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Research on Energy Consumption Control of Campus Public Buildings based on Passive Design

FENG YAN[1] AND SAIHONG ZHU[2]
[1]*Hebei University of Technology, Tianjing, 300401, China*
[2]*Xingtai University, Hebei, Xingtai, 054001, China*
Email: *kycyf@126.com*

Abstract: In order to reduce the energy consumption and improve the performance of campus public buildings, the passive design method is used in this paper. The passive design which is very environmentally friendly can adjust the house to the appropriate temperature with very small energy consumption. This is an important factor to the design of campus public buildings, especially for the office buildings. In this paper, the passive design is used to reduce the energy consumption and the experiment results of this paper have a reference value for the application of passive design method in the design process of campus public buildings which can also promote the overall performance substantially.

Keywords: *Evaluation standard; energy consumption control; campus public buildings; passive design*

1. Introduction

Currently, to working with nature, creating friendly environment and healthy lifestyle have been paid attentions by human increasingly. Study on design method for responsive climate building has a meaningful inspiration and will be helpful for architectural sustainable development. According to certain requirements and comfortable climate condition, this thesis proceeds from the design theory of biological climate, and introduces the detailed bioclimatic chart principle and method of plotting. Through discussing the relationship between sole object design and the application of passive design strategy, we summarize the bio-climatic strategies about the aspect of sole object design to achieve the expected comfortable environment.

The climate and technology has been the key elements affecting architecture forms and development. With the development of society, the building area grows up rapidly. How to create a comfortable indoor environment with less building energy consuming has become an important issue. After reform and opening up, campus areas develop quickly and the energy demand rises up. If campus dwellings inherit the construction methods from traditional dwellings or simply copy the methods from urban dwellings, the consequence may lead to bad environmental quality, increase of energy consuming and pollutant emission. Therefore, the only way is to study on passive design strategies depend on local climate. The passive design approaches for transformation of campus buildings are carried out by studying the bioclimatic experiences used in traditional dwellings, the problems existing in modern dwellings and the local thermal comfort zone. Absorbing the bioclimatic experiences used in the old, modern climate adapted approaches and other outer factors organically are integrated into design methods.

It is now a widely known fact that the current pace of global economic development is incompatible in the long term with energy availability trends. In this new framework of competition for limited resources, saving energy becomes day after day a more strategic issue. It has also become general knowledge that energy consumption under the current technologies has a tremendous environmental and social cost. In this sense, saving energy also means trying to limit negative impacts on the environment and on future generations. These issues are nowhere are acute as in Asia, a small portion of the world's area that houses more than half of the human population. And there they are nowhere as acute as in China, because of the frenetic cycle of economic development that is on-going there: in most cases, priority is not on economic development, but on economic development as much and as fast as possible. The resulting dynamism, a chance for the country to build a future of wealth and power, also generates a series of negative collateral damages: large-scale environmental deterioration, social imbalances, neglect of valuable heritage from the past, etc.

From the point of view of society structure, there is an on-going transition from a blue-collar society towards a situation more balanced between blue-collars and white-collars. The consequence in the field of architecture is the construction of important numbers of new office buildings. In this context, the question of how to design better office buildings-both more energy efficient and providing a better environment for occupants becomes extremely important. The goal of this study is to bring a modest contribution to this question.

2. Overview

From 2001 to 2011, the total built area in China has risen from 32 billion square meters to 46 billion, i.e. an average increase of 1.3 billion square meters per year: that's slightly more than the total area of New York city (1.2 billion square meters) urbanized each year Residential buildings (both in cities and rural areas) take up over 80% of this each year Residential buildings (both in cities and rural areas) take up over 80% of this increase. Over the same period, building energy intensity has increased from 11 kgce /m2 to 14.4kgce/m2. However, with an average energy intensity of 21.4kgce/m2 (non-including district heating in the north of China), non-residential buildings have the highest energy intensity, which justifies a focus on them. There is a total area of 8 billion square meters of non-residential buildings, a stock that has increased by about 20% from 2001 to 2011, which means on average an increase of 121km2 (an area bigger than the centre of Paris) each year.

