# CORPORATE ENVIRONMENTAL MANAGEMENT

# UN COMPOUND IN BEIJING


# PEER REVIEW

# Final Report

April 2018

## Table of contents

## Executive Summary

### 1. PEER REVIEW PROCESS

The United Nations Environment Management Group (EMG) initiated the Peer Review project in 2012, with the aim to peer review the environmental sustainability profile and performance of its members, focusing on corporate environmental management of members' facilities and internal operations.

The pilot phase of the project, undertaken from 2013 to 2016, included the peer review of the United Nations Industrial Development Organization (UNIDO) on behalf of the Vienna International Centre (VIC), World Meteorological Organization (WMO), UN Environment (UNEP) and the International Monetary Fund (IMF). Further peer reviews were conducted in the field offices of the United Nations Relief and Works Agency for Palestine Refugees (UNRWA), the World Food Programme (WFP) and United Nations Development Programme (UNDP) in Amman during 2016-17.

The Peer Review process is guided by a Peer Review Body (PRB) made up of senior representatives from various UN entities. The PRB meets once or twice a year and reviews the Peer Review process and Peer Review reports.

The process builds on the accumulated international experience of several international organizations in carrying out peer reviews that are governed by principles of mutual trust among peers, voluntary participation and non-binding recommendations, which differentiate them from traditional environmental and energy audits.

Peer Review teams carry out the reviews with representatives from UN entities, international organizations and local government authorities. The following organizations have provided reviewers to date: Canton of Geneva, International Civil Aviation Organization (ICAO), Organisation for Economic Co-operation and Development (OECD), UN Habitat, United Nations Children's Fund (UNICEF), United Nations Industrial Development Organization (UNIDO), UN Environment (UNEP), United Nations Offices for Project Services (UNOPS), Universal Postal Union (UPU), World Food Programme (WFP), World Meteorological Organization (WMO) and the World Bank. The EMG Secretariat coordinates the process and supports the Peer Review teams.

The Peer Review relies solely on the data and information that is made available by the reviewed entities, as it tries to identify achievements, challenges, good practices and lessons learned, and proposes strategic and practical recommendations that could be useful for the reviewed entity and the UN system as a whole. It does not undertake any measurements or any complex analysis such as energy modeling or simulation exercises.

### 2. PEER REVIEW OF UN COMPOUND, BEIJING

The peer review of UN COMPOUND was conducted with a visit to the premise during the 4$^{th}$ week of October 2017. The 5-day site visit of 23-27 October 2017 allowed reviewers from the EMG Secretariat to visit the facilities of UNICEF, UN COMPOUND, UN Women and WHO in Beijing.

This Executive Summary shares the findings related to the peer review visit of UNICEF, in terms of status, achievements, challenges and recommendations. The full version of the report provides a more comprehensive presentation of the same topics.

In the spirit of the Peer Review, the recommendations are non-binding and subject to validation by the Peer Review Body. Good practices, lessons learnt and recommendations are expected to help UN COMPOUND in the efforts to improve environmental performance. It is advisable that UN COMPOUND conducts a more detailed analysis of the recommendations to confirm the expected environmental and economic benefits and their technical and organizational feasibility.

# 3. UN COMPOUND IN BEIJING

## 3.1. Location

UN Compound in Beijing is located at the perimeter of Beijing's diplomatic district, at the corner of Liangmahe S Road and E 3rd Ring Road N, and fronts the Landmark River in Chaoyang District. It has a land area of 6,145 m² with a build-up area of 3,723 m². The build-up spaces are distributed over 3 buildings: the main office building, annex building and garage. The main office has 3 floors, the annex building has 2 floors and the garage is a single floor structure. These buildings were built in the 1960s. The main building is orientated north-south and the others east-west, following the city grid of Chaoyang District.

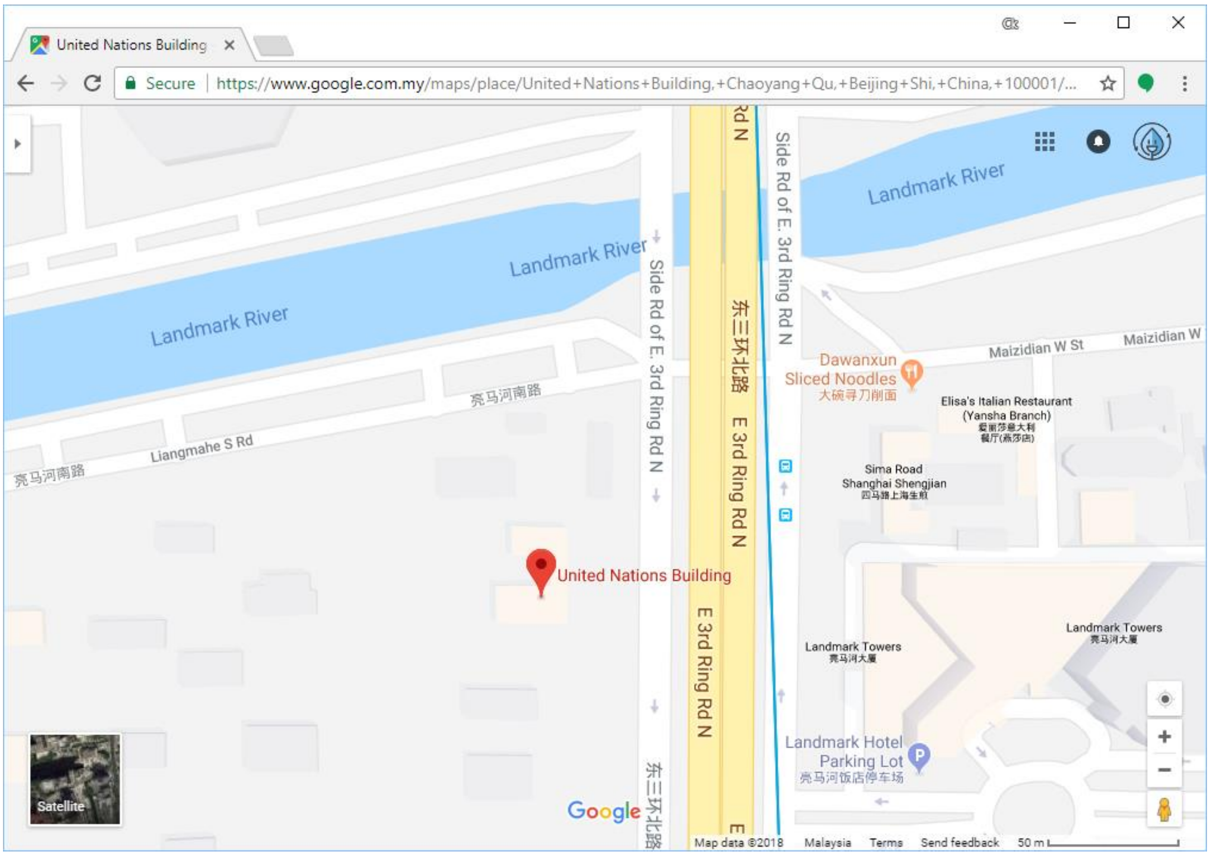



**Figure 1 Google Map Location of UN Compound in Beijing**

Beijing is the capital of China and has a history over 3,000 years. It is located 39.9°N of equator and 116.4°E of Greenwich, London, and it has a temperate and continental monsoon climate, as well as four distinct seasons and high differences in temperature between day and night. Summer in Beijing is hot and humid, winter is cold and dry, spring and autumn are short and cool. About 75% of the annual precipitation is concentrated in summer from June to August, with frequent showers in July and August. The coldest month is January at an average of -4 °C, and the hottest month is July at an average of 26 °C.

As of March 2016, Beijing had a population of 21.5 million, over an area of 17,000 km².

### 3.2. Achievements

The facility has a 30 kWp photovoltaic system installed on the rooftop, providing an annual energy output of ~33,000 kWh annually.

The lighting level for offices and meeting rooms were found to be kept at the appropriate level of 300 lux to 500 lux and not overly lit: excessively bright spaces (more than 500 lux) increase energy consumption unnecessary.

Although not the entire facility has been retrofitted yet, energy efficient LED lamps are beginning to be used. It was also observed that several energy-efficient inverters-based split-units, including a multi-split inverter, were found in this facility.

Other achievements that were observed are:

- There were at least 3 nos of electrical car charging station at the facility.
- Outdoor lighting with daylight and occupancy sensors are used at the front entrance.
- The sharing of printers was seen to be commonly practiced throughout the facility.

During the peer review visit, it was also observed that the UN Compound staff was keen to learn more on the issue of Green House Gas emission.

### 3.3. Challenges

A key challenge is the need to negotiate a better deal for the heating provided by the local district heating supplier. Heating provided by the local supplier is charged at a fixed rate based on the area (m²) basis and operating hours, not on the amount of heat used: this reduces the incentive to be energy efficient during winter months. The analysis of UN Compound heating costs indicates that the 5 months of heating cost is higher by a factor of 1.8x of the annual (12 months) electricity cost in 2016. Based on this, it will be more cost effective to generate heating via a centralized heat pump system that uses electricity, instead of purchasing heat from the local district heating supplier. Worst still, the expensive heating provided by the district heating supplier is inadequate for the building occupants, as personal electric heaters were seen at almost every desk at the facility.

The facility of UN Compound is very similar to UNICEF. However, unlike UNICEF, daylight use at UN Compound is not as commonly practiced, indicating a possibility to increase building occupant awareness of and commitment to greenhouse gas-emission reduction: these will fix a series of minor bad practices noticed in this facility, at a low cost.

### 3.4. Recommendations

As a start, it is recommended to share the awareness and sensitization program implemented in UNICEF with UN Compound. At least half of the energy reduction achieved in UNICEF over the last 2 years was non-technical. The use of daylight and switching off office equipment, lights and air-conditioning when they are not necessary is not only very effective, but it is also a free strategy to reduce carbon emission in buildings.

The awareness program will be greatly enhanced by a power/energy monitoring and reporting system, which should be adopted to provide a regular reporting of the energy use by the facility and the energy produced by the photovoltaic panels. This will allow to closely monitor the facility energy performance, to undertake corrective measures and to make further improvements as required in order to optimize GHG emission reduction.

UN Compound should explore the possibility of disengaging the service of the local heating supplier and install an energy-efficient heat pump and a thermal energy storage system. A thermal energy storage system buys electricity for heating during periods with low electricity tariff (midnight hours), to provide heating to the facility during the working hours. This option will reduce the overall operating cost of UN Compound significantly. The same heat pump system with the thermal storage facility can be judiciously used in summer to provide comfort cooling at a lower cost thanks to the shift in electricity use from the peak to trough hours.

There is also a possibility to implement a series of small improvements on the building to further reduce GHG emission of the facility:

- Increase task lighting and daylight use at each working desk;
- Replace the remaining older conventional split-unit air-conditioning system with higher efficiency inverter based split and multi-split inverter units;
- Reduce lux level (brightness) by de-lamping the overly bright corridors;
- Implement a purchasing guide for energy efficient office equipment such as computers, printers, and pantry equipment, including refrigerators;
- Replace inefficient refrigerators;
- Improve data center cooling strategy;
- Install a timer to charge the electrical vehicle during the hours with the lowest tariff (after midnight);
- Install timer on water dispenser, printers and other pieces of equipment that are not needed after office hours;
- Install a reversible ceiling fan that forces warm air near the ceiling down into the occupied space during winter. This option will reduce the temperature set-point below 30$^{o}$C during winter, while in summer the ceiling fan allows the air-temperature set-point to be set higher, as it creates a higher air speed for comfort.

Finally, UN Compound should start a dialogue with the landlord to initiate an overall building upgrading program that incorporates the latest energy efficient building construction methodologies such as walls and roofs insulation, double low-e glazing, door and window frames with thermal break and a centralized fresh air treatment and ventilation strategy together with a heat recovery system. These improvements will reduce the operating cost of the facility that will more than compensate the increase of the rental over the next 20 years to pay for these improvements to be made. More importantly, these improvements will provide an opportunity to ensure that adequate fresh air is provided to improve air quality in the UN Compound.

### 3.5. Conclusion

UN Compound has started to reduce greenhouse gas emission at its facility, with sporadic use of energy efficient lights, daylight sensor and motion sensors, and a few inverter-based air-conditioning.

The analysis showed that UN Compound will be more cost effective and provide better heating for the facility during winter, by using electricity at midnight hours (at the lowest tariff). Finally, a series of minor technical improvements in combination with an increased awareness and commitment can lead to a significant greenhouse gas emission reduction in this facility.

# A. INTRODUCTION

## 1. PEER REVIEW PROCESS

The United Nations Environment Management Group (EMG) initiated the Peer Review project in 2012 with the aim to peer review the environmental profile and performance of its members, focusing on corporate environmental management of members' facilities and internal operations.

The pilot phase of the project, undertaken from 2013 to 2016, included peer reviews of United Nations Industrial Development Organization (UNIDO) on behalf of the Vienna International Centre (VIC), World Meteorological Organization (WMO), United Nations Environment (UNEP) and the International Monetary Fund (IMF). Further peer reviews were conducted in the field offices of UNRWA, WFP and UNDP in Amman during 2016-17.

The Peer Review process is guided by a Peer Review Body (PRB), made up of senior representatives from various UN entities, which meets once or twice a year and reviews the Peer Review process and Peer Review reports.

The process builds on the accumulated international experience of several international organizations in carrying out peer reviews. The principles that govern these peer reviews, such as mutual trust among peers, voluntary participation and non-binding recommendations, differentiate it from traditional environmental and energy audits.

Peer Review teams carry out the reviews with representatives from UN entities, international organizations and local government authorities. The following organizations have provided reviewers to date: Canton of Geneva, International Civil Aviation Organization (ICAO), Organisation for Economic Co-operation and Development (OECD), UN Habitat, United Nations Children's Fund (UNICEF), United Nations Industrial Development Organization (UNIDO), UN Environment (UNEP), United Nations Offices for Project Services (UNOPS), Universal Postal Union (UPU), World Food Programme (WFP), World Meteorological Organization (WMO) and the World Bank. The EMG Secretariat coordinates the process and supports the Peer Review teams.

The Peer Review relies solely on the data and information that is made available by the reviewed entities. It tries to identify achievements, challenges, good practices and lessons learned, and proposes strategic and practical recommendations that could be useful for the reviewed entity and to the UN system. It does not undertake any measurements or any complex analysis such as energy modeling or simulation exercises.

## 2. PEER REVIEW of UN COMPOUND, BEIJING

The peer review of UN COMPOUND was conducted with a visit to the premise on the 4$^{th}$ week of October 2017. The 5-day site visit of October 23$^{rd}$-27$^{th}$, 2017, allowed reviewers from the EMG Secretariat to visit the facilities of UNICEF, UN COMPOUND, UN Women and WHO in Beijing.

This Executive Summary shares the findings related to the peer review visit of the UN Compound, in terms of the status, achievements, challenges and recommendations. This full version of the report presents the same topics more comprehensively.

In the spirit of the Peer Review, the recommendations are non-binding and subject to validation by the Peer Review Body. The good practices, the lessons learnt and the recommendations are expected to help UN Compound in its efforts to improve its environmental performance. It is advisable that UN Compound conducts a more detailed analysis of the recommendations to confirm the expected environmental and economic benefits and their technical and organizational feasibility.

# B. GENERAL INFORMATION ON UN COMPOUND, BEIJING

## 1. General information

The UN Compound is managed by UNDP in Beijing and it houses a few UN agencies under one roof. At the main entrance lobby these agencies were listed: UNDP, UN Environment, World Food Programme, UNDSS and UN VOLUNTEERS.

UNDP is also the custodian of the Resident Coordinator system, as mandated by the UN General Assembly. The UNDP Resident Representative serves as the UN Resident Coordinator of the UN System in China and he/she is the highest-ranking UN official and the chief of the UN diplomatic mission in a country. The responsibilities of the Resident Coordinator cover areas of advocacy for the UN System, operational coordination, management coordination, humanitarian and emergency assistance, and annual reporting, appraisals and agreements.

The UN has had a presence in China since 1979 and has witnessed China's profound economic and social transformation. With the continued and rapidly evolving development process in China, the UN system has repositioned itself in adapting its engagement to the current context in the country by aligning its work with national development priorities.

The successive United Nations Development Assistance Frameworks (UNDAFs) for China have highlighted the strategic and fruitful partnership between the UN and the Chinese Government. The new UNDAFs for 2016-2020 have identified three broad cooperation areas: 1) Reduction of Poverty and Equitable Development; 2) Improved and Sustainable Environment; and 3) Enhanced Global Engagement. The UN system in China engages in these priority areas by providing high-level policy inputs, supporting normative work and promoting global exchange.

## 2. Location

UN Compound in Beijing is located at the north of Beijing's diplomatic district. Located at the corner of Liangmahe S Road and E 3rd Ring Road N, it fronts the Landmark River in Chaoyang District.

Beijing is the capital of China and has a history over 3,000 years. It is located 39.9$^{o}$N of equator and 116.4$^{o}$E of London.

## 3. UN Compound Building

The building occupied by UN Compound was formerly a residential house in Beijing. It has a land area of 6,145 m² with a build-up area of 3,723 m². The build-up space is distributed over 2 buildings, the main office building and annex building. The main office is 3 floors while the annex building is 2 floors. Buildings were built in the 1960s with the main building orientated north-south while the annex building is east-west, following the city grid of Chaoyang District.

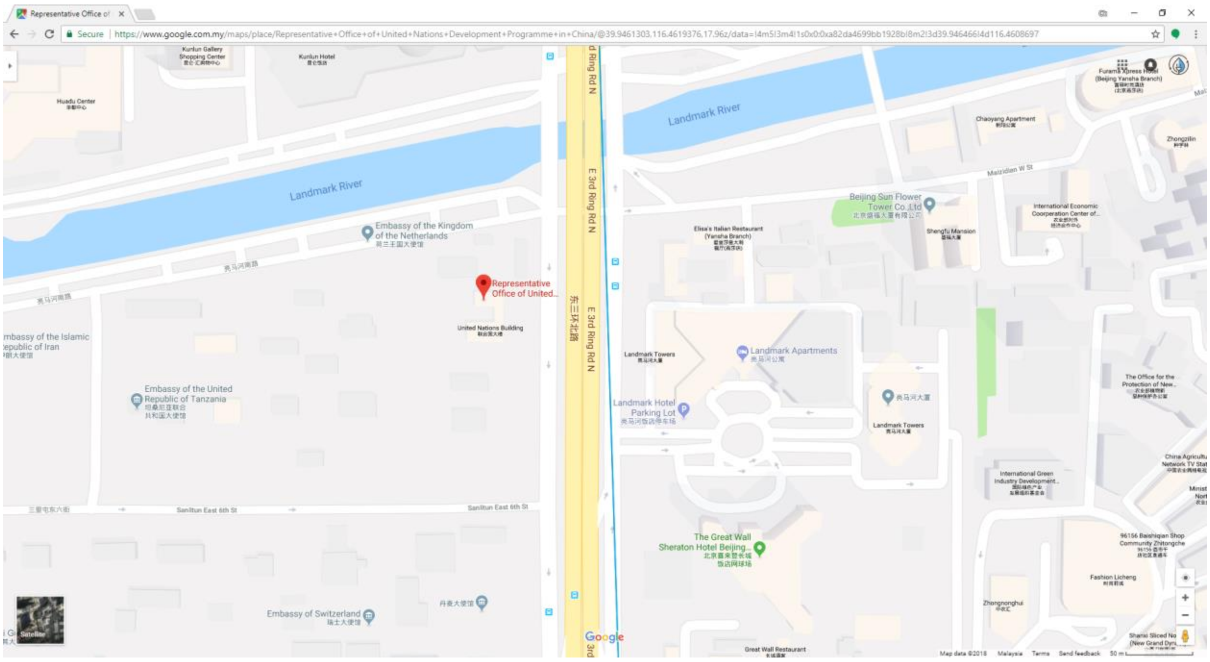



**Figure 2 Google Map Location of UN Compound in Beijing**

The building fabric consists of walls that are uninsulated full brick wall, screed over, painted and approximately 200mm thick. The windows are double glazed without low-e coating, with uninsulated aluminum frame. Based on the measured temperature of the ceiling underneath the roof, the roof is unlikely to be insulated or with very minimal insulation.

