A CLIMATE RESPONSIVE DESIGN TOOL TO PROMOTE PASSIVE AND LOW ENERGY DESIGN

Authors:
Van Den Wymelenberg, K., Djunaedy, E., University of Idaho – Integrated Design Lab

Date:
May, 2009

A version of this document is published in:

Please cite this paper as follows:
ABSTRACT

This paper outlines an approach to integrated design that addresses many common challenges to incorporating passive and low energy design into new building projects. This approach, developed by the Pacific Northwest University Design Lab Network, focuses on synthesizing patterns of climate, patterns of use, and architectural and passive system design to minimize the primary energy loads of a building. This paper describes a novel design tool that can be used by designers to help them explicitly understand the energy savings potential and other implications of considering climate as a resource within the integrated design process. Specifically, it addresses the synthesis of patterns of climate with patterns of use and building design considerations, including both passive and active systems, to first reduce primary building energy loads and to then meet these loads with passive and low energy systems.

1. INTRODUCTION

Member institutions of the Pacific Northwest University Design Lab Network (Lab Network)* utilize an approach to integrated design that: “… synthesizes climate, use, loads and systems resulting in a more comfortable and productive environment, and a building that is more energy-efficient than current best practices.” (Fig. 1) [1] For the integrated design process to work properly and help designers succeed at dramatically reducing the energy consumption of buildings while also maintaining comfort for inhabitants, designers must understand the intricacies of climate phenomena of the region in which they are designing. Too often, designers assume they understand the climate they are designing for but do not adequately recognize the implications of phenomena such as diurnal or seasonal wind speed and direction variation or cloud cover trends.

Fig. 1 – The integrated design process

From our experience, there are seven main obstacles to incorporating passive and low energy design into the early schematic design stages of a project:

a. The lack of passive low energy design as an embedded principle in the design process
b. The inability to quickly determine whether passive low energy design strategies will be successful
c. The overwhelming amount and complexity of climate data that is not useful to design teams
d. The limited ability to prioritize passive low energy design strategies
e. The inability to quickly quantify the value of passive low energy design strategies
f. The gap in a designer’s technical knowledge of how to incorporate passive low energy design strategies into the myriad other issues that must be attended to when designing a building
g. An assumption that patterns of occupancy are fixed rather than variable and malleable

A mechanism that addresses these obstacles and helps to minimize or overcome them is necessary in order to dramatically increase the use of passive low energy design strategies. We have created a Climate Responsive Design Tool (CRD Tool), a web-based application that addresses each of the barriers listed above in some capacity while focusing significant attention to items b-d. This tool is the first funded project within a larger initiative titled the Pacific Northwest Carbon Neutral Building Initiative [2], which is intended to provide regionally specific technical resources to help design and construction teams keep pace with the milestones of the 2030 Challenge. [3]

The Climate Responsive Design Tool, currently available in a beta release web-based application [http://www.buildingcarbonneutral.org/], helps designers digest complex climate

---

* The PNW University Design Lab Network includes the University of Idaho, University of Oregon, University of Washington, Washington State University, and Montana State University, and consists of design assistance, research and outreach labs in Boise, Eugene, Portland, Seattle, Spokane and Bozeman.
phenomenon by using a color-coded graphic display of raw data that also shows key data interactions through x-y annual hourly area plots and side-by-side comparison. Understanding these climate phenomena helps designers to prioritize the most appropriate passive design strategies for each climate location.

2. CLIMATE RESPONSIVE DESIGN TOOL

To address many of the issues described above, we developed an interactive and graphical web-based design tool that combines climate-specific data with several passive design strategies. Specifically, design strategies are paired with climate data in a way that facilitates playful user interaction; side-by-side data comparisons reveal differences in effectiveness by design strategy or climate location; and other innovative display features help designers make early decisions that improve the implementation of passive and low energy design. The tool can also be used to encourage owners to make an early commitment to passive low energy design and the integrated design process by illustrating the climate-specific feasibility of energy saving strategies in a format conducive to early decision-making. The tool educates design teams on how to interpret relevant climate data and make the connections to the most climate-appropriate strategies.

