New Climate Analysis Tool for Early Phases in Building Design

Petra Liedl
University of Texas at Austin
School of Architecture
310 Inner Campus Drive Stop B750
Austin, TX 78712-1009
pliedl@utexas.edu

ABSTRACT

Detailed climate analysis provides the basis for sustainable architecture. This paper presents ClimateTool, a new interactive, graphics-based, easy-to-use planning tool for climate analysis. ClimateTool's outcome is demonstrated by discussing its input parameters and analyzing a location in the subtropics. The aim of the tool goes beyond just offering climate data to conjunctively show the challenges and potentials of each location, providing users with the basis to develop sustainable buildings for a specific location. ClimateTool facilitates the analysis of the climate relevant aspects in planning, presenting results in charts for any given location on earth. World maps using and combining the necessary parameters show differences in climate caused by specific geographic factors like height or proximity to the sea. Also included is UrbanTool, a tool which enables shading and insolation examinations for buildings to be evaluated, e.g. the potential of solar power systems on roofs and facades.

1. INTRODUCTION

Climatic and demographic changes have defined the 21st century. Together these factors will exert substantial influence over future building concepts. Moreover, rapid population growth in emerging countries will call for a multitude of building design features that cannot be simply derived from North American and European building concepts.

This would lead to architecture that is detached from climate aspects, perceiving technology and energy as a demonstration of technical skill in dealing with climatic demands – a model that is not sustainable (1).

The architecture of the future responds to climatic conditions in a way similar to traditional building methods. It makes better sense to consider building design as an approach to climatic challenges, rather than looking exclusively at technology. A detailed climate analysis examining elements of solar radiation, temperature, humidity and wind is the basis for sustainable architecture. Only by examining the specific climate and traditional architecture of a given localation can energy-efficient buildings and optimized energy concepts be realized – maximizing comfort for the users. An attempt should be made to consider climatic aspects in the early stages of building conceptualization. Using e.g. passive energy sources such as soil sensors for cooling, or regenerative active systems such as solar cooling, involves a precise examination of the ambient climatic conditions. In emerging countries like China, India or the middle east, the main issue is ensuring comfort in the summer months due to intense sunlight. Another challenge is the high humidity in tropical and subtropical regions which calls for dehumidification; a practice that generally requires a great deal of energy and technology.

Because there is such a strong desire in emerging countries to rapidly improve the standard of living, architecture and urban development trends change within just a few years, whereas building culture in "old Europe" had developed over decades or even centuries. In international projects, the rapid development of building activity means that the time available for planning is increasingly short.

Building is progressively becoming an international issue, and projects are increasingly being announced worldwide. All things considered, there is often a lack of planning experience when it comes to considering climatic influences. Nevertheless, an exact analysis of both the climatic conditions and the site are essential when planning buildings with optimized energy and indoor climate systems in order to ensure that the structure of the building and the facade are aligned accordingly; reaping the full benefits of the energy and room climate concept.

Tools that act as a guide for assessing the climate conditions in the absence of detailed planning data are essential for project drafting in the conceptual phase. Furthermore, universities must provide the tools and framework for enlisting these new challenges.

2. BRIEF DESCRIPTION OF CLIMATETOOL

ClimateTool's (2) principal focus is detailed, graphic- based climatic analysis, which will serve as a basis for the architecture of the future. While demonstrating the challenges and potential for a particular location, it also illustrates the planning relevance of individual climatic elements such as solar radiation, temperature, humidity and wind. In addition, ClimateTool allows any site to be allocated to a specific climate zone (see point 4.), in order to plan the measures necessary for a comfortable room climate. In this regard, the tool is user-friendly in its analysis and operational plotting of climate data. ClimateTool is written in MATLAB.

ClimateTool's distinction lies in its ability to register every location worldwide by inputting the longitude and latitude. In addition to reading 14.400 locations between 60° south and 60° north, analysis can also be based on a city name selection for hundreds of locations.

Climate elements can be analyzed either separately (e.g. courses or frequencies of temperature or humidity), combined (e.g. psychrometric chart) or related to building specific questions (e.g. solar radiation on different facades). Results are rendered into charts due to the fact that graphic-based outputs will be more planning appropriate. Charts can be saved in any image format.

Because the tool is an interactive, the user can manually define the reporting periods to compare e.g. climate conditions between day (office hours) and night. Most analyses are possible to conduct on annual, monthly - and in terms of solar radiation – also daily terms. To be able to compare several locations, it is also possible to define a range in specific units. In terms of solar radiation, each angle and orientation can be analyzed.

