

溫室環控工程決策支援軟體之建立 IV. 溫室通風系統設計

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摘要

本文旨在介紹使用 MATLAB 程式語言建立的自然通風與強制通風系統設計軟體。第一套軟體取名為 NV，為英文的自然通風(Natural Ventilation) 的首字，係基於穩態能量守恆。第二套軟體取名為 VETH，係基於穩態能量與質量守恆，探討通風(Ventilation)，蒸發散(Evapotranspiration)，溫度(Temperature)與溼度(Humidity)四者之間的關係。舉凡強制通風，使用水簾或噴霧系統的蒸發冷卻降溫系統均屬 VETH 軟體的探討範圍。本文同時示範如何使用 VETH 軟體設計噴霧系統。此兩套軟體頗適合溫室環境控制工程領域之教學，研究與實務分析之用。

關鍵字：通風，MATLAB，VETH，決策支援，蒸發冷卻，溫室，環控農業

Development of decision support software for greenhouse environmental control. IV. Design of Greenhouse Ventilation Systems

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Abstract

Two decision support software to support the natural ventilation and forced ventilation systems design were developed using MATLAB. The first program, entitled 'NV', short for Natural Ventilation, is based on steady-state energy balance. The second program, entitled 'VETH', is based on simultaneous steady-state energy balance and mass balance analysis. VETH deals with the coupled relationships of Ventilation, Evapotranspiration, Temperature and Humidity. Forced ventilation alone, pad and fan evaporative cooling system and fogging system designs are all within the scope of analysis utilizing the VETH software. Subprograms to calculate amount of water evaporated of a fogging system was included in VETH program. An example for designing and/or operating a fogging system is demonstrated using the VETH program. Both programs are user friendly and can be used as teaching/research tools in the field of controlled environment agriculture (CEA).

Keywords: Ventilation, MATLAB, VETH, Decision support, Evaporative cooling, Greenhouse, Controlled Environment Agriculture (CEA)

1. Introduction

Greenhouse environmental control differs greatly from the environmental control of industrial and commercial buildings. With the very large relative area of glazing, dynamic changes in the amount of solar insolation create large and frequently sudden changes in cooling load. Greenhouses located in temperate regions can often be designed to depend upon natural ventilation to remove excess heat, particularly in cooler seasons of the year. Tropical and subtropical greenhouses generally require forced ventilation and frequently also require pad and/or fog evaporative cooling systems to provide a suitable range of temperature for most crops throughout the year.

1.1. Natural ventilation

The driving forces for natural ventilation include wind and thermal buoyancy. Boulard et al. (1996) proposed a model based on these two driving forces to estimate the natural ventilation rate in greenhouses with only roof openings. Kittas et al. (1997) and Sase et al. (2002) using similar approach to study the natural ventilation rates of twin-span greenhouse with continuous roof ventilators and open roof with side vents, respectively. Sase et al. (2002) concluded that the thermal buoyancy effect is predominant for wind velocity at 1 m/s or less.

Consistent wind speed and direction is not typically assured for all times when ventilation is needed. Thus, natural ventilation system design must consider that ventilation is driven only by thermal buoyancy as there are significant periods when this is the case. Equation 1 shows an empirical equation in calculating ventilation by thermal buoyancy for situations of different inlet and outlet areas (Albright, 1990; Albright, 2002).

$$V = 0.65 A (1+F) [g \ ? h (T_i - T_o)/T_i]^{0.5} \quad (1)$$

where

V: Ventilation rate, m³/s

A: Smaller area between inlet and outlet opening area, m²

F: increase in ventilation rate due to inlet/outlet opening areas, decimal

g: Acceleration of gravity, m/s²

?h: Elevation difference between inlet and outlet, m

T_i: Absolute temperature of indoor air, K

T_o: Absolute temperature of outdoor air, K

Factor F ranged from 0 to 0.4, depending on the ratio of inlet vs. outlet area, or vice-versa, as shown in Figure 1. Factor F equals 0 when size of inlet and exit area are the same.

Equation 1 indicates that ventilation increases proportionally to the square root of the elevation difference (inlet to outlet) and air temperature difference and directly with the size of the opening area. As designs were being developed for warmer areas efforts were made to increase the roof opening since the investment required in the structure for increasing Δh is high. The typical Dutch greenhouse has a roof opening of 18.75% for natural ventilation. Similar greenhouse designs for New Zealand have 30% roof opening. An extreme case for increasing opening area for a natural ventilation system is the open-roof system in which the entire roof panels are opened to a vertical position. One should not forget the 'A' in equation 1 is the smaller value of the inlet and outlet areas.

Equation 2 shows the steady-state energy balance model for natural ventilation. Equation 3 shows the calculation of the sensible thermal flux. The solution of the model is the value of V where equations 1, 2 and 3 balance (Albright, 1990).

$$Q = (\rho V / A) C_p + U) (T_i - T_o) \quad (2)$$

$$Q = S_i R_s \quad (3)$$

where

- Q: Sensible thermal flux, W/m²
- ρ : Air density, kg/m³ (approximately 1.2 kg/m³)
- A: Unit floor area, m²
- C_p: Specific heat, J/kg/K (1050 J/kg/K)
- U: Unit floor area structural heat exchange coefficient, W/m²/K
- S_i: Indoor solar insolation, W/m²
- R_s: Portion of the indoor solar radiation converted to sensible heat, decimal

1.2. Forced ventilation

The term Q in equations 2 and 3 is the heat flux that is the portion, R_s, of indoor solar radiation related to temperature increase, termed sensible heat. The balance of the indoor radiation, 1-R_s, is converted to latent heat by transpiration from plants, evaporation from free water surfaces and fog if that is used. The maximum energy that can be converted to latent heat is limited by the capacity of the ventilating air to hold water. This approach requires a good estimate of R_s. Another approach is to consider the reduction of sensible heat flux due to evapotranspiration from plants and

other free surface of water as shown in equation 4.

$$Q = Si - l E \quad (4)$$

$$Si = t So (1-a) (1-s) \quad (5)$$

where

l: Latent heat of water, kcal/g or kJ/kg (0.58 kcal/g in general)

E: Evapotranspiration rate, g vapor/m²/min

t: Transmissivity of glazing, decimal

So: Outdoor solar insolation, kcal/m²/min or W/m²

a: Indoor solar reflectance, decimal (0.1 in general)

s: Degree of shading, decimal

In order that the total amount of *E* produced will be absorbed by and removed through the exchange of indoor/outdoor air, *E* must be calculated using equation 6.

$$E = 0.06 (Xi - Xo) ? V \quad (6)$$

where

0.06: unit conversion, 60 s/min kg/1000 g

Xi: Humidity ratio of indoor air, kg vapor/kg dry air

Xo: Humidity ratio of outdoor air, kg vapor/kg dry air

Noted that conditions can occur that *Q* becomes negative, such as when outdoor air is very dry, there is relatively little sun or a high ratio of shading and a high rate of total evaporation in the greenhouse. Adequate airflow must be provided under these conditions for this to occur.