Cooling and supplementary heating is provided by 108 sets of split unit reversible air-conditioning units in the building. Each unit typically provides 2.6 kW of cooling and 4.3 kWh of heating.  The split units are typically set to 22-25$^{o}$C during summer and 27-30$^{o}$C during winter. In addition to this, personal electrical heating radiator were found at almost every desk at the facility.

Natural ventilation and free cooling are practiced in between seasons, whenever weather permits. Primary heating is provided by the building radiators via district heating system but supplemented by the reversible air-conditioning units and personal electricity-based heater.

The facility in UN Compound houses 120 staffs. Typical working hours are 8 per day, with a 5 days' work per week. Major holidays are Chinese New Year in February where the office is down to ~25% staffs for 2 weeks, May Day (Labor Day, beginning 1$^{st}$ of May) is 3 days with an average of ~80% of staffs working and National Day in October where the office is down to ~30% staffs for 1 week.

The lightings at this facility are a mix of technologies, ranging from very energy efficient LED lights, to fluorescent tubes and compact fluorescent for downlights, and even incandescent bulb. Task lighting was also found to be provided for a few desks, although not widely used.

Other energy usage of the facility are 75 units of notebooks, 60 units of desktop computers, 6 large multifunction printers and a range of personal printers. There are 9 units of water dispensers, 10 hot water kettles, 8 nos refrigerators (range from 145 liters to 345 liters) and a minimum of one PM 2.5 air filtration device per room. There is one data center room with one rack in it. The building has a total of 12 exhaust fans for 12 toilets, and it has no outdoor air supply fan. The toilets exhaust fan would create negative pressure for the building when it is used, increasing infiltration rates.

Finally, based on the preliminary questionnaire sent, the occupants complained that the building is cold during winter season as the heating provided is insufficient.

## 4. Climate

Beijing peak summer temperature reaches up to 40$^o$C, while in the winter it can drop to a cold -20$^o$C. However, the average monthly temperature is more moderate, with an average peak just above 30$^o$C in July and an average low of -9$^o$ in January (see Figure 3).

The city has four seasons. A short and windy spring (April-May), a long and warm summer (June-August), cool pleasant autumn (September – October) and a long chilly winter (November-March).

On average, the warmest months are June, July and August, while most rainfall is in July and August. Beijing has dry months in January, February, March, April, October, November and December.

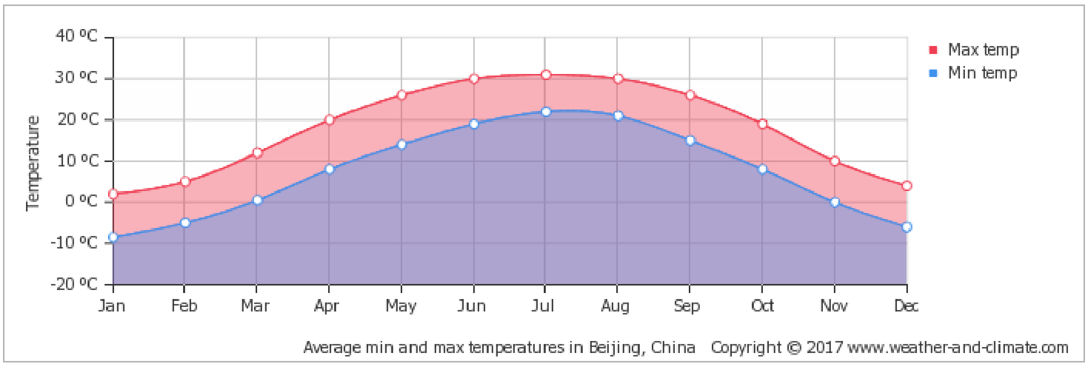



**Figure 3 Average minimum and maximum temperature in Beijing**

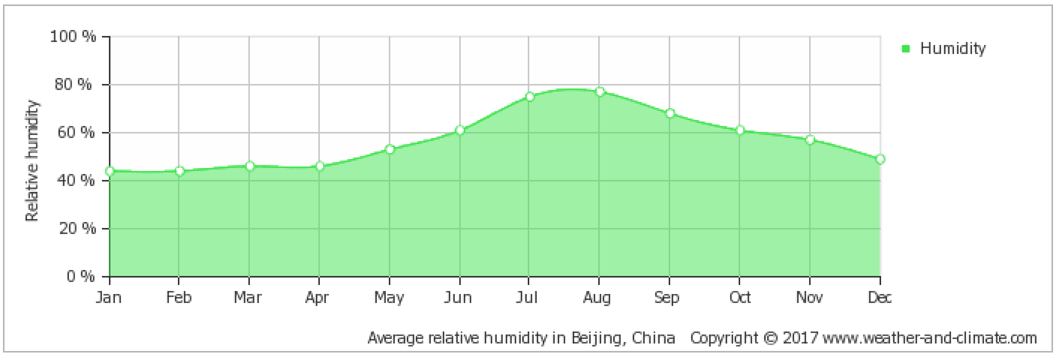



**Figure 4 Average relative humidity in Beijing**

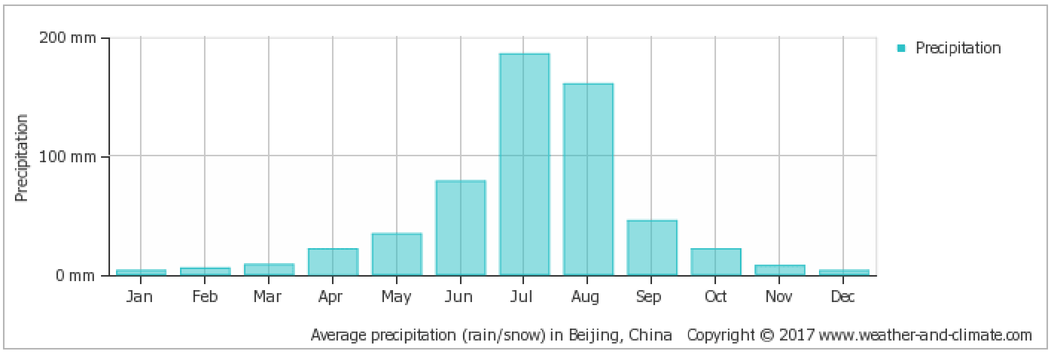



**Figure 5 Average precipitation (rain/snow) in Beijing**

## C. Building/Facilities Related GHG Emissions

### 1. Introduction

In UN Compound in Beijing, GHG emissions are contributed to by electricity consumption and district heating. As the district heating usage is not metered, it was not possible to estimate the facility energy use from heating.

**Table 1 Commercial Energy, Floor Area, and EUI, 2001**

| Location / Region | GWh/yr | Sq M, millions | kWh/sqm |
|---|---|---|---|
| North America | 2,326,000 | 7,900 | 294 |
| OECD Europe | 2,085,000 | 7,400 | 284 |
| OECD Pacific | 651,000 | 2,400 | 274 |
| China | 668,000 | 2,600 | 261 |
| Asia (other) | 960,000 | 3,900 | 248 |
| Former Soviet Union | 659,000 | 2,600 | 253 |
| Other | 1,261,000 | 5,800 | 216 |
| World | 8,609,000 | 32,500 | 265 |

Source: Hinge & MacDonald 2004

Unlike UNICEF, the result of the analysis from the UN Compound's electricity bill and its 3-day reading of energy meter do not tally with one another. Based on the electricity bill, UN Compound has had an energy index of 30 kWh/m² per year in 2016. Meanwhile, extrapolating the 3-day energy meter reading to a full year provides an energy index of ~210 kWh/m² per year for the same facility. The average energy index for commercial buildings in China is stated to be 261 kWh/m² per year[1], from a study published by International Energy Agency (IEA) in 2004, Table 1. In addition, an energy index of 30 kWh/m² per year for any facility, in any part of the world, is an excellent performance of a low energy building. However, based on the observation of the peer-review team at UN Compound, an average to good building scenario is a more judicious description of the facility, rather than an excellent building. In short, there seems to be a possibility of billing error, resulting in much lower energy cost than it should be.

[1] Comparing Commercial Building Energy Use Around the World, Adam Hinge, Sustainable Energy Partnerships, Paolo Bertoldi, European Commission DG Joint Research Centre, Paul Waide, International Energy Agency

Based on the electrical bills, UN Compound electricity consumption in 2016 was 111,625 kWh, contributing to an annual carbon emission of 121 Mton of $CO_2$ (Table 2) by the facility to the environment, or 59 $kgCO_2$ per $m^2$ of built-up area and 1,519 $kgCO_2$ per occupant per annum.

**Table 2 China Electricity Grid Emission Factors[2]**

| Electricity grid emission factor: ($kgCO_2$/kWh) | |
|---|---|
| Northeast electricity grid: | 0.9803 |
| North China electricity grid: | 1.0852 |
| East China electricity grid: | 0.8367 |
| Central China electricity grid: | 1.0297 |
| Northwest electricity grid: | 1.0001 |
| South electricity grid: | 0.9489 |

## 2. Energy

### 2.1. Energy Sources

UN Compound is supplied with electricity that powers the facility's reversible split unit air-conditioning system, lighting and all other plug load. The electricity use is metered and billed based on the energy consumed by the facility. During winter, primary heating is supplied by the centralized district heating system. Unfortunately, the primary heating was inadequate to keep the space comfortable; hence, reversible split units and oil-filled radiant compact personal electric heater are used to provide supplementary heating to facility, incurring electricity operational cost.

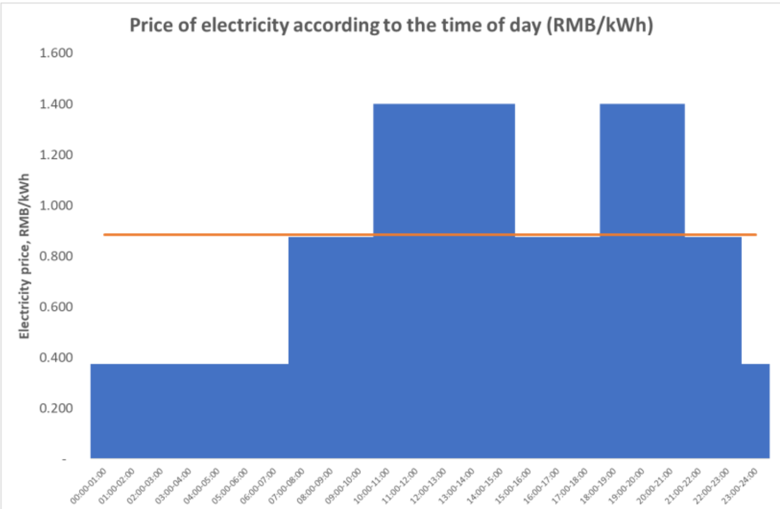



**Figure 6 Price of electricity according to the time of day**

The electricity bills showed a time variable tariff for UN Compound in Beijing that is shown by Figure 6. The peak rate of 1.4 RMB/kWh is charged during 10am to 3pm and 6pm to 9pm. The lowest rate of 0.3748 RMB/kWh is charged from 11pm to 7am. A middle rate of 0.8745 RMB/kWh is applied for all other hours. The combination of these 3 rates provides an average electricity cost of 0.883 RMB/kWh.

---

[2] Z. Liu, Carbon Emissions in China, Springer Theses, Springer-Verlag Berlin Heidelberg 2016

The peak tariff during the day is more than 3.5 times the lowest tariff during midnight hours (see Figure 7).

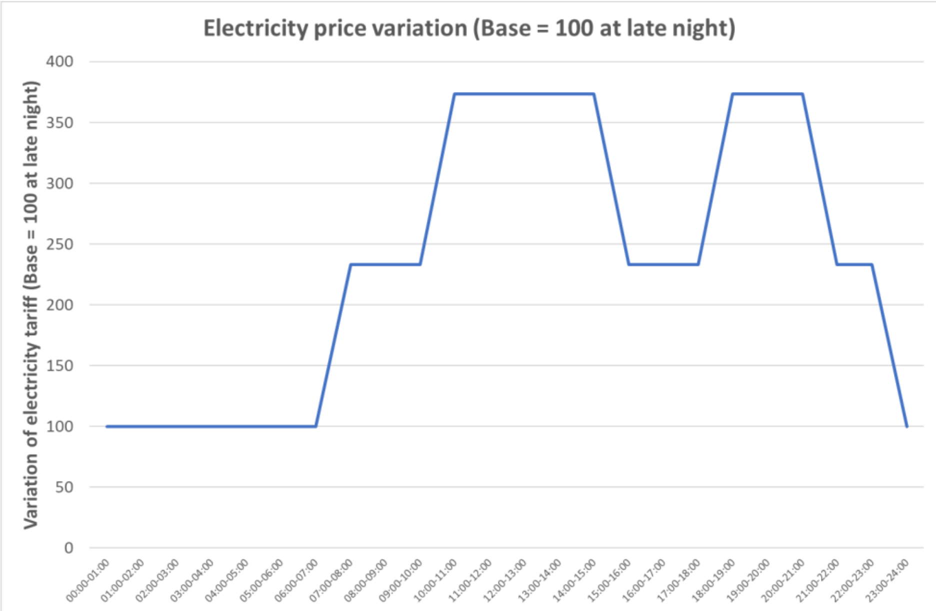



**Figure 7 Electricity price variation with time**

During winter season, the primary heating is provided by the local district heating supplier. The amount of hot water and temperature supplied (heating energy) are not measured or metered. The billing of heating by the local district heating suppler is based on the area ($m^2$) of the facility and hours of hot water supplied.

Any efforts to lower the heating load in this building will not reduce the primary heating bills received from the district heating supplier. However, it will help to reduce electricity cost from the operation of reversible split units and oil-based radiant personal heaters during winter.

## 2.2. Energy Consumption

Only the electricity bills were analysed, as they are based on actual energy consumption of the facility: it is not possible to analyse the energy consumption due to heating because the heating bill is not based on actual heat consumption of the facility.

The monthly electricity consumption over 4 years (Figure 8) showed that peak electricity occurs twice a year, during the hottest month and coldest month. Low energy consumption occurs during the change of season from winter to summer and summer to winter, reflective of the reduction of cooling and heating load during these months. The electricity peak can be clearly seen from Figure 9 below, of 2016 bills, where it peaked in January and July. The peak in the winter month of January is higher than the peak in the summer month of July. More electricity is used to provide supplementary heating in the winter than the cooling required in the summer. December electricity consumption is lower than November, most likely due to the year-end holiday season, when many expatriates may have taken leaves: having less people in the office reduces the electricity consumption of computers and supplementary heating by split-units and oil-based personal heaters.

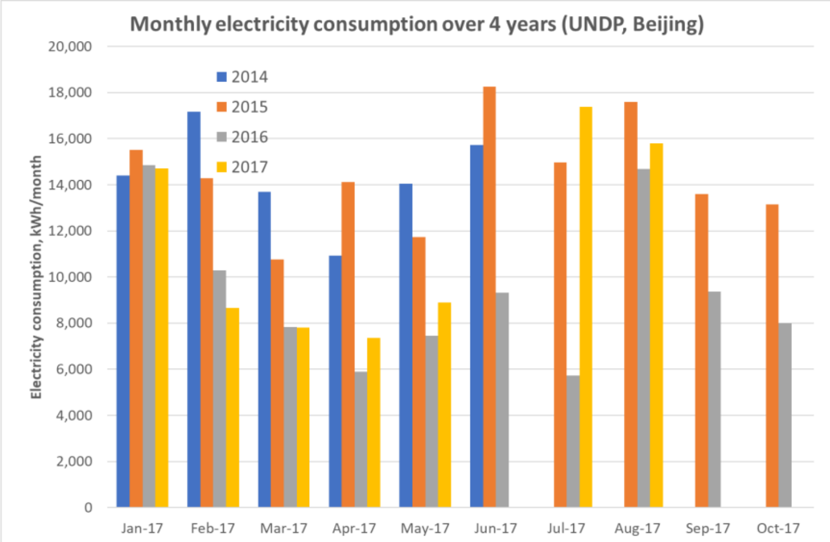



**Figure 8 Monthly electricity consumption over 3 years in UN Compound, Beijing**

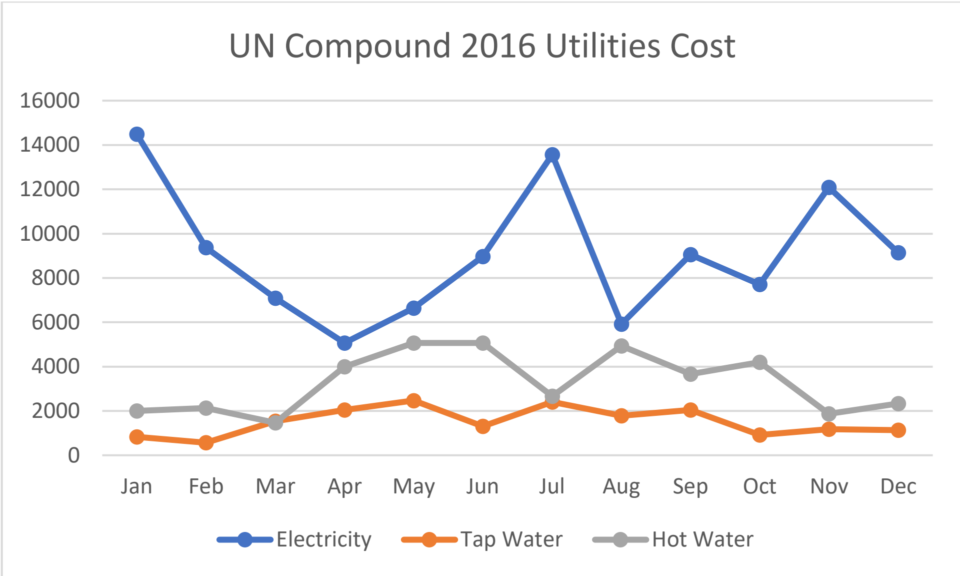



**Figure 9 UN Compound 2016 Utilities Cost (without District Heating)**

### 2.3. Energy Cost

UN Compound's energy cost is divided into electricity and heating. Electricity is billed according to the amount of energy used and, in UN Compound, this is used for lighting, office equipment, reversible air-conditioning that provides cold air in the summer and warm air in the winter and oil-based personal heaters.

