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Novartis Energy and Utility Utilization

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Degree of Bachelor of Science

by

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This report represents the work of one or more WPI undergraduate students
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List of Equations

Equation #1: Trimming Pump Impeller

- Current and required flow rates of the pump
- Current and necessary diameters of the pump impeller

Equation #2: Brake Horsepower of a Fan

- Calculated fan energy in brake horsepower (BHP)
- Volume of air being pushed through the system in cubic feet per minute (CFM)
- Pressure in inches water column required to push air through the system
- ε = Fan efficiency selected from list:
  - Plug Fan – backward included
  - Plug Fan – forward inclined
  - Backward inclined squirrel cage
  - Forward inclined squirrel cage
- VFD efficiency - Question user: “Do the fans have VFD’s?”
  - If “Yes” divide the equation by 1
  - If “No” divide by 97% (3% of power lost through VFD)

Equation #3: Electric Cost of a Fan

- Cost to run the fan
- Number of hours in operation per year
- Cost per kWh

Equation #4: Air Temperature Off Return Fan

- Temperature out of return fan
- Rise in air temperature through fan (BTU/hr)
- CFM = Air flow through fan (CFM)
- Temperature entering return fan

Equation #5: Mixed Air Conditions

- Mixed air dry bulb temperature
- Flow of return air (CFM)
- Return air dry bulb temperature
- Flow of outdoor air (CFM)
- Outdoor air dry bulb temperature
- Flow of supply air (CFM) =

Equation #6: Energy Input of Coil

- Energy through coil (BTU/hr)
- Outdoor air dry bulb temperature
- Mixed air dry bulb temperature

Equation #7: Flow of Water Through a Pump

- Flow through the coil (GPM)
- Depends on the type of coil, either tons of cooling or therms of heating
- Water temperature change through coil

Equation #8: Brake Horsepower of a Pump

- Brake horsepower (BHP)
- Flow through the coil (GPM)
- Design head of the pump
- Specific gravity = 1
- Pump efficiency

Equation #9: Energy Calculator’s Fan Brake Horsepower Equation

- BHP = Brake horsepower
- CFM = Airflow
- ε = Mechanical efficiency

Equation #10: Energy Calculator’s Fan Energy Cost

- EC = Electric cost of fan for one year
- H = Number of hours in operation
- C = Cost per kilowatt-hour

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ABSTRACT

The Vaccines & Diagnostics division of Novartis attempts to evaluate their energy efficiency to find ways to cut cost. By investigating their HVAC, chillers, pumps, and lighting systems of individual production sites, we have built a user friendly Excel-based model that will allow the company to explore ways to tweak their current systems to attain optimum energy efficiency. We have also developed a guide that explores good standards and practices to promote possible implementations to substantially decrease overall energy usage.

1. INTRODUCTION

1.1 COMPANY BACKGROUND

As one of the largest healthcare companies in the world and a leader in the pharmaceutical industry, Novartis International AG ranks number one in revenues and number three in sales accruing over $53 billion and $36.172 billion respectively in 2008[1]. Novartis was formed in December 1996 through a merger between two Swiss companies called Ciba-Geigy Ltd. and Sandoz Laboratories, who together have a collective history of 250 years of existence. Headquartered in Basel, Switzerland, this company operates four major divisions within itself; they are the Pharmaceutical Division, Vaccines & Diagnostics Division, Sandoz Division, and the Consumer Health Division.

The Pharmaceutical Division has more than fifty key products on the market and has 148 projects in various stages of clinical development which include potential new products and new formulations for existing products. This division has five major therapeutic areas which make up the Pharmaceutical Division, they are cardiovascular and metabolism, oncology, neuroscience and opthalmics, respiratory, and immunology and infectious diseases. Some of the bestselling drugs include Diovan for hypertension which has over $5 billion in sales in 2007[2] and Ritalin used to treat AD/HD. In 2008, Novartis Pharmaceuticals successfully launched eleven new products in the United States and the European Union[3].

The Vaccines & Diagnostics Division is made up of two businesses (Novartis Vaccines and Chiron). Novartis Vaccines provides more than twenty products to fight vaccine-

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[1] "Top 15 Global Corporations"
[2] "Novartis Product Sales"
[3] Novartis Products 2009

