A Study on the Sustainable Approaches for the Building Renovation in the Subtropical Region: taking Kaohsiung City Hall as a demonstration project on the Energy-saving and Occupant-healthy Benefits.

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ABSTRACT: Sustainable Development is a worldwide trend that analyzed from the lately international conference. It is in search of 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 that assembling the “outer shading devices” for saving the HVAC power and the energy consumption. The performances of these devices will be addressed, and the occupants’ health will also be considered. The renovation project adopts the POE (post-occupancy evaluation) method. These field-measurement results for the determination of the equipment capacities will be examined via the quantitative assessment. After renewal, it will demonstrate the quantitative assessment with the field-measurement results. Proposed a standard procedure, harmonized with practical state, is especially for the renovation of the existing building in the subtropical region.

Conference Topic: 6 Recycled architecture (re-use, upgrading and rehabilitation of buildings)
Keywords: Energy Saving, POE, Human Health, the Subtropical Region

1. INTRODUCTION

Issues of sustainability are, at present, generally incorporated into the design or renovation process for building. 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 Kaohsiung City Hall will be a first demonstration project via the quantitative assessment to conduct the old buildings in Kaohsiung City.

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.

2. PRESENTATION

2.1 The building

The four sides of, Kaohsiung City Hall, are next to roads. The building has twelve floors above ground and two floors below ground. It is a rectangular form. The facades of the building are regular. The four sides all have horizontal banding direction windows, as shown in Figure 1.

Figure 1: Photograph show the facade of Kaohsiung City Hall, Kaohsiung City, Taiwan.
Because the architectural style can’t dissipate 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 sun’s heat and sunshine.

2.2 The Climate Conditions of building
Kaohsiung City Hall is on the south of Taiwan, and is located at the hot-and-humid tropical climate zone. The annual average temperature is about 25 °C. There are six months that the temperature is over 25 °C. 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 2.

From comprehensive analyses, it can be in perfectly good condition to utilize the abundant solar energy on Kaohsiung City Hall.

Figure 2: The climate condition and location of Kaohsiung City, Taiwan. The shadow parts show an amenity climate condition.

3. THE TECHNOLOGICAL METHOD

3.1 The Process
The renovation project adopts the POE (post-occupancy evaluation) method, the procedure of building renovation as analyzed in Figure 3. 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.

The second step is to compare the data of the field measurement and numerical simulation in order to decide critical factors that affected the occupied quality of the building, and operating works that on the basis of key factors of buildings renovation which aim at health and energy-saving. In order to improve building renovation, through digital simulation for the operating works.

After the improvement, the third step is field-measurement of operating works, and to verify the simulation with the following field-measurement results. Finally, propose a standard procedure for the renovation of the existing building.

3.2 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 interior and exterior environmental performance into three categories: 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>
<thead>
<tr>
<th>Category</th>
<th>Field-measurement items, Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal comfort</td>
<td>Indoor dry-bulb temperature (DBT), °C</td>
</tr>
<tr>
<td></td>
<td>Indoor relative humidity (RH), %</td>
</tr>
<tr>
<td></td>
<td>Indoor air velocity, m/sec</td>
</tr>
<tr>
<td>Indoor air quality</td>
<td>Conc. of suspended particulate matter (PM_{10}), μg/m³</td>
</tr>
<tr>
<td></td>
<td>Conc. of carbon monoxide (CO), ppm</td>
</tr>
<tr>
<td></td>
<td>Conc. of carbon dioxide (CO₂), ppm</td>
</tr>
<tr>
<td></td>
<td>Conc. of formaldehyde (HCHO), ppb</td>
</tr>
<tr>
<td></td>
<td>Conc. of volatile organic compounds (TVOC), mg/m³</td>
</tr>
<tr>
<td>Illumination</td>
<td>Average illuminance of the ambience, lx</td>
</tr>
<tr>
<td></td>
<td>Uniformity illumination ratio</td>
</tr>
</tbody>
</table>

3.2 The Location of the Field-Measurement
For attained to the integrated results of the field measurement. The locations are mainly composed of lower-level offices (included 1F, 2F, 3F), middle-level offices (included 4F, 5F, 6F, 7F), higher-level offices (included 8F, 9F, 10F, 11F), atrium, and exterior space. It also considered the direction of the location, as shown in Figure 4.
3.3 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.

4. MEASURED RESULTS AND SIMULATION OF THE ORIGINAL

4.1 Measured Results of Thermal Comfort

Thermal comfort included indoor Dry-Bulb Temperature (DBT), and indoor relative humidity (RH). 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. Figure 5 shows 24-hour field-measured results via devices. The average of Dry-Bulb Temperature is approximately 18~22°C, but the indoor temperature difference is great. Such as lower-level offices, the indoor exterior-zone temperature is near to outdoor temperature, also is much higher than the interior-zone temperature. The measured results of DBT and RH are showed in Figure 6.

4.2 Measured Results of Indoor Air Quality

The critical factors of indoor air quality are CO₂, CHOH, Particulate Matter (PM₁₀), and TVOC, especially the measured data of CHOH and TVOC exceed the benchmark, the measured results as showed in Figure 7. The first critical factor is CO₂. The data of CO₂ conc. rises to 1000ppm at the daytime office hours. Another critical factor, Particulate Matter (PM₁₀), exceed 0.15mg/m³ of the benchmark at daytime office hours. The other critical factors are CHOH and TVOC. The measured results CHOH and TVOC are beyond the benchmark of 0.1ppm and 3ppm in the greater part offices from the measured results. TVOC and CHOH belong to the high-risk carcinogenic substances.

