Life Cycle Energy Analysis of Eight Residential Houses in Brisbane, Australia

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Abstract

Life cycle energy analysis (LCEA) of eight residential buildings in and around Brisbane, Queensland, Australia, is undertaken in this study. Energy used in all three phases of construction, operation and demolition are considered. It is found that the main contribution to the operational energy in residential buildings is from use of general appliance. The choice of building materials is shown to have significant effects on the embodied energy for the production, construction, maintenance and demolition phases. From this study, it is shown that the embodied energy may vary from 10\% to 30\%, while the operational energy may vary from 65\% to 90\%. The demolition energy generally accounts for less than 4\% of life cycle energy.

Keywords: life cycle energy analysis; residential buildings; building embodied energy; building operational energy; building demolition energy

Nomenclature

| Symbol | Definition |
|--------|------------|
| EE\textsubscript{assembly} | embodied energy for an individual assembly |
| EE\textsubscript{material} | embodied energy for an individual building material |
| EE\textsubscript{total} | total embodied energy for an individual house |
| EE\textsubscript{average} | average embodied energy for a house |

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1. Introduction

Buildings, as one of the most significant infrastructure in modern society, use energy throughout their life, from its construction to its demolition (e.g. from cradle to grave). Worldwide, buildings are responsible for 40% of the world’s total energy use, having a significant influence on the total natural resource consumption and the emissions released. It was found that for the greenhouse emissions related to buildings, 40–95% of these emissions are caused by operational energy use, with the remainder being caused by construction and demolition [1].

In order to design environmentally-conscious buildings, various methods and tools have been developed to measure and compare the environmental impacts of buildings over their whole life cycle. Generally, materials and energy flows of a building system may include three phases of upstream of construction (e.g. extraction, production, transportation and construction), operation or use and downstream of deconstruction (deconstruction and disposal) [2].

In this paper, a life cycle energy analysis of eight residential buildings in and around Brisbane, Queensland, Australia, was conducted. After brief introduction, the methodology used for this study is introduced, including the overall study approach, the information of the study houses and the study assumptions adopted. This is followed with results and analysis of energy used during all three phases of construction, operation and demolition.

2. Methods

2.1. Overview of the methodology

Life cycle energy analysis (LCEA) is an approach that accounts for all energy inputs to a building in its life cycle [2], consisting of four stage processes as shown in Figure 1(a). First, the purposes and system boundaries of the study are defined. Then the appropriate data and information will need to be collected and analyzed to quantify the material and energy flows in various stages of a system lifecycle. The contributions of various constituents on the environmental indicators can be finally evaluated and interpreted to show the significant issues and potential environmental impacts.

Figure 1(b) further illustrates the energy involved in the life cycle of buildings. Embodied energy is the energy consumed by all of the processes associated with the production of a building, from the mining and processing of natural resources to manufacturing, product transport and delivery, and building construction and installation. It is the ‘upstream’ or ‘front-end’ component of the life cycle impact of a building [3]. Operational energy is the energy
required for maintaining comfort conditions and day-to-day maintenance of the buildings [2]. It is the energy used for heating, ventilation and air conditioning (HVAC), domestic hot water, lighting, and for running appliances. The demolition energy is the energy occurring during the last destruction phase, which includes the energy used to demolish the building and transportation of dismantled materials to landfill sites and/or recycling plants.

Potential energy savings from recycling or reusing the demolished building materials is not considered in this study. This is because there is currently no agreement over the method of attributing this saved energy to the demolished building, although it would be more appropriate if this energy can be incorporated in the life cycle energy estimation in overall sense [2].

