IMPACT OF ADVANCED ENERGY RECOVERY SYSTEM ON LIGHT COMMERCIAL BUILDING

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ABSTRACT

Commercial buildings such as educational and commercial offices require large amounts of fresh air to maintain the indoor air quality as required by the building codes. This raises the energy costs of the buildings, especially when the number of occupants are large. In order to reduce the energy costs, traditionally, energy is recovered from the outgoing exhaust air to the incoming fresh air by use of various energy recovery technologies. The proposed advanced energy recovery system consists of desiccant, and heat wheels along with an indirect evaporative cooler (M-cycle). When this system is integrated into the air-conditioning system of the building it has a potential to significantly reduce the energy costs, and pave the way for use of PV/T panels to make the building a zero energy building.

ACKNOWLEDGMENTS

I am grateful for the tremendous support I received during my pursuit of a master's degree in engineering from all the professors involved. I also want to specifically thank my thesis advisor, Dr. Prakash Dhamshala, for his support and for the tools he developed to make the results of this thesis possible. I would also like to thank the committee members Dr. Charles Margraves and Dr. Reetesh Ranjan for their feedback and suggestions to improve the thesis for its final submission to the University of Tennessee at Chattanooga. I would also like to thank my mother for all of her support through the process of obtaining my graduate degree. Without her support this would not have been possible.

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LIST OF ABBREVIATIONS

A/C, Air-Conditioning

ASHRAE, American Society of Heating, Refrigerating, and Air-Conditioning Engineers

COP, Coefficient of Performance

EIA, Energy Information Administration

H1, Heater 1

H2, Heater 2

IEC, Indirect Evaporative Cooler

IECC, International Energy Conservation Code

MB, Mixing Box

M-Cycle, Maisotenko Cycle

MDWS, Model of Desiccant Wheel System

OA, Outside Air

PCL, Peak Cooling Load

PHL, Peak Heating Load

PVT, Photovoltaic Thermal Hybrid

RC, Room Conditions

SA, Supply Air

SHR, Sensible Heat Ratio

TABLER, Transient Analysis of Building Loads and Energy Requirements

TMY, Typical Meteorological Year

LIST OF SYMBOLS

h, Enthalpy (kJ/kg or Btu/lb)

ṁ, Mass Flow Rate (kg/s or lb/min)

Q, Heat/Energy Rate (kW or Btu/hr or tons)

RH, Relative Humidity (%)

SHR, Sensible Heat Ratio

T, Temperature (°C or °F)

V, Volumetric Flow Rate (L/s or ft^3/min)

ε, Effectiveness

ν, Specific Volume (m^3/kg or ft^3/lb)

φ, Relative Humidity (%)

ω, Humidity Ratio (kg water vapor/kg dry air)

CHAPTER 1: INTRODUCTION

1.1. Background

In 2014 an Icelandic glaciologist named Oddur Sigurdsson pronounced the glacier Okjokull officially dead. This means the glacier is no longer thick enough to move. Okjokull is the first Icelandic glacier to officially lose its status as a glacier. In August of 2019 a plaque was placed on the site of the former glacier, which is located northeast of Reykjavik, to commemorate the loss of its status as a glacier. The dedication includes to following text:

"A Letter to the Future

Ok is the first Icelandic glacier to lose its status as a glacier. In the next 200 years all our glaciers are expected to follow the same path. This monument is to acknowledge that we know what is happening and what needs to be done. Only you know if we did it."

At the end of the dedication the concentration of carbon dioxide in the air globally at the time of the dedication is included (415 ppm CO_2) [1]. This event serves as a reminder to what may be one of the greatest challenges we face in our immediate future and will have a lasting impact on future generations. Since the mid 1960's global temperatures have been steadily increasing at a rate of 0.0135°C and has been most commonly called global warming (or climate change) [2]. The increase in temperature is attributed by the majority of the global scientific community to the increased emissions of greenhouse gases (like carbon dioxide). Increasing the amount of these gases in the atmosphere begins to make our planet behave like their namesake, a greenhouse. Greenhouse gases prevent heat loss from the planet into space by trapping heat energy released from the Earth in the atmosphere. This raises the temperature of the planet by radiating heat back to the surface. This causes a myriad of problems from the melting of glaciers and the polar ice caps to increases in severe weather (droughts, hurricanes, tornados, etc.) due to unusual weather patterns. In 2016 more than 180 countries signed the Paris Agreement to help mitigate some of the concerning issues surrounding global warming. This agreement is a long-term commitment to limiting the increase in global temperature to 1.5°C to help reduce the risks and impacts on the planet attributed to global warming [3]. One way to help combat the effects of climate change includes developing new technologies to remove greenhouse gases from the atmosphere, finding ways to reduce our current emissions, and finding better alternatives to our industries that generate greenhouse emissions (such as industrial and power industries).

1.2. Commercial Energy Consumption

Since the 1970's the United States has seen a steady rise in end use electricity consumption [4]. End use electricity includes any source that is directly used by the end user such as heating, lighting, computers, and more. Figure 1 shows the increase in consumption over past decades in billions of kilowatt hours.

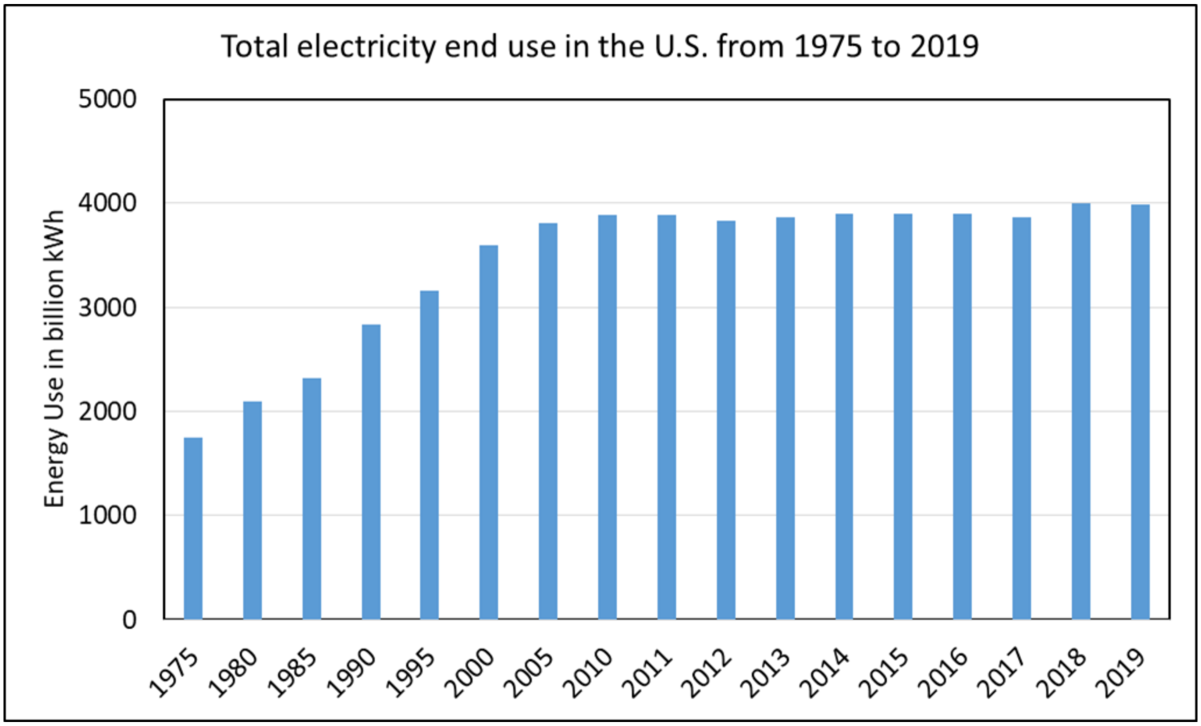

Figure 1 Total End Use Electricity Consumption in the U.S. [4]

While the use of electricity has been rather steady throughout the most recent years, it is still expected to rise over future decades. The largest consumers of electricity are commercial and residential sectors [4]. Heating and cooling account for a large portion of each of the previous sectors consumption [5].

1.3. Peak Cooling & Heating Loads

Before determining the size of a heating system, the heat that must be extracted or added (load) must be determined first. The load will vary based on a number of factors such as building size, desired room conditions, ambient (outdoor) conditions, number or occupants, and equipment in use to name a few. Some of these factors will have fixed values (such as building size), while some of these factors, like the ambient conditions, will vary not just daily, but from hour to hour. For this reason determining the largest load placed on the system is required. The largest load occurs typically at two different times in the year. The maximum load associated with heating is called the peak heating load (PHL). The maximum load associated with cooling is the peak cooling load (PCL). By designing a system to these two conditions, the system will be able to handle all other conditions encountered throughout the typical year.

To determine the ambient conditions for a given location the typical meteorological year (TMY) dataset is used. This dataset uses the hourly ambient data for a range of years to determine what the typical values for a given hour would be. The TMY dataset is currently on its third iteration (TMY3) and aggregates the data from more than 1000 weather stations spanning from 1976 through 2005. This dataset is maintained by the National Renewable Energy Laboratory and is openly available to the public.

1.4. Thesis Objectives

The objective of this thesis is to show that a system utilizing advanced energy recovery technologies can be employed to satisfy the cooling and heating requirements for a small commercial building. The individual technologies employed will be reviewed and the proposed system comprised of these will be presented. Using this system design, a model of the heating and cooling operation for the peak load conditions is developed. The model and results will be discussed in detail for the city of Chattanooga, TN. Other selected locations have also been analyzed and will be presented in the appendices of this thesis. A simple cost analysis for this system will also be reviewed to further demonstrate the benefits of the advanced recovery system.

CHAPTER 2: LITERATURE REVIEW & THEORY

2.1. Indirect Evaporative Cooling

Evaporative cooling is based on a simple principle, as water evaporates the latent heat of vaporization is absorbed from the surrounding air and the water source resulting in a cooling of the water and air. This is a concept that has existed as far back in time as the ancient Egyptians. Conventional cooling systems operate using a refrigeration cycle, but require higher operation and initial costs. Evaporative cooling systems have begun gaining traction as a viable option for modern air-conditioning systems due to their simplistic structure and use of water evaporation as a means of heat absorption. The downside to using a direct evaporative process is that the air and water source are in direct contact. This results in the evaporated water being combined with the air to create a more humid environment. This can lead to discomfort in the conditioned areas that the system services. This issue has led to a newer design to this process called Indirect Evaporative Cooling (IEC). In IEC the air and the water source are kept separated through the use of a heat exchanger. During operation there are two different areas, a wet-side and a dry side of the heat exchanger plates. A simple example is shown in Figure 2.

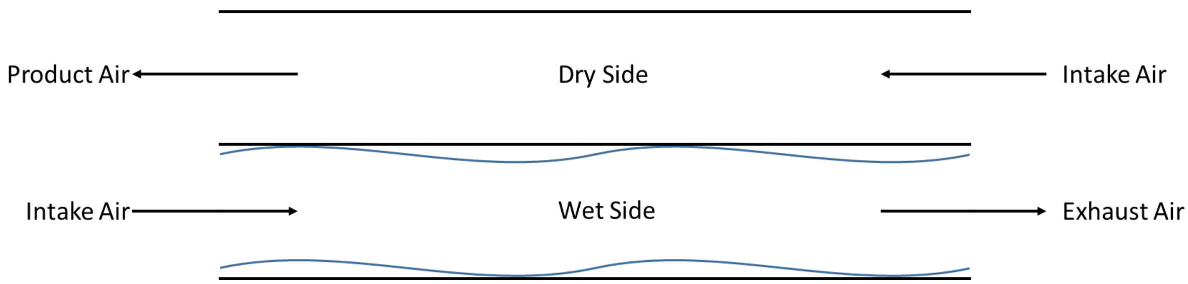

Figure 2 Example of Indirect Evaporative Cooling

The air that is to be cooled (product air) passes over the dry side of the plates, and the secondary (exhaust) air is passed over the wet side. The wet side air stream absorbs heat from the product stream by water evaporation. This cools the dry side air while the latent heat of the vaporized water is transferred to the wet side air stream. This provides cooling to the dry air without the addition of moisture from the evaporation from the wet-side plates. This cooler air can now be supplied to the space that requires air-conditioning. This setup can yield a coefficient of performance (COP) of 15 or higher [6]. This is much higher than the COPs yielded through vapor compression cycles (2 to 3) or absorption systems (0.4 to 1.2) [6]. Another benefit to this type of system is that the working fluid is water as opposed to some version of refrigerant. The one major limitation to this system is that it directly relies on the ambient conditions. Specifically, the temperature difference between the dry-bulb and wet-bulb temperatures directly drives the IEC system.

2.2. M-Cycle Indirect Evaporative Cooling (IEC) System

To overcome the limitations of the Indirect Evaporative Cooling (IEC) system, Dr. Valeriy Maisotenko proposed a new approach to the heat exchanger operation that would become known as the Maisotenko Cycle (or M-Cycle). Through the use of a flat plate perforated heat exchanger in a counter-flow configuration, the M-Cycle gains extra usable energy from the ambient air conditions. The M-Cycle allows for the supplied air to be cooled to the dew point temperature as opposed to the wet bulb temperature without adding moisture content. The heat exchanger setup differs from traditional IEC systems by using the working intake air for cooling and saturation and then cooling the dry air. Figure 3 shows a simple schematic of the M-Cycle cooler. The incoming air (State 1) is initially brought into the dry channels and cooled due to the temperature difference between the dry and wet sides of the exchanger plate. Part of the air stream is diverted through the perforated holes into the wet channels. The air flowing through the wet channel removes the evaporated water from the wet plate surface and receives the sensible heat transfer across the plate. This hot and saturated air is then exhausted from the M-Cycle cooler to the ambient conditions. The air flowing across the dry side of the plate (State 1 to State 2) is cooled close to the dew point temperature.

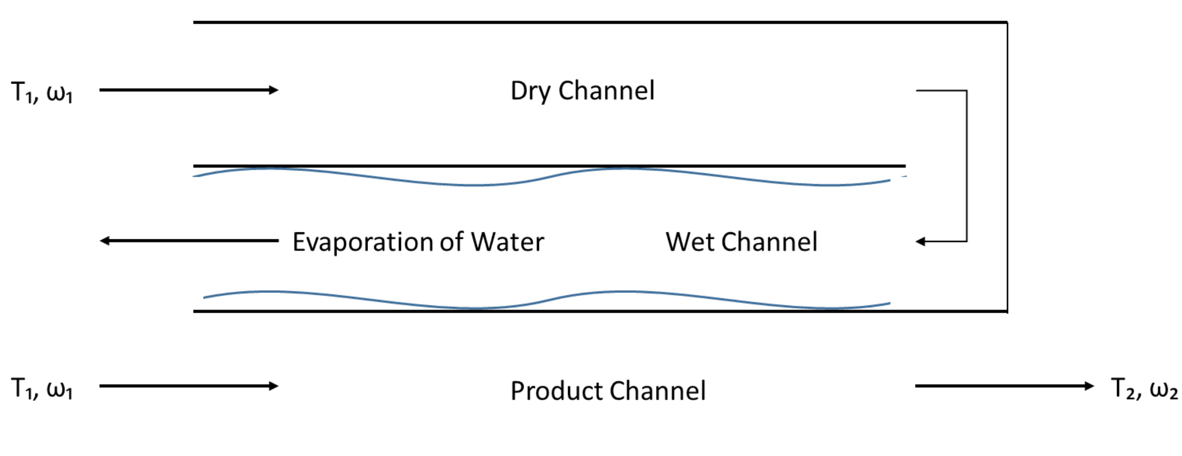

Figure 3 Indirect Evaporative Cooler (M-Cycle) Configuration

The performance of the M-Cycle can be characterized by using the following equations for wet-bulb effectiveness and dew-point effectiveness.

$$\text{Wet-Bulb Effectiveness}, \varepsilon_{WB} = \frac{T_1 - T_2}{T_1 - T_{WB,1}} \qquad (1)$$

$$\text{Dew-Point Effectiveness}, \varepsilon_{DP} = \frac{T_1 - T_2}{T_1 - T_{DP,1}} \qquad (2)$$

The typical range for the wet-bulb effectiveness is 92-114% with a reasonable average assumption of 105% [7]. The typical range for the dew-point effectiveness is 58-84% with a reasonable average assumption of 72% [7].

2.3. Rotary Air-To-Air Energy Wheels

A rotary air-to-air energy exchanger, or enthalpy wheel, has a rotating cylinder filled with an air-permeable medium with large internal surface area. The two air streams flow through half of the exchanger in a counter-flow orientation (Figure 4). The material used for heat transfer can be chosen to only recover sensible heat or both sensible and latent heat.

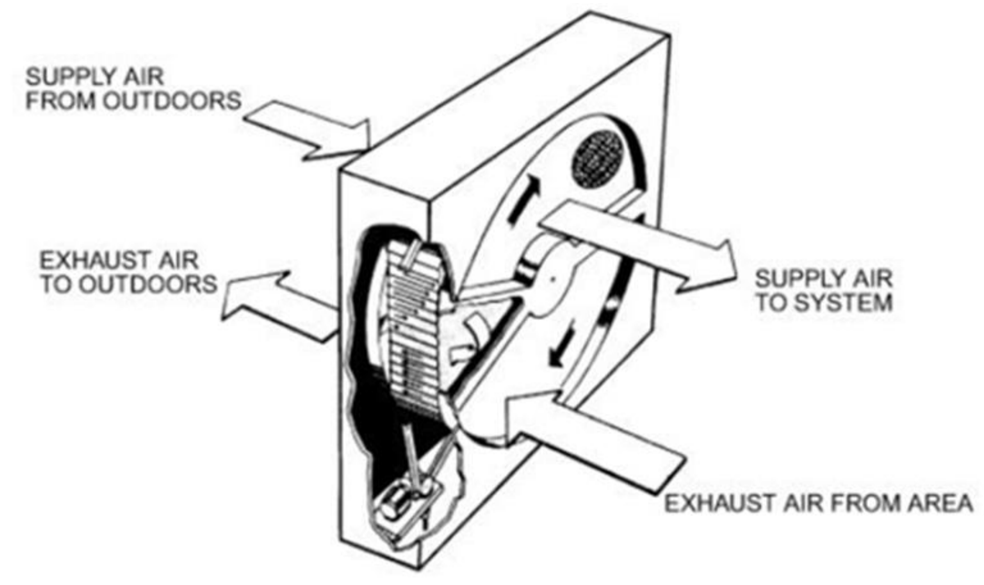

Figure 4 Rotary Air-To-Air Heat Exchanger [8]

For sensible only heat transfer, the medium picks up and stores heat from the hot air stream and releases it to the cold stream. Latent heat transfer occurs when a medium is selected and treated with a desiccant that can absorb water vapor from the stream with the higher humidity and desorbs it to the lower humidity air stream. The moist air is dried, while the drier air stream is humidified. These types of exchangers are compact and can achieve a high transfer effectiveness. Typical desiccant treatment include zeolites, molecular sieves, silica gels, activated alumina, titanium silicate, synthetic polymers, lithium chloride, or aluminum oxide and are chosen by their specific moisture recovery properties. Leakage between the two air streams can occur primarily by either carryover or seal leakage. This can be mitigated to some extent by including a purge section or by placing blowers so that they promote leakage from the outdoor air to the exhaust stream. Carryover cannot be completely eliminated in these exchangers, but can be greatly reduced by using a purge section. Due to this, applications that require strict control over carryover such as hospitals, laboratories, and clean rooms may not be ideal. For most other applications recirculating some air is not typically a large concern. Rotary wheel exchangers require little maintenance and are self-cleaning due to the reversal of airflows in each rotation.

2.3.1. Heat Wheels

A thermal wheel, or heat wheel, is a device that exchanges energy between two streams of air. A heat wheel typically consists of a matrix of heat absorbing material that slowly rotates between the exhaust and supply air streams. As the wheel rotates, heat is captured from the exhaust air stream and releases to the supply air stream. For the application of this thesis the heat wheel to be used is intended to recover temperature only. The heat wheel employed is considered to be sensible meaning the moisture content of each stream is unchanged. A diagram of heat wheels for summer and winter operation are shown in Figure 5.

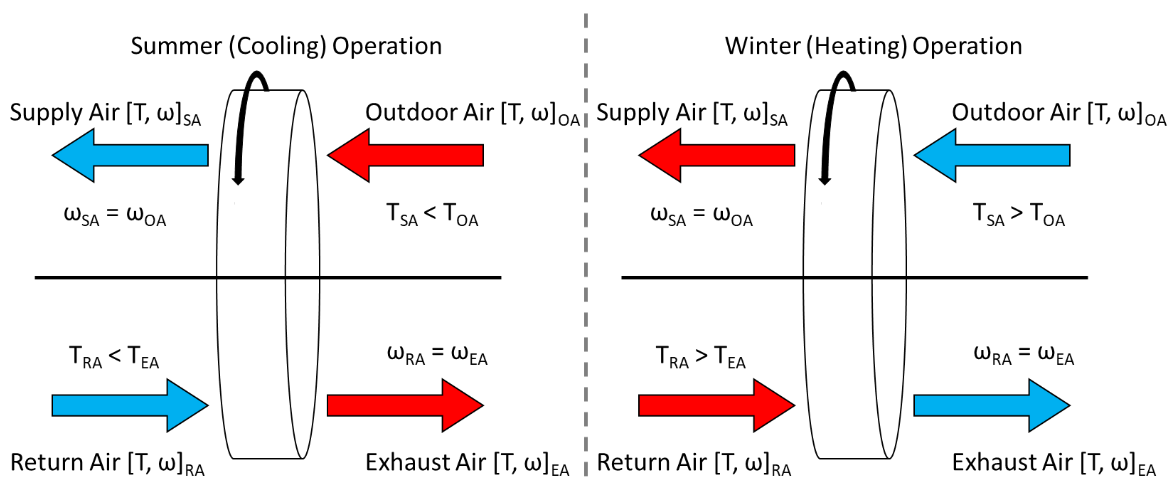

Figure 5 Sensible Heat Wheel

A heat wheel is only used to exchange heat energy (temperature) and is proportional to the temperature gradient across each side. For summer operation, the temperature of the supply air is decreased, while the exhaust air temperature increases. During winter operation the supply air temperature is increased, while the exhaust air temperature decreases. Energy wheels also have the ability to adjust rotational speed via a variable speed motor. The ability to adjust the rotational speed of the wheel also allows for more control over the heat transfer that occurs. Heat wheels have two main advantages over a flat plate exchanger. The first being that heat wheels are very compact for large volumetric flow rates. The second is that heat wheels have higher efficiencies (65-80%) than flat plate exchangers (50-75%) [8].

2.3.2. Desiccant Wheels

A desiccant is a substance that is used to remove moisture in whatever application it is used. One of the most common encounters of a desiccant would be the little packages of silica gel found in retail shoe boxes. These little porous packages contain beads of silica gel which are employed to absorb humidity from the product (in this example the pair of shoes). A desiccant wheel aims to do the same job on a larger scale by removing moisture from an air stream as it passes through. For air-conditioning systems, a rotary desiccant wheel system is employed. A desiccant wheel is very similar in composition to a heat wheel with one key difference. The matrix that is in contact with the air streams is coated with an agent with the sole purpose of dehumidifying one of the air streams. The air stream that requires dehumidification enters the desiccant wheel, where the moisture is removed via the desiccant material by the sorption process. The dehumidified air then exits the wheel hot and dry. The other stream that is going being humidified by the desiccant wheel is also preheated prior to entering the wheel to increase the amount of moisture that is transferred. The air that is to be dried is passed through the rotating wheel where the desiccant material will adsorb moisture from the stream. The desiccant then passes through the regeneration stream where the higher temperature air stream adds enough energy to the stored water molecules to overcome the chemical attraction between them and the desiccant. This is a temperature driven process and by using a preheater for the regeneration stream, the amount of moisture that can be removed is increased. An example of this system can be seen in Figure 6 where the upper stream is the regenerating stream that is preheated and the lower stream is the process air that is going to have its moisture content reduced. It should be noted that for summer (cooling) operation, the process stream will begin with the outdoor conditions. The stream returning from the conditioned space is the regeneration stream. For winter operation, this process is reversed. The outdoor air will enter the system cold and dry and need to be humidified before ultimately being supplied to the conditioned space.

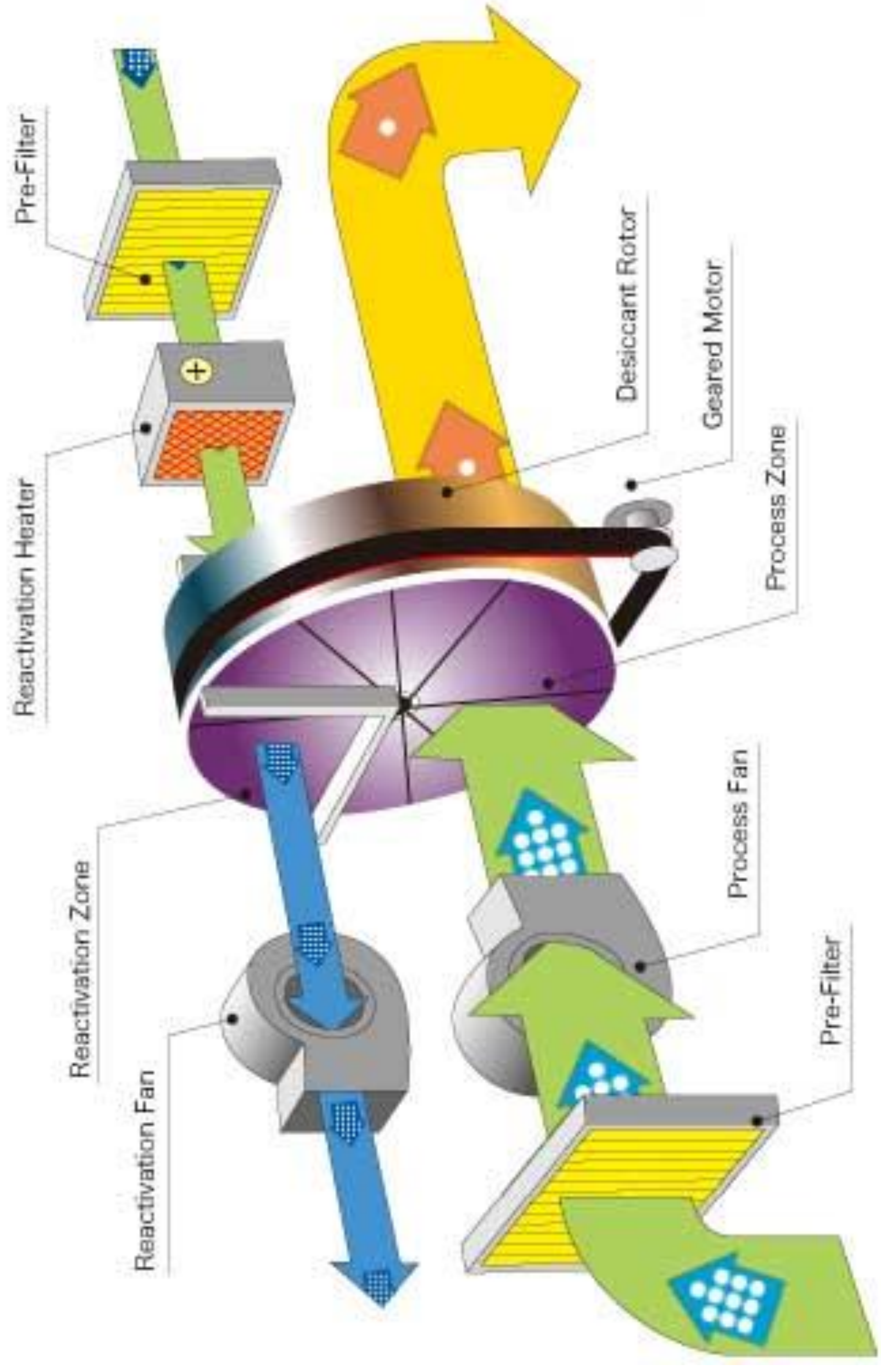

Figure 6 Example of Desiccant Wheel Operation [9]

CHAPTER 3: DESIGN CRITERIA

3.1. Analysis Locations

The system proposed by this thesis is to be analyzed for various cities that represent different climate zones (Figure 7) in the continental United States as given by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).

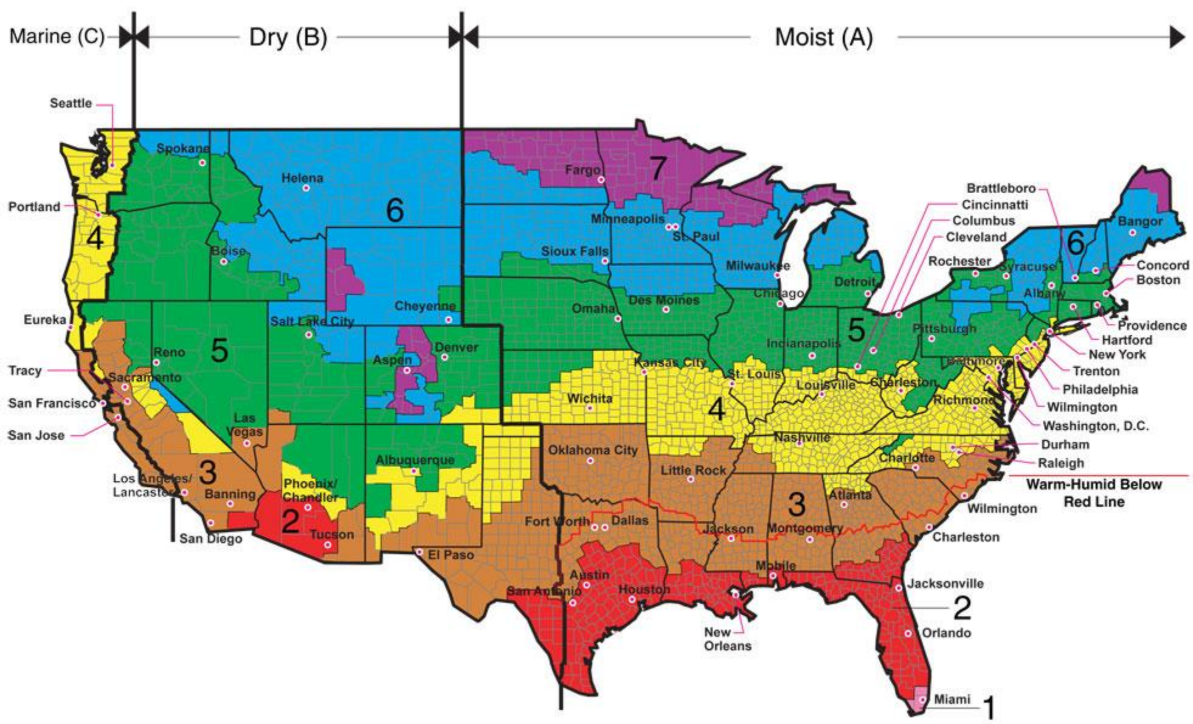

Figure 7 ASHRAE/IECC Climate Zone Map [10]

The cities selected (see Table 1) to represent each zone were chosen to ensure that the weather data was available to find the design day loads via the Transient Analysis of Building Loads and Energy Requirements (TABLER) program. The chosen cities represent areas with significant populations (>100,000) that would potentially benefit the most from the proposed advanced recovery system and have reliable weather data available.

Table 1 Cities representing ASHRAE zones

Zone	Represented Cities		
Zone 1	Miami, FL		
Zone 2	Houston, TX	Phoenix, AZ	
Zone 3	Abilene, TX		
Zone 4	Chattanooga, TN	New York City, NY	
Zone 5	Chicago, IL		

Zone 2 has two locations selected to cover the moist and dry sections of the ASHRAE map (Figure 7). Phoenix, AZ was selected to determine the benefits of using this system in a zone where the outdoor moisture content will be significantly lower for the summer load. New York City, NY represents zone 4, but also sits very close to the boundary for zone 5. Chattanooga, TN is the sample case from Dr. Dhamshala’s initial analysis of this system and is included as a benchmark case.

