

CLIMATE CONSULTANT 3.0: A TOOL FOR VISUALIZING BUILDING ENERGY IMPLICATIONS OF CLIMATES

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ABSTRACT

Designing and remodeling buildings that are truly climate responsive depends first on gaining a detailed accurate understanding of the local climate. A newly revised design tool called Climate Consultant 3.0 has just been released that is intended for architects, students of architecture, builders, contractors, and knowledgeable homeowners. It reads the local climate data for all 8760 hours per year in EPW (EnergyPlus Weather) format files which are now available for over a thousand stations around the world. For any chosen location Climate Consultant 3.0 will display dozens of different graphic images of various weather attributes and will suggest building design strategies appropriate for the unique characteristics of that climate. Both Climate Consultant and EPW Climate Data are available on the web at no cost.

Compared to the prior versions, the new Climate Consultant 3.0 is now written in Java making it compatible with both Mac and PC machines. Instead of using the older compressed TMY climate data, it now directly reads EPW files which include over a thousand new stations. It now also allows instant conversion between Imperial (inch-pound) and Metric (SI) units. Climate Consultant 3.0 also adds a number of new features, especially the new Wind Wheel.

1. OBJECTIVES:

The purpose of Climate Consultant 3.0 is not simply to plot climate data, but rather to organize and represent this information in easy-to-understand new ways that reveals the subtle attributes of the climate and its impact on built form. The goal is to help users create more energy efficient, more sustainable buildings, each of which is uniquely designed for its particular spot on our planet.

The basic plots are the usual temperature, radiation, and humidity bar graphs, while beyond these are more sophisticated graphic analysis options. A few of the following charts will illustrate the power of Climate Consultant 3.0:

- Table of Mean Climate Data
- Set Criteria
- Temperature Range Bar Chart
- Radiation Range Bar Chart
- Sky Cover Range Bar Chart
- Wind Speed Bar Chart
- Dry Bulb vs. Relative Humidity Chart
- Dry Bulb vs. Dew Point Chart
- Sun Shading Chart
- Sun Chart
- Time Table Plots
- 3D Charts
- Psychrometric Charts
- Wind Wheel

2. USER FRIENDLINESS:

When in doubt about what to do next, simply click NEXT in the lower right corner of the screen. This will take you to the next logical screen in order. On any screen where you do not understand a term click on Help in the tool bar. On many charts there are other buttons on the left hand side panel which can also be tested. Do not worry about trying out different options because you can always return to the Set Criteria table and click the Restore Default Values button.

3. EPW CLIMATE DATA:

EPW(Energy Plus Weather) data is provided by the US Department of Energy. Each EPW climate data file contains hourly data for all 8760 hours per year. These files were assembled by climatologists from actual months of recorded data for that site. Although the months might be selected from different years, the objective was to make the average temperatures for the EPW data year match the long term average data for the site. Where possible the record temperatures in the EPW file matched the average highest and average lowest temperatures in the long-term statistics. To prevent jumps in the data between months, special statistical smoothing functions were used to modify data for three days at the end of each month and the beginning of the next. This approach tries to preserve the unique patterns of actual data, sequences of extremes data, and recurring weather patterns. Recorded long term radiation data is rarely available for most sites so instead is calculated.

4. SET CRITERIA

On the Set Criteria table you can change any of the criteria or decision points that are used throughout Climate Consultant 3.0, especially on the Psychrometric Chart and Wind Wheel screens. These include, for example, the definition of the comfort range that is shown on many of the charts. While default values for parameters used to define criteria are built-in, they can be modified to reflect alternative conditions. These numerical values are different depending on whether Imperial or Metric units were selected on the prior screen. Note that if you make any changes here using Imperial Units, but later change to Metric, all your values will be automatically converted appropriately. Note also that on the bottom of the screen there is a button that lets you Restore Default Values.

5. TEMPERATURE RANGE:

The simplest Charts are Temperature Range, Radiation Range, Sky Cover Range, and Wind Speed Range. The Temperature Range chart will be used as an example of all these.



