Visualisation of climatic environments based on the “Test Reference Year”

Frank De Troyer¹, Karen Allacker¹, Abel Tablada de la Torre¹,²

¹University Leuven, Faculty of Engineering, Department of Architecture, Urban and Regional Planning
²Historian Office of Havana, Faculty of Architecture, ISPJAE, Cuba

Kasteelpark Arenberg, 1, B-3001 Leuven, Belgium
Tel.: + 32 16 32 13 72 / Fax: + 32 16 32 19 84
Email: Frank.DeTroyer@asro.kuleuven.ac.be; Karen.Allacker@asro.kuleuven.ac.be; Abel.Tablada@asro.kuleuven.ac.be

ABSTRACT: This paper describes how the wealth of information stored in a Test Reference Year can be visualised making use of a set of macros in Excel. The aim is to make users aware of the fact that the same daily, monthly, and yearly average values can hide a wide variety of realities. Visualised aspects are temperature, relative humidity and the combination of both, wind direction and speed, a comfort indicator for tropical climates based on the three previous parameters, solar irradiation on a horizontal plane and on sloped planes with different orientations. Solar radiation is analysed as well in an open environment as with standardised or specific vertical obstructions. For the analysis of irradiation EnergyPlus is used. Havana (Cuba) is used as an illustration.

Conference Topic: 2 Design strategies and tools
Keywords: Thermal comfort, Test Reference Year, Fanger, Olgyay, Visualisation

1. INTRODUCTION

Architectural and urban projects should always be evaluated in relation to their specific climatic context. Since architects and urban designers often focus on visual representations (as is demonstrated by the importance of photos, drawings and sketches in most of the magazines), the best solution is to provide a graphical description of the climate.

The multitude of parameters influencing comfort will not allow representing a context in a few graphs. Macros in Excel offer the possibility to step through a year in periods of one month or 14, 10 or 7 days. The default period can be changed depending on the resolution of the screen and the readability.

2. TEMPERATURE AND RELATIVE HUMIDITY

2.1 Classic representation

In a classic representation the following monthly values are represented for temperature and relative humidity: average, average of daily maximum and daily minimum, long term extreme maximum and minimum. The last two values are important when one has to consider resistance to extreme loads in design. In almost all cases discomfort in those cases will be accepted. Values are not critical for survival as for instance is the case with resistance to peak wind loads or evacuation of peak rainfall. So the monthly extreme values derived from the “average months” that are combined to the “Test reference year” (TRY) [1] are less extreme than the traditional ones but provide more relevant information as far as comfort is concerned.

![Figure 1: Hourly fluctuations of temperature (°C) based on TRY (Havana, Cuba).](image1)

![Figure 2: Detail of figure 1 for 20 days (from hour 1680 till 2160).](image2)
An overview of all the hourly values (figure 1) pictures a global image and is comparable with the classic representation but is unreadable in the details. Macros will allow zooming in and stepping through the year.

Figure 2 represents a period of 20 days whereby the second part consists of almost identical daily swings around the monthly average and the first part shows the superposition of daily swings on fluctuations over several days.

In a similar way the evolution of Relative Humidity (RH) can be visualised.

2.2 Combined representation of temperature and RH

For comfort in tropical climates the combination of temperature and relative humidity is important. The most widespread representation is on Olgyay’s chart [2, p51], [3, p11], [4, p59]. The most commonly used chart is the one for a person sitting and wearing summer cloths. Charts for other conditions are, however, available. In the rest of this text the most common version is used as under-layer for the graphical representation in order to make the TRY comparable with familiar representations.

2.3 Overview of whole year

In a common representation each month is described by a line linking following two points:
- The monthly average value of the daily minimum relative humidity and average value of the daily maximum temperature (early afternoon)
- The monthly average value of the daily maximum relative humidity and average value of the daily minimum temperature (early morning)

By doing so in one graph the average daily swing for each month of the year is represented (Figure 3 and 4). [7, p36] [8, p24]

The TRY allows us to look critically at this representation by adding the hour-by-hour combination of RH and temperature to the graph for one month. The general conclusion is that monthly average value for each hour of the day will be close to the corresponding line (following a loop or an eight), but the hourly values can follow a quite different pattern. For some months the hourly evolution of each day will not differ significantly from the monthly average (Figure 5), in other cases the daily variations can fluctuate in a wide range around the monthly average (Figure 6).

Olgyay’s chart indicates that the comfort zone is reduced to the right of the graph; this is where high temperatures are combined with high relative humidity. The graph shows also how comfort can be reached by providing ventilation when the temperature is too high and by compensating heat losses by radiation when the temperature is too low. Of course the same information can be represented on a chart with on the horizontal axis the operative temperature and on the vertical axis the vapour pressure. In this text we will briefly refer to this representation as ASHRAE’s chart.