Fig. 2 shows an example of one the output charts. Hourly data for a typical year is displayed, with days of the year plotted on the horizontal axis and hours of the day on the vertical axis. In each case, hours shown in green indicate when a particular strategy will meet the load; hours shown in white indicate when the strategy will not meet all of the load. Hours in black show when the strategy is not needed. In this example, the design strategy is cross ventilation, a cooling strategy. Black cells are times when cooling is not needed (based on a balance point temperature); all of the remaining hours need cooling. This chart is for north-facing inlets, so the green hours are those when a north-facing opening will act as an inlet for cross ventilation. This sample is from an unreleased prototype that includes graphic scales for both axes and crosshairs to aid in orienting oneself to the data while moving between plots. The crosshairs in this case are located on the solar middle of the year: June 21, noon. The fact that climate phenomena are not symmetrical, over the period of a day or a year, is made graphically clear here.

The benefits and feasibility of several energy design strategies are graphically displayed in over 30 chart types, which show raw climate data as well as data interactions with implications for the major building energy consumption categories of heating, cooling, ventilating, and lighting. The charts help users to understand when specific strategies will work to meet the comfort and functional needs of building occupants given certain user inputs and assumptions built into the tool.

2.1 Tool Specifications

Raw Data and Pre-Strategy Processing:
- Dry bulb temperature
- Relative humidity
- Heating need (variable balance point temperature)
- Cooling need (variable balance point temperature and variable use of ceiling fan)
- Wind direction and speed
- Global horizontal illumination
- Global horizontal radiation

Passive Low Energy Strategies:
- Solar Heating (50% and 100% direct, 100% with mass)
- Stack Ventilation, Cross Ventilation (E,W,N,S)
- Daytime Ventilation (variable ceiling fan)
- Night Ventilation of Mass (50 Btu/sf,hr, 150 Btu/sf,hr, 250 Btu/sf,hr)
- Shading (E,W,N,S)
- Navigation Lighting from Daylight (5 fc at daylight factors of 1%, 2%, and 4%)
- Ambient Lighting from Daylight (20 fc at daylight factors of 1%, 2%, and 4%)
- Task Lighting from Daylight (45 fc at daylight factors of 1%, 2%, and 4%)
- Evaporative Cooling (variable Max dbt, variable Max RH)

**Interactions:**
- compare climate cities
- compare patterns of occupancy

### 2.2 Data Sources

The CRD Tool is built primarily upon TMY 2 weather data, with the exception of Lewiston, ID. (Table-1) The method used to determine representative days for inclusion in the TMY-2 weather data set does not necessarily result in representative wind direction and speed data. [4] Therefore, predominant wind speed and direction data were determined from the SAMSON 30-yr data set.

**TABLE 1: CLIMATES INCLUDED IN EPA R-10**

<table>
<thead>
<tr>
<th>AK</th>
<th>ID</th>
<th>OR</th>
<th>WA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchorage</td>
<td>Boise</td>
<td>Eugene</td>
<td>Olympia</td>
</tr>
<tr>
<td>-</td>
<td>* Lewiston</td>
<td>Medford</td>
<td>Seattle</td>
</tr>
<tr>
<td>-</td>
<td>Pocatello</td>
<td>Portland</td>
<td>Spokane</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>Salem</td>
<td>-</td>
</tr>
</tbody>
</table>

Lewiston, ID uses TMY-1 data

### 3. TOOL USE SCENARIOS

#### 3.1 Building Designers and Strategy Feasibility

The most important application for the CRD Tool is in early building design by architects and engineers. Several example outputs are provided.

