Eliminating the need for mechanical cooling

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ABSTRACT

This paper challenges the conception that comfort can exist only w/in strict parameters, should be achieved w/o inhabitant interaction, and cannot be achieved w/o mechanical means. A period of research was conducted followed by the redefinition of several standards of practice. A mixed-use adaptive re-use design application was developed and simulated in an effort to combat the perceived necessity of mechanical cooling systems (Fig. 1).

1. INTRODUCTION

As the sustainable design movement gains momentum, populations need the appropriate tools for environmental design within their respective regions. Until now, most sustainable design applications have been constructed in climates of either relatively temperate or unvaried conditions. The advantages and simplicity of applying sustainable strategies within these climates are overtly apparent, whereas the application feasibility of similar methods is greatly reduced when high annual or seasonal temperatures exist. Due to the level of complexity which increased temperatures present, such climates have mostly been, neglected thus far. This paper attempts to provide those climates with a means of remediation.

2. CLIMATE

St. Louis, Missouri (USA) was chosen as the site because of the presence of high summer temperatures and the author’s familiarity with it.

Although the temperatures can reach the upper 30’s, even during the hottest summer months, the average diurnal temperature remains within the comfort range, suggesting that passive strategies could achieve comfort levels. There is also a consistent average daily temperature fluctuation of 10^{o}C year-round, which had the potential to prove extremely beneficial for eliminating the perceived need for mechanical cooling.

Consistently between 60% and 80% throughout the year, humidity levels in St. Louis only augment the perception of excessively hot summer conditions. Restricted use of evaporative cooling was considered, but increased air movement was decided more likely to provide efficient relief.

The average annual air velocity is 4.1m/s, and the majority of the time speeds remain between 1.5m/s and 4.5m/s. These speeds supported the relevance of natural ventilation as a means of coolth.

3. PASSIVE MEANS OF FACILITATION

An expanded comfort range was included and overall environmental quality was considered

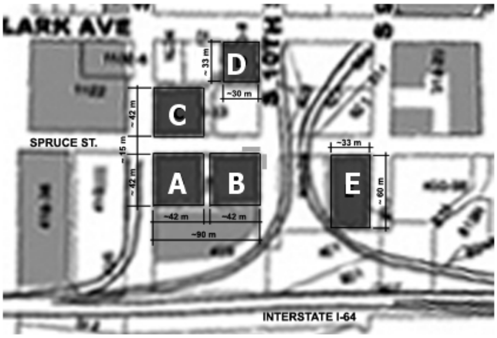

Figure 1: Site plan.

throughout the process. PMV values of ±0.25 and ±0.5 are accepted by CIBSE and ASHRAE, respectively. However, the "PMV equation tends to over-estimate how warm the subjects felt when warmer conditions prevail" (CIBSE, 1999). People who vote extreme thermal experiences are not necessarily dissatisfied with the conditions but acknowledging the variation of environmental qualities present (Baker, 2000). Thus, an expanded range of ±1 PMV was accepted during simulation and analysis (Fig. 2).

The standard temperature range of 21-24^{o}C was not appropriate either. It does not take into account the potential advantages which effective ventilation and consideration of seasonal acclimatisation can provide (Koenigsberger, 1973). An increased range of 18-30^{o}C was therefore defined, conditional upon the inclusion of additional environmental provisions (Rivera, 2004).

The means which demonstrated potential of passively achieving comfort were:

1. Revised Structural Geometry,
2. Increased Ventilation,
3. Effective Solar Control,
4. Increased Thermal Mass,
5. Incorporation of Vegetation.

It was hypothesised that these methods together could provide comfortable conditions in St. Louis during summer, eliminating the need for mechanical means of cooling. Focus was placed on internal modifications and superficial applications which would not physically alter the external façades, as they are historically protected.

Throughout the process economic feasibility was considered. The number of strategies was kept to a minimum to control final costs. Resources were used when necessary and where appropriate (Hawken, 2003).

