Potential for Improved Outdoor Comfort by Design in U.S. Climates

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Summary

This white paper presents the potential for passive design strategies to improve comfort in outdoor environments in different regions of the US. These strategies, which are frequently used by Transsolar, include improved ventilation, shading, and misting in the summer and improved solar access and wind protection during the winter.

The study shows that climate zones in the middle of the continental US, from the Mid-Atlantic and Southeast across to the southern Midwest and Southwest, have the most potential for comfort improvement – 40-50% of the summer and winter that would have been uncomfortable can be made comfortable through design. As you move north or south from this band, the potential diminishes, but most climates show the potential to make an additional 20-30% of the summer and winter comfortable through design.

In addition, the Pacific Coast climate zones displayed exceptional baseline comfort without any of the improvement strategies. In the case of the Pacific Northwest during winter, this baseline comfort was also accompanied by significant potential for comfort improvement (up to 75% absolute increase from the baseline).

These results demonstrate the value of intentional design to improve outdoor comfort in most of the U.S. with corresponding improvements in human comfort, wellbeing, and efficient use of energy in outdoor spaces.

Process

We chose the Universal Thermal Climate Index (UTCI) to quantify comfort. UTCI is calculated using the dry bulb temperature, mean radiant temperature (MRT), humidity ratio, wind speed, metabolism, and clothing. It effectively measures what the temperature “feels like”. We assumed the comfortable UTCI range to be 10-26°C.

The next step was to determine what scenarios we would simulate in order to accurately represent improvement potential. Winter and summer months were separated, by November to April and May to October respectively. Next, “worst case” scenarios were designated as the control or baseline cases for both seasons. In the summer, the control is the warmest possible scenario with a MRT 20°C greater than the ambient temperature and no wind. The winter control is the coldest possible, with MRT equal to the ambient temperature and wind at 3 m/s. Improvement scenarios were then assigned to both seasons. In the summer, breeze, shade, and misting were introduced through 3 m/s wind, MRT equal to ambient temperature, and 60% adiabatic cooling. In the winter, improvements were achieved by raising the MRT to 10°C above the ambient temperature and removing wind. For this study, only daytime hours are considered based upon the assumption that outdoor spaces would be most frequently used during the day. We calculated the daylight hours for each of city for summer and winter by taking the average of the sunrise and sunset times between the applicable solstice and spring equinox.

Once the scenarios were established, we collected data from a variety of cities across the United States. These cities were chosen to represent all 16 ASHRAE climate zones (Figure 1). Two cities were chosen in every zone expect for 4A and 5A which each contained four. To get the necessary data, we used hourly weather data in the typical meteorological year (TMY3) data files from the National Solar Radiation Database as inputs into our internal JavaScript-based weather visualization tool. This tool allows us to input the weather files and easily calculate UTCI values at hourly increments based upon applied changes in wind and MRT.

We analyzed the resulting UTCI values by graphing the percentage of daytime hours within the comfortable UTCI range for each city under each scenario. As improvements were applied by changing MRT or wind, the best-case scenario for each hour was chosen. For example, if in the summer control scenario a certain hour is within the comfortable UTCI range but when shading is introduced the hour drops out of comfort, this hour would still be considered comfortable. This assumption is reasonable for most scenarios, since shading or ventilation can be adjusted if there is wind or sun present. If they are not, active strategies, such as fans or heated slabs, may need