Primary heating in UN Compound is provided by a district hot water system channeled through radiators within the facility. The primary district heating system is not billed according to the energy use but according to the facility area and hours of supply. Heating at the facility is also supplemented by the installed reversible air-conditioning system and oil-based personal heaters that incur electricity consumption during winter.

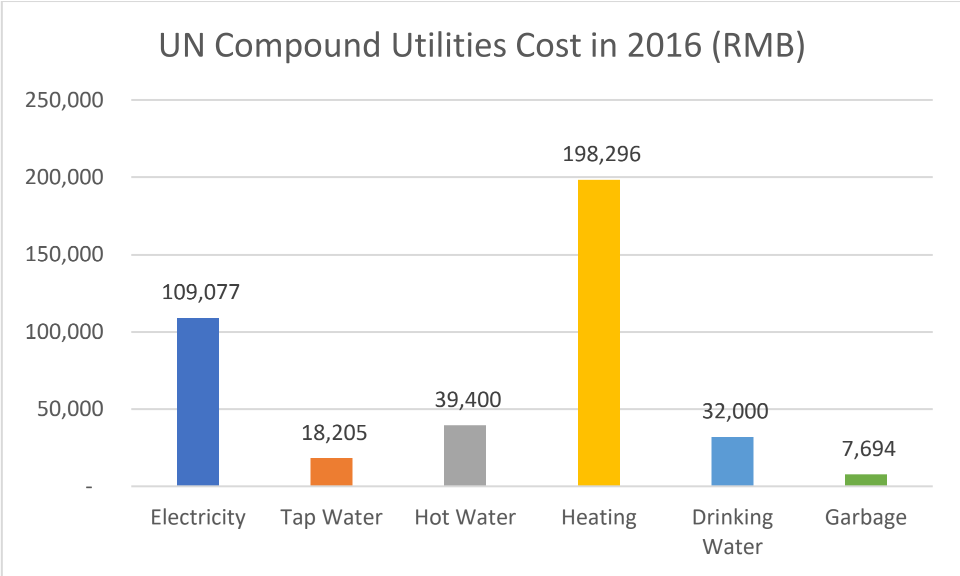



**Figure 10 Annual Utilities Cost in 2016 in UN Compound**

The heating bills showed that district heating was provided to UN Compound for approximately 4½ months in 2016. As shown in Figure 10 and Figure 11, the heating cost in UN Compound for 4½ months is 180% of the annual electricity cost. While in UNICEF, heating cost is 80% of its annual electricity cost. The electricity cost in Figure 10 and Figure 11 includes the usage of air-conditioning for cooling and supplementary heating throughout the year.

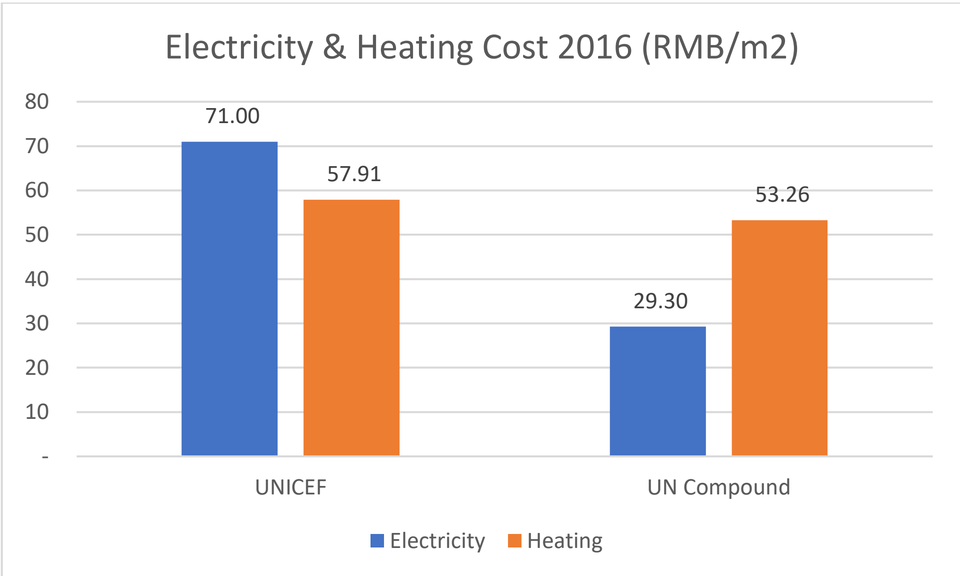



**Figure 11 Electricity & Heating Cost in UNICEF and UN Compound**

An analysis of the facility electricity index in kilowatt-hour per meter square per year ($kWh/m^2$ per year) was made for all the visited facilities in Beijing and compared in Figure 12. The energy index of UNICEF and UN Compound are grouped together because both facilities operated under similar conditions (i.e. both pay for the air-conditioning directly via the electricity bill), while UN Women and WHO are grouped together because both facilities' air-conditioning and heating are provided as part of the office space rental.

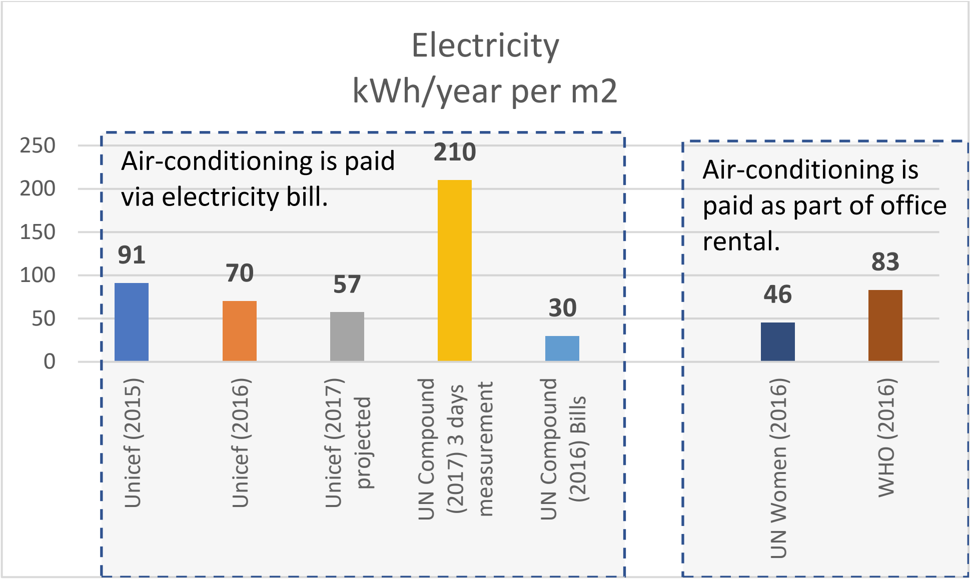



**Figure 12 Electricity Index Comparison of UN's Facilities in Beijing**

The 2016 data in UN Compound gave 2 possible conflicting results that need further understanding and verification. A possible high electricity index in UN Compound of 210, that was estimated from 3 days of meter readings, matches with China's average office building of 261 (that is inclusive of heating) [3]. On the other hand, the low electricity index in UN Compound of 30 (computed using the electricity bills shared with the Peer Review team) is doubtful based on the technology that is at use at the facility. Interestingly, UNICEF's electricity index in 2016 is shown to be lower than WHO's electricity index in 2016. This is appreciable because WHO's electricity index does not include energy used by primary air-conditioning while UNICEF electricity index does.

**Table 3 Three days and night reading of energy meter in UN Compound**

| Date | Time | Meter reading (kWh) (factor of 40) |
|---|---|---|
| October 11th, 2017 | 6:30pm | 5757.23 |
| October 12th, 2017 | 8:30am | 5760.32 |
| October 12th, 2017 | 6:30pm | 5837.44 |
| October 13th, 2017 | 8:30am | 5839.56 |
| October 13th, 2017 | 6:30pm | 5911.29 |
| October 16th, 2017 | 8:30am | 5915.44 |
| October 16th, 2017 | 6:30pm | 5975.58 |

Table 3 indicates that the average office hours (8:30am to 6:30pm) power consumption during these days was 280 kW, while the average after-office hours (6:30pm to 8:30am) power consumption was 9

[3] Adam Hinge, Sustainable Energy Partnerships, Paolo Bertoldi, European Commission DG Joint Research Centre, Paul Waide, International Energy Agency, Comparing Commercial Building Energy Use Around the World.

kW. The after-office hours average power consumption of 9 kW is similar to UNICEF's 10 kW; however, the office hours average power consumption of 280 kW is 9x higher than UNICEF's (30 kW). Extrapolating from these values, assuming 9 hours working day and 290 working days a year, provided an energy index of 210 kWh/m² per year for UN Compound. This value is radically different from a value of 30 kWh/m² per year, estimated using the electricity bill.

The after-office hours power use is approximately 3% of office hours power use. After-office power use is indicative of the electricity used by the data center, pantry equipment (refrigerators, etc.), electric car charging and other phantom loads, when the building is unoccupied. Even after accounting for the longer hours of after-office hours, as compared to the typical office hours per year (Figure 13 Estimate of Annual Energy Use Between Office Hours and After-office Hours), the office hour energy use is still the dominant factor affecting energy consumption at this facility. Focus should be placed on reducing the power use during daytime to reduce energy consumption at this facility.

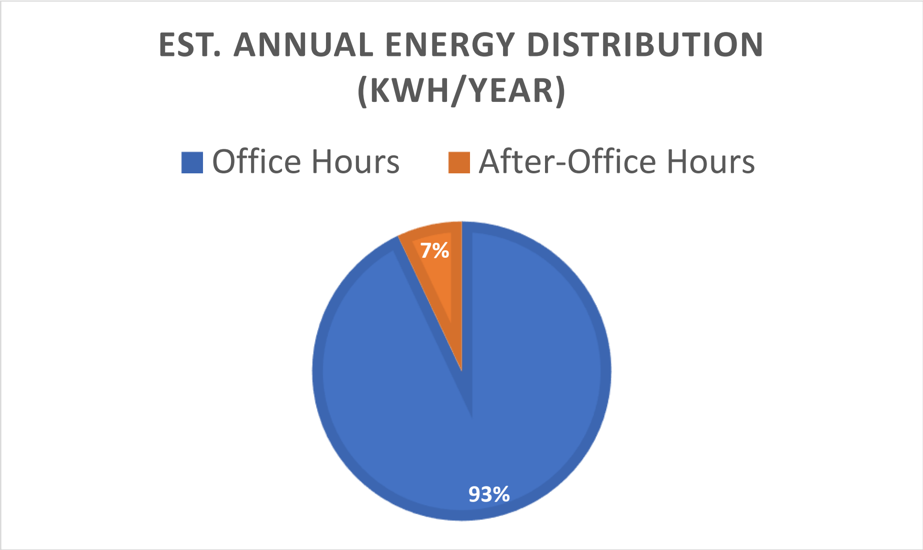



**Figure 13 Estimate of Annual Energy Use Between Office Hours and After-office Hours**

## 3. Achievements

### 3.1. Photovoltaic

A 30 kWp photovoltaic system is installed on the roof top, Figure 14, and has been operational for the past several years.

**Figure 14 Photovoltaic in UN Compound**

### 3.2. Lighting Sensors

Daylight and motion sensors were found to be used for the lights attached to the entrance door, Figure 15.

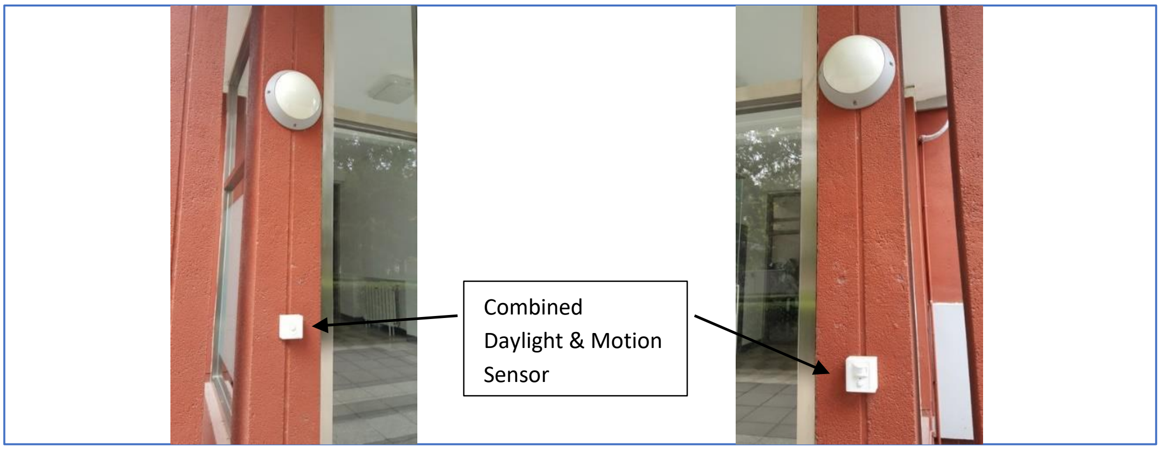



**Figure 15 Combined Daylight & Motion Sensor for Lights at Entrance Door**

### 3.1. Use of Inverter-Based Multi-Split Air-Conditioning Unit

An inverter air-conditioning system operates at highest efficiency during part load. An inverter-based multi-split air-conditioning unit has a higher opportunity to operate at part load most of the time because it is unlikely that all the indoor units would be operating at full load at the same time.

**Figure 16 Multi-Split Unit in UN Compound**

### 3.2. Appropriate Lighting Level

Lighting level for the most part of the facility was found to be within the recommended standard that is optimal for productivity and energy efficiency.

**Figure 17 Lighting Lux Level on Desk and Corridors are Within Recommended Standard**

### 3.1. Electrical Car Charging Stations

A minimum of 3 nos of electric car charging station were found at the facility, Figure 18

**Figure 18 Electric Car Charging Stations**

### 3.1. Efficient Refrigerators

Many of the refrigerators found at UN Compound are rated with the high efficiency, Figure 19.


**Figure 19 Refrigerators in UN Compound are Rated Efficient**

## 3.2. Low After-Office Hours Power Consumption

After-office hour power/energy management was observed to be very well managed in UN Compound. The daytime and nighttime energy meter reading over 3 days showed an average power use of 9 kW after-office hours as compared to an average of 280 kW during office hours, Figure 20. This is a reduction of 97% from the power that is used daytime.

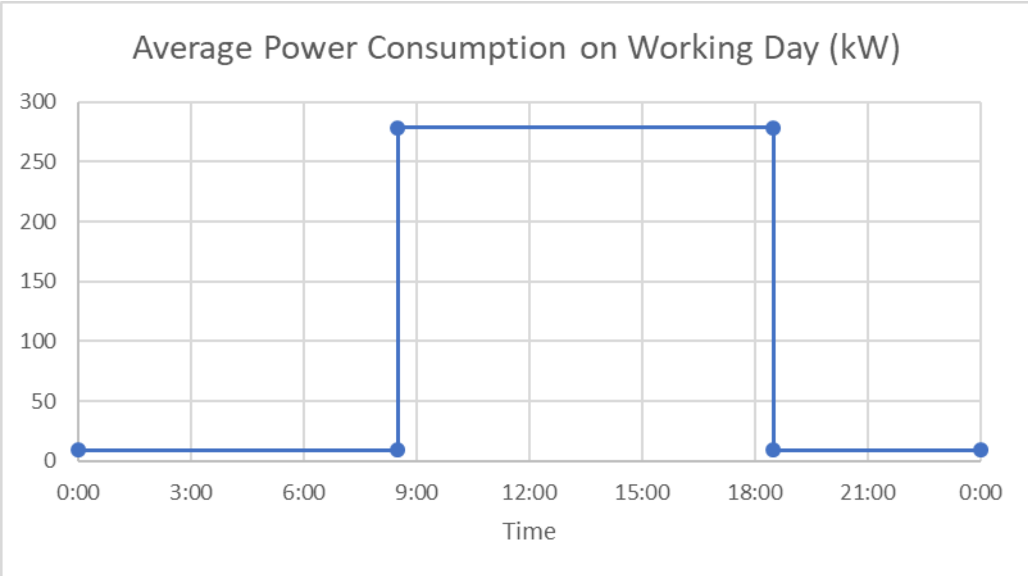



**Figure 20 UN Compound Average Power Consumption on a Typical Working Day**

## 3.3. Greeneries

UN Compound facility is well landscaped both outdoor and indoor with greeneries.

**Figure 21 Outdoor Greeneries in UN Compound**

Studies have shown that lush greeneries outdoor allow occupants' eyes to relax and destress when occupants look out of their windows from their desks.

Greeneries indoor (Figure 22), not only create a nicer environment, but they have also been documented to improve occupant productivity by 15%[4], and improve internal air quality by removing VOC[5] and $CO_2$. Indoor plants were found throughout the facility.

**Figure 22 Indoor Greeneries in UN Compound**

### 3.4. Air-Tightness

Fresh air is provided to the building via infiltration through doors and windows, opening and crack. The facility does not have a mechanical fresh air supply system: infiltration is the uncontrolled leakage of outdoor air into the building. If the building is leaky and allows entry of too much outdoor air, it can lead to very high energy consumption. Some of the doors in UN Compound have 2 layers of rubber seal, and windows are double glazed and sealed well.

The measured $CO_2$ data from the facility indicates that the building is air-tight. The standard office spaces have a measured $CO_2$ level of 1000-1200 ppm. This $CO_2$ level is perfect for having good air quality while minimizing energy consumption.

Densely populated rooms, such as a meeting rooms, were measured to have $CO_2$ level above 2000 ppm. In such rooms, it is recommended to install a fresh air supply fan whose operation is controlled by a $CO_2$ sensor.

[4] Nieuwenhuis, M., Knight, C., Postmes, T., & Haslam, S. A. (2014). The relative benefits of green versus lean office space: Three field experiments. Journal of Experimental Psychology: Applied, 20(3), 199-214.

[5] Department of Horticulture, University of Georgia, Athens, GA 30602-7273, Screening Indoor Plants for Volatile Organic Pollutant Removal Efficiency.

**Figure 23 Windows in UN Compound**

# 4. Opportunities for Improvement

## 4.1. Heating

UN Compound annual energy cost in 2016, shown in Figure 11, indicated that the cost for heating is unreasonably high. It is possible for UN Compound to install its own heating system to provide heating to the facility at a fraction of the current heating cost, while also lowering the GHG emissions in comparison to that from the centralized district heating network operated using coal as fuel.

