). This method is required by Leadership in Energy and Environment Design (LEED) (USGBC, 2005), and I assume this to be a more stringent baseline than the unknown 1980 standard. The inputs of the baseline models are in the Appendix.

Preparation of Model Inputs

The objective of my project is to evaluate the potential energy savings by improved appliance efficiency based on the latest Chinese appliance standards. Therefore, I needed to collect data from technical specifications of appliances and to estimate a reasonable schedule about when and how often occupants would use those appliances. My main data sources were the most recent Chinese energy efficiency standards on home appliances available in China (i.e., not only Chinese models but also all the models in the market). I chose the standards using the following two criteria: (1) the appliance had more than 40% ownership rates (penetration) in rural households by 2005; and (2) each family used the appliance at least once a week. Five appliances were chosen: refrigerators, washing machines, televisions, computers and rice cookers. In the following section, I estimated the unit and aggregate energy consumption for each kind of appliance. Then I further calculated the power density and developed an occupant usage schedule to be used as the eQUEST model inputs.

1) Refrigerator

China's current national standard for refrigerators is called "The maximum allowable values of the energy consumption and energy efficiency grade for household refrigerators" (SAC, 2008). The standard gives the following formula[1] to calculate the baseline energy consumption values:

$$E_{base} = 0.8 \times (0.697 \times V_{adj} + 272 + CH) \times S_r/365$$

where E_{base} is the energy consumption basis (kWh/day), V_{adj} is the adjusted volume in liters, CH refers to the adjustable chiller modified coefficient, and Sr refers to the ice-maker modified coefficient. A chiller compartment is a storage compartment used to keep meats, fish or other produce at 32°F. When a refrigerator has a 15L or larger chiller compartment with adjustable temperature, the value of CH is equal to 50 kWh; otherwise CH is equal to 0. By 2008, only about 3% of refrigerators in China had a chiller compartment with adjustable temperature (Fridley et al., 2009). This market share means only a small number of families own a refrigerator with a chiller compartment with adjustable temperature. Thus I set CH as 0. Sr refers to the ice-maker modified coefficient. When the volume of the refrigerator is smaller or equal to 100L or bigger than 400L, and has an ice dispenser function, the value of Sr is equals to 1.10; otherwise Sr is equal to 1. The percentage of household with 270-liter refrigerators will be more than 93% by 2020 (Webber et al., 2000), when the Tianjin eco-city residents move in. Therefore the ice-maker modified coefficient, Sr, would be equal to 1. From the above, the energy consumption basis of a refrigerator for my project is 1kWh/day.

The Chinese refrigerator standards define energy efficiency levels for refrigerators. The following formula determines an energy efficiency value:

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[1] This formula applies for a refrigerator with both a refrigerator compartment and a freezer compartment. There are no free reports accessible for me to distinguish the market shares for refrigerators and freezers.

$$\eta = \frac{E}{E_{base}} \times 100\%$$

where η is the energy efficiency value and E represents the tested value of energy consumption (kWh/day) of a refrigerator under room temperature (77°F) . Table 1 shows the energy efficiency grades with their matching energy efficiency values for household refrigerators.

For the eQUEST model, power density (w/sf) is the input to model the energy consumption of appliances. However, a refrigerator does not use the same amount of energy all the time. Most of the energy consumption happens once in a while when the compressor is working. For example, a 200-watt refrigerator only runs at 300 watts when the compressor is working, and the rest of time the refrigerator is basically in "standby mode," using 5 watts or so.

Table 1. Energy efficiency grades and index for household refrigerators in China (SAC, 2008).

Energy Efficiency Grade	Energy Efficiency Index Refrigerator/Freezer
1	$\eta \leq 40\%$
2	$40\% < \eta \leq 50\%$
3	$50\% < \eta \leq 60\%$
4	$60\% < \eta \leq 70\%$
5	$70\% < \eta \leq 80\%$

However the eQUEST inputs are not so detailed, and thus for my analysis, I assumed the power of a refrigerator is constant. Power is a fundamental concept of physics which refers to the rate at which energy is converted (Myers, 2006). Therefore, I converted the daily energy consumption of a refrigerator into power, and I defined this constant value as a power equivalent value for a refrigerator.

$$P_{\text{refridgerator}}\ \text{equivalent} = \frac{Daily\ energy\ use\ of\ a\ refridgerator}{24\ hours}$$

$$= E_{test}\left(\frac{kWh}{day}\right) \times \frac{1000W}{1kW} \times \frac{day}{24h} = E_{test} \times \frac{1000}{24}(W)$$

Assuming each family in Tianjin eco-city will purchase a refrigerator with a 15L or larger chiller compartment with adjustable temperature, the value of CH would be equal to 50 kWh. So the maximum allowable energy for a household refrigerator would be 408 kWh/year or 1.12 kWh/day. I plugged this power equivalent value into Table 1 and got the values of real energy consumption for different grades of energy efficient refrigerators (Table 2).

Table 2. Estimated power and annual energy use of household refrigerators in China (SAC, 2008).

Energy Efficiency Grade	Annual energy use (kWh/year)	Power (W)
1	163	19
2	204	23
3	245	28
4	286	33
5	327	37

2) Clothes Washer

China’s current national standard for washing machines is called “The maximum allowable values of the energy consumption and energy efficiency grade for electric clothes washing machines” (SAC, 2004). Table 3 lists the maximum unit energy consumption for different energy efficiency grades of washing machines.

Table 3. Energy efficiency grades for household washing machines in China (SAC, 2004).

Energy Efficiency Grade	Electricity Consumption (kWh/cycle/kg)	
	Top-loading	Front-loading
1	0.012	0.19
2	0.017	0.23
3	0.022	0.27
4	0.027	0.31
5	0.032	0.35

The market share of top-loading washers was about 90% in 2004. Although many people have started to buy top-loading washers (Liang, 2004), only a small amount of families owned front-loading washers by 2007 (Webber et al., 2000). So I only modeled top-loading washers in my analysis. For a regular cycle, I assumed it would take an hour and the load would be 5 kg (Li, 2010). An ordinary family would wash two loads per week (Jiang, 2009). So the annual maximum allowable energy for a household refrigerator would be

$$E\ (\text{kWh/year}) = E(\text{kWh/cycle/kg}) \times 5\ (\text{kg}) \times 2\ (\text{cycle/week}) \times 52\ (\text{week/year})$$

A standard cycle per load is about 40 minutes (Jiang, 2009), and I calculated the power demand of washing machines to be:

$$\text{Power of a clothes washer} = \frac{\text{Energy use per cycle}}{time\ use\ per\ cycle}$$

$$= \frac{\text{E(kWh/cycle/kg)} \times \frac{1000W}{1kW} \times 5\ \text{(kg/cycle)}}{40min/(\frac{60min}{h})}$$

Table 4 shows the estimated power and annual energy consumption for different grades of energy efficient washing machines in China.

Table 4. Estimated power and annual energy use of top loading washing machines in China (SAC, 2004).

Energy Efficiency Grade	Annual energy use (kWh/year)	Power (W)
1	8	90.0
2	12	127.5
3	15	165.0
4	18	202.5
5	22	240.0

3) Television

China's current national standard for televisions is called "The maximum allowable values of the energy consumption and energy efficiency grade for color television machines" (SAC, 2005).

The formula to calculate the baseline energy consumption of color televisions is:

$$E_R = \sum_{i=1}^{4} P_{i,R} \times t_i$$

where *i*=1 for "on" mode; *i*=2 for active standby mode; *i*=3 for passive standby mode; *i*=4 for "off" mode; E_R is daily baseline energy consumption for a color TV (W·h); $P_{i,R}$ is the baseline wattage for "on" mode of a color TV (W); $P_{2,R}$, $P_{3,R}$ and $P_{4,R}$ are in Table 5; and t_i is hours in *i* mode of a color TV(h) (Table 6). Table 7 lists the parameters I used to calculate television power. Due to the wide variety of sizes and types of televisions, it was hard to estimate the power for a television the way I did for refrigerators and washing machines. So I estimated a range of the power demand of televisions based on different sources. According to All View Consulting, a marketing consulting firm in Beijing, by 2009, sales of CRT televisions were five million, decreased by 58% from 2008; and sales of flat screen televisions were ten million, increased by

58.3% from 2008 (Electrical Appliances, 2009). Financial Times reported in 2009 that the average size of flat screen televisions sold in China was thirty-seven inches (ninety-four centimeters) (Duke Energy, 2009). I assumed that the sales and sizes of flat screen televisions would keep increasing. So I thought ninety-four centimeters was a reasonable average size of a television in Tianjin Eco-city.