- *Revised Structural Geometry:* Buffer zones of unconditioned spaces, either incorporated into the building's geometry, would provide an intermediate zone between the extreme exterior conditions and the comfortable interior. They also offered valuable amenities (i.e. meeting places and green areas) Operable glazing and a trellis with deciduous vegetation would permit solar gains in winter and provide shade in summer for seasonal flexibility.
- *Increased Ventilation:* Most methods of measuring thermal comfort underestimate the effective cooling potential of air movement. A 2-3^{o}C benefit can be provided from .57-.85m/s air movement (Florida Solar Energy Center) and humidity levels of up to 90% can become tolerable with sufficient air movement (Ahmed, 2000) 2.28m/s was the maximum recommended air velocity in order to avoid distraction (Cook, 1989). Ceiling and personal fans were also assumed.
- *Effective Solar Control:* The most significant component is direct radiation. Focus was placed on controlling direct solar radiation and encouraging diffused and reflected light into the spaces. Shading devices and high-albedo surface were specified to encourage penetration of indirect natural light into the building.
- *Increased Thermal Mass:* The already significant thermal mass of the existing concrete structure and masonry façades was determined an asset to take full advantage of the diurnal temperature fluctuations.
- *Incorporation of Vegetation:* Incorporating nature into the built environment, reduced direct solar gains, lowered ambient temperatures through evapotranspiration, and reduced the amount of heat stored in the building fabric. Through a "partnership with plants," daily temperature extremes experienced in urban areas can be reduced by several degrees (Lay, 2001) (www.oru.com). A vegetative cover of 30% could provide "a noontime oasis of up to 6^{o}C" whilst reducing overall local air temperatures by 4^{o}C throughout the day (Taha, 1997).

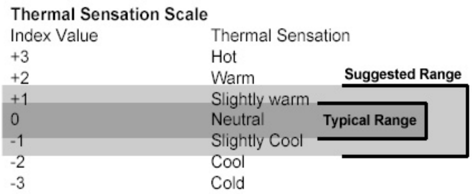

Figure 2: Standard vs. Proposed PMV ranges.

4. SIMULATIONS

Passive means to provide conditions within the revised range of comfort were proposed through implementation in a design and simulation exer-

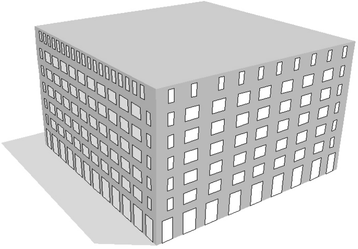

Figure 3: Perspective of Generic Building Exterior.

cise. The prototype (Fig. 3) was modelled and the hypotheses were applied and simulated using Ecotect, Radiance, and TAS to determine thermal and general daylighting performances. The middle level of office space was chosen for evaluation, as the internal gains and lighting requirements of office programmes are the largest and thus present the greatest challenges for eliminating the need for mechanical cooling.

4.1 Assumptions

In order for a sustainably constructed and detailed building to function in the way intended, its operation must also be conducted in such a manner. There were several parameters defined which remained unchanged throughout the process.

- Air changes per hour: 1ach/hr for mechanically ventilated periods and .5ach/hr continuous infiltration in office spaces. Note: Ventilation infiltration rates specified for mechanical systems only. Conditions within the building are only affected by it when mechanical systems are in operation, not when a naturally ventilated.
- A standard reinforced concrete structure was assumed, at it is the most common type of detailing for these buildings in the region.
- Brick work and window openings at the exterior were not modified.
- Average Sensible and Latent Heat Gains assumed for Occupants were 5W/m^2 and 7.7W/m^2, respectively, after industry averages (Rivera, 2004).

4.2 Standard vs. Proposed Practice

The first phase of simulations was conducted with the entire main area of the floor plate as a single zone. The first run demonstrated Standard Practice of operation for office buildings in the United States. The next runs were progressively inclusive: larger temperature and relative humidity ranges, reduced equipment and lighting loads, and the exclusion of an air conditioning system (Fig. 4). The final base case simulation, Proposed Practice, was then used as a basis for comparison of subsequent runs. The base for comparison of the reference model was energy demand.

The proposed scenario produced a 30% decrease in energy usage, when compared to Standard Practice. However, conditions within the building were outside the comfort range for 3744 hours of the year. The remaining simulations focused on reducing and eliminating those hours.

4.3 Applications

In the next series, different applications were input into the model. Solar control, ventilation strategies, and thermal mass, were defined into the “Proposed Practice” model. Figure 5 shows the effectiveness of each method to reduce the number of hours above the previously determined comfort range of 30^{o}C.

Shading devices and increased material reflectances were incorporated to reduce the solar gains, which had contributed 1/3 of the daily summer gains (Guzowski, 2001). Shading devices were geometrically defined for both summer and winter and input as feature shading de-

RUN	Temperature Range	Relative Humidity Range	Mechanical Systems Operation	Lighting Gains	Goal Illumination	Sensible Heat Gains (Equipment)	Window Operation	Peak Cooling Demand
STANDARD PRACTICE	21-24^{o}C	45-65%	Always On	20 W/m2 *	500 lux	5 W/m2 *	CLOSED	80,000 kWh
TEMP. & HUM. RANGE	19-26^{o}C	40-70%	Always On	20 W/m2 *	500 lux	5 W/m2 *	CLOSED	70,000 kWh
EQUIP. & LIGHT. GAINS	19-26^{o}C	40-70%	Always On	15 W/m2	300 lux	3.5 W/m2	CLOSED	60,000 kWh
PROPOSED PRACTICE	min 18^{o}C	no max/min	No A/C	15 W/m2	300 lux	3.5 W/m2	CLOSED	56,000 kWh

* Standard Practice gains were based on average values, not worst-case scenario.