ClimateTool makes it possible to allocate any site into a building specific climate zone (see point 4.), as well as provide an estimation of measures for a comfortable room climate.

World maps using and combining the climate elements illustrate differences in climate caused by specific geographical factors, such as height or coastal proximity, enabling a global view of climate analysis (see 3.6)

Embedded within ClimateTool, UrbanTool facilitates examinations of shading for urban environments; serving as a foundation for fundamental evaluations of e.g. the potential of solar power systems on roofs and facades, or estimations of solar loads into rooms. For existing buildings, any images (e.g. floor plans or maps) can be imported so that buildings and vegetation can be defined very easily.

ClimateTool's analyses are supplied with data from the global climate database Meteonorm (3) using a 8,760 hour format. Meteonorm is a global climate database. The software enables the calculation of both year-long and up-to-date monthly values, as well as of hourly values for a typical year. It was developed for use within simulation programs for solar systems and for buildings. Because the data represents typical, as opposed to extreme conditions, the input of other climate data is possible by request to conduct further or special examinations or to align with worst-case scenario. In ClimateTool, data for various time periods (1961 – 1990 and 1986 – 2005) are currently provided. Changes in climate conditions can be read for one specific location, in addition to providing a global view with the world maps.

The tool aims to support architects, engineers, planners and students with planning buildings in an international context, especially in the conceptual phase. However, homeowners und municipalities can also benefit from having a simple tool which enables them to be an active partner within the planning process. The tool is used in design studios to show, at the very early stages of design, the interactions between climate and building concepts in other climate zones. It is also used in classes to teach and visualize interdependencies of climatic elements and their impact on buildings.

There are, of course, other tools, which analyze climatic conditions. Many of them are integrated into energy simulation tools and are therefore not appropriate for users who - although interested in dealing with climate aspects - do not require energy related simulations. Furthermore, there is no easy-to-use planning tool, according to the user's knowledge, that combines all the following features:

- Analysis of any worldwide location (14,400 locations)
- Comparison of climate data for different periods of time
- Creation of world maps (information for 14,400 locations) according to building specific questions
- Defining a building specific climate classification.

3. CLIMATETOOL’S OUTPUT

In the following section, the possibilities for climate analysis with ClimateTool are presented. Outputs are shown according to the main functions of the tool, with discussions of each parameter concerning planning relevance. The words in italic illustrate an aspect that is an outcome of the tool.

All charts (Fig. 1 to Fig. 13) are results of ClimateTool (database Meteonorm, temperature 1961-1990, solar radiation 1985 – 2000) and represent the climate analysis of a location in the subtropics.

3.1 Annual Courses

Courses for annual global radiation, direct and diffuse, [W/m^2] (Fig. 1) and [kWh/m^{2}d), *outdoor air temperature* [°C], *absolute humidity* [g/kg], *precipitation* [mm], and *temperature difference between maximum and minimum values within one day* [K] provide an initial overview of the climate for each given location.

Values for the 8,760 hours of the year are relevant, as are the monthly mean values and extreme values. The amount and distribution of diffuse and direct radiation make it possible to determine e.g. periods of heavy cloud cover as well as those when sunshine permits the use of solar power. The seasonal course of outdoor air temperature shows the seasons and periods with a high cooling or heating energy demand, as well as periods when natural or night ventilation is possible. Changes in daily temperature determine the use of passive cooling strategies such as night ventilation and concrete core activation with free recooling. The temperature level of the soil in layers close to the surface indicates the cooling potential of the soil as well as its ability to prewarm the supply airflow. The average annual temperature goes down into the soil to a depth of about 10–15 m. The soil temperature can be accessed as a source of heat or cold via e.g. earth pipes. The development of absolute humidity over the course of the year highlights the periods when there is a need for humidifying or dehumidifying. The precipitation frequency, the monthly precipitation rate and the maximum precipitation levels may represent important planning data, depending on the specific location.

Extreme values (annual minimum, maximum, average) provide dimensioning for technical equipment. *Degree days* are quantitative values giving information on the energy demand for *heating and cooling or (de)humidifying* (4). In ClimateTool, values for the comfort zone like heating and cooling setpoint, as well as (de)humidification can be defined by the user.