Table 5. Baseline power demand in watts of color televisions in standby and off mode (SAC, 2005).

	Do not automatically shut off		Automatically shut off	
Mode	Without an internal digital decoder	With an internal digital decoder	Without an internal digital decoder	With an internal digital decoder
Passive standby mode $P_{2,R}$	4	4	6	6
Active standby mode $P_{3,R}$	0	12	0	12
Off mode $P_{4,R}$	0	0	0	0

Table 6. Estimated daily total hours of each mode of television usage (SAC, 2005).

	Do not automatically shut off		Automatically shut off	
Mode	Without an internal digital decoder	With an internal digital decoder	Without an internal digital decoder	With an internal digital decoder
On	4	4	4	4
Passive standby	0	10	0	2
Active standby	20	10	4	2
Off	0	0	16	16

Table 7. Parameters for television power calculation (SAC, 2005).

Parameters	Explanation	Baseline value
S_F	coefficient of screen type	0.80 for nonwidescreen and 0.87 for widescreen
S_S	diagonal size (cm)	
S_A	screen area calculated from S_S and screen type (dm^2)	
Δ	coefficient of scan mode	0W when using 50Hz 625 lines interlaced scan mode; otherwise the baseline value is 23W

Table 8 shows the eight possibilities for baseline television power. The average power demand is 133W.

Table 8. Baseline power calculation for televisions (SAC, 2005).

Digital	Widescreen	50Hz 625 lines interlaced scan mode	Power (W)
Y	Y	Y	136
Y	Y	N	164
Y	N	N	158
Y	N	Y	130
N	Y	Y	108
N	Y	N	136
N	N	N	130
N	N	Y	102

Calculation of baseline power of an on-mode television

For digital televisions:

$$power = 44 + \frac{0.75 \times S_F \times S_S + 0.38 \times S_A + \Delta}{0.825}$$

For non-digital televisions:

$$power = 16 + \frac{0.75 \times S_F \times S_S + 0.38 \times S_A + \Delta}{0.825}$$

The energy efficiency index of color televisions is $EEI = \frac{E}{E_R}$, where *EEI* is energy efficiency index; *E* is the actual daily energy consumption standard of a TV in standard test conditions (W•h)； and E_R is the baseline daily energy consumption standard of a television (W•h).

This standard also sets a limit of standby power for all the televisions to 3W and for an energy efficient television to 1 W.

4) Computer

China does not have a national energy efficiency standard for computers, but there is a voluntary energy labeling specification called “Technical specifications for energy conservation product certification for computers” (CSCC, 2003). This standard only regulates the standby power usage to be no more than 3 W. Nevertheless, to estimate the annual energy consumption, I needed to know the power of a computer in its active mode. I did not find any literature or official site indicating the average power of an ordinary desktop computer in China, but an online forum mentioned that it was 350W (Wo, 2008).

5) Rice Cooker

China’s national energy efficiency standard for rice cookers is called “The maximum allowable values of the energy consumption and energy efficiency grade for rice cookers (SAC, 2008). This standard regulates the standby power usage to be no more than 2 W. For energy efficient products, the standby power usage must be no more than 1.6 W.

Similar to the computer case, I still needed to know the power of a rice cooker in its active mode. Similar to the computer power, in an online forum I found the power of an ordinary rice cooker in China is 500 W (Hai, 2007).

Usage Schedule

It was very challenging to develop an occupant usage schedule and I used various sources. Because eQuest requires very detailed time schedules, I had to distinguish schedules between weekdays and weekends. For refrigerators, we know that they are usually always on. For washing machines, I assumed a family washes 2 loads of 5kg of laundry every Sunday morning. For televisions, the Chinese standard suggests a 4-hour daily use of televisions (on mode) (SAC, 2005). For computers, Ipsos Insight, a marketing research consultancy, conducted a survey in 2006 and they found that Chinese spent about 18 hours per week on the internet (Ipsos, 2006). Thus I assumed that a Tianjin family uses their desktop computer for 2 hours per day on weekdays and 4 hours per day on weekends. For rice cookers, I assumed each family cooks every day, and for a 500 W rice cooker, it usually takes 30 minutes to cook a pound of rice per household per day (Hai, 2007). Figures 5 and 6 demonstrate the estimate weekly electricity usage schedule of an ordinary family. People use home appliances differently on weekdays and on weekends. There is a peak when people go home after work and turn on all the TVs and rice cookers. And there is another peak when people are watching TVs and surfing online at night.

Space Area

The mid-rise buildings consisted of two types of dwelling units, Unit B1 and Unit C2; the high-rise buildings consisted of two types of dwelling units, Unit A2 and Unit B2. Table 9 lists the total and individual square footage and number of dwelling units in the mid-rise and the high-rise buildings.

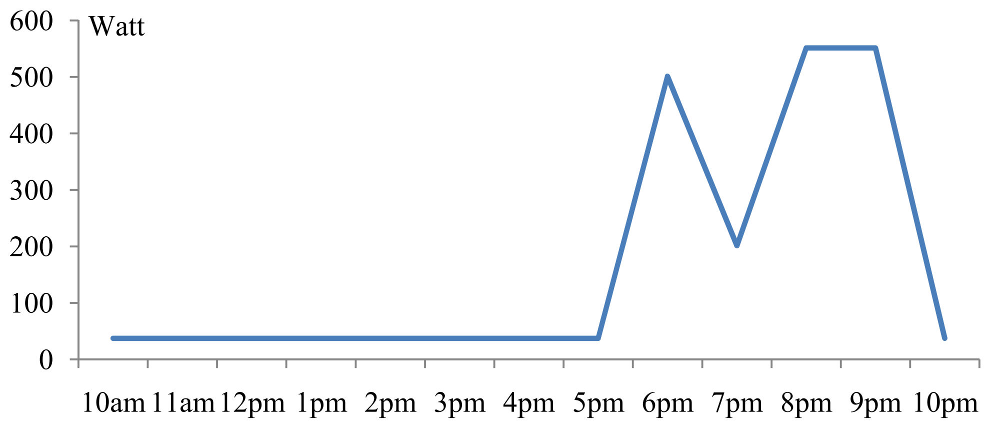


Figure 5. Occupant electricity usage schedule on weekdays.

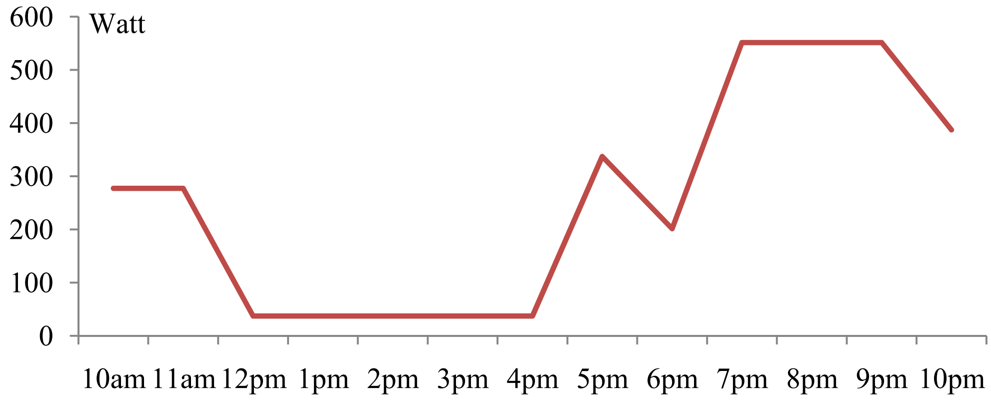


Figure 6. Occupant electricity usage schedule on weekends.