Figure 4: Standard vs. Proposed Practice Inputs.

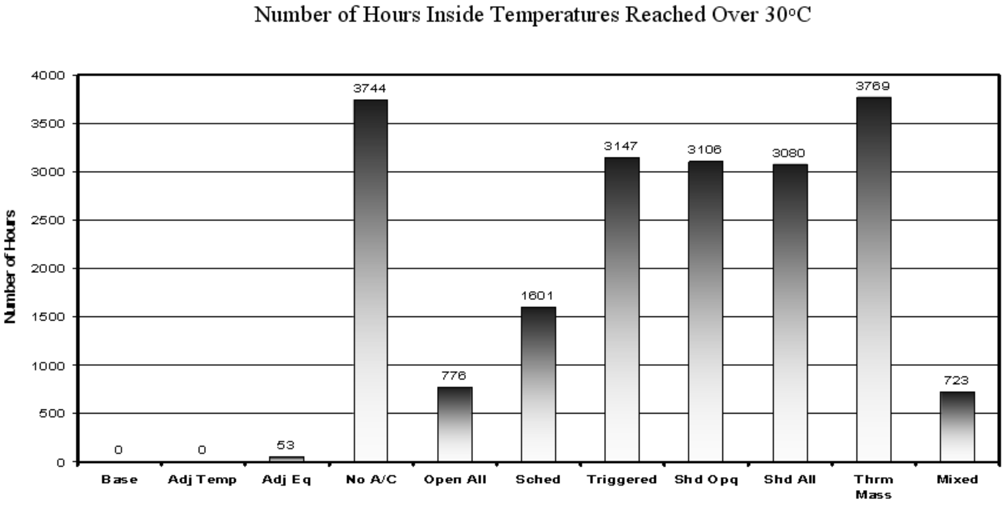

Figure 5: Results from Standard and Proposed Practice simulations.

vices and for the appropriately orientated windows (Rivera, 2004). This reduced the number of hours above the comfort zone by 18%.

The addition of thermal mass into walls defined materials with a 9-12hr lag time. They were incorporated into both internal and external fabric of the building. They increased the number of uncomfortable hours to 3769hrs/yr, though.

Ventilation strategies were also simulated. The operation variations were: Always Open, Night Ventilation, Triggered Open and Scheduled Open. The most effective method by far was to open all of the apertures 24 hours a day 7 days a week, reducing the number of hours to 778.

Open Always was then combined with the opaque shading devices to produce the best result, "Mixed". The number of hours was further reduced. However, the resultant conditions were still not acceptable. An equivalent of approximately 30 days of the year still remained above the comfort zone.

The applications had an unforeseen lack of influence on the conditions within the building. It was hypothesised that this was due to the proportionately small area of exterior walls to the depth of the floor plate, which necessitated that the same simulations be repeated on the building with it zoned differently.

4.4 Perimeter Area

By defining separate thermal zones for the main interior and a 5m perimeter, it was possible to repeat simulations on the prototype and analyse the external zone separately and determine whether any of the applications could achieve greater influence on a narrower geometry (Fig. 6).

The provisions did have a greater impact on the conditions within the perimeter area. A reduction of the floor plate depth was necessary in order to improve internal conditions.

4.5 Revised Geometry

In the final phase of simulations, the centre of the building was cut into, producing a terraced courtyard type building and providing adequate façade surface area access to natural variables. The applications were then simulated on the re-

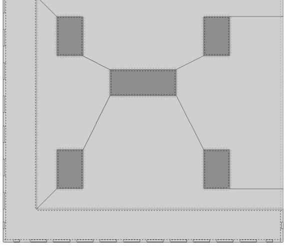

Figure 6: Floor Plan - Perimeter zone as marked.

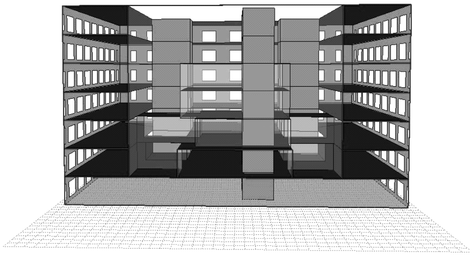

Figure 7: Proposed courtyard geometry of structure.

sulting geometry (Fig. 7).

