CHHAYA 2.0 - *USING A DYNAMIC BALANCE POINT TO EXTEND THE PASSIVE SEASON*

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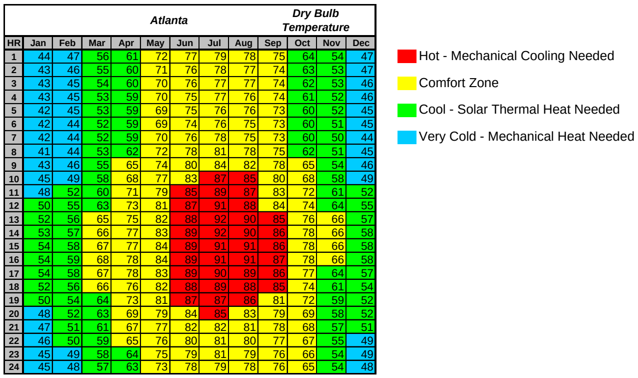
ABSTRACT

Energy modeling has become commonplace, with designers seeking to obtain high performance design solutions for their projects. Although project teams sometimes interact closely with their engineering counterparts, the process is mainly a linear one, with very little iterative simulation. The questions asked of the engineering team are most often ones of size and efficiency. The most pertinent question that very rarely gets asked is “How far can this building go without needing a mechanical HVAC system?”.
Chhaya 2.0© is an Excel based design tool that helps designers optimize glazing size and orientation, shading and natural ventilation to extend the period that the building can run passively. It used TMY2 weather data and a series of interactive matrices to help the user come up with optimal design solutions. The use of slider bars to allow the user to increase window sizes as well as shades in each direction and ventilation rates allows the architect to enter the world of the engineer with instantaneous interactive feedback to building shell decisions.

1. INTRODUCTION

Chhaya 1.0© was first presented at the ASES 2004 conference in Portland, where it was a basic tool that calculated sun angles and building balance point. It has since then become more interactive with real-time feedback including sliding shade options and peak HVAC tonnage from solar heat gain (this allows users to gauge the tonnage reduction from building shades).

Despite the improvements to the program, its fundamental premise remains the same as in 2004. The idea is that is you can track when the building moves from heating mode to cooling mode, and correlate that to a sun angle, you could figure out an optimal shade size for each building orientation without needing iterative simulations. For the purpose of brevity, this paper will not detail the sun angle calculation method or data import method covered in the 2004 paper.



						Atlanta					Dry Bulb Temperature	
HR	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	44	47	56	61	72	77	79	78	75	64	54	47
2	43	46	55	60	71	76	78	77	74	63	53	47
3	43	45	54	60	70	76	77	77	74	62	53	46
4	43	45	53	59	70	75	77	76	74	61	52	46
5	42	45	53	59	69	75	76	76	73	60	52	45
6	42	44	52	59	69	74	76	75	73	60	51	45
7	42	44	52	59	70	76	78	75	73	60	50	44
8	41	44	53	62	72	78	81	78	75	62	51	45
9	43	46	55	65	74	80	84	82	78	65	54	46
10	45	49	58	68	77	83	87	85	80	68	58	49
11	48	52	60	71	79	85	89	87	83	72	61	52
12	50	55	63	73	81	87	91	88	84	74	64	55
13	52	56	65	75	82	88	92	90	85	76	66	57
14	53	57	66	77	83	89	92	90	86	78	66	58
15	54	58	67	77	84	89	91	91	86	78	66	58
16	54	59	68	78	84	89	91	91	87	78	66	58
17	54	58	67	78	83	89	90	89	86	77	64	57
18	52	56	66	76	82	88	89	88	85	74	61	54
19	50	54	64	73	81	87	87	86	81	72	59	52
20	48	52	63	69	79	84	85	83	79	69	58	52
21	47	51	61	67	77	82	82	81	78	68	57	51
22	46	50	59	65	76	80	81	80	77	67	55	49
23	45	49	58	64	75	79	81	79	76	66	54	49
24	45	48	57	63	73	78	79	78	76	65	54	48

🟥 Hot - Mechanical Cooling Needed
🟨 Comfort Zone
🟩 Cool - Solar Thermal Heat Needed
🟦 Very Cold - Mechanical Heat Needed

Fig. 1: Annual Dry Bulb temperature matrix for Atlanta,

2. BALANCE POINT TEMPERATURE

A building’s balance point temperature is the outdoor dry bulb temperature required for the building to be in thermal balance. To put it in simple terms, it is the temperature that the outdoors needs to be at to maintain the indoors at the design temperature (in this case, the thermostat setpoint temperature) without any additional heating or cooling. The balance point temperature can be calculated from the following formula:

$$Q_{INT} = Q_{OUT} + Q_{VENT} \qquad (1)$$

$$Q_{SOL} + Q_{EQU} + Q_{PPL} = M*C_P\ UA_{BLD} \times (T_{DES} - T_{BAL}) \qquad (2)$$

Where Q_{INT} = Internal heat gain
Q_{OUT} = Heat loss (through the building skin)
Q_{VENT} = Heat loss through ventilation.
Q_{SOL} = Solar heat gain (through windows)
Q_{EQU} = Heat gain from lights and equipment.

Q_{PPL} = Heat gain from people.

UA_{BLD} = Average building skin conductance x total building surface area

M = Mass of ventilation air

C_P = Specific Heat Capacity of Air.

T_{DES} = Design internal temperature.

T_{BAL} = Balance point temperature.

In theory if the balance point is equal to the outdoor dry bulb temperature (DBT), the building would need neither cooling nor heating; losing all of its internal heat gain through ventilation and skin conductance. In most buildings this happens on very few occasions through the year. During the heating season, the balance point is often higher than the outside DBT, and in the cooling season it is often lower.