Table 9. Summary of Tianjin eco-city residential apartment units (Keppel Land, 2009).

Space Area	Square footage	Number of units
Mid-rise	4306	40
Unit B1	915	20
Unit C2	1238	20
High-rise	5274	198
Unit A2	807	132
Unit B2	1023	66

Power Density

The power density refers to the power of the appliance divided by the area of a HVAC zone. According to the ANSI/ASHRAE/IESNA Standard 90.1-2007, “Multifamily residential spaces shall be modeled using at least one thermal block per dwelling unit” (ASHRAE, 2007a), and thus I designed each dwelling unit as a HVAC zone. So in this case:

Power density (w/sf) $= \frac{Power\ of\ an\ appliance}{Square\ footage\ of\ a\ dwelling\ unit}$.

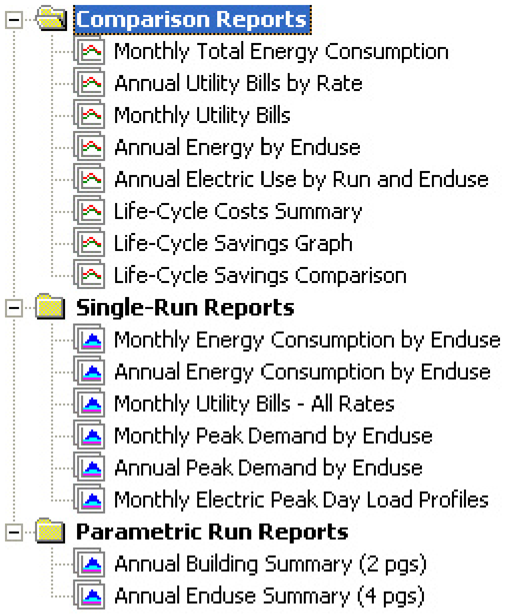
Because the energy efficiency standards only regulate the standby power of televisions, computers and rice cookers, I used the power of the most common sizes and types of those appliances to estimate total energy usage. Table 10 lists the power density for all the appliances in mid-rise and high-rise buildings.

I assumed five scenarios and ran five energy models. The first scenario was that people chose to use all Grade 1 refrigerators and washing machines, the most efficient ones; and similarly, the other scenarios were people chose to use all Grade 2 refrigerators and washing machines, Grade 3 refrigerators and washing machines, and so on.

The eQUEST model provides graphical and detailed reports. Figure 7 shows the components of graphical reports. Detailed reports include load reports, system reports, plant reports and economics reports. Due to the huge volume of detailed reports, I do not reproduce the entire reports here. The outputs I used to analyze the impact of appliance efficiency are electricity, natural gas, steam and total energy consumption for appliances and HVAC systems.

Table 10. Summary of Tianjin eco-city residential units power density for various grades of household appliances.

Appliance	Energy Efficiency Grade	Mid-rise power density (w/sf)		High-rise power density (w/sf)	
		Unit B1	Unit C2	Unit A2	Unit B2
Refrigerator	1	0.020	0.015	0.023	0.018
	2	0.025	0.019	0.029	0.023
	3	0.031	0.023	0.035	0.027
	4	0.036	0.026	0.040	0.032
	5	0.041	0.030	0.046	0.036
Top loading washer	1	0.098	0.073	0.111	0.088
	2	0.139	0.103	0.158	0.125
	3	0.180	0.133	0.204	0.161
	4	0.221	0.164	0.251	0.198
	5	0.262	0.194	0.297	0.235
Television	n/a	0.145	0.107	0.165	0.130
Computer	n/a	0.383	0.283	0.434	0.342
Rice cooker	n/a	0.546	0.404	0.619	0.489



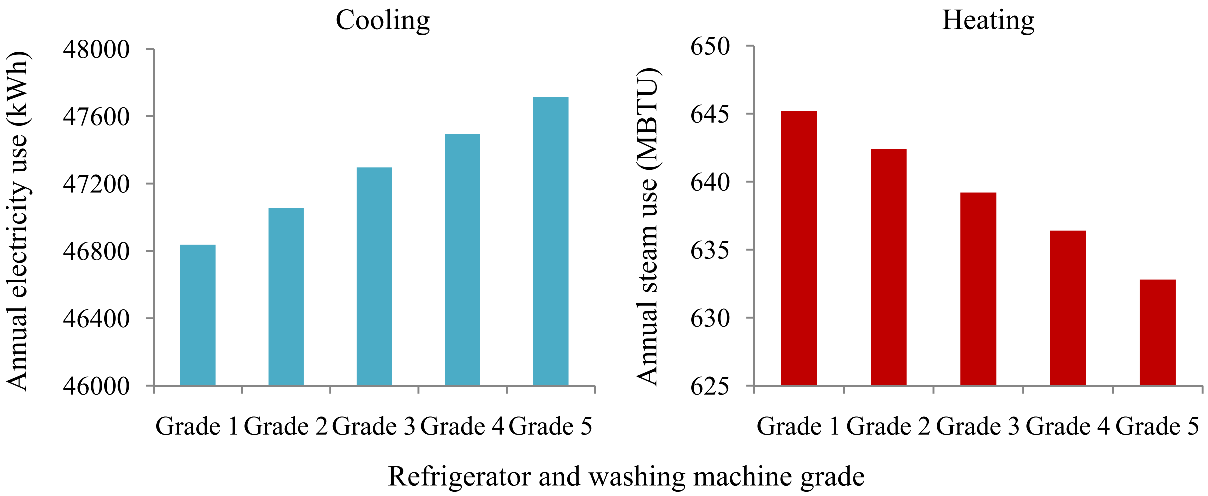
- **Comparison Reports**
  - Monthly Total Energy Consumption
  - Annual Utility Bills by Rate
  - Monthly Utility Bills
  - Annual Energy by Enduse
  - Annual Electric Use by Run and Enduse
  - Life-Cycle Costs Summary
  - Life-Cycle Savings Graph
  - Life-Cycle Savings Comparison
- **Single-Run Reports**
  - Monthly Energy Consumption by Enduse
  - Annual Energy Consumption by Enduse
  - Monthly Utility Bills - All Rates
  - Monthly Peak Demand by Enduse
  - Annual Peak Demand by Enduse
  - Monthly Electric Peak Day Load Profiles
- **Parametric Run Reports**
  - Annual Building Summary (2 pgs)
  - Annual Enduse Summary (4 pgs)

Figure 7. Component tree of graphical reports from eQuest model.

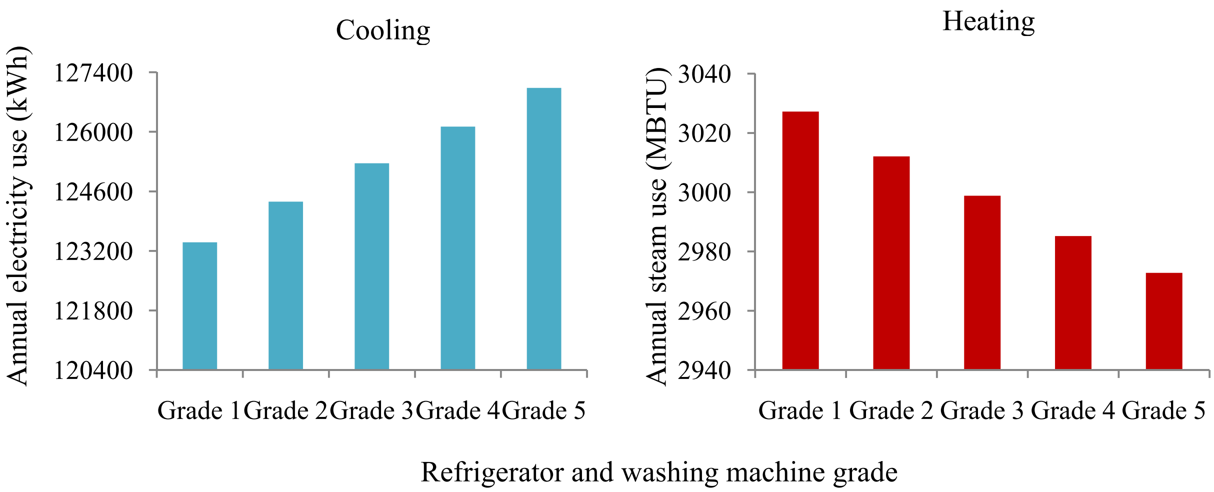
Results

The modeling reports showed that both the mid-rise and the high-rise building used less electricity for space cooling when occupants chose to use more efficient appliances. However, the building would use more steam for heating if people used more efficient products (Fig. 8). Because I used the same heating and cooling days for all the simulations, weather was not the cause of the differences in energy use for heating and cooling. Rather, the waste heat generated by appliances created a microclimate in the buildings and affected the heating and cooling loads. The waste heat increased the cooling loads during cooling degree-days and decreased the heating loads during heating degree-days.

