溫室環控工程決策支援軟體之建立 I. 台灣地區溫溼度與輻射

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摘要

環控系統規劃需要特定地點的氣象資料作為系統設計依據。過去使用的夏季/冬季設計溫度值與度日數在使用上誤差較大，氣象 bin data 可提供良好的參考，但因為數值呈現多以表格方式，且各溫度區間為定值，使用上常需要作內插，頗不方便。在電腦盛行的今日，使用機率分布為最新的做法。

本研究使用 MATLAB **程式語言建立** MS Windows **環境下的軟體，涵括氣象局十個測站過去十四年的逐時溫度、溼度資料與過去十二年的輻射、日照時數等資料，允許使用者選擇地點查詢合乎使用者設定的溫度與/或溼度範圍內的一年中發生的小時數與機率值。軟體同時提供其他十個功能包括：上述溫、溼度機率分布的 2D 與 3D 繪圖，月平均/最高/最低溫、溼度，季平均溫、溼度，月平均日照量，平均日照時數，十四年中有最熱的一小時那天/最熱的一日的逐時溫、溼度資料與各地區的濕球降等。**

本研究所提供的資訊可進一步協助以下溫、溼度與輻射相關之決策，包括：判斷某一地區是否適合栽種某一作物，那些月份需要加熱/冷卻，加熱/冷卻系統設計負荷與操作成本的決定，遮陰系統的設計需求與控制方式，蒸發冷卻降溫系統的降溫極限與效能等。

關鍵詞： **氣象、台灣、決策支援、環控農業、**MATLAB

Development of decision support software for Taiwan local weather

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Abstract

For controlled environment agriculture (CEA) related facility planning and design, weather information for the specific location are required for the estimation of heating/cooling loads and design of environmental control components and systems. Summer/Winter design temperature and degree day were the traditional methods used by the engineers to estimate the annual cooling/heating load. Weather bin data is more advanced but provided in tabular format. Accumulative probability weather data is more flexible to use than tables or graphs and more easily computerized.

Software developed in this study, using MATLAB under Windows environment, is capable of providing probability data for any user defined range of temperature (T) and/or relative humidity (RH) for any selected location provided in the database. Such information can also be presented as 2D and 3D plots. Monthly and seasonal information on T, RH, solar radiation and sunshine duration are also available. The software also identified the day with hottest average temperature and the day with hottest hourly temperature, and showed the trends of dry bulb, wet bulb temperature and relative humidity of these two particular days. Wet bulb depression of selected location is also available in the software.

The applications of this software in temperature, humidity and radiation related decision making includes the determination on the suitability of growing certain crops in certain location, months required heating/cooling and the determination on cooling/heating load/costs, shading requirement, shading control and the limit on the performance of the evaporative cooling applied in certain locations, etc.

Keywords: Weather, Taiwan, Decision support, CEA, MATLAB

1. Introduction

Weather stations worldwide generate huge amounts of weather data. Most of these listed in literature are in Table form or drawn in contour line format. Both are generally inconvenient to utilize in computerized applications often requiring interpolation or other processing.

For controlled environment agriculture (CEA) related facility planning and design, weather information for the specific location are required for the estimation of heating/cooling loads and design of environmental control

components and systems.

Cumulative probability weather data is more flexible to use than tables or graphs and more easily computerized. The author developed computer-software, using cumulative probability weather data for years 1981 to 1992, under DOS environment in 1993. This software was never published or released but used as a teaching tool only and posted on the web-site. Subsequently, 2 more years of data were collected (Fang, 1995). The software described in this paper is a re-development of the above mentioned program under Microsoft Windows based environment. Several new features were added due to the capability of the programming language has been improved throughout the years.

2. Materials and methods

General mathematical software such as MATLAB (Mathworks, USA) has been taught in many engineering courses. With the strong graphical user interface (GUI) and powerful toolboxes provided, the development of the software can be shortened. Takakura and Fang (2002) wrote a CEA related textbook dealing with dynamic simulations of bio-engineering systems using MATLAB. Cundiff and Mankin (2003) wrote another textbook focusing on the dynamics of biological systems, again using MATLAB. It is obvious that the MATLAB software is well accepted by Agricultural/Biological engineers.

It is generally well accepted by researchers that an accumulation of at least 10 years of weather data for a particular location can be used as representative of that place (Albright, 1990). Fourteen years of hourly weather data from 10 representative Taiwanese weather stations prior to 1995 were contained in the software developed in this study using MATLAB. It is assumed that this data can represent general trends and can still be used for the years after the present year of year 2003.

3. Description of 'TaiwanWeather' software

After entering 'TaiwanWeather' in the command window of MATLAB, the popup menu as shown in Figure 1a will appear. The 2nd line shows the option to select weather data from 10 weather stations as shown in Figure 1b.

3.1. Probability of defined range of Tdb and RH

As shown in Figure 1, blocks starting from lines 3 and 8 allow users to enter ranges of temperature (T) and relative humidity (RH) of interest, respectively. After defining these two ranges, press the 'Prob. of occurrence' button and then the program will retrieve the selected data file, filtering all the data based on 3 criteria, looking for those hours with 1.) T only, 2.) RH only, and 3.) T and RH within the predefined range. The software will finally sum the hours, and then divide by 8760 to derive the probability that conditions will be within the range specified.