Fig.1: This Temperature Range Chart is the simplest of all charts, in this case showing dry bulb temperatures for Cleveland for all 12 months and also for the full year.

In the Temperature Range Chart (Fig.1) the Record High and Low Temperatures (round dots) are the highest and lowest Dry Bulb Temperatures in each month or over the full year in the EPW file. Note that they are probably not the all-time record high for that site but rather represent the average of the annual record highs.

The single bar on the right hand side shows the Annual Design High or Low Temperatures (top and bottom of green bars). They are used to calculate the size of the heating and cooling equipment, and are defined on the Criteria screen as a percentage of hours not met per year (the default percentages are from the California Energy code). These same Design Temperatures are also shown for each individual month using that same percentage of hours in that month.

Average High and Low Temperature (top and bottom of yellow bars) are the average of the highest or lowest dry bulb temperatures for each day during the month, or annually.

Mean or Average Temperature (open slot) is the average of all Dry Bulb temperatures in that particular month or annually.

6. SUN SHADING CHART:

The next examples show how local climate data can increase the power and applicability of design tools, in this case two tools that help create and evaluate sun controls for windows.

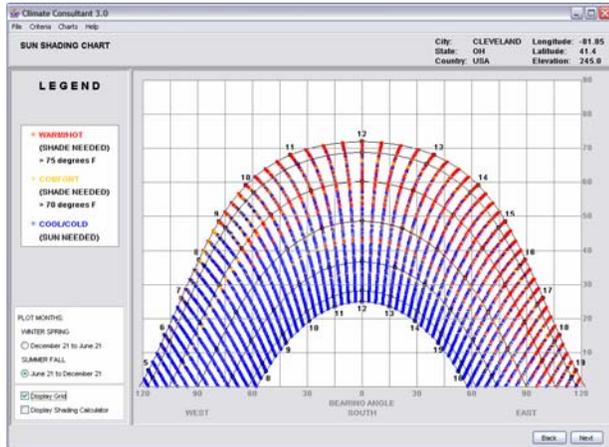


Fig.2: This Sun Shading Chart for Cleveland shows the sun's bearing (along the bottom) and altitude (vertically) for every 15 minutes of the year in colored dots.

On this Sun Shading Chart (Fig.2), the yellow dots indicate comfort conditions when the dry bulb temperature is within the comfort zone as defined on the Criteria Screen. Red dots indicate overheat conditions when the dry bulb temperature is above the top of the comfort range. Blue dots indicate underheat conditions when dry bulb temperatures are below the bottom of the comfort zone. Ideally for a passive heated house, the windows should be fully exposed wherever there are blue dots, and to prevent overheating the windows should be fully shaded wherever there are red or yellow dots.

There are two different sets of Plot Months, one for winter and spring (December 21 to June 21), and the other for summer and fall (June 21 to December 21). Switching between these two will show that summer and fall have many more overheat hours.

To design window protection that blocks the sun for most of the overheat hours an overlay is available to show the cut-off altitude for an overhang and the cut-off bearings for the left and right fins (Fig.3). By checking the Display Shading Calculator box in the lower left corner, this overlay will be plotted showing the cutoff

angle of a simple overhang (measured vertically as indicated by the curved lines) and for side fins (measured along the horizontal axis and represented by vertical lines). Initially it is assumed that the window is facing due south. However this Shading Calculator can be moved to the actual bearing by sliding one of the arrowheads at the bottom of the chart to represent a window facing in any direction (for a more detailed explanation of how to use this chart to design sun shading devices see Lechner, Mazria, Milne, or Olgyay).