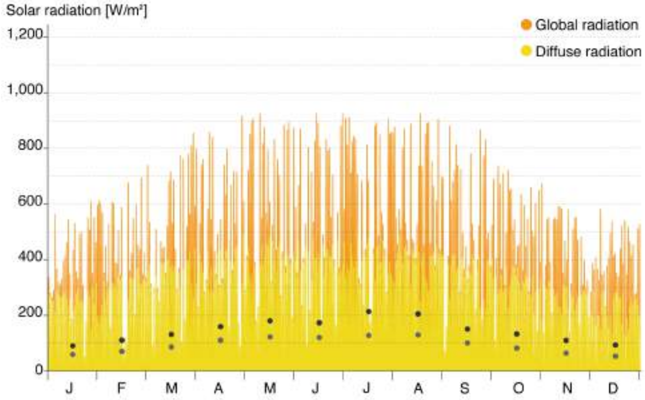


Fig. 1: Solar radiation over the course of a year with monthly mean values.

3.2 Psychrometric chart

The *psychrometric chart* (Fig. 2) corresponds to Richard Mollier’s h-x diagram. It shows changes in the moisture content of air and requirements imposed on room conditioning by the outdoor climate. In the international context the temperatures are given on the x-axis, while their absolute humidity levels are given on the y-axis. The graph curves represent levels of relative humidity. The psychrometric chart enables the allocation of a location to a climate zone with regard to building climatology (see point 4.) and room conditioning (Fig. 3), (5). For comparison, the common *climate diagram according to Walther, Lieth* (6) with monthly average values for temperature and precipitation visible.

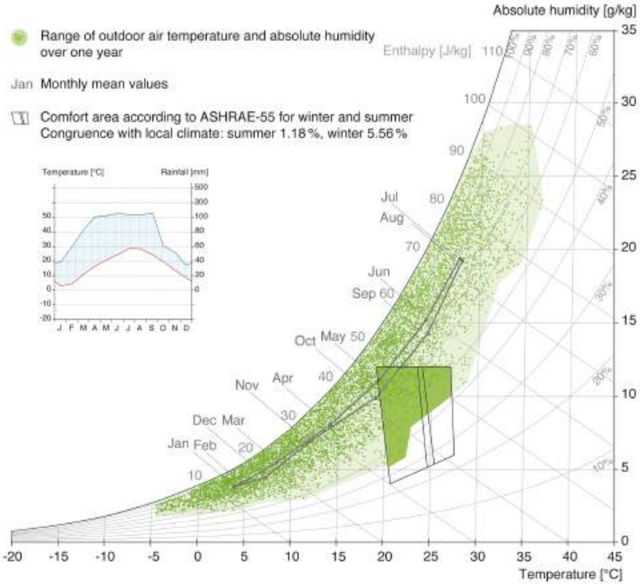


Fig. 2: Psychrometric chart with comfort zone according to ASHRAE-55 (7) and the local climate, presented with 8.760 hourly values for temperature and absolute humidity and the monthly average values. The small chart shows the climate diagram according to Walther, Lieth.

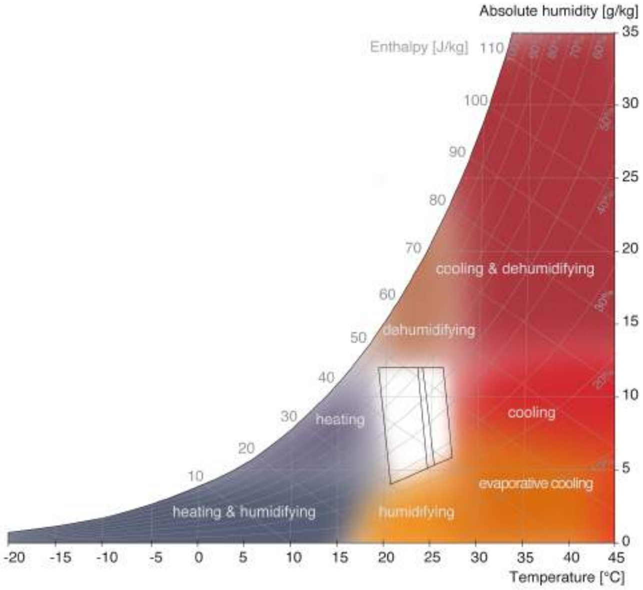


Fig. 3: Room conditioning methods shown in psychrometric chart with comfort zone according to ASHRAE-55.