3.2. Weather Profile

The hourly building loads for the design day (heating or cooling) are given in the TABLER data sheet (Figure 10). These data sheets display the design conditions of the building space and give the hourly data for the peak cooling and heating days. Using the specified data at the hour of the peak load, the maximum load on the system can be determined. The reason for applying the system to the peak cooling and heating load is that the greatest load on the system occurs at these dates and times. Any other date and time should fall below the max loads and can easily be handled by a system designed with respect for them. For example the heating and cooling loads for the design days for Chattanooga, TN are shown in Figure 8 and Figure 9. These figures include the hourly ambient temperature (A. Temp), relative humidity (R. Hum), setback temperature (S. Temp), and the space load (Sp. Load). These values are plotted for the date where the peak loads occur according to the TABLER data sheets. These figures show how the space load changes in relation to the ambient conditions (temperature and relative humidity) during the 24-hour period.

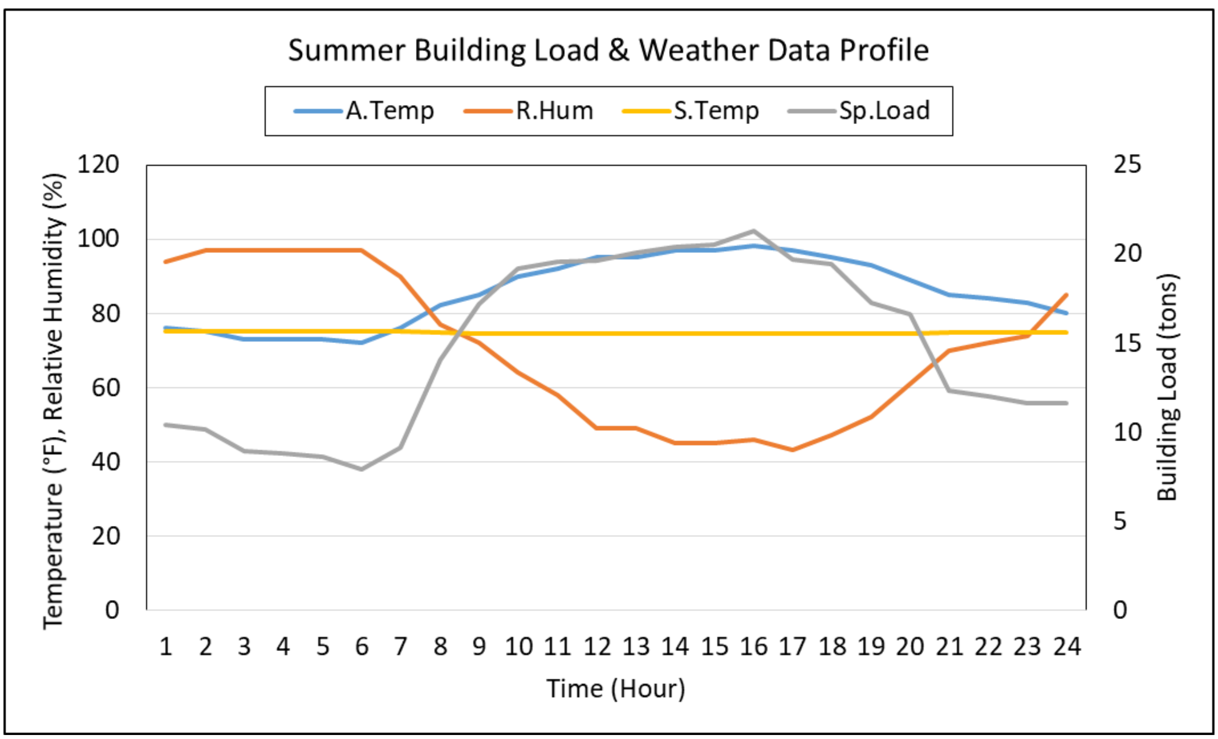

Figure 8 Summer Building Load & Weather Profile

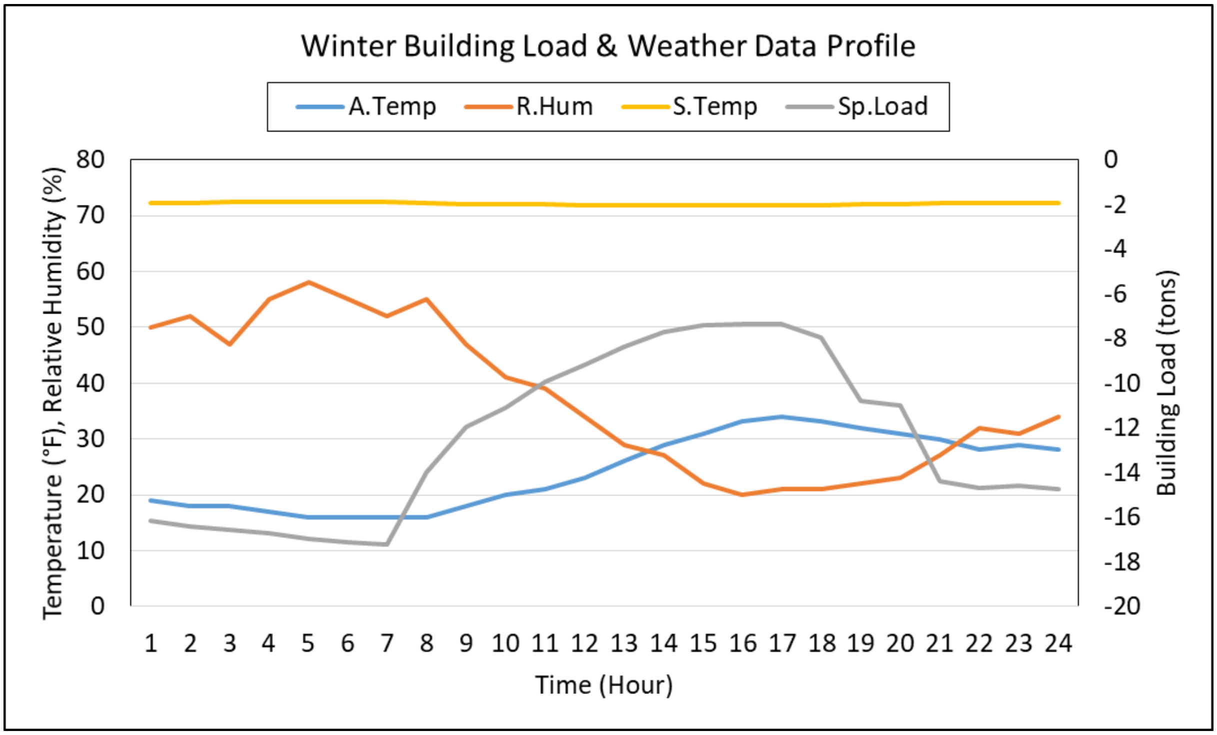

Figure 9 Winter Building Load & Weather Profile

The TABLER sheet also provides information regarding the economic impact of the design day load conditions. The utility cost analysis is generated for each month of the year based on the inputs to the program. The TABLER program computes cost analysis based on the entire years' worth of data from the TMY3 dataset. One thing to note about the TABLER data sheet seen below is that the relative humidity is not included. This value will be retrieved from the TMY3 dataset for each city as needed to establish the state properties for the outdoor air conditions. The TABLER data sheets for the other selected locations are located in APPENDIX A. The example TABLER sheet shown in Figure 10 can be broken up into three sections. The top section includes information relevant to the building load. This includes the input parameters for the TABLER program that include the building dimensions, heat transfer factors, number of expected occupants, infiltration requirements, and electrical loads due to equipment and lighting. All of these items factor into the calculated building loads the program outputs. The second section, in the middle of the table, is the hourly load conditions for the peak heating and cooling loads. Also given here is the total load and latent load at the peak conditions. The lower part of the TABLER sheet includes a monthly utility cost analysis based on the various inputs for electrical loads, heating, and cooling. This is based on the price of electricity that is given in the top portion of the data sheet.

CHATTANOOGA TN 35 2 85 12 75

Time 5:03:23 PM Date: 11/1/2019

(TABLER)Transient Analysis of Building Loads and Energy Requirements Zone:1

Envelop	Roof	East Wall	South Wall	West Wall	North Wall	Floor	NE Wall	SE Wall	SW Wall	NW Wall
Area(ft^2):	6400	800	600	800	600	6400	0	0	0	0
Glass Area (ft^2):	0	0	200	0	200	0	0	0	0	0
U-Factor(Btu/hr ft^2.F):	0.055	0.251	0.251	0.251	0.251	0.08				
Type:	5	13	13	13	13	6				

No of Occupants (day) = 100 (night) = 0 (holidays) = 0

Renw System:1 Mode:1 Life(yrs): Util P.Fac:2 Cap Cost:2.7 Payback =

Equip Elc Load, kW (day) = 6 (night) = 0 (holidays) = 0

No hrs/yr: Heat Eqpmt on: 0 Cool Eqpmt on: 0 Eqpmt Off: 0

Elec. Lights,W/ft^2 = 0.5 (night) = 0.1 (holidays) = 0.1

DCV System Off Zc = Energy Recovery System: Off Sen.Eff: 0.85 Lat.Eff: 0.85

Infiltration,fraction of ACH = 0.15 Ventilation,cfm/person = 15

Hot Water Cons.gal/person/day = 2 U-of Glass(Btu/hr.ft^2.F) = 0.8

S.C. of Glass = 0.85 Elec Power Cost,cents/kWh = 12

Gas Fuel Cost, cents/therm = 90 Economiser: OFF Elec kW limit: 20 kW cost: 10

Wint:Therm set = 72 F N. Setback = 72 F Throtl Range = F

Sum: Thrm set = 75 F N.Setback = 75 F Throtl Range = F

Pk H/lat.Load,tons = -17.23/4.7 in Month = 12 on Day = 20 at hr = 7

: Peak C/maxll, tons = 21.29/7.9 in month = 6 on Day = 28 at hr = 16

Approx Recommended Cap of Heating Equipment, tons = 22

: Approx Recommended Cap of Heating Equipment, tons = 26

On Peak Heating Day:

Time hr	A.Temp (deg F)	S.Load (Btu/hr)	H.Added (Btu/hr)	S.Flux (Btuh/sft)	S.Temp (deg F)
1	19.04	-193983	-189330.3	0	72.3
2	17.96	-196763	-192334.2	0	72.3
3	17.96	-198677	-194586.3	0	72.4
4	17.06	-200499	-195285.8	0	72.4
5	15.98	-203596	-197604.5	0	72.4
6	15.98	-205216	-198612.1	0	72.4
7	15.98	-206804	-199738.9	0	72.4
8	15.98	-167915	-157786	0	72.2
9	17.96	-143366	-131647	0	72.1
10	19.94	-133392	-121356	0	72
11	21.02	-119238	-107267	0	72
12	23	-110279	-97708	0	71.9
13	26.06	-100626	-88402	0	71.9
14	28.94	-92406	-79892	0	71.9
15	30.92	-88955	-75950	0	71.8
16	33.08	-88496	-74407	0	71.8
17	33.98	-88217	-77060	0	71.8
18	33.08	-95724	-85922	0	71.9
19	32	-129708	-121916	0	72
20	30.92	-132047	-124777	0	72
21	30.02	-172736	-168762	0	72.2
22	28.04	-176203	-172407	0	72.3
23	28.94	-175137	-169984	0	72.2
24	28.04	-176967	-172292	0	72.3

On Peak Cooling Day:

Time hr	A.Temp (deg F)	S.Load (Btu/hr)	Heat Extr (Btu/hr)	S.Flux (Btuh/sft)	S.Temp (deg F)
1	75.92	124942	123247	0	75
2	75.02	121975	120996	0	75
3	73.04	106888	105496	0	75
4	73.04	105229	103342	0	75
5	73.04	103599	101142	0	75.1
6	71.96	94832	92810	0	75.1
7	75.92	109232	108534	0	75
8	82.04	168935	171954	0	74.7
9	84.92	206424	210612	0	74.6
10	89.96	229771	235617	0	74.5
11	91.94	234600	240623	0	74.4
12	95	235652	240406	0	74.4
13	95	240794	244772	0	74.4
14	96.98	244446	247951	0	74.4
15	96.98	246032	249205	0	74.4
16	98.06	255502	259008	0	74.4
17	96.98	236299	238614	0	74.5
18	95	232800	235715	0	74.5
19	93.02	207225	208725	0	74.6
20	89.06	199071	200265	0	74.6
21	84.92	148153	145557	0	74.9
22	84.02	144176	142471	0	74.9
23	82.94	139546	138186	0	74.9
24	80.06	139636	138819	0	74.9

Utility Cost Analysis

	Jan	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**t.year**
ac:	0	0	0	463	951	1487	1776	1613	1228	536	0	0	8054
eqp:	151	144	158	151	158	151	151	166	137	166	151	137	1821
aux:	126	99	79	69	75	106	128	114	76	65	71	122	1130
lit:	122	113	125	120	125	120	122	128	114	128	120	116	1453
edmd:	0	0	0	178	182	203	201	194	186	171	0	0	1315
wat:	58	57	54	48	48	40	38	44	39	53	54	53	586
telc:	456	413	416	1030	1539	2107	2415	2258	1779	1119	396	427	14355
erht:	0	0	0	0	0	0	0	0	0	0	0	0	0
heat:	725	574	351	188	50	2	0	0	7	169	350	726	3142
cheat:	0	0	0	0	0	0	0	0	0	0	0	0	0
cexet:	0	0	0	0	0	0	0	0	0	0	0	0	0
RevRn:	0	0	0	0	0	0	0	0	0	0	0	0	0
tuty:	1181	987	767	1218	1589	2109	2415	2258	1786	1288	746	1153	17497

nhy1 = 3439 nhy2 = 735 nhy3 = 492 nhy4 = 4094

Pk kW Dem: 40.3 kWh. Conp/yr: 113325 kWh Cost/yr,$: 13043 therms/yr: 0 GasCost,$: 0 E.D.Cost,$/yr: 1315

Figure 10 TABLER Data Sheet for Chattanooga, TN

3.3. Building Profile

The building that will be considered for this thesis will be a light commercial building with 100 occupants. The building profile will also be consistent across all the cities that are considered. The TABLER data sheets include the areas and heat transfer coefficients (U-factors) for the walls, roof, and floor. The building will be maintained at 76°F (24.4°C) and 55% relative humidity during the summer and 72°F (22.2°C) and 50% relative humidity for the winter conditions. Other building characteristics are shown Table 2.

Table 2 Building Properties

Floor Area	6,400 - 10,000 ft^2
Walls	Face brick and 4 in h.w. concrete with 0.61 in insulation
Occupants	100
Lighting	0.5 W/ft^2
Equipment	6 kW
Ventilation	15 cfm/occupant

A consistent building profile is to ensure a reasonable comparison between cities. The analysis for Chattanooga was based on previous analysis done by Dr. Dhamshala and the area of that building was 6,400 square feet. The other cities analyzed for this thesis have a building floor area of 10,000 square feet. The building profile is loaded to the TABLER program developed by Dr. Prakash Dhamshala to give the hourly load profile for the date the peak cooling and heating loads occur. This data sheet is generated using the transfer function method which is outlined in detail in APPENDIX E. Due to the transient nature of ambient temperature and solar energy, the building load at any given hour is affected by the conditions of the previous hours as heat dissipates throughout the roof, walls, and floor of the building.

The transfer function method takes into account the thermal storage effect of the solar energy, occupants, lighting, and equipment in use. Using the properties of the building, the base case information can be obtained. The program outputs the building loads for a conventional heating and cooling system (Figure 11). We can then use this data to determine the effectiveness of the proposed systems for the same ambient conditions.

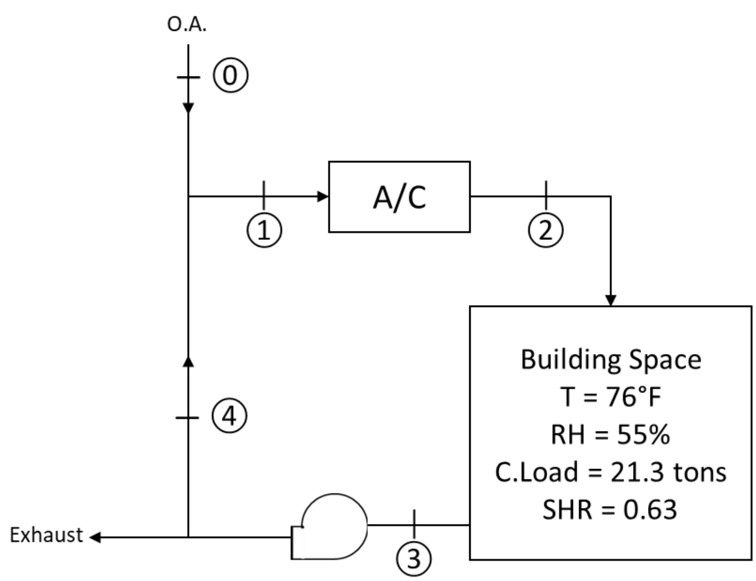

Figure 11 Typical Air Conditioning System

The proposed system will utilize a desiccant wheel and heat wheel system in the heating and cooling system. An indirect evaporative cooler (M-Cycle) will also be used for the cooling load setup. The goal is to determine the reduction of the heating and cooling loads, determine the yearly savings over a conventional system, and to determine the viability of this system for each location selected to represent the ASHRAE climate zones.

3.4. System Setup & Design

The system proposed in this thesis will combine the use of a heat wheel, desiccant wheel, and M-Cycle system (for cooling load). For the heating load scenario, the M-Cycle system will need to be able to be removed or bypassed as it is not needed. Figure 12 shows the proposed system for summer time operation. State 1 as shown in Figure 12 corresponds to the ambient conditions or outside air (OA) conditions. The temperature, T_1, and humidity ratio, ω_1, are dependent on the location and will vary from city to city. The mass flow rate, $\dot{m}_1$, is building specific and is based on the building air flow requirements and estimated peak load. The air enters the desiccant wheel at temperature T_1 and humidity ratio ω_1 while regenerated air from State 12 at temperature T_{12} and humidity ratio ω_{12} is supplied to dehumidify the OA. Heat energy is supplied via heater H to increase the temperature T_{12} to assist in dehumidifying the OA. The greater the value of T_{12}, the greater the amount of dehumidification that occurs with the OA in the desiccant wheel. Due to the rise in temperature after dehumidification that occurs between State 1 and State 2, the air stream is then passed through the heat wheel to reduce the temperature to State 3 (T_3). To reduce the temperature at State 3, a mixture of air is passed through the heat wheel from State 10. The air at State 10 is a mixture of the exhaust air from the building space (State 8) and air brought in from the outdoor conditions (State 9) through mixing box 1 (MB1) to balance the mass flow rate through the system. To further reduce the temperature of the supply air stream, an indirect evaporative cooler is employed between State 3 and State 4. The air at State 4 is then mixed with the return air (State 7) from the building space in mixing box 2 (MB2) so that the temperature and humidity ratio at State 5 is much lower than a conventional system. This results in a lower required cooling capacity for the air-conditioner (A/C).

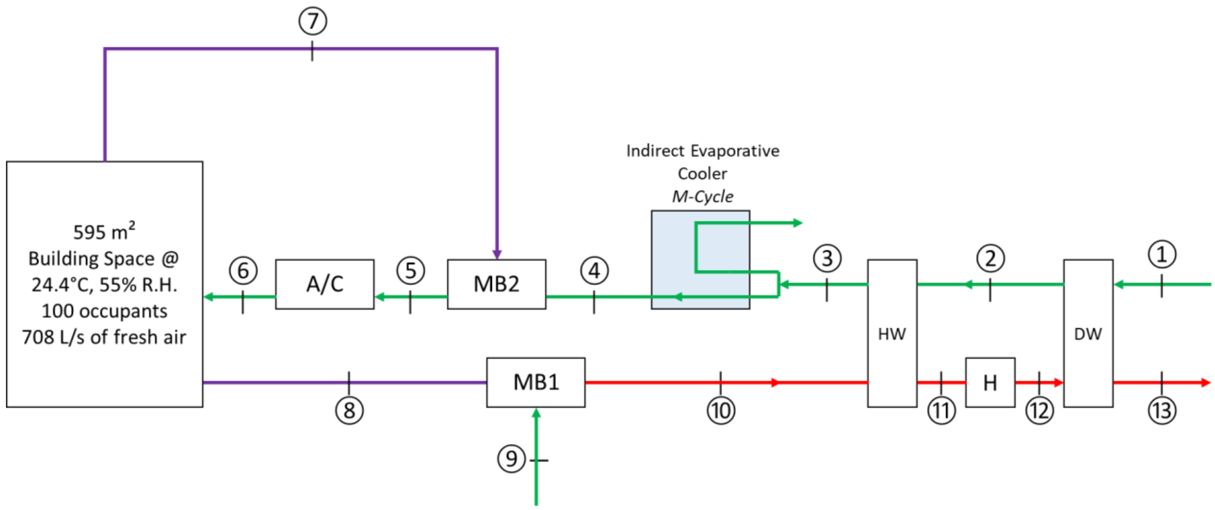

Figure 12 System Design for Summer Operation (Cooling Load)

Figure 13 shows the configuration used for the winter operation conditions. It should be noted that for the winter operation, the M-Cycle is bypassed as it is not needed to reduce the temperature in this system. State 0 is the outdoor air conditions (T_o, ω_o) based on the weather data for the location. Heat is supplied to the heater (H1) to the air leaving the heat wheel to raise its temperature to a suitable value (T_2) for regeneration via the desiccant wheel. Raising the temperature at State 2 to a suitable value helps with recovering moisture from the air entering the desiccant wheel at State 8. The air exiting the desiccant wheel (State 9) is used in the heat wheel to raise the temperature of the outside air (State 0) to reduce the required heat that must be supplied to the heater, H1. A humidifier is utilized to increase the humidity of the air at State 3. The water supplied to the humidifier at State 11 is much lower than what would be required by a conventional system due to humidification occurring through the desiccant wheel prior to reaching the humidifier. The humidified air at State 4 is then mixed with the return air from the building space at State 7 in the mixing box (MB). By recovering heat energy in the heat wheel and moisture in the desiccant wheel from the return air stream the amount of heat required by the second heater (Heat 2) in the system is lower than a conventional system.

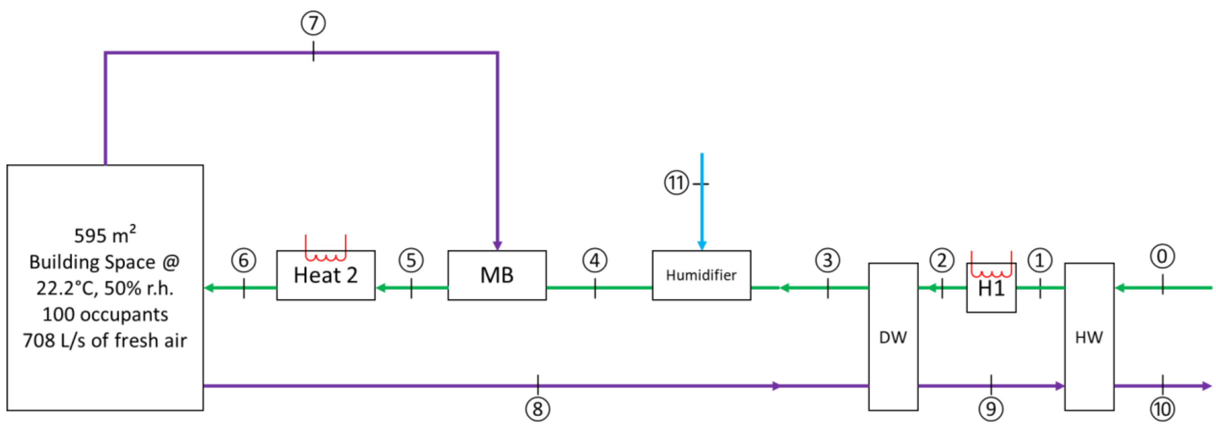

Figure 13 System Design for Winter Operation (Heating Load)

3.5. System Model

For the proposed system, two programs developed by Dr. Prakash Dhamshala are utilized for determining the output values for the heat wheel and desiccant wheel. The heat wheel program was developed utilizing the methods outlined by Yilmaz & Büyükalaca [11]. A second program, based on the methods from De Antonellis et al. [12], is employed to determine the exit conditions for the desiccant wheel. Figure 14 shows the interface for the Model of Desiccant Wheel System (MDWS) program that is used to model the performance of the desiccant wheel. The blue boxes are the user inputs. For this thesis the values for the process air velocity (2.12 m/s), wheel speed (15.5 rev/h), and velocity of regeneration air (2.34 m/s) will be constant for each location. Silica Gel will be the desiccant material used for each case.

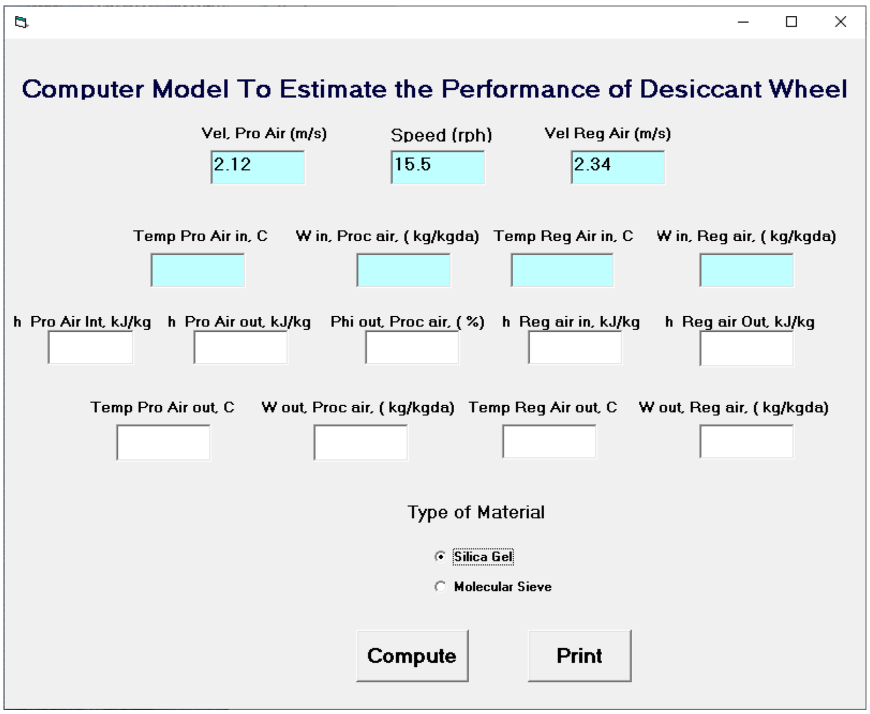

Figure 14 Program Interface for Desiccant Wheel Model

For the mixing boxes in the system we employ the following equation related to the diagram shown in Figure 15.

$$X_3 = X_1 + \frac{m_2}{m_1 + m_2}(X_2 - X_1) \tag{3}$$

Where X can be either the specific humidity (ω) or enthalpy (h). The temperature (T) may also be used in this equation is the difference in the two incoming air streams is not large. Utilizing these tools and the psychrometric chart, the relevant values for each state can be determined.

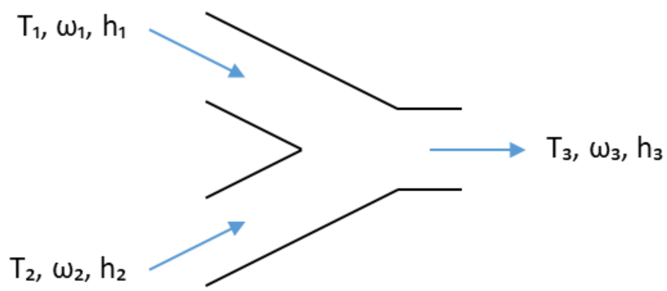

Figure 15 Air Mixing Diagram

There are also five set temperature values that will be consistent throughout the calculation process for each location. These values are summarized below in Table 3.

Table 3 Set Values for Cooling & Heating Load Calculations

Description	Parameter	Value	
Cooling Load (Summer Operation)			
Room Supply Air Temperature	T_6	61°F	16.1°C
Desiccant Wheel Regen. Air Temp.	T_{12}	178°F	81°C
Heating Load (Winter Operation)			
Room Supply Air Temperature	T_6	100°F	37.8°C
Desiccant Wheel Proc. Air Temp.	T_2	122°F	50°C
Humidifier Water Temperature	T_{11}	45°F	7.2°C

CHAPTER 4: MODEL RESULTS

4.1. Summer Operation (Cooling Load)

For this section, the results case for Chattanooga, TN will be used. Utilizing the psychrometric chart and ASHRAE psychrometric correlations the parameter values for humidity ratio (ω), relative humidity (ϕ), enthalpy (h), and specific volume (v) can be determined. It is important to note that all heaters in the system are assumed to be sensible (constant ω). The psychrometric parameters for state 1 and state 9 are the same (outdoor conditions) and the parameter values for state 7 and 8 are the same (room conditions). The required mass flow rate for this system is determined from the given required fresh air flow (V̶) and the specific volume (v) of the outdoor air. For the summer operation utilizing the M-Cycle, the value for the required fresh air will need to be doubled due to flow rate splitting between states 3 and 4. The flow rate equations are shown below.

$$\dot{m}_1 = \frac{2\forall}{\nu_1} \tag{4}$$

$$\dot{m}_1 = \dot{m}_2 = \dot{m}_3 = \dot{m}_{10} = \dot{m}_{11} = \dot{m}_{12} = \dot{m}_{13} \tag{5}$$

$$\dot{m}_4 = \dot{m}_8 = \dot{m}_9 = \frac{\dot{m}_1}{2} \tag{6}$$

$$\dot{m}_5 = \dot{m}_6 = \dot{m}_7 + \dot{m}_4 \tag{7}$$

In order to determine the mass flow rate for state 7, the Sensible heat ratio (SHR) and the psychrometric chart are used. The sensible heat ratio (9) is the ratio of sensible heat to total heat (sensible and latent) of the space shown in equations (8) and (9).

$$\mathrm{Q_T} = \mathrm{Q_S} + \mathrm{Q_L} \tag{8}$$

$$\mathrm{SHR} = \frac{\mathrm{Q_S}}{\mathrm{Q_T}} = \frac{\mathrm{Q_S}}{\mathrm{Q_S} + \mathrm{Q_L}} \tag{9}$$

By translating a parallel line corresponding to the SHR value between the temperatures at state 7 and 6, the psychrometric parameters for state 6 can be found. An example is shown below in Figure 16 where RC represents the room conditions (76°F, 55% RH) and SA represents the supply air temperature (61°F).