2.1 HEATING SEASON

To lower the balance point temperature in winter, a designer has four options:

1. Lower the ventilation rates, thereby reducing heat loss from air (this is restricted by the minimum air change rate)

2. Lower heat loss by conductance by increased insulation.

3. Increase internal heat gain. Since people, lights and equipment will be mostly constant through the year, this is done through increasing solar heat gain – either with increased window sizes or increased shading coefficients in the glazing.

4. Decrease the design temperature. ASHRAE's adaptive comfort model (*1998, de Dear, Braeger* - See Figure 1) allows for design temperatures to be lowered to up to 65°F – 68°F in winter provided the mean monthly temperatures are between to 50°F – 55°F.

2.2. COOLING SEASON

Analyzing the cooling season is more complex than the heating season. It can be broken up into two seasons – the first one – a true cooling season, when the outside air has no cooling potential, and the second one when the outside air has the potential for cooling (natural ventilation season).

2.2.1 TRUE COOLING SEASON

A true cooling season occurs when the dry bulb temperature is above the setpoint temperature. At this point, there is no potential for passive conditioning of the building, and the aim is to reduce the load on the HVAC system by raising the balance point temperature. To do this, the designer has three options:

1. Lower the ventilation rates, thereby reducing heat gain from air (this is restricted by the minimum air change rate).

2. Lower heat gain through the building skin by increased insulation

3. Decrease internal heat gain. This is done with reduction of lighting loads (not addressed in this program), and reducing solar heat gain through shades, optimized glazing and shading coefficients.

2.2.1 NATURAL VENTILATION SEASON

During the natural ventilation season, the outside air is cooler than the building setpoint, but the building is still in cooling mode because of internal heat gains. The designer can increase the balance point temperature using any of the following three options:

1. Increase the heat loss through ventilation.

2. Reduce internal heat gains with shading and daylighting.

3. Increase the design temperature. ASHRAE's adaptive comfort model (*1998, de Dear, Braeger* - See Fig. 2) allows for design temperatures to be raised to up to 84°F – 86°F in summer, provided the mean monthly temperatures are between to 90°F – 95°F.

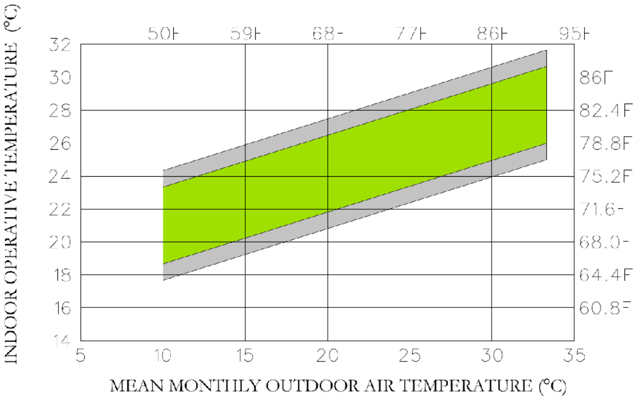


Fig. 2: Acceptable operative temperature ranges for naturally conditioned spaces (Adapted from ASHRAE Std 55-2004).

3. COOLING CAPACITY OF AIR

The cooling capacity of air is obtained with the following equation

$Q_{VENT} = M * C_P * (\Delta T)$ (3)

Where

M = Mass of ventilation air

C_P = Specific Heat Capacity of Air.

ΔT = Design internal temperature - Balance point temperature.

C_P is given as 1.006 kJ/kg.°C, or 0.2403 Btu/lb°F.

The weight of air varies with its temperature, but since this analysis deals with air between 65°F and 85°F, the weight of air for this analysis is assumed to be a static 0.075 lbs/ ft^3

Mass of air per air change = 0.075 * V

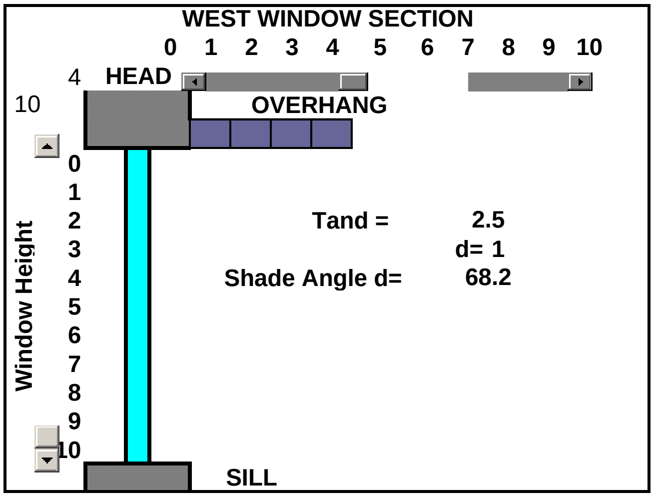
Where V = Volume of building

Therefore from equation (3) for 1 air change:

$$Q_{VENT} = 0.075 * V * 0.2403 * (\Delta T)$$
$$= 0.018 * V * (\Delta T)$$

4. COOLING EFFECT OF SHADES

In order to provide the cooling effect of shades on the windows, each orientation (except north) is provided with a window section (Fig. 3) to allow the user to play with the window section by either sliding the overhang back and forth, or sliding the window height up and down, or both. The program calculates the shade angle (d) formed from the base of the window sill to the outer edge of the overhang.



Tand = 2.5
d= 1
Shade Angle d= 68.2

Fig. 3: West window section showing options for shade manipulation

A horizontal shade will provide a dynamic shading coefficient that will change depending on the profile angle of the sun on the window. In order to derive the effect of the shade, the window shade angle must be compared to the profile angle at each hour in the profile angle matrix (Fig. 4).