3.3 <u>Frequencies</u>

Specific questions when defining building and room conditioning concepts make it important to know for how many hours of the year climate parameters are higher or lower than a defined value. The *circles of frequency* in the climate elements in the ClimateTool provide help in determining aspects such as the *outdoor air temperature, the dew point temperature, absolute humidity* (Fig. 4), *solar radiation, the distribution of radiation, illuminance and wind* (Fig. 5) over a month or one year. This makes providing a quick overview of the climate parameters relevant in planning with regard to orientation, room conditioning and energy conceptualization. The frequency with extreme weather has e.g. implications for the effectiveness of passive cooling systems and for the configuration of the technology used. Dew point issues can also significantly reduce the effectiveness of surface cooling systems, making dehumidifying the air inflow essential. The wind situation onsite is a critical factor in construction planning.

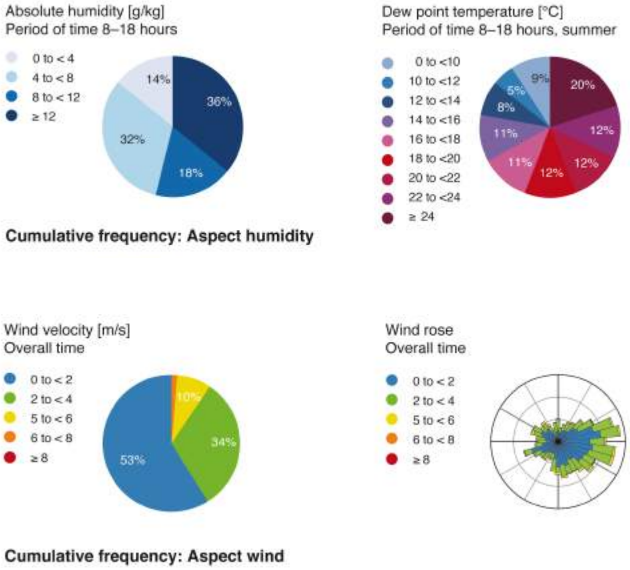


Fig. 4: Examples of cumulative frequency on an annual basis for the aspects of absolute humidity, dew point temperature and wind.

Daylight provision in a room is determined by the level of daylight transmission of the glazing, the glazing amount, and the outdoor illuminance when the sky is overcast. In ClimateTool, room depths combining these parameters show, based on simulations with Radiance (8), where the *levels of illuminance* (Fig. 5) needed for office work will be reached.

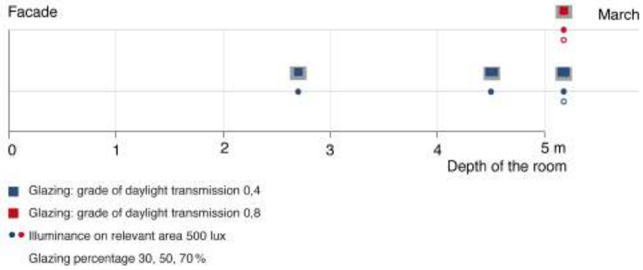


Fig. 5: The points define room depths in an office room (depth = 5m) with 300 or 500 lux illuminance on a user level depending on glazing amount (30, 50 and 70%) and daylight transmission of glazing τ =0,4 and 0,8).

3.4. Solar

The course of the sun during the day and over the year (Fig. 6) is an important parameter when planning sunshading concepts, laying out the orientation and the distance between buildings, estimating daylight concepts as well as planning solar energy systems. The ClimateTool enables determining the *solar radiation on any inclined surface as the power or energy amount for individual days, months* (Fig. 7) *or the whole year* (Fig. 8). Percentages of the diffuse and direct radiation can also be determined.

The diffuse radiation on inclined surfaces is calculated according to the Perez diffuse radiation model (9) considering the isotropic, circumsolar and horizon component as well as the albedo.

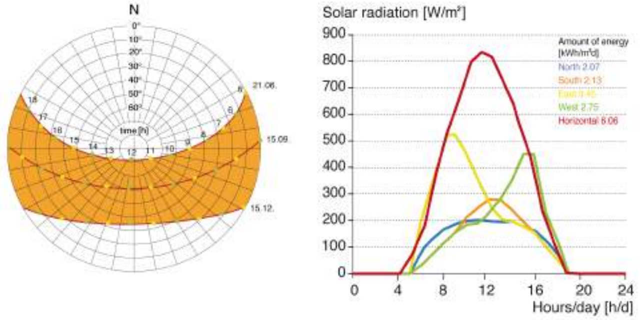


Fig. 6: Sun path (left) and daily global solar radiation on different orientations as power and energy amount. The calculation for any day and any inclination is possible.