As the building and its detailing evolved, the first priority was producing a shape to improve daylighting and reduce the lighting heat gains within the structure. The structure was first modelled in Ecotect, using Radiance to obtain grid point values. An original doughnut-shaped building was not successful**,** so seasonally appropriate set-backs for solar access were determined (Rivera, 2004).

Additional tiered set-backs were incorporated at the south, east and west sides of the courtyard. The interior circulation areas at the lower levels were reduced, and the skylights at the ground level were positioned further to the north. A loft level was also added to the building along the northern half of the roof area to include high-end loft apartments overlooking downtown. These units could earn premium rental rates to counteract some of the income lost due to the square footage given up in the formation of the courtyard (Fig. 8).

Material reflectances and fenestration were considered. Internal reflectances were set according to CIBSE's code for lighting: .3-floor, .6-walls, .7-ceiling. External reflectances were also improved: .6-walls and .7-roofs. Additional glazing areas were then incorporated into the courtyard façades. The enclosure of the four stair cores was changed to a translucent triple glazing curtain wall rather than the original opaque concrete block construction. Several of the north and east-facing walls at the lower levels of the courtyard were also changed to translucent or transparent curtain walls. This was feasible because of the degree of protection created by the courtyard. Then the illuminance levels and daylight factors were re-established.

Figure 8: Resultant courtyard geometry.

These modifications improved the average illuminance level to 253lux, a daylight factor of 3.6%. The resultant geometry and material descriptions were then input into TAS which enabled the Auxiliary Lighting Settings in TAS to dim in and out more effectively, reducing the lighting gains.

Further modifications were then made in TAS according to the structure's thermal performance. Several runs were conducted with various combinations of applications. None of the trials were as successful as hoped, though, so simulations attempting to incorporate the benefits of vegetation were conducted.

The shading devices were changed to a translucency of .6 and the windows were given interior blinds of translucency .8. The layering of translucent materials was meant to simulate the depth of vegetation (Lay, 2000). A small cooling source was also added, but neither of the methods produced the benefits of coolth depicted in the previously conducted research. There were still 620 hours above the comfort zone.

Several sources had described up to a 6°C noontime oasis temperatures, a 4°C overall reduction of daily temperatures and a 2°C reduction of temperature extremes with only a 30% vegetation cover. The vegetation cover simulated in TAS was 40-50% coverage, so these benefits were assumed achievable.

An exercise was conducted using the performance of the "Combo" run as a base (Fig. 9). The results were weighted according to the aforementioned data. The temperatures at 12:00 (noon) were decreased by 5°C, altering each hour were gradually less until 0:00 (midnight), which was increased by 1°C. This process is illustrated by the solid line in Figure 8. Even though these proposed results were more conservative than previous studies, acceptable con-

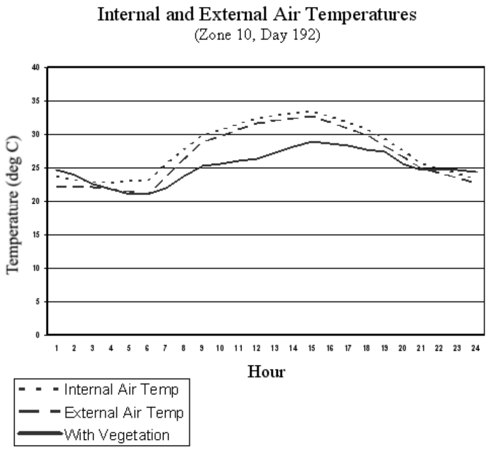

Figure 9: Proposed impact of vegetation.

ditions within the structure were facilitated.

5. CONCLUSIONS

The logical exercise showed that acceptable conditions were feasible. The number of hours which remained above the comfort zone was reduced to only 39. Efficient building usage, a reduced floor plate depth, improved material specifications, adequate solar control, and the inclusion of vegetation, made it possible to eliminate mechanical air conditioning systems within office spaces in the American mid-west.

However, two main areas of future research should be conducted. More accurate methods for the estimation of the benefits of vegetation and means of simulation are needed and a method to better predict the psychological benefits should also be generically sought.

Additionally, improved daylighting should be sought so that the lighting loads could be further reduced. With the resultant reduced heat gains, comfortable conditions within the structure would be more easily facilitated.

Throughout this process, the subjective parameters of comfort and environmental perception have continually been considered. The potential they exhibit to produce more satisfying environments and eliminate mechanical systems is too great to ignore.

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