As shown in the example in Figure 1b, the selected city is 'Taipei' and the defined T range is 20 to 30 ^{o}C and the defined RH range is 65 to 85%. The probabilities of T, RH, and T and RH within the defined ranges are 57.8, 50.8 and 33.27 % respectively.

As Taiwan is an island surrounded by ocean, people generally say that summer is humid and hot. While this is true it does not convey all the information needed to understand and design environmental control systems for CEA. Maximum temperature and maximum humidity seldom co-exist. Based on the knowledge of moist air properties, it is clear that when temperature increases while dew point temperature and humidity ratio remain relatively constant, the relative humidity decrease but the wet bulb depression increase. Table 1 is derived from this software and shows that conditions when T is greater than 30 ^{o}C and RH is greater than 80 % simultaneously are rare for all locations in Taiwan as shown in the last column.

The feature of providing probability information of T and RH is much more flexible for use in system design than traditional tabulated or contour line graphs of weather data of just T and RH alone. Table 2 shows the maximum temperature range for 10 locations in Taiwan. It is quite clear that for all of the plain area of Taiwan, the temperature is within range of 10 to 39 ^{o}C. As shown in Table 3, weather station of 'Alishan', being at the relatively high elevation of 600 meters, it is both the coldest and has the highest relative humidity of the 10 locations. In the plain area, 'Ilan' followed by 'Chiayi' are the two locations of highest relative humidity and the range of RH for the plain area of Taiwan is almost always over the 50% range.

3.2. Hourly 2D and 3D plot

As shown in the bottom of Figure 1, there are 11 buttons for various displays and actions below the line of 'Other options'. The first two are 'hourly 2D plot' and 'hourly 3D plot' which will show the same data with different formats as shown in Figures 2 and 3. The 2D plot is color-coded and one cannot as easily interpret differences in a black and white print format as on a color monitor or color print. The two horizontal and vertical cross bars on the figures are the user selected ranges of RH and T as shown in the boxes on the right section of Figure 2.

3.3. Monthly T&RH

Selecting the 'Monthly T&RH' button will generate 3 more figures as shown in Figures 4a, 4b and 4c. The legends of the figures as shown in Figure 4a were moved to prevent visual blocking of data. The MATLAB software provides users with the capability of moving the legend around. The cross bars are the defined T and RH ranges as shown in Figure 1.

Figure 4b shows monthly daily average temperature and relative humidity for 'Hualien'. This data is useful to evaluate 'Hualien' for suitability for growing certain crops. The cross bars are user defined range of T and RH. This defined range can be the suitable range for certain crops. The periods outside the range of T or RH as selected to be shown in Figure 4b are January, February, March and December. In these 4 months, the average temperature is too low for a candidate crop that requires more than an average 20 ^{o}Ce. If more detailed information for candidate crops is given, for example, suitable daytime and nighttime temperature, then the information shown in Figure 4c can be useful. For example, one can tell that for March, it was the nighttime temperature that is not in the preferred range and in December, the daytime RH is below the defined range. Using such analysis, the suitability of certain crops for certain locations can be evaluated.

Using *Phalaenopsis* (moth orchid) as an example, the suitable daytime temperature is 25 to 30 ^{o}C and nighttime temperature is 18 to 24 ^{o}C for one of the species. Figure 4d shows the suitable months for meeting daytime temperature requirements of moth orchid in 'Tainan' are 4, 5, 10, 11 (April, May, October, November) while conditions are too hot in 6, 7, 8, 9 (June to September) and too cold in 12, 1, 2, and 3 (December to March). Figure 4e shows the situation in the nighttime. Due to the shift of the suitable temperature range by just few degrees for the nighttime, it is clear that in May and October, the daytime temperatures are satisfactory as shown in Figure 4d, are barely acceptable for the nighttime as shown in Figure 4e. Figure 4e also indicates that, with a little heating at night, March and December can be safely within the predefined proper range for the moth orchid.

If a users' interest is in the extreme temperatures of the month, the upper part of Figure 4a can be studied in more detail, as shown in Figures 4f and 4g, with defined cross bars showing a preferred daytime temperature range of 25 to 30 and a nighttime temperature range of 18 to 24, respectively. The suitable months for the daytime (the highest temperature curve) are January, February, and December and for the nighttime (the lowest temperature curve) are from June to September. It is quite clear that when growing moth orchid in 'Tainan', cooling in daytime is required from March to December as shown in Figure 4f and heating is required except from June to September in the nighttime as shown in Figure 4g.

3.4. Seasonal T&RH

Selecting the 'Seasonal T&RH' button will generate 2 more figures as shown in Figures 5a and 5b according to the use selected city. Numbers 1 to 4 represent 4 seasons as indicated in the lower right of Figure 5a. The upper left shows the seasonal average T and RH, the upper right shows seasonal daytime T and RH and the lower left shows seasonal nighttime T and RH. Again, the cross bars are the range defined in Figure 1.

3.5. Monthly radiation

Selecting the 'Monthly Rad.' button will generate 2 more figures showing the monthly radiation for 12 years' data. Figures 6 shows the data for 'Hualien' with MJ/m^2 as unit of the Y axis. Another Figure using cal/cm^2 as the Y axis unit also provided in this software.