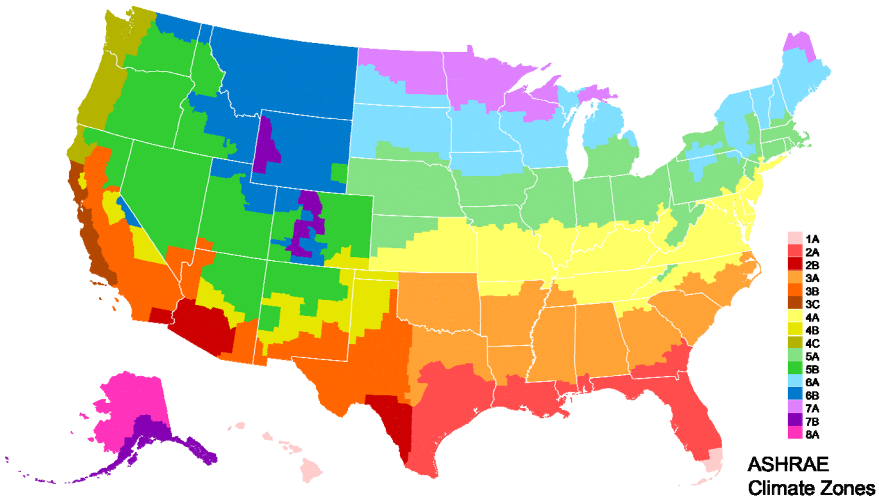

Figure 1: ASHRAE Climate Zones for the U.S.

to be implemented to achieve these conditions. We also graphed the potential of each city to improve the percentage of hours within the comfortable UTCI range by taking the difference in percentage points between improved scenarios and control. Finally, we averaged out the comfort percentages for cities in the same climate zone and calculated the difference between the baseline and best-case scenarios (Figures 2-3), which shows the potential for improvement through design intervention.

For mapping, we used a d3 mapping script, which assigns values to every US County based upon its FIPS code. We used two data files, each with over 30,000 rows of data, one which paired US Towns with ASHRAE Climate Zones and another which paired US Towns and FIPS codes. To expedite this process we wrote a script to match Climate Zones with FIPS codes and then paired our data for each climate zone's baseline comfort and improvement potential in both the winter and summer. This allowed us to populate the map and show the variation in both best-case comfort with design interventions (Figures 4 & 6) and the improvement potential of the best-case compared to a case with no interventions (Figures 5 & 7) across climate zones.

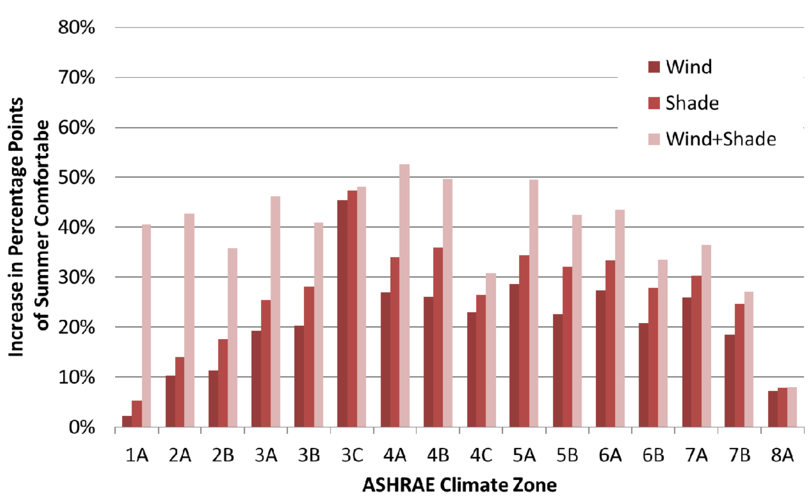

Figure 2: Increase in percentage points of summer comfortable with design interventions by climate zone

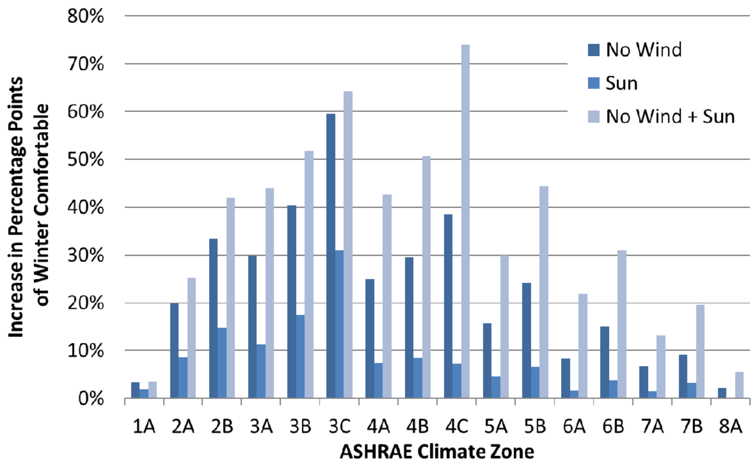

Figure 3: Increase in percentage points of winter comfortable with design interventions by climate zone