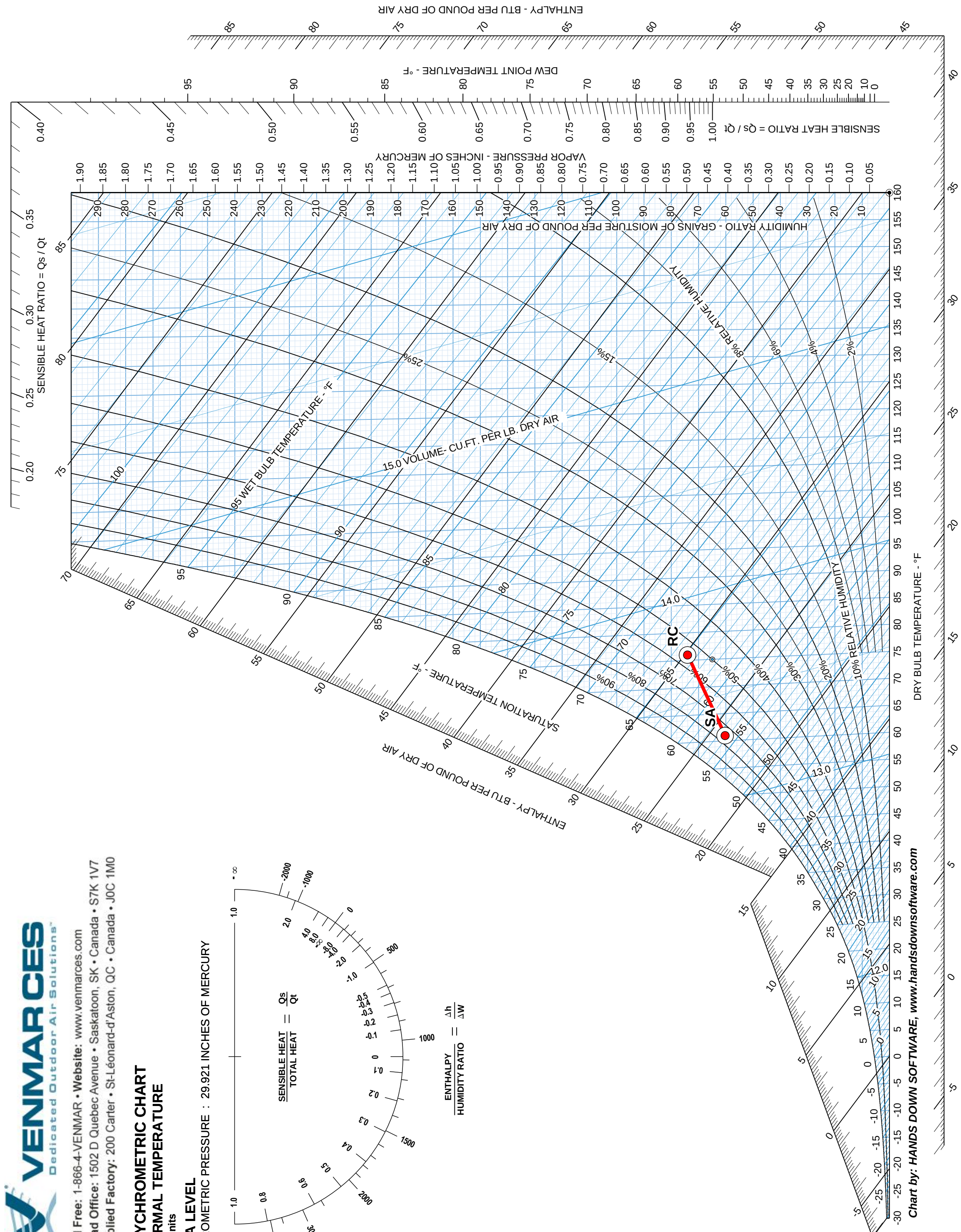

Figure 16 Summer Psychrometric Properties Using SHR and Psychrometric Chart [13]

Utilizing equation (10), we can determine the mass flow rate for state 6.

$$\text{Peak Load, Q} = \dot{m}_6(h_7 - h_6) \tag{10}$$

Then using equation (7) the flow rate for state 7 can be determined. Once the flow rates have been determined, employing the mixing box equation (3) to the two mixing boxes will yield the final psychrometric parameters. The rest of the parameters are determined by using the equations for wet-bulb effectiveness (1) and the programs for the heat wheel and desiccant wheel.

The second portion of calculations needed for this thesis is for the system without the heat wheel, desiccant wheel, and indirect evaporative cooler (M-Cycle). To determine the load for the simplified system, we translate the ambient conditions to State 4. Using the mixing box equations (3) we can find a modified state 5'. Once the psychrometric parameters are determined for state 5', equation (11) can be used to compare the load difference for the two systems.

$$\text{Q}_{\text{A/C}} = \dot{m}_5(h_6 - h_5) \tag{11}$$

For the summer operation for Chattanooga, TN a savings of 24.4% occurs by using the proposed system over a conventional system without the M-Cycle, desiccant and heat wheels. The key psychrometric values are shown in Figure 17 and Figure 18.

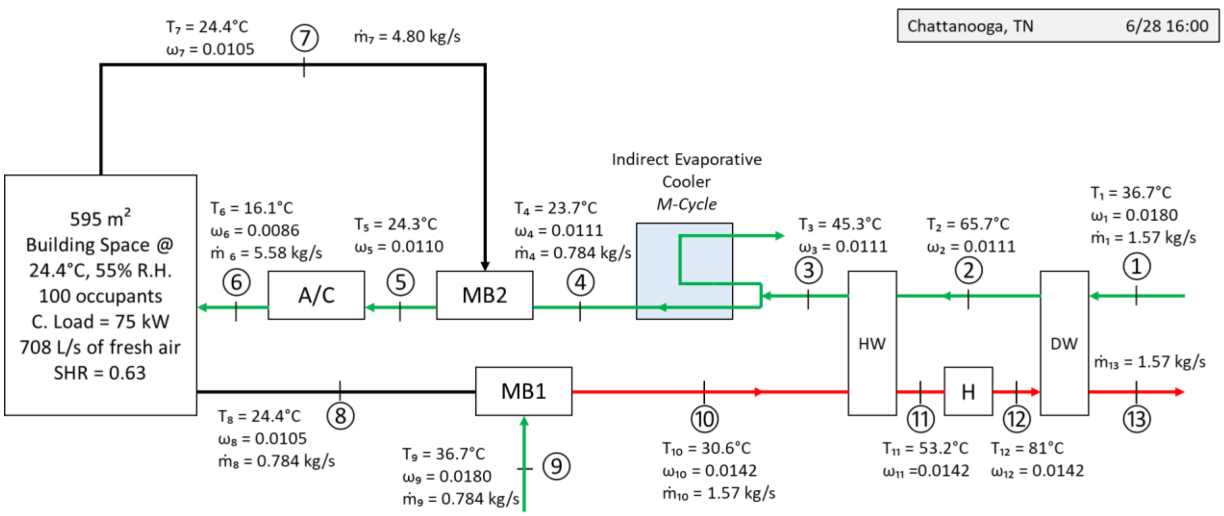

Figure 17 Energy Recovery System for Summer Application, SI Units

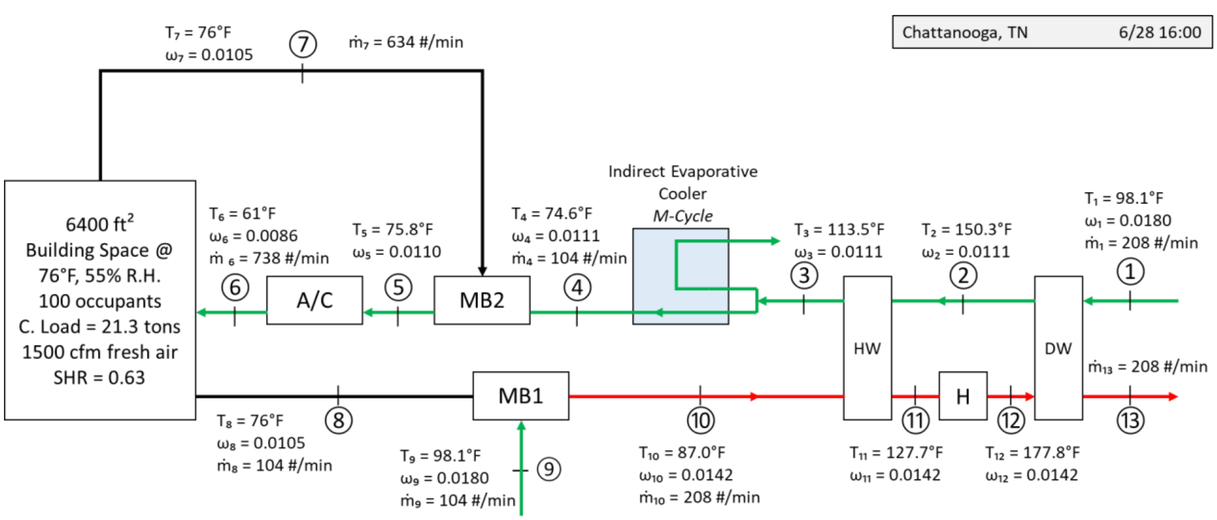

Figure 18 Energy Recovery System for Summer Application, IP Units

4.2. Winter Operation (Heating Load)

For this section, the results case for Chattanooga, TN will be used. Utilizing the psychrometric chart and ASHRAE psychrometric correlations the parameter values for humidity ratio (ω), relative humidity (ϕ), enthalpy (h), and specific volume (v) can be determined. It is important to note that all heaters in the system are assumed to be sensible (constant ω). The psychrometric parameters for state 7 and 8 are the same (room conditions). The psychrometric properties for the states at the inlet and exit of the heat and desiccant wheels are determined by using the computer programs. The required mass flow rate for this system is determined from the given required fresh air flow (Ɏ) and the specific volume (ν) of the outdoor air. Unlike the summer conditions, there is no diverting of air flow via the M-Cycle. The flow rate equations are shown below.

$$\dot{m}_0 = \frac{\forall}{\nu_0} \tag{12}$$

$$\dot{m}_0 = \dot{m}_1 = \dot{m}_2 = \dot{m}_3 = \dot{m}_4 = \dot{m}_8 = \dot{m}_9 = \dot{m}_{10} \tag{13}$$

$$\dot{m}_5 = \dot{m}_6 = \dot{m}_7 + \dot{m}_4 \tag{14}$$

In order to determine the mass flow rate for state 7, the Sensible heat ratio (SHR) and the psychrometric chart are used. By translating a parallel line corresponding to the SHR value between the temperatures at state 7 and 6, the psychrometric parameters for state 6 can be found. An example is shown below in Figure 19 where RC represents the room conditions (72°F, 50% RH) and SA represents the supply air temperature (100°F).

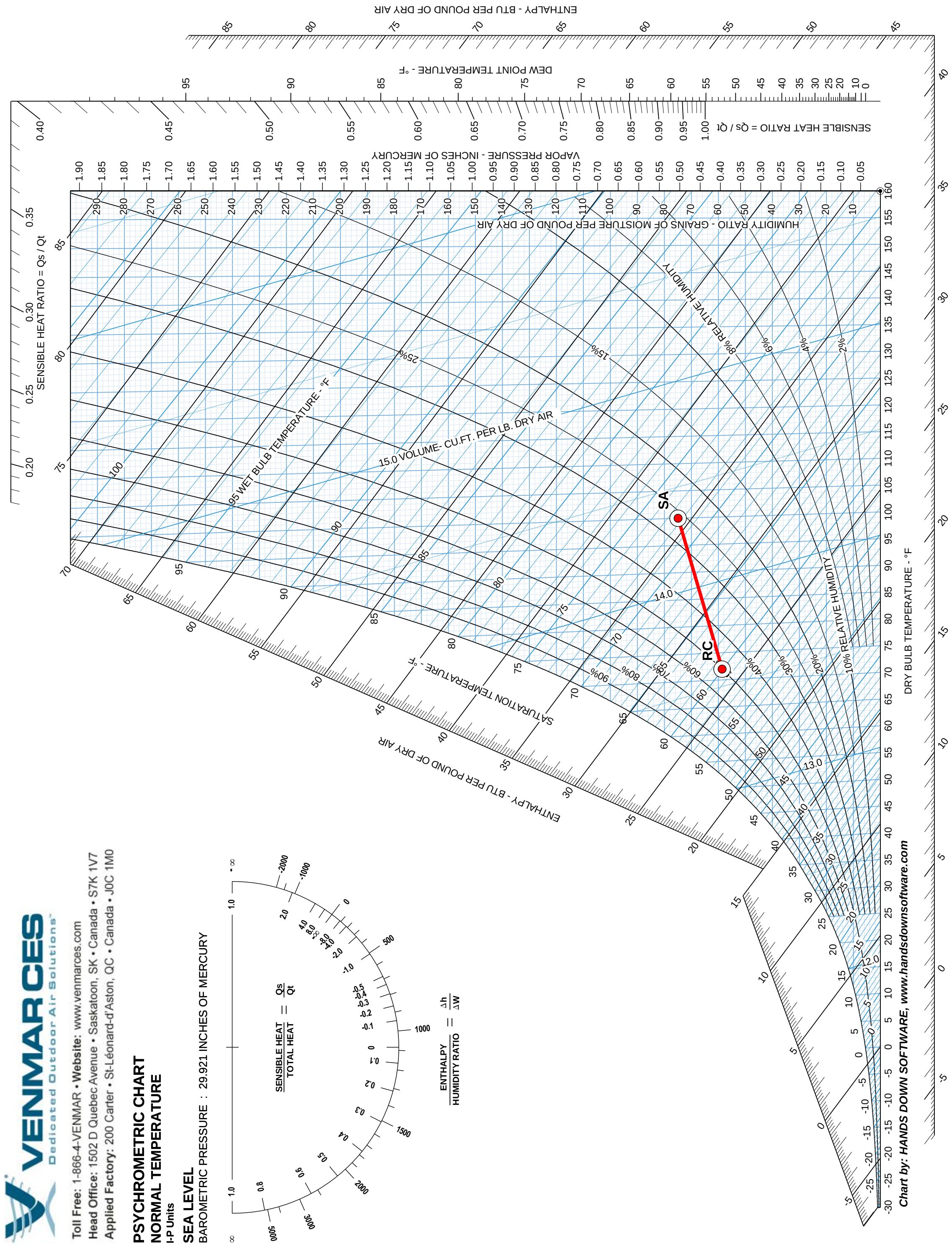

Figure 19 Winter Psychrometric Properties Using SHR and Psychrometric Chart[13]

Using equation (10) from the previous section, the mass flow rate for state 6 can be determined. Then using equation (7) the flow rate for state 7 can be determined. Since the mechanism between state 6 and 5 is a heater which is assumed to be sensible we find that the humidity ratio is constant between them ($\omega_6 = \omega_5$). Using the mixing box equation (3) the humidity ratio for state 4 can be determined. Equation (15) is used to determine the flow rate of the water through the humidifier.

$$\dot{m}_{11} = \dot{m}_w = \dot{m}_3(\omega_4 - \omega_3) \tag{15}$$

Using the value for the fluid enthalpy of the water at the temperature for state 11, the enthalpy for state 4 can be determined by performing an energy balance on the humidifier resulting in equation (16).

$$\dot{m}_4 h_4 = \dot{m}_{11} h_{f @ T_{11}} + \dot{m}_3 h_3 \tag{16}$$

4.3. Model Results

The results of the model for the Peak Cooling Load (Summer Operation) are summarized in Table 4, where $Q_{A/C}$ is the load on the system with the advanced components and $Q'_{A/C}$ is the load on the system without the advanced components.

Table 4 Peak Cooling Load (summer) Model Results

Location	$\lvert Q_{A/C} \rvert$ (tons)	$\lvert Q'_{A/C} \rvert$ (tons)	% Difference
Abilene, TX	24.7	32.0	22.7%
Chattanooga, TN	21.4	28.3	24.4%
Chicago, IL	21.1	27.7	23.6%
Houston, TX	27.1	33.6	19.2%
Miami, FL	24.0	30.4	21.1%
New York City, NY	22.0	28.0	21.2%
Phoenix, AZ	19.8	27.1	27.1%

The model applied to the ambient conditions for the peak cooling load given by the TABLER data sheets yields a reduction between 19-28% for the chosen locations. The results of the model for the Peak Heating Load (Winter Operation) are summarized in Table 5, where Q_{H2} is the heat supplied to the heating coil (H2) with the advanced components and Q'_{H2} is the heat supplied to the coil for the system without the advanced components.

Table 5 Peak Heating Load (winter) Model Results

Location	$\lvert Q_{H2} \rvert$ (tons)	$\lvert Q'_{H2} \rvert$ (tons)	% Difference
Abilene, TX	25.5	45.2	43.7%
Chattanooga, TN	13.5	30.6	56.0%
Chicago, IL	33.5	57.0	41.2%
Houston, TX	14.4	28.9	50.2%
Miami, FL	8.7	21.1	58.6%
New York City, NY	25.6	44.3	42.2%
Phoenix, AZ	14.4	28.0	48.5%

The model applied to the ambient conditions for the peak heating load given by the TABLER data sheets yields a reduction between 41-59% for the chosen locations.

4.4. Economic Analysis

Using the table of equivalent full load cooling and heating hours from ASHRAE [14] and the calculated loads for heating and cooling, an estimation of payback period can be determined. The relevant subset of the complete table of equivalent hours is shown in Table 6.

Table 6 Subset of Equivalent Full Load Cooling and Heating Hours

	Office — 8 to 5 Five Days / Week			
	Cooling		Heating	
Location	Low[1]	High[2]	Low[1]	High[2]
Atlanta, GA	950	1360	480	690
Chicago, IL	420	780	820	920
Dallas, TX	1100	1580	340	520
Houston, TX	1240	1770	250	350
Miami, FL	1500	2150	35	45
New York City, NY	540	1040	790	870
Phoenix, AZ	1130	1610	210	290

[1] Assumes unit is off when unoccupied for cooling, and 10°F set-back in heating
[2] Assumes no set-back control

Table 6 shows the equivalent full load hours for heating and cooling annually for an office building operating five days a week between the hours of 8 A.M. and 5 P.M. The low hours assume the unit is turned off when the building is unoccupied and has a 10°F set-back temperature for heating. The high hours assumes no set-back control. It should be noted that the given data for equivalent does not include Abilene, TX or Chattanooga, TN. For the purposes of calculating the estimated costs, the closest geographical city given is used (Atlanta, GA for Chattanooga and Dallas, TX for Abilene, TX). The cooling load cost will be based on the average cost of electricity for each city given by the U.S. Energy Information Administration (EIA) in the

Electric Power Annual 2019 [15] report. The estimated cost for heating will use the average annual cost of natural gas for each city given by the U.S. EIA in the Natural Gas Annual 2019 [16] Report. These values are summarized below in Table 7.

Table 7 Average Annual Cost of Electricity and Natural Gas for Commercial Use [15, 16]

Location	Avg. Cost Electricity (¢/kWh)	Avg. Cost Natural Gas ($/therm)
Abilene, TX	8.06	0.60
Chattanooga, TN	10.65	0.78
Chicago, IL	9.08	0.68
Houston, TX	8.06	0.60
Miami, FL	9.27	1.11
New York City, NY	14.06	0.70
Phoenix, AZ	10.25	0.70

Another consideration for the cost associated with heating is an assumed average efficiency of 63% for the natural gas furnace is used. Figure 20 and Figure 21 show the cooling and heating costs for the conventional and advanced systems.

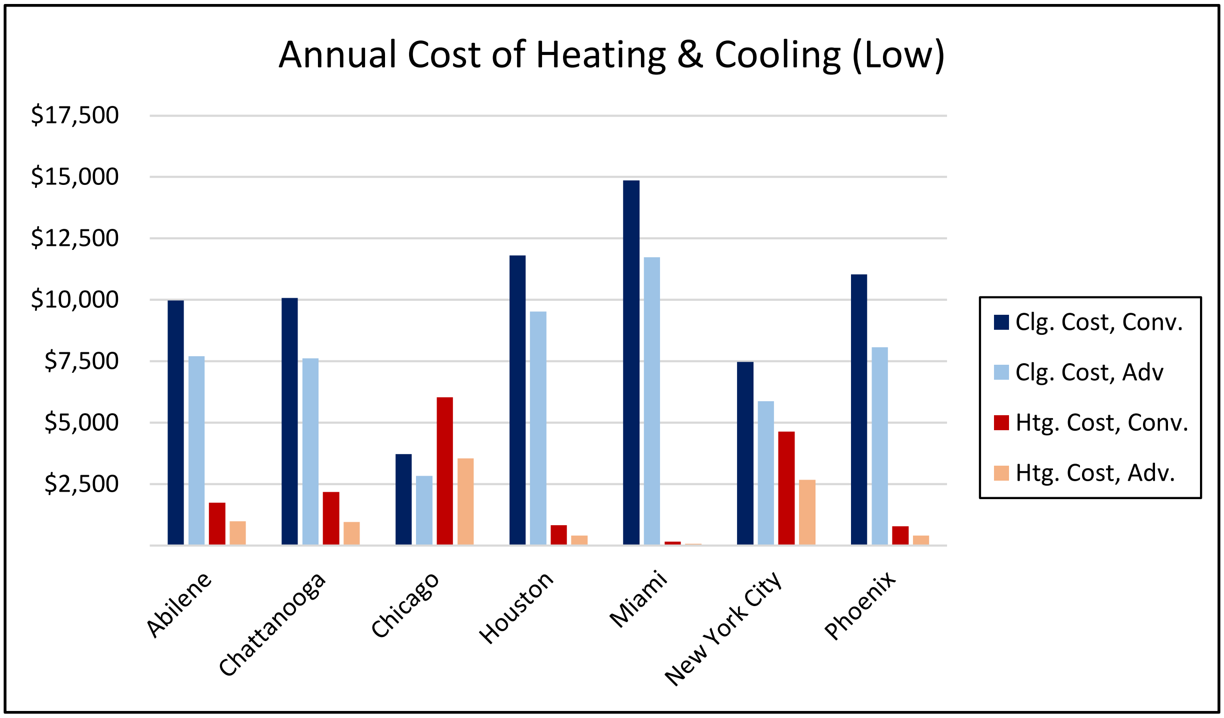

Figure 20 Annual Heating & Cooling Costs (Based on Low Equivalent Hours)

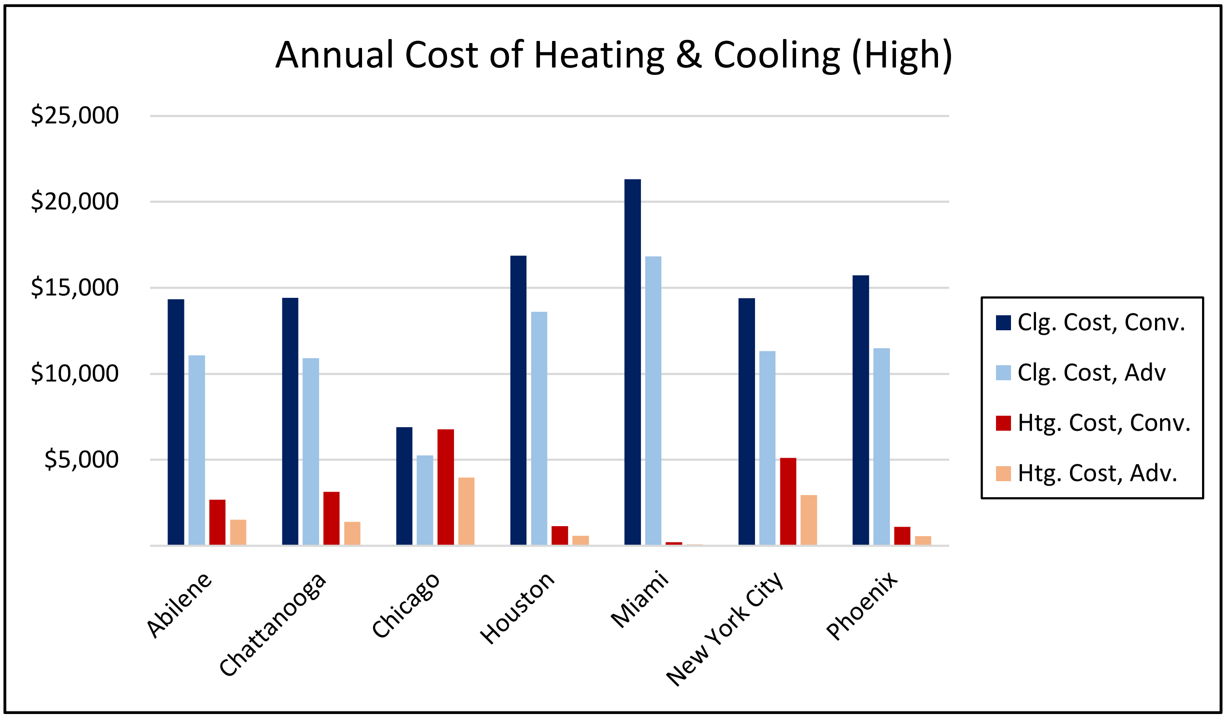

Figure 21 Annual Heating & Cooling Costs (Based on High Equivalent Hours)

Using a capital cost of $5,000 for the M-Cycle cooler and $4,000 for the desiccant and heat wheels [17], a simple payback period can be determined for the high and low equivalent hour cases. Table 8 summarizes the annual savings for heating and cooling and payback periods for the high and low cases of equivalent full load hours.

Table 8 Total Savings and Payback Period Based on Equivalent Full Load Hours

	Total Annual Savings ($)		Payback Period (years)	
Location	(Low)	(High)	(Low)	(High)
Abilene, TX[1]	$ 3,037	$ 4,432	2.96	2.03
Chattanooga, TN[2]	$ 3,676	$ 5,270	2.45	1.71
Chicago, IL	$ 3,370	$ 4,432	2.67	2.03
Houston, TX	$ 2,696	$ 3,837	3.34	2.35
Miami, FL	$ 3,221	$ 4,603	2.79	1.96
New York City, NY	$ 3,559	$ 5,240	2.53	1.72
Phoenix, AZ	$ 3,356	$ 4,765	2.68	1.89

[1] Uses Equivalent Hours for Closest City - Houston, TX
[2] Uses Equivalent Hours for Closest City - Atlanta, GA

Based on the results shown in Table 8 the payback period for the low equivalent hours on average is around 2.8 years while the payback period for the high equivalent hours on average is close to 2 years. While the payback period calculated is lower for the high equivalent hours, it should be noted that the annual cost will be higher since the units continuously run with no set-back temperature.

CHAPTER 5: CONCLUSIONS

Based on the results in the previous section for the model, this advanced system demonstrates the ability to improve the overall efficiency of the heating and air conditioning unit for a light commercial building. In terms of economic impact of implementing this system, the cities of Chattanooga, TN and New York City, NY have the quickest payback period ranging for both the low (2.45 and 2.53 years respectively) and high (1.71 and 1.71 years respectively) equivalent load hours. Houston has the longest payback periods for the low (3.34 years) and high (2.35 years) equivalent load hours. These annual costs could be further reduced by obtaining various federal or local incentives for implementing an environmentally friendly system for heating and cooling. The advanced heating and cooling system consisting of an M-Cycle indirect evaporative cooler, heat wheel, and desiccant wheel provide an environmentally friendly option that demonstrates the ability to handle the peak loads for the selected locations. This system also provides a step forward with regards to climate change in the area of heating and cooling. The future development of advanced systems will be further progressed via federal and local utility incentives to develop and implement these environmentally friendly solutions.

Further study on this system would involve the determination of the ability to operate these systems utilizing photovoltaic thermal hybrid (PVT) collector. If the ability to supply the heating and electric requirements for this system can be satisfied using PVT panels, this system would be a good candidate for contributing to a zero-energy building. A similar analysis could be explored for remote or exotic regions of the planet to determine if there is a benefit to applying these systems in those areas.

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APPENDIX A

TABLER DATA SHEETS

ABILENE TX 32 26 99 41 90

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(TABLER)Transient Analysis of Building Loads and Energy Requirements Zone:1

Envelop:	Roof	East Wall	South Wall	West Wall	North Wall	Floor	NE Wall	SE Wall	SW Wall	NW Wall
Area(ft^2):	*10000*	*1000*	*600*	*1000*	*600*	*10000*	*0*	*0*	*0*	*0*
Glass Area (ft^2):	*0*	*0*	*400*	*0*	*400*	*0*	*0*	*0*	*0*	*0*
U-Factor(Btu/hr.ft^2.F):	*0.055*	*0.251*	*0.251*	*0.251*	*0.251*	*0.08*				
Type:	*5*	*13*	*13*	*13*	*13*	*6*				

No of Occupants (day) = 100 (night) = 0 (holidays) = 0 Renw System:1 Mode:1 Life(yrs): Util P.Fac:2 Cap Cost:2.2 Payback =

Equip Elec Load, kW (day) = 10 (night) = 0 (holidays) = 0 No hrs/yr: Heat Eqpmt on: 0 Cool Eqpmt on: 0 Eqpmt Off: 0

Elec. Lights,W/ft^2 = 0.5 (night) = 0.1 (holidays) = 0.1 DCV System:Off Zc = Energy Recovery System: Off Sen.Eff: 0.85 Lat.Eff: 0.85

Infiltration,fraction of ACH = 0.3 Ventilation,cfm/person = 15 Hot Water Cons,gal/person/day = 2 U- of Glass(Btu/hr.ft^2.F) = 0.8

S.C of Glass = 0.85 Elec Power Cost,cents/kWh = 12 Gas Fuel Cost, cents/therm = 90 Economiser: Off Elec kW limit: 40 kW cost:10

Wint:Therm set = 72 F N. Setback = 72 F Throtl Range = F :Sum: Thrm set = 76 F N.Setback = 76 F Throtl Range = F

Pk H/lat.Load,tons = -29.21/5.6 in Month = 2 on Day = 4 at hr = 7 : Peak C/maxll, tons = 24.94/9.7 in month = 6 on Day = 19 at hr = 15

Approx Recommended Cap of Heating Eqpmt, tons = 35 : Approx Recommended Cap of Cooling Eqpmnt, tons = 31

On the Peak Heating Day :

Time hr	A.Temp (deg F)	S.Load (Btu/hr)	H.Added (Btu/hr)	S.Flux (Btuh/sft)	S.Temp (deg F)
1	6.98	-323203	-318804.2	0	72.4
2	5	-329072	-323876.4	0	72.4
3	6.98	-326461	-320531	0	72.4
4	5.9	-332179	-325935.8	0	72.4
5	2.84	-343128	-337295.5	0	72.4
6	3.92	-342205	-336693.4	0	72.4
7	1.94	-350503	-345819.8	0	72.5
8	3.9	-324981	-317091	0	72.4
9	14.9	-282270	-271103	0	72.3
10	20.8	-248159	-234030	0	72.2
11	25.9	-221309	-204975	0	72.1
12	28.9	-201389	-183994	0	72
13	32.9	-183384	-166109	0	72
14	36	-179147	-161627	0	71.9
15	37.9	-164141	-147774	0	71.9
16	37.9	-169838	-154817	0	71.9
17	36.9	-174430	-160950	0	71.9
18	34.9	-189636	-178555	0	72
19	29.8	-224536	-215569	0	72.1
20	25	-248712	-240995	0	72.2
21	27.9	-264569	-256768	0	72.2
22	27	-268575	-261038	0	72.2
23	30.9	-261521	-253777	0	72.2
24	32	-257350	-249147	0	72.2

On the Peak Cooling Day

Time hr	A.Temp (deg F)	S.Load (Btu/hr)	Heat Extr (Btu/hr)	S.Temp (deg F)	S.Flux Btuh/sft
1	86	102300	99254	75.2	0
2	84.2	95547	91832	75.2	0
3	84.2	104084	100297	75.2	0
4	82.4	108825	105274	75.2	0
5	80.6	114044	111045	75.2	0
6	80.6	111987	109367	75.2	0
7	82.4	125169	123745	75.2	0
8	86	190778	194659	75	0
9	89.6	241967	249356	74.8	0
10	93.2	257355	264465	74.8	0
11	96.8	267922	275620	74.7	0
12	98.6	284801	291784	74.7	0
13	100.4	294528	301557	74.7	0
14	104	298017	305313	74.7	0
15	104	299311	306936	74.6	0
16	104	287587	292426	74.7	0
17	104	273021	276775	74.7	0
18	104	255609	257158	74.8	0
19	100.4	202270	200704	74.9	0
20	96.8	194616	191933	75	0
21	93.2	139280	134276	75.1	0
22	91.4	129660	124146	75.2	0
23	91.4	127582	123718	75.2	0
24	89.6	121987	119207	75.2	0

Utility Cost Analysis

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	t.year
ac:	0	0	0	195	1265	1808	1419	1700	1208	470	0	0	8065
eqp:	252	240	264	252	264	252	252	276	228	276	252	228	3036
aux:	248	178	184	129	109	115	82	98	104	120	150	202	1719
lit:	190	177	195	187	195	187	190	200	178	200	187	180	2266
edmd:	0	0	0	220	265	264	239	247	258	205	0	0	1698
wat:	57	49	55	45	39	35	38	40	35	48	50	49	540
telc:	747	644	698	1029	2137	2661	2220	2561	2011	1318	639	660	17325
erht:	0	0	0	0	0	0	0	0	0	0	0	0	0
heat:	1326	914	945	534	114	20	2	8	137	418	735	1074	6227
cheat:	0	0	0	0	0	0	0	0	0	0	0	0	0
cexet:	0	0	0	0	0	0	0	0	0	0	0	0	0
RevRn:	0	0	0	0	0	0	0	0	0	0	0	0	0
tuty:	2073	1558	1643	1563	2251	2681	2222	2569	2148	1736	1374	1734	23552

Pk kW Dem: 66.5 kWh. Conp/yr: 133001 kWh Cost/yr,$: 15624 therms/yr: 0 GasCost,$: 0 E.D.Cost,$/yr: 1698