preventable viral and bacterial diseases. One of the major vaccines that Novartis Vaccines produces is Agrippal, which is a highly purified influenza vaccine for adults and children older than six months. Novartis Vaccines also produces Fluvirin which is a subunit influenza vaccine that is a leading product in the United States and is approved for sale in more than twenty countries. Some of the other major vaccines that Novartis Vaccines produces are Menjugate which is for Meningitis C, Encepur N for tick borne encephalitis, RabAvert for effective pre-exposure immunization and post-exposure treatment against rabies, and Polioral which is a Polio vaccine for developing countries. The Vaccines Division has sites around the world located in Holly Springs, North Carolina, U.S.A, Rosia, Italy, Siena, Italy, Liverpool, United Kingdom, and Marburg, Germany. The diagnostics section of Novartis Vaccines and Diagnostics is primarily run through a company called Chiron, which makes sophisticated equipment to test blood donations for infections. There are three main assays which Chiron analyzes for infection: PROCLEIX WNV Assay which is "The first Nucleic Acid Testing (NAT) solution approved by the US Food and Drug Administration for qualitative detection of the West Nile virus in RNA plasma specimens from individual donors of blood, organs, cells and tissues", the PROCLEIX HIV-1/HCV Assay which "Detects HIV and HCV in a single tube, thanks to transcription-medicated amplification (TMA) technology, and was the first NAT solution to be approved for blood screening in the US and to receive the CE Mark in Europe", and the PROCLEIX ULTRIO Assay which is "Designed to combine the early detection capabilities of NAT with a single-tube TMA technology to deliver simultaneous results for HIV-1, HCV and HBV"[4].

The third division of Novartis is the Sandoz division which develops and produces more than 950 compounds, active substances, and intermediates. Sandoz International is a company

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[4] Novartis Product Sales

owned by Novartis International AG that produces generic drugs available to 90% of the world's population. In 2008, Sandoz reported generic pharmaceutical sales of $7.6 billion and employed more than 23,000 associates in over 130 countries. The Sandoz Vision is "To be the main provider of high-quality, affordable medicines helping secure long-term access to healthcare for people around the world" [5]. Sandoz develops, produces, and markets medicines that are no longer protected by patents, along with pharmaceutical and biotechnical active substances. The main products that Sandoz produces are retail generics, but they also have two businesses that specialize in anti-invectives and biopharmaceuticals.

The fourth major division within Novartis International AG is the Consumer Health division. This division focuses on three business units: over-the-counter, animal health, and CIBA vision. Novartis Consumer Health, Inc. is the over-the-counter business unit which "is a world leader in consumer healthcare, providing self-medication products for the treatment and prevention of common illness and conditions, and the enhancement of overall health and well being"[6]. Some of the common products on the market in the US produced by Novartis Consumer Health, Inc. are Benefiber (fiber supplement), Excedrin (pain relief), Ex-Lax (overnight laxative), Gas-x (adult gas relief), Lamisil AT (athlete's foot and jock itch), Delsym (cough suppressant), among many other over-the-counter consumer health products. Novartis Animal Health is the name of the animal health business unit which is "Focused on the well-being of companion animals and on the health and productivity of farm animals"[7]. For household pets, Novartis Animal Health's products, "Are effective aids in preventing internal and external parasites and treating ailments such as arthritic pain and kidney, heart and allergic

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[5] Novartis Product Sales

[6] Novartis Consumer Health

[7] Novartis Consumer Health

diseases". For farm animals, the company, "Offers therapeutic products to treat parasitic and bacterial diseases and are consistently developing new vaccines to prevent diseases in livestock and farmed fish" [8]. CIBA Vision is "A global leader in the research, development and manufacturing of contact lenses and lens care products"[9]. The headquarters of CIBA Vision are located in Atlanta, GA and the products are available in more than seventy countries. Some of the common contact lenses they offer are AIR OPTIX, which is a family of highly breathable contact lenses that are replaced monthly, NIGHT & DAY which are contact lenses which can be worn continuously for up to thirty days and nights, DAILIES which are daily disposable lenses, and Freshlook color contact lenses which "Change, enhance or illuminate your natural eye color"[10].

1.2 PROBLEM STATEMENT

The Novartis Vaccines and Diagnostics Division of Novartis International AG manufactures more than twenty different vaccines that are distributed around the world. During the research, development, manufacturing and packaging processes, Novartis consumes massive amounts of utilities (electricity, water, heat, etc.). Since the production of energy produces by-products like greenhouse gases, the massive consumption by the company is detrimental to the environment, while also costing Novartis a vast amount of money especially with the rapidly rising energy prices in the European Union and the United States. As of right now the measurement, evaluation and conservation of utilities along the production process for Novartis is a very new concept that has only been explored at their manufacturing and production site in Rosia, Italy. Our group has a unique opportunity to save Novartis money in the long run and to

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[8] Novartis Animal Health

[9] Novartis CIBA Vision

[10] Novartis CIBA Vision

broaden the concepts of energy and utility conservation to a company who until recently has not considered it.

A majority of the energy used on-site can be attributed to the heating, ventilating, and air conditioning (HVAC) systems. This is due to the strict guidelines set forth by the FDA and the guidelines in Novartis Quality Policy 9.9.1: *Cleanliness Zoning Policy for the Manufacture of Sterile Drug Products and the Respective (Sterile) Drug Substances*. The clean rooms, labs, and fume hoods at Novartis Vaccines and Diagnostics undergo a vast number of air changes regardless of whether humans are interacting with the system or not. During hours of operation, the vast numbers of air changes are necessary in order to keep research, production, and packaging processes up to code with health and safety laws, and to keep the products and surrounding environments sterile. During daytime hours of operation, contaminants are constantly being introduced to the environment through many different sources; one of the biggest sources is from the interaction of humans working in the system during the production process. During the non-production hours the risk of contamination reduces dramatically giving the company an opportunity to decrease consumption of energy with the proper plan of action in place. We believe that there is opportunity to reduce the number of air changes when humans aren't interacting with the system to save energy and utilities.

