# PSYCHROMETRIC CHART TUTORIAL: A TOOL FOR UNDERSTANDING HUMAN THERMAL COMFORT CONDITIONS

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ABSTRACT

The Psychrometric Chart tutorial is a downloadable animated tutorial application which explains the various features of the Psychrometric Chart and how it illustrates indoor or outdoor air conditions and their relation to human thermal comfort. This tutorial is written in Flash and various audio-visual techniques are incorporated to create an effective educational resource. This paper outlines the underpinning developmental theories for the tutorial program and subsequently describes, in detail, each of the features it presents: dry bulb temperature, absolute humidity, saturation line, relative humidity, wet bulb temperature, dew point temperature, precipitation, hourly data, comfort zones, and mechanical systems. It is concluded with user feedback and indications of future enhancements.

## 1. INTRODUCTION

Houses vary greatly in their performance depending on how energy efficient they are. Energy efficiency however, is largely dependent on the environment of the site. Therefore, it is important to understand the local environment before being able to develop a suitable climate responsive house. A tool that helps one gain this understanding is the Psychrometric Chart. It presents the relationship between air temperature and humidity in graphical form, and helps describe the climate data and human thermal comfort conditions.

A software program that makes use of the Psychrometric Chart is Climate Consultant 4.0 developed by UCLA Department of Architecture and Urban Design. This software contains an expert system that automatically interprets the supplied climate data for any location to comparatively weight a set of sixteen Building Design Guidelines, based on the work of Baruch Givoni (Milne and Givoni). The Psychrometric Chart can be used to plot the temperature / humidity points that occur over the full 8760 hours of the year. Thus the Psychrometric Chart is immensely helpful in illustrating aspects of thermal comfort conditions. It is also widely used by engineers and other professionals in the HVAC field; however, the problem remains that the Psychrometric Chart can be difficult to comprehend.

In order to provide a solution to this problem and enrich the user-experience of Climate Consultant 4.0, the authors created an audio and graphic tutorial application which explains the Psychrometric Chart and its relation to thermal conditions. In developing this application, different learning theories were considered in order to provide a quality learning experience.

## 2. UNDERPINNING DEVELOPMENTAL THEORIES

The main purpose of the tutorial application is to teach the users how to read and understand the Psychrometric Chart. Therefore, as is the case with any quality learning product, it was necessary for the developers to understand the cognitive process of learning beforehand, and accommodate for the learners' needs in the final product.

Of all five senses of perceptions, visual perception contributes around 80% to all human learning (Kumar). It is easier to tell that an apple is an apple by looking at it rather than by just touching, tasting or smelling it. The same applies to human learning; we understand concepts better if we can see them. Therefore, effective use of visuals is a

must in any educational resource, and absolutely essential for this particular tutorial because teaching how to read a Psychrometric Chart cannot be done without showing the chart itself.

The use of color is an important part of visual resource development. Not only is the human eye sensitive to different colors, the degrees of activation of the sensory channel of communication with the brain are different (Kumar). Hence, if used properly, colors can be immensely helpful to learners. Color contrast can be used to differentiate components, and color matching enables the learner to connect similar concepts or ideas. The Psychrometric Chart tutorial application uses both color contrast and color matching to emphasize lines that convey different or similar information within the chart (e.g., absolute humidity, dry and wet bulb temperatures, etc.).

Kumar states that the greater the number of the senses of perception involved, the better the learning. However, in the case of an online tool, the learner is limited to two of the five senses at the most. Therefore, to maximize the learning experience within this limitation, the development of an audio-visual tutorial was considered. Although visuals contribute much more to learning than the audio channel, even so, the audio helps clarify a number of "non-graphic" concepts and thus supplements the visuals. Similarly, the audio in the Psychrometric Chart tutorial explains what is meant by the lines and curves, and how changes in the environment will be represented by changes in the chart.