CHATTANOOGA TN 35 2 85 12 75

Time 5:03:23 PM Date: 11/1/2019

(TABLER)Transient Analysis of Building Loads and Energy Requirements Zone:1

Envelop	Roof	East Wall	South Wall	West Wall	North Wall	Floor	NE Wall	SE Wall	SW Wall	NW Wall
Area(ft^2):	6400	800	600	800	600	6400	0	0	0	0
Glass Area (ft^2):	0	0	200	0	200	0	0	0	0	0
U-Factor(Btu/hr ft^2.F):	0.055	0.251	0.251	0.251	0.251	0.08				
Type:	5	13	13	13	13	6				

No of Occupants (day) = 100 (night) = 0 (holidays) = 0

Renw System:1 Mode:1 Life(yrs): Util P.Fac:2 Cap Cost:2.7 Payback =

Equip Elc Load, kW (day) = 6 (night) = 0 (holidays) = 0

No hrs/yr: Heat Eqpmt on: 0 Cool Eqpmt on: 0 Eqpmt Off: 0

Elec. Lights,W/ft^2 = 0.5 (night) = 0.1 (holidays) = 0.1

DCV System Off Zc = Energy Recovery System: Off Sen.Eff: 0.85 Lat.Eff: 0.85

Infiltration,fraction of ACH = 0.15 Ventilation,cfm/person = 15

Hot Water Cons.gal/person/day = 2 U-of Glass(Btu/hr.ft^2.F) = 0.8

S.C. of Glass = 0.85 Elec Power Cost,cents/kWh = 12

Gas Fuel Cost, cents/therm = 90 Economiser: OFF Elec kW limit: 20 kW cost: 10

Wint:Therm set = 72 F N. Setback = 72 F Throtl Range = F

Sum: Thrm set = 75 F N.Setback = 75 F Throtl Range = F

Pk H/lat.Load,tons = -17.23/4.7 in Month = 12 on Day = 20 at hr = 7

: **Peak C/maxll, tons = 21.29/7.9 in month = 6 on Day = 28 at hr = 16**

Approx Recommended Cap of Heating Equipment, tons = 22

On Peak Heating Day:

Time hr	A.Temp (deg F)	S.Load (Btu/hr)	H.Added (Btu/hr)	S.Flux (Btuh/sft)	S.Temp (deg F)
1	19.04	-193983	-189330.3	0	72.3
2	17.96	-196763	-192334.2	0	72.3
3	17.96	-198677	-194586.3	0	72.4
4	17.06	-200499	-195285.8	0	72.4
5	15.98	-203596	-197604.5	0	72.4
6	15.98	-205216	-198612.1	0	72.4
7	15.98	-206804	-199738.9	0	72.4
8	15.98	-167915	-157786	0	72.2
9	17.96	-143366	-131647	0	72.1
10	19.94	-133392	-121356	0	72
11	21.02	-119238	-107267	0	72
12	23	-110279	-97708	0	71.9
13	26.06	-100626	-88402	0	71.9
14	28.94	-92406	-79892	0	71.9
15	30.92	-88955	-75950	0	71.8
16	33.08	-88496	-74407	0	71.8
17	33.98	-88217	-77060	0	71.8
18	33.08	-95724	-85922	0	71.9
19	32	-129708	-121916	0	72
20	30.92	-132047	-124777	0	72
21	30.02	-172736	-168762	0	72.2
22	28.04	-176203	-172407	0	72.3
23	28.94	-175137	-169984	0	72.2
24	28.04	-176967	-172292	0	72.3

: **Approx Recommended Cap of Heating Equipment, tons = 26**

On Peak Cooling Day:

Time hr	A.Temp (deg F)	S.Load (Btu/hr)	Heat Extr (Btu/hr)	S.Flux (Btuh/sft)	S.Temp (deg F)
1	75.92	124942	123247	0	75
2	75.02	121975	120996	0	75
3	73.04	106888	105496	0	75
4	73.04	105229	103342	0	75
5	73.04	103599	101142	0	75.1
6	71.96	94832	92810	0	75.1
7	75.92	109232	108534	0	75
8	82.04	168935	171954	0	74.7
9	84.92	206424	210612	0	74.6
10	89.96	229771	235617	0	74.5
11	91.94	234600	240623	0	74.4
12	95	235652	240406	0	74.4
13	95	240794	244772	0	74.4
14	96.98	244446	247951	0	74.4
15	96.98	246032	249205	0	74.4
16	98.06	255502	259008	0	74.4
17	96.98	236299	238614	0	74.5
18	95	232800	235715	0	74.5
19	93.02	207225	208725	0	74.6
20	89.06	199071	200265	0	74.6
21	84.92	148153	145557	0	74.9
22	84.02	144176	142471	0	74.9
23	82.94	139546	138186	0	74.9
24	80.06	139636	138819	0	74.9

Utility Cost Analysis

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	t.year
ac:	0	0	0	463	951	1487	1776	1613	1228	536	0	0	8054
eqp:	151	144	158	151	158	151	151	166	137	166	151	137	1821
aux:	126	99	79	69	75	106	128	114	76	65	71	122	1130
lit:	122	113	125	120	125	120	122	128	114	128	120	116	1453
edmd:	0	0	0	178	182	203	201	194	186	171	0	0	1315
wat:	58	57	54	48	48	40	38	44	39	53	54	53	586
telc:	456	413	416	1030	1539	2107	2415	2258	1779	1119	396	427	14355
erht:	0	0	0	0	0	0	0	0	0	0	0	0	0
heat:	725	574	351	188	50	2	0	0	7	169	350	726	3142
cheat:	0	0	0	0	0	0	0	0	0	0	0	0	0
cexet:	0	0	0	0	0	0	0	0	0	0	0	0	0
RevRn:	0	0	0	0	0	0	0	0	0	0	0	0	0
tuty:	1181	987	767	1218	1589	2109	2415	2258	1786	1288	746	1153	
													17497

nhy1 = 3439 nhy2 = 735 nhy3 = 492 nhy4 = 4094

Pk kW Dem: 40.3 kWh. Conp/yr: 113325 kWh Cost/yr,$: 13043 therms/yr: 0 GasCost,$: 0 E.D.Cost,$/yr: 1315

CHICAGO IL 41 47 87 45 90

Time 12:15:51 PM Date: 2/14/2020

(TABLER)Transient Analysis of Building Loads and Energy Requirements Zone:1

Envelop:	Roof	East Wall	South Wall	West Wall	North Wall	Floor	NE Wall	SE Wall	SW Wall	NW Wall
Area(ft^2):	*10000*	*1000*	*600*	*1000*	*600*	*10000*	*0*	*0*	*0*	*0*
Glass Area (ft^2):	*0*	*0*	*400*	*0*	*400*	*0*	*0*	*0*	*0*	*0*
U-Factor(Btu/hr.ft^2.F):	*0.055*	*0.251*	*0.251*	*0.251*	*0.251*	*0.08*				
Type:	*5*	*13*	*13*	*13*	*13*	*6*				

No of Occupants (day) = 100 (night) = 0 (holidays) = 0 Renw System:1 Mode:1 Life(yrs): Util P.Fac:2 Cap Cost:2.2 Payback =

Equip Elec Load, kW (day) = 10 (night) = 0 (holidays) = 0 No hrs/yr: Heat Eqpmt on: 0 Cool Eqpmt on: 0 Eqpmt Off: 0

Elec. Lights,W/ft^2 = 0.5 (night) = 0.1 (holidays) = 0.1 DCV System:Off Zc = Energy Recovery System: Off Sen.Eff: 0.85 Lat.Eff: 0.85

Infiltration,fraction of ACH = 0.3 Ventilation,cfm/person = 15 Hot Water Cons,gal/person/day = 2 U- of Glass(Btu/hr.ft^2.F) = 0.8

S.C of Glass = 0.85 Elec Power Cost,cents/kWh = 12 Gas Fuel Cost, cents/therm = 90 Economiser: Off Elec kW limit: 40 kW cost:10

Wint:Therm set = 72 F N. Setback = 72 F Throtl Range = F :Sum: Thrm set = 76 F N.Setback = 76 F Throtl Range = F

Pk H/lat.Load,tons = -36.78/6.3 in Month = 2 on Day = 3 at hr = 7 : Peak C/maxll, tons = 21.86/9.2 in month = 8 on Day = 1 at hr = 13

Approx Recommended Cap of Heating Eqpmt, tons = 43

On the Peak Heating Day :

Time hr	A.Temp (deg F)	S.Load (Btu/hr)	H.Added (Btu/hr)	S.Flux (Btuh/sft)	S.Temp (deg F)
1	-14.08	-427105	-420704.5	0	72.4
2	-15.16	-430711	-425189.4	0	72.5
3	-15.16	-432027	-425065.2	0	72.5
4	-15.16	-433397	-425272.5	0	72.5
5	-16.06	-436654	-427632.3	0	72.5
6	-16.06	-437875	-428096	0	72.5
7	-17.14	-441412	-431121.9	0	72.5
8	-16.1	-417649	-405673	0	72.4
9	-14.3	-392527	-380032	0	72.4
10	-12.1	-365933	-351517	0	72.3
11	-8.1	-340830	-325680	0	72.2
12	-4	-320138	-305485	0	72.2
13	-3.1	-311479	-296752	0	72.2
14	-1.1	-304876	-289743	0	72.2
15	-1.1	-307989	-292645	0	72.2
16	-2	-317353	-302296	0	72.2
17	-3.1	-332455	-318434	0	72.2
18	-5.1	-353827	-341850	0	72.3
19	-6.2	-378644	-367496	0	72.3
20	-8.1	-384244	-374226	0	72.3
21	-9	-410257	-402606	0	72.4
22	-10.1	-413872	-406259	0	72.4
23	-10.1	-415154	-407726	0	72.4
24	-10.1	-416593	-409408	0	72.4

Approx Recommended Cap of Cooling Eqpmnt, tons = 27

On the Peak Cooling Day

Time hr	A.Temp (deg F)	S.Load (Btu/hr)	Heat Extr (Btu/hr)	S.Temp (deg F)	S.Flux Btuh/sft
1	79.3	82581	78928	75.3	0
2	79.2	87907	84290	75.3	0
3	79	75963	71851	75.3	0
4	78.8	53390	47668	75.4	0
5	77	47557	42374	75.4	0
6	78.8	49796	45139	75.4	0
7	80.6	77712	74966	75.3	0
8	84.2	157437	158214	75.1	0
9	87.8	206781	208771	75	0
10	89.6	225966	227906	75	0
11	91.4	243219	246081	74.9	0
12	93.2	255453	257474	74.9	0
13	93.2	262279	263965	74.9	0
14	93.2	253878	254826	74.9	0
15	93.2	262072	262766	74.9	0
16	93.2	260585	260971	74.9	0
17	91.4	242259	241423	75	0
18	91.4	239930	240169	75	0
19	89.6	194136	192927	75.1	0
20	87.8	191354	190989	75.1	0
21	87.8	136704	134226	75.2	0
22	86	131261	128881	75.2	0
23	86	129459	126994	75.2	0
24	78.8	61096	55048	75.4	0

Utility Cost Analysis

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	t.year
ac:	0	0	0	82	148	781	938	851	753	168	0	0	3721
eqp:	252	240	264	252	264	252	252	276	228	276	252	228	3036
aux:	233	183	153	93	83	75	82	74	88	95	123	201	1483
lit:	190	177	195	187	195	187	190	200	178	200	187	180	2266
edmd:	0	0	0	66	79	101	126	102	101	86	0	0	661
wat:	70	62	62	54	54	44	40	45	39	56	56	59	641
telc:	745	662	673	734	823	1441	1628	1548	1386	880	618	669	11807
erht:	0	0	0	0	0	0	0	0	0	0	0	0	0
heat:	2091	1643	1345	752	592	206	51	39	165	710	1064	1803	10461
cheat:	0	0	0	0	0	0	0	0	0	0	0	0	0
cexet:	0	0	0	0	0	0	0	0	0	0	0	0	0
RevRn:	0	0	0	0	0	0	0	0	0	0	0	0	0
tuty:	2836	2305	2018	1486	1415	1647	1679	1587	1551	1590	1682	2472	22268

Pk kW Dem: 52.6 kWh. Conp/yr: 93156 kWh Cost/yr,$: 11146 therms/yr: 0 GasCost,$: 0 E.D.Cost,$/yr: 661

HOUSTON TX 29 59 95 22 90

Time 12:14:48 PM Date: 2/14/2020

(TABLER)Transient Analysis of Building Loads and Energy Requirements Zone:1

Envelop:	Roof	East Wall	South Wall	West Wall	North Wall	Floor	NE Wall	SE Wall	SW Wall	NW Wall
Area(ft^2):	*10000*	*1000*	*600*	*1000*	*600*	*10000*	*0*	*0*	*0*	*0*
Glass Area (ft^2):	*0*	*0*	*400*	*0*	*400*	*0*	*0*	*0*	*0*	*0*
U-Factor(Btu/hr.ft^2.F):	*0.055*	*0.251*	*0.251*	*0.251*	*0.251*	*0.08*				
Type:	*5*	*13*	*13*	*13*	*13*	*6*				

No of Occupants (day) = 100 (night) = 0 (holidays) = 0 Renw System:1 Mode:1 Life(yrs): Util P.Fac:2 Cap Cost:2.2 Payback =

Equip Elec Load, kW (day) = 10 (night) = 0 (holidays) = 0 No hrs/yr: Heat Eqpmt on: 0 Cool Eqpmt on: 0 Eqpmt Off: 0

Elec. Lights,W/ft^2 = 0.5 (night) = 0.1 (holidays) = 0.1 DCV System:Off Zc = Energy Recovery System: Off Sen.Eff: 0.85 Lat.Eff: 0.85

Infiltration,fraction of ACH = 0.3 Ventilation,cfm/person = 15 Hot Water Cons,gal/person/day = 2 U- of Glass(Btu/hr.ft^2.F) = 0.8

S.C of Glass = 0.85 Elec Power Cost,cents/kWh = 12 Gas Fuel Cost, cents/therm = 90 Economiser: Off Elec kW limit: 40 kW cost:10

Wint:Therm set = 72 F N. Setback = 72 F Throtl Range = F :Sum: Thrm set = 76 F N.Setback = 76 F Throtl Range = F

Pk H/lat.Load,tons = -19.41/4.5 in Month = 3 on Day = 8 at hr = 7 : Peak C/maxll, tons = 25.02/11.7 in month = 8 on Day = 2 at hr = 15

Approx Recommended Cap of Heating Eqpmt, tons = 21 : Approx Recommended Cap of Cooling Eqpmnt, tons = 31

On the Peak Heating Day :

Time hr	A.Temp (deg F)	S.Load (Btu/hr)	H.Added (Btu/hr)	S.Flux (Btuh/sft)	S.Temp (deg F)
1	38.84	-203082	-200309.9	0	72.4
2	36.86	-209177	-206808	0	72.5
3	35.96	-214576	-210753.9	0	72.5
4	34.88	-220188	-215675.5	0	72.5
5	34.88	-222316	-216000	0	72.4
6	33.98	-227619	-216000	0	72.2
7	32.9	-232931	-216000	0	71.9
8	34	-180087	-172829	0	72.3
9	36.9	-130766	-117323	0	72
10	41.9	-106298	-91836	0	71.9
11	45	-84061	-68314	0	71.8
12	50	-72101	-56134	0	71.8
13	52.2	-51446	-32876	0	71.7
14	54	-41728	-22003	0	71.6
15	55.9	-37428	-18462	0	71.6
16	55.9	-40886	-22950	0	71.6
17	56.8	-46880	-30608	0	71.6
18	54.9	-59262	-45979	0	71.7
19	52	-104231	-96404	0	71.9
20	50.9	-121216	-115757	0	72
21	50	-176363	-177072	0	72.3
22	47.8	-178432	-178093	0	72.3
23	43.9	-186332	-186125	0	72.4
24	45	-186650	-184163	0	72.4

On the Peak Cooling Day

Time hr	A.Temp (deg F)	S.Load (Btu/hr)	Heat Extr (Btu/hr)	S.Temp (deg F)	S.Flux Btuh/sft
1	82	133476	128015	74.9	0
2	81	131037	125879	74.9	0
3	81	129464	124513	74.9	0
4	81	128052	123144	74.9	0
5	80.1	118530	112602	75	0
6	80.1	123990	120129	74.9	0
7	82	134230	130975	74.9	0
8	84.9	195647	199910	74.6	0
9	87.1	249957	260207	74.3	0
10	90	248474	257283	74.3	0
11	89.1	266322	275992	74.2	0
12	90	266442	274515	74.2	0
13	91.9	280137	288280	74.2	0
14	93	277366	285268	74.2	0
15	93.9	300192	310404	74.1	0
16	93	288279	296954	74.1	0
17	93	269618	274815	74.2	0
18	89.1	236596	237196	74.4	0
19	84.9	215264	213842	74.5	0
20	82	181850	177016	74.7	0
21	79	130850	121833	74.9	0
22	79	128534	119926	74.9	0
23	80.1	129319	121015	74.9	0
24	79	123793	115168	75	0

Utility Cost Analysis

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	t.year
ac:	0	0	0	459	859	1227	1529	1497	998	801	0	0	7370
eqp:	252	240	264	252	264	252	252	276	228	276	252	228	3036
aux:	199	197	167	107	65	70	86	86	74	116	163	245	1575
lit:	190	177	195	187	195	187	190	200	178	200	187	180	2266
edmd:	0	0	0	194	213	222	232	232	217	212	0	0	1522
wat:	49	46	51	44	43	38	37	41	36	46	48	46	525
telc:	690	660	676	1243	1638	1997	2327	2333	1730	1650	651	699	16294
erht:	0	0	0	0	0	0	0	0	0	0	0	0	0
heat:	489	435	409	213	51	0	0	6	55	206	466	683	3013
cheat:	0	0	0	0	0	0	0	0	0	0	0	0	0
cexet:	0	0	0	0	0	0	0	0	0	0	0	0	0
RevRn:	0	0	0	0	0	0	0	0	0	0	0	0	0
tuty:	1179	1095	1085	1456	1689	1997	2327	2339	1785	1856	1117	1382	19307

Pk kW Dem: 63.2 kWh. Conp/yr: 138764 kWh Cost/yr,$: 14774 therms/yr: 0 GasCost,$: 0 E.D.Cost,$/yr: 1522

MIAMI FL 25 48 80 16 75

Time 12:10:58 PM Date: 2/14/2020

(TABLER)Transient Analysis of Building Loads and Energy Requirements Zone:1

Envelop:	Roof	East Wall	South Wall	West Wall	North Wall	Floor	NE Wall	SE Wall	SW Wall	NW Wall
Area(ft^2):	*10000*	*1000*	*600*	*1000*	*600*	*10000*	*0*	*0*	*0*	*0*
Glass Area (ft^2):	*0*	*0*	*400*	*0*	*400*	*0*	*0*	*0*	*0*	*0*
U-Factor(Btu/hr.ft^2.F):	*0.055*	*0.251*	*0.251*	*0.251*	*0.251*	*0.08*				
Type:	*5*	*13*	*13*	*13*	*13*	*6*				

No of Occupants (day) = 100 (night) = 0 (holidays) = 0 Renw System:1 Mode:1 Life(yrs): Util P.Fac:2 Cap Cost:2.2 Payback =

Equip Elec Load, kW (day) = 10 (night) = 0 (holidays) = 0 No hrs/yr: Heat Eqpmt on: 0 Cool Eqpmt on: 0 Eqpmt Off: 0

Elec. Lights,W/ft^2 = 0.5 (night) = 0.1 (holidays) = 0.1 DCV System:Off Zc = Energy Recovery System: Off Sen.Eff: 0.85 Lat.Eff: 0.85

Infiltration,fraction of ACH = 0.3 Ventilation,cfm/person = 15 Hot Water Cons,gal/person/day = 2 U- of Glass(Btu/hr.ft^2.F) = 0.8

S.C of Glass = 0.85 Elec Power Cost,cents/kWh = 12 Gas Fuel Cost, cents/therm = 90 Economiser: Off Elec kW limit: 40 kW cost:10

Wint:Therm set = 72 F N. Setback = 72 F Throtl Range = F :Sum: Thrm set = 76 F N.Setback = 76 F Throtl Range = F

Pk H/lat.Load,tons = -14.86/3.3 in Month = 1 on Day = 25 at hr = 8 : Peak C/maxll, tons = 22.93/11.5 in month = 8 on Day = 1 at hr = 16

Approx Recommended Cap of Heating Eqpmt, tons = 14 : Approx Recommended Cap of Cooling Eqpmnt, tons = 28

On the Peak Heating Day :

Time hr	A.Temp (deg F)	S.Load (Btu/hr)	H.Added (Btu/hr)	S.Flux (Btuh/sft)	S.Temp (deg F)
1	50	-157332	-144000	0	71.9
2	48.92	-162158	-144000	0	71.6
3	47.84	-164262	-144000	0	71.5
4	47.84	-171080	-144000	0	71.1
5	47.84	-172457	-144000	0	70.9
6	47.84	-175135	-144000	0	70.7
7	46.94	-178294	-144000	0	70.5
8	46.94	-128950	-139882.3	0	72.5
9	52.9	-78033	-74310	0	72
10	55.9	-48287	-39118	0	71.8
11	59.9	-33531	-20880	0	71.6
12	61	-42182	-32484	0	71.7
13	63	-15175	-945	0	71.5
14	63.9	-18555	-5553	0	71.5
15	63.9	-11156	0	0	71.6
16	64.9	-14113	-697	0	71.5
17	63.9	-34378	-24915	0	71.7
18	59.9	-39552	-29782	0	71.7
19	56.8	-76033	-72595	0	72
20	54.9	-77206	-72693	0	72
21	54.9	-133395	-138009	0	72.5
22	52.9	-137101	-138774	0	72.5
23	52.9	-136101	-135057	0	72.4
24	50.9	-142080	-141901	0	72.5

On the Peak Cooling Day

Time hr	A.Temp (deg F)	S.Load (Btu/hr)	Heat Extr (Btu/hr)	S.Temp (deg F)	S.Flux Btuh/sft
1	77.5	89389	84820	74.9	0
2	76.8	91379	87448	74.9	0
3	75.9	82100	77368	75	0
4	75.2	65399	59480	75.1	0
5	73.4	58932	53147	75.1	0
6	73.4	57392	51376	75.1	0
7	78.8	89819	89307	74.9	0
8	82.4	162464	175268	74.3	0
9	86	201853	219921	74	0
10	89.6	225759	246248	73.8	0
11	89.6	216537	232980	73.9	0
12	93.2	245064	265189	73.7	0
13	93.2	241500	259494	73.7	0
14	93.2	246223	263058	73.7	0
15	93.2	236950	250958	73.8	0
16	91.4	275193	295662	73.4	0
17	89.6	248902	260887	73.7	0
18	87.8	238563	248173	73.8	0
19	84.2	189902	190773	74.2	0
20	78.8	135531	128090	74.6	0
21	77	73313	56326	75.1	0
22	75.2	67113	51819	75.1	0
23	77	68144	54294	75.1	0
24	75.2	73400	61960	75.1	0

Utility Cost Analysis

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	t.year
ac:	0	0	0	863	1025	803	1124	1123	776	1199	0	0	6913
eqp:	252	240	264	252	264	252	252	276	228	276	252	228	3036
aux:	174	116	143	95	76	52	72	72	50	124	131	174	1279
lit:	190	177	195	187	195	187	190	200	178	200	187	180	2266
edmd:	0	0	0	91	97	93	101	101	96	96	0	0	675
wat:	47	43	47	41	41	40	38	42	36	45	43	42	505
telc:	664	576	649	1530	1698	1428	1778	1814	1364	1940	613	624	14678
erht:	0	0	0	0	0	0	0	0	0	0	0	0	0
heat:	315	194	252	75	12	0	0	0	0	29	94	301	1272
cheat:	0	0	0	0	0	0	0	0	0	0	0	0	0
cexet:	0	0	0	0	0	0	0	0	0	0	0	0	0
RevRn:	0	0	0	0	0	0	0	0	0	0	0	0	0
tuty:	979	770	901	1605	1710	1428	1778	1814	1364	1969	707	925	15950

Pk kW Dem: 50.1 kWh. Conp/yr: 146479 kWh Cost/yr,$: 14000 therms/yr: 0 GasCost,$: 0 E.D.Cost,$/yr: 675

NEW_YORK_CITY NY 40 47 73 58 75
Time 12:13:01 PM Date: 2/14/2020

(TABLER)Transient Analysis of Building Loads and Energy Requirements Zone:1

Envelop:	Roof	East Wall	South Wall	West Wall	North Wall	Floor	NE Wall	SE Wall	SW Wall	NW Wall
Area(ft^2):	*10000*	*1000*	*600*	*1000*	*600*	*10000*	*0*	*0*	*0*	*0*
Glass Area (ft^2):	*0*	*0*	*400*	*0*	*400*	*0*	*0*	*0*	*0*	*0*
U-Factor(Btu/hr.ft^2.F):	*0.055*	*0.251*	*0.251*	*0.251*	*0.251*	*0.08*				
Type:	*5*	*13*	*13*	*13*	*13*	*6*				

No of Occupants (day) = 100 (night) = 0 (holidays) = 0 Renw System:1 Mode:1 Life(yrs): Util P.Fac:2 Cap Cost:2.2 Payback =

Equip Elec Load, kW (day) = 10 (night) = 0 (holidays) = 0 No hrs/yr: Heat Eqpmt on: 0 Cool Eqpmt on: 0 Eqpmt Off: 0

Elec. Lights,W/ft^2 = 0.5 (night) = 0.1 (holidays) = 0.1 DCV System:Off Zc = Energy Recovery System: Off Sen.Eff: 0.85 Lat.Eff: 0.85

Infiltration,fraction of ACH = 0.3 Ventilation,cfm/person = 15 Hot Water Cons,gal/person/day = 2 U- of Glass(Btu/hr.ft^2.F) = 0.8

S.C of Glass = 0.85 Elec Power Cost,cents/kWh = 12 Gas Fuel Cost, cents/therm = 90 . Economiser: Off Elec kW limit: 40 kW cost:10

Wint:Therm set = 72 F N. Setback = 72 F Throtl Range = F :Sum: Thrm set = 76 F N.Setback = 76 F Throtl Range = F

Pk H/lat.Load,tons = -29.04/6 in Month = 2 on Day = 6 at hr = 3 : Peak C/maxll, tons = 21.53/9.5 in month = 8 on Day = 3 at hr = 14

Approx Recommended Cap of Heating Eqpmt, tons = 32

On the Peak Heating Day :

Time hr	A.Temp (deg F)	S.Load (Btu/hr)	H.Added (Btu/hr)	S.Flux (Btuh/sft)	S.Temp (deg F)
1	8.06	-342382	-336000	0	72.3
2	8.06	-343373	-336000	0	72.3
3	6.98	-346885	-336000	0	72.2
4	8.1	-345772	-336000	0	72.2
5	8.1	-346350	-336000	0	72.2
6	9	-344490	-336000	0	72.3
7	8.1	-348508	-336000	0	72.1
8	9	-296657	-290313	0	72.4
9	10	-258618	-248163	0	72.2
10	12	-232170	-221027	0	72.2
11	12.9	-213013	-199740	0	72.1
12	15.1	-198769	-184885	0	72.1
13	17.1	-204583	-190445	0	72.1
14	18	-183454	-167625	0	72
15	19	-206090	-192598	0	72.1
16	19	-208005	-194382	0	72.1
17	19.9	-215388	-202237	0	72.1
18	19.9	-224851	-212791	0	72.1
19	17.1	-256547	-247685	0	72.2
20	18	-258361	-250247	0	72.2
21	18	-312098	-308467	0	72.4
22	17.1	-316030	-312138	0	72.4
23	17.1	-317346	-313473	0	72.4
24	17.1	-319226	-315500	0	72.4

Approx Recommended Cap of Cooling Eqpmnt, tons = 26

On the Peak Cooling Day

Time hr	A.Temp (deg F)	S.Load (Btu/hr)	Heat Extr (Btu/hr)	S.Temp (deg F)	S.Flux Btuh/sft
1	80.1	76736	73443	75.3	0
2	80.1	81679	79466	75.3	0
3	79	78341	76903	75.3	0
4	79	83568	83210	75.3	0
5	78.1	75317	75396	75.3	0
6	79	81346	82246	75.3	0
7	79	82793	84556	75.2	0
8	80.1	138400	142445	75.1	0
9	82	186014	193196	74.9	0
10	84.9	209113	216188	74.9	0
11	84	226136	234455	74.8	0
12	82.9	203274	208823	74.9	0
13	84	238436	246269	74.8	0
14	86	258392	267287	74.7	0
15	84	254201	261530	74.7	0
16	82.9	240038	245020	74.8	0
17	82	231394	235949	74.8	0
18	80.1	212500	215271	74.9	0
19	79	171622	172268	75	0
20	79	169403	170186	75	0
21	79	105692	102128	75.2	0
22	78.1	102351	99216	75.2	0
23	77	93377	89851	75.2	0
24	75.9	82642	78014	75.3	0

Utility Cost Analysis

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	t.year
ac:	0	0	0	59	158	761	829	944	432	356	0	0	3539
eqp:	252	240	264	252	264	252	252	276	228	276	252	228	3036
aux:	251	238	188	130	88	99	60	74	80	123	168	233	1732
lit:	190	177	195	187	195	187	190	200	178	200	187	180	2266
edmd:	0	0	0	65	78	112	96	98	84	65	0	0	598
wat:	63	62	62	53	51	43	40	45	41	55	58	56	629
telc:	756	717	709	745	834	1454	1467	1637	1042	1074	666	698	11799
erht:	0	0	0	0	0	0	0	0	0	0	0	0	0
heat:	1672	1587	1249	811	453	113	4	61	228	597	1122	1555	9452
cheat:	0	0	0	0	0	0	0	0	0	0	0	0	0
cexet:	0	0	0	0	0	0	0	0	0	0	0	0	0
RevRn:	0	0	0	0	0	0	0	0	0	0	0	0	0
tuty:	2428	2304	1958	1556	1287	1567	1471	1698	1270	1671	1788	2253	21251

Pk kW Dem: 51.2 kWh. Conp/yr: 93493 kWh Cost/yr,$: 11202 therms/yr: 0 GasCost,$: 0 E.D.Cost,$/yr: 598

PHOENIX AZ 33 26 112 1 120

Time 12:13:53 PM Date: 2/14/2020

(TABLER)Transient Analysis of Building Loads and Energy Requirements Zone:1

Envelop:	Roof	East Wall	South Wall	West Wall	North Wall	Floor	NE Wall	SE Wall	SW Wall	NW Wall
Area(ft^2):	*10000*	*1000*	*600*	*1000*	*600*	*10000*	*0*	*0*	*0*	*0*
Glass Area (ft^2):	*0*	*0*	*400*	*0*	*400*	*0*	*0*	*0*	*0*	*0*
U-Factor(Btu/hr.ft^2.F):	*0.055*	*0.251*	*0.251*	*0.251*	*0.251*	*0.08*				
Type:	*5*	*13*	*13*	*13*	*13*	*6*				

No of Occupants (day) = 100 (night) = 0 (holidays) = 0 Renw System:1 Mode:1 Life(yrs): Util P.Fac:2 Cap Cost:2.2 Payback =

Equip Elec Load, kW (day) = 10 (night) = 0 (holidays) = 0 No hrs/yr: Heat Eqpmt on: 0 Cool Eqpmt on: 0 Eqpmt Off: 0

Elec. Lights,W/ft^2 = 0.5 (night) = 0.1 (holidays) = 0.1 DCV System:Off Zc = Energy Recovery System: Off Sen.Eff: 0.85 Lat.Eff: 0.85

Infiltration,fraction of ACH = 0.3 Ventilation,cfm/person = 15 Hot Water Cons,gal/person/day = 2 U- of Glass(Btu/hr.ft^2.F) = 0.8

S.C of Glass = 0.85 Elec Power Cost,cents/kWh = 12 Gas Fuel Cost, cents/therm = 90 Economiser: Off Elec kW limit: 40 kW cost:10

Wint:Therm set = 72 F N. Setback = 72 F Throtl Range = F :Sum: Thrm set = 76 F N.Setback = 76 F Throtl Range = F

Pk H/lat.Load,tons = -18.88/5.6 in Month = 1 on Day = 20 at hr = 7 : Peak C/maxll, tons = 22.06/8.4 in month = 8 on Day = 1 at hr = 15