2.2. Information of study houses

Total eight residential houses in and around Brisbane, Queensland, Australia, were studied. The general information, details of construction materials and electrical appliance and equipment for these eight residential houses is gathered from site visits to these houses and is tabulated in Table 1, Table 2 and Table 3 respectively. The energy use for the studied houses was collected varying from one year to four years, depending on their availability. Information presented in these tables will be used later to estimate embodied energy and operational energy for these studied houses.

| House | Location  | Storey | No. Of People | Living area (m²) | Start Date | End Date | Billing days | Total energy use (kWh) |
|-------|-----------|--------|---------------|------------------|------------|----------|--------------|-----------------------|
| A     | Birkdale  | one    | 1             | 195              | 10/11/2008 | 7/11/2011 | 1093         | 15861                 |
| B     | Tingalpa  | one    | 2             | 160              | 21/05/2008 | 14/02/2012| 1365         | 28528                 |
| C     | Wynnum    | two    | 2             | 230              | 19/06/2009 | 14/09/2012| 1183         | 15449                 |
| D     | Wynnum    | two    | 6             | 510              | 12/01/2011 | 10/04/2012| 454          | 25453                 |
| E     | Manly     | two    | 4             | 350              | 19/09/2008 | 18/09/2012| 1461         | 4630                  |
| F     | Norman Park| two   | 3             | 217              | 4/10/2007  | 28/12/2011| 1546         | 41836                 |
| G     | Manly     | one    | 3             | 110              | 15/12/2008 | 13/12/2011| 1094         | 22693                 |
| H     | Tingalpa  | two    | 2             | 260              | 13/05/2009 | 8/02/2012  | 1001         | 15487                 |

It can be seen in Table 2 that most of these houses are constructed with brick walls, concrete floor and metal roofs. Because the use of insulation in roofs and walls and floors are sealed, the potential difference of insulation between these houses was ignored in this study. Moreover, the possible difference in internal finishing and decoration between different houses has also not been considered in this study. For internal walls, 20% of timber framework was assumed.

Table 2. Construction materials for eight residential houses.

| House | A             | B             | C             | D             | E             | F             | G             | H             |
|-------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Lower level floor | Reinforced Concrete | Reinforced Concrete | Reinforced Concrete | Reinforced Concrete | Reinforced Concrete | Timber | Reinforced Concrete |
| Lower level roof | Concrete tile + Plasterboard | Detromatic-tin roof + Plasterboard | Plasterboard | Timber + Fibre |
| Lower level internal walls | Plasterboard | Plasterboard | Plasterboard | Timber |
| Lower level external walls | Brick | Brick | Brick | Concrete Blocks | Brick | Timber | Brick |
| Upper level floor | Timber | Timber | Timber | Timber | Timber |
| Upper level roof | Super six fibro + Plasterboard | Timber | Timber | Timber | Concrete tile + Fibre |
| Upper level | Timber | Timber | Timber | Timber | Brick | Cement |
external walls
Upper level
internal walls
Fibre
Cement
Timber
Brick
Timber
New extension
floor
Timber
New extension
roof
Tin-iron+
Plasterboard
New extension
external walls
Timber
New extension
internal walls
Plasterboard

Table 3. Main electrical appliance and equipment in eight residential houses.

| House                      | A | B | C | D | E | F | G | H |
|----------------------------|---|---|---|---|---|---|---|---|
| Washing machine            | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Dryer                      | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Iron                       | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| TV                         | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| DVD/CD player              | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Cordless phone (or iPhone) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Clock radio                | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Computer (e.g. desk top, laptop, notepad) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Printer                    | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Dishwasher                 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Oven                       | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Stove top & electric fryer | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Fridge & freezer           | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Microwave                  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Kettle                     | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Toaster                    | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Toaster                    | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Electric toothbrush        | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Hair dryer                 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Straightener               | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Lighting                   | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Normal lights              | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Spot light                 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Halogen lights             | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Energy saving lights       | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Down lights                | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Swimming pool pumps        | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Electric hot water system  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Ceiling or Pedestal fans   | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Heater                     | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Air conditioning           | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Solar PV                   | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

2.3. Study assumptions

Following assumptions were also adopted in this study:

- The lifespan of the houses for this study was assumed to be 50 years.
- The possible influence of methods (e.g. by truck, train, ship or plane) and distance to transport building materials from one location to another was ignored in the calculation of embodied energy and demolition energy.
- The potential influence of the type of “raw” materials (e.g. natural or recycled sources) for the manufacturing of building materials was also ignored in the calculation of embodied energy.
The possible contribution of embodied energy due to renovation and maintenance over a building’s life was ignored.

The potential influence of various construction methods and different brands of a building product (e.g., different efficiency of the individual manufacturing process and the fuels used in the manufacture of the materials) on embodied energy was also ignored.