Novartis also wants to look into the feasibility of reducing the number of air changes throughout their facilities worldwide. Currently, the number of air changes are so high that the amount of particulate in the air is orders of magnitudes lower than required. Novartis wants to know how much money can be saved at each site if they were to reduce the number of air changes in different clean rooms. They will need to do lots of research to make sure the number of air changes they reduce to are safe for the product, because quality is very important, especially when the vaccines are ingested by humans. One of the scenarios they are going to test with the program is to calculate how much money can be saved by reducing the number of air changes in a Class C from forty to twenty-five. Once we have a final version of the program, the Energy Managers at each site will use it to calculate the amount of savings possible by air change reduction scenarios.

1.3 PROJECT PLAN

Our plan for this project is to research ways to cut energy cost in the case of HVAC, chillers, pumps, lighting, and a few other minor systems that are currently run on a continuous basis throughout production. All of our research will be put into our literature review and will double as a manual for cutting energy costs at Novartis. If they use just one of the methods that we have researched and described in our paper then the project will be well worth it. The bulk of the project however, will be creating a computer tool for the company to use to evaluate at least one of these systems and also calculate the possible savings that they could experience with a few modifications to the system. HVAC will most likely be the system that we will evaluate.

This tool has a few requirements that need to be fulfilled if it is going to be a success. First, it must be done using an application that is universal, and hopefully one that the company has standard on all of its computers so that any person in the company can use it at work and at home. They may be less likely to use it if they are required to purchase a new program to run it and install it on numerous computers because this will cost them time and money. It also needs to be user-friendly so that any person in Novartis that needs to use it will be able to with relative ease. If it is too complex and confusing, frustration will rear its ugly head and the tool will be in jeopardy of being discarded. Lastly, we need to keep in contact with the company at least weekly to insure that the program is exactly how they want it. This may be our project, but it will be their program and it is our mission to make sure that they are actually going to use it.

1.4 GOALS AND OBJECTIVES

The overall goal of this Energy and Utility MQP is to reduce the amount of energy and utilities consumed at Novartis Vaccine and Diagnostics sites across the globe. Novartis wants a user-friendly energy model to be created that will look into the HVAC systems, lighting, pumps, or chillers. The Rosia, Italy site is the only site that has looked into possible utility savings, and we will use their research as a starting point for our project and the user-friendly energy model.

The HVAC systems consume a majority of the energy used at pharmaceutical companies because of the need for a clean environment so that the products they are producing do not get contaminated. The systems are continuously running during both the day and night regardless of whether the clean rooms are actively being used or not. We want to reduce the number of air changes in these clean rooms when they are not being used which is mostly during nights and weekends. If there are no humans interacting with a clean room, there is a much lower risk for contaminants to be introduced into the environment, and therefore the number of air changes can be reduced during the system's inactive periods. The HVAC systems cannot be shut-down completely due to pressure differentials between the different rooms, but we want to look at significantly reducing the number of air changes. If this is a feasible solution, we will make a model which can be applied to the other sites based on the classification of the clean room and its use.

The lighting systems are necessary for when there are people working at the facilities. During the project we will look at ways to save energy through changes that can be made to the lighting systems already installed. Some of the possibilities include shutting off the lights when the last person leaves, installing motion sensors that activates the system when movement occurs, installing automatic timers for entire buildings, replacing current bulbs with more energy-efficient ones, or any combination of solutions previously mentioned.

One of the most difficult aspects of this goal is making the model user-friendly, meaning that the employees of this company have to be able to operate this model without our assistance so that it will be useful to the company for many years to come. There is also a possibility for this model to be used in other divisions in the company as well if it is done correctly. The easiest way to ensure that this will happen is to create a "how to" guide along with the model so that they have a written guide to lead them while trying to operate the program.

1.5 EXPECTED RESULTS

By the completion of the Energy and Utility Usage Major Qualifying Project, we expect to have a fully-functional, user-friendly air handling unit (AHU) energy and utility calculator. This calculator will be a Microsoft Excel-based program that calculates the savings associated with making major or minor modifications to an air handling unit. Savings will be expressed in kW, gallons of water, tons of cooling, therms of heating, and USD ($).

There are many different scenarios that the program will be able to analyze. One of the main scenarios it will analyze is the calculated savings associated with reducing the number of air changes in a clean room or any other regulated space. Currently, the air change rates are very high which wastes a lot of energy. Using the program will generate data regarding the amount of savings per year, which will be used by the Site Energy Managers to help push for the appropriate changes. Another scenario the program will analyze is calculating the savings associated with relaxing the indoor air temperature settings and allowing the temperature to "float" more around the indoor set point. If the temperature range is broader, the air handling units will do less work because they won't have to heat and cool as much and/or as often.