Approx Recommended Cap of Heating Eqpmt, tons = 20 : Approx Recommended Cap of Cooling Eqpmnt, tons = 27

On the Peak Heating Day :						On the Peak Cooling Day					
Time hr	A.Temp (deg F)	S.Load (Btu/hr)	H.Added (Btu/hr)	S.Flux (Btuh/sft)	S.Temp (deg F)	Time hr	A.Temp (deg F)	S.Load (Btu/hr)	Heat Extr (Btu/hr)	S.Temp (deg F)	S.Flux Btuh/sft
1	44.06	-196598	-190851	0	72.4	1	88.7	68514	56804	75.2	0
2	44.06	-201154	-196301.2	0	72.5	2	89.1	68807	58477	75.2	0
3	41	-207381	-201677.3	0	72.5	3	89.6	81749	74032	75.1	0
4	41	-212198	-204000	0	72.4	4	90	94085	87915	75.1	0
5	39.92	-216965	-204000	0	72.2	5	89.1	89192	84037	75.1	0
6	37.94	-221848	-204000	0	71.9	6	89.1	87137	82726	75.1	0
7	37.04	-226516	-204000	0	71.6	7	88	84132	80087	75.1	0
8	37.04	-203703	-202065.6	0	72.5	8	90	143328	146670	74.8	0
9	41	-183482	-177354.6	0	72.4	9	93.9	196456	205915	74.5	0
10	46.94	-144157	-132255.5	0	72.1	10	98.1	217867	228710	74.4	0
11	51.08	-119530	-106375.5	0	72	11	99	227965	239162	74.3	0
12	51.98	-109279	-95879.1	0	72	12	100	240977	251693	74.3	0
13	53.96	-99817	-84965.8	0	71.9	13	102	250894	262409	74.2	0
14	57.02	-91000	-76149.3	0	71.9	14	104	255540	265925	74.2	0
15	60.08	-86219	-70710.7	0	71.8	15	106	264733	275199	74.2	0
16	60.98	-89708	-76435.1	0	71.9	16	107.1	260325	270346	74.2	0
17	60.98	-96159	-83277.8	0	71.9	17	107.1	253128	261862	74.2	0
18	57.92	-109890	-99110	0	72	18	107.1	247524	254340	74.3	0
19	55.04	-144663	-137596.7	0	72.2	19	107.1	206715	209278	74.5	0
20	53.96	-152852	-145541.6	0	72.2	20	105.1	199748	202175	74.5	0
21	53.06	-178775	-174484.7	0	72.4	21	102.9	132442	126566	74.9	0
22	50	-183805	-178131.1	0	72.4	22	102	129971	125560	74.9	0
23	46.94	-191130	-185158.6	0	72.4	23	100.9	126195	122404	74.9	0
24	46.94	-192401	-186290.8	0	72.4	24	98.1	119087	115055	74.9	0

Utility Cost Analysis

	Jan	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**t.year**
ac:	0	0	0	97	179	662	1791	1710	716	397	0	0	5552
eqp:	252	240	264	252	264	252	252	276	228	276	252	228	3036
aux:	218	150	151	133	114	128	156	143	103	121	147	223	1787
lit:	190	177	195	187	195	187	190	200	178	200	187	180	2266
edmd:	0	0	0	0	62	132	141	141	111	87	0	0	674
wat:	52	47	51	41	40	32	31	36	32	44	46	48	500
telc:	712	614	661	710	854	1393	2562	2505	1368	1125	632	679	13815
erht:	0	0	0	0	0	0	0	0	0	0	0	0	0
heat:	894	559	558	385	206	38	0	10	48	233	539	921	4391
cheat:	0	0	0	0	0	0	0	0	0	0	0	0	0
cexet:	0	0	0	0	0	0	0	0	0	0	0	0	0
RevRn:	0	0	0	0	0	0	0	0	0	0	0	0	0
tuty:	1606	1173	1219	1095	1060	1431	2562	2515	1416	1358	1171	1600	18206

Pk kW Dem: 54.1 kWh. Conp/yr: 110880 kWh Cost/yr,$: 13141 therms/yr: 0 GasCost,$: 0 E.D.Cost,$/yr: 674

APPENDIX B

TYPICAL METEOROLOGICAL YEAR (TMY3) DATA

Abilene, TX — Abilene Dyess AFB							WMOID 690190
Date (M/DD)	Time (Hour)	A.Temp (°F)	Rel.Hum (%)	Date (M/DD)	Time (Hour)	A.Temp (°F)	Rel.Hum (%)
2/04	1	6.98	95	6/19	1	86	55
2/04	2	5	100	6/19	2	84.2	58
2/04	3	6.98	95	6/19	3	84.2	62
2/04	4	5.9	95	6/19	4	82.4	70
2/04	5	2.84	95	6/19	5	80.6	79
2/04	6	3.92	100	6/19	6	80.6	79
2/04	7	1.94	95	6/19	7	82.4	79
2/04	8	3.92	95	6/19	8	86	70
2/04	9	14.9	86	6/19	9	89.6	63
2/04	10	20.84	72	6/19	10	93.2	55
2/04	11	25.88	56	6/19	11	96.8	47
2/04	12	28.94	51	6/19	12	98.6	45
2/04	13	32.9	43	6/19	13	100.4	42
2/04	14	35.96	38	6/19	14	104	36
2/04	15	37.94	39	6/19	15	104	36
2/04	16	37.94	39	6/19	16	104	34
2/04	17	36.86	43	6/19	17	104	32
2/04	18	34.88	46	6/19	18	104	30
2/04	19	29.84	60	6/19	19	100.4	33
2/04	20	24.98	68	6/19	20	96.8	39
2/04	21	27.86	65	6/19	21	93.2	47
2/04	22	26.96	65	6/19	22	91.4	49
2/04	23	30.92	54	6/19	23	91.4	49
2/04	24	32	59	6/19	24	89.6	52

Chattanooga, TN — Lovell Field AP							WMOID 723240
Date (M/DD)	Time (Hour)	A.Temp (°F)	Rel.Hum (%)	Date (M/DD)	Time (Hour)	A.Temp (°F)	Rel.Hum (%)
12/20	1	19.04	50	6/28	1	75.92	94
12/20	2	17.96	52	6/28	2	75.02	97
12/20	3	17.96	47	6/28	3	73.04	97
12/20	4	17.06	55	6/28	4	73.04	97
12/20	5	15.98	58	6/28	5	73.04	97
12/20	6	15.98	55	6/28	6	71.96	97
12/20	7	15.98	52	6/28	7	75.92	90
12/20	8	15.98	55	6/28	8	82.04	77
12/20	9	17.96	47	6/28	9	84.92	72
12/20	10	19.94	41	6/28	10	89.96	64
12/20	11	21.02	39	6/28	11	91.94	58
12/20	12	23	34	6/28	12	95	49
12/20	13	26.06	29	6/28	13	95	49
12/20	14	28.94	27	6/28	14	96.98	45
12/20	15	30.92	22	6/28	15	96.98	45
12/20	16	33.08	20	6/28	16	98.06	46
12/20	17	33.98	21	6/28	17	96.98	43
12/20	18	33.08	21	6/28	18	95	47
12/20	19	32	22	6/28	19	93.02	52
12/20	20	30.92	23	6/28	20	89.06	61
12/20	21	30.02	27	6/28	21	84.92	70
12/20	22	28.04	32	6/28	22	84.02	72
12/20	23	28.94	31	6/28	23	82.94	74
12/20	24	28.04	34	6/28	24	80.06	85

Chicago, IL — Midway AP							WMOID 72534
Date (M/DD)	Time (Hour)	A.Temp (°F)	Rel.Hum (%)	Date (M/DD)	Time (Hour)	A.Temp (°F)	Rel.Hum (%)
2/03	1	-14.08	48	8/01	1	79.34	7
2/03	2	-15.16	50	8/01	2	79.16	7
2/03	3	-15.16	50	8/01	3	78.98	7
2/03	4	-15.16	50	8/01	4	78.8	6
2/03	5	-16.06	53	8/01	5	77	6
2/03	6	-16.06	53	8/01	6	78.8	6
2/03	7	-17.14	56	8/01	7	80.6	7
2/03	8	-16.06	53	8/01	8	84.2	6
2/03	9	-14.26	51	8/01	9	87.8	5
2/03	10	-12.1	48	8/01	10	89.6	5
2/03	11	-8.14	46	8/01	11	91.4	5
2/03	12	-4	41	8/01	12	93.2	5
2/03	13	-3.1	39	8/01	13	93.2	5
2/03	14	-1.12	40	8/01	14	93.2	4
2/03	15	-1.12	40	8/01	15	93.2	5
2/03	16	-2.02	47	8/01	16	93.2	5
2/03	17	-3.1	46	8/01	17	91.4	5
2/03	18	-5.08	51	8/01	18	91.4	5
2/03	19	-6.16	55	8/01	19	89.6	5
2/03	20	-8.14	58	8/01	20	87.8	6
2/03	21	-9.04	54	8/01	21	87.8	6
2/03	22	-10.12	57	8/01	22	86	7
2/03	23	-10.12	57	8/01	23	86	7
2/03	24	-10.12	54	8/01	24	78.8	6

Houston, TX — William P Hobby AP							WMOID 722435
Date (M/DD)	Time (Hour)	A.Temp (°F)	Rel.Hum (%)	Date (M/DD)	Time (Hour)	A.Temp (°F)	Rel.Hum (%)
3/08	1	38.84	60	8/02	1	82.04	90
3/08	2	36.86	65	8/02	2	80.96	94
3/08	3	35.96	64	8/02	3	80.96	94
3/08	4	34.88	64	8/02	4	80.96	94
3/08	5	34.88	64	8/02	5	80.06	94
3/08	6	33.98	63	8/02	6	80.06	97
3/08	7	32.9	63	8/02	7	82.04	94
3/08	8	33.98	63	8/02	8	84.92	85
3/08	9	36.86	57	8/02	9	87.08	82
3/08	10	41.9	46	8/02	10	89.96	68
3/08	11	44.96	41	8/02	11	89.06	72
3/08	12	50	31	8/02	12	89.96	68
3/08	13	52.16	30	8/02	13	91.94	62
3/08	14	53.96	30	8/02	14	93.02	58
3/08	15	55.94	27	8/02	15	93.92	62
3/08	16	55.94	26	8/02	16	93.02	62
3/08	17	56.84	23	8/02	17	93.02	58
3/08	18	54.86	26	8/02	18	89.06	68
3/08	19	51.98	32	8/02	19	84.92	80
3/08	20	50.9	33	8/02	20	82.04	82
3/08	21	50	34	8/02	21	78.98	97
3/08	22	47.84	43	8/02	22	78.98	97
3/08	23	43.88	54	8/02	23	80.06	94
3/08	24	44.96	50	8/02	24	78.98	97

Miami, FL — Kendall Tamia							WMOID 722029
Date (M/DD)	Time (Hour)	A.Temp (°F)	Rel.Hum (%)	Date (M/DD)	Time (Hour)	A.Temp (°F)	Rel.Hum (%)
1/25	1	50	60	8/01	1	77.54	89
1/25	2	48.92	61	8/01	2	76.82	94
1/25	3	47.84	66	8/01	3	75.92	94
1/25	4	47.84	58	8/01	4	75.2	89
1/25	5	47.84	58	8/01	5	73.4	94
1/25	6	47.84	56	8/01	6	73.4	94
1/25	7	46.94	58	8/01	7	78.8	89
1/25	8	46.94	58	8/01	8	82.4	84
1/25	9	52.88	46	8/01	9	86	70
1/25	10	55.94	45	8/01	10	89.6	63
1/25	11	59.9	46	8/01	11	89.6	56
1/25	12	60.98	41	8/01	12	93.2	53
1/25	13	62.96	38	8/01	13	93.2	50
1/25	14	63.86	34	8/01	14	93.2	50
1/25	15	63.86	37	8/01	15	93.2	47
1/25	16	64.94	35	8/01	16	91.4	63
1/25	17	63.86	31	8/01	17	89.6	63
1/25	18	59.9	44	8/01	18	87.8	66
1/25	19	56.84	53	8/01	19	84.2	74
1/25	20	54.86	64	8/01	20	78.8	74
1/25	21	54.86	59	8/01	21	77	78
1/25	22	52.88	66	8/01	22	75.2	83
1/25	23	52.88	69	8/01	23	77	78
1/25	24	50.9	74	8/01	24	75.2	89

New York City, NY — J F Kennedy Intl AP							WMOID 74486
Date (M/DD)	Time (Hour)	A.Temp (°F)	Rel.Hum (%)	Date (M/DD)	Time (Hour)	A.Temp (°F)	Rel.Hum (%)
2/06	1	8.06	39	8/03	1	80.06	7
2/06	2	8.06	39	8/03	2	80.06	7
2/06	3	6.98	43	8/03	3	78.98	8
2/06	4	8.06	43	8/03	4	78.98	8
2/06	5	8.06	50	8/03	5	78.08	8
2/06	6	8.96	57	8/03	6	78.98	8
2/06	7	8.06	53	8/03	7	78.98	8
2/06	8	8.96	54	8/03	8	80.06	7
2/06	9	10.04	54	8/03	9	82.04	7
2/06	10	12.02	52	8/03	10	84.92	6
2/06	11	12.92	52	8/03	11	84.02	7
2/06	12	15.08	49	8/03	12	82.94	7
2/06	13	17.06	45	8/03	13	84.02	7
2/06	14	17.96	47	8/03	14	86	7
2/06	15	19.04	50	8/03	15	84.02	7
2/06	16	19.04	47	8/03	16	82.94	7
2/06	17	19.94	43	8/03	17	82.04	8
2/06	18	19.94	45	8/03	18	80.06	8
2/06	19	17.06	78	8/03	19	78.98	9
2/06	20	17.96	61	8/03	20	78.98	9
2/06	21	17.96	50	8/03	21	78.98	9
2/06	22	17.06	47	8/03	22	78.08	9
2/06	23	17.06	45	8/03	23	77	9
2/06	24	17.06	40	8/03	24	75.92	9

Phoenix, AZ — Sky Harbor Intl AP							WMOID 722780
Date (M/DD)	Time (Hour)	A.Temp (°F)	Rel.Hum (%)	Date (M/DD)	Time (Hour)	A.Temp (°F)	Rel.Hum (%)
1/20	1	44.06	39	8/01	1	88.7	36
1/20	2	44.06	34	8/01	2	89.06	36
1/20	3	41	42	8/01	3	89.6	40
1/20	4	41	36	8/01	4	89.96	44
1/20	5	39.92	36	8/01	5	89.06	45
1/20	6	37.94	41	8/01	6	89.06	45
1/20	7	37.04	40	8/01	7	87.98	47
1/20	8	37.04	44	8/01	8	89.96	44
1/20	9	41	38	8/01	9	93.92	38
1/20	10	46.94	29	8/01	10	98.06	33
1/20	11	51.08	24	8/01	11	98.96	31
1/20	12	51.98	20	8/01	12	100.04	30
1/20	13	53.96	17	8/01	13	102.02	28
1/20	14	57.02	15	8/01	14	104	26
1/20	15	60.08	13	8/01	15	105.98	26
1/20	16	60.98	12	8/01	16	107.06	25
1/20	17	60.98	13	8/01	17	107.06	25
1/20	18	57.92	18	8/01	18	107.06	26
1/20	19	55.04	21	8/01	19	107.06	25
1/20	20	53.96	20	8/01	20	105.08	28
1/20	21	53.06	20	8/01	21	102.92	29
1/20	22	50	26	8/01	22	102.02	30
1/20	23	46.94	30	8/01	23	100.94	31
1/20	24	46.94	30	8/01	24	98.06	34

Abilene, TX — Abilene Dyess AFB | WMOID 690190

Date (M/DD)	Time (Hour)	A.Temp (°C)	Rel.Hum (%)	Date (M/DD)	Time (Hour)	A.Temp (°C)	Rel.Hum (%)
2/04	1	-13.9	95	6/19	1	30	55
2/04	2	-15	100	6/19	2	29	58
2/04	3	-13.9	95	6/19	3	29	62
2/04	4	-14.5	95	6/19	4	28	70
2/04	5	-16.2	95	6/19	5	27	79
2/04	6	-15.6	100	6/19	6	27	79
2/04	7	-16.7	95	6/19	7	28	79
2/04	8	-15.6	95	6/19	8	30	70
2/04	9	-9.5	86	6/19	9	32	63
2/04	10	-6.2	72	6/19	10	34	55
2/04	11	-3.4	56	6/19	11	36	47
2/04	12	-1.7	51	6/19	12	37	45
2/04	13	0.5	43	6/19	13	38	42
2/04	14	2.2	38	6/19	14	40	36
2/04	15	3.3	39	6/19	15	40	36
2/04	16	3.3	39	6/19	16	40	34
2/04	17	2.7	43	6/19	17	40	32
2/04	18	1.6	46	6/19	18	40	30
2/04	19	-1.2	60	6/19	19	38	33
2/04	20	-3.9	68	6/19	20	36	39
2/04	21	-2.3	65	6/19	21	34	47
2/04	22	-2.8	65	6/19	22	33	49
2/04	23	-0.6	54	6/19	23	33	49
2/04	24	0	59	6/19	24	32	52

Chattanooga, TN — Lovell Field AP | WMOID 723240

Date (M/DD)	Time (Hour)	A.Temp (°C)	Rel.Hum (%)	Date (M/DD)	Time (Hour)	A.Temp (°C)	Rel.Hum (%)
12/20	1	-7.2	50	6/28	1	24.4	94
12/20	2	-7.8	52	6/28	2	23.9	97
12/20	3	-7.8	47	6/28	3	22.8	97
12/20	4	-8.3	55	6/28	4	22.8	97
12/20	5	-8.9	58	6/28	5	22.8	97
12/20	6	-8.9	55	6/28	6	22.2	97
12/20	7	-8.9	52	6/28	7	24.4	90
12/20	8	-8.9	55	6/28	8	27.8	77
12/20	9	-7.8	47	6/28	9	29.4	72
12/20	10	-6.7	41	6/28	10	32.2	64
12/20	11	-6.1	39	6/28	11	33.3	58
12/20	12	-5	34	6/28	12	35	49
12/20	13	-3.3	29	6/28	13	35	49
12/20	14	-1.7	27	6/28	14	36.1	45
12/20	15	-0.6	22	6/28	15	36.1	45
12/20	16	0.6	20	6/28	16	36.7	46
12/20	17	1.1	21	6/28	17	36.1	43
12/20	18	0.6	21	6/28	18	35	47
12/20	19	0	22	6/28	19	33.9	52
12/20	20	-0.6	23	6/28	20	31.7	61
12/20	21	-1.1	27	6/28	21	29.4	70
12/20	22	-2.2	32	6/28	22	28.9	72
12/20	23	-1.7	31	6/28	23	28.3	74
12/20	24	-2.2	34	6/28	24	26.7	85

Chicago, IL — Midway AP | WMOID 7253

Date (M/DD)	Time (Hour)	A.Temp (°C)	Rel.Hum (%)	Date (M/DD)	Time (Hour)	A.Temp (°C)	Rel.Hu (%)
2/03	1	-25.6	48	8/01	1	26.3	[illegible]
2/03	2	-26.2	50	8/01	2	26.2	[illegible]
2/03	3	-26.2	50	8/01	3	26.1	[illegible]
2/03	4	-26.2	50	8/01	4	26	[illegible]
2/03	5	-26.7	53	8/01	5	25	[illegible]
2/03	6	-26.7	53	8/01	6	26	[illegible]
2/03	7	-27.3	56	8/01	7	27	[illegible]
2/03	8	-26.7	53	8/01	8	29	[illegible]
2/03	9	-25.7	51	8/01	9	31	[illegible]
2/03	10	-24.5	48	8/01	10	32	[illegible]
2/03	11	-22.3	46	8/01	11	33	[illegible]
2/03	12	-20	41	8/01	12	34	[illegible]
2/03	13	-19.5	39	8/01	13	34	[illegible]
2/03	14	-18.4	40	8/01	14	34	[illegible]
2/03	15	-18.4	40	8/01	15	34	[illegible]
2/03	16	-18.9	47	8/01	16	34	[illegible]
2/03	17	-19.5	46	8/01	17	33	[illegible]
2/03	18	-20.6	51	8/01	18	33	[illegible]
2/03	19	-21.2	55	8/01	19	32	[illegible]
2/03	20	-22.3	58	8/01	20	31	[illegible]
2/03	21	-22.8	54	8/01	21	31	[illegible]
2/03	22	-23.4	57	8/01	22	30	[illegible]
2/03	23	-23.4	57	8/01	23	30	[illegible]
2/03	24	-23.4	54	8/01	24	26	[illegible]

Houston, TX — William P Hobby AP | WMOID 722435

Date (M/DD)	Time (Hour)	A.Temp (°C)	Rel.Hum (%)	Date (M/DD)	Time (Hour)	A.Temp (°C)	Rel.Hum (%)
3/08	1	3.8	60	8/02	1	27.8	90
3/08	2	2.7	65	8/02	2	27.2	94
3/08	3	2.2	64	8/02	3	27.2	94
3/08	4	1.6	64	8/02	4	27.2	94
3/08	5	1.6	64	8/02	5	26.7	94
3/08	6	1.1	63	8/02	6	26.7	97
3/08	7	0.5	63	8/02	7	27.8	94
3/08	8	1.1	63	8/02	8	29.4	85
3/08	9	2.7	57	8/02	9	30.6	82
3/08	10	5.5	46	8/02	10	32.2	68
3/08	11	7.2	41	8/02	11	31.7	72
3/08	12	10	31	8/02	12	32.2	68
3/08	13	11.2	30	8/02	13	33.3	62
3/08	14	12.2	30	8/02	14	33.9	58
3/08	15	13.3	27	8/02	15	34.4	62
3/08	16	13.3	26	8/02	16	33.9	62
3/08	17	13.8	23	8/02	17	33.9	58
3/08	18	12.7	26	8/02	18	31.7	68
3/08	19	11.1	32	8/02	19	29.4	80
3/08	20	10.5	33	8/02	20	27.8	82
3/08	21	10	34	8/02	21	26.1	97
3/08	22	8.8	43	8/02	22	26.1	97
3/08	23	6.6	54	8/02	23	26.7	94
3/08	24	7.2	50	8/02	24	26.1	97

Miami, FL — Kendall Tamia | WMOID 722029

Date (M/DD)	Time (Hour)	A.Temp (°C)	Rel.Hum (%)	Date (M/DD)	Time (Hour)	A.Temp (°C)	Rel.Hum (%)
1/25	1	10	60	8/01	1	25.3	89
1/25	2	9.4	61	8/01	2	24.9	94
1/25	3	8.8	66	8/01	3	24.4	94
1/25	4	8.8	58	8/01	4	24	89
1/25	5	8.8	58	8/01	5	23	94
1/25	6	8.8	56	8/01	6	23	94
1/25	7	8.3	58	8/01	7	26	89
1/25	8	8.3	58	8/01	8	28	84
1/25	9	11.6	46	8/01	9	30	70
1/25	10	13.3	45	8/01	10	32	63
1/25	11	15.5	46	8/01	11	32	56
1/25	12	16.1	41	8/01	12	34	53
1/25	13	17.2	38	8/01	13	34	50
1/25	14	17.7	34	8/01	14	34	50
1/25	15	17.7	37	8/01	15	34	47
1/25	16	18.3	35	8/01	16	33	63
1/25	17	17.7	31	8/01	17	32	63
1/25	18	15.5	44	8/01	18	31	66
1/25	19	13.8	53	8/01	19	29	74
1/25	20	12.7	64	8/01	20	26	74
1/25	21	12.7	59	8/01	21	25	78
1/25	22	11.6	66	8/01	22	24	83
1/25	23	11.6	69	8/01	23	25	78
1/25	24	10.5	74	8/01	24	24	89

New York City, NY — J F Kennedy Intl AP | WMOID 7448

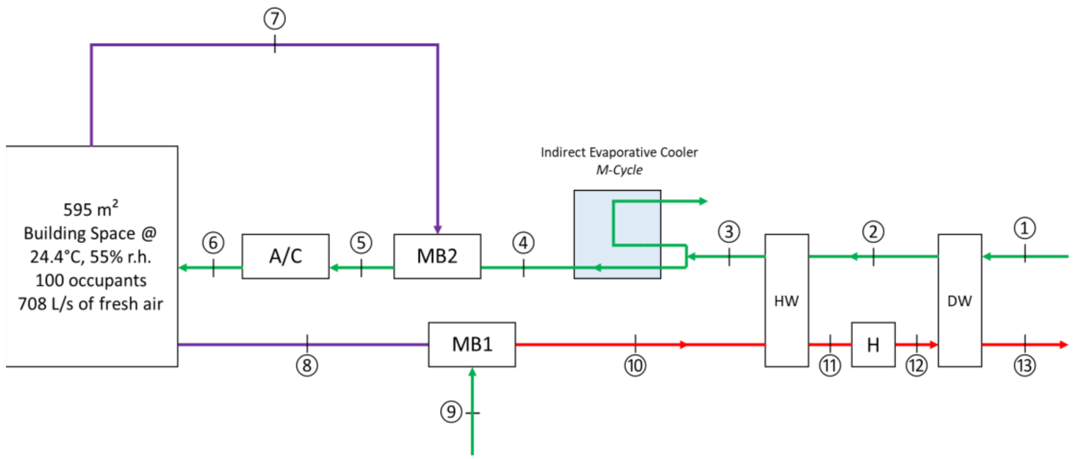
Date (M/DD)	Time (Hour)	A.Temp (°C)	Rel.Hum (%)	Date (M/DD)	Time (Hour)	A.Temp (°C)	Rel.Hu (%)
2/06	1	-13.3	39	8/03	1	26.7	[illegible]
2/06	2	-13.3	39	8/03	2	26.7	[illegible]
2/06	3	-13.9	43	8/03	3	26.1	[illegible]
2/06	4	-13.3	43	8/03	4	26.1	[illegible]
2/06	5	-13.3	50	8/03	5	25.6	[illegible]
2/06	6	-12.8	57	8/03	6	26.1	[illegible]
2/06	7	-13.3	53	8/03	7	26.1	[illegible]
2/06	8	-12.8	54	8/03	8	26.7	[illegible]
2/06	9	-12.2	54	8/03	9	27.8	[illegible]
2/06	10	-11.1	52	8/03	10	29.4	[illegible]
2/06	11	-10.6	52	8/03	11	28.9	[illegible]
2/06	12	-9.4	49	8/03	12	28.3	[illegible]
2/06	13	-8.3	45	8/03	13	28.9	[illegible]
2/06	14	-7.8	47	8/03	14	30	[illegible]
2/06	15	-7.2	50	8/03	15	28.9	[illegible]
2/06	16	-7.2	47	8/03	16	28.3	[illegible]
2/06	17	-6.7	43	8/03	17	27.8	[illegible]
2/06	18	-6.7	45	8/03	18	26.7	[illegible]
2/06	19	-8.3	78	8/03	19	26.1	[illegible]
2/06	20	-7.8	61	8/03	20	26.1	[illegible]
2/06	21	-7.8	50	8/03	21	26.1	[illegible]
2/06	22	-8.3	47	8/03	22	25.6	[illegible]
2/06	23	-8.3	45	8/03	23	25	[illegible]
2/06	24	-8.3	40	8/03	24	24.4	[illegible]

Phoenix, AZ — Sky Harbor Intl AP | WMOID 722780

Date (M/DD)	Time (Hour)	A.Temp (°C)	Rel.Hum (%)	Date (M/DD)	Time (Hour)	A.Temp (°C)	Rel.Hum (%)
1/20	1	6.7	39	8/01	1	31.5	36
1/20	2	6.7	34	8/01	2	31.7	36
1/20	3	5	42	8/01	3	32	40
1/20	4	5	36	8/01	4	32.2	44
1/20	5	4.4	36	8/01	5	31.7	45
1/20	6	3.3	41	8/01	6	31.7	45
1/20	7	2.8	40	8/01	7	31.1	47
1/20	8	2.8	44	8/01	8	32.2	44
1/20	9	5	38	8/01	9	34.4	38
1/20	10	8.3	29	8/01	10	36.7	33
1/20	11	10.6	24	8/01	11	37.2	31
1/20	12	11.1	20	8/01	12	37.8	30
1/20	13	12.2	17	8/01	13	38.9	28
1/20	14	13.9	15	8/01	14	40	26
1/20	15	15.6	13	8/01	15	41.1	26
1/20	16	16.1	12	8/01	16	41.7	25
1/20	17	16.1	13	8/01	17	41.7	25
1/20	18	14.4	18	8/01	18	41.7	26
1/20	19	12.8	21	8/01	19	41.7	25
1/20	20	12.2	20	8/01	20	40.6	28
1/20	21	11.7	20	8/01	21	39.4	29
1/20	22	10	26	8/01	22	38.9	30
1/20	23	8.3	30	8/01	23	38.3	31
1/20	24	8.3	30	8/01	24	36.7	34

APPENDIX C

PEAK COOLING LOAD DATA SHEETS



WMOID	690190
Load Type	PCL

Location	Abilene, TX	
Elevation	0 m	
Pressure	101.33 kPa	
Outdoor Conditions		
M	D	H
6	19	15
DBT	40 °C	
RH	36%	
Room Conditions		
Q	708 L/s	
T	24.4 °C	
φ	55%	
P.Load	24.94 tons	
L.Load	9.7 tons	
SHR	0.611	

MDWS Input Parameters	
Vel, Pro Air	2.12 m/s
Speed	15.5 RPH
Vel, Reg Air	2.34 m/s
Material	Silica Gel
(State 1)	
T, Pro Air In	40 °C
W, Pro Air in	0.0168 kg/kgda
(State 12)	
T, Reg Air In	81 °C
W, Reg Air In	0.0136 kg/kgda
MDWS Output Values	
(State 2)	
T, Pro Air Out	67 °C
W, Pro Air Out	0.0105 kg/kgda
(State 13)	
T, Reg Air Out	76.21 °C
W, Reg Air Out	0.0199 kg/kgda

State 1	*(Outdoor Conditions)*
T	40 °C
φ	36%
ω	0.0168 kg/kg
h	83.4 kJ/kg
v	0.911 m³/kg
ṁ	1.55 kg/s

State 2	
T	67 °C
φ	6%
ω	0.0105 kg/kg
h	95.0 kJ/kg
v	0.980 m³/kg
ṁ	1.55 kg/s

State 3	
T	46.7 °C
φ	16%
ω	0.0105 kg/kg
TWB	24.7 °C
h	74.2 kJ/kg
v	0.922 m³/kg
ṁ	1.55 kg/s

State 4	
T	23.6 °C
φ	58%
ω	0.0105 kg/kg
h	50.5 kJ/kg
v	0.855 m³/kg
ṁ	0.777 kg/s

Color Legend
Given/Assumed Values
DW Program (MDWS)
Psychrometric Chart
Heat Wheel Calc/Prog

State 5'	
T	26.3 °C
φ	53%
ω	0.011 kg/kg
h	55.3 kJ/kg
v	0.864 m³/kg
ṁ	6.35 kg/s

	kW	%Diff
Q_{AC}	-87.0	22.7%
$Q_{AC'}$	-112.6	

State 5	
T	24.3 °C
φ	55%
ω	0.011 kg/kg
h	51.3 kJ/kg
v	0.857 m³/kg
ṁ	6.35 kg/s

State 6	
T	16.1 °C
φ	74%
ω	59.1 grains/kg
ω	0.0084 kg/kg
h	37.6 kJ/kg
v	0.831 m³/kg
ṁ	6.35 kg/s

State 7	*(Space Conditions)*
T	24.4 °C
φ	55%
ω	0.0105 kg/kg
h	51.4 kJ/kg
v	0.857 m³/kg
ṁ	5.57 kg/s