Over this period, the energy intensity of non-residential buildings has also increased by 29%, from 17.9kgce/m2 to 21.4kgce/m2 (the fastest energy intensity growth rate of all building types). Non-residential buildings therefore play a big role in the energy intensity increase of the whole building sector over this period. Overall, the 2011 total energy consumption of this sector was 171 million (24.8% of total energy consumption), of which 81% was electricity (447 billion kWh) and 19% of fossil fuels (coal, gas; 33 million). Fridley, Zheng and Zhou [1] published in March 2008 a report on the total energy consumption and emissions of commercial0 and office buildings in China, with projections to 2020 [2]. According to their data, in 2010 there was a total area of 4.5 billion square meters of offices (about 25% of the total 14.6 billion square meters of commercial buildings). Over the period 2005-2020, this stock is expected to increase at an average rate of 4.4% of the 2001 value per year-that is the creation of 160 million m2 a year.

The report also provides some insight on the evolution of breakdown energy consumption: over the period 2005-2020, the electricity intensity for lighting and outlets is expected to rise by an average 2.1kWh/m2 per year (13% of the 2005 value), from 16kWh/m2.a to 50 kWh/m2.a. The electricity intensity per square meter AC area for space cooling is also expected to rise slightly by 0.47kWh/m2 per year (as a consequence of the rise of expectation levels), while the AC area might rise from 29% of total floor space in 2005 to 55% by 2020. As a result, the total primary energy consumption of office buildings would rise from 45Mtce in 2005 to 119Mtce in 2020, an increase of 164% of the 2005 value mostly due to the explosion of the energy consumption for space cooling (from 5.4Mtce to 25Mtce, +363%) and for lighting (from 11Mtce to 63Mtce, +472%).

These prospects show that there is an urgent need to find ways to limit the increase of office energy consumption. The specificity of office buildings is the fact that loads are concentrated during the day (working hours), and that occupant density and heat gains due to equipment and lighting are often extremely high. Therefore, overheating is a frequent problem in such buildings, which explains the frequent recourse to air-conditioning even under moderate climates. The worst situation is of course encountered in warm areas; where offices built accordingly to standard practice often need to be air conditioned during more than half the year, with resulting high energy consumption levels. This phenomenon could become even more important as global warming generates an increase in temperatures in many places of the world: for example, estimates by Wan et al. for Hong Kong conclude an increase in cooling loads ranging from 4.3% to 14.1% [3-4]. Xiao, Wei and Jiang have shown on the basis of a sample of government-collected electricity consumption data that office buildings in China have a specific two-peaked distribution of electricity use intensity (EUI) [5]: in most Chinese cities the main peak of the EUI distribution is centred around a 50-60kWhe/m2.a, but another peak can be observed at EUI levels higher than 100kWhe/m2.a. An example taken from their results can be found in Fig. 1 .Using original data for the city of Shenzhen, we drew Fig. 2 to try and better illustrate the difference between the two peaks: it is clear that buildings with a high EUI are large size buildings (with an area over 20.000m2).

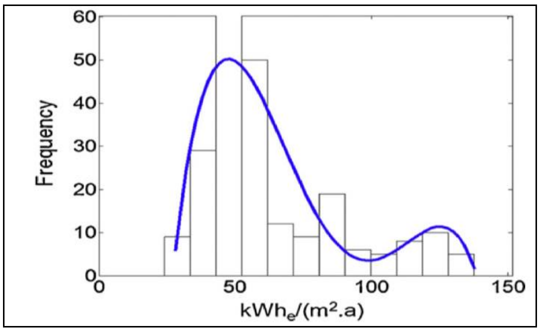


Figure 1: *Distribution and polynomial fitting plot of electricity use intensity*