The period of attention of a learner can be increased by providing stimulus variation (Kumar). Research in psychology has shown that attention can be sustained by contrast of audio and visuals, and also by movement (actual or animation) among others. Moving images catch the attention of learners better and serve as an excellent stimulus for triggering ideas and activating the learning process (Kumar). For this reason, animation is incorporated throughout the tutorial. Movement can be observed in the increase and decrease of temperature and humidity levels on the points in the Psychrometric Chart, as well as in the additional symbolic icons (i.e. thermometer and test-tube) that are used to make abstract concepts more concrete.

Organization is another key factor in learning. We learn alphabets before we learn how to write words; we learn nouns, verbs, and particles before we can compose a sentence, and so on. It is important that an educational resource is arranged in the increasing order of difficulty so that a learner can comprehend more difficult concepts or principles by applying previously gained knowledge of basic concepts. This is also known as correlative subsumption. The Psychrometric Chart tutorial begins by explaining what each line and curve on the chart represents and then combines all components to explain the concept of precipitation and the effect of HVAC systems on indoor air conditions. Hence the tutorial applies the 'parts-to-whole' cognitive strategy by way of correlative subsumption.

In an audio-visual resource, audio is as important as the visual. Therefore, it is necessary to understand the cognitive processing of information through the auditory channel. Verbal information is learnt through listening, observing, and reinforcing. Repetition and confirmation are essential in learning verbal information (Kumar). The tutorial application accommodates for this by incorporating an automated mechanism for repetition of each concept as it ends. This way the audio keeps looping until the user clicks the 'Next' or 'Previous' button to move to a different concept. This allows the learner to listen to the audio and see the graphics as many times as necessary to understand and connect the verbal information with the visual, and be able to grasp the full picture.

Meaningful learning means to take information from a source and deposit it into one's own knowledge bank through the process of understanding; if the information is not understood, it is not meaningful. This calls for self-paced learning; the learner needs his/her own time to understand a concept –this is also facilitated by the tutorial. Each individual user can decide when to go on to the next concept. They can also go back to a previous concept whenever they want. This is to allow each user to build these interlocking concepts in the correct way at their own pace.

## 2. TUTORIAL DEVELOPMENT USING FLASH

This tutorial application has been created using Adobe Flash software. Action-script is the primary programming language for user interactive features such as the navigation buttons ('Previous' and 'Next') and audio pause buttons. Motion-tweening and other animation and graphic techniques in Flash have been used for the visual display and timing of sequences. The tutorial is set to run through the sequence of animated screens through the navigational buttons. To run the application the users may be required to install Flash player on their PCs –this is easily available on the Internet and links to the site are provided on the application download page.

## 3. THE TUTORIAL APPLICATION

The Psychrometric Chart tutorial explains six different interrelated values that can be read from the chart and what they each mean. In addition, four other concepts relating to thermal conditions that can be understood from the chart are

explained. The following concepts are shown in the tutorial in this sequence: dry bulb temperature, absolute humidity, saturation line, relative humidity, wet bulb temperature, dew point temperature, precipitation, hourly data, comfort zones, and mechanical systems.

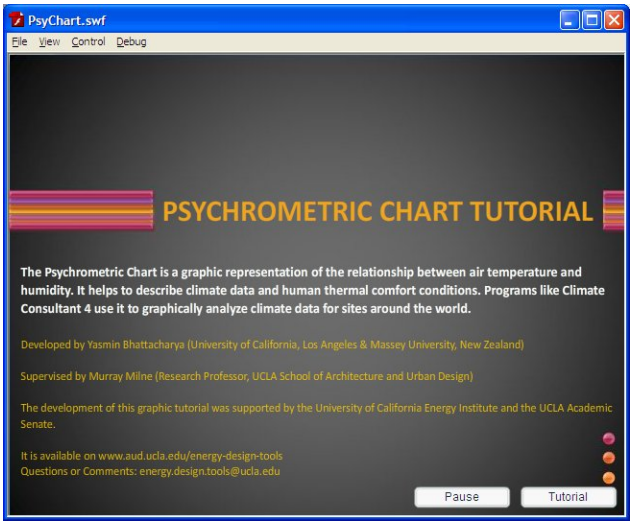

Fig. 1: Introduction screen of the tutorial

The tutorial begins with an introduction screen (Fig.1) where the audio briefly defines what a Psychrometric Chart is: “a graphic representation of the relationship between air temperature and humidity,” and its uses, such as describing climate data and human thermal comfort conditions. Then, the learner is prompted to click the ‘Tutorial’ button to begin the session.