For operational energy, this study was focused on the buildings only. Therefore the possible contribution from urban scale (e.g., the transport energy of building occupants and urban infrastructure) was not considered.

3. Results and analysis

3.1. Embodied energy

Every building uses a complex combination of many processed materials, which all contribute to the building’s total embodied energy [3]. Therefore, the choices of building materials will influence the amount of energy embodied in the structure of a building. Various approaches may be used to determine the embodied energy, including:

- Process energy analysis, which considers the energy directly related to the manufacturing processes of the product [3]. The accuracy of this method is dependent on the system boundary drawn, while all processes outside the boundary will be neglected [4].
- The input–output analysis, where the embodied energy of a product is calculated using its average price and the energy intensity of its sector. That is, all products within a sector will be assigned the same energy intensity. Moreover, the price of the product can sometimes distort the calculation results [4].
- Gross energy analysis, which is a true measure of embodied energy of a produce. In practice, however, the energy use is usually very difficult to measure [3]. Therefore, various alternative options are proposed. These include the hybrid analysis, which uses available process energy data and filling the gaps with input–output data [4].

Currently, most figures quoted for embodied energy are based on the process energy analysis [3]. In general, process energy requirement (PER) accounts for 50-80% of gross energy requirement (GER). However, by using different calculation methods, the estimation of embodied energy can vary by a factor of up to ten. Therefore, for a comparison of embodied energy, it is often desirable to use figures produced from a single source, so that the adoptions of methodology and base data are consistent.

For this study, embodied energy of common house assemblies and materials, as suggested by the “Your home – Australia’s guide to environmentally sustainable homes”, were adopted and is presented in Table 4 and Table 5. The values with symbol of “*” in Table 5 are extracted from the article “Choosing building materials” [5]. The embodied energy for an individual assembly (EE\textsubscript{assembly}) is calculated as follows:

\[
EE_{\text{assembly}} (MJ) = \text{Embodied energy (MJ/m}^2\text{)} \times \text{Area (m}^2\text{)}
\]  

(1)

For any building elements that are not listed in Table 4, the data from Table 5 would then be used instead for the calculation of embodied energy. The embodied energy for an individual building material (EE\text{material}) was calculated as follows:

\[
EE_{\text{material}} (MJ) = \text{Embodied energy (MJ/kg)} \times \text{Density (kg/m}^3\text{)} \times \text{Area (m}^2\text{)} \times \text{Thickness (m)}
\]  

(2)

Table 4. Embodied energy for assembled floors, roofs and walls [3].

| Assembly               | Embodied energy MJ/m² |
|-----------------------|-----------------------|
| Elevated timber floor | 293                   |
110mm concrete slab-on-ground 645
200mm precast concrete, T beam/infill 644
Timber frame, concrete tile, plasterboard ceiling 251
Timber frame, terracotta tile, plasterboard ceiling 271
Timber frame, steel sheet, plasterboard ceiling 330
Single skin autoclaved aerated concrete (AAC) block wall 440
Single skin AAC block wall gyprock lining 448
Single skin stabilised (rammed) earth wall (5% cement) 405
Steel frame, compressed fibre cement clad wall 385
Timber frame, reconstituted timber weatherboard wall 377
Timber frame, fibre cement earthboard wall 169
Cavity clay brick wall 860
Cavity clay brick wall with plasterboard internal lining and acrylic paint finish 906
Cavity concrete block wall 465

Table 5. Embodied energy (PER) for common building materials [3].

| Material                                      | Embodied energy (MJ/kg) | Material                                      | Embodied energy (MJ/kg) |
|-----------------------------------------------|-------------------------|-----------------------------------------------|-------------------------|
| Kiln dried sawn softwood                      | 3.4                     | In situ concrete                              | 1.9                     |
| Gypsum plaster                                | 2.9                     | Clay bricks                                   | 2.5                     |
| Plasterboard                                  | 4.4                     | Concrete blocks                               | 1.5                     |
| Plywood                                       | 10.4                    | Glass                                         | 12.7                    |
| Fibre cement                                  | 4.8                     | Fibreglass                                    | 30.3*                   |
| Cement                                        | 5.6                     | Cellulose insulation                          | 3.3*                    |
| Aluminium                                     | 170                     | Wool insulation                               | 2.5*                    |
| Galvanised steel                              | 38                      | Polyester insulation                          | 53.7*                   |