To compare the impact of improved appliance efficiency on heating and cooling, I set the least efficient level--Grade 5, as an annual energy consumption baseline.



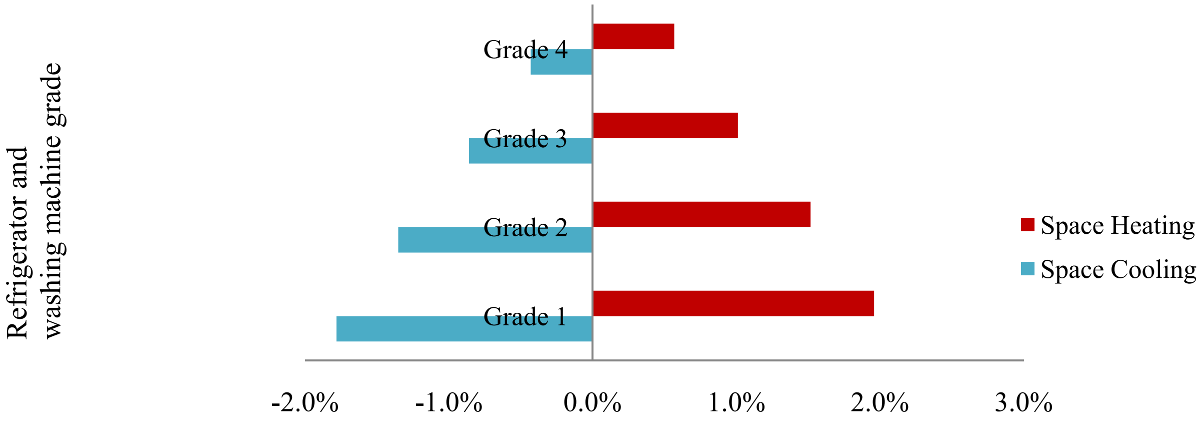
(a) Mid-rise prototype



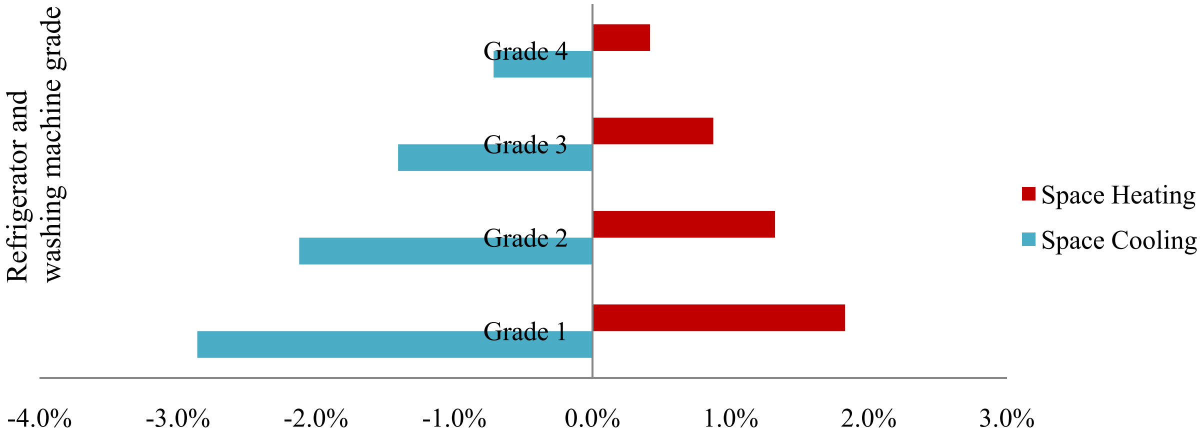
(b) High-rise prototype

Figure 8. Annual electricity use for cooling and annual steam use for heating of the (a) mid-rise and (b) high-rise prototypes in Tianjin eco-city

Figure 9 shows the percentage changes in total energy consumption of space heating and space cooling compared to the baselines in mid-rise and high-rise buildings. Improved appliance efficiency decreases the cooling load in summer and increases the heating load in winter. The absolute percentage changes of heating load and cooling load increase as appliance efficiency improves. If future residents who live in a mid-rise building use more efficient appliances, the cooling load will decrease by 0.4% -1.8%; and heating load will increase 0.6% - 2.0%. For the high-rise building prototype, if future residents improve appliance efficiency, the cooling load will decrease by 0.7% -2.9% in summer; and the heating load will increase by about 0.4% -1.8% in winter.



