Sustainable Approaches for the Renovation of the Existing Building: taking Kaohsiung City Hall as a demonstration project on the Energy-saving and Occupant-healthy Benefits.

Chiang, C.M.  
Chang, K.F.  
Chou, P.C.  
Chen, N.T.  
Lee, C.H.

1 Professor of Dept. of Architecture, National Cheng-Kung University, Tainan 70147, Taiwan.  
2 Ph.D Candidate of Dept. of Architecture, National Cheng-Kung University, Tainan 70147, Taiwan.  
3 Assistant Professor of Dept. of Interior Design, Shu-Te University, Yenchao 824, Taiwan.  
4 Management of Building Administration Section, Building Management Department, Bureau of Public Works, Kaohsiung City Government, Taiwan.  
* Corresponding author: Phone: +886 6 2090899 or +886 6 2757575 ext. 54166. Fax: +886 6 2083669.  
E-mail: daphne@archilife.ncku.edu.tw or daphnekfc@hotmail.tw

ABSTRACT

Sustainable Development is a worldwide trend to develop a system that can provide comprehensive performance on the environment-oriented, energy-saving and occupant-healthy approaches. Kaohsiung City Government is following this trend. This paper represents a demonstration project to renovate the Kaohsiung City Hall instead of the sustainable concepts. This paper shows the first-year works which include installing the “rainwater tank” for conserving water resource, utilizing the “solar-cells” for obtaining the renewable energy and shading, and assembling the “outer shading devices” for saving the HVAC power. The performances of these devices will be addressed, and the occupants’ health will also be considered. These field-measurement results for the determination of the equipment capacities will be examined via the quantitative assessment.

INDEX TERMS

Energy Saving, Rainwater Tank, Renewable Energy, Human Health

INTRODUCTION

Kaohsiung City Government develops a system that can provide comprehensive performance on the environment-oriented, energy-saving and occupant-healthy approaches. Kaohsiung City Government renovates the Kaohsiung City Hall instead of the sustainable concepts. The project, belongs to the Green Building Renovation of the old buildings, matches up with the policy of the Green Building Promotion Program that is issued by the Executive Yuan. The Kaohsiung City Hall will be a first demonstration project via the quantitative assessment to conduct the old buildings in Kaohsiung City. The first-year works of the project include installing the “rainwater tank”, utilizing the “solar-cells”, and assembling the “outer shading devices”. Therefore, the whole renovation project, included planning phase, design phase, construction phase, checking phase, and use phase. According to climate conditions of the setting site of the Kaohsiung area, through a field investigation and a numerical simulation processes to provide the criterion of improvement and the guideline of planning for the energy saving and resource conserving.
PRESENTATION OF THE RENOVATION PROJECT

1. THE CLIMATE CONDITIONS OF THE SETTING SITE

Kaohsiung City Hall is on the south of Taiwan. The Kaohsiung City is located at the hot-and-humid tropical climate zone. The annual average temperature is about 25℃. There are six months that the temperature is over 25℃. Also a lot of sunlight, that is 1578w/m²/day, are at the East and the West. The climate has six months that are amenity, as shown in Figure 1. But Kaohsiung City has the air pollution from traffic and surrounding factories, the outdoor air quality is bad, especially on January and April. Therefore, it can harmonize with indoor thermal environment by a natural draft for only four months. There is a lot of rainwater about 1860 mm/year, but the rainwater concentrates from April to September. From comprehensive analyses, it can be in perfectly good condition to utilize the abundant resources of the solar energy and rainwater on Kaohsiung City Hall.

2. THE SETTING SITE AND BUILDING DESCRIPTION

The four sides of the site, Kaohsiung City Hall, are next to roads. The building has twelve floors upon ground, and two floors under ground. It is a rectangular form. The atrium is a hollow space of the floor plan, and the atrium’s roof is a skylight window. The facades of the building are regular. The four sides all have horizontal banding direction windows, as shown in Figure 2. Because the architectural style can’t disconnect the heat and sunlight from the Sun, it is very hot and uncomfortable, especially in summer for the occupant. From the above-mentioned, the building has many problems from the outside environment, as the traffic noise, the sun’s heat and sunshine, the setting site lacks the lighting and permeable stratum and etc, as analyzed in Figure 3.

Figure 1. The climate condition and location of Kaohsiung City, Taiwan. The shadow parts show an amenity climate condition.