3.6. Sunshine hours

Pressing the 'Sunshine hrs' button will generate a figure similar to Figure 7 according to the user assigned city. The sunshine hours indicate the available hours of solar radiation. In July, the sunshine hours per month is always in between 200 to 300 hours, ie., 6.45 to 9.67 hrs per day except the year of 1987. In that particular year, sunshine duration seems to shift to the next month.

3.7. Hottest day

Pressing the 'Hottest day' button will generate a figure similar to Figure 8 according to the user assigned city. There are two temperature curves and two dates listed in the graph. One is the day with the highest daily average temperature and the other is the day with the highest hourly average temperature. The label of the X axis indicates the exact dates with the hottest hour and hottest daily average as shown in Figure 8. The wet bulb temperatures were calculated based on the available dry bulb and relative humidity data as shown in the upper part of Figure 8.

3.8. Wet Bulb Depression

Pressing the 'WBD plot' button will generate a figure similar to Figure 9 according to the user assigned city. Wet bulb depression (WBD) is the difference between dry bulb and wet bulb temperature and is the upper limit on degree of

temperature reduced of any evaporative cooling systems. Figures similar to Figure 9 can reveal important information of how effective an evaporative cooling system maybe in the desire location.

'Hualien' city is located by the Pacific Ocean and is expected to be humid throughout the year. Figure 9 shows the maximum WBD of 'Hualien' is around 10 ^{o}C and the WBD is only 3 ^{o}C for nearly 25% of the year. Assuming the efficiency is 80%, pad and fan system can provide no more than 8 ^{o}C of cooling in 'Hualien'. Summing the accumulative probability values for WBD >=5, one can find the value is around 20% and can concluded that the pad and fan system will provide 4 to 8 ^{o}C cooling for almost 20% of the year and provide less than 4 ^{o}C cooling for remaining 80% of the year.

3.9. Miscellaneous

There are 3 more buttons in the section of 'other options', pressing the 'Save Defaults' button will save the current values into a default data file. The program will use these values for the next 'run'. The 'About' button will enable a pop up window showing information about the author and the sources of the weather data. Pressing the 'Quit' button will close all figures generated by this software and exit from this software.

4. Conclusions

Software developed in this study is capable of providing probability data for any user defined range of temperature (T) and/or relative humidity (RH) for any selected location. Such information can also be presented as 2D and 3D plots. Tables were generated using this software indicating that the temperature range of the plain area of Taiwan is within 10 to 39 ^{o}C and 50 to 100% relative humidity. The wet bulb depression is at most 10 ^{o}C.

Monthly and seasonal information on T, RH, solar radiation and sunshine duration are also available. One special feature of this software is that the hottest day within the 14 years period is identified. The software identified the day with hottest average temperature and the day with hottest hourly temperature, and showed the trends of dry bulb, wet bulb temperature and relative humidity of these two particular days. Such information can be of great importance in the design of the cooling system of a CEA facility.

Reference

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3. Fang, W. 1995. Limit and effectiveness of greenhouse environmental control facilities in Taiwan. NSC Project no. NSC 84-2321-B-002-098.
4. Takakura, T. and W. Fang 2002. Climate under cover, 2nd edition. Kluwer Academic Publishers. Dordrecht /Boston.London. pp.190.

Table 1 Probability of occurrence for the selected locations of Taiwan.

City	T≥30^{o}C	RH≥80%	T≥30^{o}C & RH≥80%
Taipei	11.43 %	50.12 %	0.092 %
Hualien	6.72	48.83	0.31
Ilan	7.45	69.25	0.45
Tainan	11.89	51.68	0.45
Kaohsiung	11.38	40.36	0.38
Chiayi	8.81	67.40	0.12
Taichung	10.39	48.31	0.01
Alishan	0.05	30.07	0.25
Wuchi	8.79	47.95	0.39

Table 2 Probability of occurrence for the selected locations of Taiwan showing upper and lower temperature ranges.

City	0 ^{o}C ≤T< 10 ^{o}C	10 ^{o}C ≤ T < 39 ^{o}C	T≥39 ^{o}C
Taipei	0.62	99.37	0
Hualien	0.08	99.92	0
Ilan	0.54	99.45	0
Tainan	0.32	99.68	0
Kaohsiung	0.08	99.92	0
Chiayi	0.98	99.02	0
Taichung	0.84	99.16	0

Alishan	34.81	64.79	0
Taitung	0.00	99.999	0.001
Wuchi	0.59	99.41	0

Table 3 Probability of occurrence for the selected locations of Taiwan showing 3 ranges of relative humidity.

City	RH<50%	50 ≤ RH < 80%	RH≥80%
Taipei	1.64%	48.24%	50.12%
Hualien	0.58	50.59	48.83
Ilan	0.25	30.50	69.25
Tainan	0.75	47.56	51.69
Kaohsiung	0.64	59.00	40.36
Chiayi	0.61	31.99	67.40
Taichung	2.37	49.32	48.31
Alishan	4.54	22.32	73.14
Taitung	0.89	69.05	30.06
Wuchi	1.41	50.63	47.95