A potential high efficiency technical solution to reduce the heating cost in UN Compound is by installing a heat pump in combination with a thermal storage system. A good heat pump can have a COP of 3.8 to 4.8 today.[6] This means that it uses 1 kWh of electricity to produce up to 4.8 kWh of heat for the building. Meanwhile, a thermal storage system will allow the heat pump to run at the lowest electricity tariff hours of 11 pm to 7am (which is more than 3.5x cheaper than using it during daytime) and store the heat in an insulated tank for it to be used during working hours. The combination of such a system will be able to generate heat at a cost of 17x cheaper than a personal electrical heater.

Assuming the worst case estimated peak heating load of 70 W/m² for Beijing's offices[7], a diversity factor of 90%, 10 hours of heating/day, 5 days/week, 18 weeks of heating/year, a heat pump COP of 3.8, thermal storage efficiency of 85% and a night time electricity tariff of 0.3748 RMB/kWh; the heating cost using a heat pump with thermal storage system was estimated to be RMB 13,500 per year, versus current scenario of RMB 198,000 paid to the district heating supplier for an annual saving

[6] https://www.energystar.gov/index.cfm?c=most_efficient.me_cac_ashp

[7] Zhao, Wen, Heating/Cooling/Power Load Characteristics in China's Severe Cold Region, 13th Conference of International Building Performance Simulation Association, Chambery, France, Aug 26-28, 2013.

of RMB 185,000 per year. Assuming an acceptable payback of 10 years (as heat pump and thermal storage equipment will have a minimum lifetime of 12 years), the budget available for this investment is RMB 1,850,000.

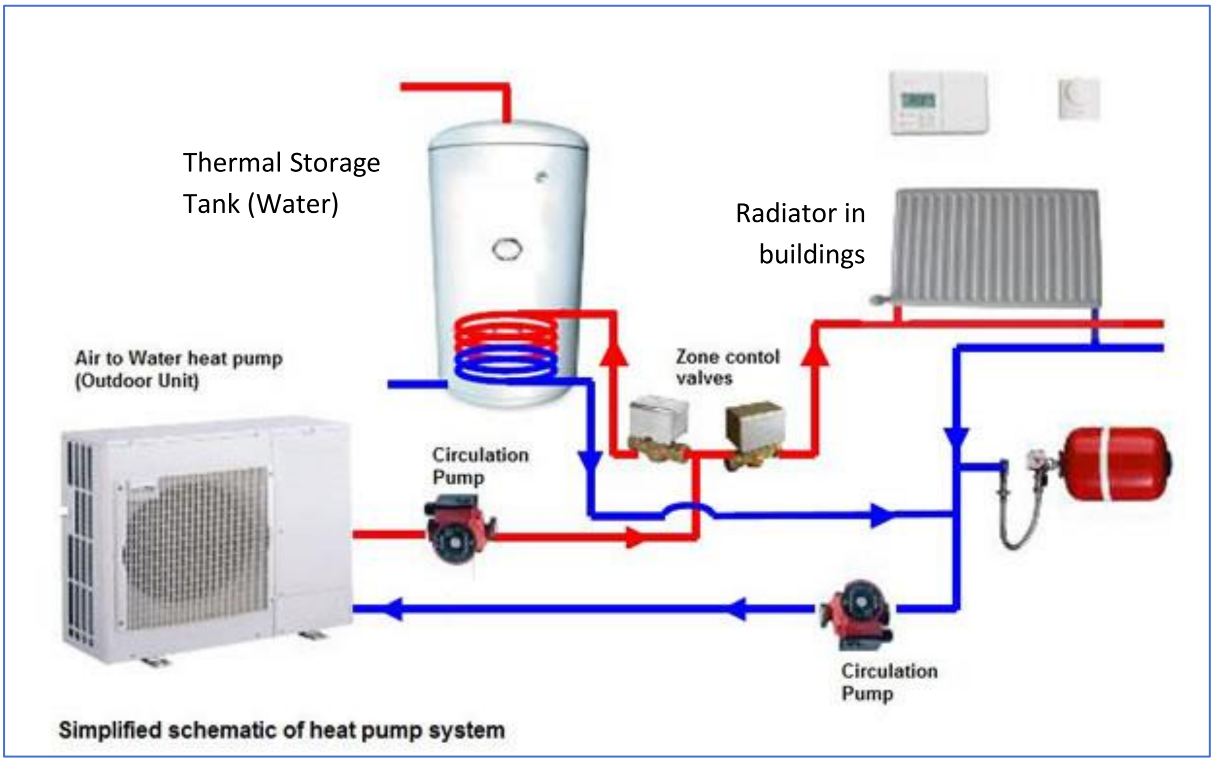



**Figure 24 Typical Heat Pump with Thermal Storage Schematic**

This scenario is only feasible if the landlord and/or district heating supplier agree to terminate the hot water supply agreement with UN Compound.

### 4.1.1. Cooling with Thermal Storage

If the heating system using heat pump and thermal storage system were to be considered, it is highly recommended to analyze the possibility of using the same system for cooling in the summer as well. It is possible with the same system to produce chilled water during night hours at the lowest electricity tariff, store it in the thermal storage system, for it to be used during daytime.

This will require the entire air-conditioning system at UN Compound to be replaced with water-based fan-coil units that provide cooling in summer and heating in winter to maximize the advantage from the system.

## 4.2. Power and Energy Monitoring

A power and energy monitoring system is recommended to be installed in UN Compound to keep track of the real-time production, storage and usage of electricity. It is recommended to select a system that will provide automatic reporting in charts and graphs to show the real-time power usage of the facility and provide daily, weekly and monthly reports.

Such a system will allow a clear understanding of the patterns of power use for the facility and help the facility manager plan and control energy use for the lowest cost. For example, the highest electricity tariff occurs between 10am to 12noon and between 3pm to 4pm at 1.53 RMB/kWh. It may be possible to put a timer to switch off the refrigerators at these hours to avoid the peak tariff rates.

In addition, it was estimated (Table 3) that the average power consumption during office hours (8:30am to 6:30pm) was ~280 kW, while the average after-office hours (6:30pm to 8:30am) power consumption was ~9 kW. The relatively high average power consumption during office hours can be investigated using such a monitoring system, to recognize the pattern of peak energy usage versus the switching on and off of facility equipment.

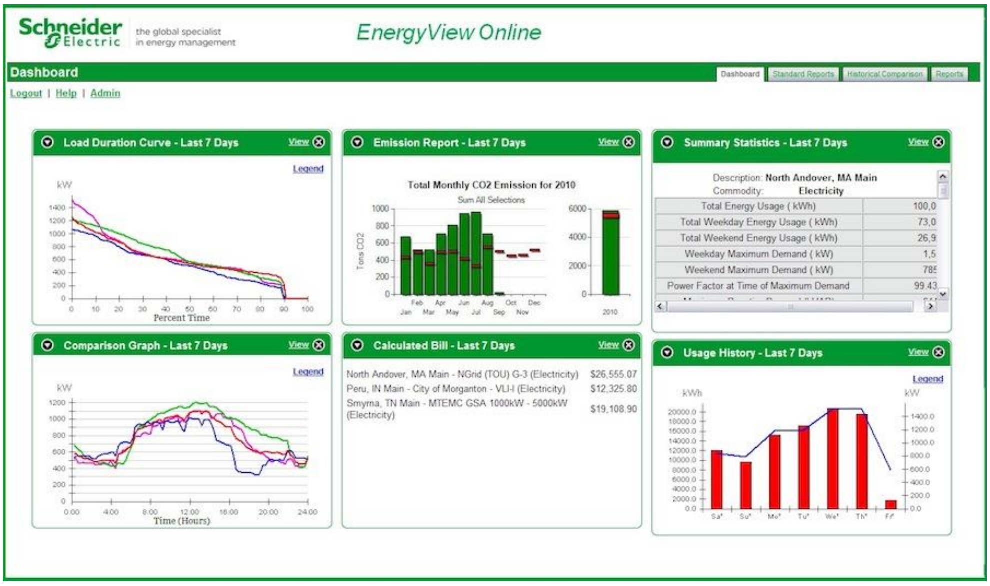



**Figure 25 Example of a typical power and energy monitoring reporting system**

Finally, such a system will allow close monitoring of the facility performance based on daily, weekly and monthly reporting. Any abnormal conditions in energy use can be quickly investigated and fixed as necessary.

## 4.3. Proposed Series of Small Improvements

High energy reduction in an office building is almost always achieved by acting on a series of small improvements. It is the accumulation of 50 or more small improvements, of ~1% energy reduction each, that result in a total building energy reduction of 50% or more for a building. Listed herewith in this section is a series of improvement measures that was observed to be feasible in UN Compound.

### 4.3.1. Air-Conditioning System

A total of 108 units of split units are installed at UN Compound. A few newer units were found to be of inverter types, with Class 1 efficiency. It was also observed that many of the existing (and some fairly new) air-conditioning units are labeled with Class 3 efficiency (see Figure 26), where Class 1 is the most efficient and Class 3 is the least efficient. A typical energy efficient air-conditioner today is approximately 35% to 50% more efficient than the least efficient air-conditioner in the market. Efficient air-conditioning systems today are typically using 'inverter' or 'variable speed' or 'variable flow' (all in reference to the same) technology.

Figure 26 also showed that on the day of visit, some of the air-conditioners were operating at heating mode of 30$^{o}$C, while some were operating at cooling mode at 21$^{o}$C: part of the building was being heated and part being cooled at the same time. There could be a range of reason for this: some rooms may be warmer and some colder, some occupants prefer a warmer environment while some prefer a colder one. Refer to Section 5, Thermal Comfort and Air Temperature Set Point for details to deal with thermal comfort issues.


**Figure 26 Typical Air-Conditioning system at UN Compound**

Outdoor compressors should be free of obstructions for the units to be operating efficiently, Figure 27. Plants and fallen leaves should be maintained to allow a clear flow of air by the outdoor units and allow the units to reject heat from the system effectively.

**Figure 27 Air-Flow of Outdoor Units Obstructed by Plants and Leaves**

**Figure 28 Obstruction of Air-Flow from Split-Units**

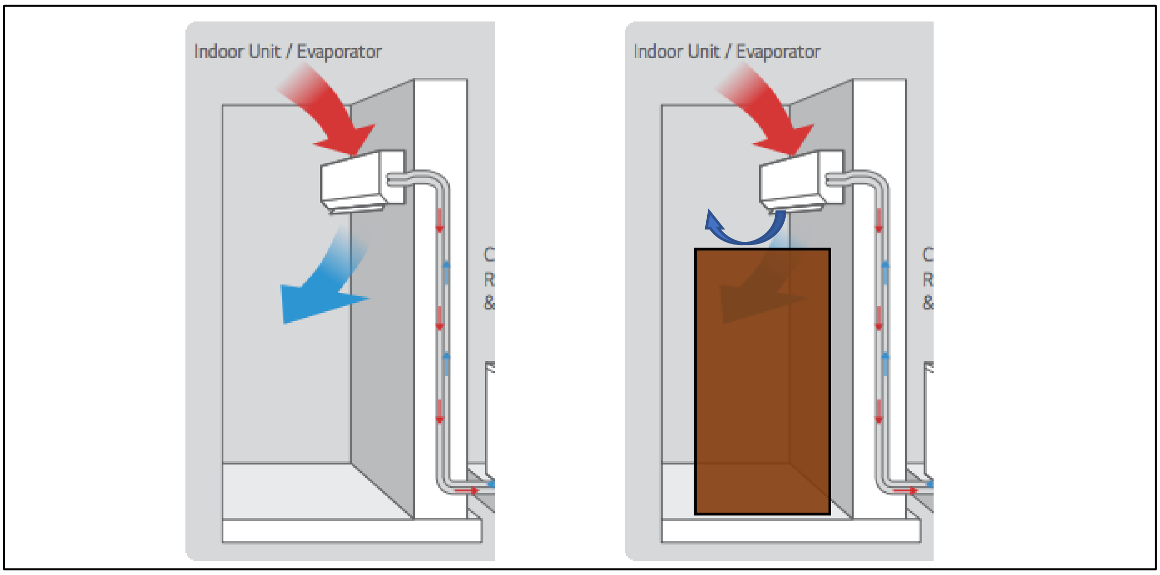



**Figure 29 Schematic of Air-Flow Obstruction**

Air flow from split-units was observed to be obstructed in a couple of cases, Figure 28. These obstructions will cause the supplied cold air to be diverted back to the return air grill without cooling the room, Figure 29. Placement of the indoor unit should be more efficiently located.

The data center split-unit was found to be rated Class 4 out of 5, Figure 30, class 1 being the most efficient and Class 5 being the least efficient equipment. The cooling in data center is operated 24 hours daily and 7 days a week: it is highly recommended to install the most efficient split-unit available in the market as the payback will be significantly shorter than one that is only operated 8-9 hours a day and is switched off during weekends.

**Figure 30 Data Center Split-Unit Rated 4 out of 5**

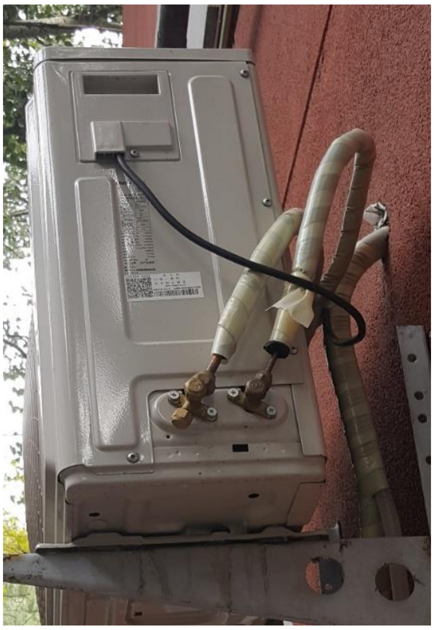


**Figure 31 Poor Insulation of Refrigerant Piping**

In general, split-unit refrigerant pipes are almost always poorly uninsulated near the inlet and outlet valves at the compressor in Beijing. The insulation provided often stopped short from the compressor fittings, exposing refrigerant copper pipes, Figure 31. Exposed copper pipes lose cooling and heating to the outdoor space. It is recommended that insulation be provided to cover the copper pipe entirely, preventing unnecessary energy losses.

#### 4.3.1.1. Efficiency of Air-Conditioning System

Efficiency of air-conditioning units is typically expressed as the Coefficient of Performance (COP).

$$COP = \frac{Total\ Cooling\ Energy\ Produced}{Total\ Electricity\ Consumed}$$

**Table 4 Typical COP of Split Unit Air-Conditioner**

| Types of Air Conditioning | COP@100% Load | COP@50% Load |
|---|---|---|
| Typical 5 years old Split Units | 2.6 | 2.6 |
| New and efficient Split Units | 3.3 | 3.3 |
| Typical Inverter Split Units | 3.3 | 4.6 |
| Typical Inverter Multi-Split Units | 3.3 | 4.6 |
| Very Efficient Inverter Split Units | 5.0 | 7.0 |

Higher COP indicates better efficiency; i.e. using less electricity to produce the same amount of cooling. As shown in Table 4, inverter split units are very efficient at part load. Inverter split units that are operated at full load typically have the same efficiency as conventional split units without inverters.

Most inverter type air-conditioners operate at their most optimum efficiency at part load of 50%. A slightly oversized inverter air-conditioning system therefore operates more efficiently than an inverter air-conditioning system that is undersized and running at 100% load all the time. It is recommended that selection of air-conditioning size be made by making actual measurement of power consumption of the equipment with a clamp meter for existing spaces on a typical hot day. This would ensure that equipment is less likely to be significantly oversized or undersized.

A multi-split unit has the advantage to connect several indoor units to a single outdoor unit. This makes it more likely for the outdoor unit to operate at part-load as some of the indoor units may be switched off or may not be used in a room with the same orientation of peak solar gain. This ensures that the multi-split system will be operating in part load conditions more often, guaranteeing better efficiency.

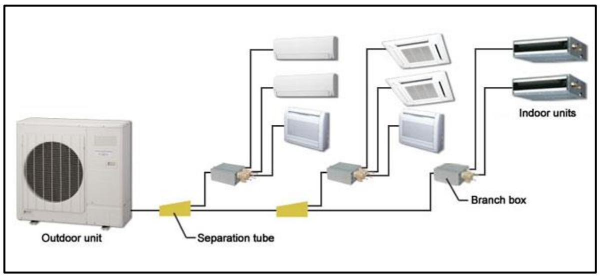



**Figure 32 Typical Multi-Split AC Unit**

In addition, the newer multi-split units have very high COP. Some of the latest multi-split systems can achieve an average COP above 6.0. See Table 5 below (extracted from Singapore governmental website).