The effective shading coefficient for each hour can be calculated with the following equation:

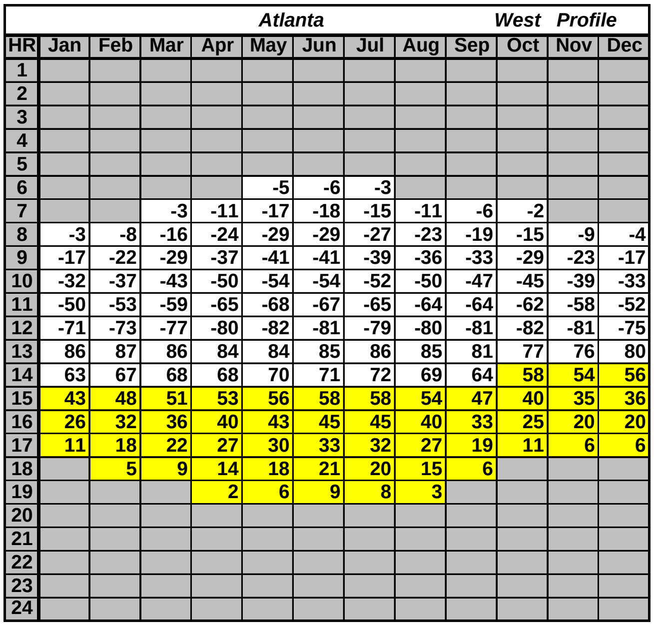
$$SC = 1- [TAN (\theta)/TAN (d)] \quad (4)$$

Where

θ = Profile Angle for the hour

d = Shade angle for the window

An important condition to put into the expression is that if the window shading angle is less than the profile angle at that hour, the entire window is in shade, therefore the shading coefficient should be zero.

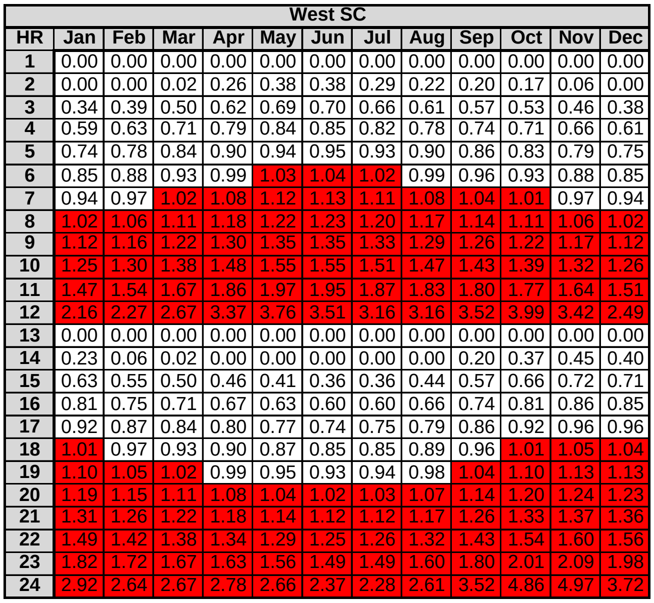


Atlanta West Profile

HR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1												
2												
3												
4												
5												
6					-5	-6	-3					
7			-3	-11	-17	-18	-15	-11	-6	-2		
8	-3	-8	-16	-24	-29	-29	-27	-23	-19	-15	-9	-4
9	-17	-22	-29	-37	-41	-41	-39	-36	-33	-29	-23	-17
10	-32	-37	-43	-50	-54	-54	-52	-50	-47	-45	-39	-33
11	-50	-53	-59	-65	-68	-67	-65	-64	-64	-62	-58	-52
12	-71	-73	-77	-80	-82	-81	-79	-80	-81	-82	-81	-75
13	86	87	86	84	84	85	86	85	81	77	76	80
14	63	67	68	68	70	71	72	69	64	58	54	56
15	43	48	51	53	56	58	58	54	47	40	35	36
16	26	32	36	40	43	45	45	40	33	25	20	20
17	11	18	22	27	30	33	32	27	19	11	6	6
18		5	9	14	18	21	20	15	6			
19				2	6	9	8	3				
20												
21												
22												
23												
24												

Fig. 4: Profile angle matrix for west windows (negative numbers indicate sun is in the east, yellow areas indicate overheated periods)

Figure 5 shows the effective shading coefficient matrix for the west window. The areas shaded in red are when the calculated shading coefficient is greater than one. This happens on each façade when the sun is not on the façade, so it is irrelevant to the shading calculations.