The total embodied energy for an individual house (EE_{total}) would be equal to the sum of all building elements (e.g. all assemblies and materials):

\[ EE_{total} (\text{MJ}) = \sum EE_{assembly} + \sum EE_{material} \] (3)

The average embodied energy for a house (EE_{average}) was defined as the ratio between the total embodied energy and the liveable area as follows:

\[ EE_{average} (\text{MJ/m}^2) = \frac{EE_{total} (\text{MJ})}{\text{Living area (m}^2\text{)}} \] (4)

The estimated PER embodied energy for the studied houses are shown in Figure 2. It can be seen that the difference in PER embodied energy can be up to 100%, with House F having the highest embodied energy, while House G having the lowest embodied energy. The results also show that the more use of timber, the lower embodied energy (e.g. comparing Houses A and B with Houses C and D in Figure 2). After removing the contribution of embodied energy from internal walls, the difference between different types of house construction becomes slightly larger.

![Estimated PER embodied energy (MJ/m²)](image_url)

Fig. 2. Estimated PER embodied energy for the studied houses.
With the improvement of energy efficiency of manufacturing process to produce building material, it would be expected that the level of embodied energy required in building materials would become small [3]. However, with increasing energy efficiency of houses and appliances, the operational energy will decrease and the embodied energy may become increasingly important.

3.2. Operational energy

Different from embodied energy of building, the amount of building operational energy will be dependent on the occupant behaviors and schedules, as well as the level of required comfort and climatic conditions. Generally, operational energy includes the energy requirements for heating ventilation and air conditioning (HVAC), lighting, demotic hot water (DHW) system and general appliance used in kitchen, living area, laundry and bathroom etc. It accumulates energy over the life time of the buildings.

The average annual energy use (OE\textsubscript{annual}) was calculated as follows, where both the billed total energy use and billing days were listed in Table 1:

\[
OE\textsubscript{annual} (\text{kWh/\text{year}}) = 365 \times \text{Total energy use (kWh)} / \text{Billing days} \tag{5}
\]

The average annual energy use per square meter (OE\textsubscript{average}) is equal to the ratio between the average annual energy use (kWh/\text{year}) and the liveable area (m\textsuperscript{2}):

\[
OE\textsubscript{average} (\text{kWh/m}^2) = OE\textsubscript{annual} (\text{kWh/\text{year}}) / \text{Living area (m}^2) \tag{6}
\]

As shown in Table 3, electrical appliance and equipment varied considerably between these studied houses. Particularly, it is noted that two houses (B and F) had swimming pool, two houses (B and H) have installed solar panel and four houses (B, C, G to H) used electric hot water system. To be consistent in the comparison, the possible energy inputs from solar panels have been removed from this study. Based on the information provided in Table 3 and the possible use of them, the breakdown end energy use for these houses was also conducted. It was found that energy used by general appliance varying from 45% to 75%, by lighting energy varying from 5% to 15%, by pool pumps varying from 20% to 35%, by air conditioner varying from 15% to 45% and by electric hot water system varying from 15% to 30%.

Table 6. Average annual energy use for the studied houses.

| House | A | B | C | D | E | F | G | H |
|-------|---|---|---|---|---|---|---|---|
| Average annual energy use (kWh/\text{year}) | 5297 | 7628 | 4767 | 20463 | 1157 | 9877 | 7571 | 5647 |
| Average annual energy use without DHW (kWh/\text{year}) | 5297 | 6127 | 3651 | 20463 | 1157 | 9877 | 4720 | 3891 |
| Average annual energy use (kWh/m\textsuperscript{2}) | 27 | 48 | 21 | 40 | 3 | 46 | 69 | 22 |
| Average annual energy use without DHW (kWh/m\textsuperscript{2}) | 27 | 38 | 16 | 40 | 3 | 46 | 43 | 15 |

Fig. 3. Estimated 50 years operational energy for the studied houses.
Average annual energy use for households is also tabulated in Table 6. It was noted that House E had much lower total energy use than the other houses. A further investigation of the electrical appliance within the household and the energy usage of house revealed that the electricity meter for the particular house might have malfunctioned for a long time (e.g. four years). The analysis of electricity energy bills showed that there are four houses use electric domestic hot water system, while other may use gas or solar energy for hot water. To be consistent in the comparison, the results of removing the large energy use by electric hot water systems are also presented in the Table 6. The estimated 50 years operational energy for the studied houses is shown in Figure 3.