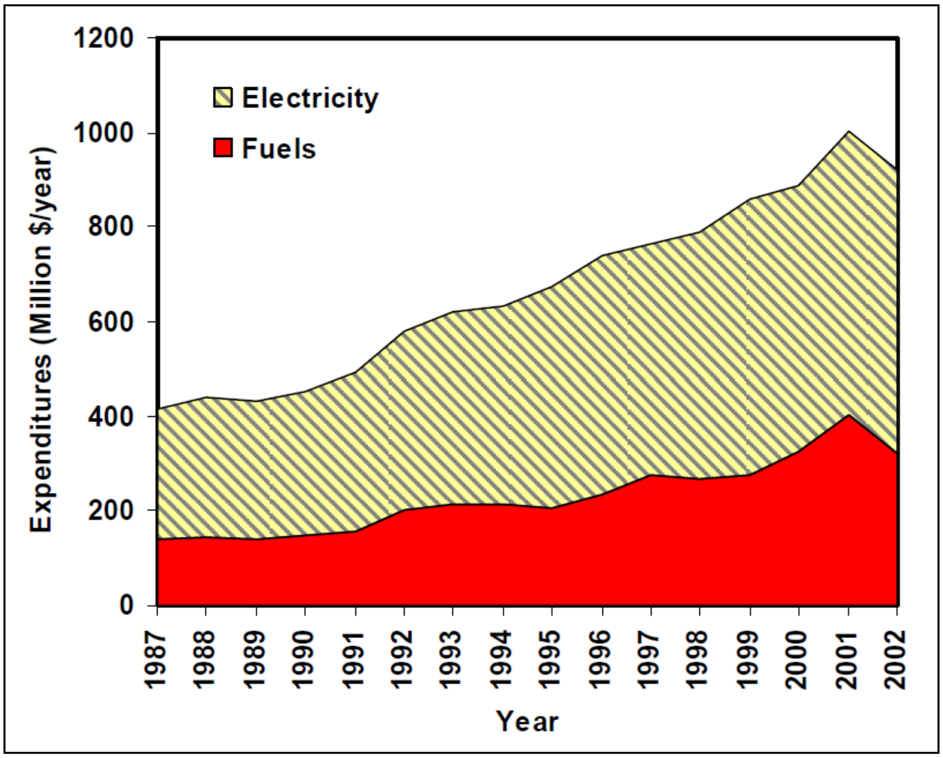
The program will have multiple worksheets, each with different information. There will be one sheet called "Inputs", which is the only worksheet the user will need to input data to prevent the possibility of a user accidentally changing any of the equations in the Excel workbook. All of the calculations will be done on two separate worksheets called "Current Outputs", and "Projected Outputs". The user will be able to look at the values for each temperature bin data and print them out, but they won't be able to physically change the contents of any of the cells because the worksheet will be locked. A worksheet called "Summary" will show the user the amount of utilities and money in USD ($) saved by changing the current air handling unit values. There will be one last worksheet called "Savings" where the overall results regarding the total money and energy saved by the program is located. There will also be three charts that take this data and show the results in a more visual manner for managers to see.

2. LITERATURE REVIEW

2.1 ENERGY USE IN THE PHARMACUETICAL INDUSTRY

Since 1987, the energy cost for the entire pharmaceutical industry has increased every single year for both electricity and fuel[11].

Figure 1: Historical Energy Expenditures of the U.S. Pharmaceutical Industry



The biggest reason for this is the fact that in order to produce safe, quality drugs to save lives, there are many factors that must be controlled mechanically. They must control climate in clean rooms with HVAC systems, illuminate dozens of buildings at the same time, and use other technologies that consumes energy at an alarming rate. In addition to these delicate processes, pharmaceutical companies must also have office buildings, warehouses that are controlled to

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[11] Berkeley National Laboratory 2005

store the finished product safely, and packaging plants that all require energy to run. A table of Pharmaceutical energy usage can be seen in Figure 1.

Table 1: Distribution of Energy Use in the Pharmaceutical Industry

	Overall	**Plug loads and processes**	**Lighting**	**HVAC**
Total	**100%**	**25%**	**10%**	**65%**
R&D	**30%**	Microscopes Centrifuges Electric mixers Analysis equipment Sterilization processes Incubators Walk in/reach in areas (refrigeration)	Task and overhead lighting	Ventilation for clean rooms and fume hoods Areas requiring 100% make-up air Chilled water Hot water and steam
Offices	**10%**	Computers Fax machines Photocopiers Printer Water heating (9%)*	Task, overhead, and outdoor lighting	Space heating (25%)* Cooling (9%)* Ventilation (5%)*
Bulk Manufacturing	**35%**	Centrifuges Sterilization processes Incubators Dryer Separation processes	Task and overhead lighting	Ventilation for clean rooms and fume hoods Areas requiring 100% make-up air Chilled water Hot water and steam
Formulation, Packaging & Filling	**15%**	Mixers Motors	Mostly overhead, some task	Particle control ventilation
Warehouses	**5%**	Forklifts Water heating (5%)*	Mostly overhead lighting	Space heating (41%)* Refrigeration (4%)*
Miscellaneous	**5%**		Overhead	

* These percentages are taken from the U.S. DOE's Commercial Building Energy Consumption Survey (CBECS) for commercial office or warehouse buildings[12] and are approximated values that will vary from one site to another.