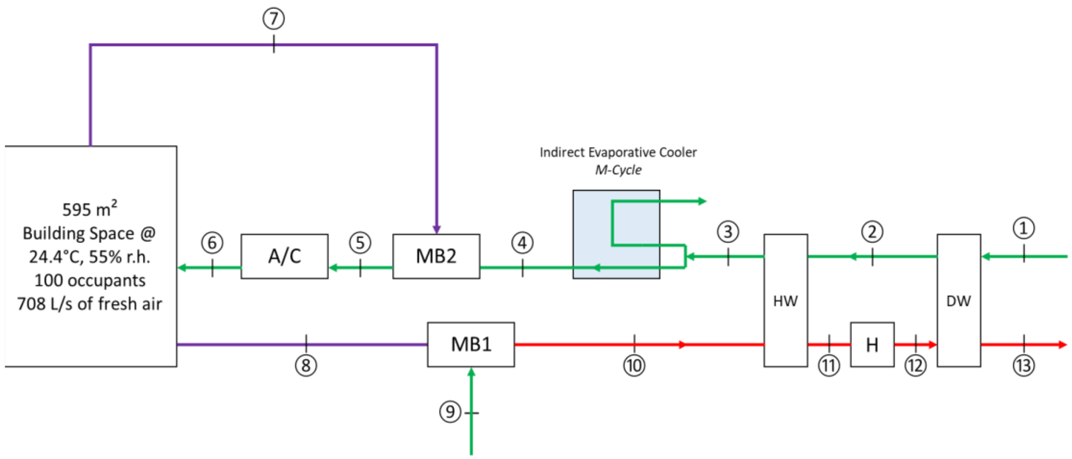
State 8	*(Space Conditions)*
T	24.4 °C
φ	55%
ω	0.0105 kg/kg
h	51.4 kJ/kg
v	0.857 m³/kg
ṁ	0.777 kg/s

State 9	*(Outdoor Conditions)*
T	40 °C
φ	36%
ω	0.0168 kg/kg
h	83.4 kJ/kg
v	0.911 m³/kg
ṁ	0.777 kg/s

State 10	
T	32.2 °C
φ	45%
ω	0.0136 kg/kg
h	67.39 kJ/kg
v	0.884 m³/kg
ṁ	1.55 kg/s

State 11	
T	54.7 °C
φ	14%
ω	0.0136 kg/kg
h	90.51 kJ/kg
v	0.949 m³/kg
ṁ	1.55 kg/s

State 12	
T	81 °C
φ	4%
ω	0.0136 kg/kg
h	117.65 kJ/kg
v	1.03 m³/kg
ṁ	1.55 kg/s



WMOID	723240
Load Type	PCL

Location	Chattanooga, TN	
Elevation	0 m	
Pressure	101.33 kPa	
Outdoor Conditions		
M	D	H
6	28	16
DBT	36.7 °C	
RH	46%	
Room Conditions		
Q	708 L/s	
T	24.4 °C	
φ	55%	
P.Load	21.29 tons	
L.Load	7.9 tons	
SHR	0.629	

MDWS Input Parameters	
Vel, Pro Air	2.12 m/s
Speed	15.5 RPH
Vel, Reg Air	2.34 m/s
Material	Silica Gel
(State 1)	
T, Pro Air In	36.7 °C
W, Pro Air in	0.0180 kg/kgda
(State 12)	
T, Reg Air In	81 °C
W, Reg Air In	0.0142 kg/kgda
MDWS Output Values	
(State 2)	
T, Pro Air Out	65.7 °C
W, Pro Air Out	0.0111 kg/kgda
(State 13)	
T, Reg Air Out	75.52 °C
W, Reg Air Out	0.0211 kg/kgda

State 1	*(Outdoor Conditions)*
T	36.7 °C
φ	46%
ω	0.0180 kg/kg
h	83.0 kJ/kg
v	0.903 m³/kg
ṁ	1.57 kg/s

State 2	
T	65.7 °C
φ	7%
ω	0.0111 kg/kg
h	95.2 kJ/kg
v	0.977 m³/kg
ṁ	1.57 kg/s

State 3	
T	45.3 °C
φ	18%
ω	0.0111 kg/kg
TWB	24.7 °C
h	74.3 kJ/kg
v	0.918 m³/kg
ṁ	1.57 kg/s

State 4	
T	23.7 °C
φ	61%
ω	0.0111 kg/kg
h	52.1 kJ/kg
v	0.856 m³/kg
ṁ	0.784 kg/s

Color Legend
Given/Assumed Values
DW Program (MDWS)
Psychrometric Chart
Heat Wheel Calc/Prog

State 5	
T	24.3 °C
φ	56%
ω	0.011 kg/kg
h	51.5 kJ/kg
v	0.857 m³/kg
ṁ	5.58 kg/s

State 6	
T	16.1 °C
φ	75%
ω	60.2 grains/lb
ω	0.0086 kg/kg
h	38.0 kJ/kg
v	0.831 m³/kg
ṁ	5.58 kg/s

State 7	*(Space Conditions)*
T	24.4 °C
φ	55%
ω	0.0105 kg/kg
h	51.4 kJ/kg
v	0.857 m³/kg
ṁ	4.80 kg/s

State 8	*(Space Conditions)*
T	24.4 °C
φ	55%
ω	0.0105 kg/kg
h	51.4 kJ/kg
v	0.857 m³/kg
ṁ	0.784 kg/s

State 5'	
T	26.2 °C
φ	54%
ω	0.012 kg/kg
h	55.8 kJ/kg
v	0.864 m³/kg
ṁ	5.58 kg/s

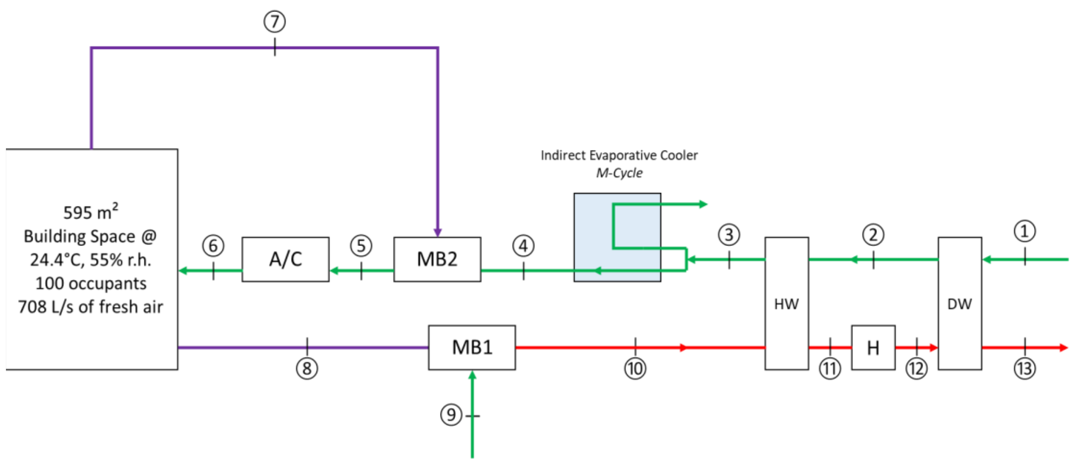
	kW	%Diff
Q_{AC}	-75.4	24.4%
Q'_{AC}	-99.7	

State 9	*(Outdoor Conditions)*
T	36.7 °C
φ	46%
ω	0.0180 kg/kg
h	83.0 kJ/kg
v	0.903 m³/kg
ṁ	0.784 kg/s

State 10	
T	30.6 °C
φ	52%
ω	0.0142 kg/kg
h	67.22 kJ/kg
v	0.880 m³/kg
ṁ	1.57 kg/s

State 11	
T	53.2 °C
φ	16%
ω	0.0142 kg/kg
h	90.51 kJ/kg
v	0.946 m³/kg
ṁ	1.57 kg/s

State 12	
T	81 °C
φ	5%
ω	0.0142 kg/kg
h	119.24 kJ/kg
v	1.03 m³/kg
ṁ	1.57 kg/s



WMOID	725340
Load Type	PCL

Location	Chicago, IL	
Elevation	0 m	
Pressure	101.33 kPa	
Outdoor Conditions		
M	D	H
8	1	13
DBT	34 °C	
RH	50%	
Room Conditions		
Q	708 L/s	
T	24.4 °C	
φ	55%	
P.Load	21.86 tons	
L.Load	9.2 tons	
SHR	0.579	

MDWS Input Parameters	
Vel, Pro Air	2.12 m/s
Speed	15.5 RPH
Vel, Reg Air	2.34 m/s
Material	Silica Gel
(State 1)	
T, Pro Air In	34 °C
W, Pro Air in	0.0168 kg/kgda
(State 12)	
T, Reg Air In	81 °C
W, Reg Air In	0.0137 kg/kgda
MDWS Output Values	
(State 2)	
T, Pro Air Out	64.5 °C
W, Pro Air Out	0.01 kg/kgda
(State 13)	
T, Reg Air Out	77.14 °C
W, Reg Air Out	0.0205 kg/kgda

State 1	*(Outdoor Conditions)*
T	34 °C
φ	50%
ω	0.0168 kg/kg
h	77.2 kJ/kg
v	0.894 m³/kg
ṁ	1.58 kg/s

State 2	
T	64.5 °C
φ	7%
ω	0.01 kg/kg
h	91.1 kJ/kg
v	0.972 m³/kg
ṁ	1.58 kg/s

State 3	
T	44.0 °C
φ	18%
ω	0.01 kg/kg
TWB	23.7 °C
h	70.1 kJ/kg
v	0.913 m³/kg
ṁ	1.58 kg/s

State 4	
T	22.6 °C
φ	58%
ω	0.01 kg/kg
h	48.2 kJ/kg
v	0.851 m³/kg
ṁ	0.792 kg/s

Color Legend
Given/Assumed Values
DW Program (MDWS)
Psychrometric Chart
Heat Wheel Calc/Prog

State 5	
T	24.2 °C
φ	55%
ω	0.010 kg/kg
h	50.9 kJ/kg
v	0.856 m³/kg
ṁ	5.27 kg/s

State 6	
T	16.1 °C
φ	72%
ω	57 grains/kg
ω	0.0081 kg/kg
h	36.8 kJ/kg
v	0.830 m³/kg
ṁ	5.27 kg/s

State 7	*(Space Conditions)*
T	24.4 °C
φ	55%
ω	0.0105 kg/kg
h	51.4 kJ/kg
v	0.857 m³/kg
ṁ	4.48 kg/s

State 8	*(Space Conditions)*
T	24.4 °C
φ	55%
ω	0.0105 kg/kg
h	51.4 kJ/kg
v	0.857 m³/kg
ṁ	0.792 kg/s

State 5'	
T	25.9 °C
φ	55%
ω	0.011 kg/kg
h	55.3 kJ/kg
v	0.863 m³/kg
ṁ	5.27 kg/s

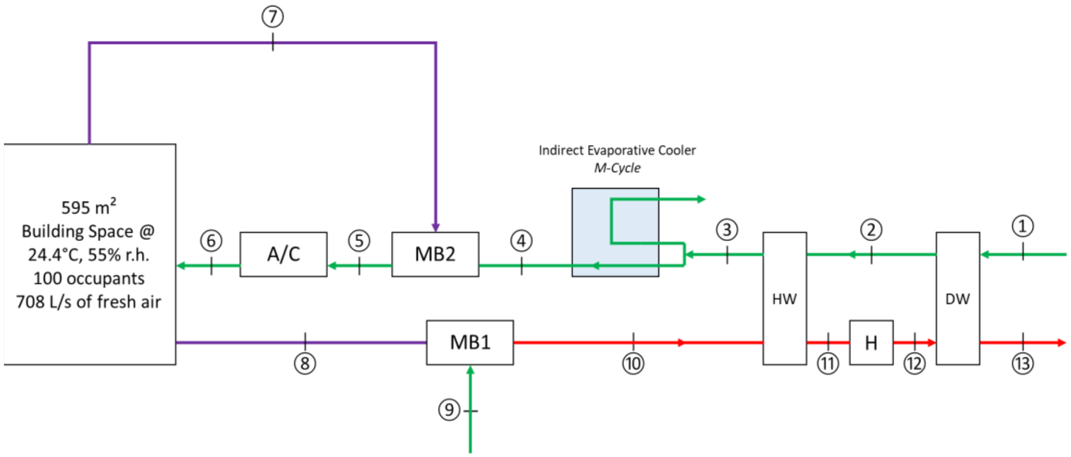
	kW	%Diff
Q_{AC}	-74.4	23.6%
Q'_{AC}	-97.3	

State 9	*(Outdoor Conditions)*
T	34 °C
φ	50%
ω	0.0168 kg/kg
h	77.2 kJ/kg
v	0.894 m³/kg
ṁ	0.792 kg/s

State 10	
T	29.2 °C
φ	54%
ω	0.0137 kg/kg
h	64.31 kJ/kg
v	0.875 m³/kg
ṁ	1.58 kg/s

State 11	
T	51.9 °C
φ	16%
ω	0.0137 kg/kg
h	87.63 kJ/kg
v	0.941 m³/kg
ṁ	1.58 kg/s

State 12	
T	81 °C
φ	4%
ω	0.0137 kg/kg
h	117.69 kJ/kg
v	1.03 m³/kg
ṁ	1.58 kg/s



WMOID	722435
Load Type	PCL

Location	Houston, TX	
Elevation	0 m	
Pressure	101.33 kPa	
Outdoor Conditions		
M	D	H
8	2	15
DBT	34.4 °C	
RH	62%	
Room Conditions		
Q	708 L/s	
T	24.4 °C	
φ	55%	
P.Load	25.02 tons	
L.Load	11.7 tons	
SHR	0.532	

MDWS Input Parameters	
Vel, Pro Air	2.12 m/s
Speed	15.5 RPH
Vel, Reg Air	2.34 m/s
Material	Silica Gel
(State 1)	
T, Pro Air In	34.4 °C
W, Pro Air in	0.0214 kg/kgda
(State 12)	
T, Reg Air In	81 °C
W, Reg Air In	0.0160 kg/kgda
MDWS Output Values	
(State 2)	
T, Pro Air Out	64.9 °C
W, Pro Air Out	0.0139 kg/kgda
(State 13)	
T, Reg Air Out	73.84 °C
W, Reg Air Out	0.0235 kg/kgda

State 1	*(Outdoor Conditions)*
T	34.4 °C
φ	62%
ω	0.0214 kg/kg
h	89.6 kJ/kg
v	0.901 m³/kg
ṁ	1.57 kg/s

State 2	
T	64.9 °C
φ	9%
ω	0.0139 kg/kg
h	101.7 kJ/kg
v	0.979 m³/kg
ṁ	1.57 kg/s

State 3	
T	44.3 °C
φ	24%
ω	0.0139 kg/kg
TWB	26.1 °C
h	80.5 kJ/kg
v	0.919 m³/kg
ṁ	1.57 kg/s

State 4	
T	25.2 °C
φ	69%
ω	0.0139 kg/kg
h	60.8 kJ/kg
v	0.864 m³/kg
ṁ	0.785 kg/s

Color Legend
Given/Assumed Values
DW Program (MDWS)
Psychrometric Chart
Heat Wheel Calc/Prog

State 5	
T	24.6 °C
φ	57%
ω	0.011 kg/kg
h	52.7 kJ/kg
v	0.858 m³/kg
ṁ	5.55 kg/s

State 6	
T	16.1 °C
φ	67%
ω	53.45 grains/kg
ω	0.0076 kg/kg
h	35.5 kJ/kg
v	0.830 m³/kg
ṁ	5.55 kg/s

State 7	*(Space Conditions)*
T	24.4 °C
φ	55%
ω	0.0105 kg/kg
h	51.4 kJ/kg
v	0.857 m³/kg
ṁ	4.76 kg/s

State 8	*(Space Conditions)*
T	24.4 °C
φ	55%
ω	0.0105 kg/kg
h	51.4 kJ/kg
v	0.857 m³/kg
ṁ	0.785 kg/s

State 5'	
T	25.9 °C
φ	58%
ω	0.012 kg/kg
h	56.8 kJ/kg
v	0.864 m³/kg
ṁ	5.55 kg/s

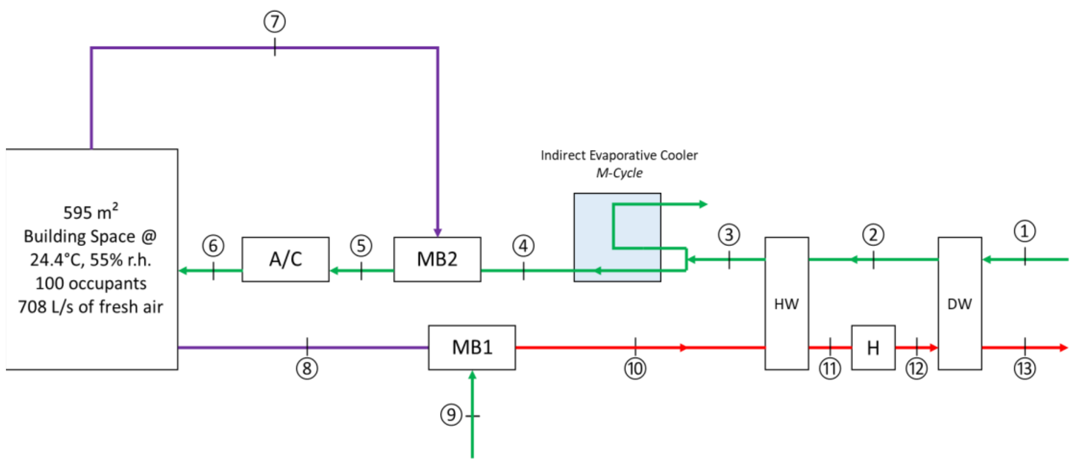
	kW	%Diff
Q_{AC}	-95.4	19.2%
Q'_{AC}	-118.0	

State 9	*(Outdoor Conditions)*
T	34.4 °C
φ	62%
ω	0.0214 kg/kg
h	89.6 kJ/kg
v	0.901 m³/kg
ṁ	0.785 kg/s

State 10	
T	29.4 °C
φ	62%
ω	0.0160 kg/kg
h	70.48 kJ/kg
v	0.879 m³/kg
ṁ	1.57 kg/s

State 11	
T	52.2 °C
φ	18%
ω	0.0160 kg/kg
h	94.01 kJ/kg
v	0.945 m³/kg
ṁ	1.57 kg/s

State 12	
T	81 °C
φ	5%
ω	0.0160 kg/kg
h	123.85 kJ/kg
v	1.03 m³/kg
ṁ	1.57 kg/s



WMOID	722029
Load Type	PCL

Location	Miami, FL	
Elevation	0 m	
Pressure	101.33 kPa	
Outdoor Conditions		
M	D	H
8	1	16
DBT	33 °C	
RH	63%	
Room Conditions		
Q	708 L/s	
T	24.4 °C	
φ	55%	
P.Load	22.93 tons	
L.Load	11.5 tons	
SHR	0.498	

MDWS Input Parameters	
Vel, Pro Air	2.12 m/s
Speed	15.5 RPH
Vel, Reg Air	2.34 m/s
Material	Silica Gel
(State 1)	
T, Pro Air In	33 °C
W, Pro Air in	0.0201 kg/kgda
(State 12)	
T, Reg Air In	81 °C
W, Reg Air In	0.0153 kg/kgda
MDWS Output Values	
(State 2)	
T, Pro Air Out	64 °C
W, Pro Air Out	0.0125 kg/kgda
(State 13)	
T, Reg Air Out	74.48 °C
W, Reg Air Out	0.0229 kg/kgda

State 1	*(Outdoor Conditions)*
T	33 °C
φ	63%
ω	0.0201 kg/kg
h	84.7 kJ/kg
v	0.895 m³/kg
ṁ	1.58 kg/s

State 2	
T	64 °C
φ	8%
ω	0.0125 kg/kg
h	97.1 kJ/kg
v	0.974 m³/kg
ṁ	1.58 kg/s

State 3	
T	43.6 °C
φ	22%
ω	0.0125 kg/kg
TWB	25.1 °C
h	76.1 kJ/kg
v	0.915 m³/kg
ṁ	1.58 kg/s

State 4	
T	24.2 °C
φ	66%
ω	0.0125 kg/kg
h	56.2 kJ/kg
v	0.859 m³/kg
ṁ	0.791 kg/s

Color Legend
Given/Assumed Values
DW Program (MDWS)
Psychrometric Chart
Heat Wheel Calc/Prog

State 5	
T	24.4 °C
φ	57%
ω	0.011 kg/kg
h	52.2 kJ/kg
v	0.858 m³/kg
ṁ	4.76 kg/s

State 6	
T	16.1 °C
φ	63%
ω	50.5 grains/kg
ω	0.0072 kg/kg
h	34.5 kJ/kg
v	0.829 m³/kg
ṁ	4.76 kg/s

State 7	*(Space Conditions)*
T	24.4 °C
φ	55%
ω	0.0105 kg/kg
h	51.4 kJ/kg
v	0.857 m³/kg
ṁ	3.97 kg/s

State 8	*(Space Conditions)*
T	24.4 °C
φ	55%
ω	0.0105 kg/kg
h	51.4 kJ/kg
v	0.857 m³/kg
ṁ	0.791 kg/s

State 5'	
T	25.9 °C
φ	58%
ω	0.012 kg/kg
h	56.9 kJ/kg
v	0.864 m³/kg
ṁ	4.76 kg/s

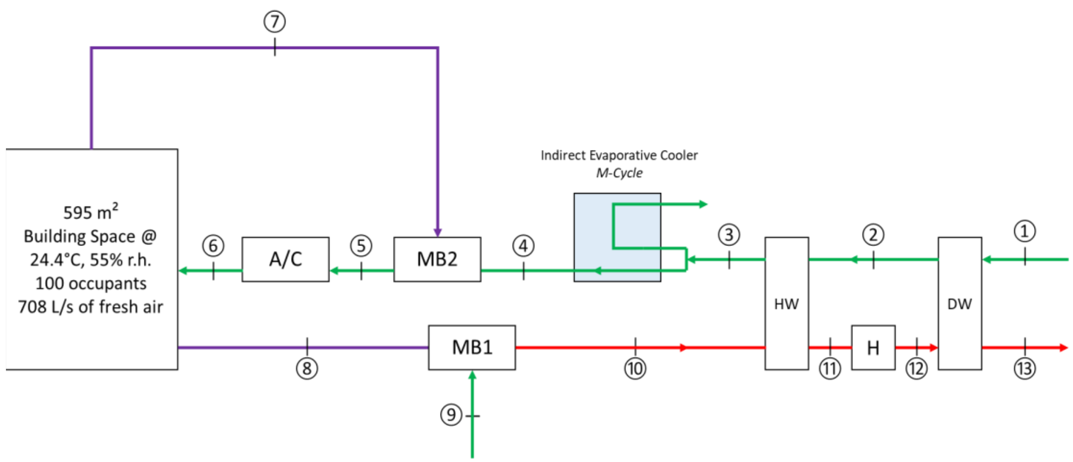
	kW	%Diff
Q_{AC}	-84.4	21.1%
Q'_{AC}	-107.0	

State 9	*(Outdoor Conditions)*
T	33 °C
φ	63%
ω	0.0201 kg/kg
h	84.7 kJ/kg
v	0.895 m³/kg
ṁ	0.791 kg/s

State 10	
T	28.7 °C
φ	62%
ω	0.0153 kg/kg
h	68.04 kJ/kg
v	0.876 m³/kg
ṁ	1.58 kg/s

State 11	
T	51.3 °C
φ	18%
ω	0.0153 kg/kg
h	91.39 kJ/kg
v	0.942 m³/kg
ṁ	1.58 kg/s

State 12	
T	81 °C
φ	5%
ω	0.0153 kg/kg
h	122.09 kJ/kg
v	1.03 m³/kg
ṁ	1.58 kg/s



WMOID	744860
Load Type	PCL

Location	New York City, NY	
Elevation	0 m	
Pressure	101.33 kPa	
Outdoor Conditions		
M	D	H
8	3	14
DBT	30 °C	
RH	72%	
Room Conditions		
Q	708 L/s	
T	24.4 °C	
φ	55%	
P.Load	21.53 tons	
L.Load	9.5 tons	
SHR	0.559	

MDWS Input Parameters	
Vel, Pro Air	2.12 m/s
Speed	15.5 RPH
Vel, Reg Air	2.34 m/s
Material	Silica Gel
(State 1)	
T, Pro Air In	30 °C
W, Pro Air in	0.0193 kg/kgda
(State 12)	
T, Reg Air In	81 °C
W, Reg Air In	0.0149 kg/kgda
MDWS Output Values	
(State 2)	
T, Pro Air Out	63 °C
W, Pro Air Out	0.0118 kg/kgda
(State 13)	
T, Reg Air Out	76.16 °C
W, Reg Air Out	0.0224 kg/kgda

State 1	*(Outdoor Conditions)*
T	30 °C
φ	72%
ω	0.0193 kg/kg
h	79.7 kJ/kg
v	0.886 m³/kg
ṁ	1.60 kg/s

State 2	
T	63 °C
φ	8%
ω	0.0118 kg/kg
h	94.3 kJ/kg
v	0.970 m³/kg
ṁ	1.60 kg/s

State 3	
T	42.3 °C
φ	23%
ω	0.0118 kg/kg
TWB	24.4 °C
h	73.0 kJ/kg
v	0.911 m³/kg
ṁ	1.60 kg/s

State 4	
T	23.5 °C
φ	65%
ω	0.0118 kg/kg
h	53.6 kJ/kg
v	0.856 m³/kg
ṁ	0.799 kg/s

Color Legend
Given/Assumed Values
DW Program (MDWS)
Psychrometric Chart
Heat Wheel Calc/Prog

State 5'	
T	25.3 °C
φ	59%
ω	0.012 kg/kg
h	55.9 kJ/kg
v	0.862 m³/kg
ṁ	5.01 kg/s

State 5	
T	24.3 °C
φ	57%
ω	0.011 kg/kg
h	51.7 kJ/kg
v	0.857 m³/kg
ṁ	5.01 kg/s

State 6	
T	16.1 °C
φ	70%
ω	55.55 grains/kg
ω	0.0079 kg/kg
h	36.3 kJ/kg
v	0.830 m³/kg
ṁ	5.01 kg/s

State 7	*(Space Conditions)*
T	24.4 °C
φ	55%
ω	0.0105 kg/kg
h	51.4 kJ/kg
v	0.857 m³/kg
ṁ	4.22 kg/s

State 8	*(Space Conditions)*
T	24.4 °C
φ	55%
ω	0.0105 kg/kg
h	51.4 kJ/kg
v	0.857 m³/kg
ṁ	0.799 kg/s

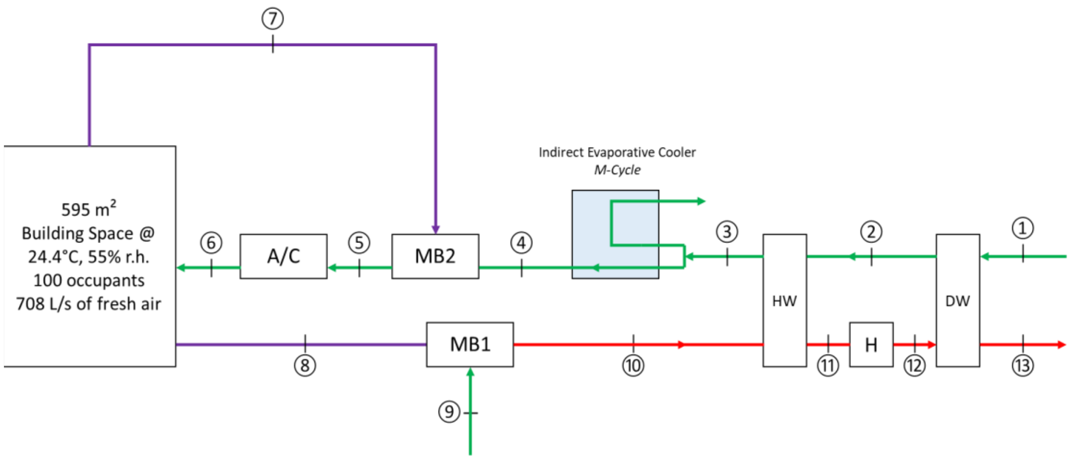
	kW	%Diff
Q_{AC}	-77.5	21.2%
Q'_{AC}	-98.3	

State 9	*(Outdoor Conditions)*
T	30 °C
φ	72%
ω	0.0193 kg/kg
h	79.7 kJ/kg
v	0.886 m³/kg
ṁ	0.799 kg/s

State 10	
T	27.2 °C
φ	66%
ω	0.0149 kg/kg
h	65.52 kJ/kg
v	0.871 m³/kg
ṁ	1.60 kg/s

State 11	
T	50.1 °C
φ	19%
ω	0.0149 kg/kg
h	89.12 kJ/kg
v	0.938 m³/kg
ṁ	1.60 kg/s

State 12	
T	81 °C
φ	5%
ω	0.0149 kg/kg
h	121.09 kJ/kg
v	1.03 m³/kg
ṁ	1.60 kg/s



WMOID	722780
Load Type	PCL

Location	Phoenix, AZ	
Elevation	0 m	
Pressure	101.33 kPa	
Outdoor Conditions		
M	D	H
8	1	15
DBT	41.1 °C	
RH	26%	
Room Conditions		
Q	708 L/s	
T	24.4 °C	
φ	55%	
P.Load	22.06 tons	
L.Load	8.4 tons	
SHR	0.619	

MDWS Input Parameters	
Vel, Pro Air	2.12 m/s
Speed	15.5 RPH
Vel, Reg Air	2.34 m/s
Material	Silica Gel
(State 1)	
T, Pro Air In	41.1 °C
W, Pro Air in	0.0127 kg/kgda
(State 12)	
T, Reg Air In	81 °C
W, Reg Air In	0.0116 kg/kgda
MDWS Output Values	
(State 2)	
T, Pro Air Out	66.1 °C
W, Pro Air Out	0.0076 kg/kgda
(State 13)	
T, Reg Air Out	80.17 °C
W, Reg Air Out	0.0167 kg/kgda

Color Legend
Given/Assumed Values
DW Program (MDWS)
Psychrometric Chart
Heat Wheel Calc/Prog

State 1	*(Outdoor Conditions)*
T	41.1 °C
φ	26%
ω	0.0127 kg/kg
h	74.2 kJ/kg
v	0.909 m³/kg
ṁ	1.56 kg/s

State 2	
T	66.1 °C
φ	5%
ω	0.0076 kg/kg
h	86.4 kJ/kg
v	0.973 m³/kg
ṁ	1.56 kg/s

State 3	
T	46.7 °C
φ	12%
ω	0.0076 kg/kg
TWB	22.8 °C
h	66.7 kJ/kg
v	0.917 m³/kg
ṁ	1.56 kg/s

State 4	
T	21.6 °C
φ	47%
ω	0.0076 kg/kg
h	41.0 kJ/kg
v	0.845 m³/kg
ṁ	0.779 kg/s

State 5	
T	24.1 °C
φ	54%
ω	0.010 kg/kg
h	50.0 kJ/kg
v	0.856 m³/kg
ṁ	5.69 kg/s

State 6	
T	16.1 °C
φ	75%
ω	59.6 grains/kg
ω	0.0085 kg/kg
h	37.8 kJ/kg
v	0.831 m³/kg
ṁ	5.69 kg/s

State 7	*(Space Conditions)*
T	24.4 °C
φ	55%
ω	0.0105 kg/kg
h	51.4 kJ/kg
v	0.857 m³/kg
ṁ	4.91 kg/s

State 8	*(Space Conditions)*
T	24.4 °C
φ	55%
ω	0.0105 kg/kg
h	51.4 kJ/kg
v	0.857 m³/kg
ṁ	0.779 kg/s

State 5'	
T	26.7 °C
φ	49%
ω	0.011 kg/kg
h	54.5 kJ/kg
v	0.864 m³/kg
ṁ	5.69 kg/s

	kW	%Diff
Q_{AC}	-69.5	27.1%
Q'_{AC}	-95.4	

State 9	*(Outdoor Conditions)*
T	41.1 °C
φ	26%
ω	0.0127 kg/kg
h	74.2 kJ/kg
v	0.909 m³/kg
ṁ	0.779 kg/s

