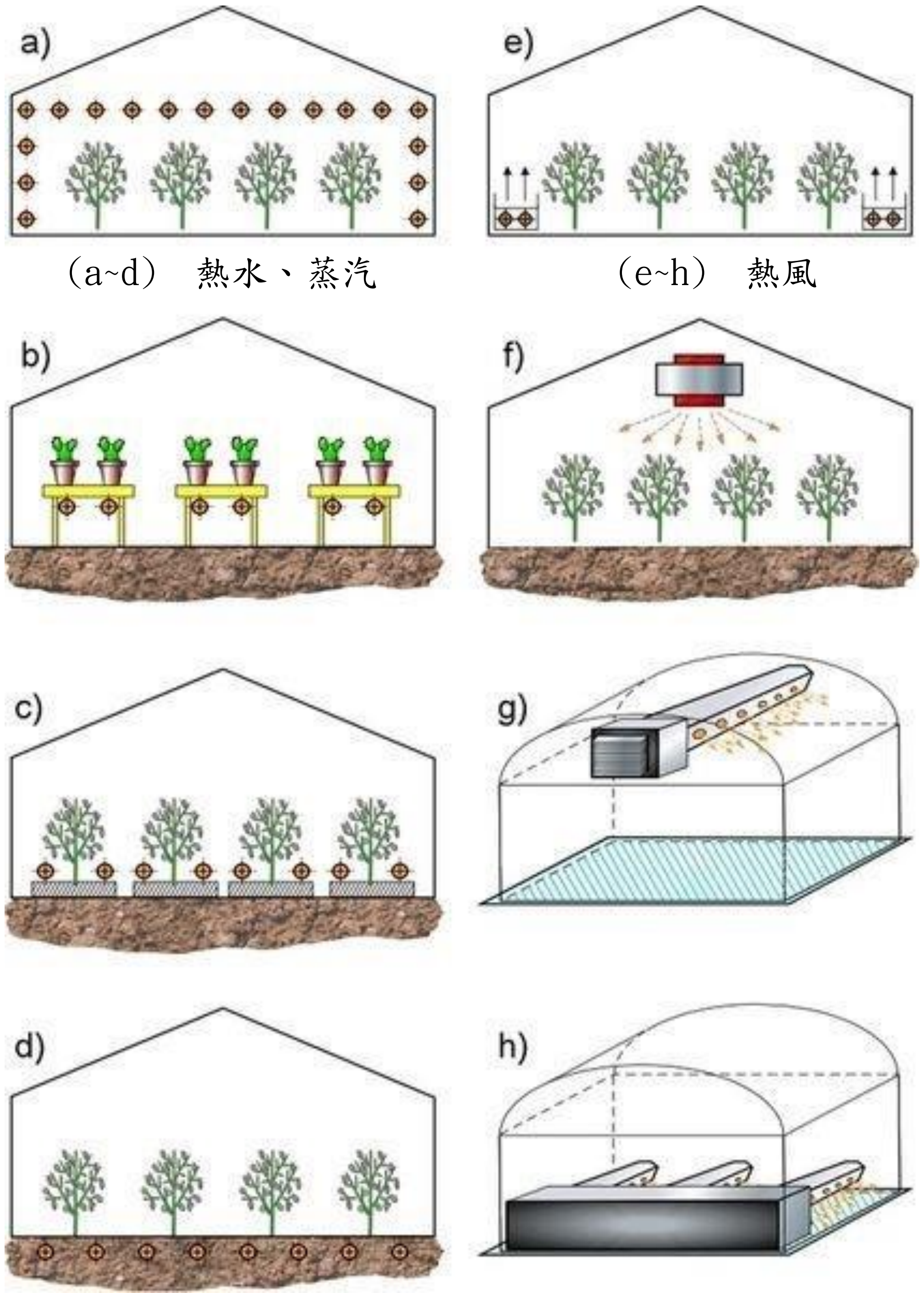
數位化溫室工程

1. 太陽軌跡與能量
2. 濕空氣熱力特性
3. 溫室通風與成本
4. 蒸發降溫系統
5. 溫室供暖
6. 二氧化碳施肥
7. 植物蒸散模式

溫室供暖八法

其中
(d) Porous concert floor heating system
搭配
太陽能熱水系統
與
雙層充氣塑膠布溫室

在70年代，能源危機期間
幫美國溫室業者節省了大量的加溫成本

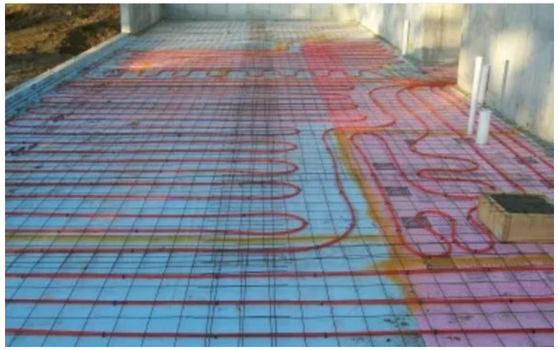


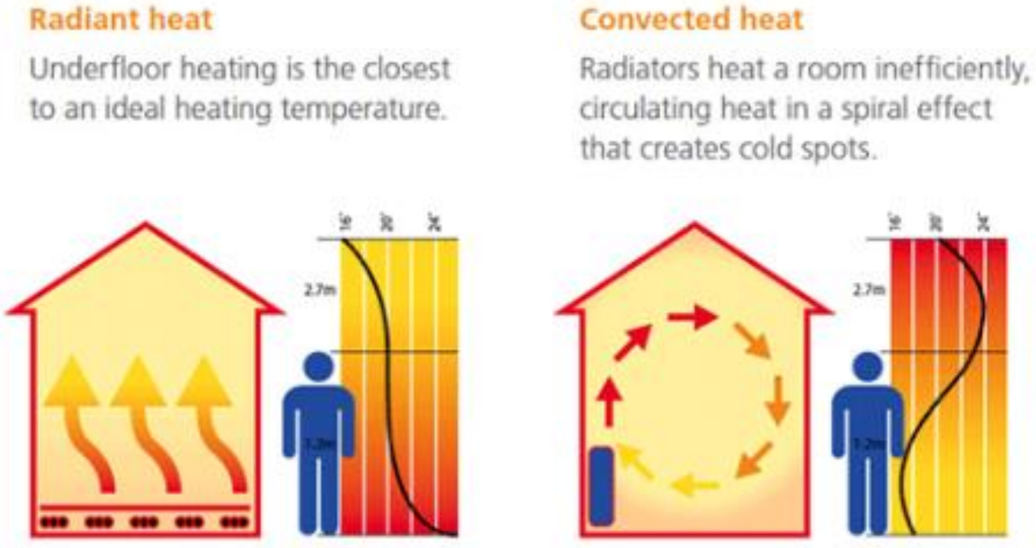
溫室供暖 － 地板加熱系統設計

MATLAB™ BASED SOFTWARE FOCUSING ON FLOOR HEATING

Wei FANG, Ph.D., Professor
Dept. of Biomechatronics Engineering
National Taiwan University

FROM GREENHOUSE TO HOUSE





FROM GREENHOUSE TO HOT YOGA

TO START

Unzip ‘heating.zip’ and copy all files to one directory, say: ‘heating’

Assign ‘working directory’ of MATLAB to the ‘heating’ directory.

Enter ‘heating’ in the command window of MATLAB, press ‘Enter’

One Window with a menu on top and the opening page of the software introducing the model developed.

Greenhouse Heating

Edit Execute Degree hours Million BTU Photo About Quit

Greenhouse Heating v.4.0

Dept. of Bio-resource Engineering

George H. Cook College

Rutgers - The State University of New Jersey, U.S.A

Software developed by Wei Fang, Ph.D., Professor

Dept. of Biomechatronics Engineering

National Taiwan University

v.3.0 Updated 02/04/2004

v.4.0 Last updated: 12/30/2020

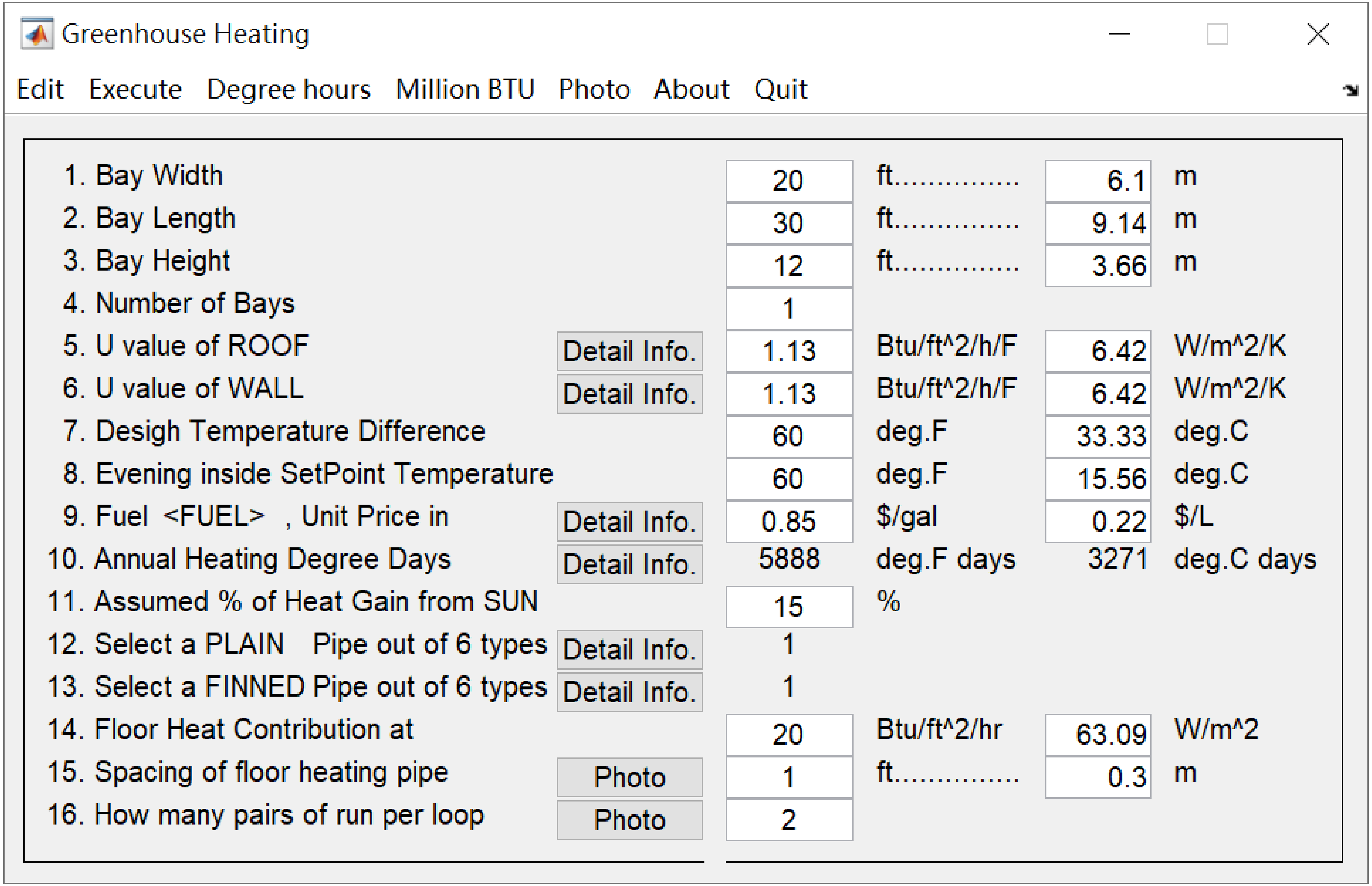
EDIT

EDIT

SAVE

After confirming all the input values, 'Execute' is now activated.

Totally, 8 buttons can be pressed for further information.



1st page of the first 'Detail info.' button.

Detail Info. of U value of ROOF

Suggested U value through various greenhouse glazing [P.V. Nelson]

Covering Materials (Glazing)	Heat Loss Coef. (U) Btu/ft^2/hr/F	W/m^2/K
Glass , single layer	1.13	6.42
Glass , double-layer, 1/4-in (6 mm) space	0.65	3.69
Glass , triple-layer, 1/4-in (6 mm) spaces	0.47	2.67
Polyvinyl Chloride (PVC)	0.92	5.22
Fiberglass-reinforced plastic (FRP)	1.2	6.81
Acrylic, single layer 1/8-in (3 mm)	1	5.68
Acrylic, double-layer pannel (16 mm thick)	0.58	3.29
Acrylic, double-layer pannel (8 mm thick)	0.64	3.63
Polycarbonate, double-layer pannel (16 mm thick)	0.58	3.29
Polycarbonate, double-layer pannel (6.5 mm thick)	0.69	3.92
Polyethylene (PE) film, single layer (2,4,6 mil)	1.15	6.53
Polyethylene (PE) film, double layer	0.8	4.54
Polyester film, Mylar	1.05	5.96
Polyvinyl fluoride (PVF), Tedlar, single layer film	1.05	5.96
Polyvinyl fluoride (PVF), double-layer film	0.76	4.32

2nd page of the first 'Detail info.' button.

Detail Info. of U value of ROOF

Suggested U values of selected insulating blanket materials in combination with a double PE greenhouse glazing [Roberts, et.al.]

Materials Description	Source	(U) Btu/ft^2/hr/F	W/m^2/K
Reemay Spunbonded Polyester	Dupont	0.63	3.58
Double Knit Cloth	Van Wingerden	0.62	3.52
Black Polyethylene	Monsanto	0.48	2.73
Reinforced Polyethylene	Shade Corp. of America	0.46	2.61
Black Polyethylene over Reemay	Shade Corp. of America	0.44	2.5
Prefacricated Aluminized Vinyl	Stauffer/Revere	0.42	2.38
Reemay over Black Polyethylene	Stauffer/Revere	0.39	2.21
Aluminized Vinyl (worn)	Stauffer	0.38	2.16
Polypropylene Shade (97 %)	Shade Corp. of America	0.38	2.16
Foylon	Duracote	0.34	1.93

Page appear when the second 'Detail info.' button is pressed.

Detail Info. of U value of WALL

Suggested U value through various greenhouse glazing [P.V. Nelson]

Covering Materials (Glazing)	Heat Loss Coef. (U) Btu/ft^2/hr/F	W/m^2/K
Glass , single layer	1.13	6.42
Glass , double-layer, 1/4-in (6 mm) space	0.65	3.69
Glass , triple-layer, 1/4-in (6 mm) spaces	0.47	2.67
Polyvinyl Chloride (PVC)	0.92	5.22
Fiberglass-reinforced plastic (FRP)	1.2	6.81
Acrylic, single layer 1/8-in (3 mm)	1	5.68
Acrylic, double-layer pannel (16 mm thick)	0.58	3.29
Acrylic, double-layer pannel (8 mm thick)	0.64	3.63
Polycarbonate, double-layer pannel (16 mm thick)	0.58	3.29
Polycarbonate, double-layer pannel (6.5 mm thick)	0.69	3.92
Polyethylene (PE) film, single layer (2,4,6 mil)	1.15	6.53
Polyethylene (PE) film, double layer	0.8	4.54
Polyester film, Mylar	1.05	5.96
Polyvinyl fluoride (PVF), Tedlar, single layer film	1.05	5.96
Polyvinyl fluoride (PVF), double-layer film	0.76	4.32

Page appear when the third 'Detail info.' button is pressed.