Equations 7 and 8 can be derived by combining equations 2, 4 and 6. These two equations are the core of the VETH model (Mihara, 1980). Given outdoor temperature (*To*) and relative humidity (*Ho*), the outdoor humidity ratio (*Xo*) can be derived using equation 9. With the user assigned airflow rate (*V*) and Evapotranspiration rate (*E*), the indoor temperature (*Ti*) and interior humidity ratio (*Xi*) can be derived. With the calculated *Ti* and *Xi*, indoor relative humidity (*Hi*) can be derived using equation 9.

$$Ti = To + (Si - l E)/(? V Cp + U) \quad (7)$$

$$Xi = Xo + E/(0.06 ? V) \quad (8)$$

$$X = 8.18 H (0.046 T^2 - 0.87 T + 16.5)/10^6 \quad (9)$$

where

H: Relative humidity, %.

T: Dry bulb temperature, °C

X: Absolute humidity, kg vapor/kg dry air

1.3. Comparison on methods in deriving absolute humidity

The conventional method for calculating the humidity ratio is based on ASAE standards (1988) and fundamentals handbooks (ASHRAE, 1993) and requires several steps. The 1st step involves the calculation of saturated vapor pressure based on absolute temperature as shown in equations 10 and 11. The 2nd step is to calculate vapor pressure (Pw) by multiplying Pws by relative humidity (H, in % divided by 100) as shown in equation 12. The 3rd step is to derive absolute humidity (X) based on Pw and Patm (101.325 kPa for sea level) using equation 13.

$$PP = A_1/Tk + A_2 + A_3 Tk + A_4 Tk^2 + A_5 Tk^3 + A_6 Tk^4 + A_7 \log(Tk) \quad (10)$$

$$Pws = \exp(PP)/1000 \quad (11)$$

$$Pw = Pws * H / 100 \quad (12)$$

$$X = 0.62198 Pw / (Patm - Pw) \quad (13)$$

where

Pws: Saturated vapor pressure, kPa

Pw: Vapor pressure, kPa

Patm: Atmospheric pressure, kPa

Tk: Absolute temperature, K

for Tk > 273.15 K,

$$A_1 = -5.8002206 * 10^3;$$

$$A_2 = 1.3914993;$$

$$A_3 = -48.640239 * 10^{-3};$$

$$A_4 = 41.764768 * 10^{-6};$$

$$A_5 = -14.452093 * 10^{-9};$$

$$A_6 = 0.0;$$

$$A_7 = 6.5459673;$$

Although equation 9 is very straightforward and has been utilized by Mihara in his VETH model (1980), the conventional method was adopted in this study because it is more accurate. Figure 2 shows the difference between using equation 9 (solid curves with '+' symbols) and equations 10-13 (dash curves with 'o' symbols) in deriving absolute humidity within the range of 10 to 30 °C and 10 to 100 % relative humidity. For relative humidity greater than 60 %, equation 9 tends to underestimate when T is above 20 °C and tends to overestimate when T is below 16 °C, equation 9.

2. Descriptions of 'NV' program

2.1. Edit Window

Figure 3, entitled 'Edit Window', appears after the user enters 'NV' at the command window in MATLAB. There are 9 parameters requiring user input. The 1st parameter is the outdoor temperature. The value entered here is also the bottom-line temperature as shown in the Y axis of Figures 5. The 2nd and 3rd parameters are needed for the determination of Q as shown in equation 3. The 4th parameter is the ratio of inlet/outlet or outlet/inlet areas, which is determined using the lesser of the two divided by the larger one. The insight of this parameter can be further revealed by selecting the '% increase in flow' icon as shown in the bottom of Figures 3.

'NV' software requires users to enter the assigned value of U or to select the type of glazing with default values of U listed as shown in Table 1 (ASHRAE, 1993). After the user select the type of glazing used, the mark on 'User assigned U' will be toggled off automatically. The default values of U were adapted from 1998 fundamentals of ASHRAE.

2.2. 'Run' with 2 options

As shown in the white block of the Edit window, there are 2 options for family of curves to select. The one as marked in Figure 3 is the default setting. The result as shown in Figures 4 is a family of curves for elevation difference between inlet and outlet openings of 1, 3 and 5 meters.

Conditions for Figure 4 are as follows: To: 30 °C, Si: 500 W/m², Rs: 0.35, inlet/outlet area ratio: 1, and 4 for Figures 4a, and 4b, respectively. Glazing: Double PE, leading to the U value of 4 W/m²/K. The only difference in Figures 5a and 5b is the ratio of inlet/outlet area. With the given values of 1 and 4, the air flow increased by 0 % and 37.69 %, respectively as indicated in the 'title' of Figures 4a and 4b.

As shown in Figure 4, the elevation difference has an effect but is not nearly as important as vent opening area. Indoor temperature approaches outdoor temperature (assuming 4 °C difference is acceptable) when smaller of the inlet or outlet areas is more than 15 % of the floor area as indicated in Figure 4a and 10 % in Figure 4b. This is with only a 1m elevation difference between inlet and outlet and the temperature difference is even less with greater outlet elevation.

Another option in the white block of the Edit window of Figure 3 is the 'family of curves for glazing' with the user assigned elevation difference listed one line below.

Figure 5 shows the outcome of selecting this option with the assigned elevation difference of 3 meters and the ratio of inlet/outlet areas equal to 4. It is quite clear that the effect of glazing is not obvious if the minimum value of inlet/outlet area can be kept at more than 10 % of the floor area.

2.3. One Air Change

Following equation 1, if floor area and height of the greenhouse are given, equation 14 can be used to estimate number of air change per min.

$$AC = 60 * V / (A_f * h) \quad (14)$$

where

AC: Number of air change per minute

A_f : Greenhouse floor area, m^2

h: Greenhouse height, m

Combining equations 1 and 14 and assuming AC equals unity, equation 15 can be derived as follows:

$$T_i = T_o / (1 - k / \Delta h) \quad (15)$$

where

$$k = 1 / ((122.1/h)(A/A_f)(1+F))^2$$

Note that parameter dh shown in Figure 6 is same as Δh shown in equations 1 and 15, and T_i is the indoor temperature required to achieve 1 air change per minute due to thermal buoyancy. Other parameters involved are outdoor temperature (T_o), ratio of flow increase (F) due to different inlet/outlet opening areas, greenhouse height (h) and % of vent area vs. floor area (A/A_f).

Assuming greenhouse height (h) is always 0.5 meter more than the elevation difference of inlet/outlet (dh), Figure 6 shows family curves of T_i at three given elevation differences of inlet/outlet, and given T_o equals 30 °C and opening area ratio equals 3. Both values can be assigned in the Edit window as shown in Figure 3.

Indoor temperature (T_i) of curve of 5 m elevation difference is always few degree higher than the curve of 1 m elevation difference as shown in Figure 6. This is because the greenhouse volume of the former is 3.67 ($=5.5/1.5$) times that of the latter greenhouse. To reach 1 AC, tall greenhouse with more air volume will need more ($T_i - T_o$) to create more draft. Thus, higher T_i derived if T_o is fixed. The difference of T_i derived among 5 m and 1 m elevation difference curves are big when vent area as

percentage of floor area is small. However, if vent area vs. floor area reaches 30%, the discrepancy between these two curves reduced dramatically. That's why the same type of greenhouse in the Netherlands has 18.75% roof opening and change to 30% in New Zealand.

3. Descriptions of 'VETH' program

After entering 'VETH' in the command window of MATLAB, three windows will appear including, 1. GH UA calculation (Figure 7), 2. VETH main window (Figure 8), and 3. VETH sub window (Figure 9).