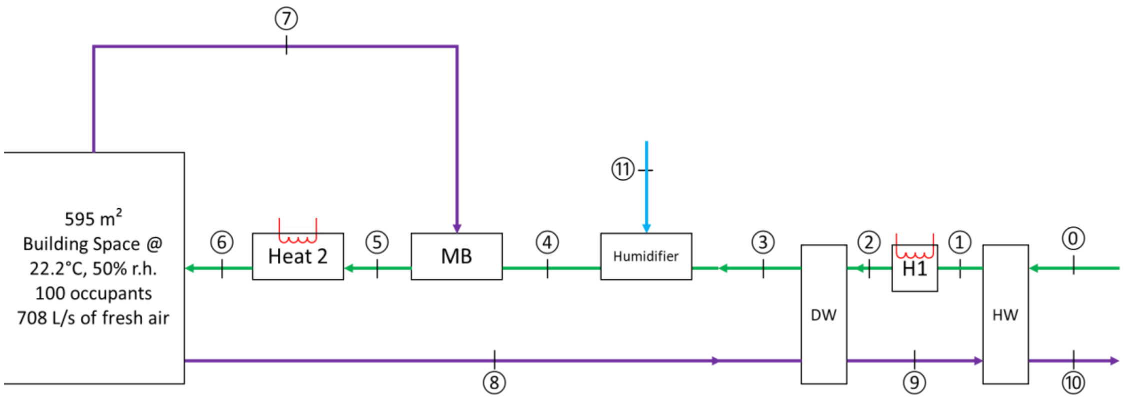
State 10	
T	32.8 °C
φ	37%
ω	0.0116 kg/kg
h	62.80 kJ/kg
v	0.883 m³/kg
ṁ	1.56 kg/s

State 11	
T	54.3 °C
φ	12%
ω	0.0116 kg/kg
h	84.94 kJ/kg
v	0.945 m³/kg
ṁ	1.56 kg/s

State 12	
T	81 °C
φ	4%
ω	0.0116 kg/kg
h	112.34 kJ/kg
v	1.02 m³/kg
ṁ	1.56 kg/s

APPENDIX D

PEAK HEATING LOAD DATA SHEETS



WMOID	690190
Load Type	PHL

Location	Abilene, TX	
Elevation	0 m	
Pressure	101.33 kPa	
Outdoor Conditions		
M	D	H
2	4	7
DBT	-16.7 °C	
RH	95%	
Room Conditions		
Q	708 L/s	
T	22.2 °C	
φ	50%	
	tons	kW
P.Load	-29.21	-102.7
L.Load	5.6	19.7
SHR	0.808	

MDWS Input Parameters	
Vel, Pro Air	2.12 m/s
Speed	15.5 RPH
Vel, Reg Air	2.34 m/s
Material	Silica Gel
(State 2)	
T, Pro Air In	50.0 °C
W, Pro Air in	0.0008 kg/kgda
(State 8)	
T, Reg Air In	22.2 °C
W, Reg Air In	0.0083 kg/kgda
MDWS Output Values	
(State 9)	
T, Reg Air Out	42.2 °C
W, Reg Air Out	0.0019 kg/kgda
(State 3)	
T, Pro Air Out	38.04 °C
W, Pro Air Out	0.0072 kg/kgda

State 0	*(Outdoor Conditions)*
T	-16.7 °C
φ	95%
ω	0.0008 kg/kg
h	-14.8 kJ/kg
v	0.727 m³/kg
ṁ	0.97 kg/s

State 1	
T	16.6 °C
φ	7%
ω	0.0008 kg/kg
h	18.7 kJ/kg
v	0.822 m³/kg
ṁ	0.97 kg/s

State 2	
T	50.0 °C
φ	1%
ω	0.0008 kg/kg
h	52.4 kJ/kg
v	0.917 m³/kg
ṁ	0.97 kg/s

State 3	
T	38.0 °C
φ	17%
ω	0.0072 kg/kg
h	56.8 kJ/kg
v	0.892 m³/kg
ṁ	0.97 kg/s

Color Legend
Given/Assumed Values
DW Program (MDWS)
Psychrometric Chart
Heat Wheel Calc/Prog

State 4	
ω	0.0164 kg/kg
h	57.1 kJ/kg
ṁ	0.97 kg/s

State 5	
ω	0.0099 kg/kg
h	46.1 kJ/kg
ṁ	5.19 kg/s

State 6	
T	37.8 °C
φ	24%
ω	69 grains/lb
ω	0.0099 kg/kg
h	63.3 kJ/kg
v	0.895 m³/kg
ṁ	5.19 kg/s

State 7	*(Space Conditions)*
T	22.2 °C
φ	50%
ω	0.0083 kg/kg
h	43.6 kJ/kg
v	0.848 m³/kg
ṁ	4.22 kg/s

State 11'	*(Humidifier)*
T_W	7.2 °C
$\dot{m}_W$	0.0152 kg/s
$h_{f@Tw}$	30.35 kJ/kg
Q'_{HUM}	0.461 kW

State 4'	
ω	0.0164 kg/kg
h	-14.3 kJ/kg
ṁ	0.97 kg/s

State 8	*(Space Conditions)*
T	22.2 °C
φ	50%
ω	0.0083 kg/kg
h	43.6 kJ/kg
v	0.848 m³/kg
ṁ	0.97 kg/s

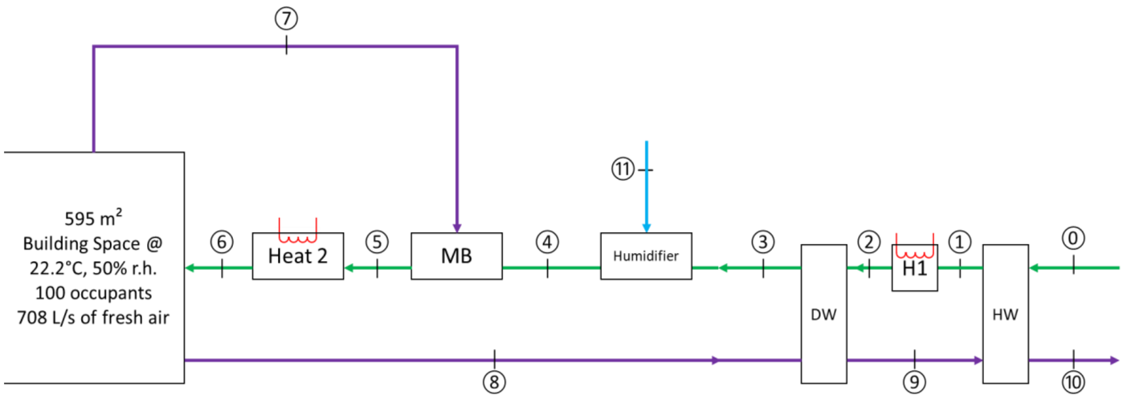
State 9	
T	42.2 °C
φ	4%
ω	0.0019 kg/kg
h	47.4 kJ/kg
v	0.896 m³/kg
ṁ	0.97 kg/s

State 10	
T	9.1 °C
φ	27%
ω	0.0019 kg/kg
h	13.9 kJ/kg
v	0.802 m³/kg
ṁ	0.97 kg/s

State 11	*(Humidifier)*
T_W	7.2 °C
$\dot{m}_W$	0.0090 kg/s
$h_{f@Tw}$	30.35 kJ/kg
Q'_{HUM}	0.273 kW

State 5'	
ω	0.0099 kg/kg
h	32.7 kJ/kg
ṁ	5.19 kg/s

	kW	%Diff
Q_{H2}	89.6	43.7%
Q'_{H2}	159.0	



WMOID	723240
Load Type	PHL

Location	Chattanooga, TN	
Elevation	0 m	
Pressure	101.33 kPa	
Outdoor Conditions		
M	D	H
12	20	7
DBT	-8.9 °C	
RH	52%	
Room Conditions		
Q	708 L/s	
T	22.2 °C	
φ	50%	
	tons	kW
P.Load	-17.23	-60.6
L.Load	4.7	16.5
SHR	0.727	

MDWS Input Parameters	
Vel, Pro Air	2.12 m/s
Speed	15.5 RPH
Vel, Reg Air	2.34 m/s
Material	Silica Gel
(State 2)	
T, Pro Air In	50.0 °C
W, Pro Air in	0.0009 kg/kgda
(State 8)	
T, Reg Air In	22.2 °C
W, Reg Air In	0.0083 kg/kgda
MDWS Output Values	
(State 9)	
T, Reg Air Out	42.2 °C
W, Reg Air Out	0.0019 kg/kgda
(State 3)	
T, Pro Air Out	38.3 °C
W, Pro Air Out	0.0073 kg/kgda

State 0	*(Outdoor Conditions)*
T	-8.9 °C
φ	52%
ω	0.0009 kg/kg
h	-6.7 kJ/kg
v	0.750 m³/kg
ṁ	0.94 kg/s

State 1	
T	20.7 °C
φ	6%
ω	0.0009 kg/kg
h	23.2 kJ/kg
v	0.834 m³/kg
ṁ	0.94 kg/s

State 2	
T	50.0 °C
φ	1%
ω	0.0009 kg/kg
h	52.7 kJ/kg
v	0.917 m³/kg
ṁ	0.94 kg/s

State 3	
T	38.3 °C
φ	17%
ω	0.0073 kg/kg
h	57.3 kJ/kg
v	0.893 m³/kg
ṁ	0.94 kg/s

Color Legend
Given/Assumed Values
DW Program (MDWS)
Psychrometric Chart
Heat Wheel Calc/Prog

State 11'	*(Humidifier)*
T_W	7.2 °C
$\dot{m}_W$	0.0135 kg/s
$h_{f@Tw}$	30.35 kJ/kg
Q'_{HUM}	0.411 kW

State 4	
ω	0.0152 kg/kg
h	57.5 kJ/kg
ṁ	0.94 kg/s

State 5	
ω	0.0107 kg/kg
h	48.3 kJ/kg
ṁ	2.76 kg/s

State 6	
T	37.8 °C
φ	26%
ω	74.9 grains/lb
ω	0.0107 kg/kg
h	65.5 kJ/kg
v	0.896 m³/kg
ṁ	2.76 kg/s

State 7	*(Space Conditions)*
T	22.2 °C
φ	50%
ω	0.0083 kg/kg
h	43.6 kJ/kg
v	0.848 m³/kg
ṁ	1.81 kg/s

State 4'	
ω	0.0152 kg/kg
h	-6.2 kJ/kg
ṁ	0.94 kg/s

State 5'	
ω	0.0107 kg/kg
h	26.5 kJ/kg
ṁ	2.76 kg/s

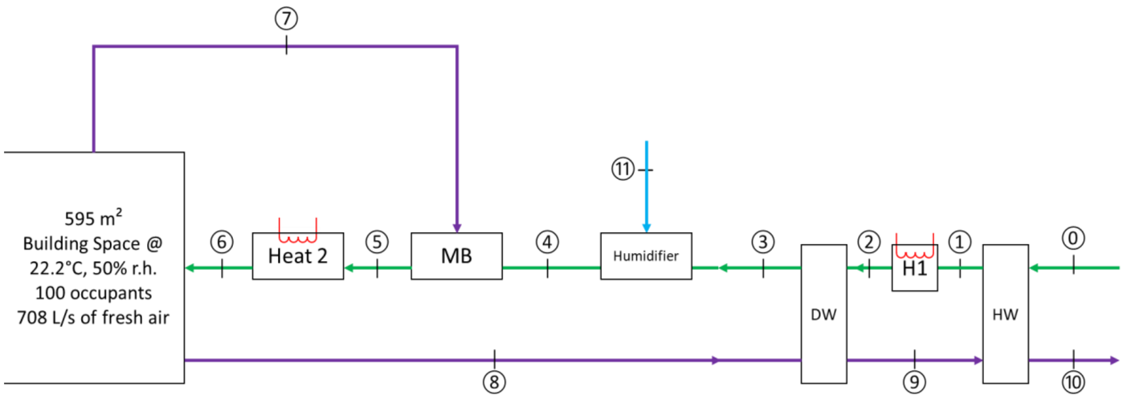
State 8	*(Space Conditions)*
T	22.2 °C
φ	50%
ω	0.0083 kg/kg
h	43.6 kJ/kg
v	0.848 m³/kg
ṁ	0.94 kg/s

State 9	
T	42.2 °C
φ	4%
ω	0.0019 kg/kg
h	47.4 kJ/kg
v	0.896 m³/kg
ṁ	0.94 kg/s

State 10	
T	13.6 °C
φ	20%
ω	0.0019 kg/kg
h	18.4 kJ/kg
v	0.815 m³/kg
ṁ	0.94 kg/s

State 11	*(Humidifier)*
T_W	7.2 °C
$\dot{m}_W$	0.0075 kg/s
$h_{f@Tw}$	30.35 kJ/kg
Q_{HUM}	0.228 kW

	kW	%Diff
Q_{H2}	47.4	56.0%
Q'_{H2}	107.6	



WMOID	725340	
Load Type	PHL	
Location	Chicago, IL	
Elevation	0 m	
Pressure	101.33 kPa	
Outdoor Conditions		
M	D	H
2	3	7
DBT	-27.3 °C	
RH	56%	
Room Conditions		
Q	708 L/s	
T	22.2 °C	
φ	50%	
	tons	kW
P.Load	-36.78	-129.4
L.Load	6.3	22.2
SHR	0.829	

MDWS Input Parameters	
Vel, Pro Air	2.12 m/s
Speed	15.5 RPH
Vel, Reg Air	2.34 m/s
Material	Silica Gel
(State 2)	
T, Pro Air In	50.0 °C
W, Pro Air in	0.0002 kg/kgda
(State 8)	
T, Reg Air In	22.2 °C
W, Reg Air In	0.0083 kg/kgda
MDWS Output Values	
(State 9)	
T, Reg Air Out	42.7 °C
W, Reg Air Out	0.0016 kg/kgda
(State 3)	
T, Pro Air Out	36.53 °C
W, Pro Air Out	0.0069 kg/kgda

State 0	*(Outdoor Conditions)*
T	-27.3 °C
φ	56%
ω	0.0002 kg/kg
h	-27.0 kJ/kg
v	0.697 m³/kg
ṁ	1.02 kg/s

State 1	
T	10.8 °C
φ	2%
ω	0.0002 kg/kg
h	11.3 kJ/kg
v	0.805 m³/kg
ṁ	1.02 kg/s

State 2	
T	50.0 °C
φ	0%
ω	0.0002 kg/kg
h	50.7 kJ/kg
v	0.916 m³/kg
ṁ	1.02 kg/s

State 3	
T	36.5 °C
φ	18%
ω	0.0069 kg/kg
h	54.5 kJ/kg
v	0.887 m³/kg
ṁ	1.02 kg/s

Color Legend
Given/Assumed Values
DW Program (MDWS)
Psychrometric Chart
Heat Wheel Calc/Prog

State 11'	*(Humidifier)*
T_W	7.2 °C
$\dot{m}_W$	0.0172 kg/s
$h_{f@Tw}$	30.35 kJ/kg
Q'_{HUM}	0.522 kW

State 4	
ω	0.0171 kg/kg
h	54.8 kJ/kg
ṁ	1.02 kg/s

State 5	
ω	0.009664 kg/kg
h	45.3 kJ/kg
ṁ	6.70 kg/s

State 6	
T	37.8 °C
φ	24%
ω	67.65 grains/lb
ω	0.0097 kg/kg
h	62.9 kJ/kg
v	0.895 m³/kg
ṁ	6.70 kg/s

State 7	*(Space Conditions)*
T	22.2 °C
φ	50%
ω	0.0083 kg/kg
h	43.6 kJ/kg
v	0.848 m³/kg
ṁ	5.69 kg/s

State 4'	
ω	0.0171 kg/kg
h	-26.5 kJ/kg
ṁ	1.02 kg/s

State 8	*(Space Conditions)*
T	22.2 °C
φ	50%
ω	0.0083 kg/kg
h	43.6 kJ/kg
v	0.848 m³/kg
ṁ	1.02 kg/s

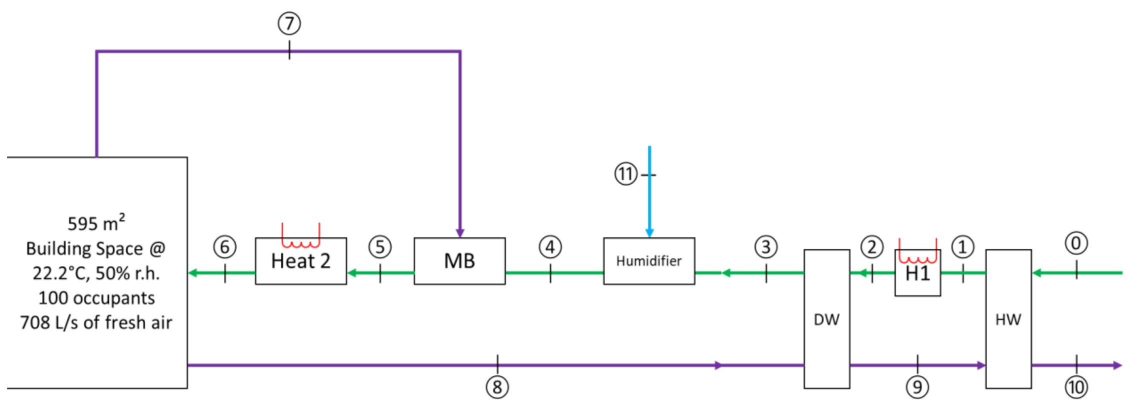
State 9	
T	42.7 °C
φ	3%
ω	0.0016 kg/kg
h	47.1 kJ/kg
v	0.897 m³/kg
ṁ	1.02 kg/s

State 10	
T	3.1 °C
φ	34%
ω	0.0016 kg/kg
h	7.1 kJ/kg
v	0.785 m³/kg
ṁ	1.02 kg/s

State 11	*(Humidifier)*
T_W	7.2 °C
$\dot{m}_W$	0.0104 kg/s
$h_{f@Tw}$	30.35 kJ/kg
Q_{HUM}	0.314 kW

State 5'	
ω	0.0097 kg/kg
h	32.9 kJ/kg
ṁ	6.70 kg/s

	kW	%Diff
Q_{H2}	117.9	41.2%
Q'_{H2}	200.6	



WMOID	722435
Load Type	PHL

Location	Houston, TX	
Elevation	0 m	
Pressure	101.33 kPa	
Outdoor Conditions		
M	D	H
3	8	7
DBT	0.5 °C	
RH	63%	
Room Conditions		
Q	708 L/s	
T	22.2 °C	
φ	50%	
	tons	kW
P.Load	-19.41	-68.3
L.Load	4.5	15.8
SHR	0.768	

MDWS Input Parameters	
Vel, Pro Air	2.12 m/s
Speed	15.5 RPH
Vel, Reg Air	2.34 m/s
Material	Silica Gel
(State 2)	
T, Pro Air In	50.0 °C
W, Pro Air in	0.0025 kg/kgda
(State 8)	
T, Reg Air In	22.2 °C
W, Reg Air In	0.0083 kg/kgda
MDWS Output Values	
(State 9)	
T, Reg Air Out	41.7 °C
W, Reg Air Out	0.0029 kg/kgda
(State 3)	
T, Pro Air Out	42.2 °C
W, Pro Air Out	0.0079 kg/kgda

State 0	*(Outdoor Conditions)*
T	0.5 °C
φ	63%
ω	0.0025 kg/kg
h	6.7 kJ/kg
v	0.778 m³/kg
ṁ	0.91 kg/s

State 1	
T	25.1 °C
φ	13%
ω	0.0025 kg/kg
h	31.5 kJ/kg
v	0.848 m³/kg
ṁ	0.91 kg/s

State 2	
T	50.0 °C
φ	3%
ω	0.0025 kg/kg
h	56.7 kJ/kg
v	0.919 m³/kg
ṁ	0.91 kg/s

State 3	
T	42.2 °C
φ	15%
ω	0.0079 kg/kg
h	62.8 kJ/kg
v	0.905 m³/kg
ṁ	0.91 kg/s

Color Legend
Given/Assumed Values
DW Program (MDWS)
Psychrometric Chart
Heat Wheel Calc/Prog

State 4	
ω	0.0153 kg/kg
h	63.1 kJ/kg
ṁ	0.91 kg/s

State 5	
ω	0.0103 kg/kg
h	49.0 kJ/kg
ṁ	3.28 kg/s

State 6	
T	37.8 °C
φ	25%
ω	71.85 grains/lb
ω	0.0103 kg/kg
h	64.4 kJ/kg
v	0.895 m³/kg
ṁ	3.28 kg/s

State 7	*(Space Conditions)*
T	22.2 °C
φ	50%
ω	0.0083 kg/kg
h	43.6 kJ/kg
v	0.848 m³/kg
ṁ	2.37 kg/s

State 11'	*(Humidifier)*
T_W	7.2 °C
$\dot{m}_W$	0.0117 kg/s
$h_{f@Tw}$	30.35 kJ/kg
Q'_{HUM}	0.354 kW

State 4'	
ω	0.0153 kg/kg
h	7.0 kJ/kg
ṁ	0.91 kg/s

State 8	*(Space Conditions)*
T	22.2 °C
φ	50%
ω	0.0083 kg/kg
h	43.6 kJ/kg
v	0.848 m³/kg
ṁ	0.91 kg/s

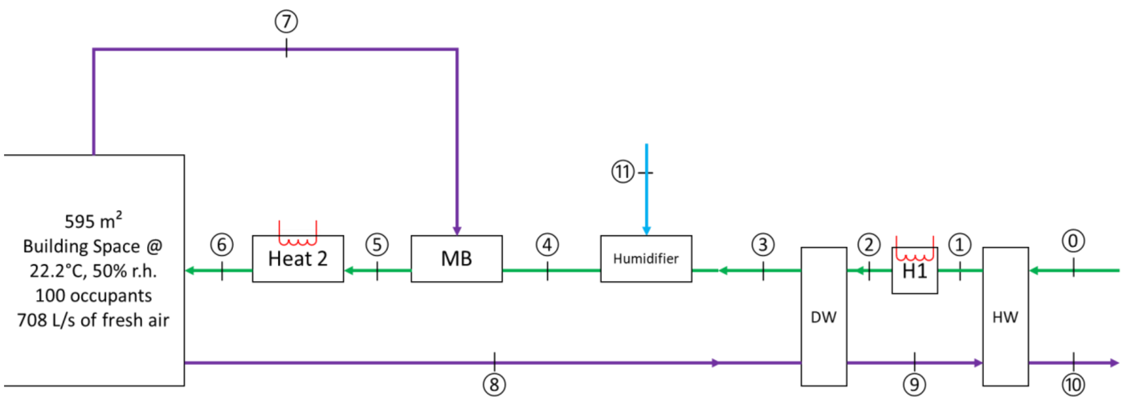
State 9	
T	41.7 °C
φ	6%
ω	0.0029 kg/kg
h	49.4 kJ/kg
v	0.896 m³/kg
ṁ	0.91 kg/s

State 10	
T	18.8 °C
φ	22%
ω	0.0029 kg/kg
h	26.2 kJ/kg
v	0.831 m³/kg
ṁ	0.91 kg/s

State 11	*(Humidifier)*
T_W	7.2 °C
$\dot{m}_W$	0.0067 kg/s
$h_{f@Tw}$	30.35 kJ/kg
Q_{HUM}	0.204 kW

State 5'	
ω	0.0103 kg/kg
h	33.4 kJ/kg
ṁ	3.28 kg/s

	kW	%Diff
Q_{H2}	50.5	50.2%
Q'_{H2}	101.5	



WMOID	722029
Load Type	PHL

Location	Miami, FL	
Elevation	0 m	
Pressure	101.33 kPa	
Outdoor Conditions		
M	D	H
1	25	8
DBT	8.3 °C	
RH	58%	
Room Conditions		
Q	708 L/s	
T	22.2 °C	
φ	50%	
	tons	kW
P.Load	-14.86	-52.3
L.Load	3.3	11.6
SHR	0.778	

MDWS Input Parameters	
Vel, Pro Air	2.12 m/s
Speed	15.5 RPH
Vel, Reg Air	2.34 m/s
Material	Silica Gel
(State 2)	
T, Pro Air In	50.0 °C
W, Pro Air in	0.0039 kg/kgda
(State 8)	
T, Reg Air In	22.2 °C
W, Reg Air In	0.0083 kg/kgda
MDWS Output Values	
(State 9)	
T, Reg Air Out	41.2 °C
W, Reg Air Out	0.0036 kg/kgda
(State 3)	
T, Pro Air Out	45.28 °C
W, Pro Air Out	0.0086 kg/kgda

State 0	*(Outdoor Conditions)*
T	8.3 °C
φ	58%
ω	0.0039 kg/kg
h	18.2 kJ/kg
v	0.802 m³/kg
ṁ	0.88 kg/s

State 1	
T	28.4 °C
φ	16%
ω	0.0039 kg/kg
h	38.6 kJ/kg
v	0.860 m³/kg
ṁ	0.88 kg/s

State 2	
T	50.0 °C
φ	5%
ω	0.0039 kg/kg
h	60.5 kJ/kg
v	0.921 m³/kg
ṁ	0.88 kg/s

State 3	
T	45.3 °C
φ	14%
ω	0.0086 kg/kg
h	67.8 kJ/kg
v	0.915 m³/kg
ṁ	0.88 kg/s

Color Legend
Given/Assumed Values
DW Program (MDWS)
Psychrometric Chart
Heat Wheel Calc/Prog

State 11'	*(Humidifier)*
T_W	7.2 °C
$\dot{m}_W$	0.0085 kg/s
$h_{f@Tw}$	30.35 kJ/kg
Q'_{HUM}	0.259 kW

State 4	
ω	0.0136 kg/kg
h	67.9 kJ/kg
ṁ	0.88 kg/s

State 5	
ω	0.0102 kg/kg
h	52.0 kJ/kg
ṁ	2.54 kg/s

State 6	
T	37.8 °C
φ	25%
ω	71.1 grains/lb
ω	0.0102 kg/kg
h	64.1 kJ/kg
v	0.895 m³/kg
ṁ	2.54 kg/s

State 7	*(Space Conditions)*
T	22.2 °C
φ	50%
ω	0.0083 kg/kg
h	43.6 kJ/kg
v	0.848 m³/kg
ṁ	1.66 kg/s

State 4'	
ω	0.0136 kg/kg
h	18.5 kJ/kg
ṁ	0.88 kg/s

State 5'	
ω	0.0102 kg/kg
h	34.9 kJ/kg
ṁ	2.54 kg/s

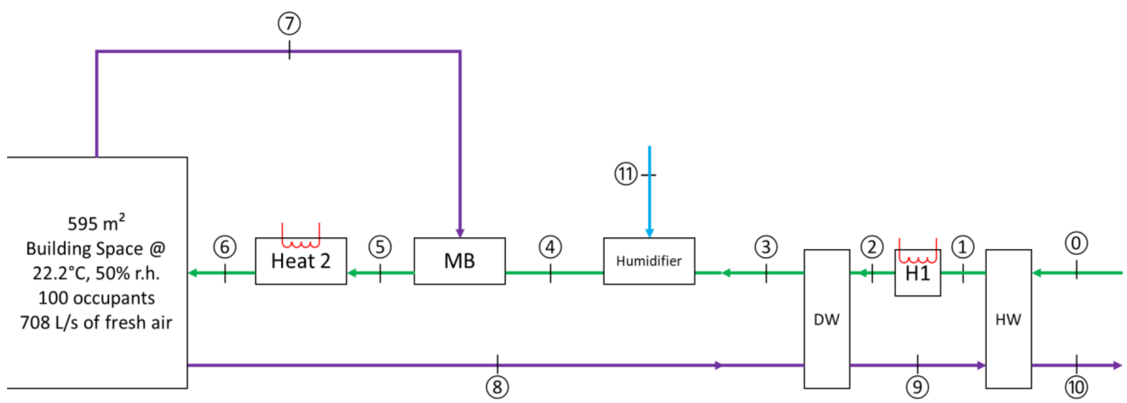
State 8	*(Space Conditions)*
T	22.2 °C
φ	50%
ω	0.0083 kg/kg
h	43.6 kJ/kg
v	0.848 m³/kg
ṁ	0.88 kg/s

State 9	
T	41.2 °C
φ	7%
ω	0.0036 kg/kg
h	50.7 kJ/kg
v	0.896 m³/kg
ṁ	0.88 kg/s

State 10	
T	23.0 °C
φ	21%
ω	0.0036 kg/kg
h	32.3 kJ/kg
v	0.844 m³/kg
ṁ	0.88 kg/s

State 11	*(Humidifier)*
T_W	7.2 °C
$\dot{m}_W$	0.0044 kg/s
$h_{f@Tw}$	30.35 kJ/kg
Q_{HUM}	0.133 kW

	kW	%Diff
Q_{H2}	30.7	58.6%
Q'_{H2}	74.4	



WMOID	744860
Load Type	PHL

Location	New York City, NY	
Elevation	0 m	
Pressure	101.33 kPa	
Outdoor Conditions		
M	D	H
2	6	3
DBT	-13.9 °C	
RH	43%	
Room Conditions		
Q	708 L/s	
T	22.2 °C	
φ	50%	
	tons	kW
P.Load	-29.04	-102.1
L.Load	6.0	21.1
SHR	0.793	

MDWS Input Parameters	
Vel, Pro Air	2.12 m/s
Speed	15.5 RPH
Vel, Reg Air	2.34 m/s
Material	Silica Gel
(State 2)	
T, Pro Air In	50.0 °C
W, Pro Air in	0.0005 kg/kgda
(State 8)	
T, Reg Air In	22.2 °C
W, Reg Air In	0.0083 kg/kgda
MDWS Output Values	
(State 9)	
T, Reg Air Out	42.2 °C
W, Reg Air Out	0.0017 kg/kgda
(State 3)	
T, Pro Air Out	37.23 °C
W, Pro Air Out	0.0071 kg/kgda

State 0	*(Outdoor Conditions)*
T	-13.9 °C
φ	43%
ω	0.0005 kg/kg
h	-12.8 kJ/kg
v	0.735 m³/kg
ṁ	0.96 kg/s

State 1	
T	18.1 °C
φ	4%
ω	0.0005 kg/kg
h	19.4 kJ/kg
v	0.826 m³/kg
ṁ	0.96 kg/s

State 2	
T	50.0 °C
φ	1%
ω	0.0005 kg/kg
h	51.6 kJ/kg
v	0.916 m³/kg
ṁ	0.96 kg/s

State 3	
T	37.2 °C
φ	18%
ω	0.0071 kg/kg
h	55.7 kJ/kg
v	0.889 m³/kg
ṁ	0.96 kg/s

Color Legend
Given/Assumed Values
DW Program (MDWS)
Psychrometric Chart
Heat Wheel Calc/Prog

State 4	
ω	0.0171 kg/kg
h	56.0 kJ/kg
ṁ	0.96 kg/s

State 5	
ω	0.0100 kg/kg
h	45.9 kJ/kg
ṁ	5.06 kg/s

State 6	
T	37.8 °C
φ	24%
ω	70.05 grains/lb
ω	0.0100 kg/kg
h	63.7 kJ/kg
v	0.895 m³/kg
ṁ	5.06 kg/s

State 7	*(Space Conditions)*
T	22.2 °C
φ	50%
ω	0.0083 kg/kg
h	43.6 kJ/kg
v	0.848 m³/kg
ṁ	4.10 kg/s

State 11'	*(Humidifier)*
T_W	7.2 °C
$\dot{m}_W$	0.0160 kg/s
$h_{f@Tw}$	30.35 kJ/kg
Q'_{HUM}	0.486 kW

State 4'	
ω	0.0171 kg/kg
h	-12.3 kJ/kg
ṁ	0.96 kg/s

State 8	*(Space Conditions)*
T	22.2 °C
φ	50%
ω	0.0083 kg/kg
h	43.6 kJ/kg
v	0.848 m³/kg
ṁ	0.96 kg/s

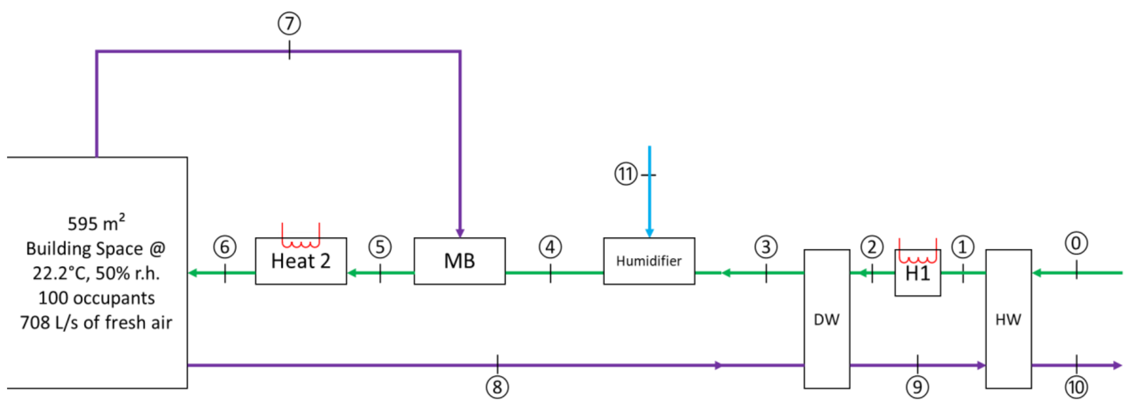
State 9	
T	42.2 °C
φ	3%
ω	0.0017 kg/kg
h	46.8 kJ/kg
v	0.896 m³/kg
ṁ	0.96 kg/s