總共有4類型共17種燃料可以選擇

包括
6種燃煤
5種燃油
4種燃氣
2種木材

各種燃料的熱值可有6種不同單位，包含英制、公制與業者常用單位

Detail Info. of Fuel Type and Unit Price

[Typical Heat Contents for Various Types of Fuel Used for Greenhouse Heating]

FUEL	Btu/lb	Btu/gal	Heat Btu/ft3	Value kJ/g	kJ/ml	kJ/dm3	Boiler Eff. %
1. COAL, Anthracite (hard)	12910			30			65
2. COAL, Semi-anthracite	13770			32			60
3. COAL, Low Volatile Bituminous	14340			33.3			65
4. COAL, Medium V.B.	13840			32.2			60
5. COAL, High V.B.	11920			27.7			55
6. COAL, Sub-bituminous	9045			21.05			55
7. Fuel Oil No. 1		13495			37.65		70
8. Fuel Oil No. 2		13880			38.75		70
9. Fuel Oil No. 4		14695			41		68
10. Fuel Oil No. 5		15200			42.4		67
11. Fuel Oil No. 6		15335			42.8		65
12. Natural (Gas)			1000			37.3	75
13. Manufactured (Gas)			550			20.5	70
14. Propane (LP Gas)		91690	2570			95.7	75
15. Butane (Gas)		10200	3225			120.1	75
16. Wood, G. Green Chips	4500			10.5			60
17. Wood, H. Dried pellets	8500			19.8			60

Detail Info. of Annual Heating Degree Days

Change Unit

Page appear when the 4 th ‘Detail info.’ button is pressed.
The units can be toggled.

Average Temperature Calculation Based on Degree Days (English Unit)

英制單位

Cities of USA	3073	ALABAMA, Huntsvill
Cities of Canada	9702	ALBERTA, Calgary
Enter YOUR degree day:	5888	

ACCEPT ° F

DEGREE DAY in January	1209	AVG_T = 26
DEGREE DAY in Febuary	1092	AVG_T = 30
DEGREE DAY in March	899	AVG_T = 36
DEGREE DAY in April	480	AVG_T = 50
DEGREE DAY in May	0	AVG_T >= 65
DEGREE DAY in June	0	AVG_T >= 65
DEGREE DAY in July	0	AVG_T >= 65
DEGREE DAY in August	0	AVG_T >= 65
DEGREE DAY in September	0	AVG_T >= 65
DEGREE DAY in October	341	AVG_T = 54
DEGREE DAY in November	720	AVG_T = 42
DEGREE DAY in December	1147	AVG_T = 28

Detail Info. of Annual Heating Degree Days

Change Unit

Average Temperature Calculation Based on Degree Days (S.I. Unit)

公制單位

	1707	ALABAMA, Huntsville
Cities of Canada	5390	ALBERTA, Calgary
Enter YOUR degree day:	3271	

ACCEPT ° C

DEGREE DAY in January	671.667	AVG_T = -3
DEGREE DAY in Febuary	606.667	AVG_T = -1
DEGREE DAY in March	499.444	AVG_T = 2
DEGREE DAY in April	266.667	AVG_T = 10
DEGREE DAY in May	0	AVG_T >= 18
DEGREE DAY in June	0	AVG_T >= 18
DEGREE DAY in July	0	AVG_T >= 18
DEGREE DAY in August	0	AVG_T >= 18
DEGREE DAY in September	0	AVG_T >= 18
DEGREE DAY in October	189.444	AVG_T = 12
DEGREE DAY in November	400	AVG_T = 5
DEGREE DAY in December	637.222	AVG_T = -2

Page appear when the 5 th 'Detail info.' button is pressed.

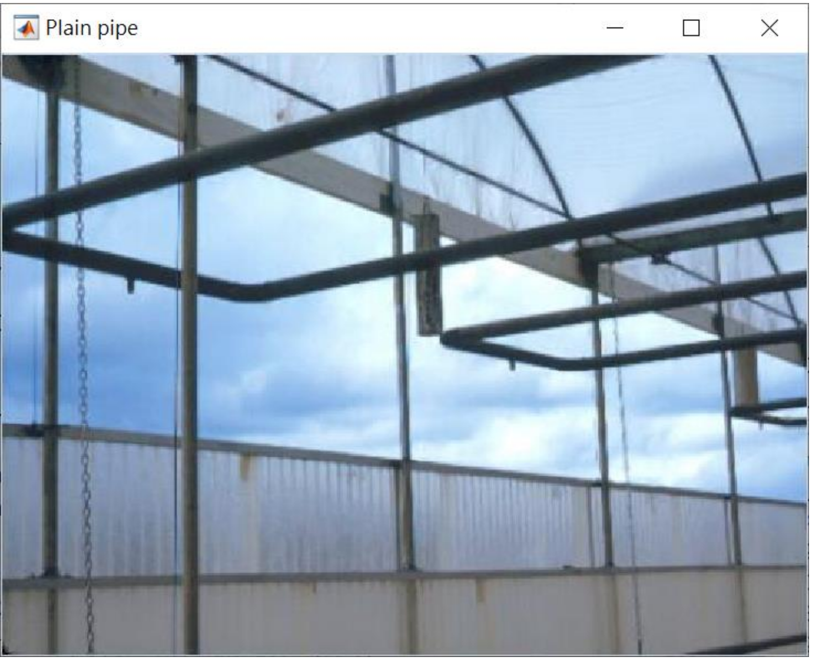


Photo depicts what is plain pipe

平滑的金屬管路
經常安裝於溫室上方或植床下方

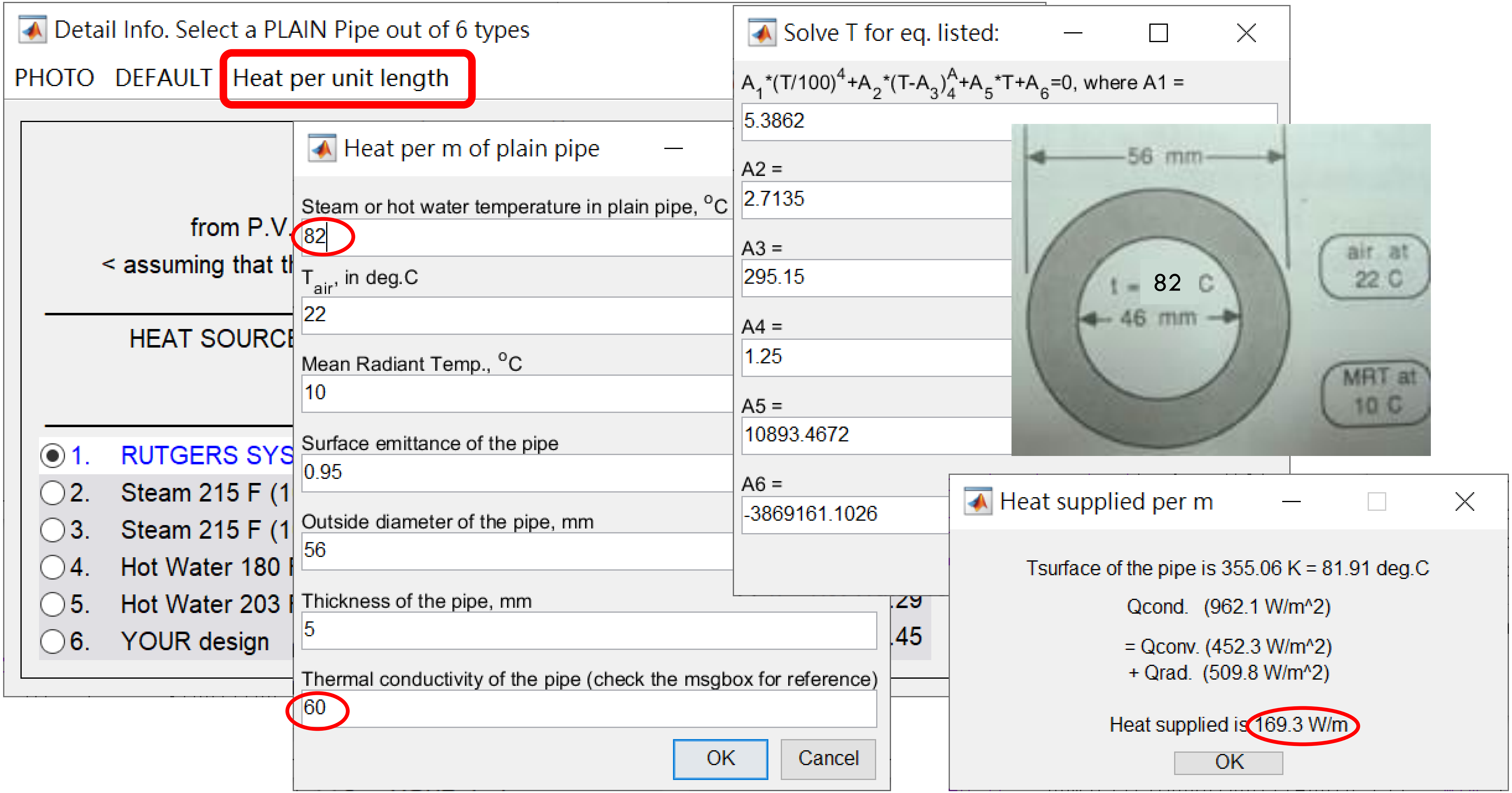
Detail Info. Select a PLAIN Pipe out of 6 types

PHOTO DEFAULT Heat per unit length

HEAT available from various PLAIN PIPE
heated by HOT water or STEAM
from P.V. Nelson's 'Greenhouse Operation and Management'
< assuming that the inside air temperature is 60 degree F (15.56 degree C) >

HEAT SOURCE	PIPE DIAMETER		HEAT SUPPLIED (Btu/hr/ft)	(W/m)
1. RUTGERS SYSTEM	2	inch (51 mm)	170	163.45
2. Steam 215 F (102 C)	1.5	inch (38 mm)	210	201.91
3. Steam 215 F (102 C)	1.25	inch (32 mm)	180	173.06
4. Hot Water 180 F (82 C)	2	inch (51 mm)	160	153.83
5. Hot Water 203 F (95 C)	2	inch (51 mm)	200	192.29
6. YOUR design			170	163.45

平滑的金屬管路每米長度的供熱能力計算

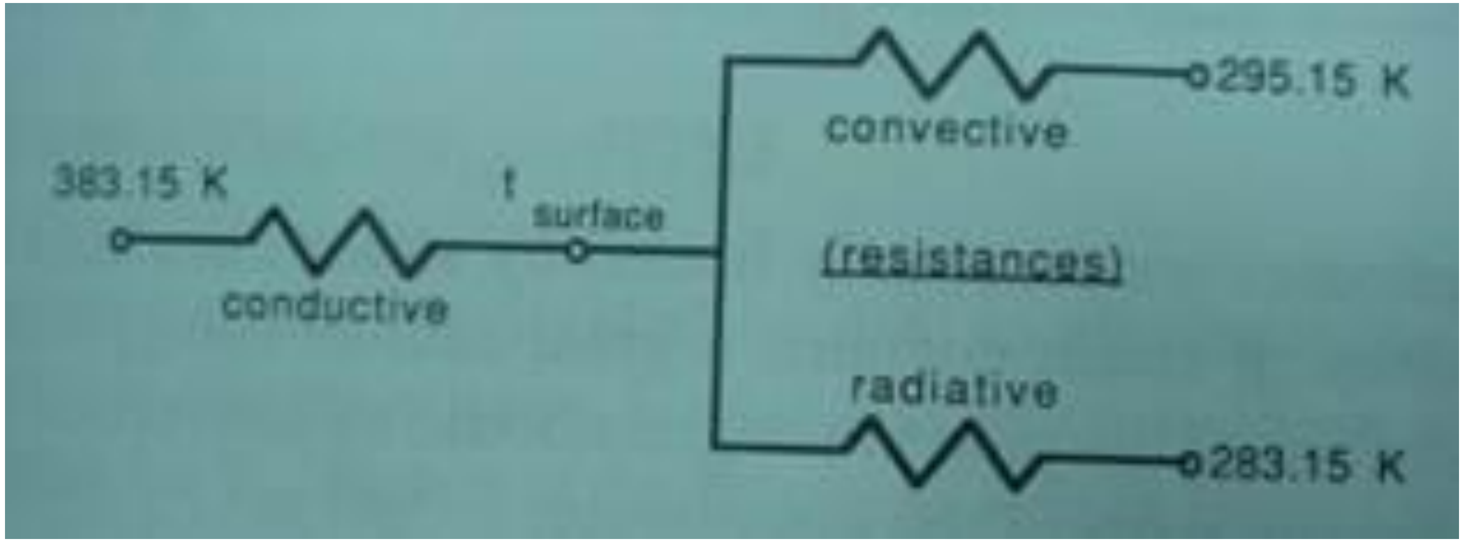


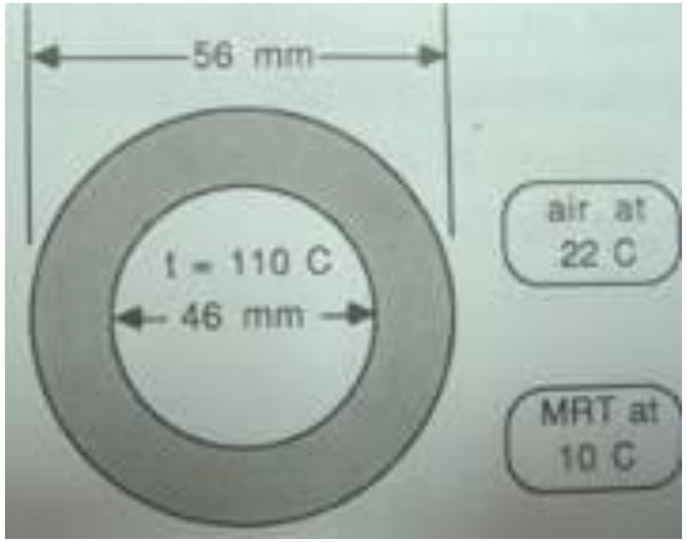
Material	Thermal Conductivity, W/mK
Metals	
Aluminum (alloy 1100)	221
Brass, red (85% Cu, 15% Zn)	150
Brass, yellow (65% Cu, 35% Zn)	120
Copper (electrolytic)	393
Gold	297
Iron, cast	47.7 (327 K)
Iron, wrought	60.4
Lead	34.8
Nickel	59.5
Silver	424
Steel, mild	45.3
Tin	64.9
Zinc, galvanizing	110