3.3. Demolition energy

The demolition phase takes into consideration of the energy used by machinery to deconstruct the existing building, as well as energy required to raze, store and transport these materials from the building site to the landfill sites and/or final treatment plants. This phase is usually quite small in comparison to that of the production and operational phases. This may be typically around 1-4% of the energy usage during the life cycle of a building.

| Construction Type         | Demolition Energy (MJ/m²) | Studied houses      |
|---------------------------|---------------------------|---------------------|
| Light (e.g. wood frame)   | 35                        | House G             |
| Medium (e.g. steel frame) | 106                       | House E             |
| Heavy (e.g. masonry, concrete) | 176                   | Houses A to D, F, H |

Based on the demolition energy calculator suggested by Matt [6] for “the greenest building is the one already built”, the demolition energy for small buildings (e.g. 465-1395 m²) is tabulated in Table 7. It is suggested that the demolition energy per unit area will decrease with the increase of building size. The proposed demolition energy for the studied houses is shown in the third column in Table 7.

It is noted that the potential reuse and recycling building materials have not been considered in this study. It was suggested that the energy savings from recycling of materials for reprocessing can vary considerably, from 20% for glass to up to 95% for aluminium. However, some materials such as bricks and roof tiles may be damaged [3].

3.4. Impact Assessment

Based on the above analysis, the life cycle energy analysis of these houses is shown in Figure 4. It can be seen that due to possible malfunction of the electricity meter, House E has an un-believably low operational energy, which should be excluded from the study. Although House G has relative low embodied energy and demolition energy, it has the highest life cycle energy if the energy used for DHW is included. After excluding DHW in operational energy and internal walls in embodied energy, it still has the third highest life cycle energy.

Fig. 4. Life cycle energy analysis of the studied houses.
Overall, it was found from this study that the demolition energy generally takes less than 4% of life cycle energy. This was in comparison with the embodied energy which may vary from 10% to 30%, and the operational energy which may vary from 65% to 90%.

4. Conclusions

Life cycle energy analysis (LCEA) of eight residential buildings in and around Brisbane, Australia, has been undertaken in this study. Energy used in all three phases of construction, operation and demolition has been considered. It has also been shown that the embodied energy may vary from 10% to 30%, while the operational energy may vary from 65% to 90%. The demolition energy generally accounts for less than 4% of life cycle. The main contribution to the operational energy in residential building is from use of general appliance. Future research should study the trade-off between the embodied energy and operational energy, as well as the adoption of renewable energy.

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The 9th International Symposium on Heating, Ventilation and Air Conditioning and the 3rd International Conference on Building Energy and Environment (ISHVAC-COBEE 2015)

This volume contains articles submitted and published at the 9th International Symposium on Heating, Ventilation and Air Conditioning joint with the 3rd International Conference on Building Energy and Environment (ISHVAC-COBEE 2015).

The ISHVAC conference series was initiated by Tsinghua University in 1991. It is the premier international HVAC conference initiated in China and has played a significant role in the development of HVAC and indoor environment research and industry in China.

The COBEE conference series was initiated by Tianjin University and Dalian University of Technology in 2008. This conference aims to provide a platform for discussing energy and environmental issues and for initiating collaboration among building engineers, environmental scientists, architects, facility managers, and policy makers.

The ISHVAC-COBEE 2015 conference was held in Tianjin, China. China is one of the main manufacturers of HVAC equipment and a significant energy consumption country. Among the total energy consumption, the building energy consumption accounts for nearly 30%, of which 65% is HVAC energy consumption and the data ranked first in the world. Besides energy, due to the serious ambient air pollution in China now, and the wide public concern of poor indoor air quality caused by various indoor sources and non-enough ventilation, the indoor environment quality in enclosed environment is also a popular topic in related field. Therefore, the significance of this conference is to learn how to promote the advancement of HVAC technology, combined with the gradual improvement of building energy consumption and the environment.