State 10	
T	10.7 °C
φ	21%
ω	0.0017 kg/kg
h	15.0 kJ/kg
v	0.806 m³/kg
ṁ	0.96 kg/s

State 11	*(Humidifier)*
T_W	7.2 °C
$\dot{m}_W$	0.0096 kg/s
$h_{f@Tw}$	30.35 kJ/kg
Q_{HUM}	0.293 kW

State 5'	
ω	0.0100 kg/kg
h	32.9 kJ/kg
ṁ	5.06 kg/s

	kW	%Diff
Q_{H2}	90.1	42.2%
Q'_{H2}	155.9	



WMOID	722780
Load Type	PHL

Location	Phoenix, AZ	
Elevation	0 m	
Pressure	101.33 kPa	
Outdoor Conditions		
M	D	H
1	20	7
DBT	2.8 °C	
RH	40%	
Room Conditions		
Q	708 L/s	
T	22.2 °C	
φ	50%	
	tons	kW
P.Load	-18.88	-66.4
L.Load	5.6	19.7
SHR	0.703	

MDWS Input Parameters	
Vel, Pro Air	2.12 m/s
Speed	15.5 RPH
Vel, Reg Air	2.34 m/s
Material	Silica Gel
(State 2)	
T, Pro Air In	50.0 °C
W, Pro Air in	0.0018 kg/kgda
(State 8)	
T, Reg Air In	22.2 °C
W, Reg Air In	0.0083 kg/kgda
MDWS Output Values	
(State 9)	
T, Reg Air Out	41.7 °C
W, Reg Air Out	0.0024 kg/kgda
(State 3)	
T, Pro Air Out	40.47 °C
W, Pro Air Out	0.0077 kg/kgda

State 0	*(Outdoor Conditions)*
T	2.8 °C
φ	40%
ω	0.0018 kg/kg
h	7.4 kJ/kg
v	0.784 m³/kg
ṁ	0.90 kg/s

State 1	
T	26.2 °C
φ	9%
ω	0.0018 kg/kg
h	31.0 kJ/kg
v	0.851 m³/kg
ṁ	0.90 kg/s

State 2	
T	50.0 °C
φ	2%
ω	0.0018 kg/kg
h	55.1 kJ/kg
v	0.918 m³/kg
ṁ	0.90 kg/s

State 3	
T	40.5 °C
φ	16%
ω	0.0077 kg/kg
h	60.6 kJ/kg
v	0.899 m³/kg
ṁ	0.90 kg/s

Color Legend
Given/Assumed Values
DW Program (MDWS)
Psychrometric Chart
Heat Wheel Calc/Prog

State 4	
ω	0.0170 kg/kg
h	60.8 kJ/kg
ṁ	0.90 kg/s

State 5	
ω	0.0110 kg/kg
h	48.9 kJ/kg
ṁ	2.91 kg/s

State 6	
T	37.8 °C
φ	27%
ω	77.2 grains/lb
ω	0.0110 kg/kg
h	66.4 kJ/kg
v	0.896 m³/kg
ṁ	2.91 kg/s

State 7	*(Space Conditions)*
T	22.2 °C
φ	50%
ω	0.0083 kg/kg
h	43.6 kJ/kg
v	0.848 m³/kg
ṁ	2.01 kg/s

State 11'	*(Humidifier)*
T_W	7.2 °C
$\dot{m}_W$	0.0137 kg/s
$h_{f@Tw}$	30.35 kJ/kg
Q'_{HUM}	0.416 kW

State 4'	
ω	0.0170 kg/kg
h	7.9 kJ/kg
ṁ	0.90 kg/s

State 8	*(Space Conditions)*
T	22.2 °C
φ	50%
ω	0.0083 kg/kg
h	43.6 kJ/kg
v	0.848 m³/kg
ṁ	0.90 kg/s

State 9	
T	41.7 °C
φ	5%
ω	0.0024 kg/kg
h	48.1 kJ/kg
v	0.895 m³/kg
ṁ	0.90 kg/s

State 10	
T	20.1 °C
φ	17%
ω	0.0024 kg/kg
h	26.3 kJ/kg
v	0.834 m³/kg
ṁ	0.90 kg/s

State 11	*(Humidifier)*
T_W	7.2 °C
$\dot{m}_W$	0.0084 kg/s
$h_{f@Tw}$	30.35 kJ/kg
Q_{HUM}	0.255 kW

State 5'	
ω	0.0110 kg/kg
h	32.5 kJ/kg
ṁ	2.91 kg/s

	kW	%Diff
Q_{H2}	50.8	48.5%
Q'_{H2}	98.6	

APPENDIX E

TRANSFER FUNCTION METHOD FOR DETERMINING BUILDING LOADS [18]

Equations of Solar Angles

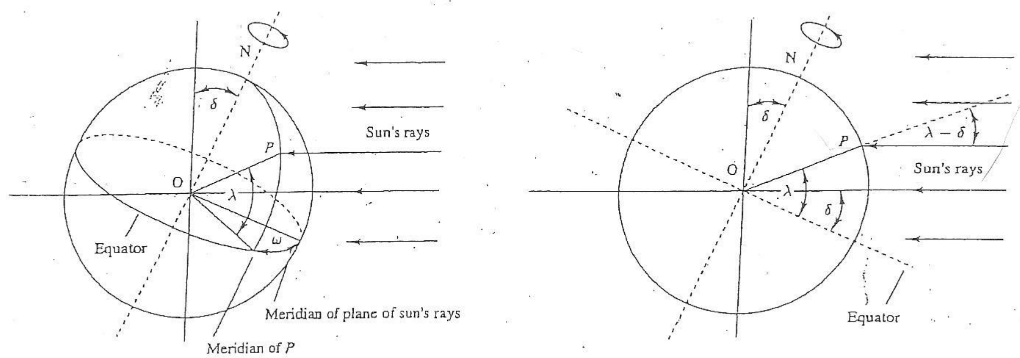


Figure 4.2 Illustration of Latitude, hour angle and solar declination

$$I_o\left(\frac{Btu}{hr\,.\,ft^2}\right) = 435.2\left[1 + 0.033\,Cos\left(\frac{360^{\circ}\,n}{365.25}\right)\right] \qquad (4.1a)$$

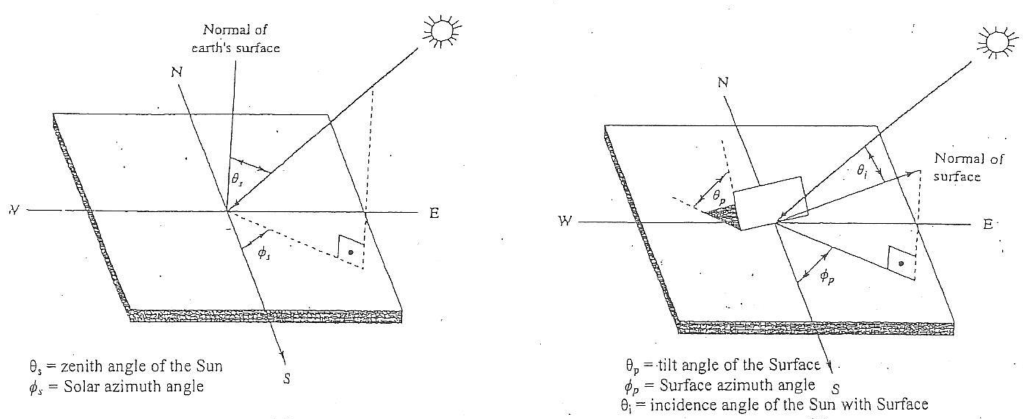


Figure 4.3 Solar Angles for a Tilted Surface

Due to rotation of the earth about its own axis as well around the Sun, the estimate of incident solar irradiance, I_t consisting of beam and diffuse components involves determining various solar angles namely:

Declination angle (δ) is the angle made by the equator with sun's rays as shown in Figure 4.2b

Surface latitude angle (λ) is the angle between the radius vector of the location from the center of the earth and equatorial plane as indicated in the Figure 4.2a

Hour angle (ω) is the angle between the meridian of plane of sun's rays make with local meridian at the center of the earth in an equatorial plane as shown in Figure 4.2a

Hour angle (ω) is the angle between the meridian of plane of sun's rays make with local meridian at the center of the earth in an equatorial plane as shown in Figure 4.2a

Solar azimuth angle (ϕ_s) is the angle between the projection of the sun's rays on a local horizontal plane and the south direction as shown in Figure 4.3a

Solar zenith angle (θ_s) is the angle between the sun's rays and the normal on the local horizontal plane as shown in Figure 4.3a

Surface azimuth angle (ϕ_p) is the angle between the normal to the surface with south direction as shown in Figure 4.3b

Surface tilt angle (θ_p) is the angle between the surface and the local horizontal as shown in Figure 4.3b

Solar incident angle (θ_i) is the angle between the normal to the surface with sun's rays as shown in Figure 4.3b

The declination angle (δ) can be given as,

$$Sin\,\delta \;=\; -Sin\,23.45^0\;Cos\,\frac{360^0\,(n+10)}{365.25} \qquad (4.2)$$

where, n is the day of the year with January 1 being n = 1.

The hour angle (ω) can be estimated in terms of solar time (t_{sol}) from,

$$\omega \;=\; \frac{360^0\,(t_{sol}-12\,h)}{24\,h} \qquad (4.3)$$

The solar time, t_{sol} is related to the local standard time, t_{std} as

$$t_{sol} \;=\; t_{std} + \frac{L_{std}-L_{loc}}{15^o\;/\,hr} + \frac{E_t}{60\,\min/\,hr} \qquad (4.4)$$

where t_{std} = local standard time

L_{std} = longitude of the standard time, for United States, Eastern = 75^0, Central = 90^0, Mountain = 105^0, Pacific = 120^0.

L_{loc} = longitude of the location in degrees.

E_t = equation of time is the difference between the solar noon and noon time based on local Time and it varies over the year.

It may be noted that solar noon refers to the time when sun reaches the highest point in the sky. The equation of time E_t is obtained from

$$E_t \;=\; 9.87\,Sin\left(\frac{360^0\,(n-81)}{364}\right) - 7.53\,Cos\left(\frac{360^0\,(n-81)}{364}\right) - 1.5\,Sin\left(\frac{360^0\,(n-81)}{364}\right) \qquad (4.5)$$

The solar zenith angle (θ_s) as shown in the Figure 4.3 can be estimated from,

$$\text{Cos } \theta_s = \text{Cos } \lambda \text{ Cos } \delta \text{ Cos } \omega + \text{Sin } \lambda \text{ Sin } \delta \qquad (4.6)$$

Now, the solar azimuth angle (ϕ_s) in terms of solar zenith angle (θ_s) is obtained as follows

$$Sin\ (\phi_s) = \frac{Cos\,\delta\ Sin\,\omega}{Sin\,\theta_s} \qquad (4.7)$$

Finally, the solar incident angle (θ_i) is given by

$$\text{Cos } \theta_i = \text{Sin } \theta_s \text{ Sin } \theta_p \text{ Cos } (\phi_s - \phi_p) + \text{Cos } \theta_s \text{ Cos } \theta_p \qquad (4.8)$$

where, ϕ_s is the solar azimuth angle given by Equation (4.7) while the surface azimuth angle ϕ_p as shown in the Figure 4.2 is the angle made by the surface normal with south direction. The tilt angle of the surface θ_p is the angle of inclination of the surface with local horizontal surface as shown in Figure 4.3b.

where, ϕ_s is the solar azimuth angle given by Equation (4.7) while the surface azimuth angle ϕ_p as shown in the Figure 4.3a is the angle made by the surface normal with south direction. The tilt angle of the surface θ_p is the angle of inclination of the surface with local horizontal surface as shown in Figure 4.3b.

$$\text{The hour angle of sunrise, } \omega_{sr} = -\text{Cos}^{-1} (-\text{Tan } \lambda \,.\, \text{Tan } \delta) \qquad (4.9)$$

$$\text{The hour angle of sunset, } \omega_{ss} = \text{Cos}^{-1} (-\text{Tan } \lambda \,.\, \text{Tan } \delta) \qquad (4.10)$$

$$\text{Length of Daylight, in hours N} = 2 \left[\text{Cos}^{-1} (-\text{Tan } \lambda \,.\, \text{Tan } \delta) \right] / 15 \qquad (4.11)$$

Now the total incident solar load I_t is the sum of

(i) the solar direct radiation (I_{dir}) incident normal to the surface

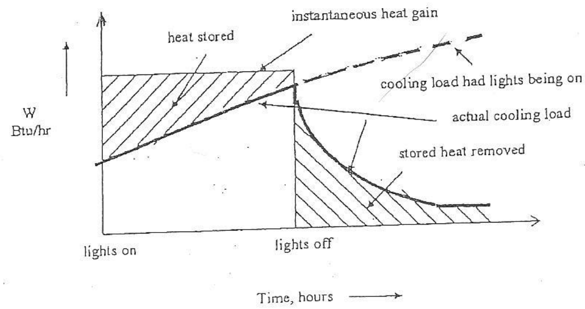
(ii) the solar diffuse radiation (I_{dif}), the diffuse radiation is the radiation scattered from the surroundings and the dust particles present in the atmosphere.

(iii) the solar radiation reflected from the ground

$$I_t = I_{dir}\, Cos\,\theta_i + I_{dif,hor} \frac{1 + Cos\,\theta_p}{2} + I_{glo,hor}\, \rho_g \frac{1 - Cos\,\theta_p}{2} \qquad (4.12)$$

where, $I_{glo,hor}$ is the global horizontal radiation incident on the horizontal surface.

The weather stations in many major cities record hourly data consisting of I_{dir}, $I_{dif,hor}$, $I_{glo,hor}$, the ambient air temperature, the dew point temperature, the relative humidity, wind speed and direction, cloud cover factor and many other data. The meteorologists obtained the average of 25 to 30 years of such data and designated this data as the typical meteorological year (TMY) for that city. Use of such data allows a more detailed and accurate estimate of solar loads. The solar energy absorbed by walls and roof gets stored as shown below.



Due to transient nature of solar energy and ambient temperature that change every hour during the day, the actual heat transfer, $q_{e,t}$ through the building element such as a composite wall or roof at time, t can be estimated from Equation (4.13).

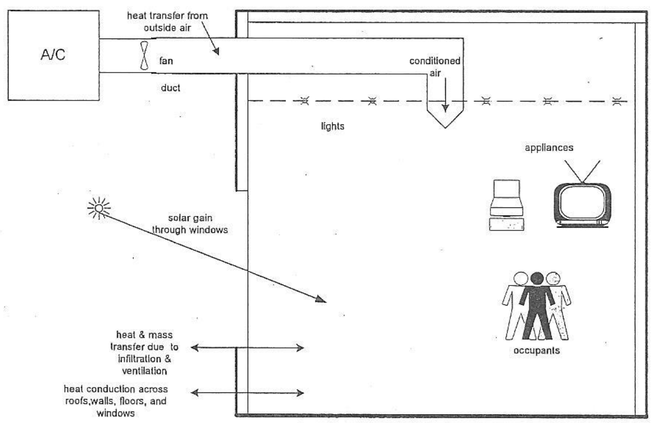


Figure 4.5 Various Contributions to the Cooling Load

External Heat Gain from Roofs and Walls

$$q_{e,t} = A\left[\sum_{n=1}^{m} b_n \left(T_{o,t-n\Delta t}\right) - \sum_{n=1}^{m} d_n \left[\frac{\left(q_{e,t-n\Delta t}\right)}{A}\right] - T_r - \sum C_n\right] \qquad (4.13)$$

where: $q_{e,t}$ = the rate of heat gain through the wall or roof at time t

b_n,c_n and d_n = conduction transfer coefficients and are generally given in separate tables; one for roofs, and the other for walls.

t = hour for which calculation was made

Δt = time interval (typically, 1 hr)

m = number of previous hours for which the values are significant

e = element under analysis, roof or wall assembly

A = area of element under analysis
$T_{o,t,t}$ = sol-air temperature at time t
T_r = room or space air temperature at time t

An expression for sol-air temperature, $T_{o\text{-}t,\,t}$ can be obtained from

$$T_{o-t,t} = t_o + \frac{\alpha I_t}{h_o} - \frac{\varepsilon \Delta R}{h_o} \quad (4.14)$$

where $T_{o\text{-}t,t}$ = sol-air temperature at time t
t_o = current hour dry-bulb temperature at time t
α = absorptance of surface for solar radiation
ε = emittance of the surface
I_t = total incident solar irradiation on a surface as given by Equation (4.12)
h_o = heat transfer coefficient by long-wave radiation and convection at the outer surface

ΔR = difference between the long-wave radiation incident on the surface from the sky and the surroundings and the radiation emitted by the black surface at the outdoor air temperature.

$\frac{\varepsilon \Delta R}{h_o}$ = long wave radiation factor = 3.7^0C (6.7°F) for horizontal surfaces;
= 0^0C (0°F) for vertical surfaces

$\frac{\alpha}{h_o}$ = surface color factor = 0.026 for light colors and 0.052 for dark colors

It may be noted that for horizontal surfaces that receive long-wave radiation from sky only, an appropriate value for $\Delta R \approx 63.07\ W/m^2$ (20 $Btu/hr.ft^2$) and if $\varepsilon \approx 1.0$
and $h_o \approx 17.0\ W/m^2.K$ (3.0 $Btu/hr.ft^2.{}^0F$) then $\frac{\varepsilon \Delta R}{h_o} = 3.7^0$C (6.7°F)

The ASHRAE identified nearly forty different composite walls and roofs made up of different composite materials used in North America for which the conduction transfer coefficients are obtained. With the specification of materials that make up the roof or wall, one can substitute the conduction transfer coefficients appropriate for each type of roof or wall group. The Equation (4.13) estimates the heat gain through a wall or roof for any hour during the year for which the ambient air temperature and solar flux are available for that hour.

In the detailed approach, the hourly weather data is employed to determine the sol-air temperature for the hour and this sol-air temperature is applied in the above equation to estimate the heat gain and later this hourly heat gain is transformed to obtain the hourly cooling load. A detailed method using transform function method is presented in a separate handout.

Transfer Function Method

Transfer function method takes into account the thermal storage effect of the solar energy, occupants, lights and equipment. For instance, the heating or cooling load $\dot{Q}$ can be considered as the response of a building or room to the effects that the temperature of the space (T_i), the temperature of the environment outside (T_o), or adjoining spaces, and the solar heat transfer rate ($\dot{Q}_{sol}$), etc. have on that building or room. The temperature of the space, the temperature of the environment outside, or adjoining spaces, the solar heat transfer rate, heat energy from occupants, equipment, and lighting $(T_i, T_o, \dot{Q}_{sol}, etc)$ are known as the driving terms. The Transfer Function Method calculates the response of a system by making the following three assumptions:

1. **Discrete time steps**: all functions of time are represented as series of values at regular time steps. (Hourly in this case).

2. **Linearity**: the response of a system is a linear function of the driving terms and of the state of the system.

3. **Causality**: the response at time t can depend only on the past, not on the future.

Take into consideration, for example, the following driving term $u(t)$ (or sometimes represented as u_t) and its response $y(t)$ (or sometimes represented as y_t) . To indicate the time dependence of the driving term and its response to make it more readable, a linear series relationship between the response and the driving term is assumed to be in the form:

$$y_t = -(a_1\, y_{t-1\Delta t} + a_2\, y_{t-2\Delta t} + \ldots + a_n\, y_{t-n\Delta t}) + (b_0\, u_t + b_1\, u_{t-1\Delta t} + b_2\, u_{t-2\Delta t} + \ldots + b_m\, u_{t-m\Delta t}) \quad (1)$$

where the *time step* $\Delta t = 1$ hour and a_1 *to* a_n *and* b_0 *to* b_m are coefficients that characterize the system.

The coefficients a_1 *to* a_n *and* b_0 *to* b_m are independent of the driving term or response. Equation (F1) satisfies the assumption of causality because y_t depends only upon the past values of the response ($y_{t-1\Delta t}$ *to* $y_{t-n\Delta t}$) and on present and past values of the driving terms (u_t *to* $u_{t-n\Delta t}$). The thermal inertia of the system is taken into account with the coefficients a_1 *to* a_n *and* b_0 *to* b_m. If these coefficients are zero, then the response is instantaneous. The greater the number and magnitude of the coefficients, the greater the weight of the past has with the system. And, the accuracy of the model increases as the number of coefficients increases and as the time step is reduced. Hourly time resolution and a handful of coefficients per driving term will be enough for load calculations. The coefficients are called transfer function coefficients.

In the symmetric form, the relationship between u and y, as seen above, in Equation (1) becomes:

$$a_o\, y_t + a_1\, y_{t-1\Delta t} + \ldots + a_n\, y_{t-n\Delta t} = b_o\, u_t + b_1\, u_{t-1\Delta t} + \ldots + b_m\, u_{t-m\Delta t} \quad (2)$$

Equation (F2) can be generalized to the case where there are many driving terms. For example, in the case of heating and cooling load calculations, if the response of the indoor temperature T_i is determined by two driving terms, heat input into the space $\dot{Q}$, and the temperature outside T_o, then the transfer function model can be written as follows:

$$\begin{aligned} a_{i,0} T_{i,t} + a_{i,1} T_{i,t-1\Delta t} + \ldots + a_{i,n} T_{i,t-n\Delta t} = {} & a_{o,0} T_{o,t} + a_{o,1} T_{o,t-1\Delta t} + \ldots + a_{o,m} T_{o,t-m\Delta t} \\ & + a_{Q,0} \dot{Q}_t + a_{Q,1} \dot{Q}_{t-1\Delta t} + a_{Q,2} \dot{Q}_{t-2\Delta t} + \cdots + a_{Q,r} \dot{Q}_{t-r\Delta t} \end{aligned} \quad (3)$$

Equation (3) can be considered as an algorithm for calculating $T_{i,t}$, hour by hour, given the previous value of T_i and the driving terms T_o and $\dot{Q}$. Likewise, $\dot{Q}$ could be calculated as the response if T_i and T_o were given as the driving terms.

The Transfer Function Method (TFM) applies a series of weighting factors, or conduction transfer function (CTF) coefficients to the various exterior opaque surfaces and to differences between sol-air temperature and inside space temperature to determine the heat gain with the appropriate reflection of thermal inertia of such surfaces.

The TFM applies a second series of weighting factors known as Room Transfer Functions (RTF) to heat gain and cooling load values from all load elements that have radiant components. The purpose is to account for the thermal storage effect in converting heat gain to cooling load. RTF coefficients relate specifically to the special geometry, configuration, mass, and other characteristics of the defined space in order to reflect weighted variations in thermal storage effect on a time basis rather than a straight-line average.

Calculating the conductive heat gain (or loss), $\dot{Q}_{cond,t}$ at time t through the roof and walls can done with the following relationship:

$$\dot{Q}_{cond,t} = -\sum_{n\geq 1} d_n \dot{Q}_{cond,t-n\Delta t} + A\left(\sum_{n\geq 0} b_n T_{os,t-n\Delta t} - T_i \sum_{n\geq 0} c_n\right) \qquad (4)$$

where: A = area of the roof or wall, can be in units of m^2 or ft^2.

Δt = time step, which is 1 hour.

$T_{os,t-n\Delta t}$ = sol-air temperature of the outside surface at time t

b_n, c_n, d_n are the coefficients of conduction transfer function

Typical values of conduction transform function are shown in the following Table.

Table 3: Roof Conduction Transfer Function Coefficients (b and d factors)

Roof Group	Layer Sequence Left to Right = Inside to Outside		n = 0	n = 1	n = 2	n = 3	n = 4	n = 5	n = 6
1	Layers E0 A3 B25 E3 A0	bn	0.00487	0.03474	0.01365	0.00036	0	0	0
	Steel deck with 3.33 in insulation	dn	1	-0.35451	0.02267	-0.00005	0	0	0
2	Layers E0 A3 B14 E3 E2 A0	bn	0.00056	0.01202	0.01282	0.00143	0.00001	0	0
	steel deck with 5 in insulation	dn	1	-0.60064	0.08602	-0.00135	0	0	0
3	Layers E0 E5 E4 C12 E3 E2 A0	bn	0.00613	0.03983	0.01375	0.00025	0	0	0
	2 in. h.w. concrete deck with suspended ceiling	dn	1	-0.75615	0.01439	-0.00006	0	0	0

For walls, the layers of wall components employed in construction of the wall can be identified from a table like the example above and with the R-value of the dominant material.

Cooling Load

Sensible

$$Q_t = Q_{rf} + Q_{sc} \qquad (5)$$

$$Q_{rf} = \sum_{i=1}\left(v_o\, q_{t,i} + v_i\, q_{t,i-t} + v_2\, q_{t,i-2t} + \ldots\right) - \left(w_1 Q_{t-t} + w_2 Q_{t-2t} + \ldots\right) \qquad (6)$$

$$Q_{sc} = \sum_{j=1} \left(q_{c,j}\right) \qquad (7)$$

where: Q_{rf} = sensible cooling load from heat gain elements having radiant components.

v and w = room transfer function coefficients, selected per element type, circulation rate, mass, and/or fixture type.

q_t = each of i heat gain elements having a radiant component; select appropriate fractions for processing,

δ = time interval (1 hr)

Q_{sc} = sensible cooling load from heat gain elements having only convective components.

q_c = each of j heat gain factors having only convective component

It is to be noted that latent heat gain is assumed to become cooling load instantly, whereas the sensible heat gain is partially delayed depending upon the nature of the conditioned space.

Table 1
Summary of Calculating Design Heating Load for Buildings

Heating Load Component	Equations
Roofs, ceilings, walls, and floors	$q = UA(t_i - t_o)$ where: U^1 is heat transfer coeft, Btu/hr.ft^2.^{o}F A is area calculated from building plans q is in Btu/hr t_i inside temperature t_o outside design temperature from table[1]
Walls and floors below grade	$q = UA(t_i - t_g)$ where $U = 0.1 \frac{Btu}{hr\ ft^2\ {}^oF}$ for concrete floors = 0.2 for walls t_g = 50°F for most of the locations
Floors around the grade	$q = U' P(t_i - t_o)$ where: P is the perimeter of the building from the drawing plans. $U' = 0.55 \frac{Btu}{hr\ ft\ {}^oF}$ for concrete floors with R-5 insulation along the edge $U' = 0.70 \frac{Btu}{hr\ ft\ {}^oF}$ for R-2.5 along edge
Infiltration and Ventilation Air. Sensible Latent	$q_s = 1.1 Q \Delta t$ where: Q = volume flow rate (CFM) $\Delta t = t_o - t_i$, °F, q_s is in Btu/hr t_i, t_o design inside and outside[1] temperature $q_s = 1.23 Q \Delta t$ Δt is in °C, q_s is in watts, Q is in L/s $q_l = 4840 Q \Delta w$ $\Delta w = w_o - w_i$, q_l is in Btu/hr, Q is in CFM w_i, w_o design inside and outside humidity[1] $ql = 3000 Q \Delta w$ Q is in L/s and q_l is in watts The infiltration flow rates can be estimated using the CRACK METHOD or AIR CHANGE METHOD as shown below
	Space Heat Load is equal to the sum of all of the above, $q = \sum q_i$
AIR CHANGE METHOD Recommended values range from 0.5 to 1.5 air changes per hour. One air change per hour would be a volumetric flow rate numerically equal to the internal volume of the space. Smaller values for well fitted windows or doors and higher values for loose fittings.	**CRACK METHOD** Recommended allowed design infiltration rates through exterior windows and doors **Item** — **Infiltration** 1. Windows — 0.5 CFM/ft sash crack 2. Sliding Glass Door (Residential) — 0.5 CFM/ ft^2 door area 3. Swinging Door (Residential) — 1.0 CFM/ft^2 door area 4. Sliding, swinging or revolving doors — 11.0 CFM/ft door area

1 these values are given in ASHRAE handbook of Fundamentals

TABLE 2
Summary of Calculating Space Design Cooling Load

Cooling Load Component	**Equations**
Roofs	$q = U\,A(CLTD_c)$ where: U is heat transfer coeft, Btu/hr.ft^2.^{0}F where, A is area calculated from building plans, ft^2 $CLTD_c = \{(CLTD+LM)K + (78-t_i)+(t_{om}-85)\}$ q is in Btu/hr t_i inside design temperature,^{0}F CLTD cooling load temperature difference,^{0}F LM correction for latitude and month K color adjustment factor (k=1 for dark surface) T_m outdoor mean temperature = t_0 - DR/2 t_o outside design temperature,^{0}F DR is the daily range
Walls	$q = U\,A(CLTD_c)$ where: U is heat transfer coeft, Btu/hr.ft^2.^{0}F where, A is area calculated from building plans, ft^2 $CLTD_c = \{(CLTD+LM)K + (78-t_i)+(t_{om}-85)\}$ q is in Btu/hr CLTD cooling load temperature difference,^{0}F for the wall obtained from a table[1]
Glass Conduction Solar	$q = U\,A(CLTD_c)$ where: U is heat transfer coeft, Btu/hr.ft^2.^{0}F where, A is area calculated from building plans, ft^2 $CLTD_c = \{(CLTD+LM)K + (78-t_i)+(t_{om}-85)\}$ q is in Btu/hr CLTD cooling load temperature difference,^{0}F for the glass[1] q = A . SC . SHGF . CLF A area of the glass window, ft^2 SC shading coefficient[1] SHGF maximum solar heat gain factor[1], Btu/hr. ft^2 CLF cooling load factor[1] for solar heat gain
People Sensible Latent	q_s = No. Sens H.G. CLF where: No number of people Sens H.G sensible heat gain[1], Btu/hr CLF cooling load factor[1] for people q_l = No . Lat H.G Lat H.G latent heat gain[1], Btu/hr
Internal Lights	q = 1.2 . INPUT . CLF INPUT input ratings from light fixtures[1] CLF cooling factor[1] for light fixtures
Appliances Sensible Latent	q_s = Heat Gain$_s$. CLF Heat Gain$_s$ recommended rate of heat gain[1] CLF cooling factor[1] for appliances q_l = Heat Gain$_l$ Heat Gain$_l$ recommended rate of heat gain[1]
Infiltration and Ventilation air. Sensible Latent	$q_s = 1.1 Q\,\Delta t$ where: Q = volume flow rate (CFM) $\Delta t = t_o - t_i$, °F, q_s is in Btu/hr $q_s = 1.23 Q\,\Delta t$ Δt is in °C, q_s is in watts, Q is in L/s $q_l = 4840 Q\,\Delta w$ $\Delta w = w_o - w_i$, q_l is in BTU/hr, Q is in CFM $ql = 3000 Q\,\Delta w$ Q is in L/s and q_l is in watts The infiltration flow rates can be estimated using the CRACK METHOD or AIR CHANGE METHOD as presented in the Table III
	Space Cooling Load is equal to sum of all of the above, $q = \sum q_i$ 1 these values are given ASHRAE handbook of Fundamentals, 1997

VITA

Stewart Glenn Garrett Jr. was born in Talladega, AL, to the parents Kathleen Garrett and Stewart Garrett Sr. He attended the University of Tennessee, Chattanooga to pursue an undergraduate degree in mechanical engineering. During his undergraduate studies, he would go on to add a second degree in nuclear engineering. In May 2014 Glenn graduated with honors with a Bachelor's of Science in Mechanical Engineering and a Bachelor's of Science in Engineering with a focus on Nuclear Power. During his undergraduate studies, he would accept an internship with the Tennessee Valley Authority (TVA) working in Performance Improvement and later nuclear engineering. Glenn would go on to pursue a Master's of Science in Mechanical Engineering graduating in the fall semester of 2020.