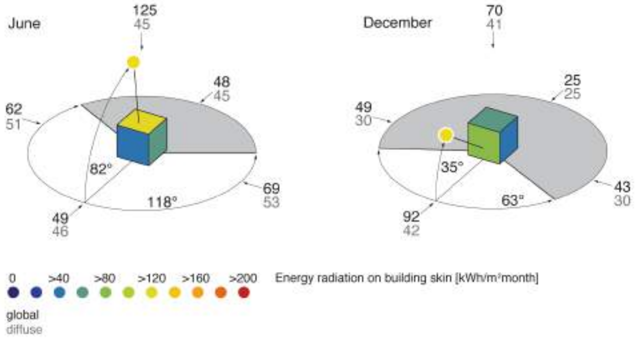


Fig. 7: Solar radiation on the facades and the roof as monthly energy amount.

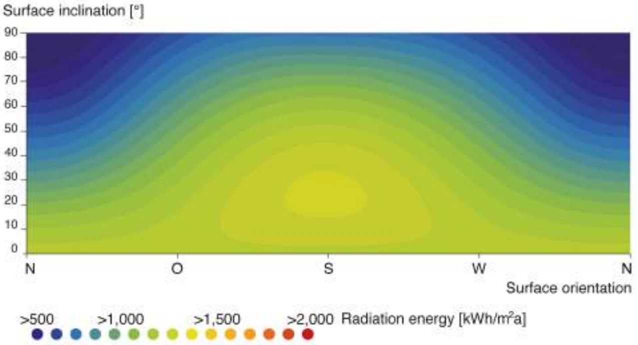


Fig. 8: Annual radiation energy correlated with orientation and surface inclination for evaluation of the alignment of solar power systems.

In addition, the tool makes it possible to visualize the *heat transfer through an outer wall* (Fig. 9). Heat transfer is calculated considering the outdoor and indoor air temperature [°C], transfer coefficients inside and outside [W/m^{2}K], absorption coefficient outside [-] as well as the material properties specific heat capacity [J/kgK], density [kg/m^3], thermal conductivity [W/mK] and the thickness of the wall [m].

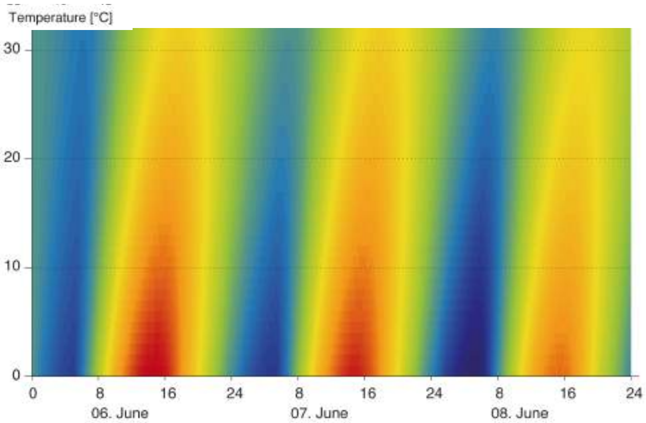
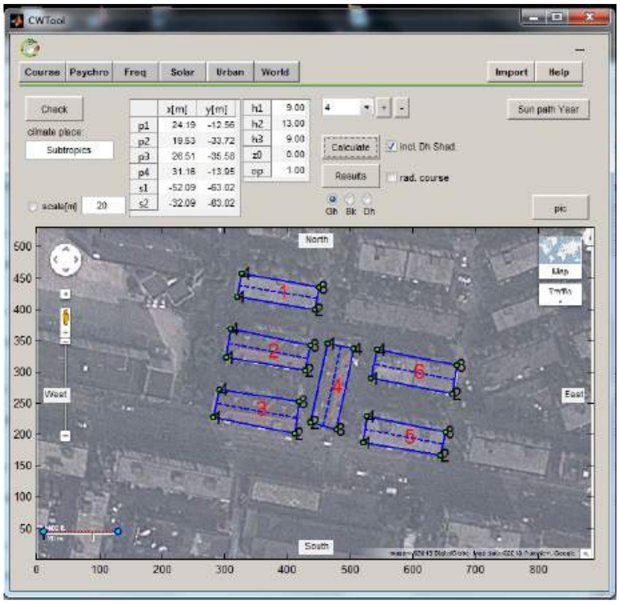


Fig. 9: Course of temperature in an outer wall.