The ISHVAC-COBEE 2015 conference attracted nearly 500 participants from 25 countries, with 484 papers being presented in the conference. In this issue, 301 papers are selected from the conference proceedings, which address crucial topics in the related area, including:

1. Building HVAC;
2. Air Cleaning Technologies;
3. Indoor Air Quality;
4. Ventilation;
5. Thermal Comfort;
6. Cabin Air Quality;
7. Building Energy;
8. Outdoor Environment.

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### Additional Articles
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The 9th International Symposium on Heating, Ventilation, and Air Conditioning (ISHVAC) and The 3rd International Conference on Building Energy and Environment (COBEE)

July 12-15, 2015
Tianjin, China

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Co-Organized by
Tsinghua University
Dalian University of Technology
Purdue University
University of Colorado at Boulder

First Announcement and Call for Papers
INVITATION

Welcome to ISHVAC-COBEE 2015, Tianjin, China

The ISHVAC conference series was initiated by Tsinghua University in 1991. It is the premier international HVAC conference initiated in China and has played a significant role in the development of HVAC and indoor environment research and industry in China.

The COBEE conference series was initiated by Tianjin University and Dalian University of Technology in 2008. This conference aims to provide a platform for discussing energy and environmental issues and for initiating collaboration among building engineers, environmental scientists, architects, facility managers, and policy makers.

The ISHVAC-COBEE 2015 conference will be held in Tianjin, China. It will be an exclusive opportunity for building engineers, environmental scientists, architects, facility managers, and policy makers to share their experience. It will provide an excellent forum for learning the state-of-art applications for indoor/outdoor environment and energy research by the participants from all over the world. In this beautiful city, you will be attracted by the charming scenery, profound culture and welcoming people.

China is one of the main manufacturers of HVAC equipment and a famous energy consumption country. In 2013, the output value of HVAC products was 560 billion RMB, which shows an increase of nearly 8% compared with that in 2012. Among the total energy consumption, the building energy consumption accounts for nearly 30%, of which 65% is HVAC energy consumption and the data ranked first in the world. Therefore, the significance of this conference is to learn how to promote the advancement of HVAC technology, combined with the gradual improvement of building energy consumption and the environment.

We look forward to meeting you in Tianjin!

President of ISHVAC-COBEE 2015
Junjie Liu, Ph.D.
Professor, Tianjin University
PAPER TOPICS

A. HVAC
1. Building energy demand and energy performance of buildings, systems, and components
2. Air cleaning and filtration for high load and low energy consumption
3. Passive heating, cooling, and renewable energy for buildings
4. Advanced or innovative HVAC&R systems and system components
5. Integration of technologies and tools for HVAC system design and operation
6. Intelligent buildings and advanced control techniques
7. Solar cooling and refrigeration

B. Built Environment and Energy
1. Advanced or innovative building envelopes, energy conservation materials, and indoor environmental techniques
2. Cabin and other semi-open space environments and their energy consumption
3. Building ventilation, infiltration, and air distribution
4. Computer tools and experimental techniques for analyzing building energy and built environments assessments
5. Retrofit and optimal operation of the building energy systems
6. Influence of climate change on building energy and environment
7. Public policies related to building energy and environment
8. Simulations and real energy consumption
9. Actual energy consumption of high performance buildings
10. The role of commissioning

C. Urban/Indoor Environment and Health
1. Indoor and outdoor air quality and its health impact related to built environment
2. Indoor air quality in urban area with heavy ambient air pollution
3. Health and productivity in indoor environment
4. Indoor and outdoor lighting, lighting control, and visual comfort
5. Thermal comfort and built environments
6. Sustainable and advanced built environments
**IMPORTANT DATES**