Results and Discussion

A few interesting trends emerge from the figures and maps produced from this study. First, in the summer, shade is more effective than wind at improving comfort. In the winter, removing wind provides more comfort improvement than adding sun. This demonstrates that wind is the more important factor to consider under colder conditions and sun is more important under warmer conditions. It is important to note that this trend emerges under our assumption that wind is blowing at 3 m/s and sun provides a 20°C or 10°C increase in MRT in the summer or winter. Also, in summer, misting was consistently less effective than wind or shade at increasing comfort. For this reason we have chosen to leave it off the figures.

The study affirms common intuition which suggests that the most comfortable regions in the summer are the northern, colder zones, and during the winter; the southern, warmer climates are more comfortable. In both seasons the zones on the pacific coast, 3C and 4C, exhibit high comfort percentages. The climate in these zones has remarkably low seasonal variation, with UTCI values hovering within or nearby the comfortable range during all months of the year.

The comfort improvement potential figures and maps show that zones in the middle of the continental US, 3A and 4A in particular, have the most potential to benefit from these strategies. As you move farther north or south, this potential diminishes either because the extreme hot or cold UTCI values are too far away from the comfortable range, or because the control comfort percentage is already high.

It is also clear that each climate zone experiences jumps in comfort improvement as a result of different strategies. For example, in the summer, zone 1A only begins to achieve significant improvement in comfort once wind and shade are both introduced together. However, in zone 3C only wind is necessary to achieve significant improvement.

In the winter, zone 4C, the Pacific Northwest, stands as an outlier. It has the largest potential for improvement of over 75% between the control and best case scenario (no wind and sun). However, other factors need to be considered alongside the data. This region generally has very little sun which may make it difficult in winter months to consistently achieve the increase in MRT which the study suggests. Similar considerations should be made with the results from all climate zones. A more robust study could be performed to get more granular, site specific data on potential.

Despite its limitations, the results of this study carry practical implications for the people designing our outdoor spaces such as urban designers, architects, and landscape architects. In certain regions, active systems such as space heaters, air conditioning, mechanical ventilation, and other energy intensive strategies may be necessary to keep patrons of an outdoor space comfortable. However, in large regions of the US, spaces can be designed elegantly to make use of the climate, including wind and sun patterns. Designers should feel compelled to take advantage of these opportunities. Doing so will not only benefit the users of the space, who will be able to dress comfortably and feel a connection to the outdoors, but the environment as well, due to more responsible energy use and, in most cases, fewer carbon emissions.