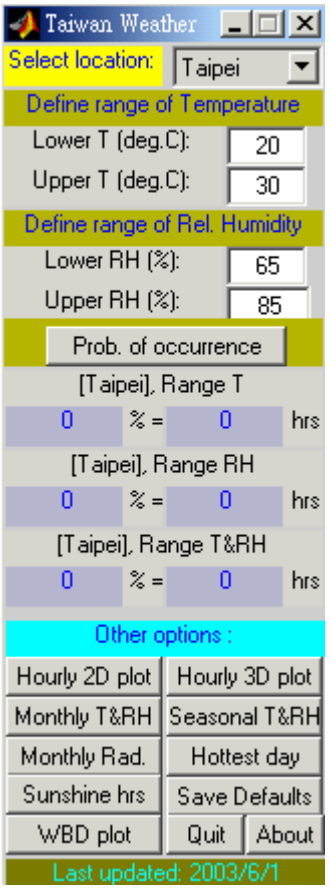

Fig. 1a Popup window of 'TaiWeather' software

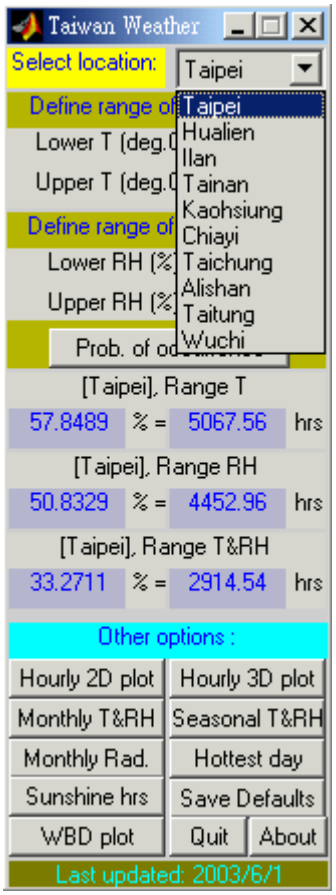

Fig. 1b Popup window shows available weather stations.

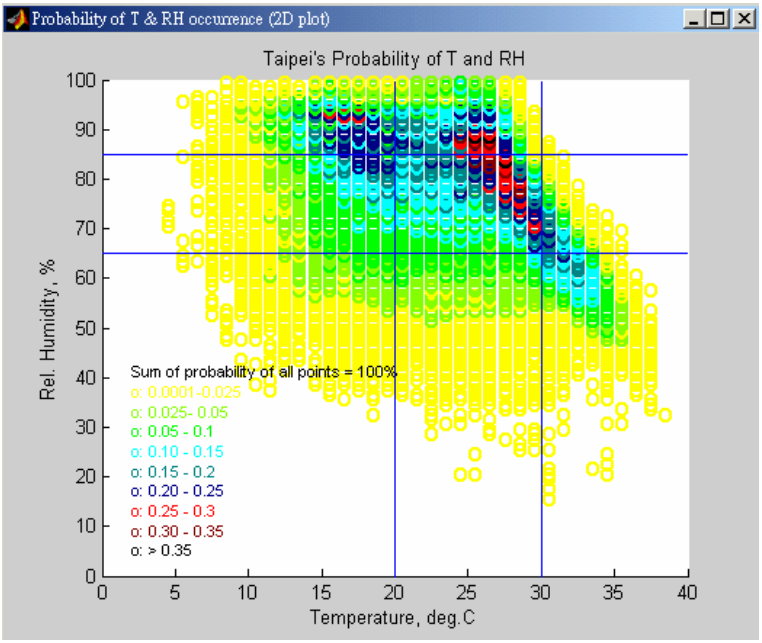

Fig. 2 Hourly 2D plot of 'Taipei' with defined T range within 20 to 30 ^{o}C and defined RH range within 65 to 85 %.

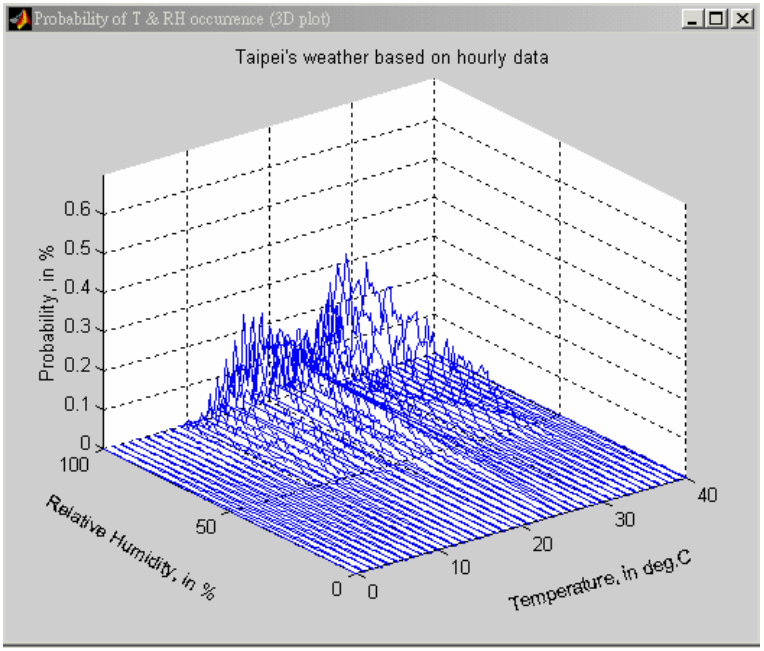

Fig. 3 Hourly 3D plot of 'Taipei'.