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[12] US DOE 1999

2.2 PERFORMING AN ENERGY AUDIT

"When considering the economic costs of energy consuming systems and equipment, it is best to look at systems on the basis of lifecycle costs. First cost, or installed cost, is only one factor in the economic equation."[13]

Energy Audit

The purpose of performing an energy audit is to evaluate the overall process and determine where energy is being used and how it is being used. The next step is to find opportunities to reduce the energy usage followed by evaluating the economic and technical practicability of applying improvements that are intended to conserve energy. Lastly, it is necessary to create a list and a plan for the actual application of these improvements.

Information that is needed to properly perform an energy audit on the systems and equipment that are consuming energy are process flow diagrams that highlight how mass and energy flow through the entire process, production data and historical data regarding energy use, batch-based variables, nameplate data of equipment, the properties of material used, profiles on the equipment that is operating, and costs of fuel and electricity costs.

The three steps that are needed to be taken when performing this audit are to first study the energy billing and survey the facilities, then create a detailed breakdown of energy use on the entire site, and an analysis of improvements that can be taken to reduce energy and utility usage to ultimately decrease the overall cost of the production process.

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[13] Mull, Thomas E. page 1

Energy Savings and Opportunities

The three types of opportunities to save energy are operations and maintenance (O&M) improvements, energy conservation measures (ECMs), and new plants and equipment.

Operations and Maintenance (O&M) Improvements

These improvements are very easy to implement and are generally low cost. They tend to save around 10-20% in consumption if implemented correctly:

- Shutting systems off when they are not in use
- Reducing outside air intake
- Reducing heating temperatures and/or increasing cooling temperatures during unoccupied periods
- Rebalancing air distribution systems
- Recalibrating and adjusting controls
- Resetting heating and cooling temperatures based on the actual load
- Reducing illumination levels
- Repairing/reducing insulation
- Repairing leaks in piping systems
- Cleaning lenses in lighting fixtures
- Adjusting fuel/air ratios on burners
- Changing filters and clean strainers
- Adjusting drive on belt-driven equipment
- Maintaining and/or replacing steam taps

Energy Conservation Measures (ECMs)

ECMs are changes made to a system that is already installed and operating in the current process but require more time and money to apply:

- Energy management systems
- Replacement of primary heating or cooling equipment
- Replacement of auxiliary heating or cooling equipment
- Reduction of loads for energy consuming equipment
- Replacement of lighting systems with more efficient systems

New Plants and Equipment

These require a huge commitment of time and money since they call for a replacement of an entire system with a more energy efficient model. These measures will not be considered in this case since the company will most likely be unwilling to replace an entire system for the simple purpose of conservation. Some ideas they should keep in mind when replacing old equipment or building a brand new site are:

- Cogeneration systems
- New central plants
- Thermal storage systems

2.3 AREAS TO CONSIDER

2.3.1 HVAC

HVAC is an acronym that stands for heating, ventilating, and air conditioning. The HVAC system helps to control relative humidity and temperature of the air within a particular space inside a building, and it is responsible for maintaining pressure relationships between spaces for air cleanliness. It is based on the principles of thermodynamics, fluid mechanics, and heat transfer. HVAC systems are generally comprised of dampers, supply and exhaust fans, filters, humidifiers, dehumidifiers, heating and cooling coils, ducts, and various sensors.[14]

HVAC systems are critical to the quality of products in the pharmaceutical industry. They are used to regulate the environmental conditions within buildings so that they are safe to produce sterile products, and also so that the people who work in the buildings are comfortable and safe from air borne contaminates. There are many different HVAC applications depending on different building or space requirements. Laboratories and manufacturing areas have strict standards set forth by the U.S. Federal Code of Regulations, British Standards, and EU standards. Currently the International Organization of Standardization (ISO) is working to create a universal set of standards that can be used worldwide.

A huge amount of energy is consumed by HVAC because of the strict quality standards set forth by the FDA and other regulation and standards organizations. In 1999, it was estimated that 65% of electricity and fuel consumed by the pharmaceutical industry was from HVAC components, which is an alarming amount.[15]

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[14] Cole 1998

[15] US DOE 1999

Ventilation

The ventilation system is the most important part of a HVAC system because it distributes the conditioned air from the air handling unit to the appropriate spaces where conditioned air is needed throughout the building. Ventilation should only be provided where needed for employee safety and comfort and for process requirements. In areas like offices, where air replacement specifications are not required for quality assurance reasons, the maximum levels of CO_2 are 950 – 1350 ppm (all areas are non-smoking areas). The minimum amount of fresh air required for offices and similar areas is seven liters per second per person and the maximum amount of fresh air required is ten liters per second per person.[16]