3.1. GH UA calculation Window

As shown in Figure 7, the upper part of the window shows edit cells which allow for the user to input required greenhouse dimensions. The program will calculate and display the results in the 'Derived' block, located at the bottom of this window. There are 3 basic types of roof that can be selected including: gable, circular arch and saw tooth. Actual U values for the roof and wall can be assigned from the 6 options as listed in Table 1. The U value listed in equation 7 is the average value based on unit floor area. This value is calculated by dividing the UA total, 10880.78 W/K, for this example, as shown in the last line of the 'Derived' block, by the total floor area, in this case 1080 m² as shown in the first line of the same block. The derived U involved in the calculation of equation 7 is then, 10.075 W/m²/K, using the materials for roof and wall of single PE and FRP, respectively as shown in Figure 7. This value also appeared in the title of VETH sub window as shown in Figures 9 to 13.

3.2. VETH main window

Figure 8 shows the VETH main window contains 5 blocks. The first block is the option selection block which has 5 predefined conditions and 1 user assigned condition. Blocks 2, 3, and 4 list the default values of environmental parameters and user defined V (ventilation rate) and E (evaporation rate of fogging system plus evapotranspiration rate of crops). Values of the first 5 options are listed in Table 2. The first 4 options contain regular summer conditions of tropical/subtropical regions such as very hot/hot, dry/humid, little sun/50% shading/no shading, etc. These options and the associated calculations are of forced ventilation only. Only V and E can be modified in these 4 options.

The fifth option is the same as option 1 but with the supplement of the pad system. By entering a pad efficiency, the air temperature, relative humidity and humidity ratio passing through the pad can be calculated automatically. The software then uses these values as the new T_o and X_o as listed in equations 7 and 8. The bottom block of Figure 8 shows the calculated indoor temperature (T_i) and relative humidity (H_i) for the example shown.

3.3. VETH sub window

Figure 9 shows the VETH sub window for option 1. In this figure, default values of parameters listed in VETH main window are used and the type of glazing for roof and wall are single PE and FRP, respectively. Table 2 shows values of related parameters of 5 options listed in the first block of VETH main window. As indicated in Figure 9, there are points marked with '+' and '*' signs showing the given outdoor and derived indoor temperature and relative humidity, respectively.

The given T_o and H_o for options 1, 2, 3 and 5 are 32 °C, 52 %, respectively. Option 4 represents weather of very hot (45 °C) and dry (15 %). Other inputs are V at 1.0 m³/m²/min for all options and E at 11, 5, 0.8, 13 and 7 g/m²/min for options 1 to 5, respectively. E value is around 7 g/m²/min for full canopy of well irrigated crop. Excess value of E can be achieved by means of humidification such as misting or fogging, etc. Table 3 shows the derived T_i and H_i under default conditions of all parameters.

Figures 10 to 13 shows VETH sub windows for options 2 to 5, respectively. Each figure has points indicating indoor and outdoor conditions with symbols of '+' and '*', respectively. In addition, in Figure 15, another point indicated with '+' symbol, labeled as ' T_{afterpad} ', located at the lower right corner, which shows the temperature and relative humidity of air after passing through the wet pad just as it enters the greenhouse. Defaults and derived values of 5 options can be found in Tables 2 and 3. The defaults of derived T_i and H_i of option 5 are 33.36 °C and 75.68 %, respectively. By changing the values of V and E to 2 and 11, respectively, T_i and H_i will change to 28.59 °C and 91.45 %, respectively.

3.4. Design of fogging system

If more water vapor is added by means of fogging, for example, the indoor temperature can be reduced further until the indoor relative humidity reaches 100 %. The upper limit indicated in Figure 14 shows only the bottom part of the VETH main window. In the case shown, input data for 'Evaporation' of 15 resulted in a calculated

relative humidity over 100% and generated the warning message shown. This indicates Evaporation must be reduced, as in the example shown in the next Figure.

Before saturation occurs, fogging can be beneficial in reducing the indoor temperature. For the case shown in Figure 15, indoor temperature below outdoor temperature occurred when ‘ % radiation \rightarrow latent heat’ is more than 100% and indoor relative humidity is less than 100%. This can be explained by equation 4 when Q becomes negative due to evaporative cooling of airflow passing through greenhouse when conditions are such that there is enough evaporation potential to utilize more heat than is coming in as transmitted radiation.

The difference in Figures 14 and 15 reveals that the maximum amount of E is in the range of 14 to 15 g/m²/min under the specified temperature and radiation conditions. If the amount of transpiration (Et) can be estimated, the maximum allowable amount of fogging (Es) can be calculated (Es=E-Et) assuming 100% relative humidity is the allowable upper limit. If there is concern for disease to be considered, the upper limit of relative humidity can be reduced, to 85% for example, and the allowable Es value can be re-calculated based on the new E value. The time required to operate the fogging system per minute can be determined by equation 14.

$$N = (E - Et) / (F * ?) \quad (14)$$

where

- E: Maximum allowable evapotranspiration plus fogging rate, g/m²/min
- Et: Estimated evapotranspiration rate, g/m²/min
- F: Mass flow rate of fogging nozzle, g/min/ nozzle
- ?: Efficiency of fogging system, decimal
- N: Number of fogging nozzles installed per m², also represent ratio of operating time per min assuming 1 nozzle per m²

Using the extreme case (no transpiration occurs) in designing the fogging system, based on Figures 14 and 15, E must be less than 14 and Et equals 0. Figure 15 shows the outcome of user-assigned evaporation and ventilation rate. At 14 g/m²/min of evaporation rate, although, the indoor humidity is still less than 100%, the latent heat required is greater than total radiation, which is not possible.

Using the data from a local nozzle manufacturer (Gene environmental control Ltd., 2003), the F is 80 g/min/nozzle if the pressure is at 70 kg/cm² and the efficiency is 100%. The number of nozzles required per m² is 14/80 = 0.175. This works out to 1 nozzle per 5.7 m². If 1 nozzle per m² is a pre-request, then N becomes the ratio of operating time per min. In this case the value 0.175 means the control system should turn on the fogging system for 10.5 sec in each minute.

Figure 16 shows sub-Window of ‘Evaporation due to fogging’. Users can access this window by pressing the 1st button listed in ‘Given V & E’ section. Equations 15 and 16 listed below were used. Efficiency of fogging system was determined based on water pressure (Bottcher, et al., 1991).

$$\eta = 0.124 + 1.35 * 10^{-4} * (100 P) \quad (15)$$

$$E_f = N * F * \eta * d / 60 \quad (16)$$

where

E_f: Estimated fogging rate, g/m²/min

P: Water pressure, kg/cm², P times 100 converts the unit to kPa

d: Number of seconds for the fogging system to turn on per minute

3.5. User assigned option

Figure 17 is the VETH main window for option 6, which allows user input all related parameters including, outdoor dry bulb temperature, relative humidity, indoor solar radiation in either kcal/m²/min or W/m² units, pad efficiency, given ventilation and evapotranspiration rates. The output of this option is similar to Figure 15 shown above.

4. Conclusion

This study has transformed well documented domain knowledge of natural ventilation and forced ventilation systems design into Windows based computer-software using MATLAB.

The first software, entitled ‘NV’, natural ventilation in short, involves steady-state energy balance analysis. NV utilizes information on the ratio of vent opening area to floor area, ratio of inlet/outlet areas, glazing type, elevation difference of inlets and outlets and predicts the indoor/outdoor temperature difference.