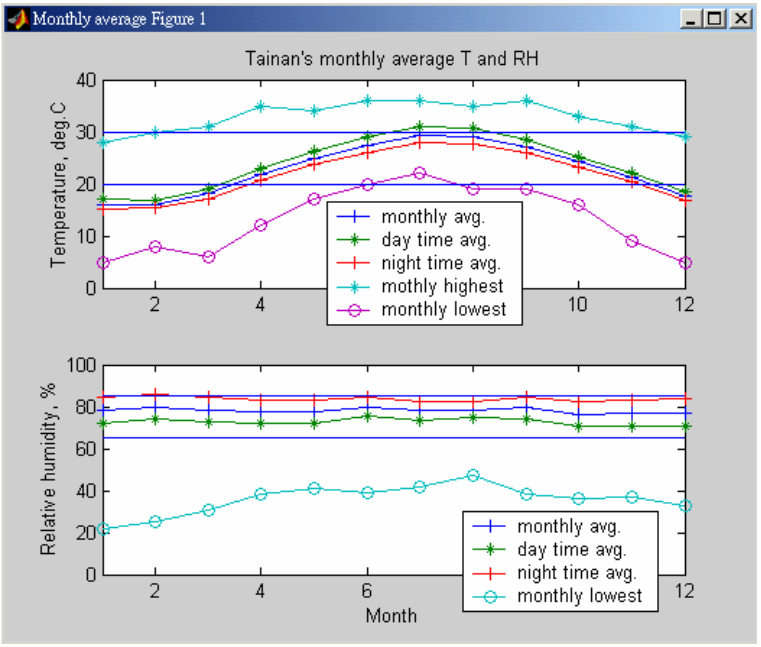

Fig. 4a Monthly temperature and relative humidity of 'Tainan'.

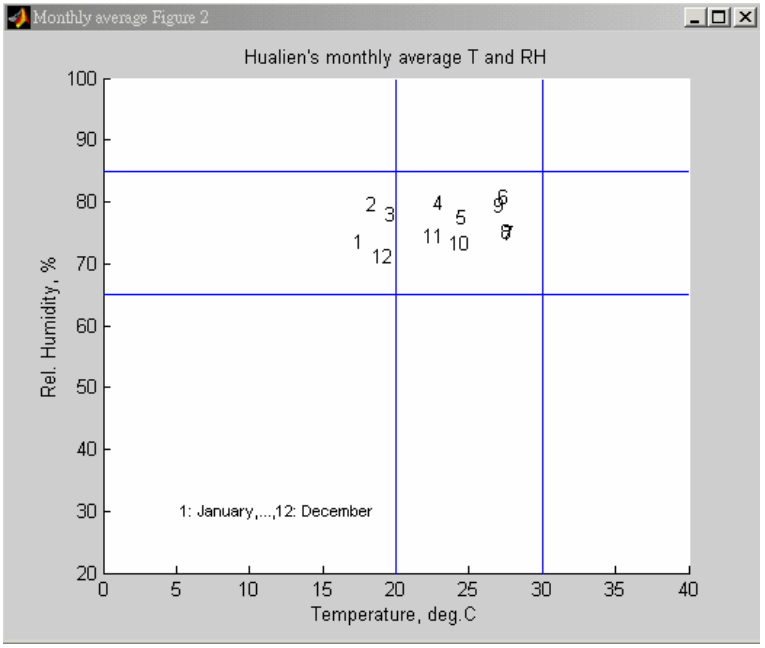

Fig. 4b Monthly daily average T and RH of 'Hualien'.

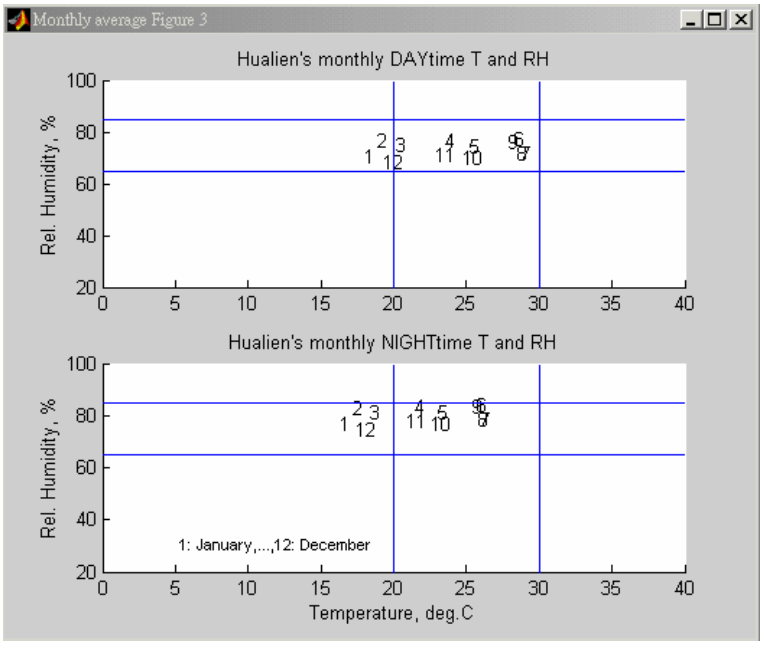

Fig. 4c Monthly daytime and nighttime T and RH of 'Hualien'.