In Novartis Corporate Health, Safety, and Environmental Guidance Note 14.2, Novartis defines the requirements for the design of new ventilation systems. These requirements can also be used to identify savings potentials on the existing ventilation systems at their facilities. In order to reduce pressure drops and energy needs for air transportation, there are constraints for maximum air velocities in ducts. The following values define the maximum air velocities in ducts based on their size in terms of air flow (m^3/h):

- $< 1{,}000\ m^3/h: \leq 3\ m/s$
- $< 2{,}000\ m^3/h: \leq 4\ m/s$
- $< 4{,}000\ m^3/h: \leq 5\ m/s$
- $< 10{,}000\ m^3/h: \leq 6\ m/s$
- $> 10{,}000\ m^3/h: \leq 7\ m/s$

The air handling units should have a maximum air velocity of 2.0 to 2.5 m/s (related to the cross section of the heat exchanger area).[17]

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[16] Novartis CHSE Guideline 14

[17] Novartis CHSE Guidance Note 14.2

Fans are used to distribute the conditioned air from the air handling unit throughout the ductwork to the areas that the air is needed in. On systems that recirculate air, there is a return fan that brings the air back to the air handling unit to be conditioned again. The fans used to move the conditioned air should be energy efficient because they are operating for a majority of the day. Novartis has defined the following values for minimum fan efficiency on new installations:

- < 100 m^3/h: ≥ 20%
- < 250 m^3/h: ≥ 30%
- < 500 m^3/h: ≥ 40%
- < 1,000 m^3/h: ≥ 50%
- < 2,500 m^3/h: ≥ 55%
- < 5,000 m^3/h: ≥ 65%
- < 10,000 m^3/h: ≥ 70%
- < 15,000 m^3/h: ≥ 75%
- > 15,000 m^3/h: ≥ 80%

These fan efficiency values should be applied to existing fan motors as well because if a fan is not very efficient, replacing it should be considered because it might have a low return on investment[18].

Air leakage can be a big problem for ventilation systems because it causes the overall system pressure drop. The system should be checked regularly through a maintenance program to make sure air is not leaking excessively. If there is a large drop in pressure through the system, the cause needs to be determined and fixed appropriately. The specific leakage rate (SLR in $l/s*m^2$) should be as follows:[19]

- $P < 500$ Pa: SLR $< 0.027 \times P^{0.65}$
- $P < 1{,}000$ Pa: SLR $< 0.009 \times P^{0.65}$

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[18] Novartis CHSE Guidance Note 14.2

[19] Ibid.

- $P < 2{,}000$ Pa: $SLR < 0.003 \times P^{0.65}$

Recommissioning

System recommissioning should be explored before replacing or upgrading any HVAC system components to improve energy efficiency. Recommissioning requires periodic examination of building equipment, systems operation, and maintenance procedures for comparison to design intent and current operational needs.[20]

CASE STUDY 1: HVAC Recommissioning Project

A HVAC recommissioning project was implemented by Dome-Tech Group in pharmaceutical research office buildings in the Northeastern United States. During their study, they identified over thirty energy conservation opportunities with more than $2.2 million in annual energy cost savings (20% of the total annual energy use), a combined one-time $7.6 million capital expenditure, and a collective simple payback of 3.3 years. The total annual CO_2 emissions offset with enacting these thirty energy conservation opportunities amounted to 12,300 metric tons.[21]

CASE STUDY 2: HVAC Recommissioning Project

In 2002, Pfizer implemented an HVAC recommissioning project in four buildings at its Morris Plains, New Jersey location. As a result of this recommissioning project, they have experienced a 21% net decrease in energy consumption per degree-day.[22]

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[20] US EPA 2004

[21] Dome-Tech 2007

[22] Berkeley National Laboratory 2005

CASE STUDY 3: Recommissioning Project

A recommissioning project on Ethicon's 180,000 ft^2 multi-use facility located in Somerville, New Jersey identified 231 opportunities for energy conservation and reduction. The recommissioning project involved design and installation reviews, data logging to identify areas on non-conformance, physical inspection of air handlers, and verification of HVAC system balance and air flows to various areas. The costs to implement the project were $53,000 and the annual savings in gas and electricity amounted to $48,000. The payback period was only 1.1 years.[23]

System Shutdown during Unoccupied Hours

Shutting down HVAC systems during unoccupied hours (nights, weekends, and non-production times) can save a lot of money for the pharmaceutical industry. When choosing which areas can be shutdown, one must take some important factors into consideration. All of the areas served by the HVAC system must be unoccupied during the shutdown period. If there are exhaust systems being used for hazardous chemicals and materials, they must continue to operate. If there are existing pressure differentials (air paths) in the building they must not be altered materially. It is not always possible to shut down HVAC systems, especially in sensitive areas such as clean rooms and labs where there need to be pressure differentials between the different classified areas in order to keep them clean from contamination. In these areas, the ventilation can be reduced through a reduction in the number of air changes, as long they stay within the safety parameters set forth by the FDA and the EU. Savings can be seen by avoiding

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[23] Ibid.

the cost of heating and cooling outside air for ventilation. Also, the fans are not running which saves electricity because the fan motors are not operating.[24]

Set-Back Temperatures during Non-Production Hours

Reducing the heating and cooling loads during non-production hours is a great way for pharmaceutical companies to save energy. This is defined as turning building temperatures up during the summer and turning temperatures down in the winter. When considering setting back temperatures, one must look into whether it will interfere with the environment.