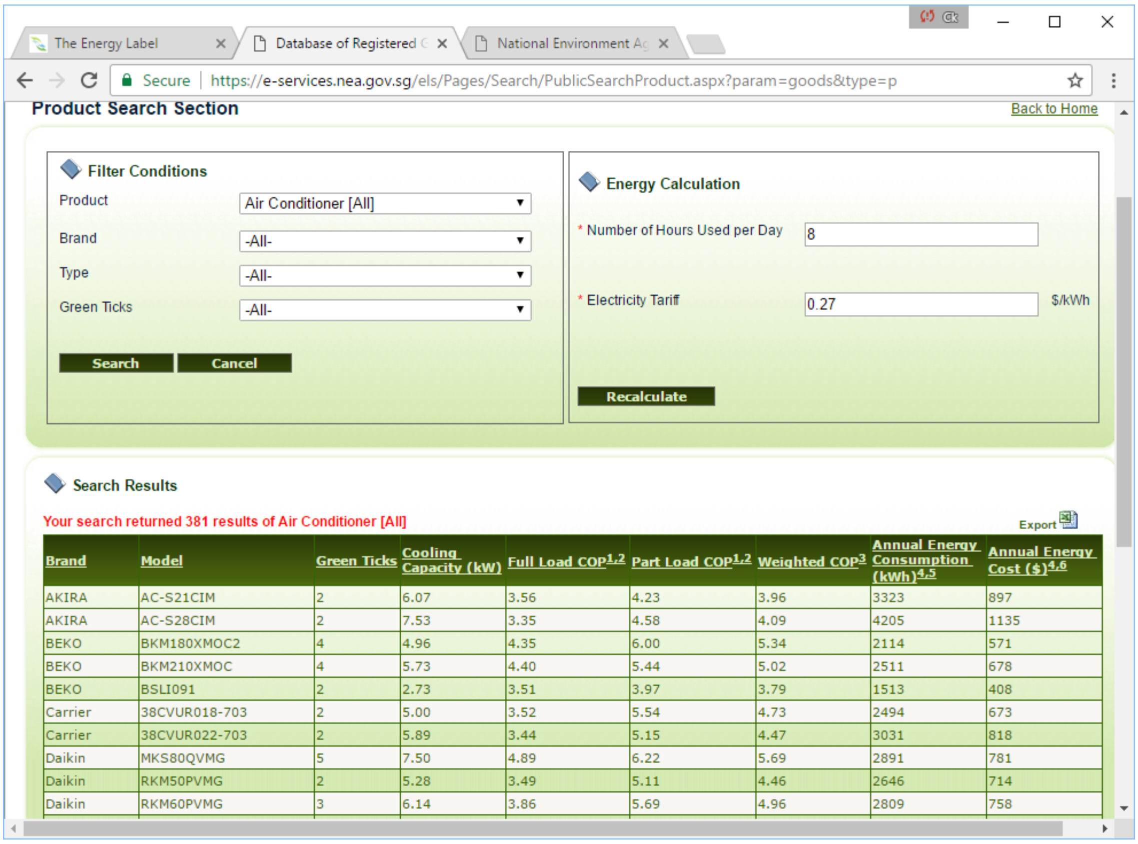
**Table 5 Sample List of Latest Split Units with high COPs**

| Brand | Model | Cooling Capacity (kW) | Full Load COP | Part Load COP | Weighted COP |
|---|---|---|---|---|---|
| Daikin | RXZ25NVMG | 2.4 | 5.69 | 7.32 | 6.67 |
| LG | ARUV030GSD0 | 9.64 | 4.52 | 7.63 | 6.39 |
| Saijo Denki | CW1A-12-CCS1 | 4.02 | 6.3 | 6.27 | 6.28 |
| Saijo Denki | CW1A-09-CCS1 | 3.19 | 6.31 | 6.06 | 6.16 |
| Mitsubishi Electric | MXY-5C125VA | 14.44 | 5.38 | 6.6 | 6.11 |
| Mitsubishi Electric | MXY-4C100VA | 11.53 | 5.75 | 6.33 | 6.1 |
| Saijo Denki | CWIA-18-CCS1 | 5.8 | 6.14 | 6.02 | 6.07 |
| LG | ARUV040GSD0 | 11.16 | 4.14 | 7.33 | 6.05 |
| Mitsubishi Electric | MXY-6C140VA | 15.84 | 5.39 | 6.49 | 6.05 |
| Mitsubishi Electric | MXY-2G20VA | 4.83 | 4.91 | 6.75 | 6.01 |
| Daikin | RXZ35NVMG | 3.41 | 5.07 | 6.59 | 5.98 |
| Mitsubishi Electric | MXY-4G38VA | 7.5 | 4.87 | 6.67 | 5.95 |
| Mitsubishi Electric | MXY-4G28VA | 6.6 | 5.16 | 6.41 | 5.91 |
| Mitsubishi Electric | MUY-FL10VE | 2.75 | 4.91 | 6.52 | 5.88 |
| Mitsubishi Electric | MXY-3G28VA | 6.12 | 5.01 | 6.43 | 5.86 |
| Daikin | MKS65QVMG | 6.15 | 5.07 | 6.36 | 5.84 |
| Mitsubishi Electric | MUY-GE10VA | 2.53 | 4.56 | 6.62 | 5.8 |
| Mitsubishi Electric | MXY-5G48VA | 9.21 | 4.99 | 6.28 | 5.76 |

A comprehensive list of split unit air-conditioner COP is available from this Singapore governmental website: http://www.nea.gov.sg/energy-waste/energy-efficiency/household-sector/the-energy-label

It is also available from Hong Kong governmental website:
http://www.energylabel.emsd.gov.hk/en/households/rac/select_ac.php

Different countries may be using different energy rating methodologies. As a rule of thumb, it is OK to compare different models from the same source. It may not be accurate to compare different models from different sources.



The Energy Label | Database of Registered | National Environment Ag

https://e-services.nea.gov.sg/els/Pages/Search/PublicSearchProduct.aspx?param=goods&type=p

**Product Search Section** Back to Home

**Filter Conditions**

Product: Air Conditioner [All]
Brand: -All-
Type: -All-
Green Ticks: -All-

Search | Cancel

**Energy Calculation**

* Number of Hours Used per Day: 8
* Electricity Tariff: 0.27 $/kWh

Recalculate

**Search Results**

Your search returned 381 results of Air Conditioner [All]

Export

| Brand | Model | Green Ticks | Cooling Capacity (kW) | Full Load COP1,2 | Part Load COP1,2 | Weighted COP3 | Annual Energy Consumption (kWh)4,5 | Annual Energy Cost ($)4,6 |
|---|---|---|---|---|---|---|---|---|
| AKIRA | AC-S21CIM | 2 | 6.07 | 3.56 | 4.23 | 3.96 | 3323 | 897 |
| AKIRA | AC-S28CIM | 2 | 7.53 | 3.35 | 4.58 | 4.09 | 4205 | 1135 |
| BEKO | BKM180XMOC2 | 4 | 4.96 | 4.35 | 6.00 | 5.34 | 2114 | 571 |
| BEKO | BKM210XMOC | 4 | 5.73 | 4.40 | 5.44 | 5.02 | 2511 | 678 |
| BEKO | BSLI091 | 2 | 2.73 | 3.51 | 3.97 | 3.79 | 1513 | 408 |
| Carrier | 38CVUR018-703 | 2 | 5.00 | 3.52 | 5.54 | 4.73 | 2494 | 673 |
| Carrier | 38CVUR022-703 | 2 | 5.89 | 3.44 | 5.15 | 4.47 | 3031 | 818 |
| Daikin | MKS80QVMG | 5 | 7.50 | 4.89 | 6.22 | 5.69 | 2891 | 781 |
| Daikin | RKM50PVMG | 2 | 5.28 | 3.49 | 5.11 | 4.46 | 2646 | 714 |
| Daikin | RKM60PVMG | 3 | 6.14 | 3.86 | 5.69 | 4.96 | 2809 | 758 |

**Figure 33 Singapore Database of Rated Split Unit Air-Conditioner**

Inverter split unit highest efficiency occurs at part load conditions. This means that it is necessary for these split units to be set at the right temperature set point for it to operate at part load. I.e. setting the split unit to operate at 18°C, while the room temperature is operating at 21°C, will cause the split unit to operate at full load condition. In addition, if infiltration rates are high due to open doors and windows, these split unit will also be operating at full load condition. Full load conditions for inverters means approximately the same efficiency as non-inverters! Don’t waste your money on inverters if you know that the units will always be operating at full load conditions.

Example of computing Full Load COP from an existing split unit.


$$Cooling\ COP = \frac{Max\ Cooling\ Capacity}{Max\ Cooling\ Power} = \frac{25000\ W}{7310\ W} = 3.42$$

$$Heating\ COP = \frac{Max\ Heating\ Capacity}{Max\ Heating\ Power} = \frac{27300\ W}{7490\ W} = 3.64$$

Since the introduction of China Energy Label in 2005 (see Figure 34), more than 25 product groups have become mandatory to be labelled, while additional classes are continually being added to the product catalogue. Among the CEL mandatory products are:

- Motors
- Air conditioners
- Refrigerators
- Washing machines
- Gas kettles
- Water kettles
- Photocopiers
- Air compressors
- Flat-screen televisions
- Fluorescent tube

It is recommended to purchase the lowest cost, highest efficiency labelled equipment whenever UN Compound plans to purchase air-conditioners.

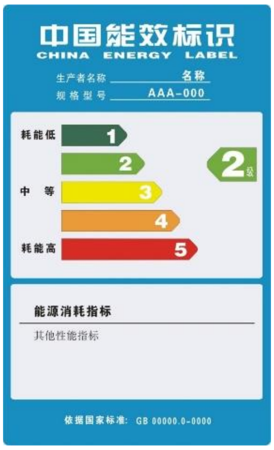



**Figure 34 China's Energy Labelling Scheme**

**Figure 35 Example of Poorly Sealed Wall Puncture**

Installation of air-conditioning refrigerant pipes holes should be sealed well to prevent air leakages into the building. Not only does excessive air leakage increase building energy consumption, but it also brings in PM 2.5 when the outdoor air quality is bad. Figure 35 shows a poorly sealed wall punctures, while Figure 36 shows better sealed wall punctures. It is recommended that these holes be sealed with appropriate sealant.

**Figure 36 Well Sealed Wall Puncture**

### 4.3.2. Heating

#### 4.3.2.1. Radiators

Due to the billing system for heating in UN Compound, there is no incentive to reduce the primary heating energy usage. However, large supplementary heating load was observed from the bills during peak winter month. Supplementary heating is provided via the reversible air-conditioning units and personal oil-based radiant electrical heater at the facility. The analysis from the electrical bills showed that these supplementary heating is extensively used during winter.

**Figure 37 No Thermostat Control on the Radiator**

**Figure 38 Personal Oil-Based Radiant Electrical Heater**

Radiators in UN Compound are, as shown in Figure 37, without any thermostat control. Installing thermostat control will provide better control of comfort during winter, especially if the rooms become too hot. A thermostat will also reduce the hot water need during winter. However, installing a thermostat today will not provide any operational cost reduction to the facility due to the reason that billing is not based on energy used from district heating. In addition, it also appears that the heat provided by these radiators are inadequate (possibly due to the supply of hot water at low temperature and/or low flow rate), as it needs to be supplemented with other electrical heating systems.

A thermostat control valve on the radiator helps to automatically adjust the flow rate by sensing the room temperature and reduce energy consumption. For details, see http://www.energysavingtrust.org.uk/home-energy-efficiency/thermostats-and-controls

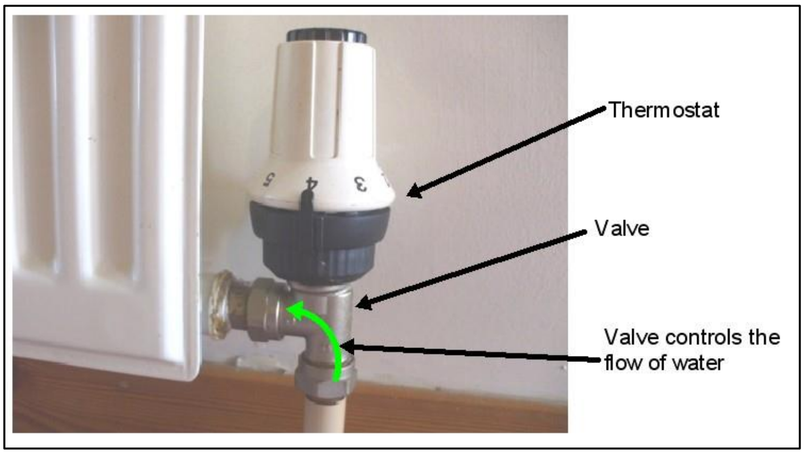



**Figure 39 Example of thermostat-based control valves**

#### 4.3.2.2. Reversible Ceiling Fan

The air-conditioning units in heating mode were found to be set at 30°C during the visit. This is a clear indication that the generated heat by the air-conditioning remained on the upper level of the room as shown by Figure 40. 30°C at occupant level will be unbearably hot for any office space. Temperature sensor on air-conditioners are located at the return air grill of fan coil unit. As air-conditioners are installed high, the temperature sensor is measuring the heat at the upper level of the room. One possible solution to bring the hot air down to occupant level is to ensure that room air is well mixed. A reversible ceiling fan is commonly used to bring down the heat at the top of the space to the occupants below (see Figure 41).

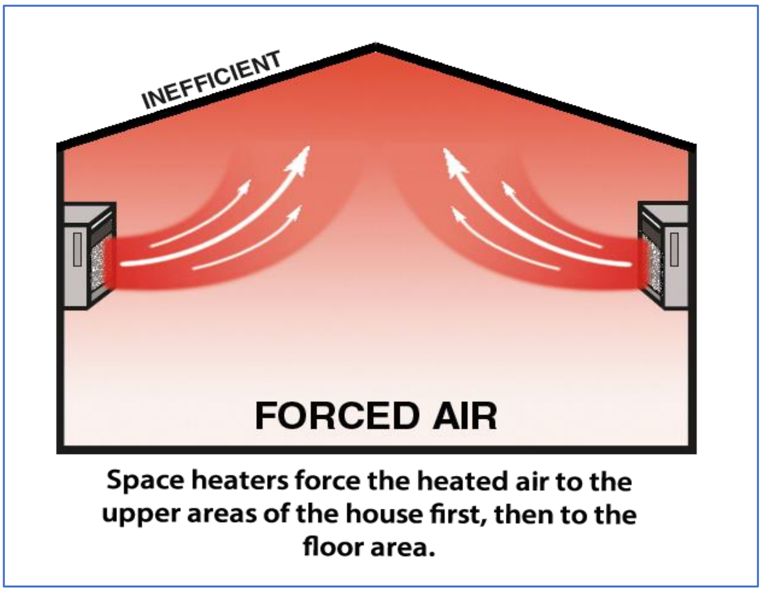



**Figure 40 Hot Air from Air-Conditioner Remaining at Upper Level of a Room**

While a typical ceiling fan produces air flow downwards to create a wind-chill effect in summer time, a reversible ceiling fan reverses the motor and operate the ceiling fan at low speed in the opposite direction during winter time. This produces a gentle updraft, which forces warm air near the ceiling down into the occupied space below, Figure 41.

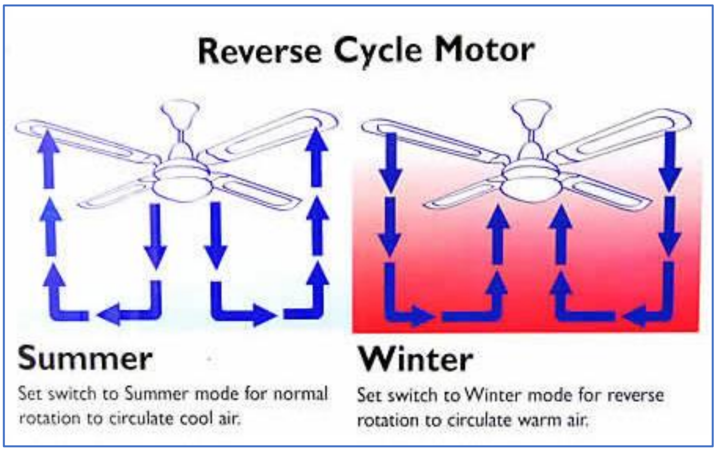



**Figure 41 Schematic Concept of Reversible Fan**

The implementation of this solution will ensure that the room air temperature is better distributed, improving thermal comfort and allowing a lower temperature set-point on the air-conditioning unit during winter time. This will help to reduce the electricity consumption of an inverter-based air-conditioner as it will be allowed to operate at part-load condition.

**Ceiling Fan & Thermal Comfort in Summer**

An installation of ceiling fan allows an office space to increase its air speed during summer. A slight increase in air speed allows the air temperature of the air-conditioning system to be set higher. According to ASHRAE Standard 55, a standard for thermal comfort, it is projected that increasing air speed from 0.1 m/s (without ceiling fan) to 0.6 m/s (ceiling fan at low speed), allowed an increase of temperature up to 3$^{o}$C. In combination, with an inverter air-conditioning unit that operates more efficiently at part-load, the electricity saved can be substantial during summer months.

Note that most ceiling fans can easily increase air speed up to 1.5 m/s at the top speed. While a higher air velocity allows a higher set-point of air temperature, it may also cause other disturbances, such as paper flying off from a desk, occupants with contact lenses may feel that their eyes dry faster, and some may even be disturbed by the high-velocity air ‘touching’ their body in an office environment. An increased air-speed up to 0.5 or 0.6 m/s should be generally acceptable for an office space, which is typically the lowest or 2$^{nd}$ lowest speed on a 5-speed motor.

### 4.3.3. Plug Loads

#### 4.3.3.1. Refrigerators

While many of the refrigerators used in the UN Compound are rated with energy efficient rating, there is at least one with very poor ratings, Figure 42 .


**Figure 42 Energy Rating of 1½ Star Refrigerator in UN Compound**

The energy consumption of an inefficient 230-liter refrigerator is approximately 450 kWh/year, while for an energy efficient one it is approximately 250 kWh/year[8]. Assuming an average electricity tariff of 1 RMB per kWh, it will provide a saving of approximately 200 RMB per year to replace 1 nos of inefficient refrigerator with efficient ones. As a refrigerator normally lasts for 10 to 15 years; allowing a payback of 10 years should provide a budget of RMB 2,000 to replace an inefficient refrigerator, while reducing GHG emissions for the world.

It is recommended to purchase the lowest cost, highest efficiency labelled equipment whenever UN Compound is purchasing or renting a refrigerator.

#### 4.3.3.2. Printers

Sharing of a common printer is more energy efficient than having many individual printers. Moreover, it is easier to shutdown these printers than many individual printers at night when it is not in use to minimize phantom energy use. While most of the offices in UN Compound practice sharing of a common printer, there were a small number of offices that have personal printers for each desk. Unless the personal printer is used for highly confidential matters, its use should be minimized.

[8] Singapore energy label. http://www.nea.gov.sg/energy-waste/energy-efficiency/household-sector/the-energy-label

**Figure 43 Common Printers in UN Compound**

**Figure 44 Personal Printers in UN Compound**

#### 4.3.3.3. Computers

Notebooks and laptops are inherently more efficient than desktops. Notebooks and laptops are approximately 70% more efficient than desktops due to the requirement of long battery life. UN Compound has a higher than typical usage of desktop with 60 units for 120 staffs as compared to other UN agencies in Beijing.

US EnergyStar provides a recommendation of efficient computers via this website: [https://www.energystar.gov/products/office_equipment/computers](https://www.energystar.gov/products/office_equipment/computers)

### 4.3.1. Phantom Load Management

The power consumption of ~9 kW unoccupied hours in UN Compound may seem low when it is compared to its daytime load of ~280 kW. However, 9 kW power consumption during unoccupied hours should still be investigated, as these are usually the low-hanging fruits of energy efficiency. Unoccupied hours power consumption in UN Compound was observed to be contributed by the electrical car charging station, data center, refrigerator and phantom load of computers, monitors, water dispensers, printers, AV devices and more. In many inefficient buildings, up to 50% or more of the unoccupied power consumption can be attributed to phantom load.

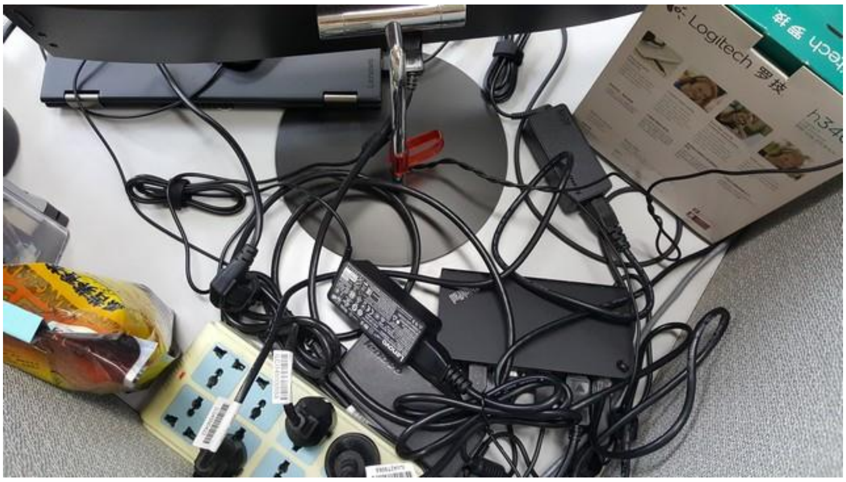




**Figure 45 Power Adapters are Common Phantom Loads in Offices**

A phantom load, also known as standby power or vampire power, is the electricity consumed by an electronic device while it is turned off or in standby mode. Modern offices are filled with appliances that consume power even when they're off. Phantom loads maintain the printer, computer, and etc. settings to allow the unit to power up quickly when the "on" button is pressed. They keep the clocks going on DVR player and microwave. Phantom loads also keep the wireless network running even when one is not online, and they make sure the wireless printer is ready to print whenever a file is sent by the computer for printing.