3.5. Urban Tool

Orientation, developments in building height and distance as well as the mutual shade buildings provide are basic questions in urban planning. ClimateTool makes it possible to determine *both the power and amount of energy on facades and roofs* for a first assessment of the influence these parameters have. The radiation can be measured on both vertical and inclined surfaces. Images of Google Maps (10) can be imported and as many buildings as necessary very easily drawn to scale (Fig. 10).



climate place: Subtropics

scale[m] 20

	x[m]	y[m]
p1	24.19	-12.56
p2	19.53	-33.72
p3	26.51	-35.58
p4	31.16	-13.95
s1	-52.09	-63.02
s2	-32.09	-83.02

h1	9.00
h2	13.00
h3	9.00
z0	0.00
op	1.00

4

☑ incl. Dh Shad.

☐ rad. course

● Gh ○ Bk ○ Dh

Fig. 10: Screenshot of the input mask ‘Urban’ with an imported image of Google maps and some redrawn buildings.

Each building can be defined by six points, four points for corners of the floor plan, one for the height of the eaves and one for the height of the ridge. In the same way vegetation can be defined by blocks while reducing the opacity.

The shading coefficients are automatically calculated in ESP-r (11). Therefore the shading buildings are being considered in block form without inclination of the roof being considered. In terms of the shaded building, however, the specific roof surface inclination is being considered. The ESP-r interface makes it possible to easily export the areal urban configurations in the thermal simulation program for further processing in relation to questions of energy.

The annual and monthly energy amount (Fig. 11) as well as courses for power is calculated for four equal parts of each façade orientation, and two parts of each roof area, to make differences in the lower and upper area of buildings visible. To visualize in a more detailed way differences in height for e.g. high-rise buildings, they can be assembled of several blocks. The results can be analyzed both for global, direct and diffuse radiation.

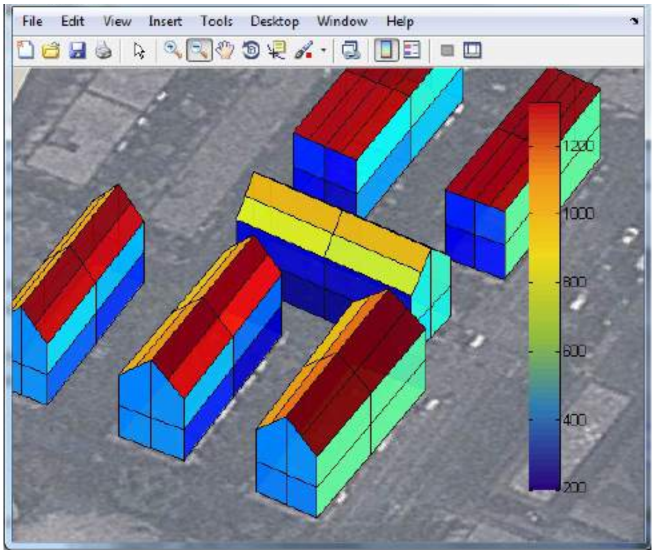


Fig. 11: Annual Energy amount on the façades and the roofs, separately for different parts of each of them.

3.6. World

World maps using and combining the climate elements (Fig. 13) show climatic differences due to geographic features like altitude or proximity to the sea. Maps allow for an evaluation not only of one special site, but also of 14,400 points, defined by their latitude, longitude and altitude. Climate distinctions given by the geographical situation can be read as can the potential of the wider surroundings.

By comparing different databases (e.g. currently 1961 – 1990 and 1986 – 2005) changes in climate conditions can be globally illustrated for various aspects. Climate elements can be regarded separately (e.g. maximum solar radiation on inclined surfaces or average, maximum and minimum temperatures below or above a certain value) or in combination (e.g. temperature in combination with absolute humidity to asses natural ventilation or temperature and solar radiation to asses solar cooling).