計算範例

溫室的加熱方式中有一種是使用蒸汽通入金屬管，透過金屬管外表面與室內空氣的對流與輻射兩種熱傳方式進行加熱。假設金屬管外與內徑分別為 56 mm, 46 mm，金屬管本身的熱傳導係數(k) 為 52 W/mK. 加壓蒸汽的冷凝溫度為 110 ºC，假設此亦為金屬管的內表面溫度。溫室的室內空氣為22 ºC，溫室內加熱鐵管周遭的平均熱輻射溫度為 10 ºC。

假設金屬管表面塗成黑色，表面的熱放射率/輻射率(ε) 為 0.95，請問金屬管與溫室之間的淨熱交換率是多少? 其中有多少是對流，有多少是輻射？





對金屬管的表面而言，傳導過來的熱 = 對流 + 輻射流失的熱

依據圓柱座標熱阻公式

$$R_{conductive} = (\ln(r_o / r_i))/2\pi kL$$
$$= (\ln(28/23))/2\pi(52)\ (1) \quad \text{(per unit length)}$$
$$= 0.000602 \text{ mK/W.}$$

每米長度有 0.1759 m^2 的表面積

$$R_{conductive} = (0.000602 \text{ mK/W})\ (0.1759 \text{ m}^2\text{/m})$$
$$= 0.000106 \text{ m}^2\text{K/W,}$$

透過熱傳導，傳到外表面的熱能計算如下：

$$q''_{conductive} = \Delta T / R$$
$$= (383.15 \text{ K} - T_{surface}) / 0.000106 \text{ m}^2\text{K/W.}$$
$$= 9441(383.15 - T_{surface})$$

加熱管輻射出的熱量假設全被溫室內空間吸收，透過輻射的熱損失計算如下：

$$q''_{radiative} = (0.95)\ (5.6697E-8)\ (T^4_{surface} - 283.15^4)$$
$$= 5.386(T_{surface} / 100)^4 - 346.3$$

由已知並無法確認管路外的對流是屬於層流或是紊流。但可透過 Eq 3-34 的分析，計算如果是紊流，所需要的溫差 (△)T

$$L^3 \Delta T = 1;\ L = 0.056\ \text{m}. \quad \Delta T = 1 / L^3 = 5694\ \text{K}.$$

以溫室環境來看溫差不可能那麼大，所以一定是層流，所以可選表 3-2 (p.65) 中公式 3-40 來計算對劉熱傳係數 (h)

$$h = 1.32\,((T_{surface} - 295.15\ \text{K}) / 0.056\ \text{m})^{0.25}, \\ = 2.713\,(T_{surface} - 295.15)^{0.25}.$$

由加熱管表面對溫室的對流熱傳遞計算如下：

$$q''_{convective} = h\Delta T = 2.713(T_{surface} - 295.15)^{1.25}.$$

Conductive gain = Radiative loss + Convective loss

$$9441(383.15 - T_s) = 5.386(T_s/100)^4 - 346.3 \\ + 2.713(T_s - 295.15)^{1.25}$$

$$5.386*(Ts/100)^4+2.713*(Ts-295.15)^{1.25}+9441*Ts-3617760 = 0$$

求解得出 Ts = 382.9967 K，代回上式，求出以下各項：

傳導： 1542 W/m^2　　單位長度傳導的熱量為 1542 * 0.1759 m^2/m = 271.2 W/m

對流： 812 W/m^2　　輻射： 730 W/m^2

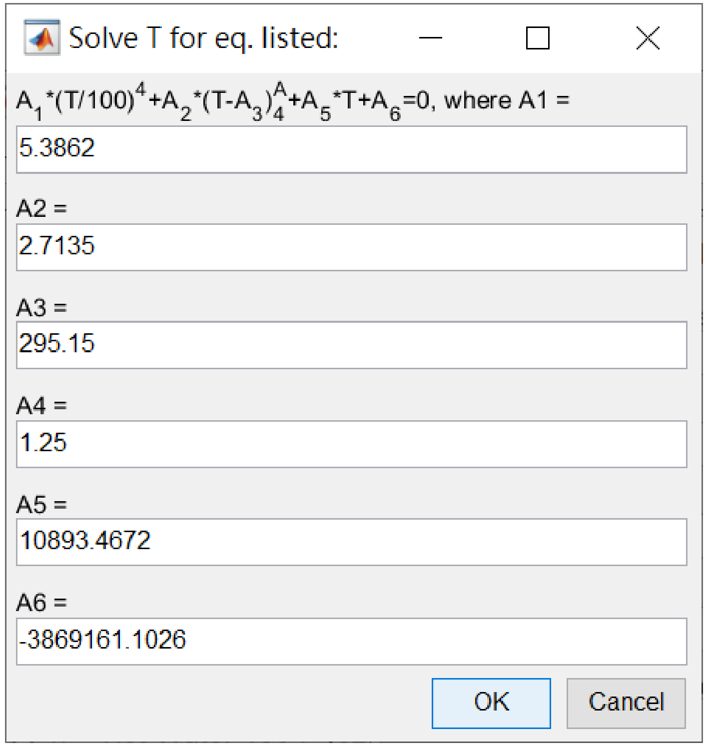
MIXED MODE 的通式

$$A1*(Ts/100)^4 + A2 * (Ts-A3)^{A4} + A5 * Ts + A6 = 0$$

傳導 Conduction related parameters: A5, A6
對流 Convection related parameters: A2, A3,   A4
輻射 Radiation related parameters: A1, A6

前兩例只有流體溫度與熱傳導係數不同，只影響熱傳導。
換言之，應該只有 A5, A6 有不同數值。

$$5.386*(Ts/100)^4+2.713*(Ts-295.15)^{1.25}+9441*Ts-3617760 = 0$$



Page appear when the 6 th 'Detail info.' button is pressed.

Detail Info. Select a FINNED Pipe out of 6 types

PHOTO DEFAULT

HEAT available from various FINNED PIPE
heated by HOT water or STEAM
< assuming that the inside air temperature is 60 degree F (15.56 degree C) >

HEAT SOURCE	PIPE DIAMETER		HEAT SUPPLIED (Btu/hr/ft)	(W/m)
1. RUTGERS SYSTEM	2	inch (51 mm)	950	913.39
2. Steam 215 F (102 C)	1.75	inch (44 mm)	1800	1730.64
3. Steam 215 F (102 C)	1.25	inch (32 mm)	1200	1153.76
4. Hot Water 180 F (82 C)	2	inch (51 mm)	950	913.39
5. Hot Water 203 F (95 C)	2	inch (51 mm)	950	913.39
6. YOUR design			950	913.39

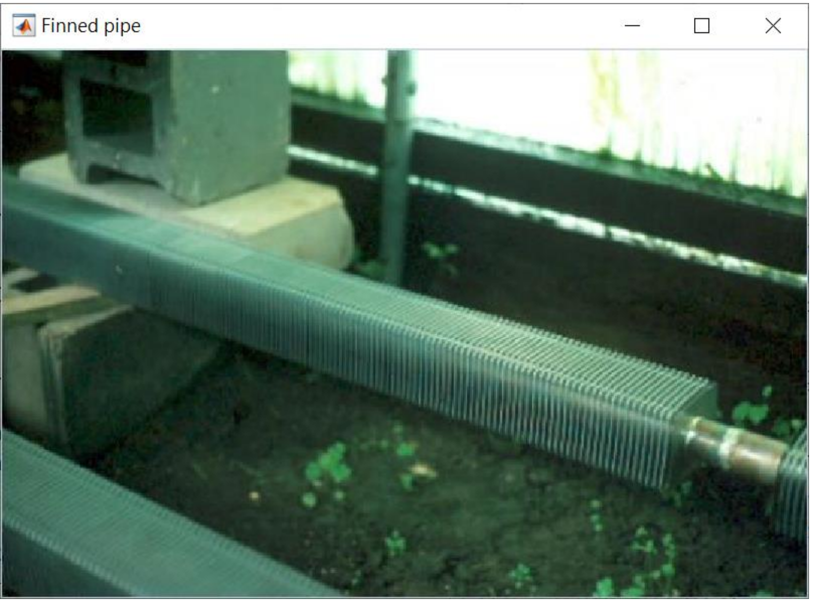
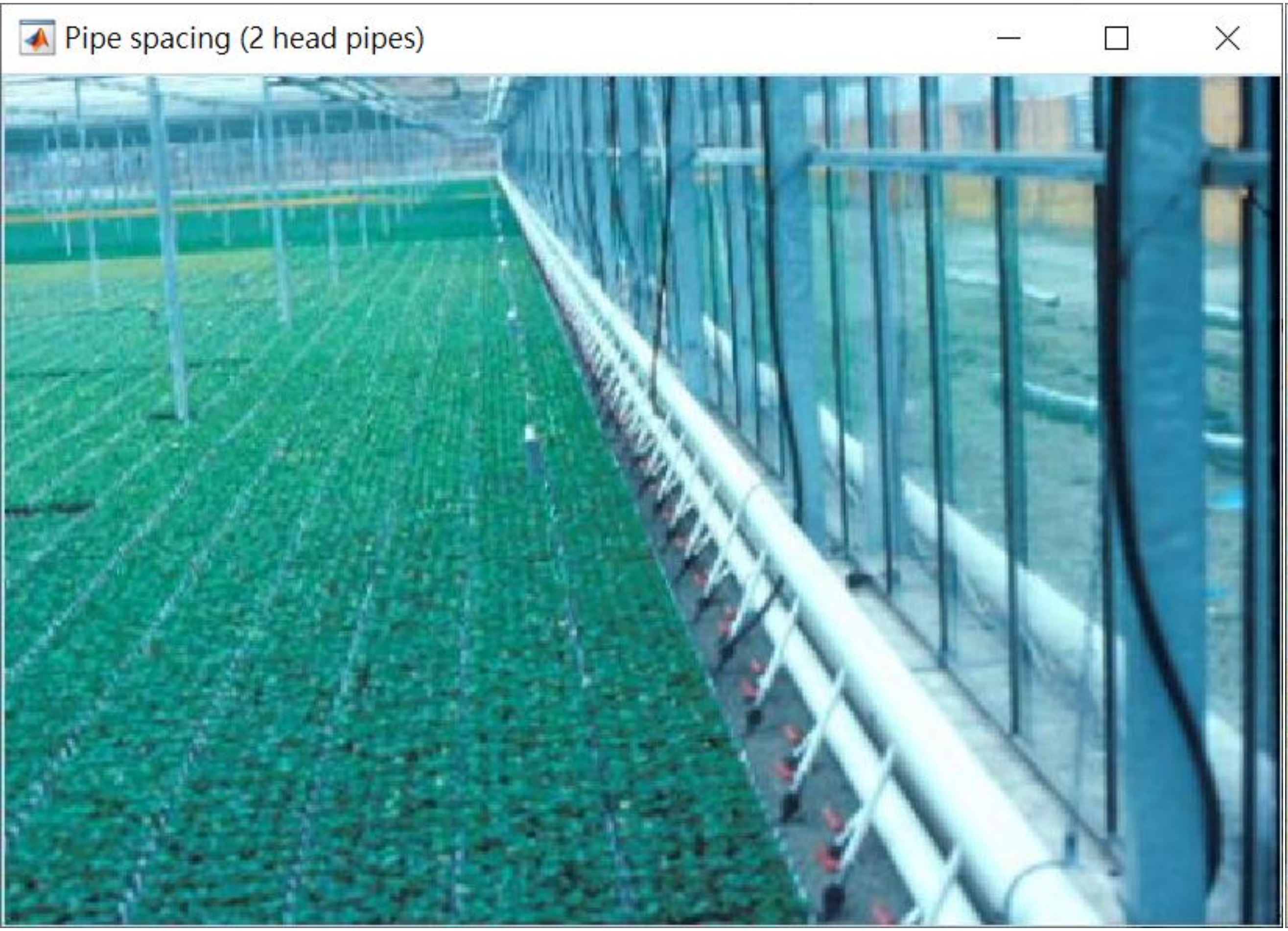


Photo depicts what is finned pipe

多鰭片的金屬管路
經常安裝於溫室靠外側的牆面



Photos depict what is 2 head pipes and 3 head pipes of a floor heating system

8 loops

2 pairs of run = 4 runs per loop

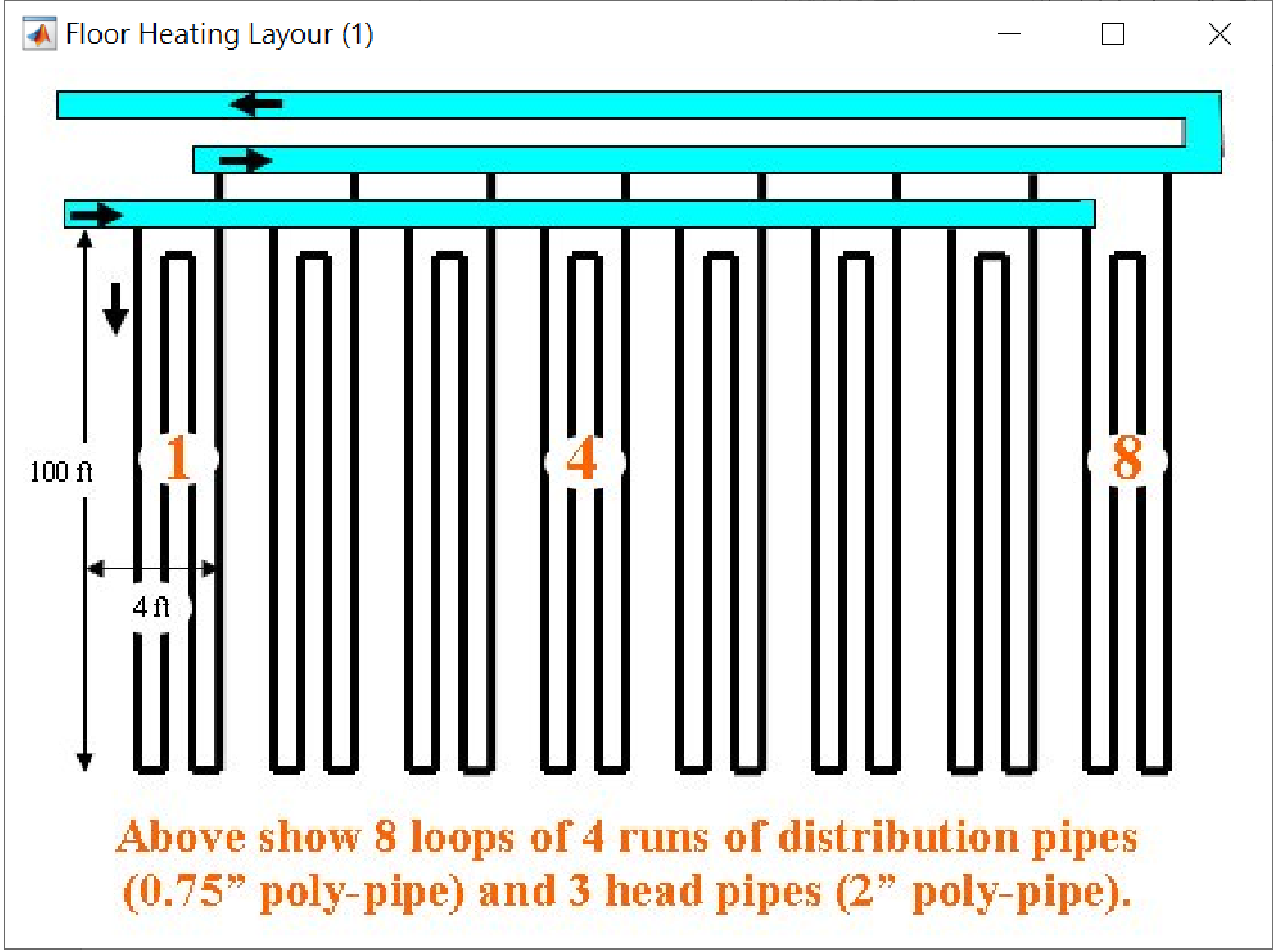


Photo depicts suggested length and spacing of distribution pipes.
Noted that 1 pair of run is 2 runs. Above shows 4 runs that is 2 pairs.