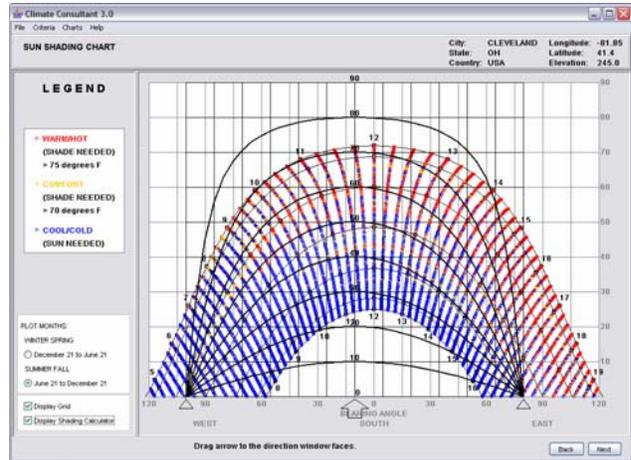


Fig.3: Sun Shading Chart showing the Shading Calculator Overlay, in this case moved 10° to the right (east)

7. SUN CHART

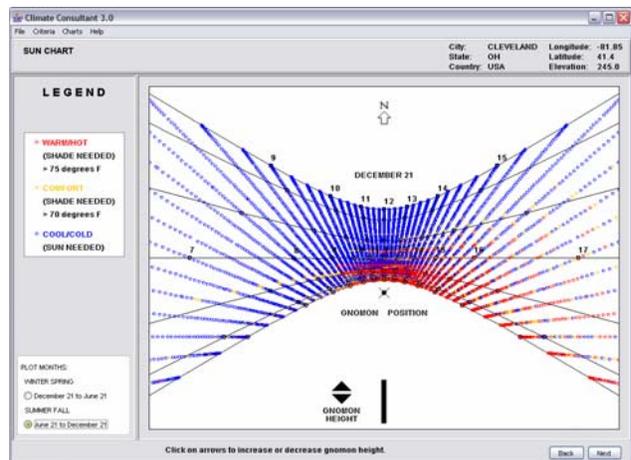


Fig. 4: The Sun Chart is like a flag pole sun dial. The gnomon is the object that casts the shadow, like a pin or flagpole mounted

vertically on the x shown as Gnomon Position. It shows in plan view the shadow cast by the gnomon every 15 minutes during the year in colored dots.

As in the previous example, the yellow dots indicate comfort conditions when the dry bulb temperature is within the comfort zone. Red dots indicate overheat conditions when the dry bulb temperature is above the Comfort High Temperature. Blue dots indicate underheat conditions when dry bulb temperatures are below the Comfort Low Temperature.

This chart can be made into a sundial to test scale architectural models of windows with sun shades. Attach the sundial to the model, and using the sun or any other distant light source, check that the windows are shaded on any hour of any day when the shadow falls into the red zone. Also check that the windows are exposed when the shadow falls into the blue zone (for an explanation of this technique see Lechner, Milne, Stein-Reynolds, and others).

8. TIMETABLE PLOTS

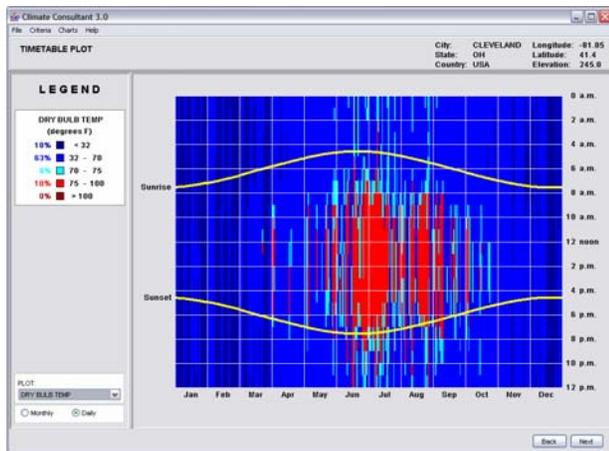


Fig. 5: This Timetable Plot shows the months of the year along the bottom, and the hours of the day along the side. The time when Sunrise and Sunset occurs for each month in this latitude is indicated by the curved yellow lines.

Any one of eight different variables can be displayed as Timetable Plots by selecting from the box in the lower left: Dry Bulb Temperature, Wet Bulb Temperature, Depression (difference between Dry Bulb and Wet Bulb Temperatures), Relative Humidity, Wind Speed, Total

Horizontal Radiation, Direct Normal Radiation, and Sky Cover. The units for each variable are indicated in the upper left, divided into five different ranges in colors from blue to red. The percentages of hours during the year that fall in each range are also shown.