An estimate of phantom load power consumption in UN Compound based on the known equipment, as shown in Table 6, showed that a minimum of 1.5 kW of phantom load is contributed by known devices. There may be other equipment that is consuming energy that may not be captured by this list.

**Table 6 Phantom Load Estimates in UN Compound**

| Devices | Typical Phantom Load (Watts) | Nos | Total (Watts) |
|---|---|---|---|
| Notebook power adaptor | 2 | 75 | 150 |
| Monitor power adaptor | 2 | 120 | 240 |
| Desktop Computer power box | 3 | 75 | 225 |
| Water Dispenser | 20 | 9 | 180 |
| Wireless device | 15 | 10 | 150 |
| Printers (large) | 70 | 6 | 420 |
| Printers (small) | 10 | 10 | 100 |
| Network Hubs | 10 | 5 | 50 |
| Total | | | 1515 |

In some large organizations, a big part of phantom load was found to be caused by desktop computers that were not shut down after office hours. If this is the case, it is highly recommended to equip every desktop computer with a device such a power strip, to automatically shut the computer down when it monitors no activity for 15 minutes.

It is also possible to kill off all "phantom" loads in an office. This can be done manually at the existing location (may require the office staff to squat/bend to switch off or unplug at the plug point), or via an extension cable that bring the plug point to the table (making it easier to switch off a button on the table before leaving the office) or via smart power strip that automatically shuts off power when it senses that the computers are off via the control plug; i.e. https://www.amazon.com/Take-Charge-Smart-Power-Strip/dp/B005DTBCD2 and http://www.smarthomeusa.com/smart-strip-power-strip-automatic-switching-surge-suppressor/

**Figure 46 Phantom load management options**

More information on phantom load can be found at https://energy.gov/eere/articles/warding-energy-vampires-and-phantom-loads.

### 4.3.2. Data Centre Energy Efficiency

#### 4.3.2.1. Operating Temperature

Measured data centre air temperature was 18$^{o}$C during the peer-review visit, as shown in Figure 47. It is recommended to maintain the data centre room temperature at 25$^{o}$C. The recommended operating air-temperature for a mission critical data centre since 2011 is between 18$^{o}$C to 27$^{o}$C (see Figure 56). Failure rates of server and storage has been shown to increase beyond these recommended and allowable temperatures as specified by ASHRAE TC 9.9 committee[9].

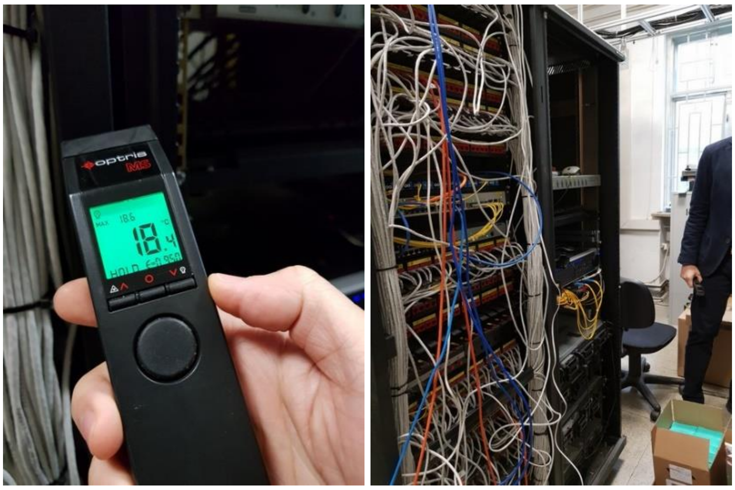



**Figure 47 Data center operating temperature at 18$^{o}$C**

[9] *ASHRAE TC 9.9, 2011 Thermal Guidelines for Data Processing Environments – Expanded Data Center, Classes and Usage Guidance, Whitepaper prepared by ASHRAE Technical Committee (TC) 9.9, Mission Critical Facilities, Technology Spaces, and Electronic Equipment*

It is recommended to maintain a minimum server room temperature of 25$^{o}$C, providing a buffer of 2$^{o}$C as a safety margin for the server. Efficiency of air-conditioning systems increases with higher operating temperature, particularly the inverter ones. Finally, all Google's data centres are operated exactly at 27$^{o}$C around the world for optimum energy efficiency.[10]

Table 4. 2011 ASHRAE Thermal Guidelines (I-P version in Appendix E)

The 2008 recommended ranges as shown here and in Table 2 can still be used for data centers. For potentially greater energy savings, refer to the section 'Guide for the Use and Application of the ASHRAE Data Center Classes' and the detailed flowchart in Appendix F for the process needed to account for multiple server metrics that impact overall TCO.

| Classes (a) | Equipment Environmental Specifications | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Product Operations (b)(c) | | | | | Product Power Off (c) (d) | | |
| | Dry-Bulb Temperature (˚C) (e) (g) | Humidity Range, non-Condensing (h) (i) | Maximum Dew Point (˚C) | Maximum Elevation (m) | Maximum Rate of Change(˚C/hr) (f) | Dry-Bulb Temperature (˚C) | Relative Humidity (%) | Maximum Dew Point (˚C) |
| **Recommended** (Applies to all A classes; individual data centers can choose to expand this range based upon the analysis described in this document) | | | | | | | | |
| A1 to A4 | 18 to 27 | 5.5ºC DP to 60% RH and 15ºC DP | | | | | | |
| **Allowable** | | | | | | | | |
| A1 | 15 to 32 | 20% to 80% RH | 17 | 3050 | 5/20 | 5 to 45 | 8 to 80 | 27 |
| A2 | 10 to 35 | 20% to 80% RH | 21 | 3050 | 5/20 | 5 to 45 | 8 to 80 | 27 |
| A3 | 5 to 40 | -12˚C DP & 8% RH to 85% RH | 24 | 3050 | 5/20 | 5 to 45 | 8 to 85 | 27 |
| A4 | 5 to 45 | -12˚C DP & 8% RH to 90% RH | 24 | 3050 | 5/20 | 5 to 45 | 8 to 90 | 27 |
| B | 5 to 35 | 8% RH to 80% RH | 28 | 3050 | NA | 5 to 45 | 8 to 80 | 29 |
| C | 5 to 40 | 8% RH to 80% RH | 28 | 3050 | NA | 5 to 45 | 8 to 80 | 29 |

Class A1: Typically a data center with tightly controlled environmental parameters (dew point, temperature, and relative humidity) and mission critical operations; types of products typically designed for this environment are enterprise servers and storage products.

Class A2: Typically an information technology space or office or lab environment with some control of environmental parameters (dew point, temperature, and relative humidity); types of products typically designed for this environment are volume servers, storage products, personal computers, and workstations.

Class A3/A4: Typically an information technology space or office or lab environment with some control of environmental parameters (dew point, temperature, and relative humidity); types of products typically designed for this environment are volume servers, storage products, personal computers, and workstations.

Class B: Typically an office, home, or transportable environment with minimal control of environmental parameters (temperature only); types of products typically designed for this environment are personal computers, workstations, laptops, and printers.

Class C: Typically a point-of-sale or light industrial or factory environment with weather protection, sufficient winter heating and ventilation; types of products typically designed for this environment are point-of-sale equipment, ruggedized controllers, or computers and PDAs.

**Figure 48 ASHRAE TC9.9 recommendations for mission critical data centre**

#### 4.3.2.2. Air-Conditioning Efficiency

As the data centre air conditioning system is operated 24 hours a day, it is most important that the most efficient air-conditioners be used for this space.

#### 4.3.2.3. Free-Cooling for Data Centre

Many Google's data centers are employing free cooling strategy in places where the climate allows. In Beijing, it is possible to utilize free cooling 24 hours daily from mid-September onwards until mid-April (see Figure 49).

[10] https://www.google.com/about/datacenters/efficiency/internal/#temperature

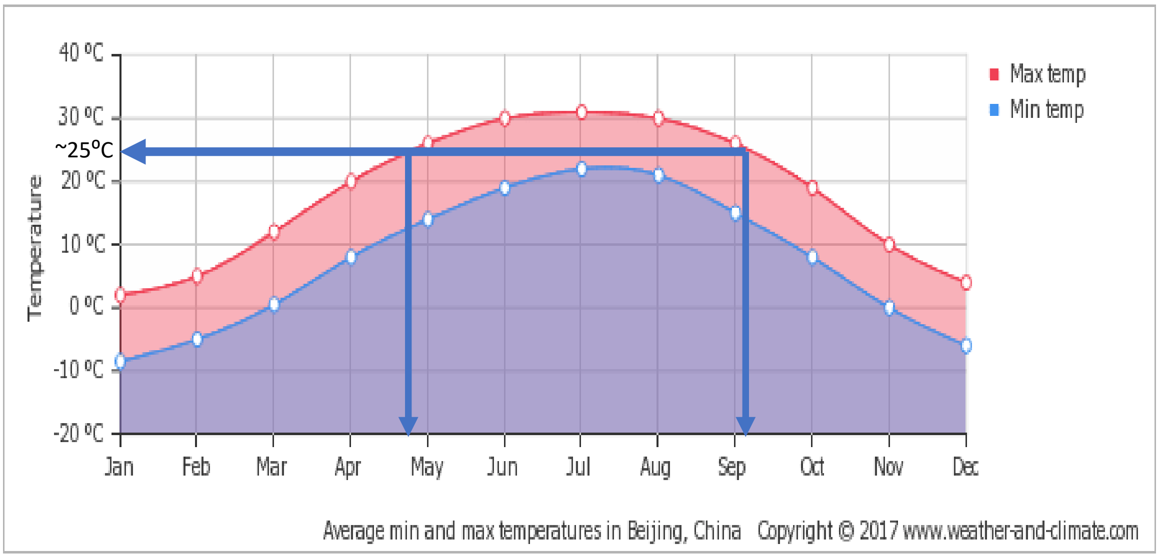



**Figure 49 Beijing Max and Min Air Temperature**

Free cooling requires additional fans, ducts and controls to be provided to bring in outdoor air into the data centre whenever the outdoor air is cooler than 25ºC. The air-conditioning system is only operated when the outdoor air is higher than 25ºC. A variable speed fan will control the right amount of cold air to be provided from outside to maintain an environment of 18ºC to 27ºC at the data centre.

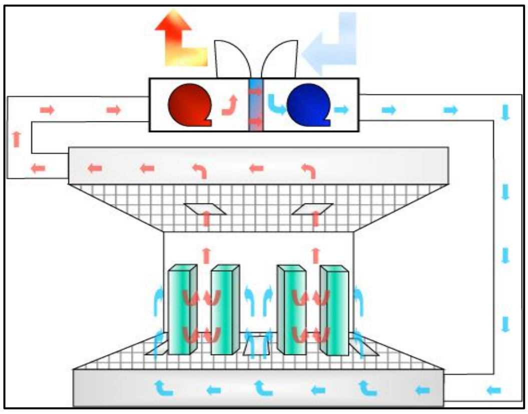


**Figure 50 Free Cooling with Outdoor Air for Data Center**

In addition, air filter of MERV 13 rating is required for utilization of outdoor air into the data center. This is to eliminate particulate matters in data center rooms that may increase the risk of equipment failure. Refer to ASHRAE 2011 Gaseous and Particulate Matter for Data Center for more details.

### 4.3.3. Lighting Improvement

Lighting at UN Compound is a mix of efficient and non-efficient technologies, see Figure 51. There were even a few incandescent light bulbs at use in this facility. Therefore, there is a good opportunity for significant energy reduction with a complete retrofit of the lighting system at this facility. Moreover, efficiency in lighting technology has improved immensely over the past several years, while reducing in cost. This is a very sensible time to conduct a major retrofit of lights at UN Compound.

Figure 52 shows the use of many inefficient downlights at UN Compound. Some of the downlights are installed with compact fluorescent lamp while others are installed with LED compact fluorescent replacement lamp. The downlight fitting is of low efficiency type with low Light-Output-Ratio (LOR).

Refer to 4.3.3.1, Efficient Lights & LOR, for details. It is recommended to replace these downlights with purpose-build LED downlight, that would reduce energy consumption by ~75%.

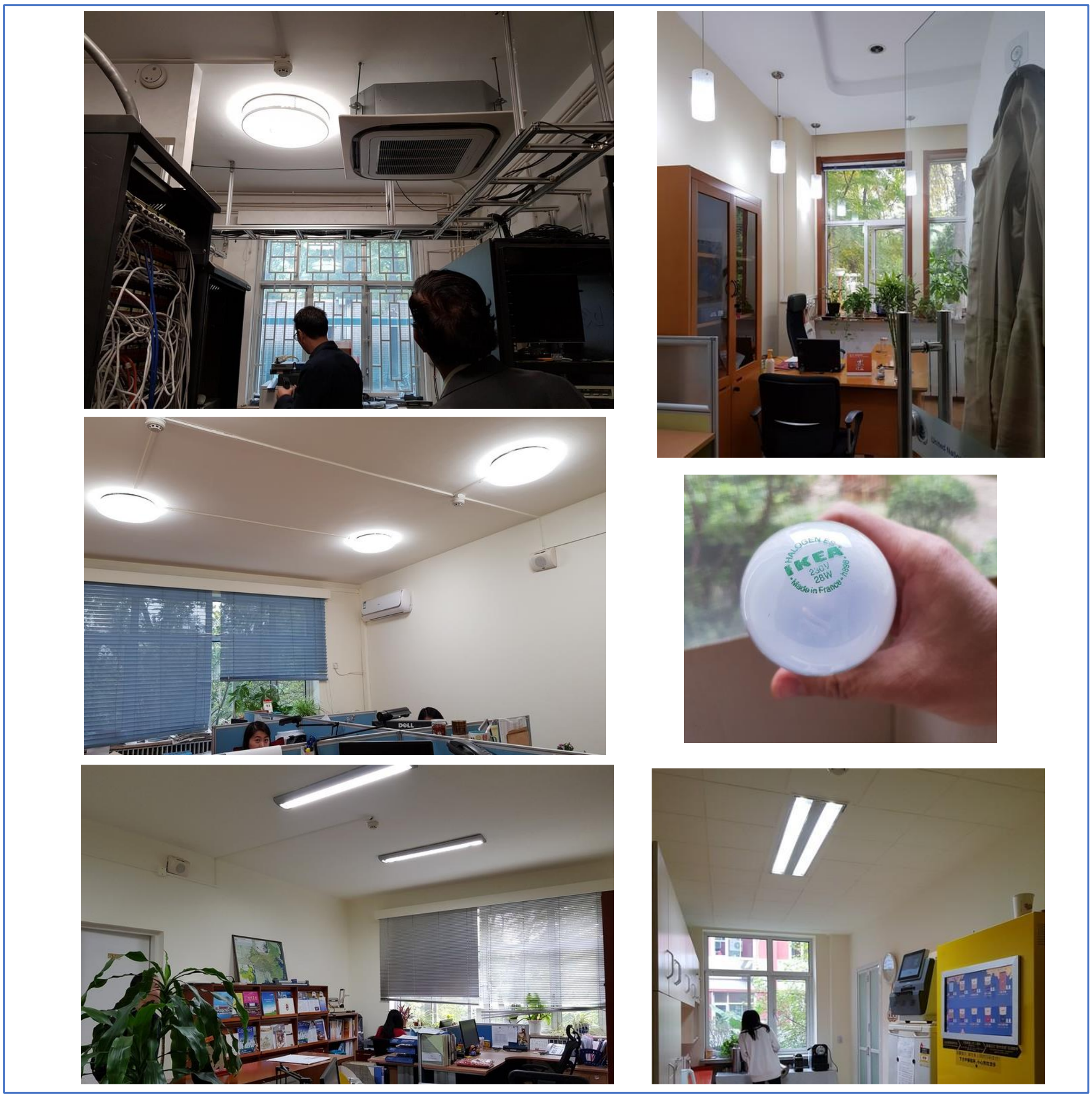



**Figure 51 Various Types of Lighting at UN Compound**

**Figure 52 Compact Fluorescent Downlights**

Light circuiting is not circuited to harness daylight. For example, it was impossible to switch off the lights next to the windows without the lights at the far end of the windows also being switched off at the office shown in Figure 53. It does appear that some of these light fitting has been retrofitted with LED lamps recently. The light fittings shown in Figure 53 was purpose-built for fluorescent tube lights that produces lights 360$^{o}$. New LED lights are directional and do not require these types of light fittings to reflect light downwards. Refer to Section 4.3.3.2, LED Tube versus LED Fitting, for details.

**Figure 53 Fluorescent/LED Light Fittings for Offices**

**Figure 54 Panel Lights with Fluorescent/LED Lamps Inside**

Panel lights with Fluorescent/LED lamps (tubes) inside was also found in some of the offices, Figure 54. These lamps lose much of the light generated within the fitting itself. A purpose-build LED panel lighting will be a significantly more energy efficient option. Refer to 4.3.3.1, Efficient Lights & LOR, for details.

**Figure 55 Task Light at UN Compound**

Use of task lighting, Figure 55, is highly encouraged together with daylight harvesting. Using a task light to light up a working area uses significantly lower energy than lighting up the entire space brightly.

**Figure 56 Vanity Mirror Lights at Toilets**

During the visit, it was found that many of the toilet lights are switched on although, one, the toilet is empty and two, the toilets were adequately daylit. Vanity mirror lights were also found to be switched on without anyone using the toilet. It is recommended to consider placing a daylight sensor for the toilet lighting, and a delay timer for the vanity mirror light. The daylight sensor will switch off the toilet lights whenever daylight is adequate (~100 lux) and the delay timer switch will turn off the vanity mirror lights 5 minutes after the button was pressed.

**Figure 57 Corridor's Lights at UN Compound**

As the UN Compound was initially a residential home, the entire facility is not deep. This allowed daylight to penetrate near 100% of the spaces. Figure 58 showed that switching off corridors' lights makes no difference in some of the places. Recircuiting may be required to allow some lights to remain switched on if the staffs are uncomfortable with an uneven light distribution, caused by switching off all the lights at the corridors.

**Figure 58 Adequate Daylight Found in Many Offices**

Ground floor offices received the least amount of daylight due to the surrounding trees and buildings. However, daylight measurement of many ground floor offices with the lux meter showed adequate daylight (300~500 lux) for office use, Figure 58. This indicates that it is possible to use daylight instead of electrical light for most office spaces at UN Compound. However due to the narrow and deep setting of office space, it may be more comfortable to install a low powered downlight near the entrance (far end from the window) to balance the daylight harvested from the windows for better light quality and comfort. I.e. it is recommended to install at least two (2) downlights for the offices shown in Figure 58, circuited parallel to the window to allow users to control their lighting preference while harnessing daylight use.