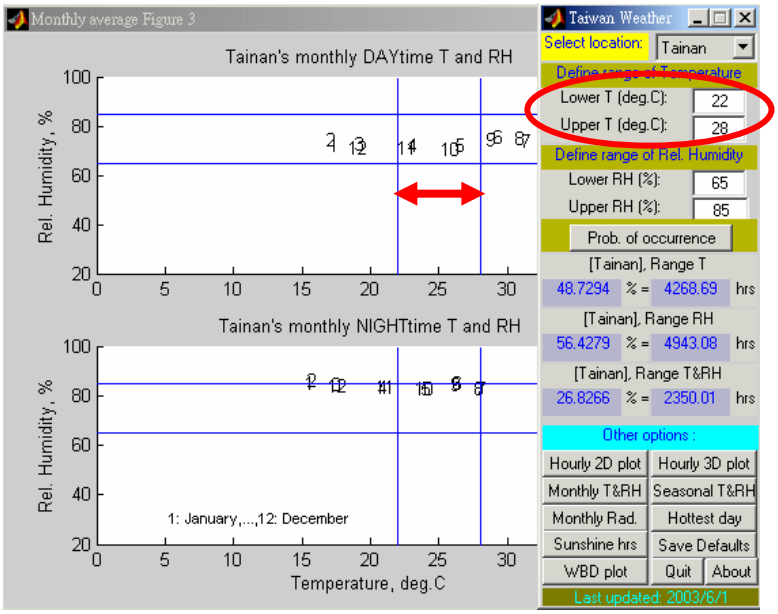

Fig. 4d Figure of Monthly daytime temperature and defined daytime temperature range for the growth of moth orchid.

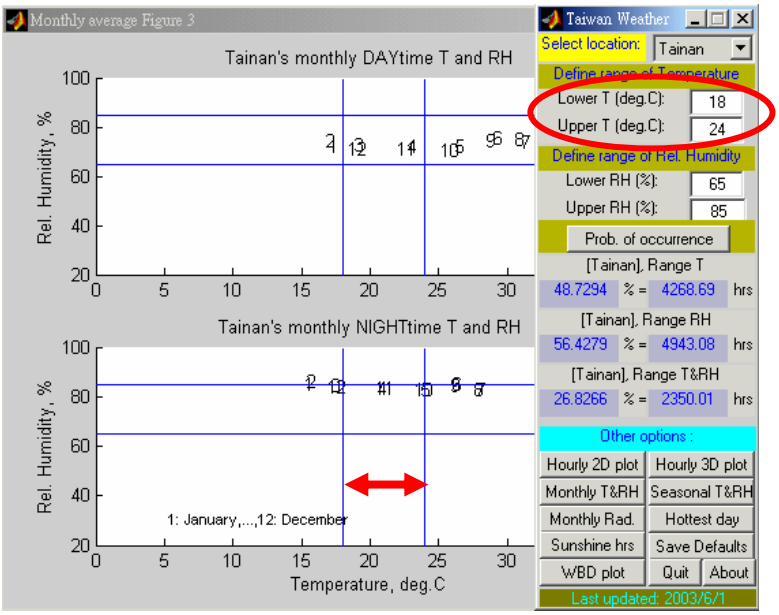

Fig. 4e Figure of Monthly nighttime temperature and defined nighttime temperature range for the growth of moth orchid.

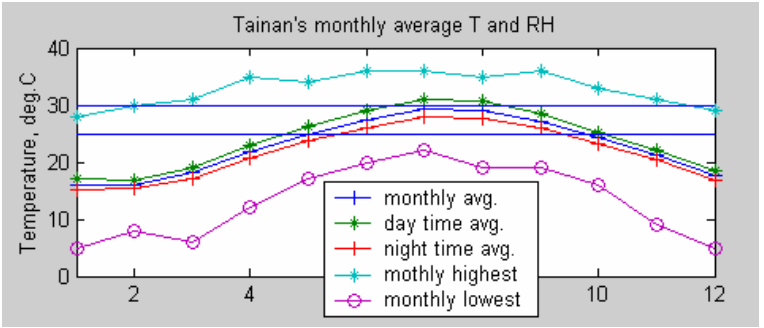

Fig. 4f. Upper part of Figure 4a showing monthly avg. T and preset daytime range of 25 to 30 °C.

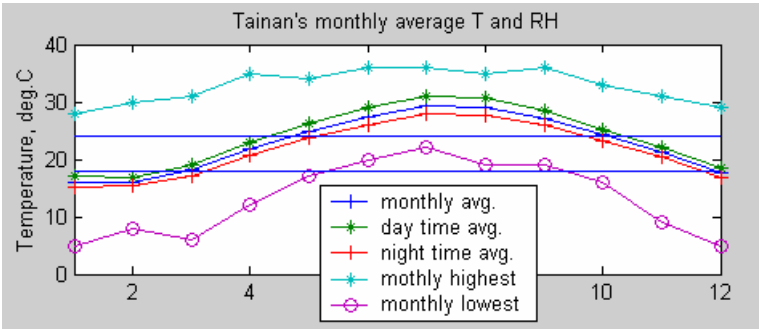

Fig. 4g Upper part of Figure 4a showing monthly avg. T and preset nighttime range of 18 to 24 °C.