Fig. 3 is an example of a plot showing the strategy of night ventilation of mass in Boise. Black indicates hours when cooling is not needed; green shows hours when cooling is needed and the minimum daily temperature is cool enough that night ventilation of mass can cool a building with a cooling load of 150 Btu/sf*hr. White indicates days when the minimum daily temperature is too high for such cooling. In this case a user might decide that night ventilation of mass is not sufficient by itself and that other strategies need to be explored. Or, they may establish a goal to reduce the internal loads from people, lights, equipment, and heat gains from the envelope such that there is only a 50 Btu/sf*hr cooling load. Fig. 4 shows the result for comparison.

Fig. 3 – Boise night ventilation of mass potential (150 Btu/sf*hr internal load); Green indicates hours when need is met, White indicates hours unmet

Fig. 4 – Boise night ventilation of mass potential (50 Btu/sf*hr internal load); Green indicates hours when need is met, White indicates hours unmet
3.2 Climate Comparisons to Aid Understanding

Designers often rely on an intuitive, experiential understanding of a climate, but this can be misleading. Perceptions of a familiar climate may be distorted by memories of extreme weather events, while perceptions of an unfamiliar climate may be even more unreliable if based on sporadic visits to the climate or assumptions based on a neighboring but geographically dissimilar climate. Comparing different climates, whether known or unknown, can break down assumptions and provide a quick way to grasp their differences and similarities. It also helps to put known, local experiences into a larger context.

Fig. 7 shows an example of a side-by-side comparison from an unpublished version of the CRD Tool. Portland and Boise have somewhat similar cooling needs, as displayed by the shape of the colored area. Daytime ventilation with ceiling fans works well as a cooling strategy in Portland; there are a minimal number of hours in summer when the strategy does not meet the need (shown in white). In Boise, however, the majority of summer afternoons are too hot to use this strategy. If the strategy does not meet the need during occupied hours, a different strategy should be considered.
3.3 Applications During a Charrette

Like design professionals, owners and other stakeholders in the design process may rely on perceptions of climate, but they usually have less experience in understanding an objective description of the conditions. The CRD Tool, with its simple, consistent, and easily grasped representation, can assist in clarifying climate patterns. During a design charrette the CRD Tool can be used by the design team to rapidly show a building owner the percentage of hours during a typical year that a building of a certain balance point (or with given internal gain assumptions) is kept comfortable and functional considering a suite of passive strategies. Establishing the effectiveness of specific strategies relative to one another can help increase owner buy in, assuage owner or user fears, and establish quantifiable goals for building design.

For instance, Fig. 8 shows the hours of the year when a building in Seattle with a daylight factor of 2 (2% of outdoor illumination available indoors) can provide functional illumination for task lighting (45 fc). Fig. 9 shows the same for ambient lighting (20 fc), and Fig. 10 for navigational lighting (5 fc).

The CRD Tool can also be used to graphically emphasize the major climatic priorities that must be considered during the design process. For instance, a design team based in Seattle may need to communicate the potential of evaporative cooling for a building they are designing in Boise.

Fig. 11 shows the evaporative cooling potential for Seattle. The maximum air temperature is set at 75° with maximum relative humidity of 35%. When using the CRD Tool, users can drag a slide bar to set both the temperature and the relative humidity. The cooling hours for Seattle are low in the first place (227 hours or 3% of the time). Out of these
hours, only 20% can be handled by evaporative cooling. Comparing that to Boise (Fig.12), there are more than 1000 cooling hours (12% of the year). Out of those cooling hours, almost 92% can be handled by evaporative cooling, leaving only 88 hours that must be met with conventional cooling systems. These unmet hours occur mainly during the months of July and August at the extremes of the day when it is either too hot (afternoon) or too humid (morning) to meet the cooling requirements with evaporative techniques.

By studying these graphs, the designer can illustrate how using evaporative cooling can reduce the need for mechanical cooling. For the design of many schools, for example, the need for mechanical cooling can be eliminated altogether because the unmet hours occur during summer vacation.