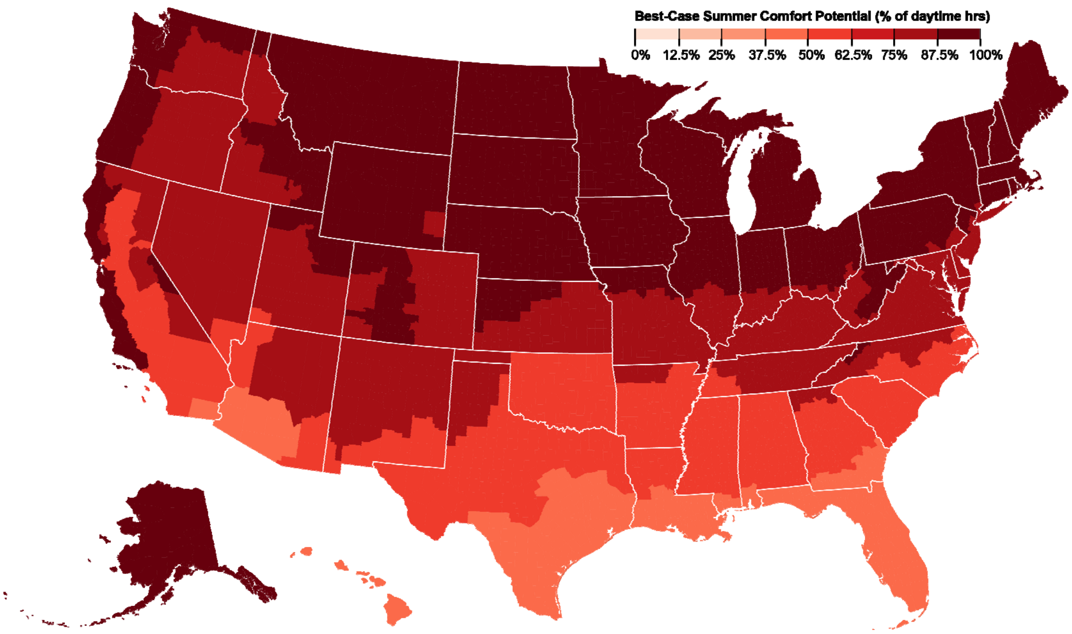

Figure 4: Best-case percentage of summer daytime hours comfortable with design interventions

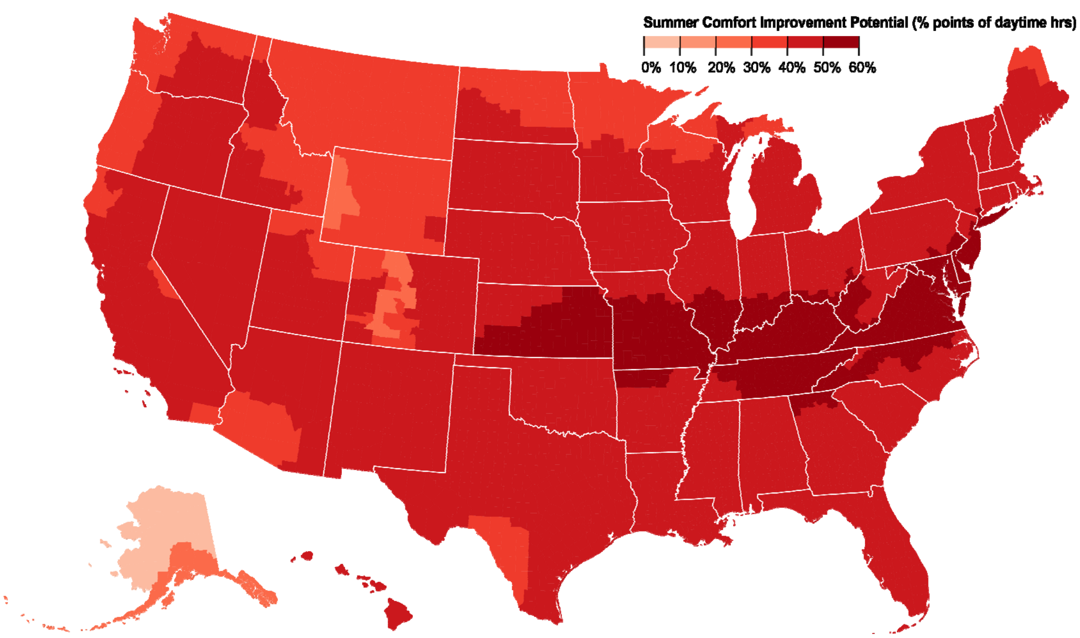

Figure 5: Increase in percentage points of comfortable daytime hours in summer with design interventions versus without (10% = increase in percent of comfortable hours from 50% to 60%)

