Out of the box – reinventing the industrial warehouse

C. Fong
Architectural Association School of Architecture London, UK

ABSTRACT

This paper looked into the possibilities of adaptive reuse through the environmental retrofit of an existing warehouse. The project was built on the intent of converting an abandoned building into an exhibition hall, within the tropical island climate of Subic Bay, Philippines. Analyses of the existing warehouse were undertaken; from this initial study, three main strategies were identified – shading, the use of thermal mass, and ventilation. These three aspects formed the core of the research, and were further investigated through the use of computer simulations. Environmental design standards and targets were established through literature review and a small-scale comfort survey. Results of the entire exercise were used to inform a design solution for the chosen building. Key features of the proposal are the use of a double-roof system, the introduction of thermal inertia to the walls, and the use of high-level inlets and outlets for natural ventilation. Computer analyses of the final design solution showed an improvement in internal building conditions; however, mechanical cooling is still necessary for certain periods of the year. The design also employed a modular system which allows repetitive application in different settings and buildings, facilitating adaptive reuse efforts.

1. INTRODUCTION

In a world that is becoming increasingly conscious of environmental issues, adaptive reuse has become common practice in many developed nations. Redundant industrial buildings have been given new life as art galleries, science centres, and the like. However, in a developing country such as the Philippines, the environmental imperative is not as strong, making adaptive reuse not as popular. Moreover, the concept of “never is better” dominates society, and recycling – from paper to buildings – is rarely practiced.

Abandoned industrial buildings are quite common in the Philippines; these are often shed-type warehouse structures made of steel and concrete. In recent years, a few of these empty warehouses have been converted into badminton courts. This in itself seems promising, but so far there has been little evidence exploring other reuse possibilities for the industrial shed. The strong potential for the conversion of this building type lies in its ubiquity within growing cities, and the large unobstructed volumes within. This paper has undertaken a process of redefining the industrial warehouse to create a new typology that allows such simple structures to be reused.

2. CONTEXT

2.1 Climate

Subic Bay is found in the northern island of Luzon, in the Philippines. It lies 14.75°N of the equator, and has a characteristically warm-humid tropical island climate. There is little seasonal and diurnal variation in temperatures, with extremes often falling within 10°C of each other. The hottest period of the year occurs from March through May, where the average maximum is 32°C. Relative humidity ranges from 60 to 100% and absolute humidity values fall between 12 to 25 g/kg (Fig. 1).

Figure 1: Psychrometric Chart of Olongapo City, Subic. Weather data (average year) from Metenorm V5.0, illustrated in Weather Tool.
Because of the low latitude, the sun is often found directly overhead. As such, horizontal surfaces receive the greatest amount of solar radiation, almost twice as much as east-west vertical surfaces. Radiation levels peak during the hottest months, indicating the importance of solar protection. Both direct and diffuse radiation play a significant role in solar heat gain, as the sky is partly cloudy to overcast for over half of the year.

2.2 Site
Subic Bay Freeport grew from a converted US naval base, covering an area of over 50 hectares. Many of the old navy structures were retained and converted to new use, with much of the utilitarian character remaining intact. Part of the area’s twenty-year masterplan involves the conversion of an old laundry hall into a convention centre. This building was used as a representative model for the warehouse typology, and the subsequent investigations were based on this structure.

2.3 Building
The old laundry hall, marked as Building 650, is a fully-detached structure that is exposed on all sides (Fig. 2). The rectangular building follows the gridiron street pattern of the Subic Bay business district, with the shorter side orientated along the southeast-northwest axis. The building has a 30 x 48m footprint, which is mostly a large open space. The main hall is approximately 6m high, with additional airspace underneath the gabled roof. The primary building materials are pre-painted corrugated metal sheets. Foil-backed insulation is provided underneath the steel roof to avoid the ingress of heat. Structural elements are made of pre-fabricated steel sections, found in 6m bays. The floor slab is made of reinforced concrete, and is the only thermally massive element of the building. Windows and doors are scattered along the perimeter of the building, with no form of solar protection.

3. DESIGN REQUIREMENTS

Design requirements were defined as a range of values, which were ascertained through a review of a previous comfort studies in hot-humid climates, plus a small-scale comfort survey conducted on-site. Research began by studying a few existing models and indices; most sources give a neutral range between 23 and 30°C (Table 1). To verify these figures, a small-scale comfort survey was conducted on-site, patterned after a similar comfort studies. Raw data from de Dear’s Adaptive Comfort Survey were also used to supplement collected data. Combined results show that almost 50% of users in naturally-ventilated spaces can tolerate indoor temperatures slightly above 30°C. This condition generally occurs in spaces with appreciable air movement. Based on this, the upper limit of the comfort range was placed at 30°C; temperatures up to 31°C are acceptable if there is a breeze of at least 0.5 m/s, and exposure is limited to a maximum of one hour.