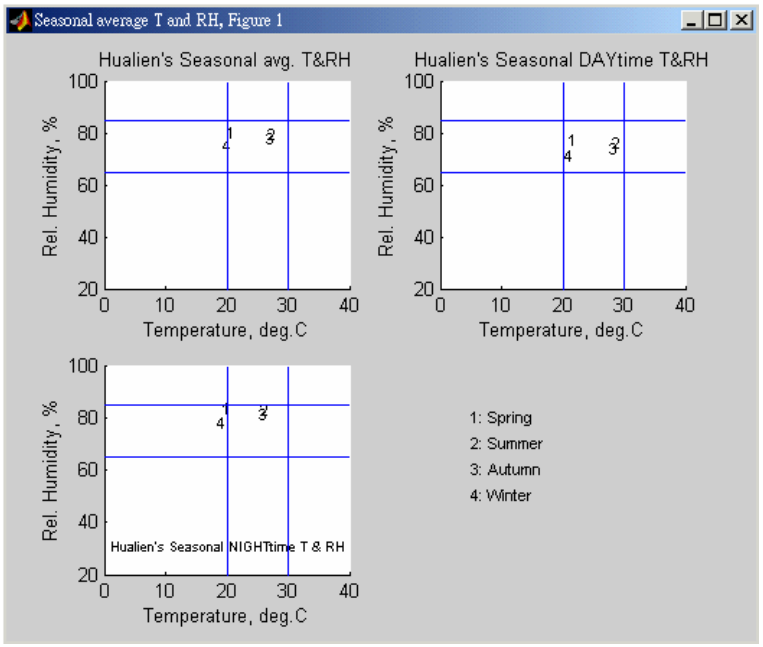

Fig. 5a Seasonal temperature and relative humidity of 'Hualien'.

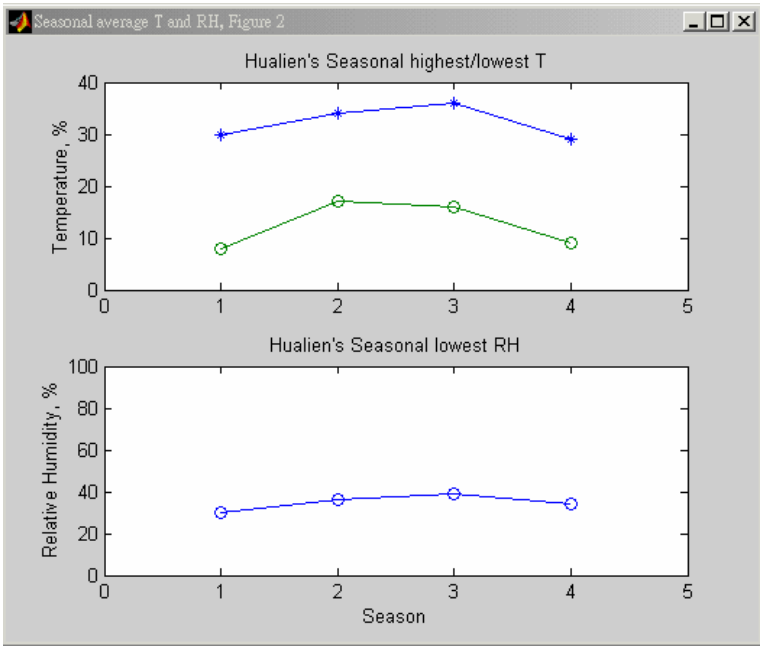

Fig. 5b Seasonal highest and lowest T and lowest RH of 'Hualien'.

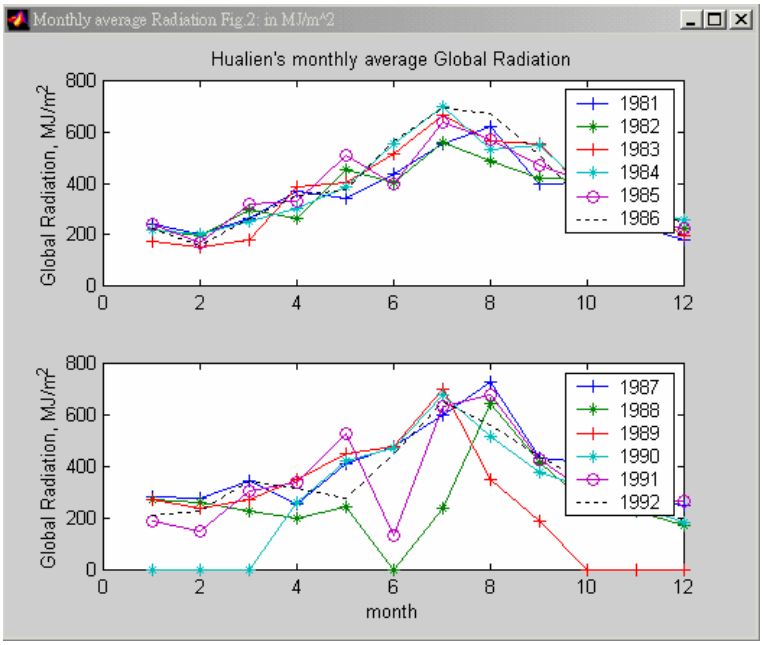

Fig. 6 Monthly average solar radiation of 12 years in 'Hualien' using MJ/m^2 as Y axis unit.