(a) Mid-rise Prototype

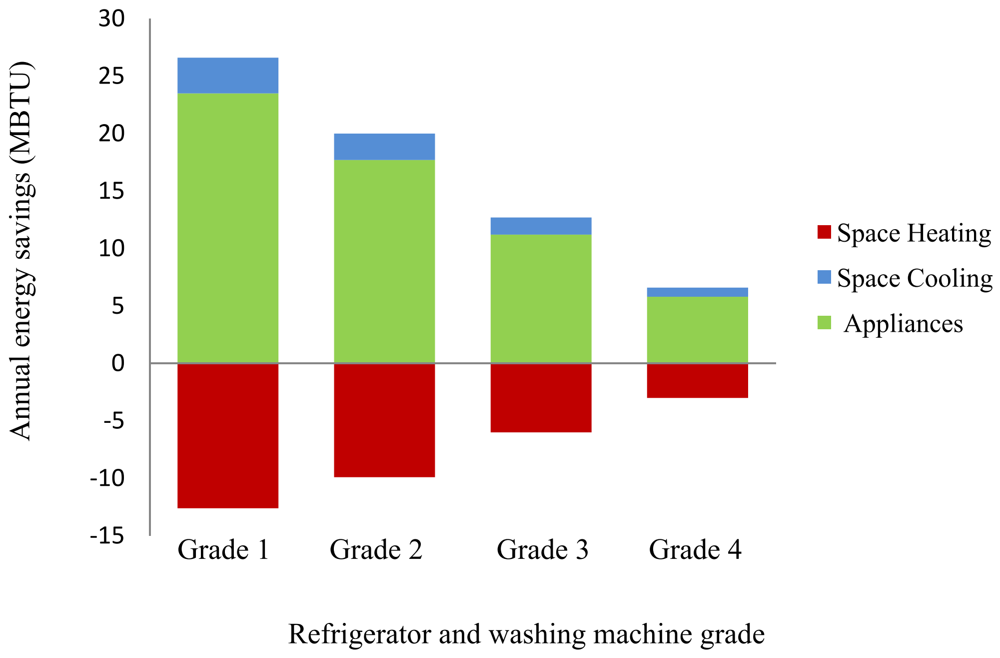


(b) High-rise Prototype

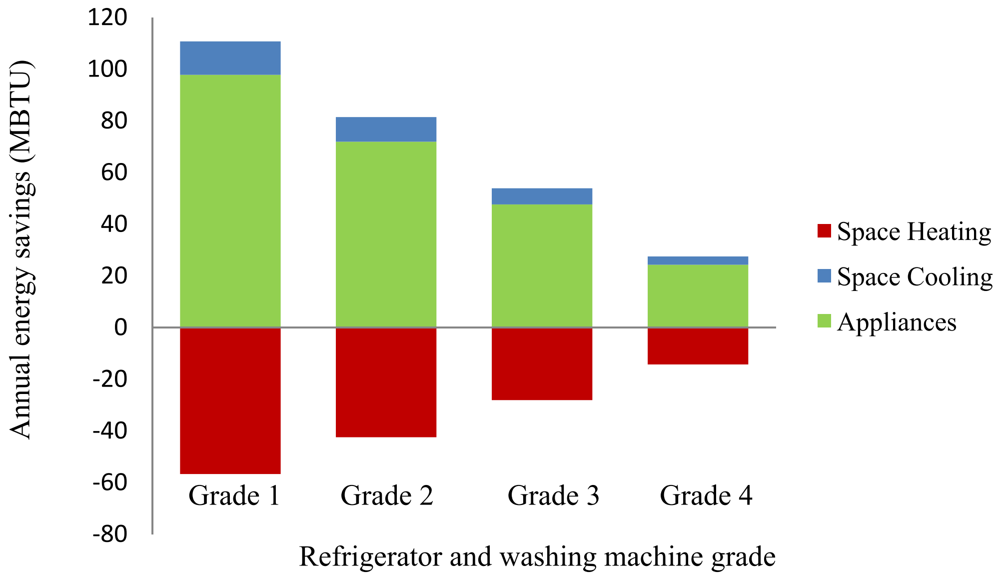
Figure 9. Percentage changes in energy consumption compared to usage for the least efficient grade of appliances (Grade 5) in Tianjin eco-city for the (a) mid-rise and (b) high-rise prototypes.

In the mid-rise building prototype, using Grade 1 appliances generated about a 2% difference for both cooling and heating compared to using Grade 5 appliances. In the high-rise building prototype, the energy saving for cooling was even greater, about 3%. Compared with the mid-rise building prototype, the high-rise building prototype had a larger electricity savings from using more efficient appliances, and a larger percentage saving compared to usage for the least efficient grade of appliances (Grade 5) for space cooling, but a smaller percentage increase for space heating than those in the mid-rise building. That was because the baseline electricity consumption of appliances in the high-rise building was more than that in the mid-rise building.

There is a tradeoff the between the energy saving for space cooling and the energy demand increase for space heating. However, the reduced wattages from using more efficient appliances were still the major source of energy savings (Fig. 10). If all future residents used Grade 1 refrigerators and washing machines, a mid-rise building could save about $430 every year compared to using Grade 5 refrigerators and washing machines; and a high-rise building could save about $1700 a year. The whole eco-city could thus save about $1.2 million by improved appliance efficiency. The peak load would also be reduced due to the improved energy efficiency. In the mid-rise building, the peak load would be decreased by 5% if people chose to use Grade 1 refrigerators and washing machines rather than Grade 5 appliances; this saving is about 1% in the high-rise building. This difference was also because the baseline electricity consumption of appliances in the high-rise building was more than that in the mid-rise building. In the case of Tianjin eco-city, the peak load reduction can be beneficial to a power plant near the eco-city.



(a) Mid-rise prototype



(b) High-rise prototype

Figure 10. Energy savings in Tianjin eco-city from using more efficient appliances compared to a baseline of the least efficient (Grade 5) for (a) mid-rise and (b) high-rise prototypes.

Sensitivity Analysis

The inputs of eQUEST models required exhaustive literature review and calculation. However, I made some assumptions about how future residents will use their home appliances because of limited data source. Therefore, I conducted a sensitivity analysis to help build confidence in my results. I set different hours of use, time of day and time of week to see how a change in the input on appliance use might change the modeling results. I increased the use of television from five hours to eight hours on weekends. I replaced doing laundry on Sunday morning with doing laundry on a weekday night. The results showed that the percentage changes in space heating and cooling loads are not very sensitive to hours of use or schedule changes. The net effect of these changes from my original results was never more than 3% and usually less than 1%.

Discussion

This project is a pilot study on the impact of appliance efficiency on building energy performance in a particular region. I have identified several limitations of my study. But if further studies can overcome these limitations, this topic will help mechanical engineers design appropriately sized HVAC systems as well as propose more robust energy policies in the building sector.

According to a study in the late 1990s, "no country had directly measured the actual energy savings resulting from efficiency standards due to the difficulty of defining baseline energy use and isolating the impact of technical improvements in efficiency from other changes in usage patterns" (Meier, 1997, p.111). I did not find any subsequent studies that measured the actual impact of appliance efficiency standards. A building is a complicated system, and the interactions among appliances and other parameters--including local climate, types of heating and cooling systems, efficiencies of heating and cooling systems, and time schedules of appliances--lead to complex effects on overall energy consumption. To evaluate the overall impact of appliance efficiency in buildings requires detailed computer modeling using building energy simulation programs (Ugursal & Fung, 1996). Because developers and investors usually want to finish their construction projects as quickly as possible, learning about the energy system is not their priority (Lovins, 1992). There are studies on comparing various computer-based simulation programs or applying a particular program to a pilot project (Crawley et al., 2008; Gowri, 2005; Tsave, 2009; Zhu, 2006). However, relatively few researchers have studied the impact of appliance efficiency in buildings. Since 1998, several Canadian scholars have modeled residential energy consumption in Canada (Aydinalp et al., 2002; Aydinalp et al., 2003; Fung et al., 1998; Fung et al., 2001; Guler et al., 2008). The findings in Fung et al. (1998) on the increase in energy use for space heating are similar to the results from my study. They also used an hour-by-hour building energy simulation program. While they used the Expanded STAR database (Fung et al., 1998), I used the eQUEST modeling program.

Due to limited time and data available, there are five major limitations of my study. First, this study was based on a specific building design, climate zone, and efficiency standards in a particular country. The heat gain from appliances could have a different magnitude for other building designs, climate zones, and appliance power densities. Tianjin has cold winters and thus a significant amount of heating load in winter. In tropical areas where no heating is usually required in winter, the improved appliance efficiency should have a more positive impact on the HVAC systems.

Second, I chose only five of the most popular and most energy-consuming appliances in an ordinary Chinese family. But to evaluate the peak load more comprehensively, I may consider other appliances that also contribute to the loads, e.g., audio equipment, hair dryers, alarm clocks and printers (Tupper, 2010).

Third, this project did not include a cost benefit analysis due to very limited time and funding to access market analysis reports. It would be very helpful to the future residents if I could have developed a list of energy efficiency products available in the market, and analyzed the payback time for investing in those products.

Fourth, it is also important to take into account the various energy sources, because the costs and greenhouse gas emissions of different energy sources are not the same. Keppel Land, SOM Skidmore and Owings & Merrill LLP (2009) mentioned that 40% of households in Tianjin eco-city use geothermal energy for space heating, space cooling, and water heating. However, because this information did not distinguish renewable energy sources among space heating, space cooling and water heating, I could not apply this information in the eQUEST model.

Fifth, I used an American building code as my baseline inputs. As I mentioned, this method is required by Leadership in Energy and Environment Design (LEED) (USGBC, 2005), and I assumed this to be a more stringent baseline than the unknown 1980 standard for China. If China’s Ministry of Housing and Urban-Rural Development revises the Chinese building codes and includes regulations on HVAC systems and changes the current prescriptive standards to performance-based standards (Hong, 2009), the simulation will fit the real Chinese situation even better.

In spite of the limitations I discussed above, mechanical engineers of the eco-city may still consider the results of my pilot study to design more appropriately sized HVAC systems. My results showed that improved appliance efficiency could reduce peak load and energy use for space cooling in the modeled building prototypes, which implied potentially smaller sizing for HVAC systems. Oversizing of HVAC systems is still a problem in today's buildings (Tupper, 2010). Mechanical engineers often place a safety margin on HVAC systems, i.e., "guess high or round up when in doubt," but this may lead to major oversizing of cooling equipment. Dynamic thermal simulation costs only a small fraction of project costs, but it can help the designer to better understand the peak thermal loads of a building (Lovins, 1992). The Tianjin eco-city project intends to serve as a sustainability demonstration project in China, and it is important to inform stakeholders in the entire eco-city, including designers, engineers, and future residents, to be aware of energy efficiency technologies available. The Chinese government is now subsidizing some energy efficient home appliances (Xinhua News Agency, 2009), which gives incentives to Chinese people, including future eco-city residents, to buy more efficient home appliances. If mechanical engineers were to consider my computer simulation results for residential buildings in the eco-city, they would avoid putting an overly high safe margin for the HVAC system, which would help save energy.