4.3 Measured Results of Illumination

The measured results of the average indoor illumination displayed that conform to 500-lux of the benchmark. Average illumination of the ambience is about 1900-lux, for example as middle-level offices and higher-level offices. But the data of indoor illumination distributes disproportionately, uniformity illumination ratio 0.25 that the benchmark is 0.33, a lot of illumination distributed in the exterior zone indoors, as showed in Figure 8.
4.4 Numerical Simulation

Through the numerical simulation, forecast the influence of sunlight on this building renovation. The simulated results show that the severe sun-exposedness on East, West and South from 10:00 a.m. to 15:00 p.m., as showed in Figure 9. Input the basic data of the local climate

Sum up the analyzing and comparing data of critical affected factors. Through consideration practiced ability, energy-saving and occupant-healthy benefits, Indoor dry-bulb temperature of Thermal comfort, the ambience average illuminance and uniformity illumination ratio may be given precedence over others, as showed in Table 2. In order to reduce a lot of thermal energy to consume the HVAC power and glaring sunlight to influence indoor physical environment, it is more efficient to assemble shading devices on the facades of South, East and West. But conditions of this setting site are suitable to design outer grid shading devices on East and West, which combined horizontal and vertical shading devices, as showed in Figure 10.

Table 2: List the critical affected factors from field-measured results

<table>
<thead>
<tr>
<th>Category</th>
<th>Critical affected factors</th>
</tr>
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<tbody>
<tr>
<td>Thermal comfort</td>
<td>Indoor dry-bulb temperature (DBT)</td>
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<tr>
<td></td>
<td>uniformity illumination ratio</td>
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5. CRITICAL AFFECTED FACTORS AND OPERATING WORKS

Through measurement and examination, critical affected factors of interior physical environmental investigation were “Illumination” and “Thermal Comfort”. The critical affected factors of Illumination are average luminance of the indoor ambience and uniformity illumination ratio; “Thermal Comfort” is indoor average temperature; “Indoor Air Quality” (IAQ) that were PM10, CO2, HCHO and TVOC.
6. EXPECTATION OF AN IMPROVEMENT EFFICIENT

6.1 Numerical Simulation of Thermal Comfort
Simulated at the outdoor maximum temperature in the winter, the outdoor average temperature below the outer shading devices of Eastern facade is 2.4 lower than which no outer shading devices.

The difference in temperature between indoor average and outdoor windowsill temperature is 3.3 in the original. While set outer shading devices, the difference in temperature between indoor average and outdoor windowsill temp. is 1.7. The temperature of setting outer shading devices can lower 1.6 than the original, as showed in Figure 13.

6.2 Numerical Simulation of Illumination
The Illumination simulation of the 45° shutters of the "outer shading devices" assembled on East and West, there is a low incidence between assembling the “outer shading devices” with no outer shading devices that simulated at the outdoor maximum temperature in the winter, as showed in Figure 14.

7. VERIFICATION OF SUSTAINABLE APPROACHES

7.1 Verification in Thermal Comfort
Compared with assembled the “outer shading devices” in Thermal Comfort, the Indoor average temperature difference was 0.2 between the indoor measured result and the simulated-result that simulated the Indoor average temperature by the outdoor measured temperature. The temperature difference, which the temperature difference between indoor average and outdoor windowsill, between measurement and simulation of setting outer shading devices is 0.1, as showed in Table 3 and Figure 15.

Table 3: Lists of the critical environmental items of the essential categories

<table>
<thead>
<tr>
<th>Thermal Comfort</th>
<th>Simulation</th>
<th>Measurement</th>
<th>Compared statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Indoor average temperature is 25.9°C.</td>
<td>2. The temperature difference between indoor average and outdoor windowsill is 1.9°C.</td>
<td>1. The indoor average temperature is 25.7°C.</td>
<td>2. The temperature difference between indoor average and outer windowsill is 2.0°C.</td>
</tr>
<tr>
<td>1. The temperature difference of 1. between simulation and measurement is 0.2°C.</td>
<td>2. The temperature difference of 2. between simulation and measurement is 0.1°C.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
measurement results. Verified a practical evaluation procedure, demonstrated the high correlation between the measured results with no shading devices in simulation of Illumination.

**Figure 15:** Compare setting outer shading devices with no shading devices in simulation of Illumination.

7.2 Verification in Illumination

The Illumination simulation of the renewal was in accordance with the original. The relation coefficient ($R^2$) is 0.94 by linear relation analysis. It display a high correlation between the measured results with simulated results in indoor average illuminance of the ambience. Simulated and measured results of indoor average illuminance of the ambience are 750 lx and 720 lx, which both exceed the benchmark of 500 lx, as showed in Figure 16.

**Figure 16:** High-relation between simulated-results and measured-results in Illumination.

**CONCLUSION AND IMPLICATIONS**

From the above-mentioned verification of a high correlation between the measurement and simulation in Thermal Comfort and Illumination, it can prove a practicable assessment procedure, demonstrated the numerical simulation approximated to the field-measurement results. Verified a practical evaluation by the numerical simulation performed before the renovation. The follow-up work is better to measure in the summer solstice, in order to promote the accuracy of the numerical simulated results. The research results can propose a sustainable procedure, harmonized with practical state, are especially for the renovation of the existing building in subtropical zone.

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**REFERENCES**