West SC												
HR	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.02	0.26	0.38	0.38	0.29	0.22	0.20	0.17	0.06	0.00
3	0.34	0.39	0.50	0.62	0.69	0.70	0.66	0.61	0.57	0.53	0.46	0.38
4	0.59	0.63	0.71	0.79	0.84	0.85	0.82	0.78	0.74	0.71	0.66	0.61
5	0.74	0.78	0.84	0.90	0.94	0.95	0.93	0.90	0.86	0.83	0.79	0.75
6	0.85	0.88	0.93	0.99	1.03	1.04	1.02	0.99	0.96	0.93	0.88	0.85
7	0.94	0.97	1.02	1.08	1.12	1.13	1.11	1.08	1.04	1.01	0.97	0.94
8	1.02	1.06	1.11	1.18	1.22	1.23	1.20	1.17	1.14	1.11	1.06	1.02
9	1.12	1.16	1.22	1.30	1.35	1.35	1.33	1.29	1.26	1.22	1.17	1.12
10	1.25	1.30	1.38	1.48	1.55	1.55	1.51	1.47	1.43	1.39	1.32	1.26
11	1.47	1.54	1.67	1.86	1.97	1.95	1.87	1.83	1.80	1.77	1.64	1.51
12	2.16	2.27	2.67	3.37	3.76	3.51	3.16	3.16	3.52	3.99	3.42	2.49
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.23	0.06	0.02	0.00	0.00	0.00	0.00	0.00	0.20	0.37	0.45	0.40
15	0.63	0.55	0.50	0.46	0.41	0.36	0.36	0.44	0.57	0.66	0.72	0.71
16	0.81	0.75	0.71	0.67	0.63	0.60	0.60	0.66	0.74	0.81	0.86	0.85
17	0.92	0.87	0.84	0.80	0.77	0.74	0.75	0.79	0.86	0.92	0.96	0.96
18	1.01	0.97	0.93	0.90	0.87	0.85	0.85	0.89	0.96	1.01	1.05	1.04
19	1.10	1.05	1.02	0.99	0.95	0.93	0.94	0.98	1.04	1.10	1.13	1.13
20	1.19	1.15	1.11	1.08	1.04	1.02	1.03	1.07	1.14	1.20	1.24	1.23
21	1.31	1.26	1.22	1.18	1.14	1.12	1.12	1.17	1.26	1.33	1.37	1.36
22	1.49	1.42	1.38	1.34	1.29	1.25	1.26	1.32	1.43	1.54	1.60	1.56
23	1.82	1.72	1.67	1.63	1.56	1.49	1.49	1.60	1.80	2.01	2.09	1.98
24	2.92	2.64	2.67	2.78	2.66	2.37	2.28	2.61	3.52	4.86	4.97	3.72

Fig. 5: Shading coefficient matrix for west windows (numbers over 1 shaded in red)

4. CALCULATING THE HEATING AND COOLING SEASON MATRIX

Figure 1 is an example of the dry bulb temperature matrix developed by the program. The X-axis represents a typical day for each month of the year, and the Y-axis represents every hour of the day. Together they provide a comprehensive annual temperature map. A matrix similar to Fig. 1 is produced for the building's balance point temperature. The difference between balance point temperature and outdoor dry bulb temperature results in a heating and cooling season matrix (Fig. 6), where positive numbers indicate heating required (in cyan) and negative numbers indicate cooling required (in red).

5. TEST BUILDING IN ATLANTA

We created a test building located in Atlanta. The footprint is a square shoebox 50 feet long by 50feet wide by 15 feet high (roughly the size of an average home). Each orientation has a 50% window-wall ratio. The design setpoint is 78°F.

Figure 7 is a screenshot of the test building before shades or natural ventilation are added to the equation. The glass shading coefficient is 0.6 for all orientations. From 8am to 6 pm, the building has an internal heat gain of 1.5 W/ft^2 and an occupancy count of 15. It can be seen that the building is overheating for almost the entire period from March – November. The red cells represent drastic overheating where the difference between the balance point temperature and the dry bulb temperature is greater than 30°F. The yellow cells indicate slightly warm temperatures, and the green cells indicate comfort temperatures. The blue cells occur when the building switches to heating mode.

Figure 8 is the same screenshot after shades have been added to the East, West and South windows. A shade angle of 45 degrees has been used here. A natural ventilation rate of 1.5 air changes per hour has also been added to the equation. It should be noted that to prevent the modeling of natural ventilation during times when it is unfeasible, a high and low temperature option has been added. This allows the user to select temperatures such that if the outdoor dry bulb temperature runs outside this range, the ventilation rates drop down (assuming windows will remain closed at this time). It is seen that the red period has been restricted to the months of Julyy, August and September, allowing the building to run in passive mode for around six extra months.

6. CONCLUSIONS/ FUTURE WORK

This project is in a work that has been in continuous development for a couple of years now. The new shading options as well as the ability to analyze ventilation options is one that we feel will allow architects to better explore these ideas, and ask more pertinent design questions. The ease with which the slider bars allow designers to play around with shades and window sizes, and get instantaneous feedback is invaluable to the schematic design process, allowing this to integrate early in the design process. Future work will include a variable setpoint range allowing a full utilization of the adaptive comfort range. At this point, the air change rates are guessed t by the user. We plan to derive those from window sizes and climate data. There is also the possibility of adding a thermal mass option as well as a daylighting switch (to reduce internal heat gains when light levels are high enough).

7. REFERENCES

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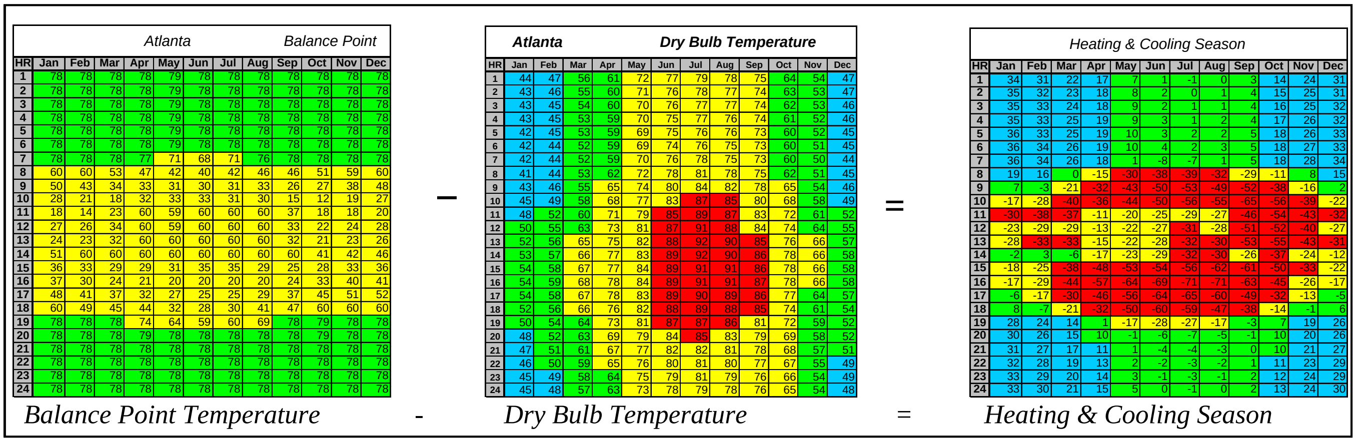