#### 4.3.3.1. Efficient Lights & LOR

Efficiency of lighting is not just about the lamp technology, i.e. LED versus fluorescent, but it is also about the lighting fixture (housing for the lamp). A term called Light Output Ratio (LOR) is used to describe the efficiency of the lighting fixture. An example of LOR is shown in Figure 59 below between a 100 W Lamp and a 8 W LED, with both providing the same lumen output to the space below.

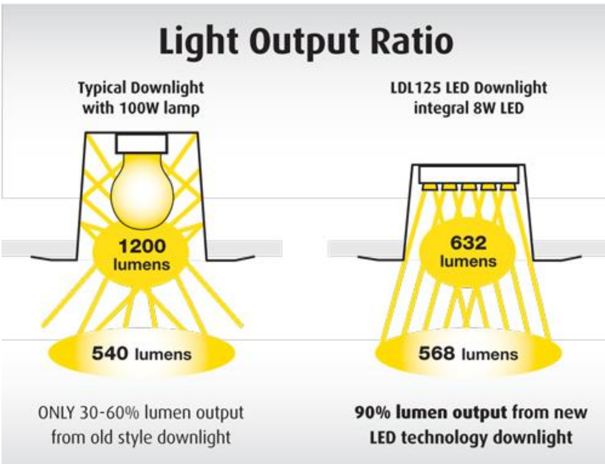



**Figure 59 Light output ratio (LOR) of conventional fitting and LED fitting**

LED lights, being directional, have the advantage of providing significantly higher LOR than traditional light fittings. Due to this, it is always more efficient to replace the entire fitting with a purposely built LED fitting than to replace traditional lamps with LED that is designed to look like traditional lamp.

#### 4.3.3.2. LED Tube versus LED Fitting

LED tube lights that are fitted into existing T5 or T8 florescent light fittings inherit the inefficiencies of the existing reflectors on the fitting itself. The LOR of typical florescent light fittings ranges from a low of 50% to a high of 95%.

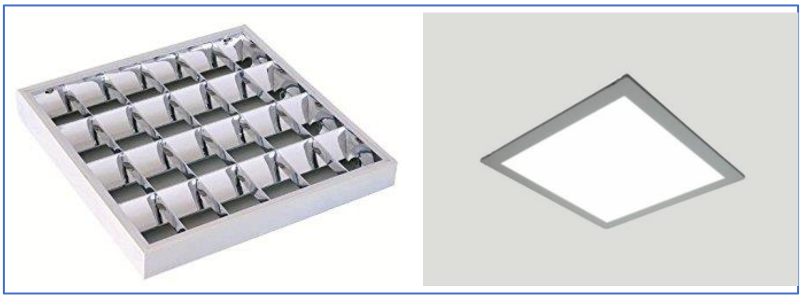


**Figure 60 (Left) Conventional light fittings. (Right) LED built-in light fitting (no lighting tube required)**

Meanwhile, latest versions of LED office lighting do not use reflectors at all, as the LED technology is directional and can be positioned to distribute lights in the direction desired, sometimes aided by special lenses, producing LOR of 100%. These LEDs are embedded into the light fitting itself and come as a single item. Such design increases the efficiency of the light delivery to the space, allowing lighting power densities as low as 3 W/m² while providing more than 300 lux level in offices.

Table 7 Less efficient LED options versus More efficient LED options

| Less Efficient LED Options | More Efficient LED Options |
|---|---|
|  |  |
|  |  |

#### 4.3.3.3. Key indicator of Lighting Efficiency

The most important indicator of lighting efficiency is Lighting Power Density (LPD) in W/m². It is basically the total lighting power (Watts) used in a room divided by the room area (m²).

Recommended Lighting power densities for renovation of lighting system or for new buildings is provided in Table 8 below:

Table 8 Recommended lighting power densities

| Spaces | Bad (W/m²) | Good (W/m²) | Very Good (W/m²) |
|---|---|---|---|
| Offices | 15 | 9 | <5 |
| Walkways/Pantries/Toilets | 8 | 6 | <3 |

#### 4.3.3.4. De-Lamping

De-lamping is the act of removing fluorescent tubes and bulbs from a light fitting to reduce energy consumption at overly bright spaces. Areas that were identified for highest potential for de-lamping at UN Compound are the walkways, staircase lobbies and entrance lobbies.

**Figure 61 Potential Area for De-Lamping Exercise**

#### 4.3.3.5. Lighting circuit (wiring)

Ideally, lights should be zoned (circuited) parallel to the window as shown in Figure 62 below. This allows the electrical lights to be switched on as needed to balance the light provided from the windows.

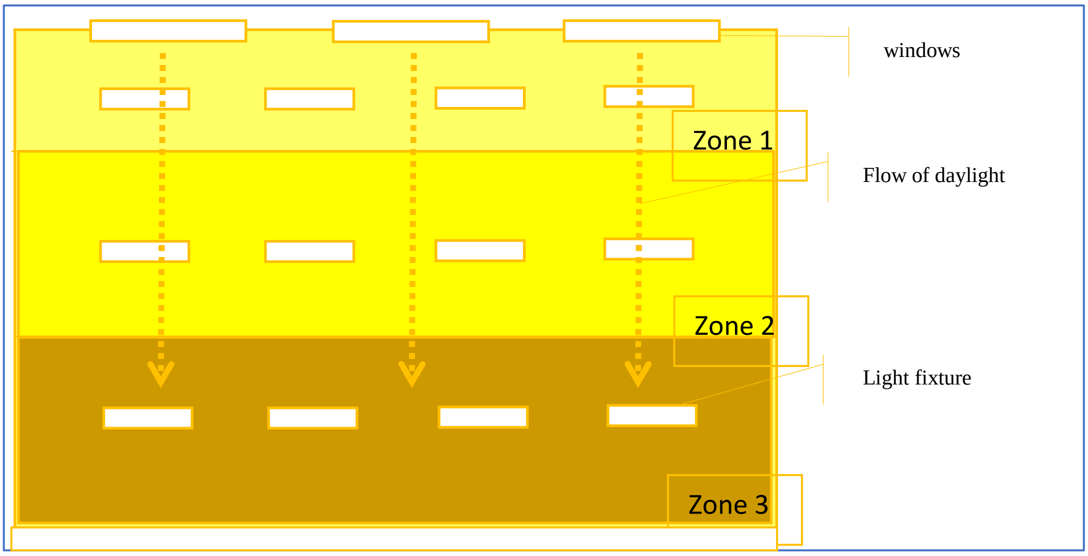



**Figure 62 Circuiting (Zoning) of Lighting Fixture According to Daylight**

#### 4.3.3.6. Occupancy & Daylight Sensor

Occupancy and daylight sensor may be used to further improve lighting energy consumption.

Dark corridors that are only occasionally used can be fitted with an occupancy sensor that switches on the lights when it is used, rather than maintaining the lights to be switched on all the time. If necessary, one or two lights can be excluded from the sensor to allow the space to have minimal light during office hours, instead of total darkness.

Daylight sensors are recommended for all common area that may be occasionally dark due to the changing weather condition, such as a heavy rain during daytime. Daylight sensors are recommended to be implemented with the option of auto off/manual on function.

### 4.3.4. Electric Car Charging Hours

Currently, the electrical car is charged immediately after office hours by the driver. As the electrical tariff is still high until 11 pm, it is recommended to install a timer on the charging system to turn on the charger at the period of lowest tariff. The driver may plug in the car to be charged before ending his work at 5/6 pm, but the timer will only turn on the charger at the right time for the electric car to be charged during the lowest tariff period.

### 4.3.5. Building Envelope Improvement

Finally, the building envelope may be further improved to reduce GHG emission. Improving the insulation of the existing uninsulated roof, walls and window frames will reduce the heat loss during winter and heat gain during summer. In addition, the latest double glazing with double low-emissivity (Low-E) coating on surface 2 and 3, limits the solar heat transmission into the building during summer and heat loss out of the window during winter, Figure 63. More importantly, these improvements will moderate the surface temperature of the internal space of the building, allowing the air-conditioning system to operate at higher efficiency (refer to Section 5 on Thermal Comfort and Air Temperature Set Point for details).

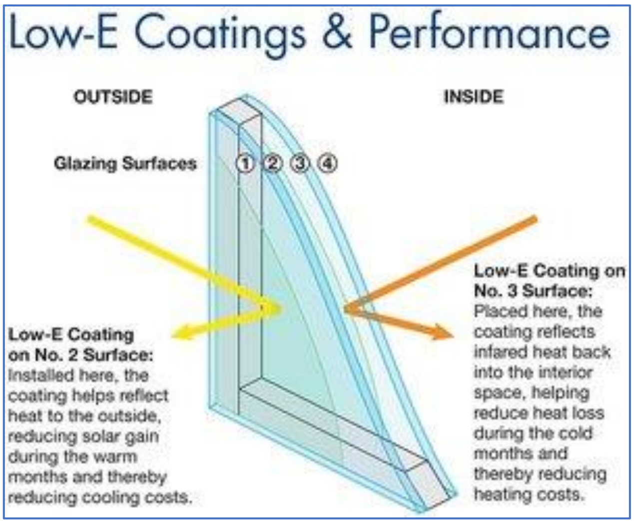



**Figure 63 Double Glazing Low-E Properties**

Unfortunately, building envelope improvement in existing buildings typically has a long payback of 10 years or more, if the entire glazing, wall or roof is to be replaced. Add-on solutions, such as adding insulation to the roof and walls, are less expensive and should be explored together with the landlord.

Improving air-tightness via weather strips is a very cost-efficient solution for buildings that are leaky. More interestingly, improving the building envelope air-tightness will allow heat recovery devices to be implemented, Figure 64. A heat recovery device will significantly reduce the energy consumption of the building when implemented right, by recovering cooling from exhausted air in the summer and recovering heat from exhausted air in the winter.

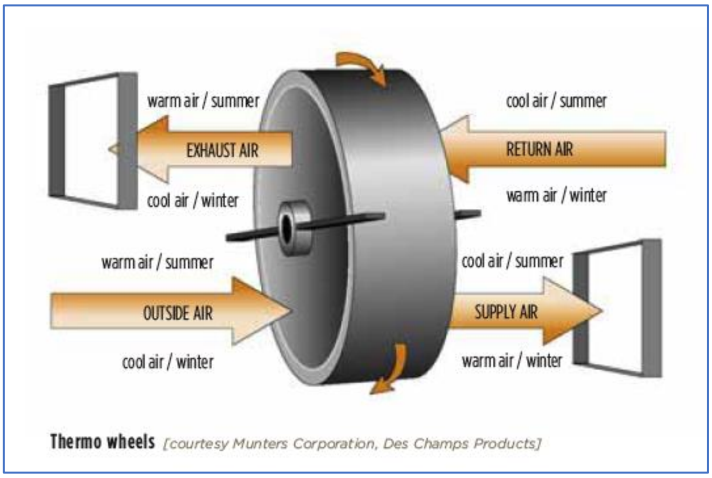



**Figure 64 Heat Recovery Concept**

## 5. Thermal Comfort and Air Temperature Set Point

Providing thermal comfort to building occupants is more important than energy efficiency in buildings. The monetary value of 1% improvement in human productivity far outweighs 50% reduction in energy consumption in buildings. For most buildings around the world, 1°C change in temperature set point will provide approximately 1%~2% change in building energy consumption. Therefore, thermal comfort and productivity should not be compromised at all, especially not in the name of energy efficiency.

Air temperature alone is not a good indicator of thermal comfort. Thermal comfort is affected by 6 parameters:

- Air temperature
- Mean radiant temperature (average surface temperatures)
- Humidity
- Air Speed
- Clothing (insulation)
- Metabolic rate (type of activity)

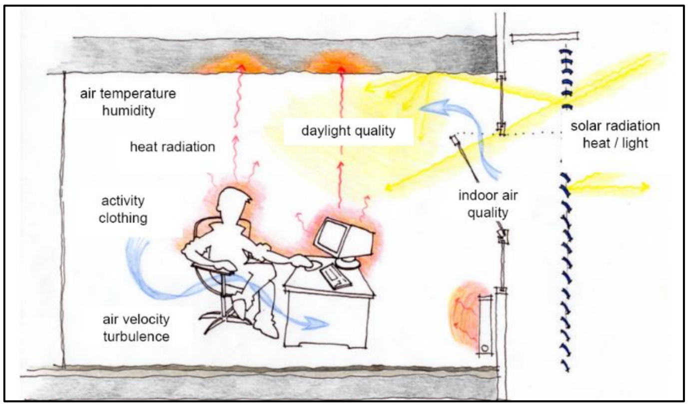



**Figure 65 Factors Affecting Thermal Comfort in an Office Space**

### 5.1. Air Temperature

The indication that air temperature of split units was set as low as 21°C and 30°C during the visit is an indication that thermal comfort is an issue that needs to be addressed. The energy consumption of air-conditioning system can be reduced, especially if it is an inverter type, by setting the temperature set-point closer to the outdoor condition.

### 5.2. Mean Radiant Temperature

The uninsulated walls and roofs in UN Compound will cause a low indoor surface temperature during winter and a high surface temperature during summer. During winter, the low surface temperature requires a higher air temperature set-point to obtain thermal comfort, while during summer, the high surface temperature requires a lower air temperature set-point to achieve thermal comfort. These conditions increase building energy consumption. Insulation on the wall and roof not only reduces the thermal transmission but it also improves comfort by allowing temperature set-point closer to the outdoor condition.

### 5.3. Humidity

Although relative humidity has a smaller impact on thermal comfort than the air-temperature and air speed, it was highlighted by the building occupants that it is uncomfortable when it is too dry during the winter season with the heater running. The simple solution to dry air is to place a bowl of water near to the heat source or a damp cloth over the radiator to increase relative humidity in the room; while the proper solution is to provide a humidifier in rooms that are especially dry.

### 5.4. Air Speed

ASHRAE recently published Figure 66 below: it suggests that it is possible to increase summer time thermal comfort with increased air speed, and shows the possibility of increasing temperature by 3$^{o}$C, from 24$^{o}$C to 27$^{o}$C, by increasing air speed from 0.1 m/s to 0.6 m/s, with the same thermal comfortable sensation.

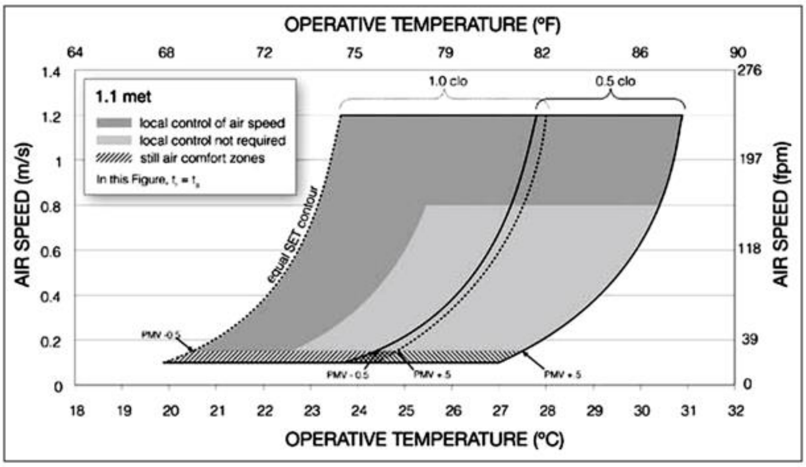



**Figure 66 Air speed and thermal comfort temperature**

### 5.5. Clothing Insulation

Clothing insulation also has a big effect on thermal comfort. Clothing insulation values are shown in the sketches below.

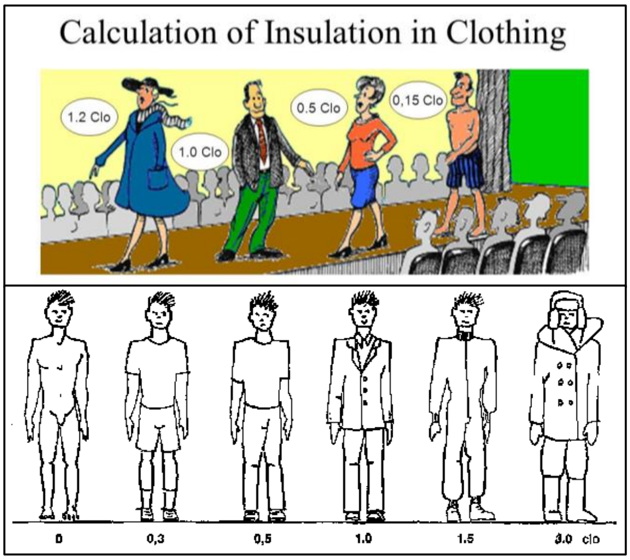



**Figure 67 Clothing insulation values of different dressing style**

For good energy efficiency in buildings, it is recommended to dress appropriately for the season. I.e. dressing down during summer and dressing up in winter.

## 6. Air Quality and Occupant's productivity

The latest research indicates that indoor air quality has a measurable impact on occupants' productivity. Studies have shown that a 1% improvement in productivity would exceed monetary value saved in a building that is 50% more energy efficient. The reduced sick leaves and higher outputs more than compensate the energy that could be saved. In short, energy efficiency and GHG emission reduction cannot, and should not, be achieved at the expense of productivity. These are 4 basic measures of air quality that is most relevant for an office building in Beijing:

1. Carbon Dioxide ($CO_2$) measured in ppm (parts per million)
2. PM 2.5 small particles (measured in Air Quality Index, AQI)
3. Volatile Organic Compound (VOC) (measured in mg/$m^3$ of air)
4. Thermal Comfort.

$CO_2$ is used as an indication of quantity of fresh air available inside a building. Inadequate fresh air is indicated by $CO_2$ values above 1,100 ppm. High $CO_2$ levels cause occupants to feel sleepy, tired and reduces productivity in an office space due to the lack of oxygen provided.

PM 2.5 are very fine particles that have harmful effect similar to smoking cigarettes. AQI below 150 is known to be a healthy level, while a value above 300 is known as hazardous.

VOC is a range of chemicals that causes minor discomfort of throat and eyes when found in small quantities. However, long-term exposure to high VOC has been linked to increased risk of cancer in building occupants.

Thermal comfort is more complex and is linked to local environment of air temperature, surfaces temperature, air speed, relative humidity, clothing and metabolic rates and was discussed in the previous section.

*Fresh Air*

It is mandatory in many countries to incorporate a minimum active fresh air supply to permanently occupied office spaces via a mechanical fresh air supply system. The fresh air is needed to provide adequate oxygen and dilute indoor air contamination to a healthy level. Except for UN Women office, active fresh air supply was not seen in any other UN facility in Beijing.

It is common for residential buildings, i.e. UNICEF & UN Compound, that fresh air is assumed to be infiltrated into the building. This is a reasonable assumption for a residential building because it has a lower occupancy density, larger ratio of external doors and windows compared to indoor spaces, and windows and doors not designed to be air-tight. However, in recent years, construction quality has been improving around the world, including China, where doors, windows and other construction joints are made more air-tight for both energy efficiency and to reduce infiltration of PM 2.5 from outdoor.