4. RESEARCH STUDY & FINDINGS

4.1. Thermal Test Series
Investigation began with the analysis of the existing structure and its performance, using this as the reference case. All thermal studies were done in Thermal Analysis Software by EDSL, using a simple box model approximating the dimensions of the existing building. This model was zoned into three spaces – the occupied zone, the intermediate zone, and the roof space. Simulations were run using typical climatic data during the overheated period of March to May. The reference case model – unventilated and without internal gains – experiences strong thermal stratification, especially during midday. A maximum temperature difference of 4°C occurs between the occupied zone and
the roof space. Indoor resultant temperatures closely follow outdoor air temperatures, as is expected from a building of lightweight construction. At night, ambient air temperatures are two degrees lower than indoor temperatures, showing potential for night-purge ventilation.

Table 1: Comfort standards (still air conditions)

<table>
<thead>
<tr>
<th>Standard</th>
<th>Temperature °C</th>
<th>Humidity g/kg</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>min</td>
<td>max</td>
</tr>
<tr>
<td>ASHRAE</td>
<td>23.5</td>
<td>31.0</td>
</tr>
<tr>
<td>Givoni</td>
<td>20.0</td>
<td>29.0</td>
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<tr>
<td>Humphreys</td>
<td>24.8</td>
<td>27.0</td>
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<tr>
<td>Ahmed</td>
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<tr>
<td>Auliciens</td>
<td>23.1</td>
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<td>de Dear</td>
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The first environmental intervention explored was the use of sunshading. Taking the double roof and double wall ideas, four different shading configurations were tested (Fig. 3). A series of parametric tests were run on four representative models; results show that the external double-roof system had the greatest temperature drop across all three zones.

The second step introduced thermal inertia to the existing models. Reinforced concrete was used for the roof or wall constructions, replacing the sheet metal. From the results, it was determined that thermal mass is most beneficial when located near the occupied zone, i.e. on the walls. The final series in thermal tests involves the establishment of ventilation regimes. Models were ventilated with 6 ACH, based on the requirements for an exhibition hall. Two different schedules were used, one with continuous ventilation and another with only night-time ventilation, which ran from 23.00 to 06.00 the next day. Resultant temperatures for the occupied zone were lower with night-time ventilation, especially during the day. With continuous ventilation, roof space temperatures were close to ambient air temperatures throughout daytime hours.

Internal gains were then introduced to simulate an occupied condition. In this case, continuous ventilation provided a better indoor environment for all zones. Additional tests showed that ventilating the roof cavity simultaneously with the indoor space further improved overall conditions.

Finally, tests were conducted to see how the ventilation rate of the air cavity affects the indoor environment. As expected, resultant temperatures drop with increasing air changes; however, the relationship is non-linear (Fig. 4). The hyperbolic curve suggests diminishing temperature drops with the increasing air changes, with the critical point approximately 6 ACH. This value was then designated as the optimal ventilation rate.

4.2 CFD test series

Studies using STAR-Design CFD were conducted to determine wind behaviour around the site, and to experiment with different ventilation strategies. An average wind speed of 4 m/s was used in the tests, with 1 m/s as the worst-case scenario. Four different ventilation strategies were studied, with results focusing on air movement and heat dissipation (Fig. 5).

![Figure 3: shading configurations tested in TAS](image)

![Figure 4: graph showing correlation of indoor resultant temperature to number of air changes per hour](image)

![Figure 5: isoplots from Star-Design CFD; clockwise from left – (1) cross-ventilation velocity plot, (2) wind scoop + thermal stack temperature plot, (3) dual wind scoops velocity plot, and (4) wingwalls temperature plot.](image)
The first ventilation strategy explored was cross-ventilation; using a window area that is 10% of the floor area, windows were first placed on non-windward walls. Results show that air movement is insufficient when using this configuration. However, introducing openings directly facing the prevailing wind resulted in a relatively strong air stream running down the length of the building. The second series of tests was based on Givoni’s study on wing-walls (1998); horizontal protruding elements were introduced in non-windward windows, with increasing wall widths. Results show better air distribution, but minimal improvement in indoor airspeeds. Opening up the windward and leeward faces of the building improves indoor conditions, but shifts the pattern of air movement; again, an air stream runs along the length of the hall. Increasing the width of the wing-walls did not result in any marked improvement.