CASE STUDY 4: HVAC Temperature Setback

At Merck in Rahway, New Jersey, the HVAC systems in the laboratory facilities are designed with once-though air-exchange based on safety considerations. This uses a large amount of electricity because the system is constantly conditioning the outside air so that it is the appropriately set temperature. To improve the energy efficiency of the system, a control technology was utilized to lower the building's indoor air temperature from 72°F to 64°F during nights and weekends. This was applied to 150 individual laboratory spaces totaling 350,000 ft^2 where lowering the air temperature wouldn't affect any of the scientific equipment. The energy savings associated with this project totaled nearly 30,000 MBtu per year which amounted to 1,700 tons of CO^2 being offset each year.[25]

Variable-Air-Volume (VAV) Systems

Variable-air-volume systems adjust the rate of air flow into a room or space based on the current air flow requirements within that space or room. The air supply temperature is constant,

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[24] Smith, 14-15

[25] US EPA 2005; Berkeley National Laboratory 2005

so the air flow rate must vary in order to meet the rising and falling heat gains and losses within the thermal zone served. This helps to optimize the air flow within the HVAC ductwork which reduces the loads on building air-handling units leading to reduced electrical consumption.[26]

Adjustable Speed Drives (ASDs)

Adjustable speed drives match the flow and pressure requirements of air handling systems so that fans are not constantly running at full speed. These can be installed on VAV systems and on recirculation fans. A significant amount of energy can be conserved if fan motors are not running at full speed and it also puts less stress on the motors, so they will need less maintenance and operate longer. These would be used during normal daytime hours, and they could also be incorporated into reducing the number of air changes when the building is unoccupied.

CASE STUDY 5: Adjustable Speed Drives (ASDs)

The Louis Stokes Laboratories of the U.S. National Institutes of Health implemented a VAV system with adjustable speed drives (ASDs). The ASDs led to the supply and exhaust fans being 25% more efficient than the previous standard inlet vane control. In turn, the VAV system uses 30-50% less energy than the previous system. The VAV system also allows the volume of air delivered to be reduced during hours when the building isn't in use. Before the VAV/ASD system was put into use, the volume of air conditioned when the building wasn't in use was 400,000 cfm (15 ACH) and now it has been reduced to 160,000 cfm (6 ACH).[27]

Note: cfm = cubic feet per minute, ACH = air changes per hour

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[26] US EPA 2005

[27] US DOE 2001

Energy Monitoring and Control Systems

An HVAC energy monitoring and control systems provide valuable data about system energy consumption for building engineers and energy managers by monitoring, controlling, and tracking energy consumption. There have been several case studies by the Department of Energy (DOE) Industrial Assessment Center at Rutgers University. The average payback period for an HVAC control system is about 1.3 years.[28]

CASE STUDY 6: HVAC Microprocessor Controls

Novartis installed HVAC microprocessor controls at a plant located in Rzeszow, Poland. The microprocessor controls balanced the plant heating based on outside temperatures, and also reduced the heating loads on weekends when the building wasn't in use. It is estimated that this project will reduce the overall heating consumption of the plant by 10%.[29]

Heat Recovery

Heat recovery systems reduce the energy required to heat or cool facility air intake by harnessing the thermal energy of the facility's exhaust air. There are many different kinds of heat recovery systems, but the most common ones are heat recovery wheels, heat pipes, and run-around loops. Heat recovery is especially important for laboratory areas because they require 100% make-up air meaning that air is not recirculated through the air handling unit. Studies have shown that heat recovery systems can reduce a facility's heating/cooling cost by about 3% for each degree (Fahrenheit) that the intake air is raised/lowered which can account for a large

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[28] IAC 2009

[29] Berkeley National Laboratory 2005

amount of savings. The typical payback period for a heat recovery system is three years or less.[30]

CASE STUDY 7: Heat Recovery System

In 2004, Merck installed a glycol run-around loop system in a 37,000 ft^2 laboratory building to recover heat from HVAC exhaust air. After it was installed, Merck was able to per-heat and pre-cool up to 120,000 cfm of outside air with recovered energy which resulted in a yearly energy savings of roughly 265 MBtu.[31]

2.3.2 CLEAN ROOMS

The main purpose that a clean room serves is to prevent the interference of contaminant particles and reduce static electricity in an enclosed space that the product is being handled in during production. In order for this to be done properly, a number of conditions of the room must be controlled: temperature, humidity, air flow and motions, airborne particles, and lighting.[32] These standards are in fact not set by the company itself but instead by a governing body, the United States Food and Drug Administration (FDA). Since these rooms are so highly regulated, they tend to consume a very large amount of energy which can be decreased when good practices and standards are set by a company which requires the use of cleanrooms. The distribution of energy consumption for the operation of clean rooms is roughly measured to be 56% for cooling, 36% for heating, 5% for fans, and 3% for pumps.[33]