## 3.1 Dry Bulb Temperature

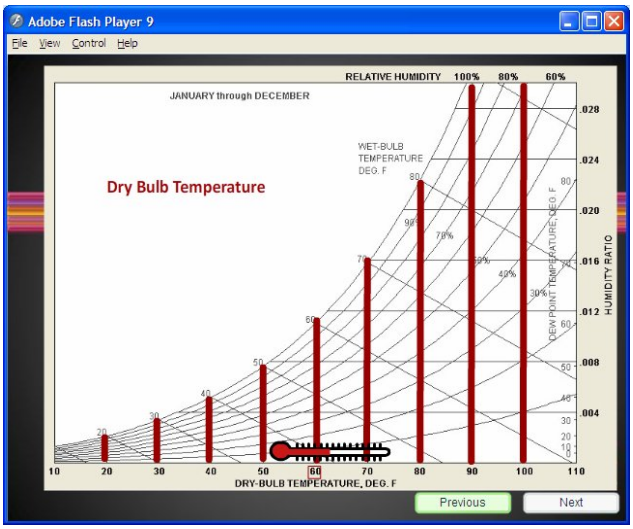

Fig. 2: Dry bulb temperature screen

This is one of the most important variables of thermal comfort. For this screen (Fig.2), the tutorial says: “Dry bulb temperature is the most common measure of temperature as measured by a thermometer with a dry bulb. On the graph, the vertical lines represent dry bulb temperature. As you go towards the right side, it means that there is more sensible heat, and as you go towards the left side, it means that there is less sensible heat.” This audio passage is reinforced by the highlighted vertical lines and an animated thermometer which illustrates the increase and decrease in temperature levels for changing point positions.

## 3.2 Absolute Humidity

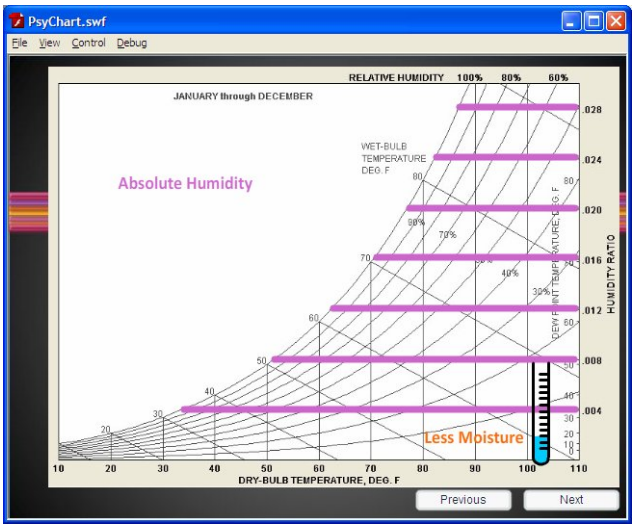

Fig. 3: Absolute humidity screen

Absolute humidity is the amount of moisture in the air as measured in pounds of water per pound of dry air. The tutorial defines this concept first, and this time, highlights the horizontal lines which represent the absolute humidity (Fig.3). The animated test-tube icon with rising and falling water levels, along with the audio, is used to show that points higher up on the chart mean that there is more moisture, and those on the lower part mean that there is less moisture.

## 3.3 Saturation Line

The tutorial audio describes that “saturation line represents the maximum amount of humidity that air can hold.” The visual (Fig.4), shows this by animation and use of color contrast. It shows that air can hold more moisture as the temperature increases (upwards movement and orange highlighting of curve), and less moisture as the temperature decreases (downwards movement and blue highlighting of curve). The tutorial also explains the concept in terms of real world example: “as it gets colder, moisture might be precipitated out in the form of dew, fog, rain, or snow.”