Another recommendation which China's Ministry of Housing and Urban-Rural Development may consider is to revise the Chinese building codes, so that in the future building energy analysts can use China's own standards to design, simulate and evaluate building performance in China. I suggest changing the current prescriptive standards to performance-based standards and requiring computer-based simulation for building energy performance.

Conclusion

For this project, I used a computer-based simulation program to evaluate the impact of appliance efficiency in buildings on energy consumption for heating, ventilation and air conditioning systems (HVAC). I studied the Chinese energy efficiency standards for refrigerators, washing machines, televisions, computers and rice cookers, and evaluated their impacts on two residential building prototypes being designed in an eco-city being planned and under construction in China. I found that improved efficiency of refrigerators and washing machines decreased peak load and the energy use for space cooling, but increased the energy use for space heating. The improved efficiency cut overall energy consumption and could lead to total annual energy savings of $1.2 million in Tianjin eco-city. Although several limitations exist in this project, mechanical engineers may still consider the method and results to design more appropriately sized HVAC systems. Moreover, China may consider revising its building codes in order to better manage the energy consumption in its building sector.

References

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). (2007a). *Ventilation for Acceptable Indoor Air Quality*, (ANSI/ASHRAE/IESNA 62.1-2007).

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). (2007b). *Energy Standard for Buildings Except Low-Rise Residential Buildings*, (ANSI/ASHRAE/IESNA 90.1-2007).

Aydinalp, M., Ugursal, V. I., & Fung, A. S. (2002). Modeling of the appliance, lighting, and space-cooling energy consumptions in the residential sector using neural networks. *Applied Energy, 71*(2), 87-110.

Aydinalp, M., Ugursal, V. I., & Fung, A. S. (2003). Modelling of residential energy consumption at the national level. *International Journal of Energy Research, 27*(4), 441-453.

China Daily. (2010, February 23). *Tianjin eco-city 2010 strive to complete projects with total investment of 20 billion RMB.* Retrieved from http://www.eco-city.gov.cn/eco/zhengfupindao/zonghexinwen/new/news_zhxw_0115.html

China Standard Certification Center (CSCC). (2003). *Technical Specifications for Energy Conservation Product Certification for Computers* (CCEC/T22-2003).

Crawley, D. B., Hand, J. W., Kummert, M., & Griffith, B. T. (2008). Contrasting the capabilities of building energy performance simulation programs. *Building and Environment, 43*(4), 661-673.

DOE2. (2009). *Weather data &weather data processing utility programs.* Retrieved from http://doe2.com/index_Wth.html

Duke Energy. (2009). *Duke energy signs MOU with china huaneng group to pursue renewable and other clean-energy technologies.* Retrieved from http://www.duke-energy.com/news/releases/2009081001.asp

Electrical Appliances. (2009, August 18). *China TV market analysis during the first half of 2009.* Retrieved from http://tech.qq.com/a/20090818/000270.htm Energy Design Resources. (2002). *Design brief: Building simulation.* Retrieved from http://www.energydesignresources.com/Portals/0/documents/DesignBriefs/EDR_DesignBriefs_buidlingsim.pdf

Enorth. (2009, January 15).*Sino-singapore Tianjin eco-city: 30 projects to be commenced with total investment of RMB 8-10bn.* Retrieved from http://english.enorth.com.cn/system/2009/01/15/003865219.shtml

eQUEST-the QUick energy simulation tool. (2009). Retrieved from http://www.doe2.com/eQUEST/

Fang, S., & Chen, Y. (2007). Evaluation on energy efficiency of windows in different climate zones of china. *Building Simulation 2007,* Beijing, China. 1638-1644.

Fung, A. S., Ugursal, V. I., & Farahbakhsh, H. (1998). A residential end-use energy consumption model for Canada. *International Journal of Energy Research, 22*(13), 1133-1143.

Feng, Y. (2004). Thermal design standards for energy efficiency of residential buildings in hot summer/cold winter zones. *Energy and Buildings, 36*(12), 1309-1312.

Fridley, D., Aden, N., Zhou, N., & Lin, J. (2007). *Impacts of china's current appliance standards and labeling program to 2020* No. LBNL-62802). Berkeley, California, USA: Lawrence Berkeley National Laboratory. Retrieved from http://china.lbl.gov/publications/impacts-chinas-current-appliance-standards-and-labeling-program-2020

Fridley, D., Zheng, N., Zhou, N., Aden, N., Lin, J., Cheng, J., & Sakamoto, T. (2009). *China refrigerator information label: Specification development and potential impact* No. LBNL-246E). Berkeley, California, USA: Lawrence Berkeley National Laboratory. Retrieved from http://china.lbl.gov/publications/china-refrigerator-specification-development-and-potential-impact

Fung, A. S., Aydinalp, M., Ugursal, V. I., Farahbakhsh, H., Halifax, N. S., Fung, A., & Ismet, D. C. (2001). A residential end-use energy consumption model for canada. *Canadian Residential Energy End-use.Data and Analysis Center.* Available on: http://www.Buildingsgroup.Nrcan.Gc.ca/eSim/documents/proceedings/Session4-4.Pdf.

Gowri, K. (2005). Desktop tools for sustainable design. *ASHRAE Journal, 47*(1), 42–46.

Guler, B., Ugursal, V. I., Fung, A. S., & Aydinalp-Koksal, M. (2008). Impact of energy efficiency upgrade retrofits on the residential energy consumption and greenhouse gas emissions in canada. *International Journal of Environmental Technology and Management, 9*(4), 434-444.

Hai, Z. (2007, June 30). Power of rice cooker and energy conservation. Message posted to http://iask.sina.com.cn/b/9711037.html

Harrington, L., & Damnics, M. (2004). *Energy labelling and standards programs throughout the world*The National Appliance and Equipment Energy Efficiency Committee, Australia. Retrieved from http://www.energyrating.gov.au/library/pubs/200404-internatlabelreview.pdf

Hirsch, J. J. (2004). *eQUEST introductory tutorial.* Retrieved from http://www.doe2.com/eQUEST /

Hong, T. (2009). A close look at the china design standard for energy efficiency of public buildings. *Energy and Buildings, 41*(4), 426-435.

Ipsos. (2006). *Internet adoption slowing – but dependence on it continues to grow.* Retrieved from http://www.ipsos-na.com/news-polls/pressrelease.aspx?&id=3030

Jiang, Z. (2009, April 14). Energy use for top-loading washing machines. Message posted to http://zhidao.baidu.com/question/93602724.html

Keppel Land. (2009). *Tianjin eco-city residential apartment units.* Unpublished manuscript.

Keppel Land, & SOM Skidmore, Owings & Merrill LLP. (2009).*Tianjin eco-city master plan assessment of sustainability design guidelines.* Unpublished manuscript.

Li, L. (2010, Jan 26). Laundry volume of household washing machines. Message posted to http://wenda.tianya.cn/wenda/thread?tid=2992d409397a2230

Liang, Y. (2004). The status quo and trend of the chinese clothes washer market. *China Economic & Trade Herald,* (004), 40-40.

Lovins, A. (1992). Energy-efficient buildings: Institutional barriers and opportunities. *E Source.Boulder, Colorad.*

Meier, A. K. (1997). Observed energy savings from appliance efficiency standards. *Energy and Buildings, 26*(1), 111-117.

Myers, R. L. (2006). *The Basics of Physics*. Westport, Connecticut, London: Greenwood Press.

National Bureau of Statistics of China (NBSC). (2009). *China statistical year book*. Beijing: China Statistics Press.

People's Daily. (2010, February 23). *500 eco-apartments in Sino-Singapore eco-city be ready by the end of the year*. Retrieved from http://www.eco-city.gov.cn/eco/zhengfupindao/zonghexinwen/new/news_zhxw_0117.html

Richman, R., Pasqualini, P., Sc, M., Kirsh, A., & Sc, B. (2009). Life-cycle analysis of roofing insulation levels for cold storage buildings. *Journal of Architectural Engineering, 15*, 55.