主管
Head pipe
2 吋塑膠管

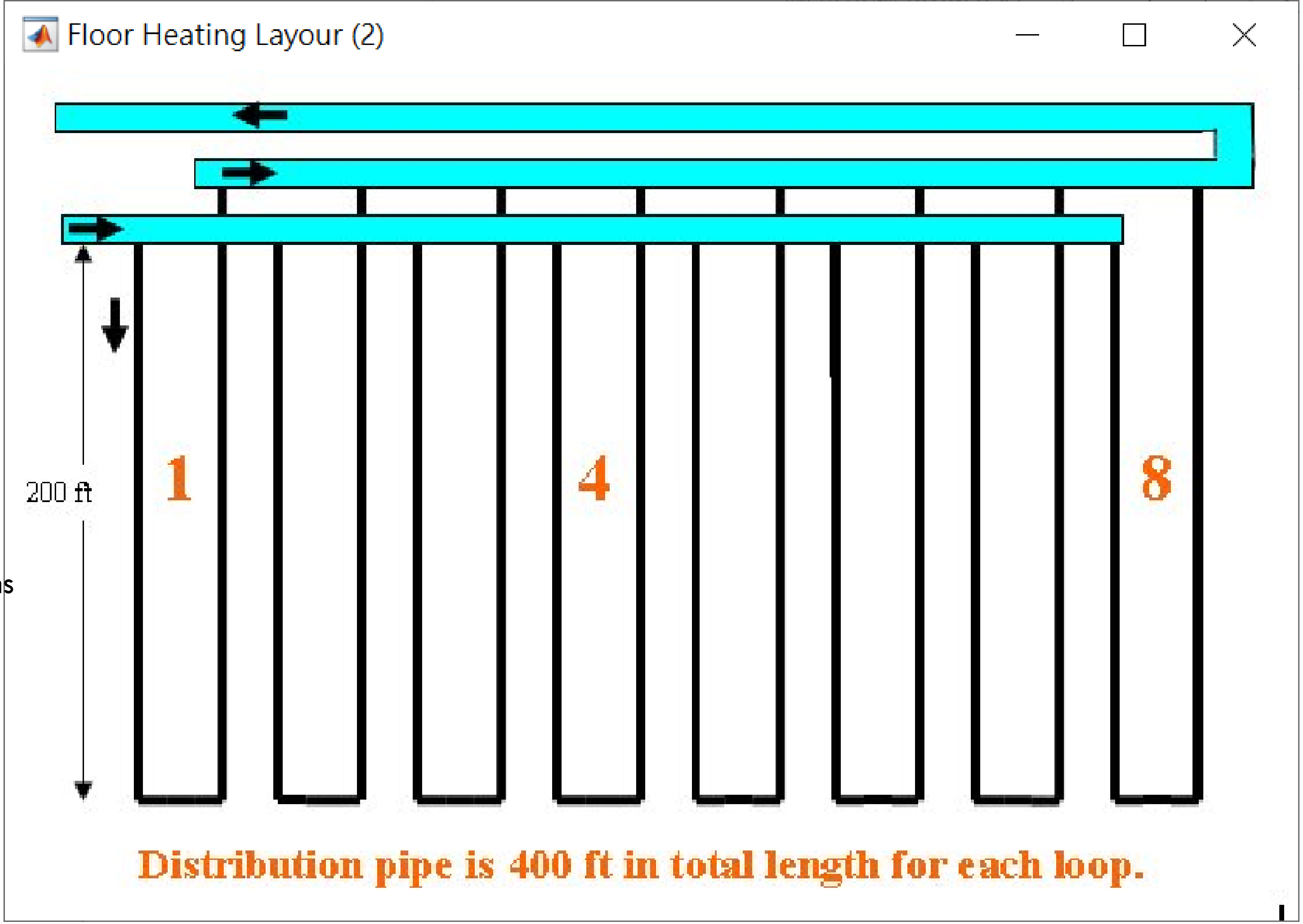
分路管
Distribution pipe
0.75 吋塑膠管

8 loops 迴路

每個分路的建議長度上限是400 英尺，因溫室寬約100 英尺，所以管路長度可有 4 個（兩對）來回 (run)

8 loops

1 pair of run = 2 runs per loop



8 loops 迴路

每個分路的建議長度上限是400 英尺，因溫室寬約200英尺，所以管路長度可有 2 runs (2個來回)

Photo depicts less pairs of runs when the length of the greenhouse get longer.
In total, suggested length for the distribution pipe is 400 ft. This allows for only 1 pairs of runs.

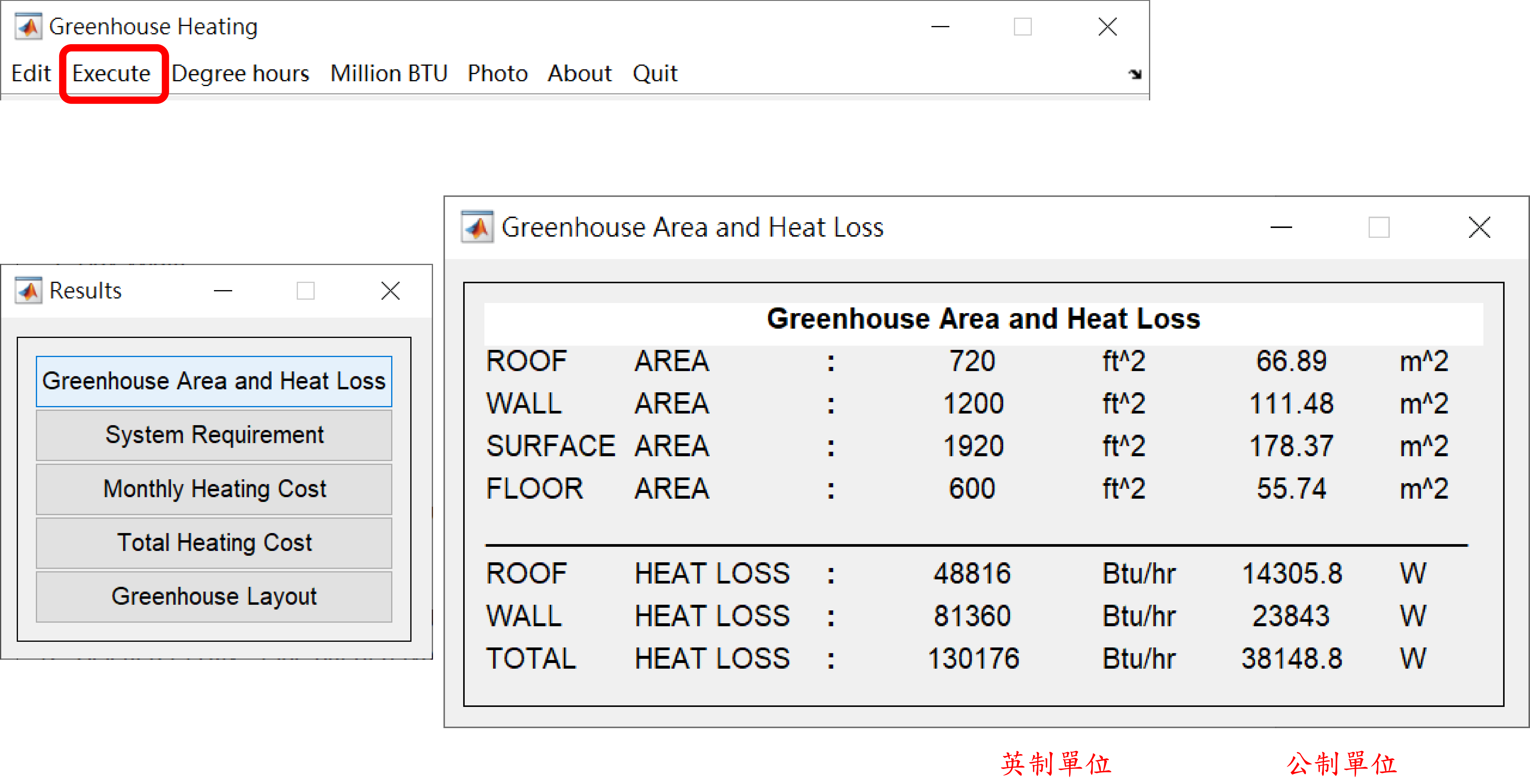
2 zones

8 loops per zone

1 pair of run = 2 runs per loop per zone

當溫室寬度達400英尺時，建議使用兩套管路，每套使用於200英尺寬度。

每個分路的建議長度上限是400 英尺，因溫室寬約200英尺，所以管路長度可有 2 runs (2個來回)


Greenhouse Heating
Edit
Execute
Degree hours
Million BTU
Photo
About
Quit
Results
Greenhouse Area and Heat Loss
System Requirement
Monthly Heating Cost
Total Heating Cost
Greenhouse Layout
Greenhouse Area and Heat Loss
Greenhouse Area and Heat Loss
ROOF AREA : 720 ft^2 66.89 m^2
WALL AREA : 1200 ft^2 111.48 m^2
SURFACE AREA : 1920 ft^2 178.37 m^2
FLOOR AREA : 600 ft^2 55.74 m^2
ROOF HEAT LOSS : 48816 Btu/hr 14305.8 W
WALL HEAT LOSS : 81360 Btu/hr 23843 W
TOTAL HEAT LOSS : 130176 Btu/hr 38148.8 W
英制單位
公制單位

Results

- Greenhouse Area and Heat Loss
- System Requirement
- Monthly Heating Cost

System Requirements (English Unit) 英制單位

Change unit

System Requirements

Assuming 1 hp of boiler can give 33500 Btu/hr

	NO FLOOR HEATING	WITH FLOOR HEATING
		<20 Btu/ft^2/hr>
PIPE HEAT (Btu/hr)	130176	118176
BOILER SIZE (hp, Pipe)	3.89	3.53
FLOOR HEAT (Btu/hr)		12000
BOILER SIZE (hp, Floor)		0.36
RUNS of PLAIN PIPE <170 Btu/hr/ft>		
per BAY	9.57	7.22
per WALL	4.79	4.79
RUNS of FINNED PIPE <950 Btu/hr/ft>		
per BAY	1.71	1.29
per WALL	0.86	0.86

FLOOR PIPE LENGTH (3-head-pipe design) Photo

HEADER PIPE (10% WASTE)	66	ft
DISTRIBUTION PIPE (5% WASTE)	630	ft

System Requirements (S.I. Unit) 公制單位

Change unit

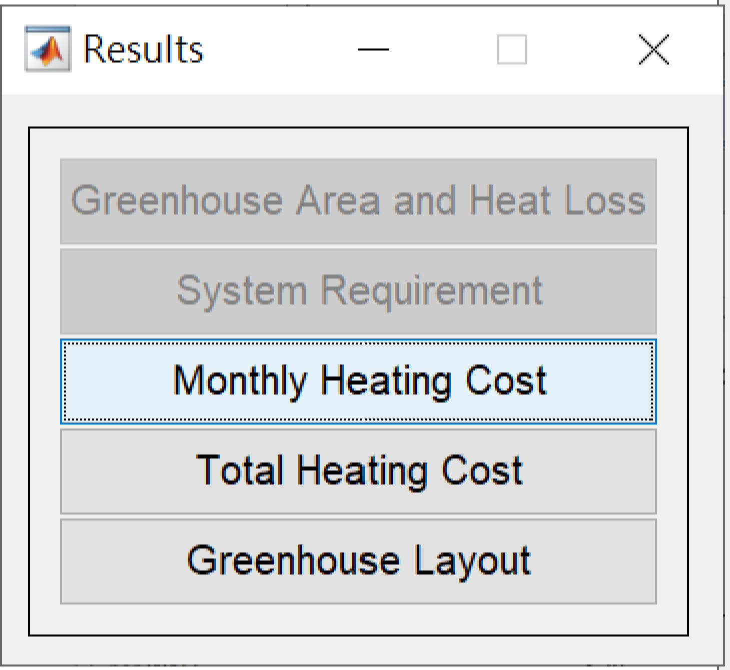
System Requirements

Assuming 1 hp of boiler can give 9817.36 W

	NO FLOOR HEATING	WITH FLOOR HEATING
		<63.09 W/m^2>
PIPE HEAT (W)	38148.8	34632.1
BOILER SIZE (hp, Pipe)	3.89	3.53
FLOOR HEAT (W)		3516.67
BOILER SIZE (hp, Floor)		0.36
RUNS of PLAIN PIPE <163.45 W/m>		
per BAY	9.57	7.22
per WALL	4.79	4.79
RUNS of FINNED PIPE <913.39 W/m>		
per BAY	1.71	1.29
per WALL	0.86	0.86