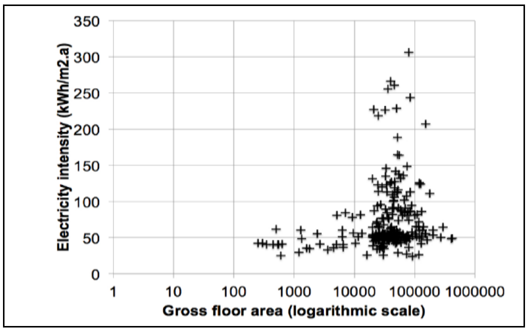


Figure 2: *The relationship between electricity intensity use and gross floor area for all buildings in the sample*

In this paper, we research on the passive design strategies of green office building in hot-summer and cold-winter zone. Finally use the passive design strategies into practice. In hot-summer and cold-winter zone, the summer is hot and wet, and the winter is cold and wet. The building should coordinate insulation and shading and cooling in the summer with thermal insulation and heating in the winter. The purpose of passive design is to extend the period of transition season, shorten the period of cooling in summer and heating in winter, while reducing active power consumption in summer and winter, and to achieve environmental benefits. Analysis climatic characteristics in hot-summer and cold-winter zone, then summarize the applicable passive design strategies, mainly including: natural ventilation, day lighting, shading, insulation, eco-green, passive rainwater utilization. By studying a large number of domestic and foreign literature and cases, explore how to use the passive design strategies. Natural ventilation should be strengthened by making full use of pressure ventilation and controlling building depth of less than14m. If the building is organized with a courtyard, the ventilation corridor should be set to improve the ventilation of the inner courtyard. Day lighting should be designed well. Flat skylight and the atrium with top lighting should not be used without shading. The shading should be designed to block the direct sunlight in summer and not to block the direct sunlight in winter. The construction should consider of the insulation, including the double-skin system and light-colour surface. Eco-green and passive rainwater utilization would achieve environmental benefits.

3. The Case of Subtropical/Tropical Climates and Design Principals

Treating this question of the limits of the applicability of natural ventilation is actually very important, not simply because it could encourage wider use of NV in offices, at least in temperate enough climates: Fig. 3 shows a superposition of the geographical repartition of subtropical and tropical climates (according to the Koppen classification), and of the map showing the localization of the different field studies used to build the ASHRAE 55 standard for naturally ventilated buildings. Two observations can be made:

1) Areas of the world which will most probably host the majority of new building construction over the next few dozens of years, such as Brazil, India or China, have important parts of their territory in subtropical or tropical climates,
2) On the contrary, the ASHRAE database only features a few buildings located in such climatic conditions, and not in the buildings primarily concerned by new building construction. As for the EN15251 standard, it was developed through a filed study of 26 European office buildings in EU countries, naturally ventilated in free-running mode outside the heating seasonally. Here too, the focus was not on identifying the extreme limits of natural ventilation applicability.

This is not to say that the stipulation of these standards is not true, but there is indeed an urgent need for more focus on the particular question of natural ventilation in subtropical and tropical areas. It could indicate whether and under what conditions natural ventilation can be applied in such climates, but also provide reasons why it can be applied with confidence in more moderate climates. Subtropical and tropical climates are characterized by high to very high levels of temperature and humidity. Defined in the Koppen classification as climates with a mean temperature above 180C during at least a few months of the year, the main difference between the two categories is the annual variation in temperature: while tropical climates are warm throughout the year, subtropical climates have a moderate cold season, usually drier, with a coldest month's mean temperature between 00C and 180C, while average temperature is above 220V during the hottest month. Subtropical and tropical areas are located between -400 and 400 latitude, so solar radiation levels are often high (at least in summer for subtropical climates). This combined with high humidity and temperature levels create problems for the design of offices, in which indoor and outdoor thermal loads are both intense and concentrated during the daily hours. Although solar protections are particularly important in such climates-the closer to the equator the more so offices are often dominated by inner loads, in which case limiting outer gains is not sufficient to reach comfortable indoor conditions and reduce energy consumption. On the contrary, using high levels of insulation in such conditions can sometimes turn out to increase the yearly cooling load [6-7]. An important issue for the design of office buildings in subtropical and tropical climates is the lack of cooling sources in the environment, which makes it difficult to lower heat loads using heat sinks: .the cold season is short or even inexistent, and temperatures do not drop very low, resulting in very low heating loads compared with summer cooling loads. Therefore, it might be difficult to achieve a yearly thermal balance using ground source heat pumps. Moreover, in areas like Asia with high population densities, there is not always enough ground area available for thermal systems (heat pumps, underground ducts...). Evaporative cooling can be envisioned in these areas, but its potential for cooling remains limited to a few degrees, and it might increase humidity. Therefore, this approach is probably limited to a role as a complement to other space cooling strategies. High solar gains make it possible to generate important quantities of electricity.