Atlanta *Balance Point*

HR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	78	78	78	78	79	78	78	78	78	78	78	78
2	78	78	78	78	79	78	78	78	78	78	78	78
3	78	78	78	78	79	78	78	78	78	78	78	78
4	78	78	78	78	79	78	78	78	78	78	78	78
5	78	78	78	78	79	78	78	78	78	78	78	78
6	78	78	78	78	79	78	78	78	78	78	78	78
7	78	78	78	77	71	68	71	76	78	78	78	78
8	60	60	53	47	42	40	42	46	46	51	59	60
9	50	43	34	33	31	30	31	33	26	27	38	48
10	28	21	18	32	33	33	31	30	15	12	19	27
11	18	14	23	60	59	60	60	60	37	18	18	20
12	27	26	34	60	59	60	60	60	33	22	24	28
13	24	23	32	60	60	60	60	60	32	21	23	26
14	51	60	60	60	60	60	60	60	60	41	42	46
15	36	33	29	29	31	35	35	29	25	28	33	36
16	37	30	24	21	20	20	20	20	24	33	40	41
17	48	41	37	32	27	25	25	29	37	45	51	52
18	60	49	45	44	32	28	30	41	47	60	60	60
19	78	78	78	74	64	59	60	69	78	79	78	78
20	78	78	78	79	78	78	78	78	78	79	78	78
21	78	78	78	78	78	78	78	78	78	78	78	78
22	78	78	78	78	78	78	78	78	78	78	78	78
23	78	78	78	78	78	78	78	78	78	78	78	78
24	78	78	78	78	78	78	78	78	78	78	78	78

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Atlanta ***Dry Bulb Temperature***

HR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	44	47	56	61	72	77	79	78	75	64	54	47
2	43	46	55	60	71	76	78	77	74	63	53	47
3	43	45	54	60	70	76	77	77	74	62	53	46
4	43	45	53	59	70	75	77	76	74	61	52	46
5	42	45	53	59	69	75	76	76	73	60	52	45
6	42	44	52	59	69	74	76	75	73	60	51	45
7	42	44	52	59	70	76	78	75	73	60	50	44
8	41	44	53	62	72	78	81	78	75	62	51	45
9	43	46	55	65	74	80	84	82	78	65	54	46
10	45	49	58	68	77	83	87	85	80	68	58	49
11	48	52	60	71	79	85	89	87	83	72	61	52
12	50	55	63	73	81	87	91	88	84	74	64	55
13	52	56	65	75	82	88	92	90	85	76	66	57
14	53	57	66	77	83	89	92	90	86	78	66	58
15	54	58	67	77	84	89	91	91	86	78	66	58
16	54	59	68	78	84	89	91	91	87	78	66	58
17	54	58	67	78	83	89	90	89	86	77	64	57
18	52	56	66	76	82	88	89	88	85	74	61	54
19	50	54	64	73	81	87	87	86	81	72	59	52
20	48	52	63	69	79	84	85	83	79	69	58	52
21	47	51	61	67	77	82	82	81	78	68	57	51
22	46	50	59	65	76	80	81	80	77	67	55	49
23	45	49	58	64	75	79	81	79	76	66	54	49
24	45	48	57	63	73	78	79	78	76	65	54	48