Abstract Submission Deadline: December 31, 2014  
Abstract Accept/Reject Notification: February 1, 2015  
**Full Paper/Extended Abstracts Submission Deadline: April 1, 2015**  
Paper Accept/Reject Notification: April 30, 2015  
Early-bird Registration: before May 20, 2015  
Papers in Final Format: May 30, 2015  
Conference Opening Date: July 12, 2015

**CALL FOR PAPERS**

**Abstract Submissions**

You are invited to submit one-page abstracts. Each abstract should be submitted separately and should contain the following information:

1. Topic code  
2. Title of the paper  
3. Full name of the author(s)  
4. Affiliation of the author(s)  
5. Mailing address and e-mail address of the corresponding author

We also accept extended abstracts.  
All abstracts must be submitted online via conference website [www.cobee.org](http://www.cobee.org). The abstract template is available on the conference website.

**Forum/Workshop Submissions**

These workshops are expected to discuss broadly the future science of indoor air, new and emerging directions of building energy applications.

Forums will be 60 minutes long and usually consist of a panel or sequence of invited speakers on a specific subject or that address prepared questions on a subject.  
Workshops will be 120 minutes long, and usually consist of invited presentations
and round-table discussions with audience participation.

Each proposal should contain the following information:

1. Title of the forum/workshop
2. Full name, affiliation and email address of the facilitators, the panel/presenters
3. The goal and a bulleted list of key issues to be discussed or presented (200 words or less)
4. The importance of the workshop/forum to ISHVAC-COBEE 2015 (100 words or less)

**EXHIBITION**

An exhibition will be held concurrently with the ISHVAC-COBEE 2015 conference and will be located at the same venue. The exhibition is to show products, software, and information related to building energy and environment to the conference participants. Exhibition spaces in the conference venue will be available at reasonable price. Exhibitors are encouraged to submit requests for more information to ishvac_cobee@tju.edu.cn.

**LANGUAGE AND PUBLICATIONS**

The official language of the conference is English.

All accepted papers will be published in the conference proceedings. Selected papers from the conference will be expanded and published as special issues by the following journals:

Energy and Buildings
HVAC&R Research
Building Simulation

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INFORMATION on Tianjin and Tianjin University

Tianjin is a charming seaport city where the famous river Hai river flows through, with a lot of sunshine, beautiful landscapes, gourmet seafood, and friendly people. You can take a ride on 'The Tianjin Eye'; the only Ferris wheel in the world built on a bridge. At the highest point, you can have a full view of the surrounding scenery. You can take the sightseeing boat in the Hai River leisurely and enjoy the beautiful exotic architectural style. Tianjin has delicious seafood and greasy Goubuli Steamed Bun to tempt your stomach. You can listen to the Chinese comic dialog to enjoy the Chinese traditional art and also can feel the humor of Tianjin native. Walking on Five Great Avenues which includes Chongqing road, Changde road, Dali road, Munan road and Machang road, you will find the colored houses are not only the relics of the history, but also the city logo and a coagulation-art.

Hai River and the "Tianjin Eye"  Goubuli Steamed Bun

Tianjin is located on the plain of North China and convergence of five tributaries. It faces the Bo Sea in the east and is adjacent to Yan Mountain. As the mother river of Tianjin, Hai River has nourished her children for many years. If the Hai River is the necklace of Tianjin, then the bridges over it are the jewels embellished in the necklace. The bridges on the Hai River have hold the historical memories and witnessed the development of Tianjin. Beautiful Tianjin welcomes you.

The map of Tianjin
Tianjin University, formerly known as Peiyang University, is China's first modern university. Based on the motto of "seek truth from facts", spirit of "rigorous scholarship" and tradition of "patriotic devotion", Tianjin University, a national key university under the direct supervision of the Ministry of Education, enjoys a worldwide reputation. It is one of the first universities entering into national "211 Project", "985 Project", "2011 Plan", "111 plan", and awarded the title of "Excellent Engineer Education And Training Plan ", and member of "University Of Excellence Alliance ".

The gate of Tianjin University

The newly established campus, known as the Northern Park campus, with a total construction area of 1.55 million square meters, is located in the Tianjin Haihe Education Park in the middle reaches of the Haihe River. The project will be basically completed in November 2015. Colleges will overall relocate to the new campus, where the main educational and research work will be conducted. And the number of students will reach 18,000.