Figure 2. Photograph show the facade and surrounding of Kaohsiung City Hall, Kaohsiung City, Taiwan.
Figure 3. Analyzing outside environment for Kaohsiung City Hall. The figure is analyzed setting site and the whole building.

RENOVATION RESEARCH OF OUTER SHADING DEVICES AND SOLAR CELLS

1. THE TECHNOLOGICAL PROCESSES

The renovation project adopts the POE (post-occupancy evaluation) method. The process of the POE method, the first step is the field measurement of environmental conditions of the setting site and building, and numerical simulation for the variation conditions of the four seasons, and the second step is to compare the data of the field measurement and numerical simulation in order to offer the strategy and criteria of buildings renovation which aim at health and energy-saving, and the third step is design and construction of building renovation for improving. After the improvement, it is to make the beneficial assessment of building renovation, the procedure of building renovation as analyzed in Figure 4.

Figure 4. The procedure of building renovation
The Field-Measurement Plan by Instruments

The 24-hour field-measurement is determined and auto-recorded physical-environment category through the use of instruments. So far as authors know, we group the indoor-and outdoor environment performance into four categories: acoustics, illumination, indoor air quality (IAQ), and thermal comfort. Each environmental category is then expressed in its relevant indicators. These critical environmental items are introduced in Table 1.

Table 1. Lists of the critical environmental items of the essential categories.

<table>
<thead>
<tr>
<th>Physical category</th>
<th>Critical items</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustics</td>
<td>Equalized sound pressure level in 24 h (Leq24h)</td>
<td>dB(A)</td>
</tr>
<tr>
<td>Thermal comfort</td>
<td>Indoor dry-bulb temperature (DBT)</td>
<td>°C</td>
</tr>
<tr>
<td></td>
<td>Indoor relative humidity (RH)</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>Indoor air velocity</td>
<td>m/sec</td>
</tr>
<tr>
<td>Indoor air quality</td>
<td>Concentration of suspended particulate matter (PM$_{10}$), 24h</td>
<td>µg/m$^3$</td>
</tr>
<tr>
<td></td>
<td>Conc. of carbon monoxide (CO), 24h</td>
<td>ppm</td>
</tr>
<tr>
<td></td>
<td>Conc. of carbon dioxide (CO$_2$), 24h</td>
<td>ppm</td>
</tr>
<tr>
<td></td>
<td>Conc. of formaldehyde (HCHO), 24h</td>
<td>ppb</td>
</tr>
<tr>
<td></td>
<td>Conc. of volatile organic compounds (TVOC), 24h</td>
<td>mg/m$^3$</td>
</tr>
<tr>
<td>Illumination</td>
<td>Average illuminance of the ambience</td>
<td>lx</td>
</tr>
<tr>
<td></td>
<td>Average illuminance at the height of the tabletop</td>
<td>lx</td>
</tr>
</tbody>
</table>

The Location Of The Field-Measurement

For attained to the integrity results of the field measurement. The locations are mainly composed of lower-level office (included 1F, 2F, 3F), middle-level office (included 4F, 5F, 6F, 7F), higher-level office (included 8F, 9F, 10F, 11F), atrium, and out-door space. It also considered the direction of the location, as shown in Figure 5.

Figure 5. The location of the field-measurement included 3 spots of lower-level office, 3 spots of middle-level office, 2 spots of higher-level office.

Numerical Simulation

From the results of the field measurement, it can depend on the numerical simulation method to forecast the variation conditions of the four seasons. Summarizing the results of the field measurement and numerical simulation, it can advance to propose completely the strategy and criteria of building renovation.
2. THE MEASURED RESULTS

Acoustics Of Indoor And Outdoor

Figure 6 shows the measured results via instruments. Almost the measured quantity exceeds the benchmark 56 dB (A) of environmental noise, especially at daytime office hours. In addition to the office occupants, machines etc. cause the mainly noise, the environmental traffic causes the lower-level offices even more noise, as showed in Figure 6. To solve noise problems, and promote the quality of acoustics environment, therefore it needs further improving the sound insulation performance between the outdoors and offices.