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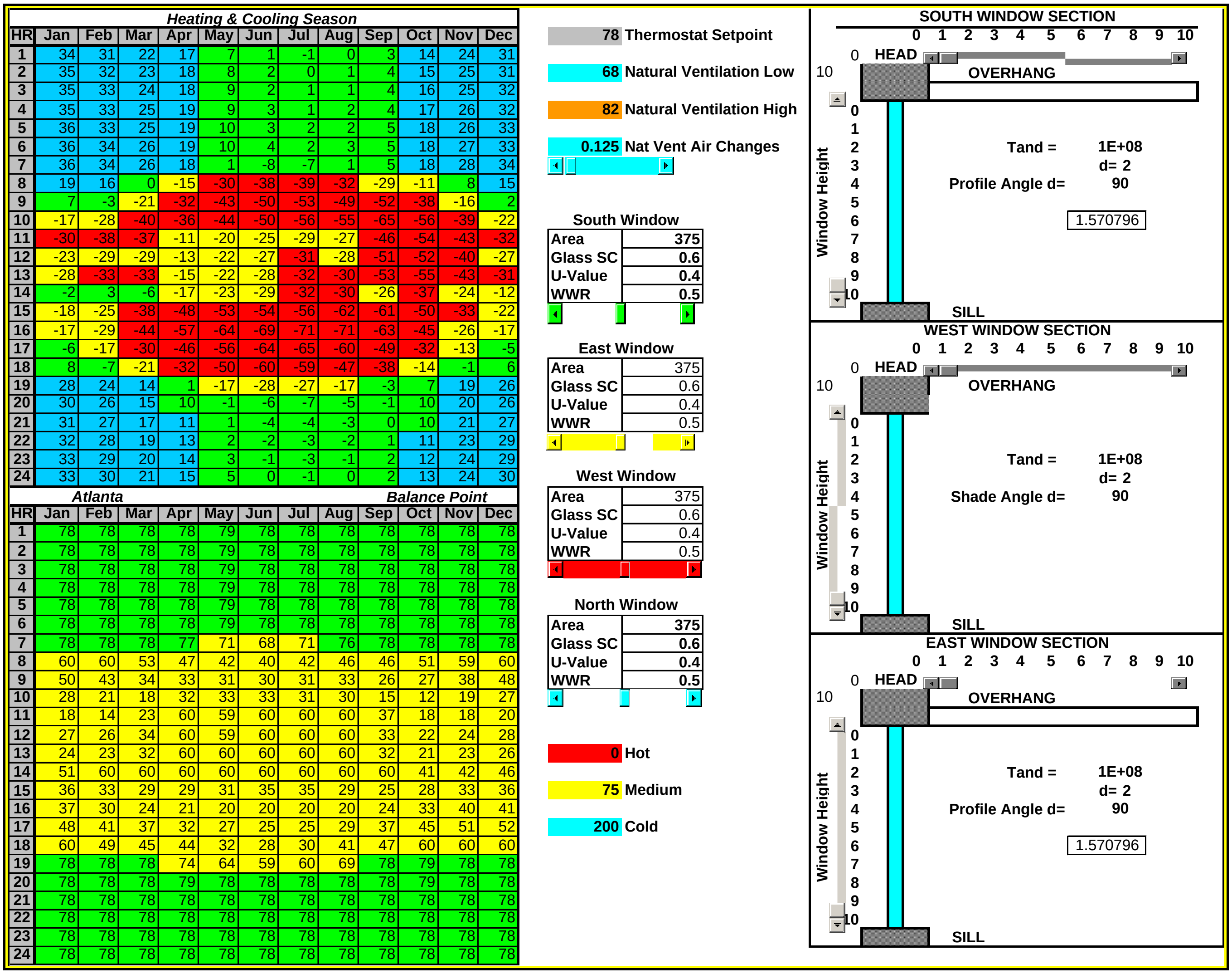
Heating & Cooling Season

HR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	34	31	22	17	7	1	-1	0	3	14	24	31
2	35	32	23	18	8	2	0	1	4	15	25	31
3	35	33	24	18	9	2	1	1	4	16	25	32
4	35	33	25	19	9	3	1	2	4	17	26	32
5	36	33	25	19	10	3	2	2	5	18	26	33
6	36	34	26	19	10	4	2	3	5	18	27	33
7	36	34	26	18	1	-8	-7	1	5	18	28	34
8	19	16	0	-15	-30	-38	-39	-32	-29	-11	8	15
9	7	-3	-21	-32	-43	-50	-53	-49	-52	-38	-16	2
10	-17	-28	-40	-36	-44	-50	-56	-55	-65	-56	-39	-22
11	-30	-38	-37	-11	-20	-25	-29	-27	-46	-54	-43	-32
12	-23	-29	-29	-13	-22	-27	-31	-28	-51	-52	-40	-27
13	-28	-33	-33	-15	-22	-28	-32	-30	-53	-55	-43	-31
14	-2	3	-6	-17	-23	-29	-32	-30	-26	-37	-24	-12
15	-18	-25	-38	-48	-53	-54	-56	-62	-61	-50	-33	-22
16	-17	-29	-44	-57	-64	-69	-71	-71	-63	-45	-26	-17
17	-6	-17	-30	-46	-56	-64	-65	-60	-49	-32	-13	-5
18	8	-7	-21	-32	-50	-60	-59	-47	-38	-14	-1	6
19	28	24	14	1	-17	-28	-27	-17	-3	7	19	26
20	30	26	15	10	-1	-6	-7	-5	-1	10	20	26
21	31	27	17	11	1	-4	-4	-3	0	10	21	27
22	32	28	19	13	2	-2	-3	-2	1	11	23	29
23	33	29	20	14	3	-1	-3	-1	2	12	24	29
24	33	30	21	15	5	0	-1	0	2	13	24	30

Balance Point Temperature - *Dry Bulb Temperature* = *Heating & Cooling Season*

Fig.6: Relationship between dry bulb temperature, Balance point temperature, and heating & cooling seasons.



Heating & Cooling Season

HR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	34	31	22	17	7	1	-1	0	3	14	24	31
2	35	32	23	18	8	2	0	1	4	15	25	31
3	35	33	24	18	9	2	1	1	4	16	25	32
4	35	33	25	19	9	3	1	2	4	17	26	32
5	36	33	25	19	10	3	2	2	5	18	26	33
6	36	34	26	19	10	4	2	3	5	18	27	33
7	36	34	26	18	1	-8	-7	1	5	18	28	34
8	19	16	0	-15	-30	-38	-39	-32	-29	-11	8	15
9	7	-3	-21	-32	-43	-50	-53	-49	-52	-38	-16	2
10	-17	-28	-40	-36	-44	-50	-56	-55	-65	-56	-39	-22
11	-30	-38	-37	-11	-20	-25	-29	-27	-46	-54	-43	-32
12	-23	-29	-29	-13	-22	-27	-31	-28	-51	-52	-40	-27
13	-28	-33	-33	-15	-22	-28	-32	-30	-53	-55	-43	-31
14	-2	3	-6	-17	-23	-29	-32	-30	-26	-37	-24	-12
15	-18	-25	-38	-48	-53	-54	-56	-62	-61	-50	-33	-22
16	-17	-29	-44	-57	-64	-69	-71	-71	-63	-45	-26	-17
17	-6	-17	-30	-46	-56	-64	-65	-60	-49	-32	-13	-5
18	8	-7	-21	-32	-50	-60	-59	-47	-38	-14	-1	6
19	28	24	14	1	-17	-28	-27	-17	-3	7	19	26
20	30	26	15	10	-1	-6	-7	-5	-1	10	20	26
21	31	27	17	11	1	-4	-4	-3	0	10	21	27
22	32	28	19	13	2	-2	-3	-2	1	11	23	29
23	33	29	20	14	3	-1	-3	-1	2	12	24	29
24	33	30	21	15	5	0	-1	0	2	13	24	30