Although the exact boundaries of this comfort zone are still an element of debate [5][6], the classic graph will be used as an under-layer in the representations.
Figure 6: Hourly evolution of Temperature and RH (Havana, Cuba, January)

The linear regression line based on hourly average values will in most cases be close to the line based on average monthly extreme points. The regression line based on hourly values over a whole month however can differ significantly since this result can be seriously influenced by some extreme values.

3. WIND

Olgyay’s chart suggests making use of wind for natural cooling. Wind however is a complex phenomenon that can change in a short period (shorter than an hour) as well in direction as in speed. The TRY allows us to picture an image based on average hourly values. The most directly readable representation is on a “radar” graph whereby the direction is visualised. (Figure 7 and 8)

The frequency that the wind is blowing from a given direction can be read directly. Additional information that can be represented is how frequent (for each direction) the wind is higher than a selected set of wind speed values. Default values can simplify the comparison of different contexts, but limits can be changed in order to fit more the range of wind speeds for a given location. The overview can be elaborated for one year (if the pattern is almost constant over the year) or per month if regular changes occur over the year as is often the case with winds in tropical areas effect by Coriolis forces. Local topography and obstructions can also influence the results.

The yearly or monthly average evolution over the 24 hours of a day can be visualised. Figure 9 reveals on average no wind in the afternoon. A histogram of wind speeds over a selected period eliminates the aspect of direction and hour of the day (Figure 10). Excel allows visualising all kind of combination of parameters.

Figure 7: Frequency of wind speed above selected values per direction (Havana, Cuba, August)

Figure 8: Frequency of wind speed above selected values per direction (Havana, Cuba, March)

Figure 9: Average occurrence of wind over 24 hours of a day (Havana, Cuba, Year)

Figure 10: Frequency of wind speed (Havana, Cuba, Year)

4. COMFORT INDICATOR FOR TROPICAL CONTEXTS

4.1 Classic representation

In tropical contexts the most problematic situation is the combination of high temperature and RH. If a low temperature will position someone downward from the comfort zone different reactions are possible: additional cloths (or blankets when in bed); exposure to direct or reflected solar radiation.
For too high temperatures the graph suggests natural ventilation. The implicit hypothesis is, if a person is in the comfort zone without ventilation, by closing shutters natural wind can be avoided.

A classic graphical representation [3, p 12-13, p 52-71] combines the “required wind speed for comfort” (Figure 11) with the “average available wind speed” (Figure 12) in a graph representing the different months of the year and the different hours of a day. In a derived graph the “deficit of winds speed in order to reach comfort” is represented. The questionable hypothesis behind this graph is the considered average wind speed for all the hours of a year. In the next paragraph a new more appropriate index for comfort based on the TRY is proposed.

4.2 Fanger confronted with Olgyay

The TRY is composed of representative months and contains for each hour of the day: temperature, RH and wind speed and direction.

The Fanger model [9] predicts the “Thermal Load” for an average person based on air temperature, average radiation temperature, RH, wind speed, activity (and the associated metabolic rate) and clothing factor. Based on this thermal load the “predicted mean vote” (PMV) and the “Predicted Percentage of Dissatisfied persons” (PPD) is estimated. In order to compare with the previous graphs a metabolic rate of 58 W/(m² skin area) (sitting person) and summer dress (“Clo” value of 0.5) will be used.

More problematic is the temperature of the surfaces surrounding a person. For tropical climates one can accept in a first approach that, when applying simple good design rules, the average radiation temperature is equal to the air temperature. This hypothesis should be looked at critically: it may not be true if walls generate a time lag between external and internal temperature or in case that the internal side becomes a hot radiating surface (corrugated iron sheets without thermal insulation) or glazing without appropriate shading.

In this hypothesis the “Thermal Load” can be calculated based on: air temperature, the RH and the wind speed.

In the graphical representation of figure 13 the comfort zone extends from a predicted mean vote of –1 to +1.

The advantage of the model is that the effect of other activities, other clothing, other wind speed and other boundaries of the comfort range can immediately be visualised (Figure 14).

4.3 Representation of “Yearly Total Thermal Load”

The Fanger model can be applied in order to picture an image of the comfort situation that can be reached over a whole year. Only overheating (positive thermal loads) are considered. Several underlying hypotheses should be made explicit.

The first assumption is that the description of the whole year is based on sum of hourly values.

For the wind speed different hypotheses are possible: the wind speed available for cooling is equal to the one reported in the TRY, is a constant fraction of this wind speed (e.g. reduced by the natural or man made obstruction), is increased by a constant factor (e.g. based on a Venturi effect) or the change in this hypothesis the “Thermal Load” can be calculated based on: air temperature, the RH and the wind speed.

In the graphical representation of figure 13 the comfort zone extends from a predicted mean vote of –1 to +1.