Thermal Comfort

Thermal comfort included indoor Dry-Bulb Temperature (DBT), indoor relative humidity (RH), and indoor air velocity. Figure 6 shows the measured results via instruments. Because the offices all belong to HVAC (Heating and Ventilation of Air-Condition) environment, thermal comfort is all controlled in a stability condition. The measured results are unchangeable, all in the scope of the benchmark, as showed in Figure 6. The average of Dry-Bulb Temperature (DBT) is approximately 18~22°C, but the indoor temperature difference is big. Such as lower-level offices, the indoor exterior-zone temperature, is near to outdoor temperature, but is much higher than the interior-zone temperature, the measured results as showed in Figure 7.

That is one of the follow up reform items, assembling the “outer shading devices”, to reduce the temperature difference, and the temperature of building envelope. Then indoors properly importing a fresh air consequently provides the occupant a healthy office environment.

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**Figure 6.** 24-hour field-measurement via instruments, included acoustics of indoor and outdoor and thermal comfort
The lower-level office (West-North)

Figure 7. Measured results of the lower-level office, the temperature near to outdoors’ is higher than the internal’s

Indoor Air Quality

The critical factors of indoor air quality are CO₂, CHOH, Particulate Matter (PM₁₀), TVOCs, especially the measured quantity of CHOH and TVOCs exceed the benchmark, the measured results as showed in Figure 8.

- The first critical factor, CO₂, rises to 1000ppm at the daytime office hours. The CO₂ conc. is over 1000ppm, and then people start to feel dizzy and have a headache. Because the more office occupants increasing, the more CO₂ concentration rising. Therefore, importing fresh air, and maintaining a good ventilation, and then can eliminate pollutants.

- Another critical factor, Particulate Matter (PM₁₀), exceed 0.15mg/m³ benchmark in at daytime office hours. To cause the high concentration of PM₁₀ is outdoor traffic. The fresh air is filtered before importing, to avoid increasing the concentration of PM₁₀ and harming to health.

- The other critical factors, CHOH and TVOCs, are beyond the benchmark in the greater part offices from the measured results. CHOH belongs to the high-risk carcinogenic substances. Causing the high concentration CHOH, the main reason is that, indoor decorated with materials of, such as organic viscose, paint, carpets, rubber- pavements etc. Besides, the offices are all in the HVAC (heating and ventilation of air condition) environment, so it can't eliminate CHOH. By way of good ventilation, importing more fresh air, that can remove the high CHOH concentration to outdoor.

TVOCs conc. also exceeds the benchmark in the greater part offices from the measured results, especially in the daytime office hours. Because the production of TVOCs is by for example, organic viscose, paint, smoke pollution, cosmetic, perfume, a Photostat etc. The elimination of TVOCs is the same way as CHOH, which is by good ventilation, and importing more fresh air.
**Illumination**

Using the instrument to measure the average indoor illumination that is at the height of the tabletop, and the outdoor that is by way of the numerical simulation to forecast the influence of sunlight in this building renovation.

The measured results of the average indoor illumination were showed that conform to 500-lux benchmark, for example South of middle-level office, but the indoor distributes disproportionate illumination. Distributing too much illumination in the exterior zone of indoor, as showed in Figure 9. While lamplight matches up the sunlight well, therefore it can save the lamp power.

**Figure 8.** 24-hour field-measurement via instruments, included CO₂ conc., PgM₁₀, CHOH conc., TVOCs

**Figure 9.** The measured results of the average indoor illumination in South of middle-level office
Inputting the basic data of the local climate to forecast the numerical simulation of outdoors that is the influence of sunlight on this building renovation. The simulated results show that the severe sun-exposedness on East, West and South from 10:00A.M to 15:00P.M, as showed in Figure 10. While assembling the “outer shading devices” on the severe sun-exposedness surface, it can prevent a lot of sunlight, and saving the HVAC power. Then South has the stable sunlight, so it can supply efficient energy to generate electric power through the “solar-cells”. In order to design efficient and accurate the “outer shading devices”, it will depend on numerical simulation of the variation climate conditions of the four seasons.