This Dry Bulb Temperature Plot was initially named by Olgay as the Timetable of Bioclimatic Needs, and was used in his text to display graphically the differences between different types of climates. It also shows in dark blue when windows should be exposed for passive heating and in light blue or red when windows should be shaded. The comfort zone is shown in light blue.

Eight different variables can be plotted in this 2-D graphic Timetable formant by selecting from the box in the lower left of this chart: Dry Bulb Temperature, Wet Bulb Temperature, Depression (the difference between Dry Bulb and Wet Bulb Temperatures), Relative Humidity, Wind Speed, Total Horizontal Radiation, Direct Normal Radiation, and Sky Cover. The units for each variable are indicated in the upper left, divided into five different ranges. The percentages of hours during the year that fall into each range are also show.

9. 3-D CHARTS

These same eight different variables can also be plotted as 3-D Charts which allow the user to see subtle differences in this same data. These variables can be selecting from the box in the lower left.

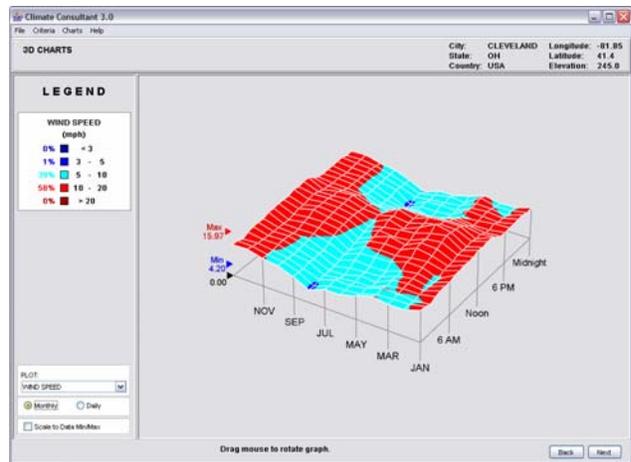


Fig.6: These 3D Charts plot the same data as the Timetable Plot, except in 3-Dimensions. It shows along the bottom the months of the year and along the side the hours of the day.

In the bottom left the plot can be changed from Daily (which shows each of the 8760 hours per year), to the Monthly (which shows the average for each hour of the month). The height of these 3-D plots can be changed by selecting the box in the lower left titled Scale to Data Min/Max. Notice that you can click and drag with the mouse to rotate this plot to any angle, which is especially helpful to see hidden data buried in some plots.

This particular example shows Wind Speed (Fig.6). Note that the lowest speeds occur at night in the summer, which means that if you were designing a high mass house in Cleveland, it would not be very successful if you were depending on natural ventilation for night flushing to cool down the thermal mass (instead you probably will need a whole house fan).

In this second example of a 3-D Chart (Fig.7) for Sky Cover in Cleveland, shows that the most overcast conditions occur in the winter, a fact you should consider carefully if you were designing a house that was to depend on passive solar heating.

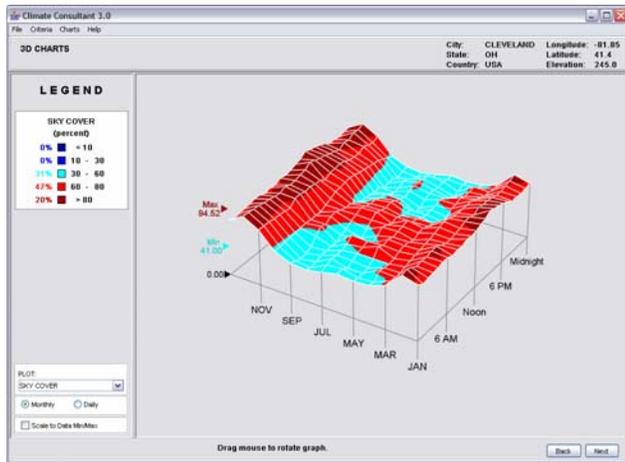


Fig.7: Another 3D Chart Shows Sky Cover

10. PSYCHROMETRIC CHART:

The Psychrometric Chart is an example of how three different attributes of the climate can be displayed concurrently to show if humans will be comfortable in spaces with these characteristics. More importantly it can also be used to show how to design buildings envelopes that can modify or filter these external climate conditions to create comfortable indoor environments.