The second software, entitled ‘VETH’, combines steady-state energy balance and mass balance analysis. VETH deals with the coupled relations of Ventilation, Evapotranspiration, Temperature and Humidity. Ventilation with fan only, pad and fan, fogging with fan and pad and fan plus fogging systems designs are within the scope of VETH software. Subprograms to calculate amount of water evaporated of a fogging system is included in VETH program. Examples of designing and/or operating a fogging system are demonstrated using VETH software. Both software tools are user friendly and can be used as teaching/research tools in the fields of controlled environmental agriculture. Both software can be downloaded from the following

website:

http://ecaaser3.ecaa.ntu.edu.tw/weifang/cea/cea_software.htm

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表 1. 各種披覆資材的 U 值

Table 1. U values of various glazing materials (ASHRAE, 1998)

Glazing	U, W/m ² /K
Single glass	6.25
Double glass	4
Single PE	7.14
Double PE	4
FRP	6.67
Double PC/Acrylic	2.86

表 2. 圖 8 中五種天候狀況的相關參數預設值

Table 2. Defaults of environmental parameters of the 5 options listed in Figure 8.

Conditions	To °C	Ho %	Radiation W/m ²	Pad efficiency, %	V m ³ /m ² /min	Evap. g/m ² /min	Transp. g/m ² /min
1) Hot, no shading, Fan	32	52	530.3	N/A	1	4	7
2) Hot, 50% shading, Fan	32	52	265.2	N/A	1	2	3
3) Hot, little sun, Fan	32	52	34.89	N/A	1	0	1
4) Very hot, dry, no shading, Fan	45	15	558.2	N/A	1	6	7
5) Hot, no shading, Fan& Pad	32	52	530.3	83	1	0	7

表 3. 表 2 中所列各種參數組合使用預設值的計算結果

Table 3. Derived indoor conditions of 5 options listed in Table 2.

Conditions	Ti °C	Hi %	T _{afterpad} °C	H _{afterpad} %
1) Hot, no shading + Fan	34.75	71.28	N/A	N/A
2) Hot, 50% shading + Fan	34.03	58.99	N/A	N/A
3) Hot, little sun + Fan	32.08	54.02	N/A	N/A
4) Very hot, dry, no shading + Fan	46.04	32.21	N/A	N/A
5) Hot, no shading, Fan& Pad	33.36	75.68	25.249	88.55

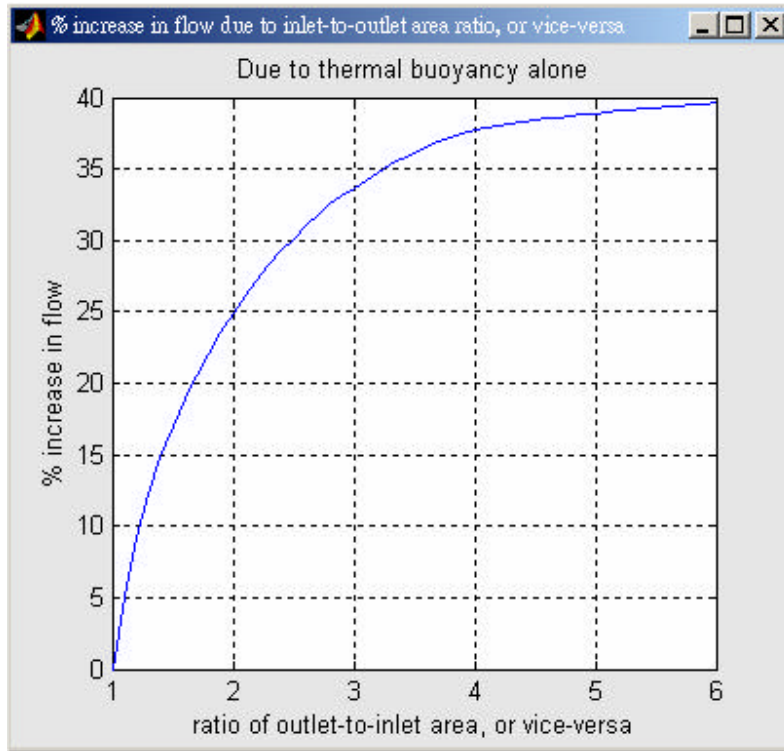


Figure 1. Percent increase in flow due to different outlet-to-inlet area ratios.

圖 1. 基於不同空氣進出口面積比所增加的風量百分比

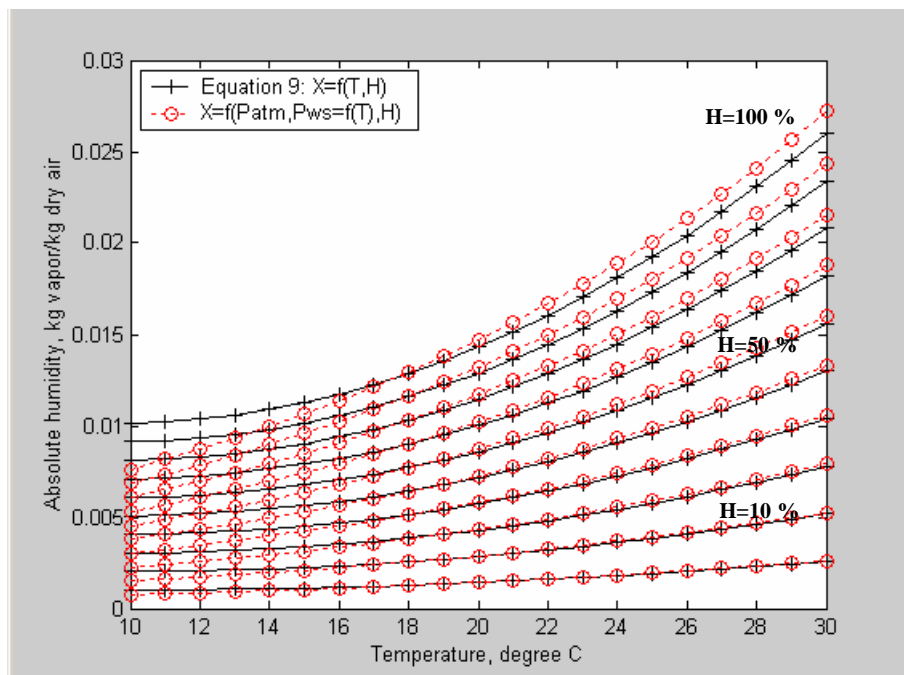


Figure 2. Comparison of two methods for calculating absolute humidity with given dry bulb temperature and relative humidity.