Rocky Mountain Institute (RMI). (2008). *Detailed scope description.* Unpublished manuscript.

Sino-Singapore Tianjin eco-city (SSTEC). (2009). *Sino-Singapore Tianjin eco-city.* Retrieved from http://www.tianjinecocity.gov.sg/

Siwei, L., & Huang, Y. J. (1993). Energy conservation standard for space heating in chinese urban residential buildings. *Energy, 18*(8), 871-892.

Standardization Administration of China (SAC). (2005). *The Maximum Allowable Values of the Energy Consumption and Energy Efficiency Grade for Color Television Machines,* (GB12021.7-2005).

Standardization Administration of China (SAC). (2004). *The Maximum Allowable Values of the Energy Consumption and Energy Efficiency Grade for Electric Clothes Washing Machines,* (GB12021.4-2004).

Standardization Administration of China (SAC). (2008). *The Maximum Allowable Values of the Energy Consumption and Energy Efficiency Grade for Household Refrigerators*, (GB12021.2-2008).

Standardization Administration of China (SAC). (2008). *The Maximum Allowable Values of the Energy Consumption and Energy Efficiency Grade for Rice Cookers*, (GB12021.6-2008).

Thomas, P. C., & Moller, S. (2009). *HVAC system size–getting it right.* Icon.Net Pty Ltd.

Tianjin Construction Management Committee (TCMC). (2007). *Tianjin Energy Efficiency Design Standard for Residential Buildings*, (DB29-1-2007).

Tsave, A. (2009). *Energy performance regulations and methodologies of energy saving in office buildings in southern Europe*. Brunel University School of Engineering and Design PhD Theses.

Tupper, K. (2010). In Fan H. (Ed.), *Re: Amory's comments on mechanical system designs in 1994.* Personal communication.

Ugursal, V.I., & Fung, A. S. (1996). Impact of appliance efficiency and fuel substitution on residential end-use energy consumption in canada. *Energy and Buildings, 24*(2), 137-146.

U.S. Department of Energy (DOE). (2009). *Buildings energy data book*D&R International, Ltd. Retrieved from http://buildingsdatabook.eren.doe.gov/docs%5CDataBooks%5C2009_BEDB_Updated.pdf

U.S. Green Building Council (USGBC). (2005). Energy and atmosphere. *LEED-NC version 2.2 reference guide* (pp. 1-416). Washington, DC: U.S. Green Building Council.

Webber, C., Brown, R., & Koomey, J. (2000). Savings estimates for the ES® voluntary labeling program. *Energy Policy, 28*(15), 1137-1149.

Wo, S. (2008, Oct 31). Power for an ordinary desktop computer. Message posted to http://wenda.tianya.cn/wenda/thread?tid=49c01e78521eb170&clk=wttpcts

World Business Council for Sustainable Development (WBCSD). (2008). *Energy efficiency in buildings: Business realities and opportunities* Retrieved from http://bit.ly/a5xAIo

World Business Council for Sustainable Development. (2009). *Manifesto for energy efficiency in building.* Retrieved March 29, 2010, from http://www.wbcsd.org/DocRoot/JGurlev2GuuUF2DAKJrd/EEBManifesto.pdf

Xinhua News Agency. (2009). *China offers subsidies for green home appliances.* Retrieved April 20, 2010, from http://www.china.org.cn/environment/policies_announcements/2009-05/22/content_17816663.htm

Zhu, Y. (2006). Applying computer-based simulation to energy auditing: A case study. *Energy and Buildings, 38*(5), 421-428.

Appendix

eQUEST Energy model inputs other than equipment power density[2].

Basic Inputs	*Inputs*				*Notes*
Project Location		Tianjin, China			
Site altitude		0		ft	
Weather File/Description					
Climate Zone	4A				Per Table B-3 and Section B-2
Space Conditioning Category		Residential		Fossil Fuel, Fossil/Electric Hybrid, and Purchased Heat	Per Section 5.1.2
Building Type		Multifamily			
Utility Information					
	Usage	*Units*			
Electricity					
On Peak Charges	*0.0735*	*[$/kWh]*			
Off Peak Charges	*0.0735*	*[$/kWh]*			
Gas	*0.92*	*$/therm*			
Steam	*11.4*	*$/unit*			
Building Operation Schedule	*M-F*	*Sat*		*Sun*	
	5pm - 7am	4pm-9am		*4pm-9am*	
Geometry	*Proposed*	*ASHRAE 90.1-2007*		*Units*	*ASHRAE Section/SOURCE*
Building Orientation		North		-	-
Floor-to-Floor Height		9.5		ft	-
Floor-to-Ceiling Height		9.5		ft	-
Plenum Height		0		ft	-
Self Shading		Yes			
Conditioned Area		45260		ft^2	-
Total Number of Floors (Full or Partial)		10			
Envelope	*Proposed*	*ASHRAE 90.1-2007*		*Units*	*ASHRAE Section/SOURCE*
Opaque Elements		*U-Value*	*Min. R-Value*		
Roof u-value		0.048	R-20.0 c.i.	u-value (Btu/hr-sf-F)	Per Table 5.5-1 - 5.5-8
Roof Reflectivity		0.3		-	Per Table G3.1 Section 5e (Baseline) & 5c (Proposed)
Roof SRI		-		-	
Above Grade Wall		0.064	R-13.0 + R-7.5 c.i.	u-value (Btu/hr-sf-F)	Per Table 5.5-1 - 5.5-8
Wall reflectivity		-		-	Not regulated
Below Grade Walls		1.14	NR	u-value (Btu/hr-sf-F)	

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[2] ASHRAE, 2007 a and b.

Above Grade Floors		0.038	R-30.0	u-value (Btu/hr-sf-F)	
Slab-On-Grade Floors		0.73	NR	f-factor (Btu/hr-ft-F)	Per Table 5.5-5 (for Unheated per Table G3.1-5)
Slab Floor Area		4526		sf	
Exposed Slab Perimeter		462		ft	
Slab U-effective				u-value (Btu/hr-sf-F)	Small slab/Large slab
Infiltration Perimeter Zones		0.500		ACH	Not regulated
Infiltration Core Zones		0.000		ACH	Not regulated
Opaque Door Swining		0.7	-	u-value (Btu/hr-sf-F)	Per Table 5.5-1 - 5.5-8
Opaque Door Non-Swinging		1.5	-	u-value (Btu/hr-sf-F)	Per Table 5.5-1 - 5.5-8
Fenestration		*U-Value*	*SHGC*		
Vertical Glazing Non-Metal Framing (all) U-Value		0.4	0.4	u-value (Btu/hr-sf-F)	Per Table 5.5-1 - 5.5-8
Vertical Glazing Metal Framing (curtain wall/ storefront) U-Value		0.5	0.4	u-value (Btu/hr-sf-F)	Per Table 5.5-1 - 5.5-8
Vertical Glazing Metal Framing (entrance door) U-Value		0.85	0.4	u-value (Btu/hr-sf-F)	Per Table 5.5-1 - 5.5-8
Vertical Glazing Metal Framing (all other) U-Value		0.55	0.4	u-value (Btu/hr-sf-F)	Per Table 5.5-1 - 5.5-8
Skylight with Curb, Glass, 0%-2% of Roof		1.17	0.49	u-value (Btu/hr-sf-F)	Per Table 5.5-1 - 5.5-8
Skylight with Curb, Glass, 2%-5% of Roof		1.17	0.49	u-value (Btu/hr-sf-F)	Per Table 5.5-1 - 5.5-8
Skylight with Curb, Plastic, 0%-2% of Roof		1.3	0.65	u-value (Btu/hr-sf-F)	Per Table 5.5-1 - 5.5-8
Skylight with Curb, Plastic, 2%-5% of Roof		1.3	0.34	u-value (Btu/hr-sf-F)	Per Table 5.5-1 - 5.5-8
Skylight with Curb, All, 0%-2% of Roof		0.69	0.49	u-value (Btu/hr-sf-F)	Per Table 5.5-1 - 5.5-8
Skylight with Curb, All, 2%-5% of Roof		0.69	0.39	u-value (Btu/hr-sf-F)	Per Table 5.5-1 - 5.5-8
Glass Door SC		0.46			
Visible Transmittance		0.63			Assumed
Glass Tvis					Not regulated
Glass SC					Not regulated
Frame u-value					Not regulated
Fenestration Assembly u-value		0.55		u-value (Btu/hr-sf-F)	Per Table 5.5-1 (same for all glass)
Fenestration Assembly Conductance		0.66		-	Looked up using eQUEST conductance table
Fenestration Assembly SHGC		0.4			Per Table 5.5-1 (same for all glass)
Fenestration Assembly SC		0.46			Calculated from SHGC
Visible Transmittance		0.63			Assumed
Window to Wall Ratio		20.0%			Per Table G3.1 Section 5c (baseline) 40% max
Overhangs		No			
Occupancy	*Proposed*	*ASHRAE 90.1-2007*		*Units*	*ASHRAE Section/SOURCE*
Dwelling Unit		14.0	323.0	people/unit sf/person	From ASHRAE 62.1-2007
Corridors		500.0		sf/person	From ASHRAE 62.1-2007
Laundry Rooms within Dwelling units		100.0		sf/person	From ASHRAE 62.1-2007