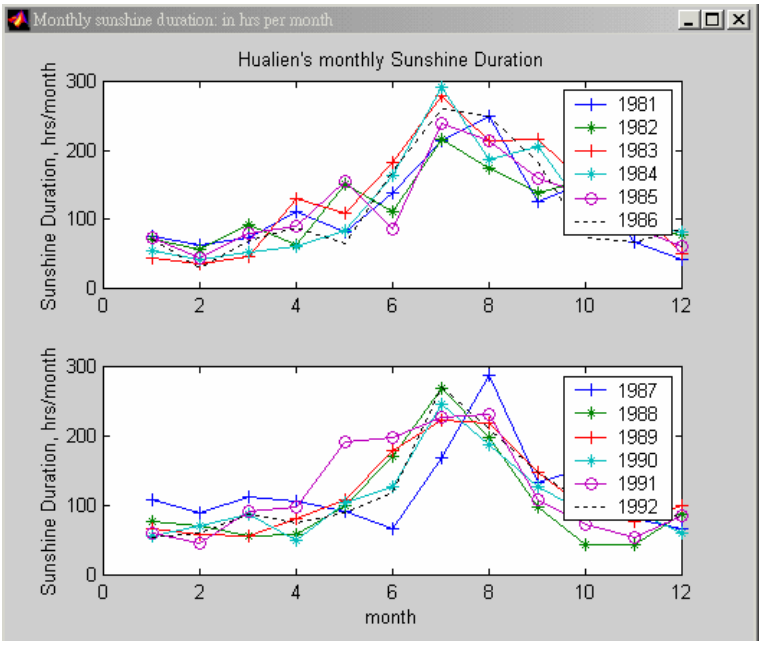

Fig. 7 Monthly sunshine hours of 'Hualien'.

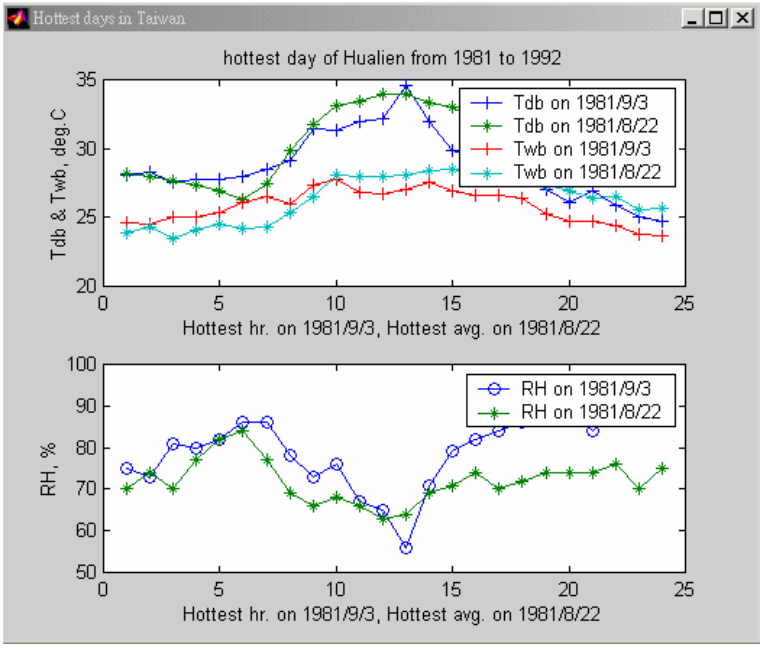

Fig. 8 Window of hottest day showing dry bulb, wet bulb and relative humidity information of days with hottest hour and hottest daily average.

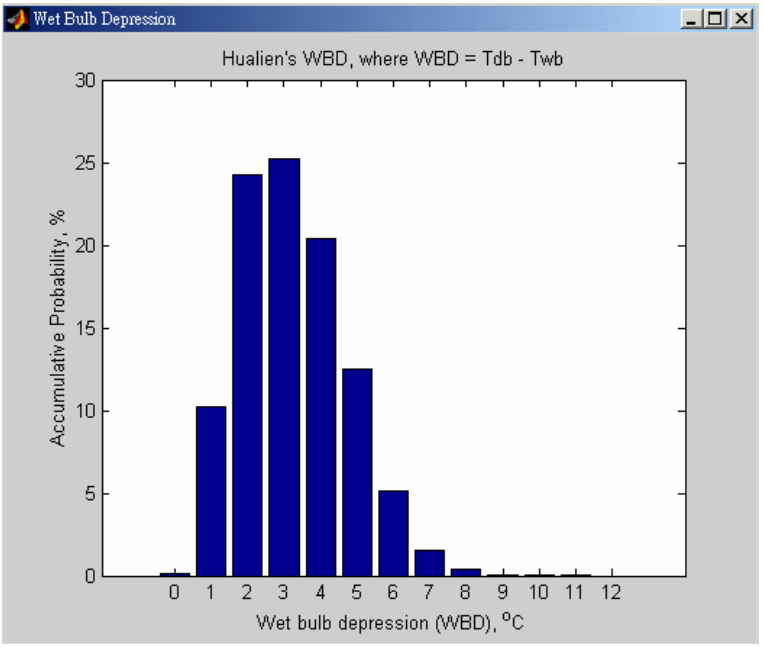

Fig. 9 Window of WBD showing accumulative probability of WBD of 'Hualien'.