圖 2. 已知空氣乾球溫度與相對濕度計算絕對溼度的兩個計算式的比較

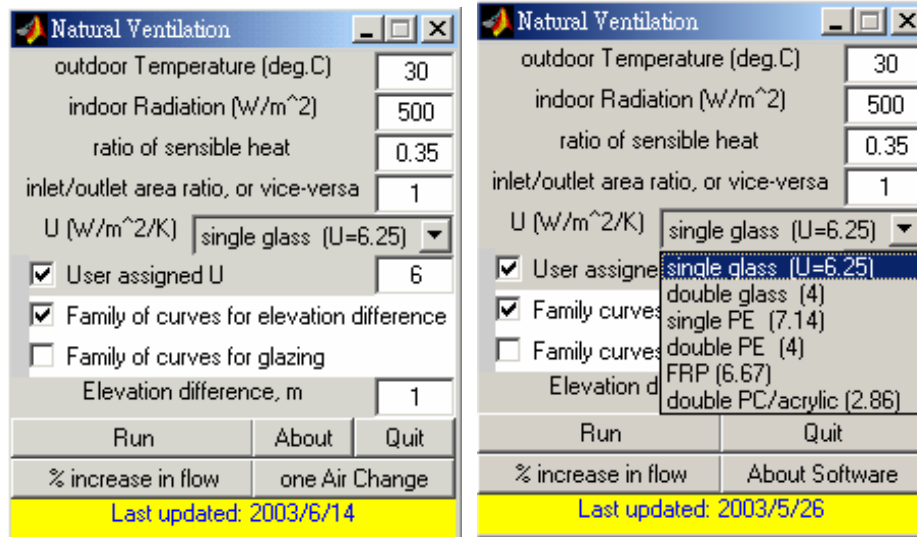


Figure 3. Edit window of 'NV' software (also showing glazing list)

圖 3. NV 軟體的參數編輯視窗 (同時顯示可選擇的披覆資材種類與 U 值)

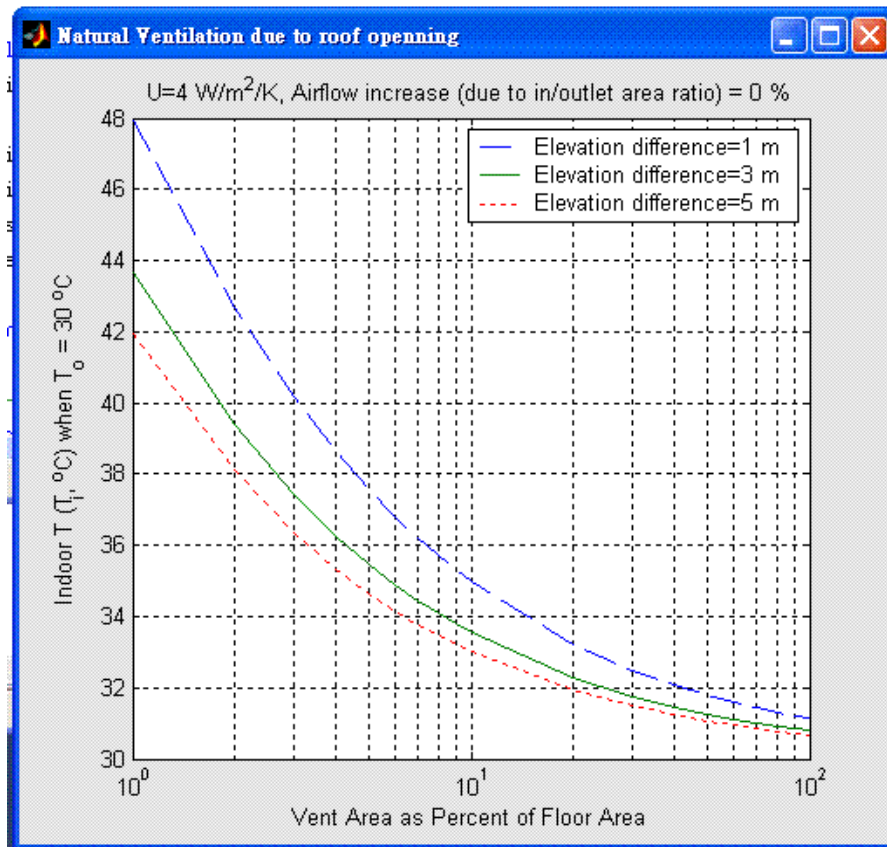


Figure 4a. Snapshot of the outcome of 'Run' for 'NV' software with the 'family of curves for elevation difference' option selected. (Other values: double PE glazing and equal inlet/outlet areas leading to no extra air flow increase).

圖 4a. NV 軟體的輸出畫面之一，選擇顯示不同溫室高度的輸出畫面，使用雙層 PE 塑膠布，空氣進出口面積相等

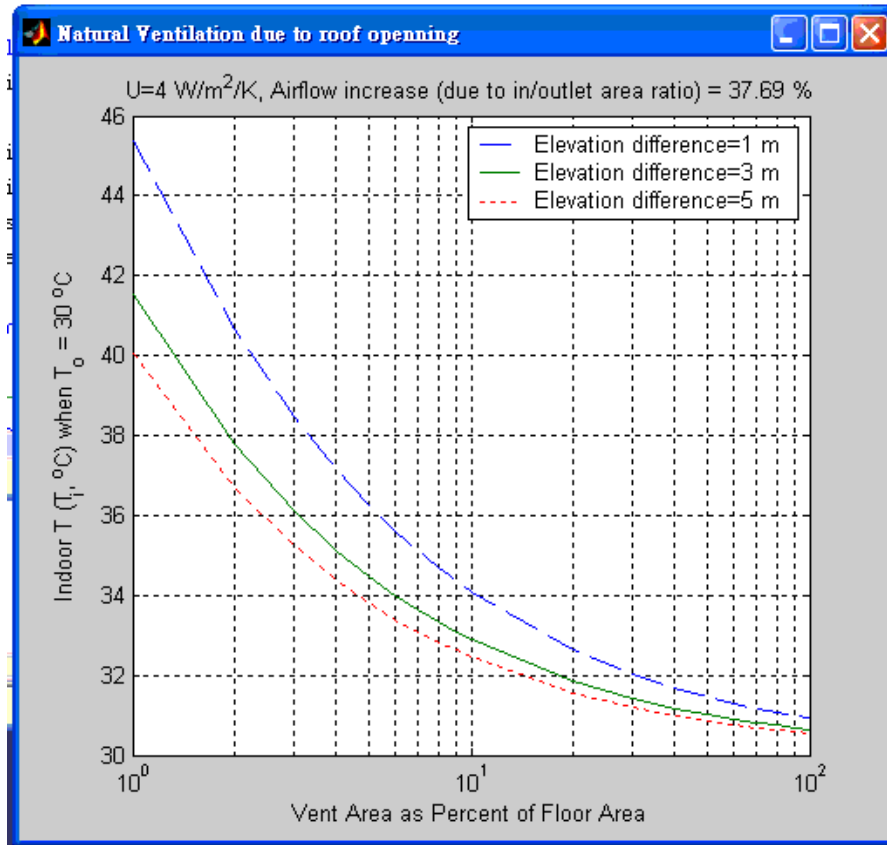


Figure 4b. Snapshot of the outcome of ‘Run’ for ‘NV’ software with the ‘family of curves for elevation difference’ option selected. (Other values: double PE glazing and ratio of inlet/outlet areas equals 4, leading to an air flow increase of 37.69%).