Ventilation CFM/Person (62.1)	*Proposed*	*ASHRAE 90.1-2007*	*Units*	*ASHRAE Section/SOURCE*
Dwelling Unit		0.08	cfm/sf	From ASHRAE 62.1-2007
Corridors		0.06	cfm/sf	From ASHRAE 62.1-2007
Laundry Rooms within Dwelling units		17.0	cfm/person	From ASHRAE 62.1-2007
Bathrooms		25.0	cfm/pbathroom	From ASHRAE 62.1-2007

Lighting Power Density by Space Type	*Proposed*	*ASHRAE 90.1-2007*	*Units*	*Occupancy Sensors?*
Dwelling Unit		1.1	w/sf	N
Corridor/Transition - General		0.5	w/sf	N
Parking Garage--Garage Area -		0.2	w/sf	N
Laundry		0.6	w/sf	N
Exterior Lighting		1.0	w/sf	N

LPD With Occupancy Sensors	*Proposed*	*ASHRAE 90.1-2007*	*Units*	*ASHRAE Section/SOURCE*
Dwelling Unit		1.1	w/sf	Table 9.6.1
Corridor/Transition - General		0.5	w/sf	Table 9.6.1
Parking Garage--Garage Area -		0.2	w/sf	Table 9.6.1
Laundry		0.6	w/sf	Table 9.6.1
Exterior Lighting		1.0	w/sf	Table 9.6.1

Lighting Controls	*Proposed*	*ASHRAE 90.1-2007*	*Units*	*ASHRAE Section/SOURCE*
Daylighting	TBD	no	-	Table G3.1 Section 6f and 6g

Exterior Lighting Power Density	*Proposed*	*ASHRAE 90.1-2007*	*Units*	*ASHRAE Section/SOURCE*
Exterior Lighting	TBD	TBD	-	9.4.5 - remember the 5% allowance

Zone Setpoints - Heating & Cooling	*Proposed*	*ASHRAE 90.1-2007*	*Units*	*ASHRAE Section/SOURCE*
Dwelling Units	68F 60% RH / 78F 60% RH	68F 60% RH / 78F 60% RH	-	China's General Office of the State Council
Corridor	68F 60% RH / 78F 60% RH	68F 60% RH / 78F 60% RH	-	China's General Office of the State Council

Main HVAC	*Proposed*	*ASHRAE 90.1-2007*	*Units*	*ASHRAE Section/SOURCE*
HVAC System Type		System 1-PTAC		Table G3.1.1A
Fan Control		Constant Volume		Table G3.1.1B
Cooling Type		Direct expansion		
Heating Type		Hot-water fossil fuel boiler		
Number of Systems	3			G3.1.1 *Please see exceptions of G3.1.1
Return Air Path	Plenum	Plenum		
Heating Oversize Capacity Factor	0	1.25		G3.1.2.2
Cooling Oversize Capacity Factor	0	1.15		G3.1.2.2

Boiler

Number	2	2		G3.1.3.2
Design Size		>300,000 & <2,500,000Btuh		
Size	0.6	0.625		G3.1.3.2
Type	Hot water loop at both system and zone	Gas-fired hot water natural draft		G3.1.3.2
Efficiency		75%	E(t) = thermal efficiency	G3.1.2.1 & Table 6.8.1F
Heat Input Ratio	1.14			
Location				
Design Supply T	135	180	degree F	G3.1.3.3
Design Return T	95	130	degree F	G3.1.3.3
Delta T	40	50	degree F	
Temp Setpoint Control	Fixed	OA reset		G3.1.3.4
Airside Heating				
Zone Supply Temp	95		degree F	
Reheat delta T	40		degree F	
Heat Recovery	Sensible Wheel	None		
Heat Recovery Effectivness	80%	-		
Operation	OA Exhaust DT - 5F	-		
Operating Mode	OA Heat/Cool			
Make-up Air Temp Ctrl	Mixed Air Reset			
Capacity Control	Bypass OA			
ERV Motor Power	0.00			
ERV Fans	Self Contained			
Additional ERV Static Pressure	1.00		"	
ERV Fan Efficiency	0.60			
Fan Motor Efficiency	High Efficiency			
Fan Power Flow	90.1 Fan Curve			
Frost Control	Preheat OA			
ERV Preheat Control	Reset Setpoint			
Preheat Air Delta T	32.00		degree F	
HW Pumping				
Loop Operation		Demand		
Number of Pumps per Boiler				
HW Pump gpm				
HW Pump power		19	W/GPM	G3.1.3.5
HW Pump motor Efficiency	Premium	High		
HW Pump Control		Primary only variable flow		
DX Cooling				
Type	-	Air-cooled		
Cooling Supply Temp	-	56	degree F	G3.1.2.8: Need 20 degree delta T (design T - supply T)
Supply Air Temp Reset	-	5	degree F	G3.1.3.12

Cooling Capacity	-	<30000Btu/h		
COP (w/ fan energy)	-	3.077		
EER (w/ fan energy)	-	10.5		G3.1.2.1 & Table 6.8.1A
EIR (w/o fan energy)	-	0.272		
Humidity Control	-	60%		
Evap Cooling				
Type	Indirect/Direct			
Cooling Supply Temp	65		degree F	
Cooling Capacity				
Sensible Cooling Capacity				
COP (w/o fan energy)				
EIR (w/o fan energy)				
Fan Control				
Fans				
Perimeter Zones	Parallel PIU	VAV boxes		
Core Zones	VAV boxes	VAV boxes		
Minimum Design Air Flow		0.4	cfm/sf	Section G3.1.3.13
VAV Minimum Flow - Core		NA	%	Not regulated
VAV Minimum Flow - Perimeter		NA	%	Not regulated
Flow	16,000		CFM	
Fan Type		Constant Volume		G3.1.3.15
Fan Placement	Draw Through	Draw Through		
Fan Power	see Fan Calcs	see Fan Calcs	kW/CFM	Table 6.5.3.1.1A
Cycle Fans at Night	yes	no		
Reheat delta T		39	degree F	Heating supply setpoint - Cooling supply setpoint
Economizer	yes	no		G3.1.2.6
Economizer Drybulb High Limit	73			
Demand Control Ventilation		Check later		

Domestic Hot Water	*Proposed*	*ASHRAE 90.1-2007*	*Units*	*ASHRAE Section/SOURCE*
Type	storage	Gas Storage		
Input Rate		143000.00	Btu/h or kW	Standard 90.1-2007 User's Manual Table G-B
Tank Size		1191.50	Gallons	
Performance Required		3975.74		
Tank UA		56.80		
Supply water temp		130.000	degree F	
Inlet water temp		80	degree F	
Delta T		50	degree F	
Peak gpm		5.185	gpm	