In the example here (Fig.8), the temperature (bottom scale) and absolute humidity (right scale) is plotted for every hour of the year, with the color indicating whether it is above the comfort zone (red) or below it (dark blue).

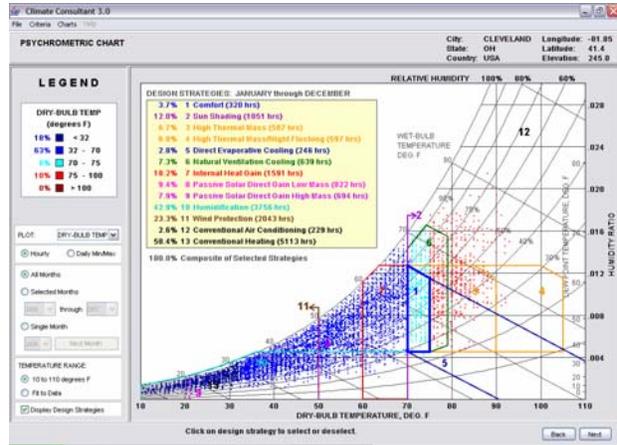


Fig. 8: The Psychrometric Chart is one of the most powerful graphic design tools in Climate Consultant 3.0 because it not only shows which building design strategies to use but also quantifies how effective each will be.

In the Psychrometric Chart each of 13 different building design strategies can be represented as different colored zones on the chart. To display this data select the ‘Display Design Strategies’ option in the lower left.

DESIGN STRATEGIES: JANUARY through DECEMBER

3.7%	1 Comfort (320 hrs)
12.0%	2 Sun Shading (1051 hrs)
6.7%	3 High Thermal Mass (587 hrs)
6.8%	4 High Thermal Mass/Night Flushing (597 hrs)
2.8%	5 Direct Evaporative Cooling (246 hrs)
7.3%	6 Natural Ventilation Cooling (639 hrs)
18.2%	7 Internal Heat Gain (1591 hrs)
9.4%	8 Passive Solar Direct Gain Low Mass (822 hrs)
7.9%	9 Passive Solar Direct Gain High Mass (694 hrs)
42.9%	10 Humidification (3756 hrs)
23.3%	11 Wind Protection (2043 hrs)
2.6%	12 Conventional Air Conditioning (229 hrs)
58.4%	13 Conventional Heating (5113 hrs)

Fig.8a: Blow up of the table in the upper left corner of the Psychrometric Chart in Fig.8 shows the percentage of hours that fall into each of these 13 zones for Cleveland’s climate.

The Table of Effective Design Strategies (Fig.8a) will be displayed in the upper left. It shows the number of hours and the percentage of time that falls within each strategy range. Changing the building design or default criteria will change these numbers. In this example for Cleveland it shows that 3.7% of the hours per year are in the comfort range.

The best single cooling design strategy is Sun Shading which accounts for 12.0% of the hours. It has the advantage of being able to be combined with all the other cooling strategies. The next most effective cooling strategy is Natural Ventilation which accounts for 7.3% of the hours. Another different strategy is High Thermal Mass which accounts for 6.7% of the hours, but this implies a very different type of construction. Note that if this strategy was combined with Night Flushing (using a whole house fan or natural ventilation) it adds only an additional 0.1% of the hours. Because Cleveland is relatively humid in the summer Direct Evaporative Cooling could account for only 2.8% of the hours. Conventional Air Conditioning is the only other option for cooling all of the hours that fall outside of these zones on the Psychrometric Chart. Note that the 2.8% figure shown here is a bit deceptive because it assumes that all of the cooling strategies are used simultaneously, something that rarely happens in reality.