However, installation costs are still too high for a general use. Another concern is that in tower-like buildings the area available for solar panels (mostly on horizontal surfaces in places with a vertical sun angle) does not make it possible to produce enough electricity to tend to the needs of all floors of the building, night-time ventilation pre-cooling is not easily applicable: this technique has recently received a lot of attention in Europe as a way to solve the summer over-heating issue frequent in many new offices (which are extremely well insulated to reduce thermal losses during the heating season): use cool air to unload the building structure during night-time, thus preparing a heat sink to limit the rise of indoor temperature during daytime [8-9]. However, the frequent indicator used in studies to determine if ventilation can be efficient in cooling the building is a difference of 3K between air and building temperatures. This means that night-time air temperature should be at most around 23-240C (in order to pre-cool the building for a 26-270C temperature level). In practice night-time minimal averages are higher than this for many months of the year in many subtropical and tropical locations (for example near Hong Kong they are higher from May to October). Another issue is the question of humidity, as experimental results on residential buildings show that, although night-time natural ventilation combined with a daytime closed building would lower daytime temperatures, it would also cause higher levels of humidity indoors during daytime. Therefore, the usual architectural practice of the moment seems to have few design solutions for office buildings in subtropical and tropical areas, other than resorting to standard air conditioning powered from the grid.

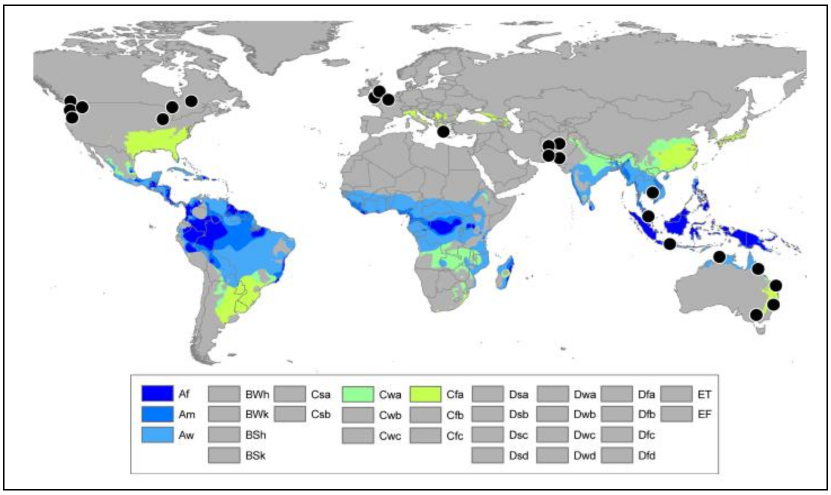


Figure 3: *Superposition of the Koppen subtropical and tropical zones and of the localization of case studies used to build ASHRAE 55 standard for NV buildings*