FLOOR PIPE LENGTH (3-head-pipe design) Photo

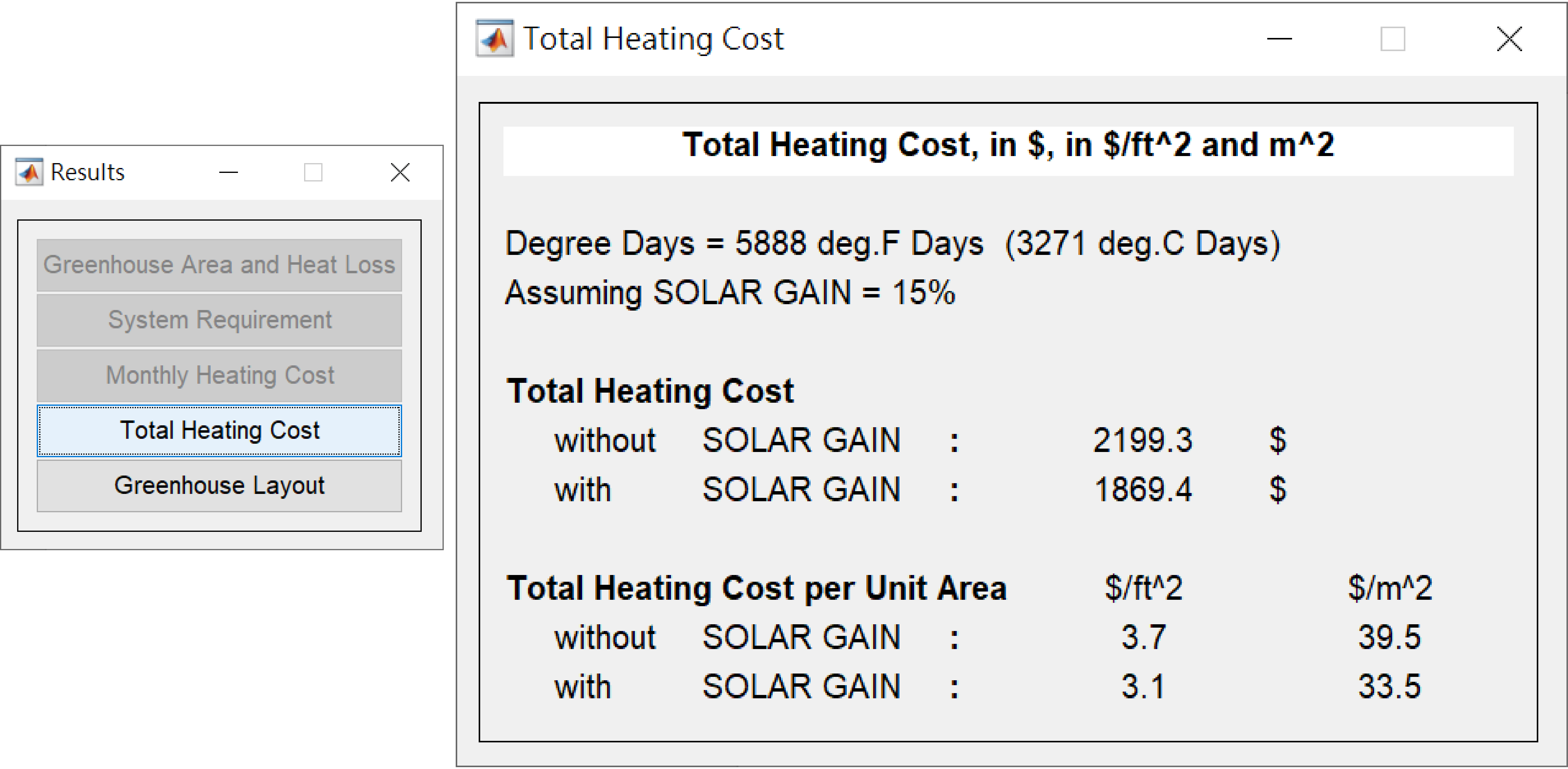
HEADER PIPE (10% WASTE)	20.12	m
DISTRIBUTION PIPE (5% WASTE)	192.02	m

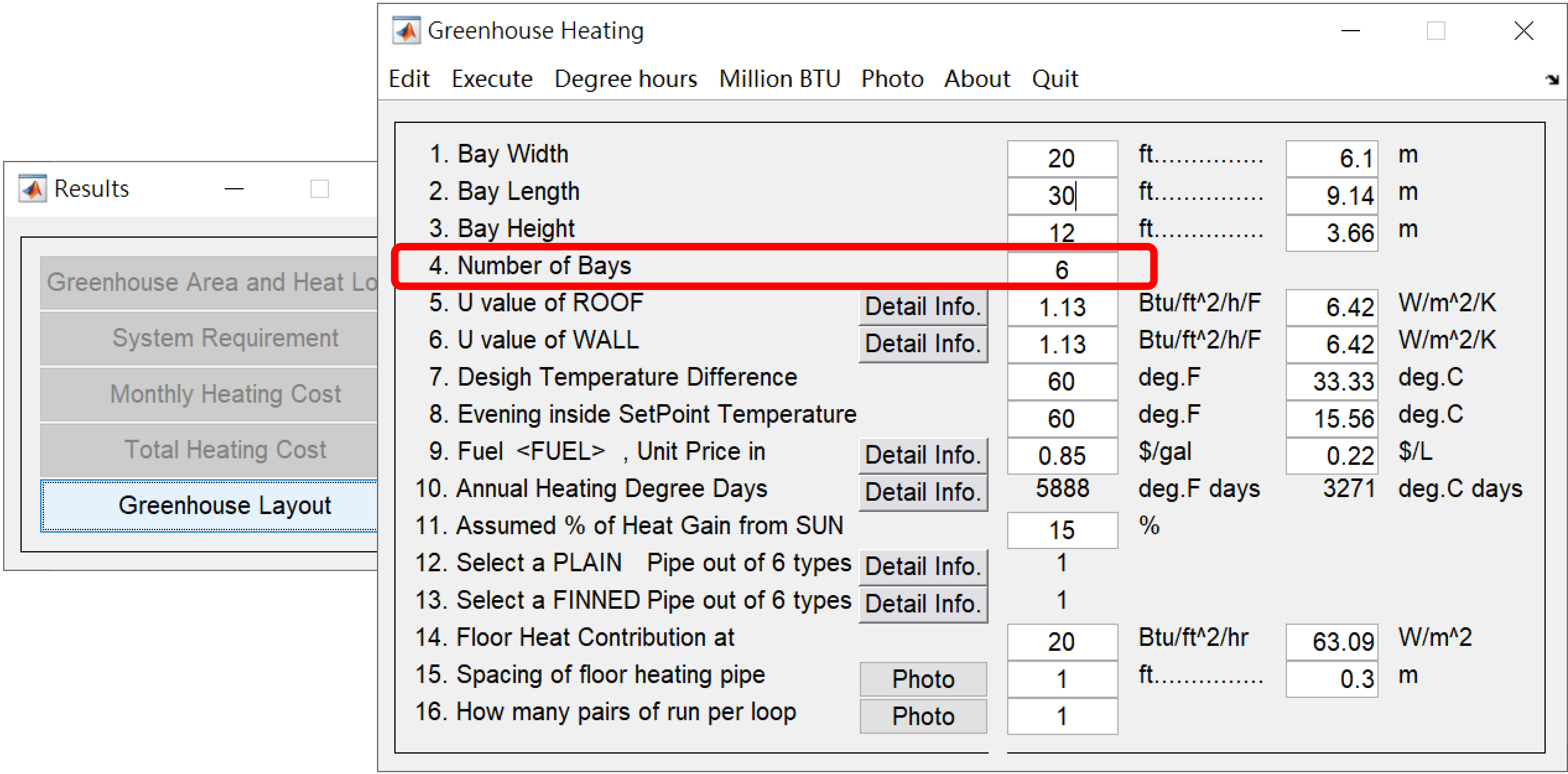


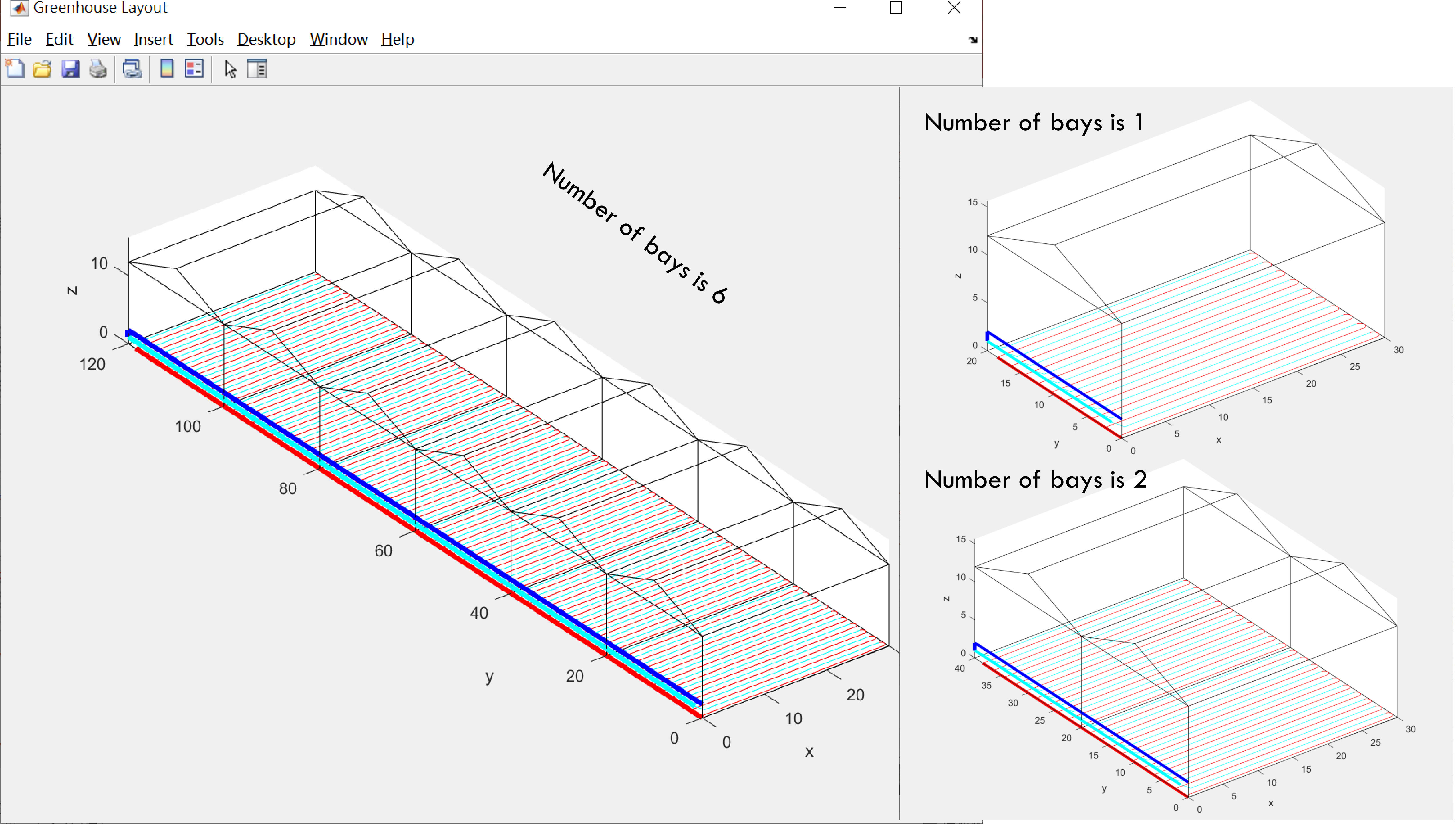
Monthly Heating Cost

Monthly Heating Cost (in $, $/ft^2 and $/m^2)
Based on Degree Days, and 15% Solar Gain

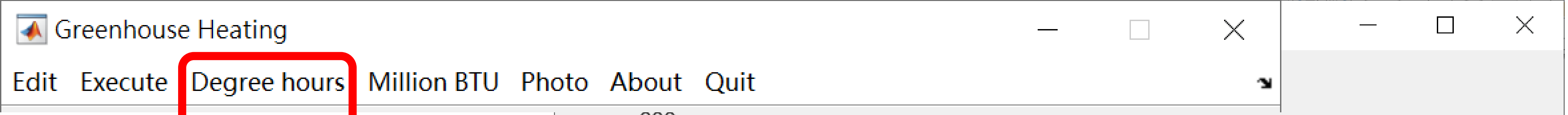
MONTH	single glass	double glass	single PE	double PE	d.PE w/ d.knit cloth	d.PE w/ Foylon	yours
January	408.1	234.8	415.3	288.9	224.6	122.8	408.1
Febuary	368.6	212	375.1	261	202.9	110.9	368.6
March	288.1	165.7	293.2	204	158.6	86.7	288.1
April	127.8	73.5	130	90.5	70.3	38.4	127.8
May	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0
October	72	41.4	73.3	51	39.6	21.7	72
November	220.7	127	224.6	156.3	121.5	66.4	220.7
December	384.1	220.9	390.9	271.9	211.4	115.6	384.1
Total, $	1869.4	1075.3	1902.5	1323.5	1029	562.5	1869.4
$/ft^2	3.1	1.8	3.2	2.2	1.7	0.9	3.1
$/m^2	33.5	19.3	34.1	23.7	18.5	10.1	33.5


Results
Greenhouse Area and Heat Loss
System Requirement
Monthly Heating Cost
Total Heating Cost
Greenhouse Layout
Total Heating Cost
Total Heating Cost, in $, in $/ft^2 and m^2
Degree Days = 5888 deg.F Days (3271 deg.C Days)
Assuming SOLAR GAIN = 15%
Total Heating Cost
without SOLAR GAIN : 2199.3 $
with SOLAR GAIN : 1869.4 $
Total Heating Cost per Unit Area $/ft^2 $/m^2
without SOLAR GAIN : 3.7 39.5
with SOLAR GAIN : 3.1 33.5

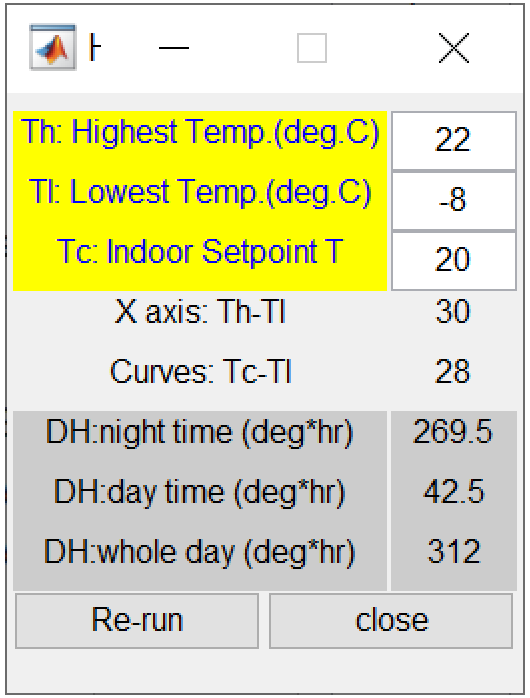

Results
Greenhouse Area and Heat Lo
System Requirement
Monthly Heating Cost
Total Heating Cost
Greenhouse Layout
Greenhouse Heating
Edit
Execute
Degree hours
Million BTU
Photo
About
Quit
1. Bay Width 20 ft............. 6.1 m
2. Bay Length 30 ft............. 9.14 m
3. Bay Height 12 ft............. 3.66 m
4. Number of Bays 6
5. U value of ROOF Detail Info. 1.13 Btu/ft^2/h/F 6.42 W/m^2/K
6. U value of WALL Detail Info. 1.13 Btu/ft^2/h/F 6.42 W/m^2/K
7. Desigh Temperature Difference 60 deg.F 33.33 deg.C
8. Evening inside SetPoint Temperature 60 deg.F 15.56 deg.C
9. Fuel <FUEL> , Unit Price in Detail Info. 0.85 $/gal 0.22 $/L
10. Annual Heating Degree Days Detail Info. 5888 deg.F days 3271 deg.C days
11. Assumed % of Heat Gain from SUN 15 %
12. Select a PLAIN Pipe out of 6 types Detail Info. 1
13. Select a FINNED Pipe out of 6 types Detail Info. 1
14. Floor Heat Contribution at 20 Btu/ft^2/hr 63.09 W/m^2
15. Spacing of floor heating pipe Photo 1 ft............. 0.3 m
16. How many pairs of run per loop Photo 1