On the heating side 18.2% of the hours would be comfortable indoors purely because of internal loads (lights, appliances, and people). Passive Solar Direct Gain with Low Mass could add an additional 9.7% of the hours, but if the building was High Mass then Passive Solar Direct Gain could create comfort conditions for only about 7.9% of the hours. If Wind Protection was provide it could improve thermal comfort for 23.3% of the hours per year. Because it is so cold in Cleveland in the winter 42.9% of the hours would be too dry for human comfort so some form of humidification would be required, however note that most human activities like cooking, bathing, and clothes washing add moisture to interior spaces, so this is seldom a problem in modern well sealed houses. But even under the best of passive heating conditions at least 58.4% of the hours per year will require Conventional Heating.

Different building design strategies can be tested by selecting or de-selecting any combination of the 13 options in this chart. In that way for example, a Los Mass House that uses Natural Ventilation for cooling and Passive Solar Direct Gain heating, along with Sun Shading and Wind Protection can be shown on the chart

and the number of hours of Conventional Heating and Cooling will be calculated.

The Psychrometric Chart has many other options that can be selected from the panel on the left. For example instead of using colors to represent Dry Bulb Temperature, it is possible to select Direct Solar Radiation, Wind Speed, or Sky Cover. Individual months can also be selected or de-selected. Yet another option is rather than show every hour as a dot on the chart, only the daily high and low can be shown with a colored line drawn between each (Fig.9). This represents the diurnal temperature differences which helps resolve questions of whether high mass building design strategies will be appropriate for this climate (for further information on the use of this chart see Milne-Givoni, Givoni, Lechner, and Stein-Reynolds).

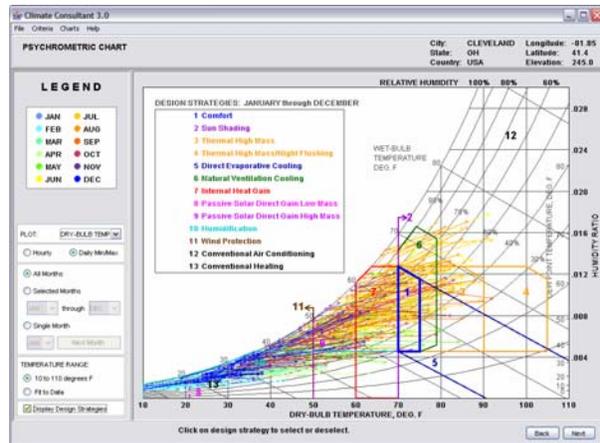


Fig.9: This second example of the Psychrometric Chart shows just the daily high and low temperature plotted with a colored line between, which gives a good visual indication of the diurnal temperature difference.

11. WIND WHEEL

A unique way of representing wind data has been added to Climate Consultant 3.0. It shows on one screen a number of different interacting variables (Fig.10). The outermost ring (brown) shows the percentage of hours when the wind comes for each direction. On the next (blue) ring the height and color of the radial bars shows the average temperature of the wind coming from each direction (light blue is in the comfort zone). The next ring shows average humidity (light green is considered comfortable). The three triangles in the innermost circle show the minimum, average, and maximum velocity of

the winds from each direction; in this case the fastest wind comes from the south southwest and reaches 45 miles per hour.

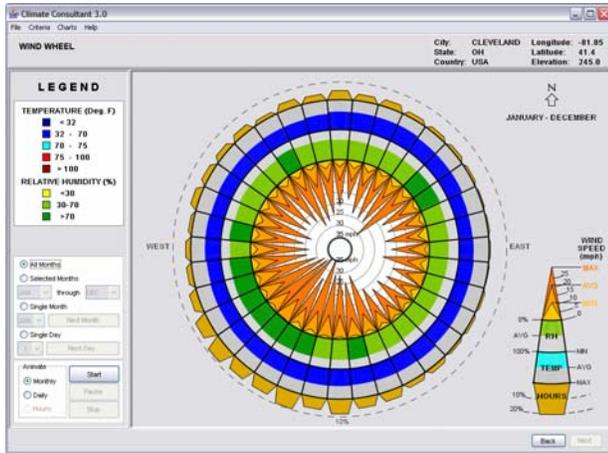


Fig. 10: WIND WHEEL: This is a new kind of graphic that was added to Climate Consultant 3. It shows on one diagram a number of variables of the local climate related to wind direction.