4. The Case Study Using Passive Design in Shenzhen, China

IBR headquarters in Shenzhen foreign language school is a 12-floor building, about 45m high and 30m deep. The total area of the building is about 20000 m2, and from 350 to 450 people work there depending on the period of the year. It has been in operation since 2008. The building is composed of two groups of enclosed spaces linked on each floor by an outside platform, which can be used as corridor, but also hosts the floor's printers, hot water room, and on some floors a casual meeting space. A picture of the building and a schematic map of a floor on the higher part of the building are provided in Fig. 4. On the lower part of the building the floor plan is roughly similar, except for fact that the central corridor platform is prolonged until the eastern facade and forms a ring that surrounds the central atrium (see Fig. 5 for a picture). The building's void-solid ratio is 0.39. The wall's global thermal conductivity K is equal to 0.69 and its thermal inertia factor D to 2. 57. Windows have a thermal conductivity value of K=3.5 and a shading coefficient SC of about 0.34 (not accounting for shading devices).

Figure 4: *Overview of the building*

Figure 5: *Corridor platforms of the upper floors with hanging vegetation and a table for meetings (left); suspended garden on the 6th floor (middle); outdoor hot water room (right)*

The building features suspended gardens on the 6th floor and on the rooftop (Fig. 6), as well as an artificial wetland area on the south half of ground floor. There are also a number of smaller planted spots on the border of open areas all over the building. Water ponds are located at the foot of the building and in the 6th floor's suspended garden. They are used for rainwater collection and air-cooling by evaporation.

Each floor has two separate indoor areas, the depth of which is limited to relatively small values: the southern area is about 15m deep and 27m long, while the northern one is about 18.5m deep and 20m long. The fifth, eighth and tenth floors are double height with mezzanine areas. The building hosts a variety of spaces with different functions: laboratories are installed in the basement and on the 4th floor north area; exhibition spaces on the second and third floor; meeting rooms and a 300-seat conference room on the 5th floor; a governmental building energy consumption follow-up platform takes up the north area of the 10th floor; apartments for visiting experts occupy a half floor, and a canteen and resting room occupies the top floor. Office areas are open, with workplaces organized in rows and a density of about 10m2 per worker. Shading is provided to the building by means of a shading platform located 9m above the rooftop (Fig. 6). It supports the building's solar water heaters and part of the solar panels (there are also some solar panels on the southern facade). All exposed windows are also equipped with shading devises: those on the lower part of the building, narrow and vertical, step back from the facade, while those on upper floors are shaded by horizontal metallic plates, 60cm long on the exterior side and 50cm on the interior side (Fig. 7). These horizontal shading plates are located 50cm lower than the top of the window, thus playing the role of light shelves, enabling natural light to be reflected deeper into the working areas and reducing the need for artificial lighting.

Figure 6: *Windows on the upper part of the building form the outside (left) and the inside of an office area (right); the horizontal lightshades can be seen, as well as blinds and user-controlled windows*

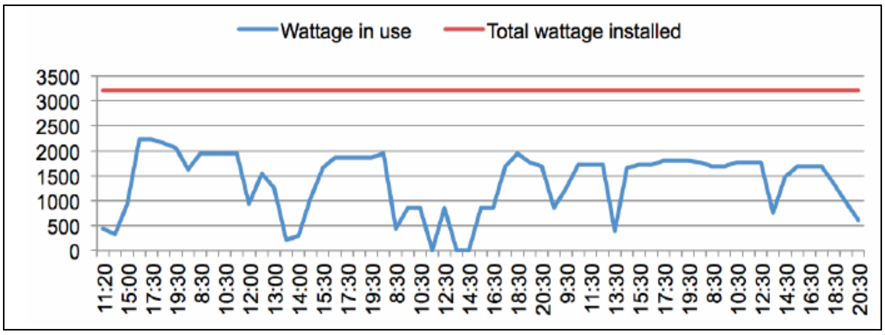


Figure 7: *Levels of artificial lighting used in a 720m2 office area of iBR during the working hours of a week (five days) in April 2016. The number of measure points obtained is different on each day. The weather during this week was particularly cloud and rainy, except on the morning of the first day, where less than SOOW of artificial lighting was used*

The north branch of the building sticks out a few meters, which enables it to catch summertime wind coming from the east or southeast (c# wind rose) and direct it more efficiently in the canyon area between the two bodies of the building, thus enhancing pressure differences between the north and south sides of each working space and improving the natural ventilation efficiency. The common spaces of the lower part of the building are also open to the outside. Last but not least, the east-facing wall of the conference room can be opened entirely for natural ventilation during a conference.