4. DISCUSSION

4.1 External Testing

We have externally tested the tool with students and professionals. In the case of students, the tool was provided to an architectural studio that was designing for three distinct Oregon climates. We described the charts in detail and assisted individuals in their use. It should be noted that climate appropriate design was an explicit requirement of the studio, and the students received substantial support in their efforts. Every student chose appropriate strategies for their designs; the ability to make comparisons across climates was especially effective in helping them understand the real conditions at each site. It was interesting, though, that some students sought out traditional wind roses, a tool they were familiar with for this purpose. On the other hand, the temperature-based plots were generally used without additional data or visualizations.

We have also used the tool with professionals in the course of providing design assistance. This testing has been more informal than that in the academic setting. We have received positive feedback in most instances and in some the reaction was quite enthusiastic. This is an area in which we anticipate substantial further testing through observation of use by our clients.

4.2 Comparison to Other Tools

The CRD Tool includes several innovations not present in other climate-based design tools. Autodesk’s ECOTECT Weather Tool [5] and UCLA’s Climate Consultant 4 [6] are both excellent resources. While the CRD Tool is still in the beta phase and has a limited number of cities developed, it accomplishes something the other climate tools do not. First, it is web-based and it is free. ECOTECT Weather Tool is currently only available as part of the ECOTECT 2009 single seat package, which retails for $2,495. Climate Consultant 4 is free; however, neither of these tools are web-based. The benefit of a web-based tool is that it facilitates impromptu use during charrettes and does not require software installation or administrative privileges to use. Second, the CRD Tool will facilitate side-by-side climate comparisons as demonstrated by the unreleased...
version shown in Fig. 7. Third, the CRD Tool is structured with user adjustable interactive variables that directly relate to building performance features and are represented in the climate-based graphic output. Examples demonstrated in this paper include the ability to select different lighting criteria (task, ambient, navigation) and daylight factors (1%, 2%, 4%) to assess daylight performance, as shown in Fig. 8 – Fig. 10, and the ability to vary maximum acceptable temperature and relative humidity in relation to evaporative cooling effectiveness, as shown in Fig. 11 and Fig. 12. The CRD Tool has several other user adjustable elements that can be employed, which helps in convincing design team members or owners of the viability of a particular passive and low energy design strategy because it can be more specifically related to their project. The component of ECOTECT Weather Tool and Climate Consultant 4 that comes the closest to this capability of the CRD Tool is the bioclimatic zonal expansion techniques seen in the psychrometric chart. However, these tools do not allow the user to manipulate the variables underlying the calculation of the comfort zone expansion as is possible with the CRD Tool. Furthermore, the psychrometric chart is not an intuitive format for design professionals to understand the implications of the design strategy. The CRD Tool outputs are presented in a simple x-y coordinate based upon the time of the day and day of the year.

5. CONCLUSION

The CRD Tool was developed to help designers, engineers and building owners communicate effectively about passive and low energy design strategies based upon understanding the climate as a resource within the integrated design process. The tool has several innovations that distinguish it from other climate analysis tools. The CRD Tool is currently available in a beta release and would benefit greatly from additional development. Specifically, we would like to further develop the side-by-side data comparison in the web application, incorporate additional climate locations in order to expand the tool’s applicability beyond the Pacific Northwest, and develop additional user adjusted variables.

6. ACKNOWLEDGMENTS

We would like to thank the Region 10 offices of the United States Environmental Protection Agency for supporting this work. We would also like to express our appreciation to the staff at the University of Idaho Integrated Design Lab, Tristan Van Slyke and Rebekah Ownbey, for their support of the project and website development. The team at the University of Oregon Energy Studies in Buildings Laboratory included Dianne Ahmann, Terry Blomquist, Ed Clark, Kristina Lang, Gwynne Mhuireach, Dale Northcutt, and Tomoko Sekiguchi.

7. REFERENCES