The advantage of the model is that the effect of other activities, other clothing, other wind speed and other boundaries of the comfort range can immediately be visualised (Figure 14).

4.3 Representation of “Yearly Total Thermal Load”

The Fanger model can be applied in order to picture an image of the comfort situation that can be reached over a whole year. Only overheating (positive thermal loads) are considered. Several underlying hypotheses should be made explicit.

The first assumption is that the description of the whole year is based on sum of hourly values.

For the wind speed different hypotheses are possible: the wind speed available for cooling is equal to the one reported in the TRY, is a constant fraction of this wind speed (e.g. reduced by the natural or man made obstruction), is increased by a constant factor (e.g. based on a Venturi effect) or the change
depends on the orientation of the wind (fixed reduction or amplification for each direction).

As a first indicator that characterises how by passive means comfort can be reached the sum of the hourly PPD per month or for the whole year with the wind speed of the TRY can be used. Additional hypotheses can be added if relevant: other activity levels, other clothing types, activity depending on the hour of the day (afternoon siesta), ... but should be clearly mentioned in order to make cases comparable.

The sum of PPD (Predicted Percentage of Dissatisfied persons) visualises per period of 3 hours of each day for each month when thermal discomfort is threatening (Figure 15).

Figure 15: Graphical representation of proposed indicator of “Yearly Total Thermal discomfort” based on Fanger (Clo=0.5; M/Ask = 58 W/m²)

5. RADIATION

5.1 Average radiation and irregularity

A last considered factor affecting (directly or indirectly) thermal comfort is solar radiation. In the conventional approach the total number of hours of sunshine or, more exceptionally, the total irradiation on a horizontal pane is considered. The last value is of course preferable since each hour the intensity is different (clouds, dust, altitude of the sun). The TRY offers the “global radiation on a horizontal surface” and the “diffuse radiation on a horizontal surface”. So the direct radiation can be calculated as the difference of both. Additional to the classic representation of average monthly values the fluctuation of average daily global radiation can be visualised (Figure 16).

Figure 16: Solar radiation on horizontal plane (Havana, Cuba, based onTRY)

These daily average values hide the important changes over a day. Figure 17 adds to the daily average values the hourly values.

Figure 17: Monthly, daily and hourly average radiation on a horizontal plane based on the TRY (Havana, Cuba)

This graph is hard to read but again macros will provide the opportunity to walk through the year with the appropriate time step (one month, 14 days, 10 days, 7 days or other periods). The difference between an almost constant blue sky, longer periods of blue sky followed by periods of covered sky and a situation of an almost continuously covered sky are only example of situations that can clearly be visualised.

A possible image is represented in figure 18. In this representation the extraterrestrial radiation on a horizontal plane (from TRY) is added. The 4 days are typical for Cuba, Havana: total radiation close to 60% of the extraterrestrial radiation, diffuse radiation as important as direct radiation, all days are relatively similar.

Figure 18: Radiation on a horizontal plane based on the TRY and extraterrestrial radiation for 4 consecutive days (Havana, Cuba)

The TRY allows us to analyse the link between the extraterrestrial radiation and the diffuse radiation. In this case there is a good correlation (R²=0.88) and a ratio of 25% (Figure 19).

Figure 20 shows that for the direct radiation almost all values between 0 and 70% of the extraterrestrial radiation are possible. The correlation is a lot worse.

The total radiation is never a zero fraction of the extraterrestrial with an in between R² value (Figure 21)
5.2 Effects of slope and orientation

More detailed information can be reported after a simulation run by EnergyPlus. Via this mechanism the irradiation on surfaces with different slopes and orientations can be obtained. An abstract model (Figure 21) with external faces with selected orientations (e.g.: every 15°) and selected slopes (e.g.: every 15°) provides an easy way of deriving such a database from the TRY. EnergyPlus takes into account the concentration of diffuse radiation around the sun.

5.3 Effect of obstruction by environment

In the same model or in a model that contains only a horizontal surface a given environment can be inserted. The represented irradiation takes into account the shadowing effects of the environment. This can be a specific urban or natural environment or, for a first analysis of a climatic context, an environment whereby the altitude of the obstruction in each direction is fixed (e.g. 30° or 45°). Also for this analysis spreadsheet tools are elaborated in order to simplify the elaboration of an obstructing environment.

CONCLUSION

The macros described in this text will allow the visualisation of the hour-by-hour changes of a climatic environment based on the “Test Reference Year” and link this to the classic representations for a whole year. A new index for visualising the “Total Yearly (positive) Thermal Load” based on the Fanger model and the TRY is proposed.

ACKNOWLEDGEMENT

This approach was elaborated as a didactical tool for confronting students coming from all over the world with each other’s climate at the Post Graduate Centre Human Settlements of the KULeuven.[10]

REFERENCES

[10] www.pgchs.be (15/05/04)