The energy values displayed above are not fully representative of the building's energy use, because iBR provides electricity to equipment used by people external to the building, which needs to be subtracted from total:

(1) Electricity provided to an experimental setup on glazed facades: 13,678kWh over the period.

(2) Electricity used by IT equipment belonging to telecommunication operators, and electricity used by equipment from a municipal building energy consumption monitoring platform installed in the building: it is installed along with iBR equipment in the building's two IT rooms, and energy monitoring data only provided global values (including equipment and air conditioning), so we had to use a rough estimate using data provided by iBR R&D office: the monthly consumption value of telecom equipment was once measured to be 3310kWh, so we used this value every to be due month (39,720kWh over the year). 25% of the remaining was considered to the municipal platform (55,630kWh over the year). The design map is shown in the figure 8.

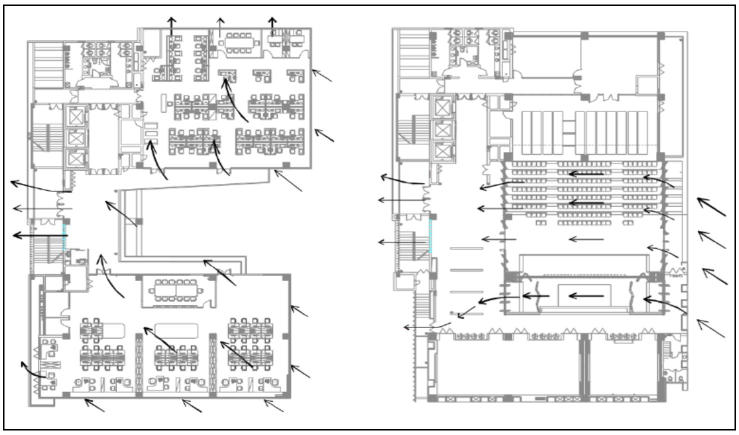
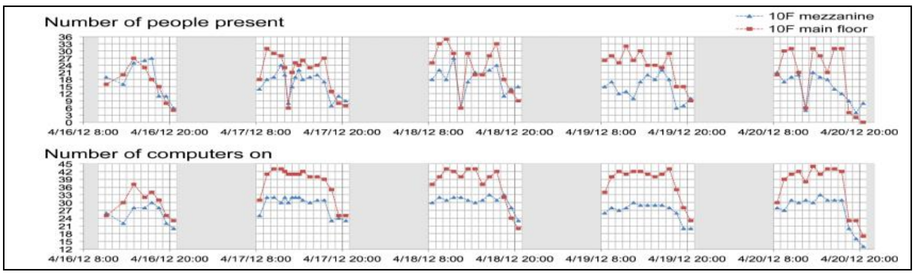


Figure 8*: Schematic illustration of natural ventilation in an office floor (left, working areas is a concept and does not correspond to the real situation) and room floor (right)*

The first step was to understand the general schedule of occupants, lights and computers use in a typical office area of the building. To this effect we investigated the office schedule in the south area of the 10th floor of the building (main floor and mezzanine) over the five working days of a week in April 2016. For every hour of the five working days, we counted the number of people present, the number of computer on, whether lights were on, and whether windows were open. Results are presented in Fig. 9. There was heavy rain on each day of the week, and the sky was cast except during the morning of the first day. Outdoor luminosity was also particularly good at times the morning of the third day, and artificial lighting was also used less than on the other days. Overall, the maximal measured lighting intensity in this office of about 380m2 was 3.2W m-2 a really low level compared to the 10-15W.m-a usual in most Chinese office buildings. This was made possible because the workplaces in the room tend to be located close to each other and to windows, and because workers almost never turn the lights of the areas without workplaces. Non-systematic observation during our other visits confirmed that most lights are off if outdoor luminosity is good in southern areas, and that in northern areas (which are deeper) lights in the centre of the room are open more frequently.