Atlanta ***Balance Point***

HR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	78	78	78	78	79	78	78	78	78	78	78	78
2	78	78	78	78	79	78	78	78	78	78	78	78
3	78	78	78	78	79	78	78	78	78	78	78	78
4	78	78	78	78	79	78	78	78	78	78	78	78
5	78	78	78	78	79	78	78	78	78	78	78	78
6	78	78	78	78	79	78	78	78	78	78	78	78
7	78	78	78	77	71	68	71	76	78	78	78	78
8	60	60	53	47	42	40	42	46	46	51	59	60
9	50	43	34	33	31	30	31	33	26	27	38	48
10	28	21	18	32	33	33	31	30	15	12	19	27
11	18	14	23	60	59	60	60	60	37	18	18	20
12	27	26	34	60	59	60	60	60	33	22	24	28
13	24	23	32	60	60	60	60	60	32	21	23	26
14	51	60	60	60	60	60	60	60	60	41	42	46
15	36	33	29	29	31	35	35	29	25	28	33	36
16	37	30	24	21	20	20	20	20	24	33	40	41
17	48	41	37	32	27	25	25	29	37	45	51	52
18	60	49	45	44	32	28	30	41	47	60	60	60
19	78	78	78	74	64	59	60	69	78	79	78	78
20	78	78	78	79	78	78	78	78	78	79	78	78
21	78	78	78	78	78	78	78	78	78	78	78	78
22	78	78	78	78	78	78	78	78	78	78	78	78
23	78	78	78	78	78	78	78	78	78	78	78	78
24	78	78	78	78	78	78	78	78	78	78	78	78