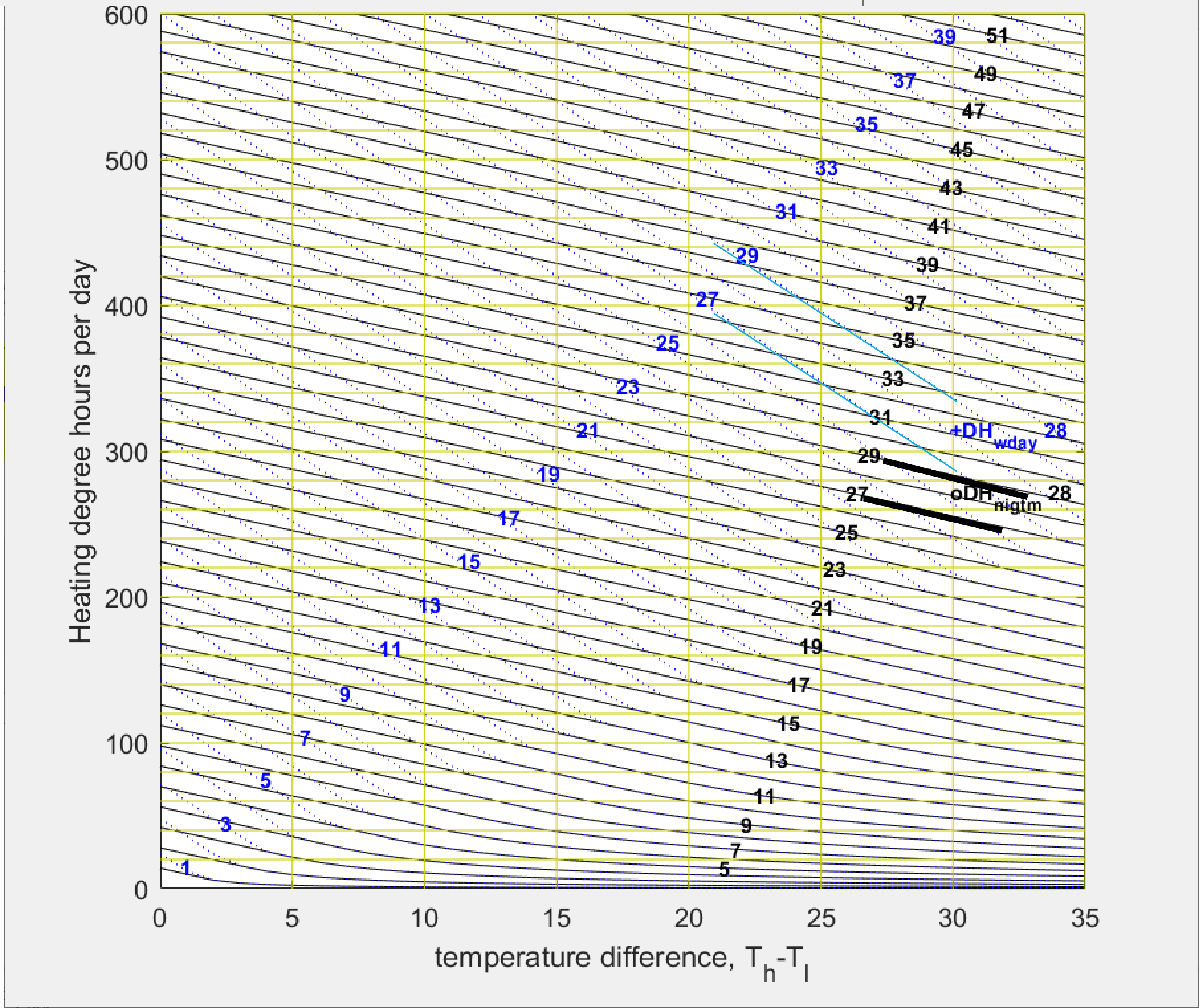
Greenhouse Layout
File Edit View Insert Tools Desktop Window Help
Number of bays is 6
Number of bays is 1
Number of bays is 2
x
y
z



依據室外的最高、最低溫與室內的設定溫度，推估加熱所需度時數



全日的加熱所需度時數（藍字）= 夜間度時數（黑字）+ 日間度時數



Greenhouse Heating

Edit | Execute | Degree hours | Million BTU | Photo | About | Quit

https://tc.unithelper.com/energy/

提供百萬BTU (1055 MJ = 293 kWh) 所需的燃料數量

邊際單價

MillionBTU calculation for various types of fuel used in Boiler

Fuel Type	Heat Value		Boiler Eff.(%)	To reach MBTU You nead		Marginal Unit Price	
1. COAL, Anthracite (hard)	12910	Btu/lb	65	0.06	ton	105.8	$/ton
2. COAL, Semi-anthracite	13770	Btu/lb	60	0.061	ton	104.17	$/ton
3. COAL, Low Volatile Bituminous	14340	Btu/lb	65	0.054	ton	117.52	$/ton
4. COAL, Medium V.B.	13840	Btu/lb	60	0.06	ton	104.7	$/ton
5. COAL, High V.B.	11920	Btu/lb	55	0.076	ton	82.66	$/ton
6. COAL, Sub-bituminous	9045	Btu/lb	55	0.101	ton	62.72	$/ton
7. Fuel Oil No. 1	134950	Btu/gal	70	10.586	gal	0.6	$/gal
8. Fuel Oil No. 2	138800	Btu/gal	70	10.292	gal	0.61	$/gal
9. Fuel Oil No. 4	146950	Btu/gal	68	10.007	gal	0.63	$/gal
10. Fuel Oil No. 5	152000	Btu/gal	67	9.819	gal	0.64	$/gal
11. Fuel Oil No. 6	153350	Btu/gal	65	10.032	gal	0.63	$/gal
12. Natural (Gas)	1000	Btu/ft^3	75	13.333	therm	0.47	$/therm
13. Manufactured (Gas)	550	Btu/ft^3	70	25.974	therm	0.24	$/therm
14. Propane (LP Gas)	2570	Btu/ft^3	75	518.807	therm	0.01	$/therm
15. Butane (Gas)	3225	Btu/ft^3	75	4.134	therm	1.52	$/therm
16. Wood, G. Green Chips	4500	Btu/lb	60	0.185	ton	34.04	$/ton
17. Wood, H. Dried pellets	8500	Btu/lb	60	0.098	ton	64.3	$/ton
<<<<BASE FUEL>>>> 基準燃料	138800	Btu/gal 熱值	80 效率	9.01	gal	0.7	$/gal

以基準燃料的鍋爐效率與燃料單價為基準，當其他燃料的市價低於表列的邊際單價時，可以考慮以該種燃料替換

有些設備可使用多種燃料(1~6, 16, 17; 7~11; 12~15)，也有的可切換使用不同燃料譬如燃油或瓦斯(7~15)

最常用的是編號8與14，有些設備允許切換使用，主要使用液化天然氣(LP gas)，但缺料時可改用二號燃油

HEAT PUMP

Heat pump (HP) is a much more energy efficient system for heating, but It is also much more costly than the boiler.

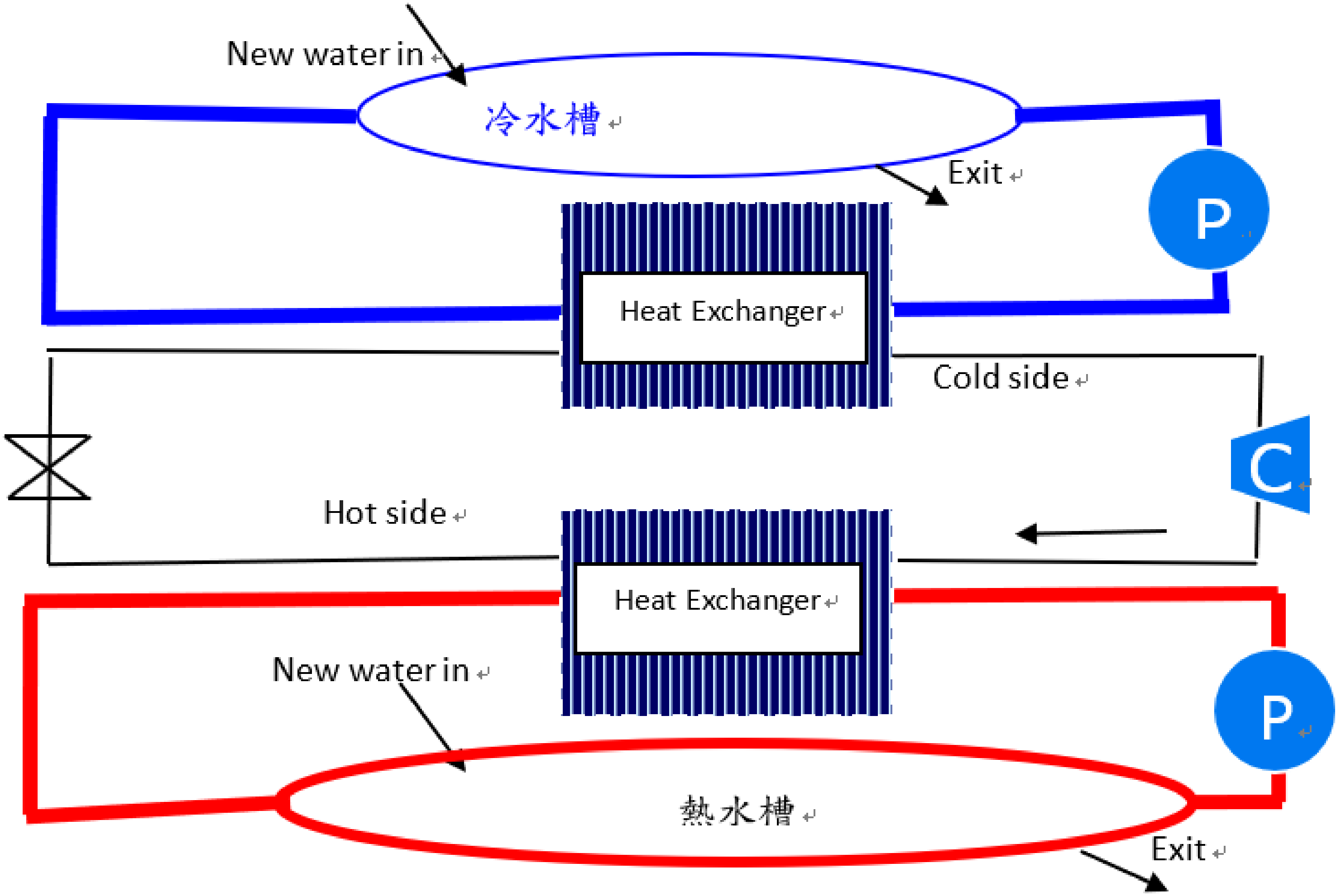
The heating cost of using HP can be calculated using following equation:

Heating cost@ HP = Heating cost@boiler * eff_boiler / COP_ HP

Assuming no.2 fuel was used. 1 MBTU (293 kWh) required 10 gal, the Boiler eff. Is 70% and the heating cost of the greenhouse assuming is 35 $\$/m^2$

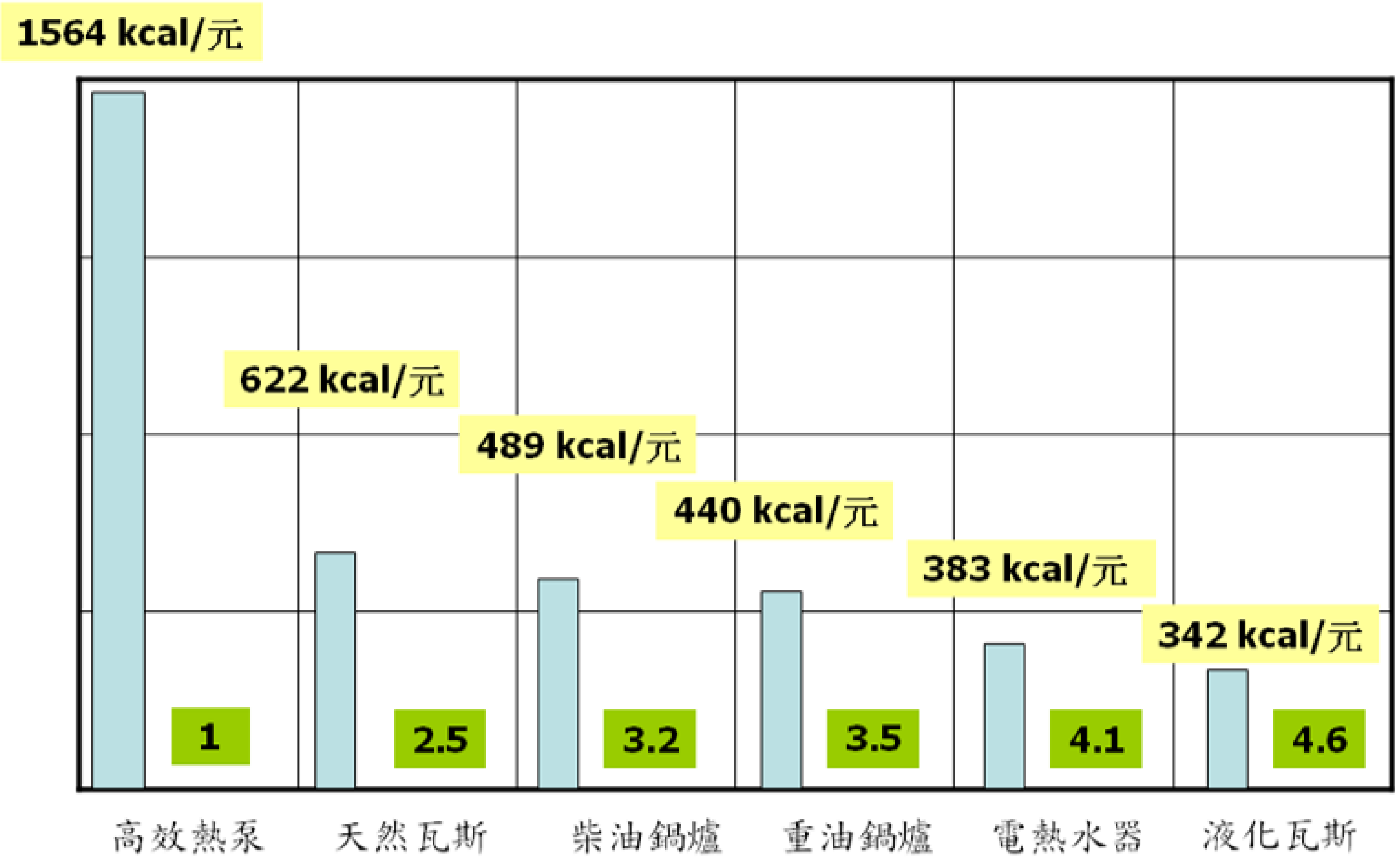
Assuming the COP of the HP is 4, that means consuming elec. 1 kWh can provide 4 kWh of heat. Compare with the efficiency of the burner, 0.7, the heating cost of using HP should be reduced to $35*4/0.7 = 6.14\ \$/m^2$