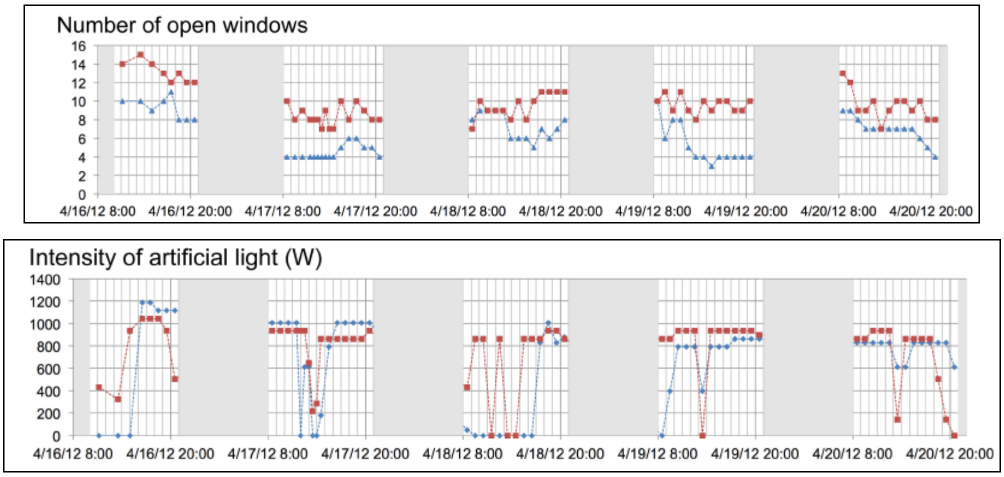


***Figure 9**: Schedules measured in 10F south area from April 16 to April 20. The exact time of measurements varied, which explains for example that the drop in the number of people present in the room at lunchtime it not observed every day*

From this experimental set of data, we can estimate that the maximum number of people present is about 80% of that of computers. We also have two weekly schedules, which we can use to vary the pattern of room use throughout rooms in our modelled building. During our stay we also investigated the number of computers present in all the working areas, so as to estimate roughly the repartition of workers in the building. We found out that most of iBR headquarters occupants work in the upper part of the building. We also obtained information on the monthly number of people present in the building over year 2015: it ranged from 349 in March to 450 in July. As most workers are located in the upper part of the building, and most of the working areas on lower grounds are non-office like, we decided to limit our simplified model to the upper part of the building. The lower body was modelled as a group of empty and closed rooms. In order to further simplify, we transformed the areas with mezzanine on floors 8 and 10 into real floors. Therefore, the simplified model has a total of 8 floors between the suspended gardens of floor 6 and the roof. Floor height is 3.6m.

(1) A model representative of the real building: DeST only takes closed rooms into account in models, so the outdoor platforms and separation walls are not represented;
(2) A model of the building with the common platform as an interior space separated into different rooms according to function.

5. Conclusions

The passive design which is very environmentally friendly can adjust the house to the appropriate temperature with very small energy consumption. This is an important factor to the design of campus public buildings, especially for the office buildings. In this paper, the passive design is used to reduce the energy consumption. The core issue for providing high levels of service is the concern that uncomfortable working environments might have a negative impact on work efficiency. Results on work performance experiments in climatic chambers showed that cool and stable temperature conditions (around 23-240C) fostered higher efficiency. However, there are discussions as to the accuracy of simulated work as a means to measure performance of real work, and some results tend to indicate that higher temperatures might not have any obvious negative impact on performance.

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