圖 4b. NV 軟體的輸出畫面之一，選擇顯示不同溫室高度的輸出畫面，使用雙層 PE 塑膠布，空氣進出口面積比為 4

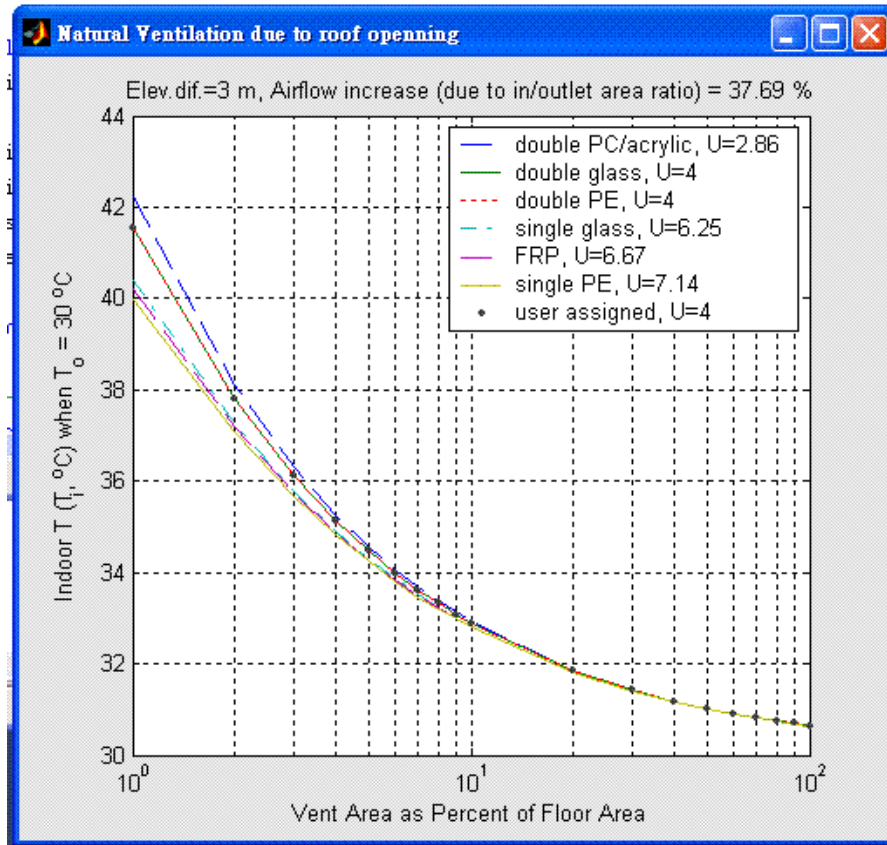


Figure 5. Snapshot of the outcome of ‘run’ for ‘NV’ software with ‘family of curves for glazing’ option selected. (Other values: elevation difference equals 3 meters and ratio of inlet/outlet areas equals 4).

圖 5. NV 軟體的輸出畫面之一，選擇顯示所有不同批覆資材的輸出畫面，溫室高度為 3 公尺，空氣進出口面積比為 4

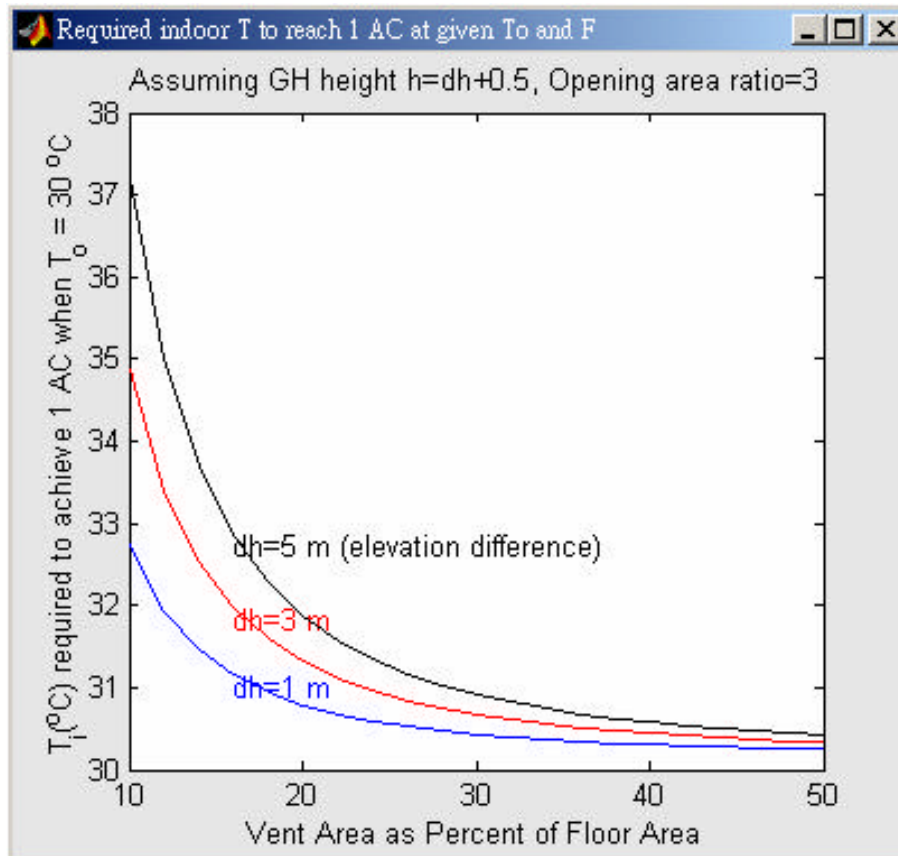


Figure 6. Indoor temperature required to achieve 1 AC at various conditions.

圖 6. 要達到每分鐘交換一次同溫室體積的通氣量所需要的溫室室內溫度

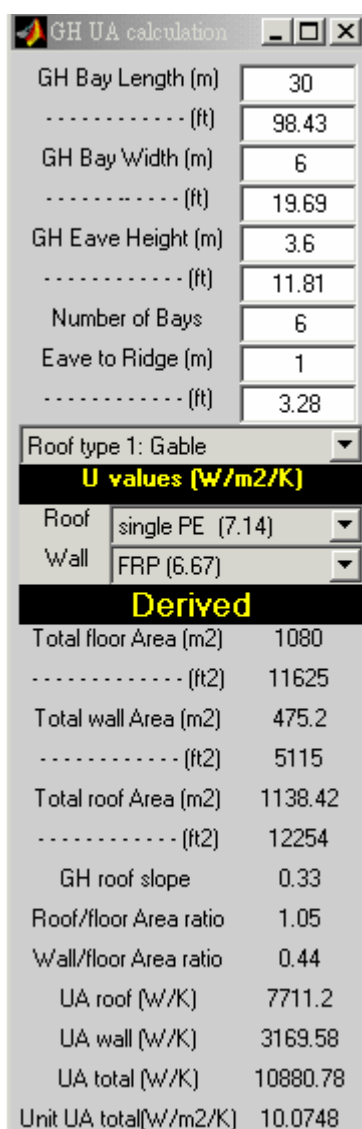


Figure 7. Greenhouse UA calculation window.

圖 7. 溫室 UA 值計算視窗

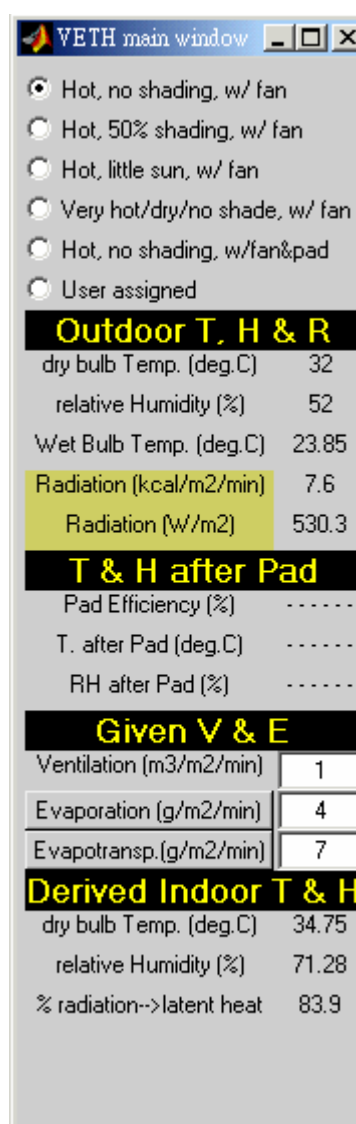


Figure 8. VETH main window.