3. Proposed Criteria Harmonized with Numerical Simulation and Measured Results
Sum up the analyzing and comparing data, the numerical simulated results and measured results, East, West and South envelopes accumulate a lot of thermal energy to consume the HVAC power. The sun-angle of Kaohsiung is partial to South, which the reference, Taiwan Nine Indexes Of Green Buildings, showed that it is efficient to assembling the horizontal shading devices on South and grid shading devices on East and West. Therefore, design the horizontal outer shading devices on South. Assembled the outer shading devices on East and West, which combined horizontal shading devices with vertical shading devices.
Besides, it can utilize “solar-cells” to obtain the renewable energy and shading. Because South has the stable sunlight to generate the electric power, therefore, it may assemble the "solar-cells" on the highest floor envelope of South. To propose the strategy and criteria of the “outer shading devices” through the numerical simulation, and which conformed building laws to utilize the shutter-conformation outer shading devices, as showed in Figure 11.
Through numerical simulation to Compared the 45-degrees shutters of "outer shading devices" with the 90-degrees shutters of the "outer shading devices". We select a superior one, the “outer shading devices” made up of 45-degrees shutters, which can reduce the importable sunshine and sun-energy, as showed in Figure 12.
For example, the middle-level office of indoor average illuminance of the ambience, measured results to compare with simulated-results through the 45º shutters of the "outer shading devices” amounted to a high-relation. The relation coefficient (R²) between a simulated-result and a measured-result is O.99. The detailed consequence is analyzed in Figure 13.
**Figure 11.** Numerical simulation for illumination of the building ambience, the position of simulation is from south of the setting. The Intermediate building is this renovation project.

**Figure 12.** Compared the 45° shutters of the "outer shading devices" with the 90° shutters of the "outer shading devices". A superior one, the 45°- shutter devices, can reduce the importable sunshine and sun-energy.

**Figure 13.** The measured results of the average indoor illumination in South of middle-level office.
RENOVATION RESEARCH OF CONSERVING WATER RESOURCE

1. The Technological Processes
Firstly, investigating and estimating water resources of the renovation buildings, analyzing the advantages of gray water and rainwater. According to the aim of the water quality, cost saving, management maintenance etc., it is better to plan the collection of the rainwater resource. Secondly, considering the using purposes, deciding the rainwater tank size, and a process system of rainwater. Finally, constructing the rainwater tank, analyzed in Figure 14.

2. The Design State
Above-mentioned, a great effect of climate on rainwater is evident. The renovation project, Kaohsiung City Hall, aims for watering plants and educating teaching. Therefore, installing an absolute-construction rainwater tank for watering plants, and outside the building does an independent outdoor rainwater tank for educating teaching, as showed in Figure 15.
Determining the quantitative capacities will be via the rainfall record of the setting site. From the historical rainfall record of the setting site, the average of no-rainfall period is a ten-day. Installing a 200-ton rainwater tank, according to calculate a ten-day of no-rainfall period. It can provide 20-ton rainwater one day.

In accordance with the abundant-rainfall period, from April to October, to estimate the total collected rainwater is about 4500-tons. The collected area is about 3000 m², located on 11F roof-level. A quantitative conserving water resource plan is proposed in Table 2.

Besides, setting two independent units of outdoor rainwater tanks. The contents one is 250 liters, another is 1000 liters.

<table>
<thead>
<tr>
<th>Table 2. Proposed a quantitative conserving water tank resource plan</th>
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<tr>
<td>Proposing the collected area (m²)</td>
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<tr>
<td>3000</td>
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CONCLUSION AND IMPLICATIONS

This paper proposed a technological procedure for the outer shading devices, solar cells, and rainwater. From the above-operated, installed the outer shading devices, solar cells, the average of Dry-Bulb Temperature (DBT) of the indoor-outdoor temperature difference is from 8 ◦C to 3.6 ◦C through the computational fluid dynamics (CFD), corresponded to lower the temperature ratio 45%, the simulation results analyzed in Figure 16. The follow-up proposes a suitable mode for the opening-closing windows, and we will precede a field-experiment plan to evaluate the renovation benefit in the end of the year. The numerical simulation for the renovated appearance of Kaohsiung City Hall showed in Figure 17.

Proposed a standard procedure, harmonized with practical state, are especially for the renovation of the existing building in subtropical zone. The research results are useful and practical for the designers and architects.

**No outer shading devices**

- Simulation at 12:00 Am
- the HVAC temperature is 22 ◦C
- The indoor-outdoor temperature difference is 8 ◦C

**Installed the shading devices**

- Simulation at 12:00 Am
- the HVAC temperature is 22 ◦C
- The indoor-outdoor temperature difference is 3.6 ◦C

*Figure 16.* The computational fluid dynamics (CFD) of Dry-Bulb Temperature (DBT) of the indoor-outdoor temperature difference.
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