冷熱水雙效熱泵系統



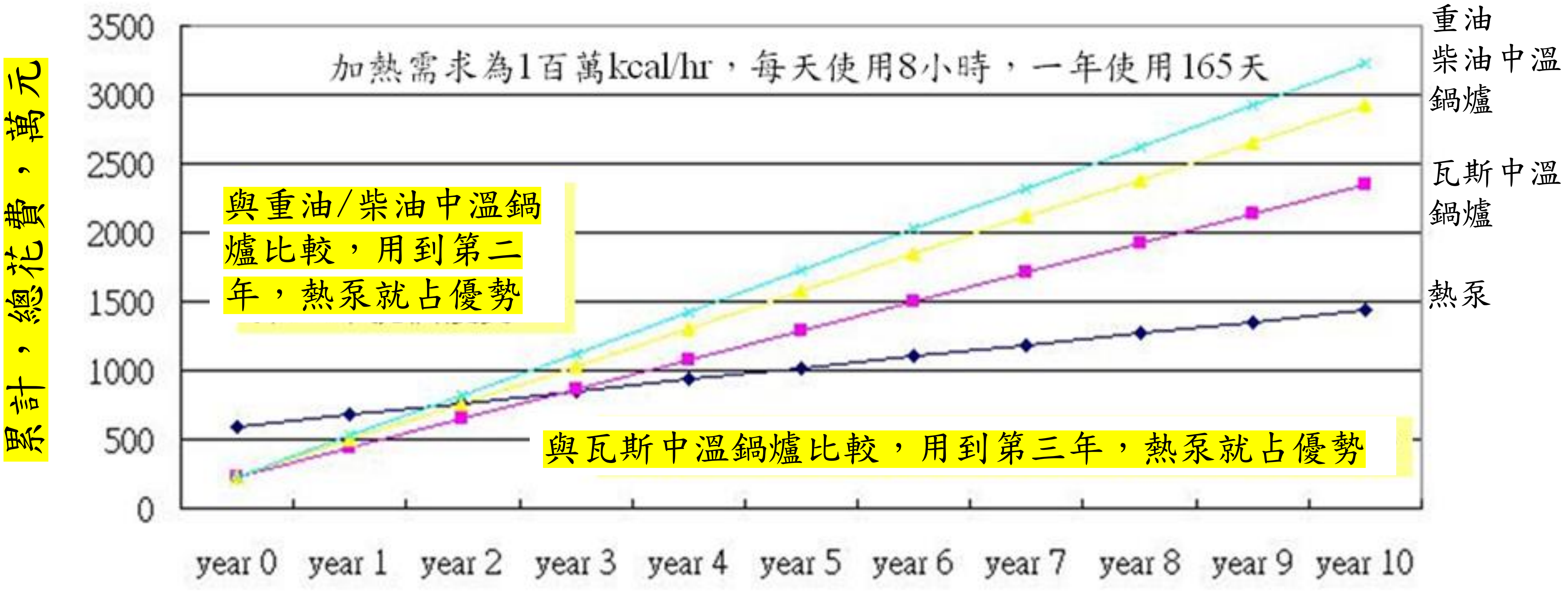
New water in
冷水槽
Exit
P
Heat Exchanger
Cold side
C
Hot side
Heat Exchanger
New water in
P
熱水槽
Exit