As an alternative to cross-ventilation, the use of wind scoops was explored. The height of the wind catcher is approximately 6m above the roof ridge, as determined by behaviour of the wind on-site. The size of the openings was kept consistent with the previous test series. Using a central wind scoop with outlet windows on the south-east and north-east walls, results show improved air distribution within the space; images from a thermal plot also indicate good heat dissipation. However, indoor airspeeds are too low for physiological cooling. Multiple wind scoops were then introduced to see if conditions would improve. Indoor airspeeds increased, especially below the first wind scoop. There were also lower indoor temperatures compared to the previous single-scoop model. Finally, the use of a thermal stack was explored. With an inlet window in the south-west wall, a central stack was used as an outlet for the building. Evidence shows that there is very little air movement when relying on stack effect for the exhaust. Heat is well-dissipated on occupant level, but there are still small pockets of hot air near the heat sources. Indoor air speeds are generally low, between 0.3 to 0.6 m/s. However, when the outdoor airspeed is at 1 m/s, indoor temperatures rise above comfort level, and large pockets of hot air are trapped within the space. As a variant of this model, a wind scoop was used as an inlet; the scoop and the stack were placed in the centre of the building, with a wall separating the two. This configuration created two zones of air movement in the space – one towards the front (south-west), where the air comes in, and another towards the back (north-east), where the air goes out. The front half of the room is generally cooler than the rear half due to the location of the inlet. Indoor air velocity is quite low, but did not seem to impede heat loss.

5. DESIGN APPLICATION

Taking all the observations from the previous experiments, a final design proposal was created as a response to the project brief. A series of environmental design interventions were introduced to the building, retaining as much of the existing fabric as possible.

First, the existing walls were replaced by concrete masonry walls, increasing the amount of thermal mass in the building. The removed wall panels were then used to create an external roof to shade the existing one. Air was allowed to flow freely between the two layers by means of a cavity construction. This facilitated material cooling through convection.

The introduction of thermal mass at occupant level ensures lower radiant temperatures, especially during the daytime. To maximise the cooling potential of the exposed concrete, mechanical fans were used to increase the air-change rate at night. Increasing the ventilation rate to 30 ACH in the late evenings resulted in a 1°C drop in peak internal temperatures.

The most significant intervention is the creation of new sections within the current building. These new modules were worked into the existing 6-metre structural grid, and inserted in alternate bays. The segments contain design elements that introduce daylight and ventilation into the hall. The exposed faces of the new sections can also hold advertisements and other graphics, creating a more vibrant façade.

Sitting atop the rectangular modules are rotating wind scoops or wind cowls that bring fresh air into the space (Fig. 6). This top-down ventilation strategy is suitable for an exhibition hall because the large volume allows for supply air to mix within the space. Furthermore, high ceilings allow for thermal stratification, and hot air from the hall can be exhausted through high-level vents at the exposed gables.
On days when there is low wind speed, opposite ends of the new module can be opened to allow for cross-ventilation. Additional windows on the south-west and north-east façades can further supplement air movement when necessary.

The model was tested thermally in TAS, and results show a marked improvement in indoor resultant temperatures; conditions exceed the 30°C upper limit for only 20% of the annual occupied hours, compared to the existing model which overheats 78% of same period. This translates to fewer days when mechanical cooling is required. One of the strengths of the design is the flexibility it offers; the rectangular modules can be used to delineate and subdivide the hall into smaller sections, enabling three exhibitions to run concurrently. The large volume space and high ceilings also allows for small, temporary mezzanines floors, providing more exhibition space or special viewing platforms.

6. CONCLUSION

Given the nature of the tropical climate, it is impossible to achieve comfort conditions all the time by relying on passive strategies alone. The best option is to provide a mixed-mode system where active cooling operates at times when passive cooling is insufficient. Because the energy consumption of the new building has been lowered through environmental design interventions, the use of an air-conditioning system is now more viable and less wasteful in terms of energy.

Overall, the design solution strives to retain some of the character of the existing fabric while introducing new, architecturally distinct elements as part of the conversion (Fig. 7). By keeping most of the changes within a modular unit, much of the old structure can be preserved. The modularity of the solution also facilitates repetition in similar projects, further simplifying the process of adaptive reuse. Moreover, the juxtaposition of the new and old creates a strong architectural image — one filled with visual contrast.

All three strategies – shading, thermal inertia and ventilation – are equally important in achieving comfort conditions. However, in the warm-humid tropical island climate of Subic Bay, air movement can provide the fastest relief from thermal stress.

The application of the above strategies in a new design brief illustrate that the conversion of redundant buildings need not be a complicated and resource-intensive process. Materials can even be recycled and reused; as in the proposal, metal wall panels can be taken down to create a second roof. Furthermore, examples from around the world — such as the Tate Modern and the Magna Project — stand as strong evidence that disused industrial structures can be successfully transformed into places of cultural and social significance.

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REFERENCES