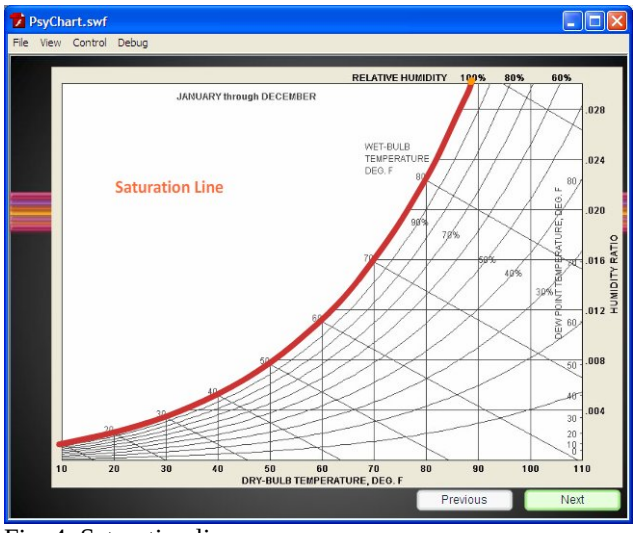

Fig. 4: Saturation line screen

## 3.4 Relative Humidity

The concept of relative humidity is related to the previously learned concept of saturation line. The tutorial explains: "Relative humidity is the percentage of humidity in the air relative to the saturation line, which is the maximum that it can hold." The animated and highlighted curves and percentage values reinforce the concept (Fig.5).

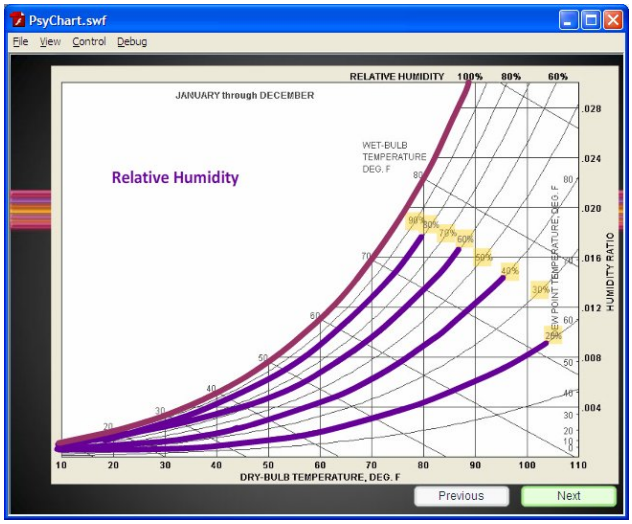

Fig. 5: Relative humidity screen

## 3.5 Wet-bulb Temperature

Wet-bulb temperature is defined as "the temperature as measured by a thermometer whose bulb is surrounded by a damp wick" in the tutorial. It is used to show adiabatic changes on the Psychrometric Chart –that is a change that does not result in a change of total-heat content of the air. The visual animation (Fig.6) shows that lines of constant wet bulb temperatures run diagonally up and to the left on the chart (yellow), and the audio explains that wet bulb temperature is always lower than the corresponding dry bulb temperature (orange) because evaporation makes it cooler. Wet bulb temperature is introduced beforehand, because is important in illustrating the functions of an evaporative cooler, which will be explained later in the tutorial correlated with several other concepts.