圖 8. VETH 軟體主視窗

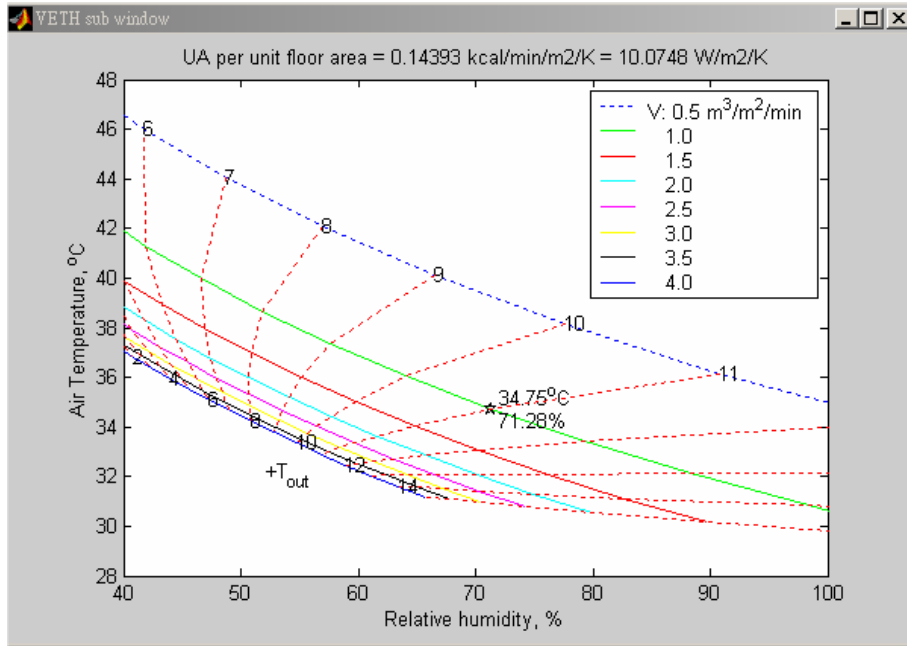


Figure 9. VETH sub window for option 1 (Hot, no shading, Fan only).
 圖 9. VETH 軟體執行選項 1 之輸出視窗 (熱, 無遮蔭, 使用風扇)

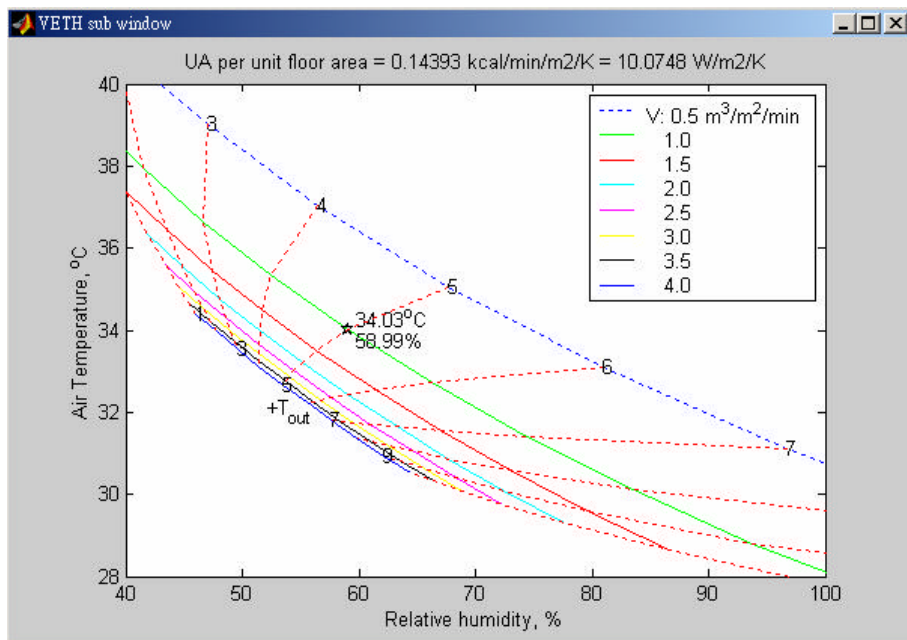


Figure 10. VETH sub window for option 2 (Hot, 50% shading, Fan only).
 圖 10. VETH 軟體執行選項 2 之輸出視窗 (熱, 50%遮蔭, 使用風扇)

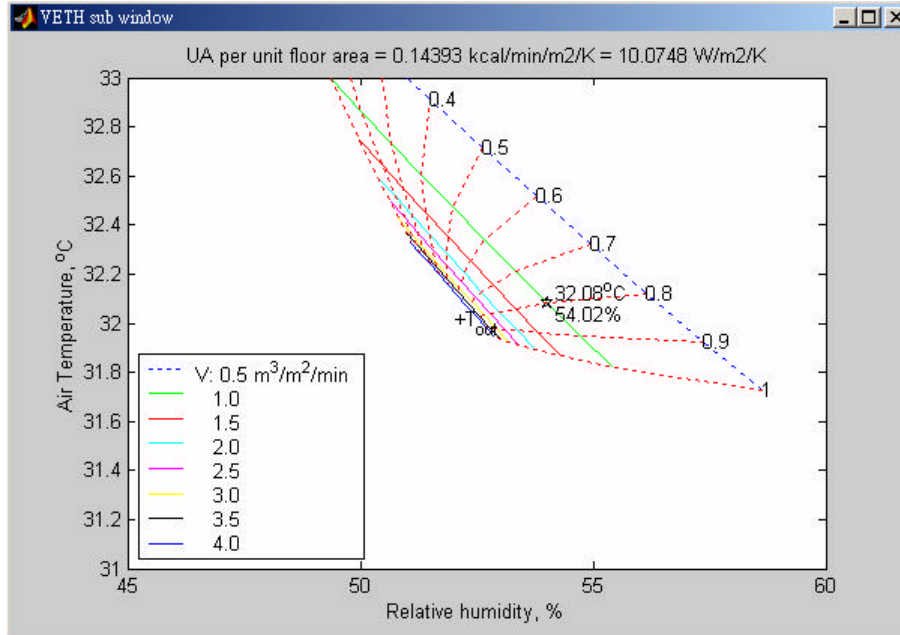


Figure 11. VETH sub window for option 3 (Hot, little sun, Fan only).
圖 11. VETH 軟體執行選項 3 之輸出視窗 (熱, 陰天, 使用風扇)