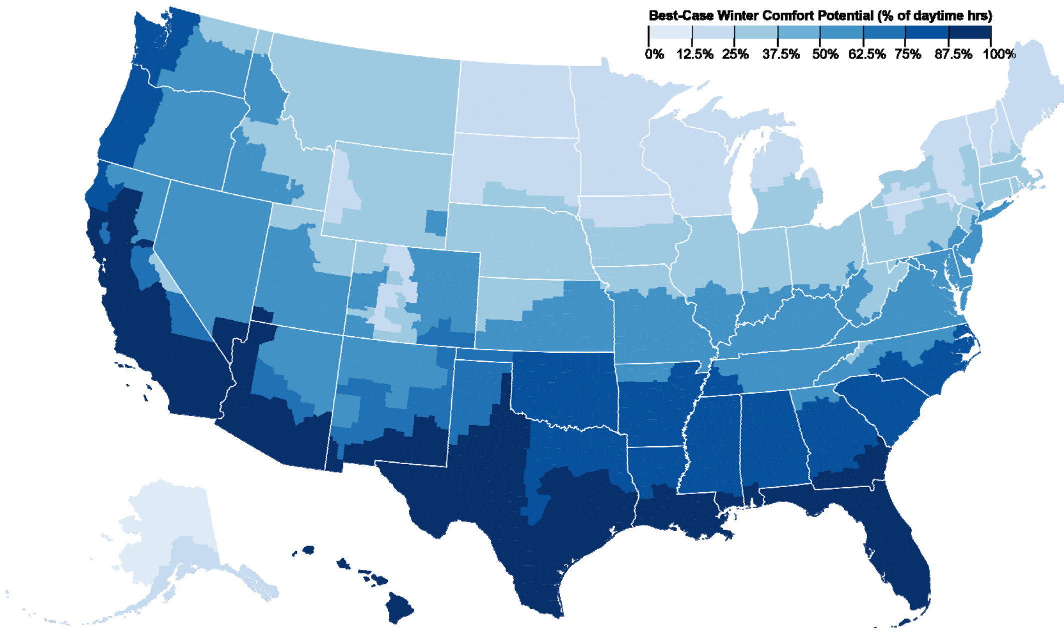

Figure 6: Best-case percentage of winter daytime hours comfortable with design interventions

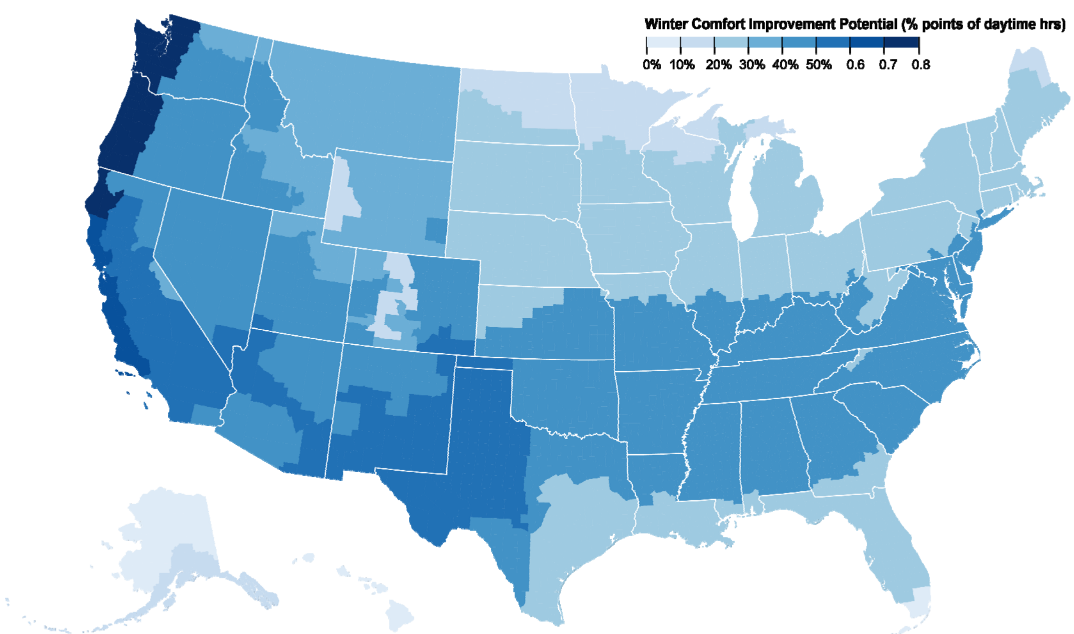

Figure 7: Increase in percentage points of comfortable daytime hours in winter with design interventions versus without (10% = increase in percent of comfortable hours from 50% to 60%)