78 Thermostat Setpoint

68 Natural Ventilation Low

82 Natural Ventilation High

0.125 Nat Vent Air Changes

South Window

Area	375
Glass SC	0.6
U-Value	0.4
WWR	0.5

East Window

Area	375
Glass SC	0.6
U-Value	0.4
WWR	0.5

West Window

Area	375
Glass SC	0.6
U-Value	0.4
WWR	0.5

North Window

Area	375
Glass SC	0.6
U-Value	0.4
WWR	0.5

0 Hot

75 Medium

200 Cold

SOUTH WINDOW SECTION

Tand = 1E+08
d= 2
Profile Angle d= 90
1.570796

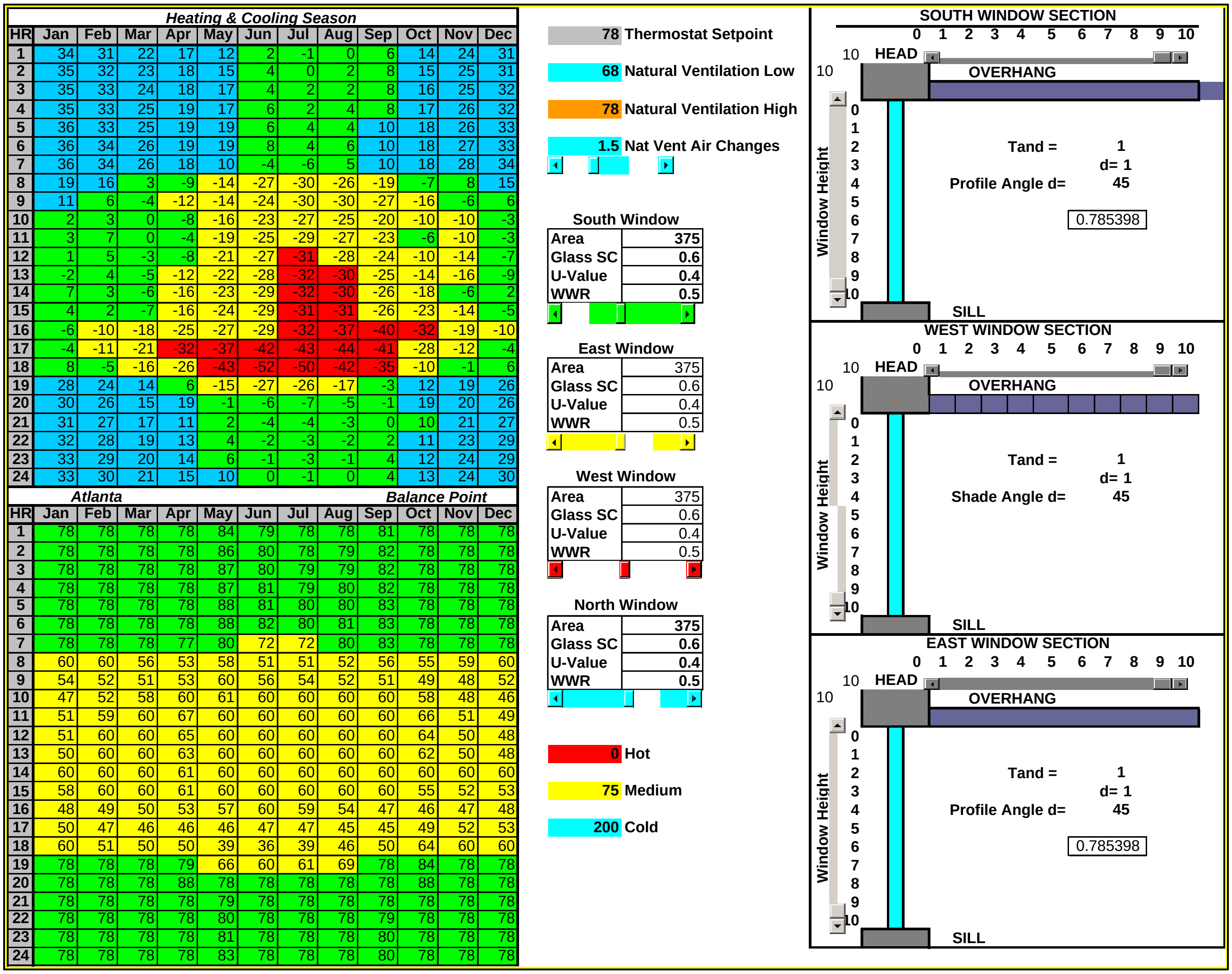
WEST WINDOW SECTION

Tand = 1E+08
d= 2
Shade Angle d= 90

EAST WINDOW SECTION

Tand = 1E+08
d= 2
Profile Angle d= 90
1.570796

Fig.7: Test building in Atlanta without shades and no natural ventilation.



Heating & Cooling Season

HR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	34	31	22	17	12	2	-1	0	6	14	24	31
2	35	32	23	18	15	4	0	2	8	15	25	31
3	35	33	24	18	17	4	2	2	8	16	25	32
4	35	33	25	19	17	6	2	4	8	17	26	32
5	36	33	25	19	19	6	4	4	10	18	26	33
6	36	34	26	19	19	8	4	6	10	18	27	33
7	36	34	26	18	10	-4	-6	5	10	18	28	34
8	19	16	3	-9	-14	-27	-30	-26	-19	-7	8	15
9	11	6	-4	-12	-14	-24	-30	-30	-27	-16	-6	6
10	2	3	0	-8	-16	-23	-27	-25	-20	-10	-10	-3
11	3	7	0	-4	-19	-25	-29	-27	-23	-6	-10	-3
12	1	5	-3	-8	-21	-27	-31	-28	-24	-10	-14	-7
13	-2	4	-5	-12	-22	-28	-32	-30	-25	-14	-16	-9
14	7	3	-6	-16	-23	-29	-32	-30	-26	-18	-6	2
15	4	2	-7	-16	-24	-29	-31	-31	-26	-23	-14	-5
16	-6	-10	-18	-25	-27	-29	-32	-37	-40	-32	-19	-10
17	-4	-11	-21	-32	-37	-42	-43	-44	-41	-28	-12	-4
18	8	-5	-16	-26	-43	-52	-50	-42	-35	-10	-1	6
19	28	24	14	6	-15	-27	-26	-17	-3	12	19	26
20	30	26	15	19	-1	-6	-7	-5	-1	19	20	26
21	31	27	17	11	2	-4	-4	-3	0	10	21	27
22	32	28	19	13	4	-2	-3	-2	2	11	23	29
23	33	29	20	14	6	-1	-3	-1	4	12	24	29
24	33	30	21	15	10	0	-1	0	4	13	24	30

Atlanta *Balance Point*

HR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	78	78	78	78	84	79	78	78	81	78	78	78
2	78	78	78	78	86	80	78	79	82	78	78	78
3	78	78	78	78	87	80	79	79	82	78	78	78
4	78	78	78	78	87	81	79	80	82	78	78	78
5	78	78	78	78	88	81	80	80	83	78	78	78
6	78	78	78	78	88	82	80	81	83	78	78	78
7	78	78	78	77	80	72	72	80	83	78	78	78
8	60	60	56	53	58	51	51	52	56	55	59	60
9	54	52	51	53	60	56	54	52	51	49	48	52
10	47	52	58	60	61	60	60	60	60	58	48	46
11	51	59	60	67	60	60	60	60	60	66	51	49
12	51	60	60	65	60	60	60	60	60	64	50	48
13	50	60	60	63	60	60	60	60	60	62	50	48
14	60	60	60	61	60	60	60	60	60	60	60	60
15	58	60	60	61	60	60	60	60	60	55	52	53
16	48	49	50	53	57	60	59	54	47	46	47	48
17	50	47	46	46	46	47	47	45	45	49	52	53
18	60	51	50	50	39	36	39	46	50	64	60	60
19	78	78	78	79	66	60	61	69	78	84	78	78
20	78	78	78	88	78	78	78	78	78	88	78	78
21	78	78	78	78	79	78	78	78	78	78	78	78
22	78	78	78	78	80	78	78	78	79	78	78	78
23	78	78	78	78	81	78	78	78	80	78	78	78
24	78	78	78	78	83	78	78	78	80	78	78	78

78 Thermostat Setpoint

68 Natural Ventilation Low

78 Natural Ventilation High

1.5 Nat Vent Air Changes

South Window

Area	375
Glass SC	0.6
U-Value	0.4
WWR	0.5

East Window

Area	375
Glass SC	0.6
U-Value	0.4
WWR	0.5

West Window

Area	375
Glass SC	0.6
U-Value	0.4
WWR	0.5

North Window

Area	375
Glass SC	0.6
U-Value	0.4
WWR	0.5

0 Hot

75 Medium

200 Cold

SOUTH WINDOW SECTION

Tand = 1
d= 1
Profile Angle d= 45
0.785398

WEST WINDOW SECTION

Tand = 1
d= 1
Shade Angle d= 45

EAST WINDOW SECTION

Tand = 1
d= 1
Profile Angle d= 45
0.785398

Fig.8: Test building in Atlanta with shades and natural ventilation.