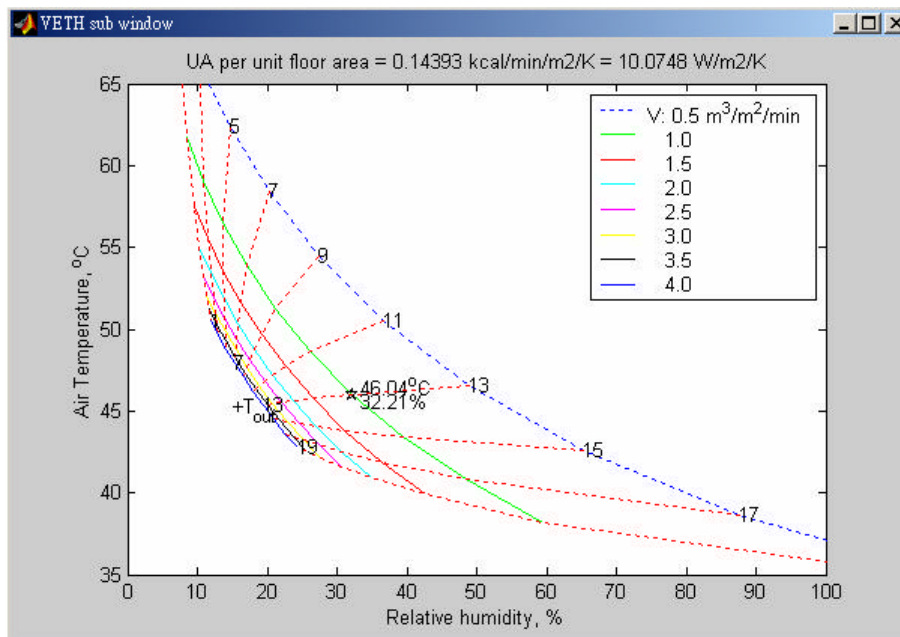


Figure 12. VETH sub window for option 4 (Very hot, dry, no shading, Fan only).
圖 12. VETH 軟體執行選項 4 之輸出視窗 (極熱且乾燥, 無遮蔭, 使用風扇)

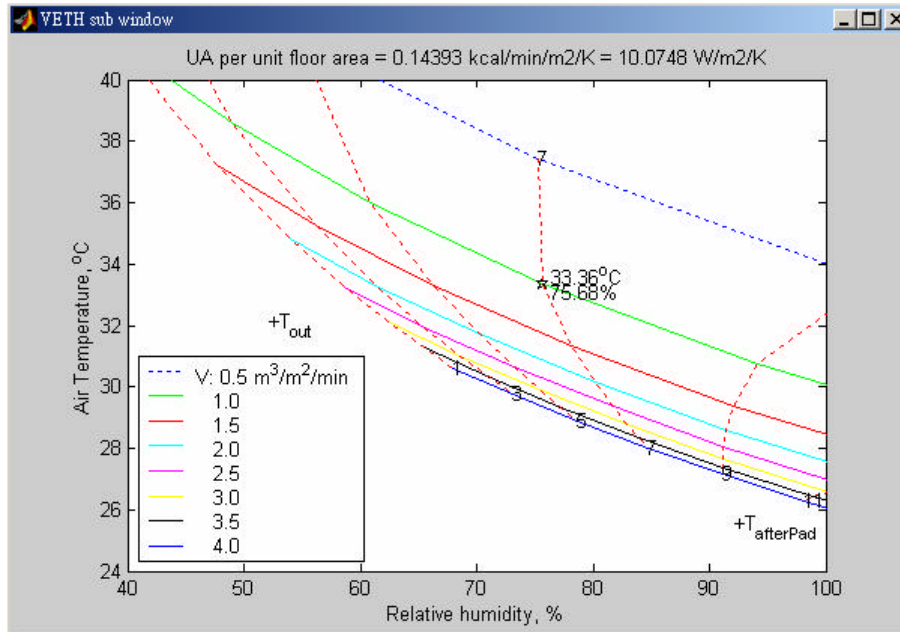


Figure 13. VETH sub window for option 5 (Hot, no shading, pad and fan).
圖 13. VETH 軟體執行選項 5 之輸出視窗 (熱, 無遮蔭, 使用風扇與水牆)

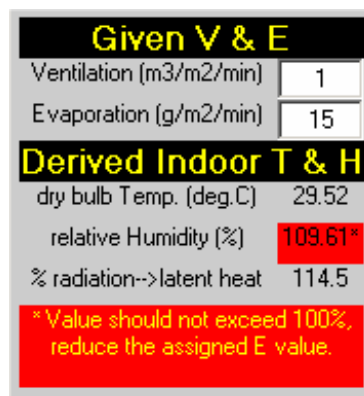


Figure 14. A warning message appears at the bottom lines when calculated indoor relative humidity exceeds 100%.

圖 14. 視窗下方顯示警示訊息告知相對溼度超過 100%，顯示使用者預期溫室內所能蒸發的水分已超過極限

Given V & E	
Ventilation (m ³ /m ² /min)	1
Evaporation (g/m ² /min)	14
Derived Indoor T & H	
dry bulb Temp. (deg.C)	30.83
relative Humidity (%)	98.39
% radiation-->latent heat	106.8

Figure 15. Snapshot window shows the outcome of user-assigned evaporation and ventilation rate. As shown above, at 14 g/m²/min of evaporation rate, although, the indoor humidity is still less than 100%, the latent heat required is greater than total radiation, which is not possible.

圖 15. 針對使用者輸入風量與蒸發速率的計算視窗。結果顯示當每分鐘每平方米有 14 克的水分可蒸發時，室內空氣濕度雖然仍小於飽和值，但已屬不可能，因為所需的潛熱已經超過輻射熱。

Evaporation due to fogging	
Number of nozzles installed per m2, #/m2	0.2
Amount of water sprayed at highest pressure, g/min/nozzle	80
Water pressure applied to the nozzles, kg/cm2	70
Duty cycle of the fogging operation, sec/min	20
Efficiency of fogging system, decimal	1
Amount of water Evaporated, g/m ² /min	5.333

Figure 16. Sub-Window of Evaporation due to fogging.
圖 16. 使用噴霧系統產生的水分蒸發量相關子視窗。

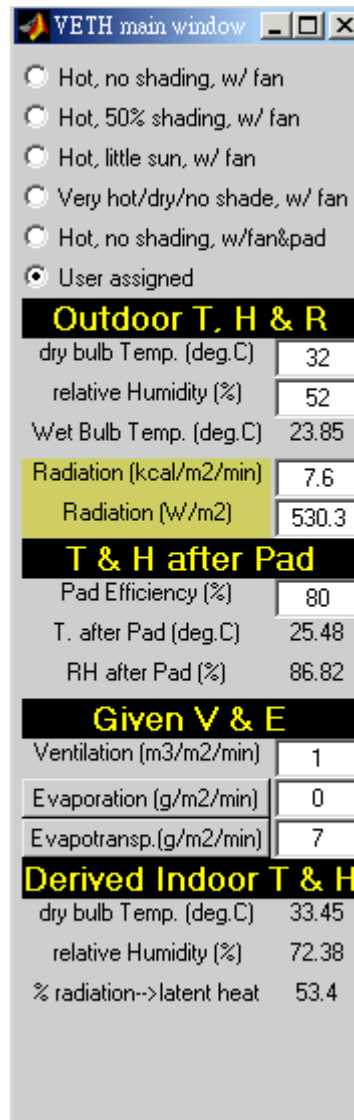


Figure 17. VETH main window for the user assigned option.

圖 17. 允許使用者輸入參數值的 VETH 軟體主視窗