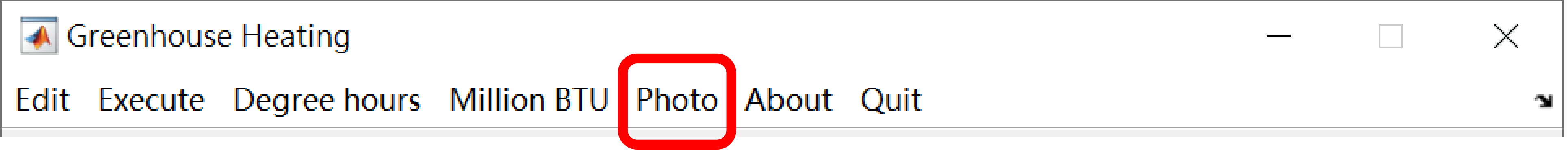
不同熱源加溫成本的比較



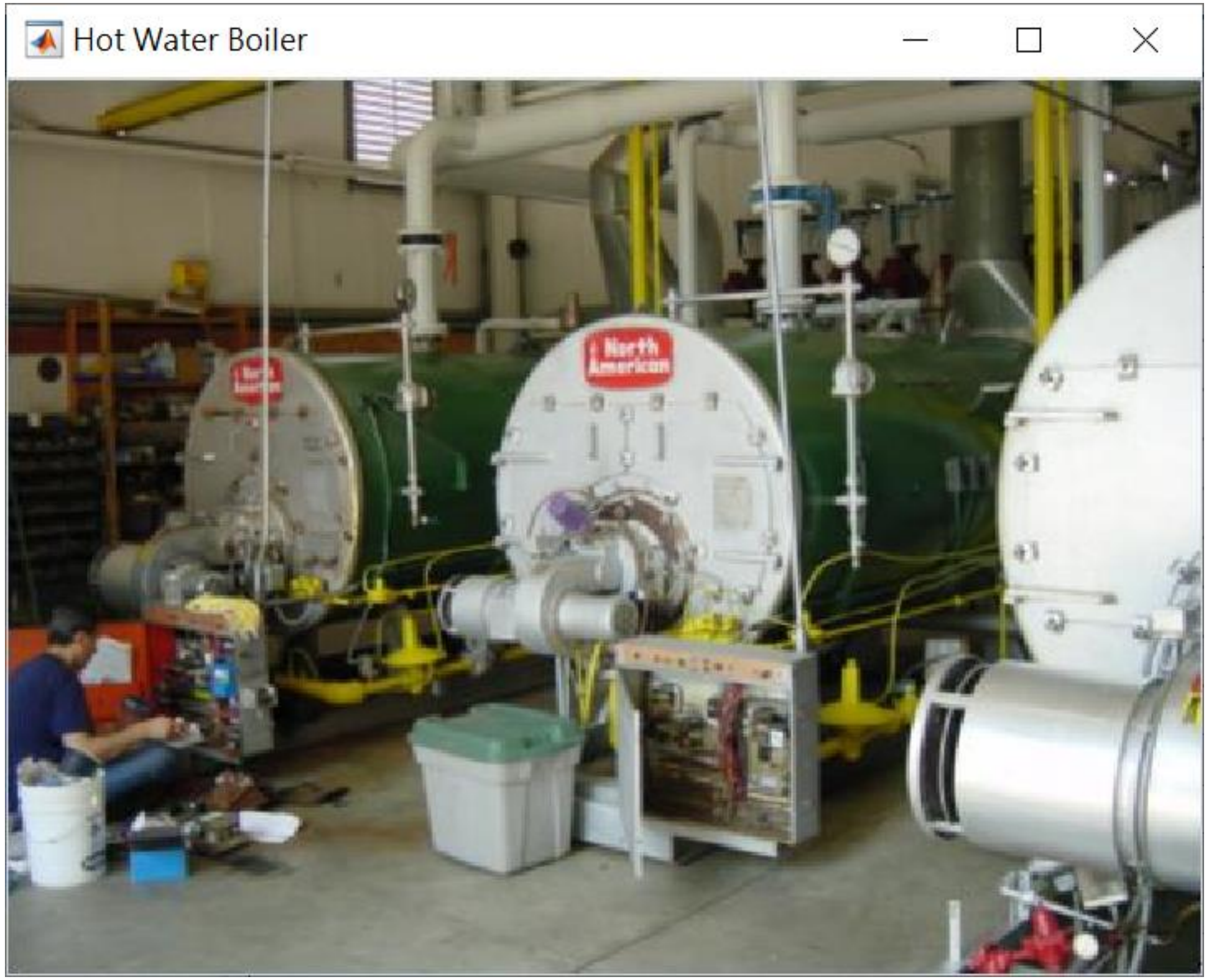
百萬大卡	639	1608	2045	2273	2611	2924	元

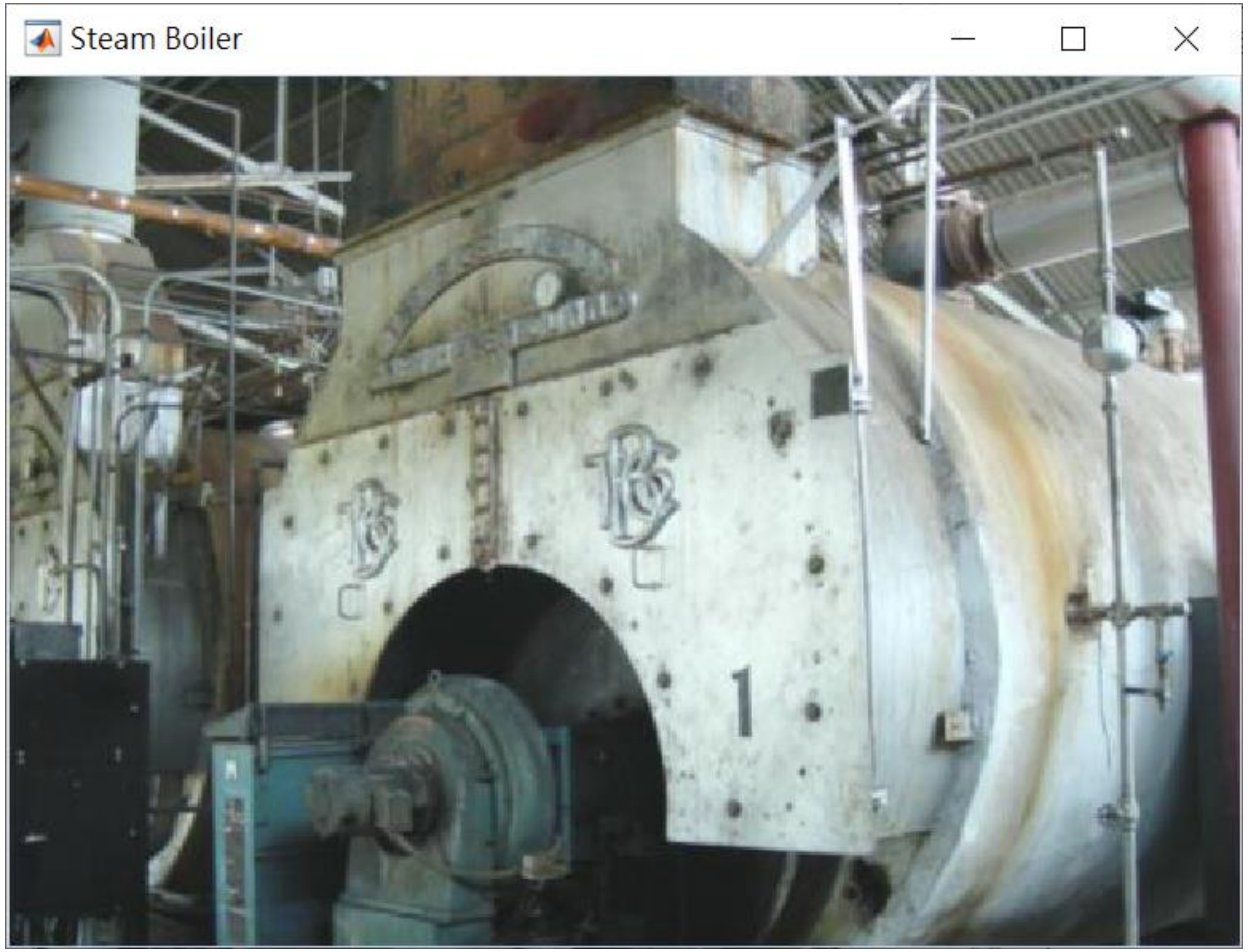
不同熱源系統設置與操作成本的比較

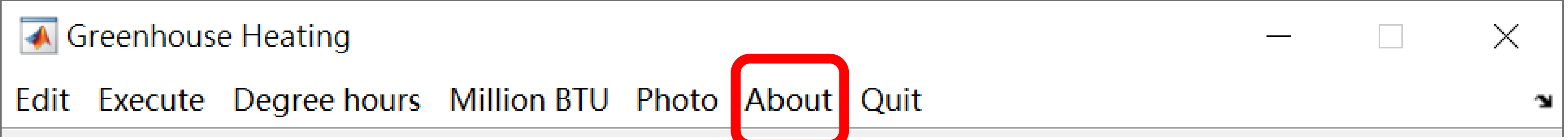




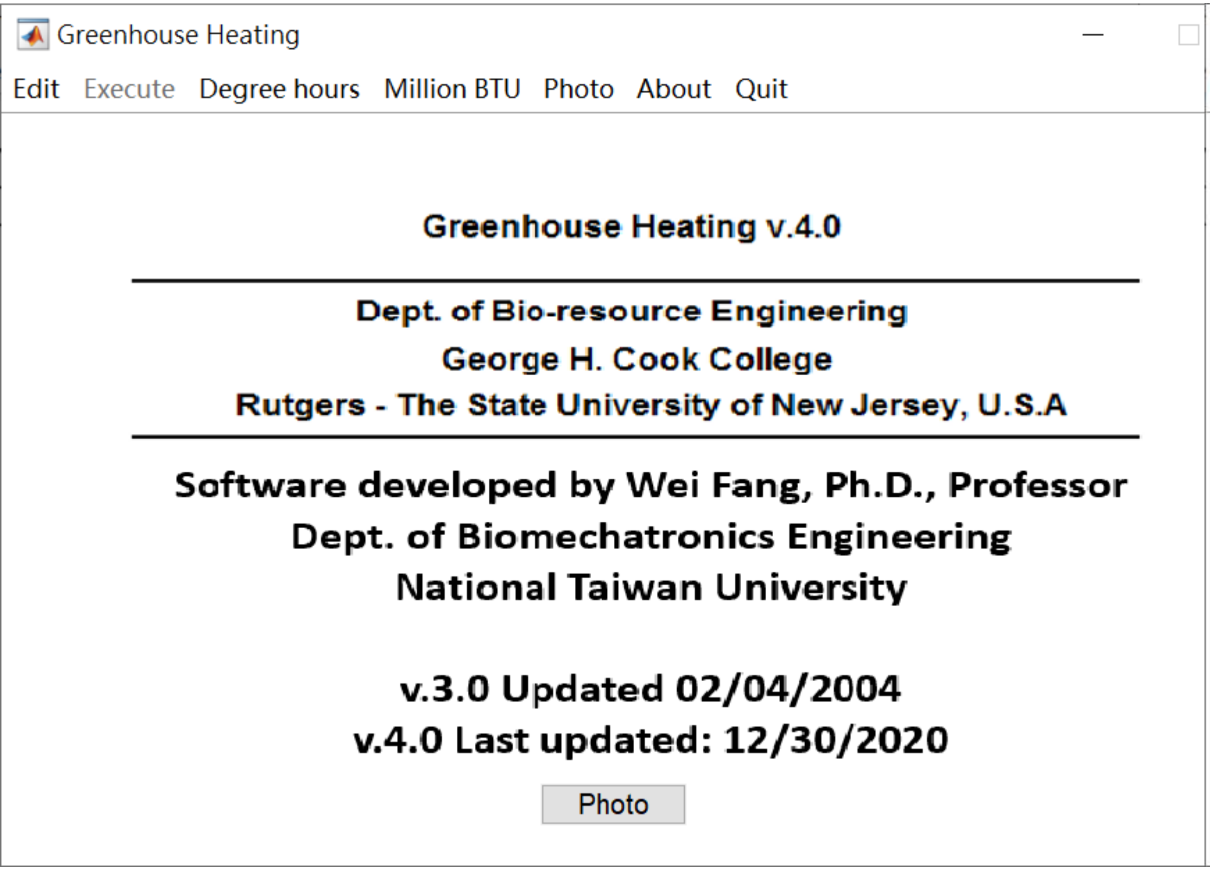
All the photos appeared previously can be found under this menu except these two.

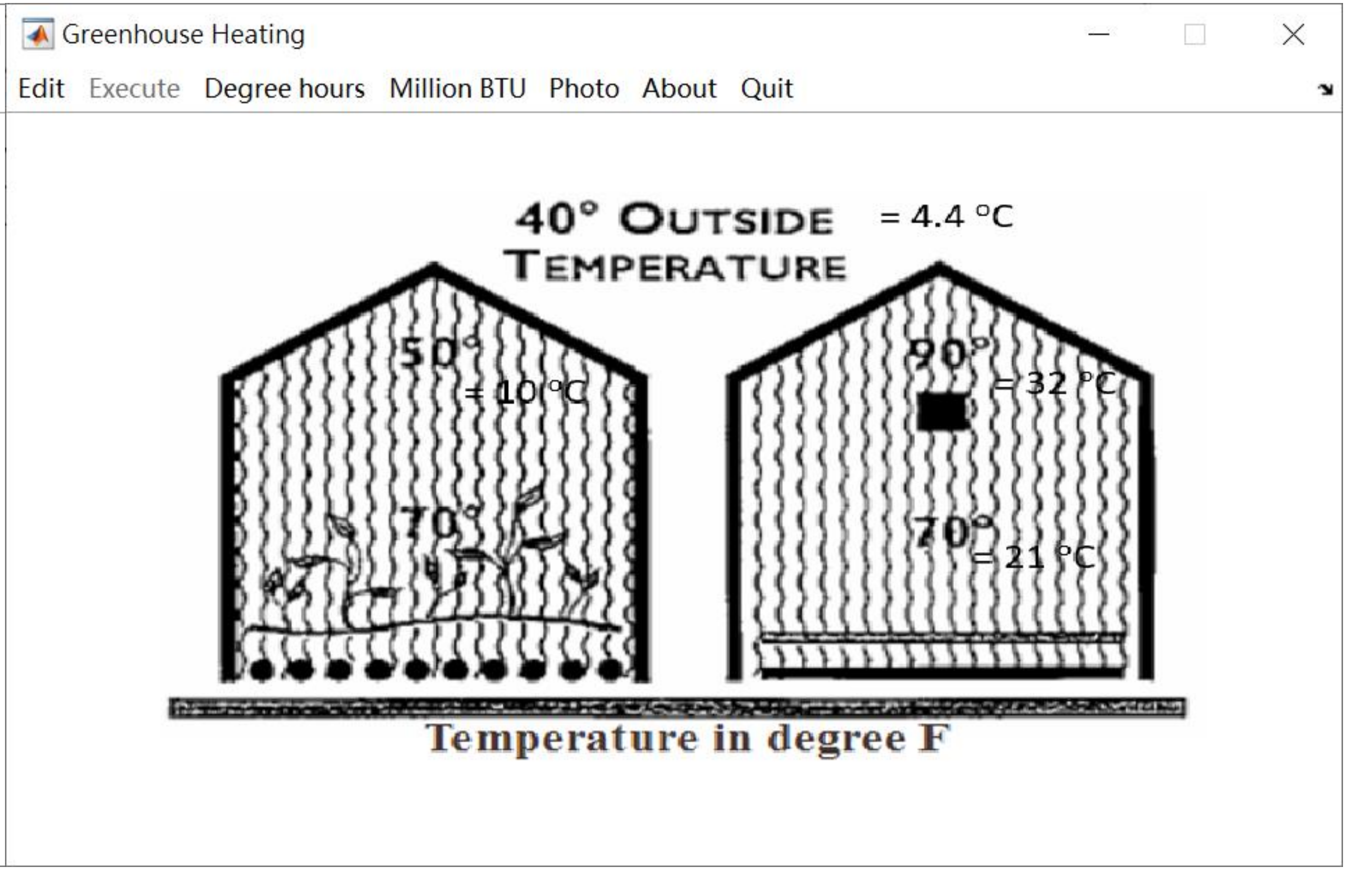






Two more photos can be found under this menu. The first is the photo appeared in the opening page as shown below. The second shows the energy saving potential of the floor heating system.





CREDIT

The credit should go to researchers (Prof. William Roberts, David Mears, K.C. Ting, Gene Giacomelli and Mr. Tom Manning) at the Rutgers University when the author was a Ph.D. student in 1986.

The floor heating system was developed by Professor Roberts and colleagues back in 70s during the energy crisis. Together with the invention of air-inflated double-poly greenhouse, these two technologies help many growers a great deal to remove financial burden on heating.

The first DOS version program was developed by Prof. Roberts in 1980.

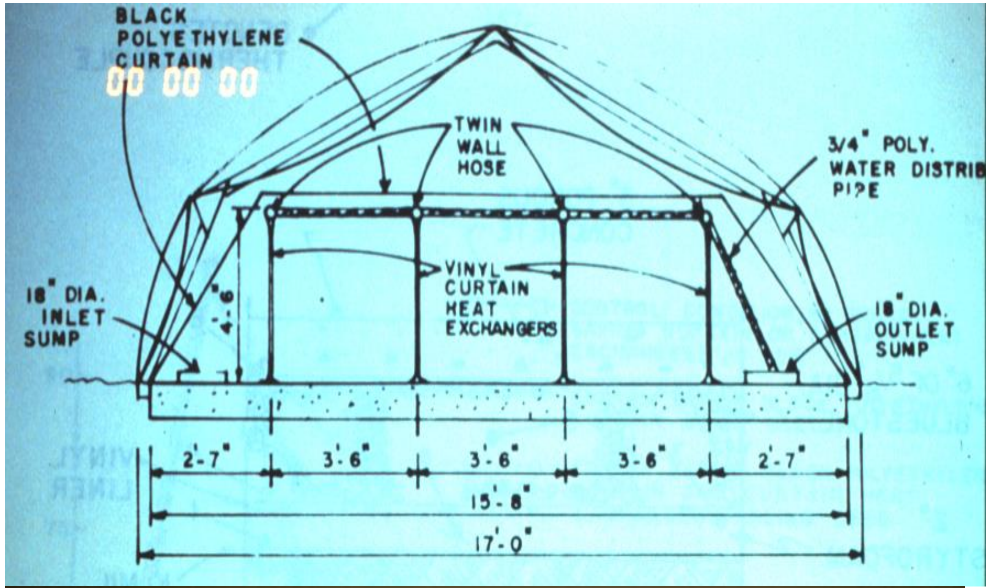
The previous Matlab version of the software was written in 2004. New version imported the concept of 'heating degree hour per day'.

Re-written of the software was to pay my respect to late Professor Roberts, who was RIP in 2020 during the COVID-19 pandemic.

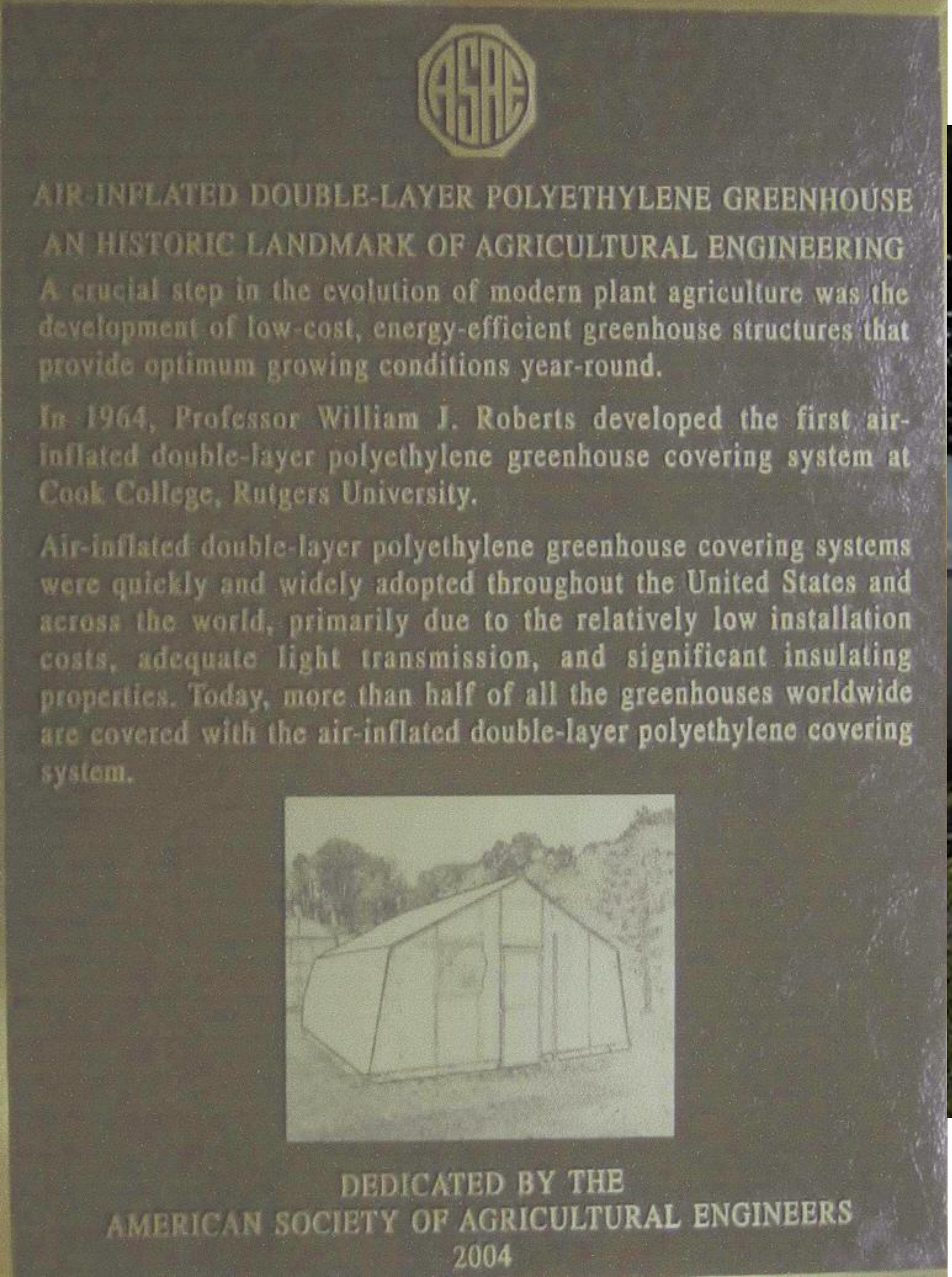

William J. Roberts教授
1st CCEA director
Rutgers Univ.
Merle Jensen教授
1st CEAC director
U. of Arizona
Gene Giacomelli教授
2nd CEAC director
U. of Arizona
Prof.@Rutgers U.
Mr. Tom Manning
RA@Rutgers U.
Post Doc.(1989/10~1992/1)
CCEA@Rutgers U.
2004/6 Rutgers Univ.

雙層充氣塑膠布溫室的起源

- 1964 年創於美國紐澤西州羅格斯大學(Rutgers)，40年後獲得ASAE 頒發超卓成就獎牌並立碑紀念
- Roberts, W.J. and D.R. Mears. **1968**. **<u>Double Covering a Film Greenhouse Using Air to Separate Film Layers</u>**. ASAE paper 68-402. 發表於 Logan, Utah.
- Published in Transactions of the ASAE V12, No.1 **pp.32, 33, 38**. **1969**.



Professors William J. Roberts and David R. Mears



The 43rd Landmark of ASAE

充氣設計
需要導入
室外空氣
避免在雙
層塑膠布
內產生結
露

不僅單棟
溫室可用
連棟溫室
同樣可以

ASSUMPTIONS OF THE 1980 MODEL

1. A boiler provides 33500 BTU/h per HP
2. An extra 5% of Floor pipe length is needed for construction.
3. An extra 10% Header pipe with double return is needed.
4. Three Header pipes are needed, 1 supply and 2 return.
5. Floor pipes are spaced 1 foot (30 cm) center to center.
6. # 2 Oil has a heating efficiency of 70 %; therefore, the heat output is approximately 100,000 BTU/gallon.
7. The boiler size is determined based on the design temperature difference.
8. The heating system runs 24 hs/day at ($T_{setpoint}$ - $T_{outside}$)
9. $T_{outside}$ was determined based on the heating degree day of a specific location. The heating degree day calculation was based on 65 °F (18.3 °C).

CONTACT INFORMATION

The software was written by Professor Wei FANG for the purpose of teaching the Controlled Environment Agriculture related courses.

The software is free to distribute for education purpose only.

Any commands and/or suggestions are welcomed.

Contact info.:

E-mail: weifang@ntu.edu.tw

WeChat and Line ID: weifang0257