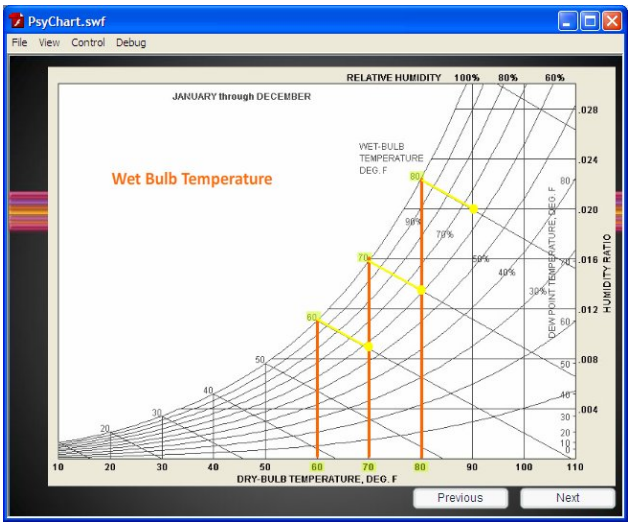

Fig. 6: Wet bulb temperature screen

## 3.6 Dew-point Temperature

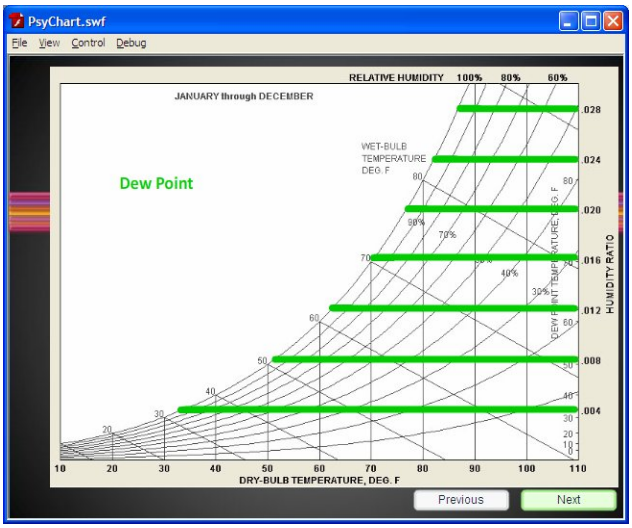

Fig. 7: Dew point temperature screen

This screen (Fig.7) is intentionally organized in sequence after the saturation line and wet bulb temperature so that the learner can connect the previously learned principles to this new concept of dew point temperature. The tutorial explains: "Dew point temperature is the temperature at which the air becomes completely saturated and the water

starts to precipitate out of the air (fog, rain, snow, etc)," and highlights the horizontal lines.

### 3.7 Precipitation

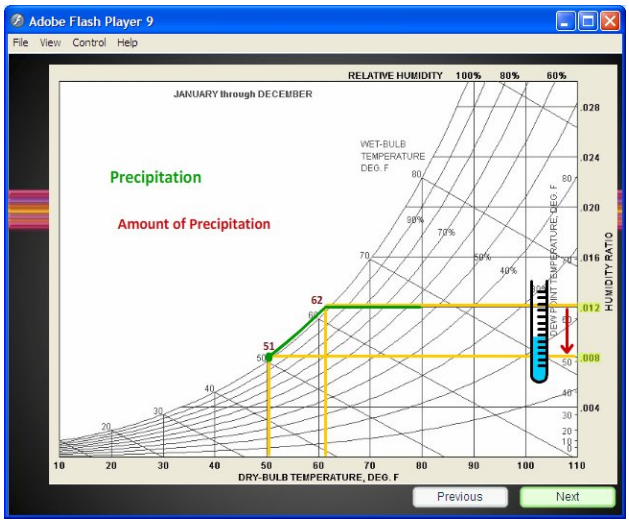

Fig. 8: Precipitation screen

The concept of precipitation can only be explained by linking several other concepts. An example of precipitation is presented on the Psychrometric Chart (Fig.8) showing the changes in temperature / humidity points through animation. The audio explains that "precipitation is the amount of water that is taken out of the air by a surface that is below the current dew-point temperature," and reinforces this through the use of an animated test-tube with decreasing water level.