## 6.1. VOC

VOC is a range of gasses (more than 600 types) that are off-gassed from chemical-based products, construction finishes and furnishings. It is crudely measured using VOC meters as the one shown in Figure 70, that was used by the peer-review team at Beijing. The measured values from such meter is only useful as an indicator of air quality concern. Once identified as a problem, detailed analysis using gas chromatography technology is conducted to identify the exact type of gas causing the problem.

Unfortunately, the world has not converged on the acceptable limits of VOC in offices. There are a few known standard measurements of VOC in the building industry at this moment. However, the limit of VOC is still debated upon. In general, the values being discussed by the industry are summarized in Table 9.

**Table 9 VOC Values & Remarks**

| VOC values | Remarks |
|---|---|
| <0.2 mg/m$^3$ | No irritation or discomfort. |
| <0.3 mg/m$^3$ | European Community targeted guideline. |
| 1-5 mg/m$^3$ | Values being discussed for US standards. |
| 2 mg/m$^3$ | Minimum value measured for a ‘sick building’ syndrome.[11] |
| 1 mg/m$^3$ | Taiwan Suggested Legal Limit in 2014 |

Based on Table 9, it can be concluded that any measured VOC value above 5 mg/m$^3$ is a cause for concern for further detailed study.

If VOC is measured to be of concern, i.e. > 5 mg/m$^3$, while the $CO_2$ level is below 1100 ppm, it is recommended to conduct a detailed measurement using more accurate and expensive equipment, such as gas chromatography, to identify the type of gas causing the problem, to narrow down the

[11] Kacergis J.B. et al. 1996. Air quality in an animal facility: particulates, ammonia, and volatile organic compounds. American Industrial Hygiene Association Journal 57(7):634-640

source and eliminate it. A temporary solution could be to increase fresh air rates to dilute the VOC to acceptable value.

### 6.1.1. Sources of VOC

The main sources of indoor air contaminant that produce VOC are: building finishes, furnishing and all plastic based product. Building construction finishes such as paint, glue, varnish, carpet, sealant and compressed wood from kitchen cabinets are a major source of VOC production indoor.

Another source of VOCs indoor, is the use of chemical-based agents, such as cleansers, solvents, pesticides, disinfectants, glues and paints.

VOCs are also produced by all kinds of plastic-based products, such as plastic bottles (for storage of detergents, shampoo, toothpaste, etc.), TV and computer plastic-based housing, plastic-based mouse and keyboards, printers, remote controllers, plastic cups and plates, and more. Almost all household items have plastic contents in them and these plasticizers off-gas VOCs constantly.

While new products usually have a higher rate of VOCs off-gassing (as in new car/building smell); disintegrating and rotting items, such as very old carpets, clothing, etc. will also have a higher rate of VOC off-gassing than items in good order. It may be necessary to discard old disintegrating items to remove the source of VOC in a building.

VOC are linked to smells indoor. In fact, the best VOC detectors are not scientific equipment, but our noses. It is common knowledge among scientists and engineers working on this field that women are more sensitive to VOC smell than men. Pregnant women are known to be even more sensitive to VOC in the air. Somehow, expecting mothers are preprogramed to protect and safe-guard their baby (still in the womb) from exposure to air pollution.

Formaldehyde is a distinctive VOC gas that is emitted from wood-based products, varnish, compressed particleboard, plywood, fiberboard, wood-based glue and adhesive. It is usually identified separately due to its particularly harmful effect to health because of its link to cancer.

### 6.1.2. Known Solutions for High VOC

It is not possible to eliminate VOC totally from any modern-day offices. The common and easiest solution is to dilute the VOC contaminant with fresh air. However, excessive fresh air use increases energy consumption in offices.

The second easiest alternative is to stop purchasing products with high VOC content. Today, many paint manufacturers and carpet installer offer low-VOC alternatives. Manufacturers are also beginning to offer glue that are low-VOC. There are also furniture manufacturers that offers low-VOC solutions. Implementing a purchasing guide to only purchase low-VOC content products will reduce VOC emission indoor. Sometimes insisting on a certificate for low-VOC may increase the cost of a product significantly. However, our nose is also a good detector of VOC, therefore, it is also possible to purchase products based on our sense of smell.

Finally, technologies such as ultra-violet lights and activated carbon filters are known to be able to reduce VOC in offices. However, the success of these technologies is limited, as it may work very well in some cases and not so well in other cases.

## 6.2. PM 2.5 in Beijing

PM2.5 refers to fine particulate matters that are smaller than 2.5 microns. Our hair is approximately 100 microns in thickness. PM2.5 is therefore referring to particulate matters that are at least 40 times smaller than the width of our hair. These particulate matters are very light, remain in the air for many days and travel very far in hundreds of kilometres just being blown by the wind. PM2.5 is typically caused by open burning of any types of solid materials, such as a forest fire or open burning of rubbish, tyres, coal, cigarettes etc.

PM 2.5 air pollution is commonly displayed as AQI, air quality index, to the public. AQI of outdoor air displays the worst air quality from a range of measured pollutants. Typical pollutants measured are PM2.5, PM10, Ozone, Carbon Monoxide, Sulfuric Dioxide and Nitrogen Dioxide. Each indicator provides one calculation of AQI. The worst AQI is then displayed to the public. Therefore, depending on the day which pollution is the highest, the AQI announced may be caused by Ozone or PM2.5, or any one of the measured indicators.

The AQI equation allows different types of pollutants with different units of measurements (ppd, ug/m3, etc.) to be calculated into values ranging from 0 to 500. It is then categories as such:

**Table 10 AQI Indicators**

| AQI values | Descriptions |
|---|---|
| 0-50 | Good |
| 51-100 | Moderate |
| 101-150 | Unhealthy for Sensitive Groups |
| 151-200 | Unhealthy |
| 201-300 | Very Unhealthy |
| 301-400 | Hazardous |
| 401-500 | Very Hazardous |

In Beijing, PM 2.5 pollution is the most frequently quoted AQI. Besides coal-based power plants, burning of charcoal and wood for cooking and heating during winter, is a major cause of PM 2.5 contamination of air in Beijing.

Almost all office buildings in Beijing are equipped with PM 2.5 air filtration devices.

### 6.2.1. PM2.5 Filtration Technologies

There are two (2) known technologies that will filter PM2.5: mechanical air filter and electro-static air filter.

Mechanical filtration is basically a very fine filter that will take out particulate matters as small as 0.3 microns. Some manufacturers allow mechanical air filter to be washed and reused, while other manufacturers require the air filters to be replaced when it is full of dust. Mechanical air filter typically has higher pressure drop than electro-static air filter. This means that the fan energy consumption will be higher when mechanical air filter is used.

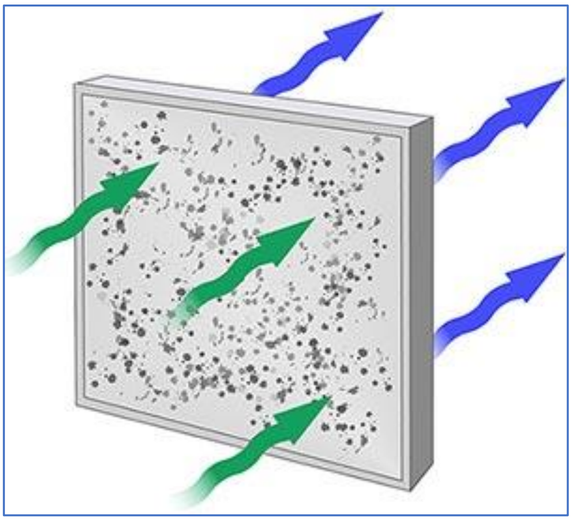


Figure 68 Mechanical Air Filters

Mechanical air filters that can filter PM 2.5 reasonably well are rated by Americans as MERV 13 or higher, and by the European air filter classification of Class F7 or higher. Air filters, designated as HEPA, are specifically named for the use of critical spaces such as hospitals and clean rooms. HEPA air filters have a filtration efficiency of PM 2.5 of 99.9%. While MERV 13 (or Class F7) air filters have a filtration efficiency of PM 2.5 of a minimum of 70%. This means that a HEPA air filter will be able to remove 99.9% of PM 2.5 particles with a single pass, while a MERV 13 air filter will remove at least 70% of small particles with a single pass. Pressure drop of a MERV 13 air filter is similar to conventional filters used by office air-conditioning systems. Pressure drop of a HEPA air filter is approximately 3x higher than the pressure drops of a MERV 13 air filter, meaning that HEPA air filters use 3x higher fan energy than MERV 13 air filter. In addition, MERV 13 air filters can replace conventional air-conditioning air filters without requiring the fan to be upsized.

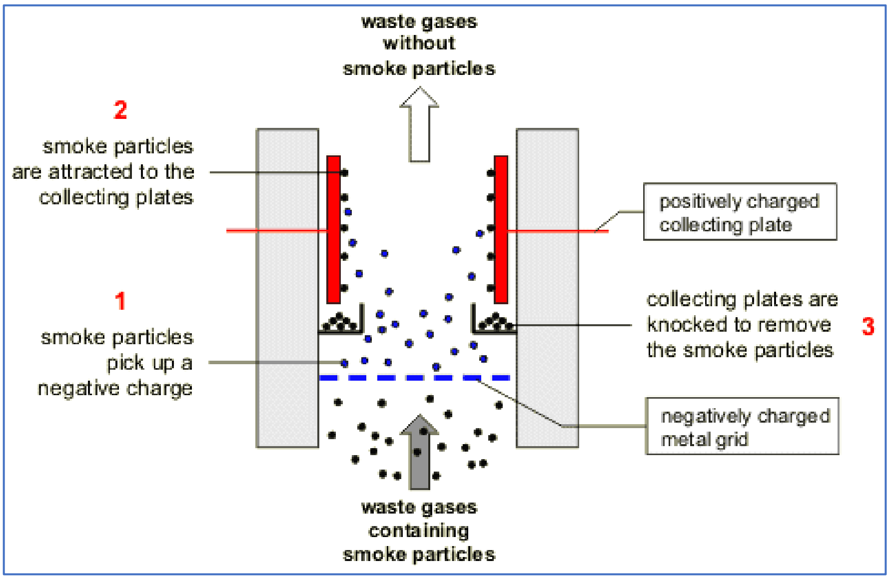



Figure 69 Electrostatic Air Filters

Electro-static air filters are based on charging particulate matters with negative charges: these negatively charged particulate are then attracted to the positively charged plates on the filter. These plates need to be cleaned regularly to maintain its performance. This technology has very low pressure drop, therefore it is a very energy efficient solution. Removal efficiency depends significantly on the velocity of the air flow and the plate size. Some electrostatic air-filters produce ozone as a by-project. It is important to select electrostatic air-filters that meet the allowable ozone production rate for these types of devices.

Be aware that the performance of any air filtration device is only as good as its maintenance. In some cases, it may add on to the particulate counts due to the lack of maintenance.

## 6.3. Air Quality in UN Compound

During the peer-review visit, $CO_2$ levels were measured to be lower than the limit of 1,100 ppm for offices. Densely populated rooms and meeting rooms (when occupied) were found to have higher $CO_2$ levels. A meeting room, when crowded, was measured to have $CO_2$ level as high as 2500 ppm. This indicates a lack of fresh air provided for the meeting room when it is packed.

Meanwhile VOC were measured between a level of 2 to 3 mg/m³.


**Figure 70 Measured $CO_2$, VOC and PM 2.5 AQI Level in UNICEF**

During the peer-review visit at UN Compound, the outdoor PM 2.5 was hovering around 270 AQI, while a measured indoor AQI was 170 without any PM 2.5 being operated.

### 6.3.1. Air Quality Improvement Possibilities

During days when outdoor PM 2.5 level is high, bringing in outdoor air to reduce $CO_2$ and VOC level will increase PM 2.5 indoor. These are the possibilities of improving air quality in UN Compound while optimizing energy efficiency:

#### 6.3.1.1. Simple Solution

All meeting rooms should be installed with a silent air extraction fan, to extract air to the outside. This will create a negative pressure in the meeting room, increasing infiltration of fresh air into the room during period of occupancy. The fan can be manually operated by the occupants but ideally, the fan should be connected to a $CO_2$ sensor to be operated only when measured $CO_2$ level is high and shut off when measured $CO_2$ level is low.

During days of high PM 2.5, the existing air filters for PM 2.5 shall be operated to filter it.

#### 6.3.1.2. Advanced Solution

Provide a system for fresh air supply and exhaust air system with heat recovery. Fresh air supply shall be filtered with MERV 13 air filters that limit the intake of PM 2.5 into offices. In addition, fresh air supply into each room is controlled via a motorized damper based on measured $CO_2$ and/or VOC level. This solution will optimize both energy use and air quality for the building.

# 7. Technical Awareness and Motivation for Maintenance

Occupants' behavior plays a big role in ensuring the success of energy efficiency implementation in any existing building. When occupants choose to bypass technologies that promote efficiency and sustainability, the implementation will fail. Therefore, it is important to start a continuous program to improve technical awareness and to motivate the staffs in UN Compound.

## 7.1. Technical Awareness

Technical training and information sharing on energy efficiency and sustainability awareness should be regularly conducted and repeated after a period of time. Topics provided should be of interest to the end-user, where they can apply at their own home. For example:

- China Energy Label – What it is and what does it means for our home?
- Selection of Energy Efficient Lighting
- Selection of Water Efficient Fittings
- Waste Recycling Options in Beijing
- What is Phantom Load?
- Air Quality of PM 2.5, VOC and $CO_2$
- Etc.

Such information will be valued by employees because it will also help to reduce energy cost and improve light and air quality at home, and subconsciously lead them to practice these habits at work as well.

It is also recommended to purchase a range of portable measuring devices that can be used during these training sessions for them to be able to 'see and feel' the information being discussed. This equipment may be lent to the staff so that they can measure the energy performance of their homes too. This will help to bring greater awareness of energy efficiency, air and light quality in their homes as well as at work. The recommended devices to be made available at UN Compound (many of which can be purchased from *AliExpress*) are shown in Table 11:

**Table 11 Recommended Portable Measuring Devices**

| No | Items | Descriptions |
|---|---|---|

| | | |
|---|---|---|
| 1 | Lux meter | Measure lighting level.<br>Corridors: ~ 100 lux<br>Offices: 300 to 400 lux<br> |
| 2 | Energy meter | Measure energy consumption and phantom load.<br>Desktop Computer: 80 to 100 Watts<br>Notebooks: 10 to 30 Watts<br>Refrigerators: 100 to 500 Watts<br>Water Dispenser: 30 to 100 Watts<br> |
| 3 | Energy Clamp | Measure energy consumption and phantom load of large items such as Electricity Distribution Board and larger motors and air-conditioners.<br> |
| 4 | PM 2.5 meter | Measure PM 2.5 level in AQI<br>> 200 AQI: Very Unhealthy<br>> 300 AQI: Hazardous<br> |
| 5 | VOC meter | Measure VOC in mg/m$^3$<br>> 2 mg/m$^3$: Potentially Unhealthy<br>> 5 mg/m$^3$: Unhealthy<br> |
| 6 | $CO_2$ meter | Measure $CO_2$ in ppm<br>> 1200 ppm: Unhealthy<br><br> |
| 7 | Infrared Temperature Sensor | Measure surface temperature.<br> or  |
| 8 | Temperature and Humidity meter | Measure and display temperature and humidity.<br> |

| | | | |
|---|---|---|---|
| 9 | Temperature and Humidity datalogger | Measure and data log air temperature and humidity over several days. |   |
| 10 | Anemometer | Measure air speed<br>> 1.5 m/s (draft in winter)<br>0.1 - 0.6 m/s (good for summer)<br>> 0.6 m/s (potential discomfort in summer) |  |

Finally, a real-time energy monitoring program, available on-line, will help everyone understand the energy performance of UN Compound facility daily, monthly and yearly. This allows the building occupants to participate in the optimization of the building and become more conscious of their behavior towards the performance of the building.

### 7.2. Maintaining Motivation

Employees' engagement and motivational program must be continuously conducted to drive long term behavioral change. Mental barriers such as "someone else will save the planet", "my contribution is just too small to count", etc. need to be openly discussed.

Organizations such as "The Cloud Institute" for Sustainability Education offer good educational tools on YouTube channels addressing these issues: https://www.youtube.com/user/cloudinstitute

In addition, many energy efficiency implementations also yield better environmental quality that improves building occupants' health. For example, access to daylight improves sleep at night and increases productivity during daytime; and access to adequate outdoor clean and fresh air improves oxygen level, improving daytime alertness. These health benefits should be communicated throughout the organization.

## 8. Future Direction

UN Compound has an opportunity to showcase large improvements on energy efficiency on the building by targeting a minimum reduction of 50% from current consumption by implementing a series of low-cost, high-return and easy to implement solutions on the facility.

### 8.1. Low-Cost, High Return & Easy to Implement Solutions

#### 8.1.1. Retrofit of Lighting System

Recent advancement and cost reduction of advanced lighting systems makes this tool one of the low-hanging fruit to increase efficiency easily at UN Compound. Lighting typically contributes up to 25% to 30% of a building energy consumption. Taking UNICEF in Beijing as an example, approximately 80% of the lighting energy can be reduced via daylight harvesting and switching off lights at common spaces when it is not required. When implemented right with low lighting power density, when daylight is harvested and motion sensors and delay sensors are in place, a saving of 20% to 25% of annual electricity bill will easily be provided.

### 8.1.2. Retrofit of Air-Conditioning System

Recent advancement of split-unit air-conditioning systems made this a simple solution to reduce energy consumption due to cooling and heating needs. Coupled with a reversible ceiling fan, the high electrical consumption during winter time has a potential to be reduced significantly, while improving comfort.

### 8.1.3. Increase Awareness and Sensitization of Sustainability

UNICEF in Beijing has demonstrated the effectiveness of this strategy to reduce energy consumption year on year at their facility.

### 8.1.4. Implement a Green Purchasing Guideline

A green purchasing guideline to purchase energy efficient office equipment and appliances will contribute significantly to GHG emissions reduction. In addition, this guideline should also address VOC risk from purchased furniture, carpets and other indoor finishes.

### 8.1.5. Implement an Energy Monitoring System

An energy monitoring program will help the facility to visualize the savings achieved daily, weekly, monthly and yearly. It will also help to identify better operational habits at the facility to reduce operating costs of electricity at the facility.

## 8.2. Non-Easy Solutions

These solutions require major retrofits and renovation to be conducted:

### 8.2.1. Implementation of the facility's own heating system.

This requires a major retrofit of the entire cooling and heating system at the facility, which will cause major renovation work. It also involves negotiating with the landlord to allow the facility to be disconnected from the costly district heating system, which may or may not be possible politically.

### 8.2.2. Implementation of a mechanical fresh air supply system

A properly implemented fresh air supply system will improve air quality while reducing energy consumption. This implementation is most logical to be installed together with the facility's own heating system, as major renovation work is required to attach the fresh air supply to the air-conditioning system.

## 8.3. Summary

UN Compound has an opportunity to become a showcase study of high GHG emissions reduction for an existing facility, just by embarking on low-cost and easy solutions.