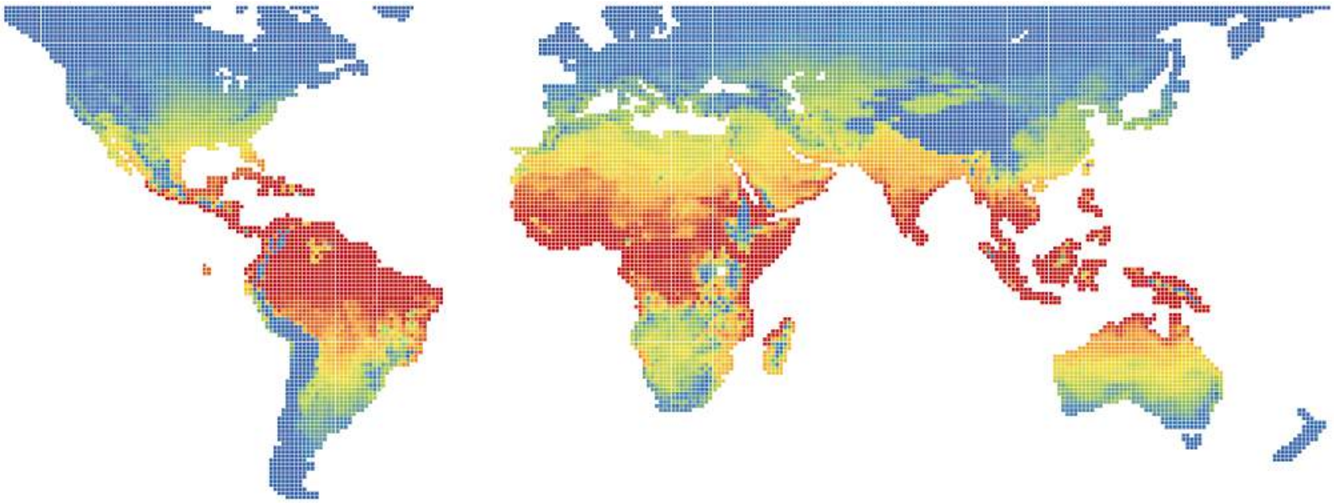


Fig. 12: Potential of global night ventilation as an example for an analysis of climate elements worldwide.

4. BUILDING SPECIFIC CLIMATE CLASSIFICATION

Key values for room conditioning include absolute air humidity and the temperature. A division of climate zones according to temperature and precipitation (e.g. according to Koeppen and Geiger, 12), or to natural and scenic aspects, fails to allow clear conclusions regarding room conditioning measures. It is not possible to directly identify which measures are necessary to ensure a comfortable room climate. The climate in deserts close to the sea with its high absolute humidity is completely different from the dry continental desert climate. Neither the divisions named above nor the common climate diagrams show these differences. An extensive climate data evaluation of outdoor temperatures and absolute humidity was needed to arrive at a representative climate zone division for building climatology (Fig. 13), (2).

For a representative number of several hundred cities the hourly values of a year for the outdoor air temperature and the absolute humidity were projected in a psychrometric chart. This provides an outline of a location's climate that shows whether heating or cooling, humidifying or dehumidifying is required, or whether a temperate climate is being dealt with, which places no major demands on building climatology systems. The international standard ASHRAE-55 (7) is used to define a comfort area for low wind speeds. It also shows in combination with the cooling and heating degree days as well as the (de)humidifying gram days whether a comfortable indoor climate can be achieved by taking passive measures, or whether active cooling is needed throughout the year.

Differences exist in terms of latitude, altitude and continentality. The heating and cooling degree days and the humidifying and dehumidifying degree days give more specific information about the local climate and show specific aspects, in that all the data are mean values. Given that no micro climatic influences were considered, more detailed examinations are necessary for individual cases.