One of the most interesting options is that the Wind Wheel can animate any set of days or months so you can watch how wind direction, velocity, and all the other variables change. This example (Fig.10) shows a full year (8760 hours), but individual days or months can also be animated.

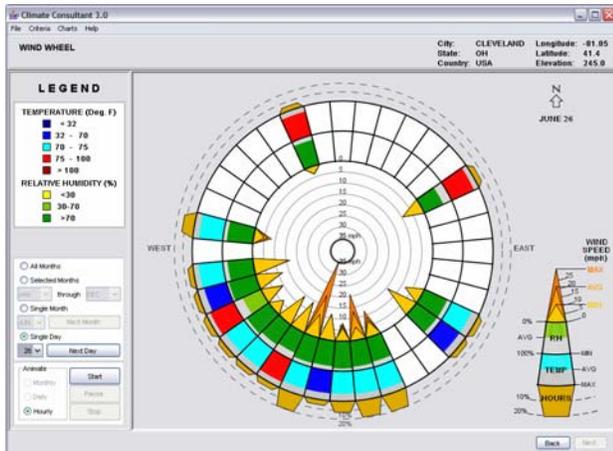


Fig.11: Another example of the Wind Wheel, this time for June 26 in Cleveland, shows a summer storm that came from the South South-West and reached 35 miles per hour. Note that about 20% of the time the wind blew from that direction (brown outer ring).

Still another option with the Wind Wheel is that any individual day or hour can be plotted. This example for June 26 (Fig.11) shows what appears to be a storm that arrives from the south-southwest accompanied by higher humidity and cooler temperatures. This can be confirmed by animating the Wind Wheel hourly for this date (see Al-Shaali for additional information on the use and development of the Wind Wheel).

12. SUMMARY

The beauty and power of these graphic approaches to climate data analysis is that they communicate in a way that allows users to see extremely subtle distinctions that would otherwise be lost in a page full of numbers. If 'information' is defined as the recognition of small differences that make a difference, then these techniques makes it possible to recognize some very subtle differences, indeed.

WEB SITE:

Climate Consultant 3.0 is available at no cost from www.aud.ucla.edu/energy-design-tools . It is written in JAVA and will run on both PCs and MACs. It replaces an earlier DOS-based version.

Weather data in the EPW format (Energy Plus Weather) can be downloaded from the US Department of Energy's EnergyPlus site, or from the link in www.aud.ucla.edu/energy-design-tools . Be sure to download the EPW file into the c:\Program Files\Climate Consultant folder (you should see a number of other files in EPW format already in this folder). If there is nothing listed in EPW format for your city on the EPW site, you can download the entire zip file which contains a zipped copy of the EPW file. Files in this folder that begin CZxx.epw are for California Climate Zones, and the number xx corresponds to zones 1 to 16. To delete a file from this folder simply move it to your Recycle Bin

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Additional bibliographic material related to Climate Consultant is available on www.aud.ucla.edu/energy-design-tools.

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This version of Climate Consultant is the evolution of a number of previous versions developed by various authors, in all cases working with Professor Murray Milne. The first version was developed by Yun S. Kim as a Masters of Architecture thesis, with financial support from the UCLA Academic Senate. The second version was developed by Mark Clayton and Alex Acenas, as a joint Masters of Architecture thesis in 1987, also with financial support from the UCLA Academic Senate and from the University Energy Research Group.

Yung-Hsin Li developed the third version in Pascal for his Masters of Architecture thesis in 1994. Ameet Nindra developed the next version for her Masters of Architecture thesis in 1998. This current version of Climate Consultant was developed by Professor Robin Liggett, written in Java, with input from Rashed Al-Shaali. This current version could not have been possible without the financial support from the University of California Energy Institute.

Over the years various colleagues have contributed to the development of the ideas illustrated in this program. They include Baruch Givoni, Carlos Gomez, Jeff Harbel, Larry Helmerich, Jurg Lang, and Donald Watson.