### 3.8 Hourly Data

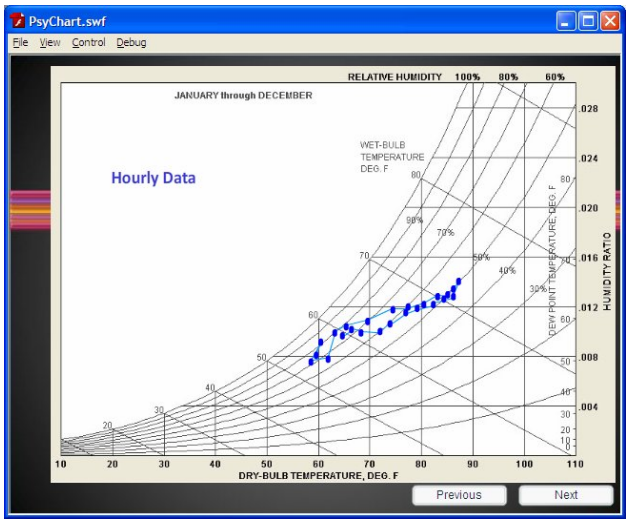

Fig. 9: Hourly data screen

This screen (Fig.9) in the tutorial is animated to show how the recorded temperature / humidity points are plotted on the Psychrometric Chart for a twenty-hour period (where one plotted point is represented as an hourly figure). The audio also explains that this can be shown for every hour of the year in some software programs (in Climate Consultant 4.0 for example).

### 3.9 Comfort Zones

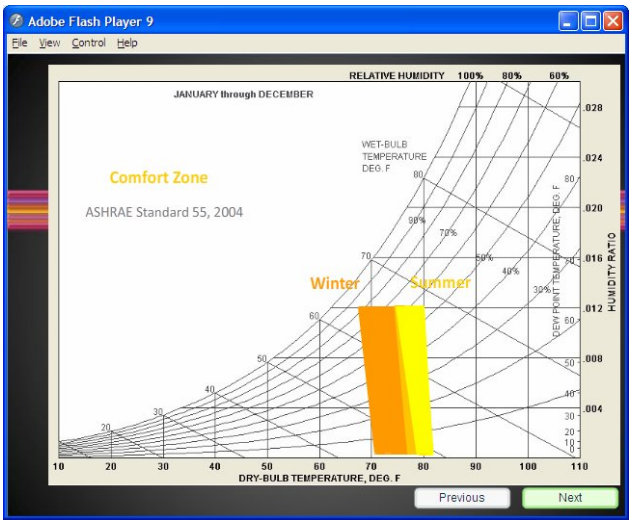

Fig. 10: Comfort zone screen

Thermal comfort is defined by environmental conditions that are comfortable and acceptable outside or inside buildings. Givoni states that this is essentially determined by the elimination of thermal (heat/cold) 'discomfort'. The human body involuntarily regulates its production of internal heat to compensate for the thermal conditions of the environment. Eventually the metabolic generation of heat offsets the heat losses so the individual experiences only very small variations (discomfort) in the feeling of thermal comfort and thereby feels at ease (Goulding et al). The ASHRAE comfort zone is developed on this basis, and it specifies boundaries of air temperature and humidity for sedentary people. The tutorial maps this comfort zone on the Psychrometric Chart (Fig.10) and explains that "different temperature ranges are given for winter (orange) and summer (yellow), to take into account changes in 'seasonal clothing habits'."

### 3.10 Mechanical Systems

This final screen (Fig.11) brings together all concepts to explain the effects of HVAC (heating, ventilating, and air conditioning) systems on indoor air conditions, and how this can describe the mechanisms for causing a shift in indoor conditions on the Psychrometric Chart. Distinguished by the separate colors, the functions of furnaces, air conditioners, and evaporative coolers are explained through animation and audio. The four common ways a building's HVAC

system can change indoor air conditions are introduced in the following sequence: increase in dry bulb temperature; decrease in dry bulb temperature; decrease in dry bulb temperature while increase in humidity level; dehumidification of air by precipitation and reheating to a resulting lower absolute humidity.