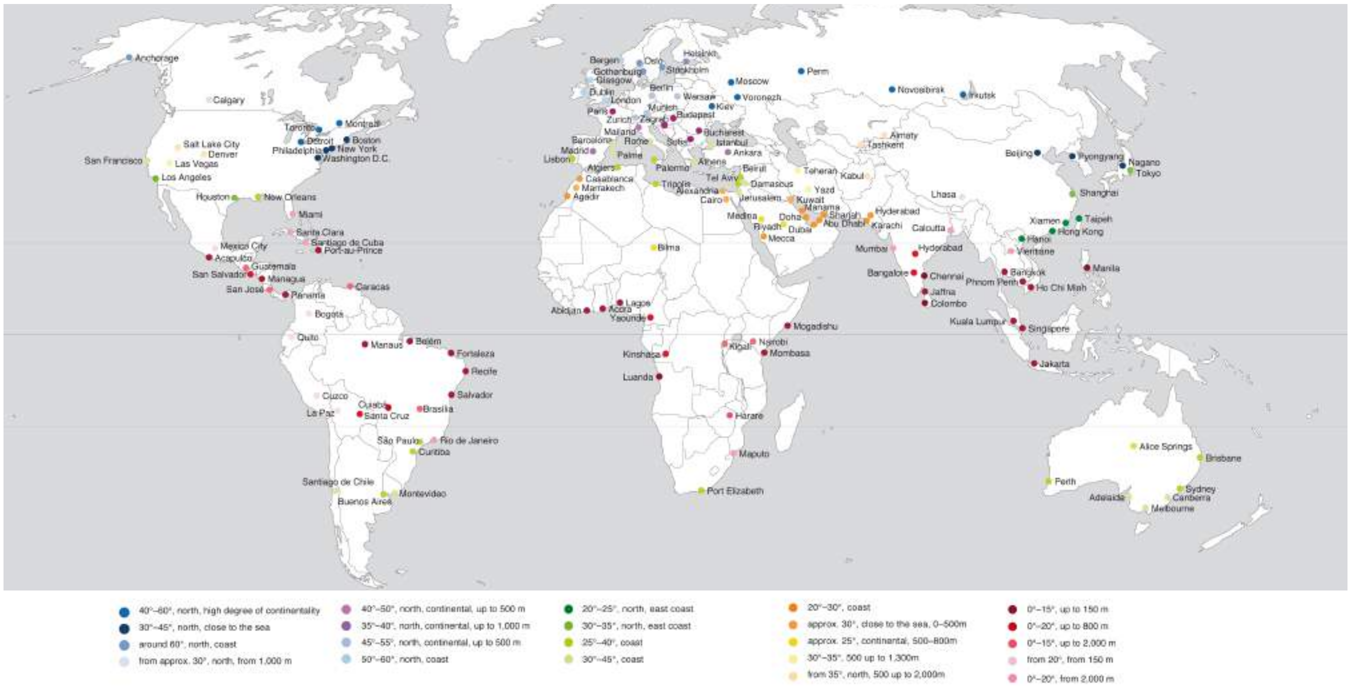


Fig. 13: Building specific climate classification (2).

5. SUMMARY AND OUTLOOK

The paper presented the possibilities for a climate analysis with the interactive graphic based ClimateTool. This easy-to-use planning tool has been developed for early phases of design to help architects, engineers, students and homeowners examine the potentials and challenges of a location and develop building concepts in line with sustainable architecture. The tool will be further developed to include different comfort zones and in terms of the UrbanTool to implement the maximum yield of PV systems. The Urban Tool will be validated using the weather station and the two research facilities of the Thermal Lab (13) at UT Austin.

REFERENCES

(1) Hausladen, G., Liedl, P., de Saldanha, M.: Building to suit the climate– A Handbook, Basel 2012

(2) Liedl, P.: Interaktion Klima-Mensch-Gebaeude. Development of easy-to-use planning tools for early phases of design. Dissertation, Technische Universitaet Muenchen, Muenchen, 2011.

(3) Meteonorm – Global Solar Radiation Database. Version 6.0. WWW: <http://www.meteonorm.com>

(4) Recknagel, H., Sprenger, E., Schramek, R.: Taschenbuch fuer Heizung und Klimatechnik 11/12, Muenchen, 2011

(5) Olgay, V.: Design With Climate. Bioclimatic Approach to Architectural Regionalism, New Jersey, 1963

(6) Walter, H.; Lieth, H.: Klimadiagramm-Weltatlas, Jena, 1967

(7) ASHRAE, ASHRAE Standard 55: Thermal environmental Conditions for Human Occupancy, Atlanta, 2009

(8) Radiance – Lightig simulation tool. WWW: http://www.radiance-online.org

(9) Perez, R. e.a: Anisotropic hourly-diffuse Radiation Model for SlopingSurfaces, SolarEnergy 36, pp. 481 – 497, 1986

(10) Google Maps. WWW: <http://maps.google.com>

(11) ESP-r – Dynamic building simulation program. WWW: <http://www.esru.strath.ac.uk/Programs/ESP-r.htm>

(12) Kottek, M., Grieser, C., Beck, B., Rudolf, Rubel, F.: World Map of the Koeppen-Geiger climate classification updated. WWW: <http://koeppen-geiger.vu-wien.ac.at>

(13) Thermal Lab of School of Architecture at University of Texas at Austin. WWW: <http://soa.utexas.edu/csd/research/experimental-research>.