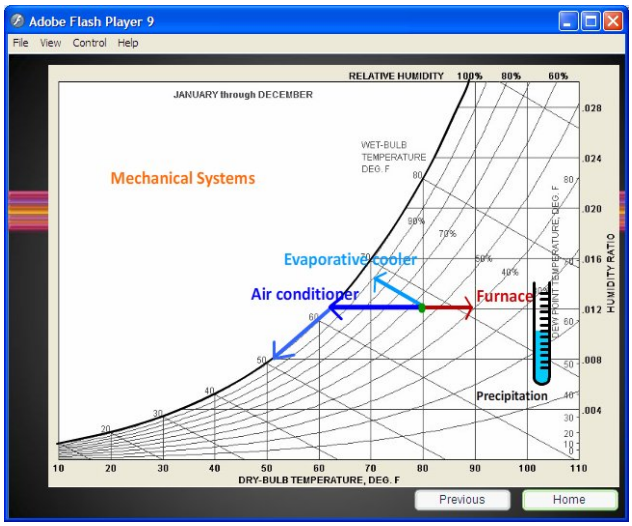

Fig. 11: Mechanical system screen

## 4. USER FEEDBACK

Some of the users who downloaded the Psychrometric Chart tutorial program, have provided their feedback on the system. Feedback is highly valuable for improving and enhancing a resource, and has provided the author with directions on future development of the program.

The feedback provided thus far can be separated in two major parts: learning and technical aspects. On its function as a learning tool, the following conclusions can be made from the raw user feedback data:

- All users found the tutorial useful in understanding the Psychrometric Chart.
- The sequencing in the increasing order of complexity has helped most users understand the individual concepts and extend their relations to address human thermal comfort.
- All users have expressed that the last few screens, in particular, help them connect all they have learned.
- Some users have suggested the incorporation of interactive features in the tutorial; such as query-based simulation with context-specific data and so on, to help drill in the concepts.
- Some users have also suggested that the tutorial progresses in an overlapping nature, i.e. the highlighted lines from the previous screen remain on the current screen and the new concepts are shown on top of this, to make the recognition and relation learning easier.

On technical aspects of the tutorial, the following conclusions can be made:

- All users find the combination of audio and visual animations with color coding as the most effective feature of the tutorial.
- The brief nature of the tutorial is also regarded as its positive point.
- Most users have found the repetition of audio helpful in understanding the ideas, but at the same time some have expressed irritation in its continuous looping and suggested for a ‘Pause’ button or putting repetition under user control.
- Most users have suggested for an overview of the tutorial (in the form of contents) before beginning so they have a clearer idea of their progress and the time it will take to complete.
- Though everyone has found the audio helpful, some have concerns on its quality and consistency –this may arise due to the users’ speakers or the program’s sound recording.

## 5. CONCLUSION

The Psychrometric Chart tutorial is a successful educational resource and provides an effective solution for understanding the complex features of the widely used Psychrometric Chart. It accommodates for a variable audience whether they are engineers or laypersons and explains individual concepts and relating ideas through various audio-visual techniques. The future developments for this tutorial will focus on improving the program based on the user feedback and also extend its features to include user-interactivity and other components.

## 6. SOFTWARE AVAILABILITY

The Psychrometric Chart tutorial has been available, along with Climate Consultant 4.0, since September of 2008 at no cost on UCLA’s Energy Design Tools website (www.aud.ucla.edu/energy-design-tools).

## 7. ACKNOWLEDGMENTS

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## 8. REFERENCES


Milne, M., et al., “Climate Consultant 4.0 Develops Design Guidelines for Each Unique Climate,” Proceedings of the American Solar Energy Society, Buffalo New York, 2009.

Givoni, B., Man Climate and Architecture, Van Nostrand Reinhold, 1981.

Milne, M. and Givoni, B., Chapter 6, “Architectural Design Based on Climate”, in Energy Conservation through Building Design, Donald Watson, Editor, McGraw-Hill, New York 1979.

Kumar, K. L., Educational Technology, New Age International, New Delhi, 1996.

Driscoll, M. P., Psychology of Learning for Instruction, Pearson Education, Florida State University, 2005.

Goudling, J. R., Lewis, J. O. & Steemers, T. C. (Eds.)., Energy Conscious Design: A Primer for Architects, B.T. Batsford Ltd., London, 1992.

Givoni, B., Climate Considerations in Building and Urban Design, John Wiley and Sons, New York, 1998.