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[30] Berkeley National Laboratory 2005
[31] Berkeley National Laboratory 2005
[32] Mills 1996
[33] Berkeley National Laboratory 2005

Reduction of Air Circulation

Decreasing the number of air changes in a clean room will obviously save energy and money but it can also be done while maintaining quality and regulation standards. One of the best ways to do this is try to reduce resultant heat load from fan energy.[34]

Improving Air Filtration Quality and Efficiency

A good way to lower energy consumption would be to find a way to lessen the number of times that a clean room needs to be reheated or cooled. This can be achieved by using newly designed filters that trap ultra-fine particles called High Efficiency Particulate Air (HEPA) filters and/or Ultra Low Penetration Air (ULPA) filters.[35] By trapping particles and recirculating air instead of forcing it out as exhaust, less new air needs to be treated so that it meets the room's standards when introduced into the system. This will provide considerable savings since the HVAC systems of the clean rooms are doing less overall work. Also, incorporating low pressure drop filters is believed to save on energy because the fans do less work.

Water Chillers and Cooling Towers

More often than not, the chilled water system of a clean room is not set to run at optimized energy efficiency which gives the company an opportunity to conserve energy. A more energy efficient alternative to water chillers is using cooling towers, which can provide the same results but use less energy so the overall consumption of the clean room HVAC system

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[34] Berkeley National Laboratory 2005

[35] Berkeley National Laboratory 2005

decreases. Another step that can be taken would be to run multiple cooling towers at once but at a reduced fan speed to conserve electricity.[36]

Reducing Clean Room Exhaust

The measures that can be taken for energy saving with reduced air exhaust is the same as for the fume hood section. Energy usage can be reduced by not having to reheat and re-cool a clean room if the air is not all simply forced out of the room. Filtering the air and keeping it in the system reduces the need to spend money on electricity for controlling outdoor temperature.

Declassification

Clean rooms that are classified at the higher end of the cleanliness spectrum obviously consume much more energy than those that are at the other end since they are required to maintain a stricter set of temperature, humidity, air flow, and air quality. A simple way to save energy would be to reevaluate the room's classification and try to set its classification to the next one down if it will still meet the standards. Many times a company will set a clean room to be high than necessary in order to ensure that their product remains safe and uncontaminated during production.

2.3.3 FUME HOODS

In the pharmaceutical industry, fume hoods are installed to ensure that all hazardous gasses produced in the research and development laboratories are contained and expelled out of the workspace via a vent on the top of the hood to protect the employees from breathing them in. These metal cupboards are designed with a sliding glass window for opening and closing on the

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[36] Berkeley National Laboratory 2005

front to allow access and trapping gasses called a sash.[37] Although the inside of a fume hood is a relatively small area to maintain a certain temperature and air change rate, a good percentage of HVAC energy used in a laboratory is drawn directly from these contraptions. More often than not, fume hoods are operating at their highest air change rate in order to ensure that none of the workers in the lab are forced to inhale any dangerous gasses. However, many times this is an unnecessary precaution and there is a lot of energy and money that can be saved while still assuring the health of all employees working in the laboratory.

Proper Storage Habits

Unfortunately, in many labs the employees might use the fume hoods as closets for their equipment, unfinished work and other hazardous and delicate chemicals required for the processes they are involved in. This requires that the hoods be operating overnight causing the machine to consume vast amounts of unnecessary energy. It is important for the company to have and enforce strict policies that prevent these practices, and provide their workers with the proper receptacles to store chemicals and other substances used and produced during the process they are used for.

Prevention of Sash Openings

By limiting the number of times that the sash on a fume hood is opened while operating is another important practice to employ during production. This will decrease the number of times that the machine needs to increase its energy usage to return to its set specifications for temperature, humidity, and air change rate. There are two other smaller measures that can be

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[37] Mills and Sartor 2003

taken; installing horizontal sashes on all the units to help block the air from moving out of the device and making sure that all the hoods that are not being used are closed.

Vortex in the Top Exhaust Vent

Installing a “bi-stable” vortex in the adjustable panels at the top exhaust vent of a fume hood can decrease both the direct and in-direct consumption of energy and improve a hood’s containment performance. The application of this change can cause the machine to consume only 40% the amount of energy used previously while providing maximum containment.[38]

Variable-Air-Volume (VAV) Hoods

An alternative to having a simple hood that is always running at the same volumetric exhaust would be to install variable-air-volume hoods. These monitor the air conditions inside the machine and automatically adapt its settings to provide the necessary flow to maintain the correct volumetric flow to the machine. This feature provides a company with large energy savings since the machines do not always need to be running at maximum capacity in order to ensure that their materials are being kept at the right conditions to properly produce their product.

2.3.4 PUMPS

Operations & Maintenance Improvements

The improvements that can be done in the case of a hydronic pumping system are very few in numbers, but are also very valuable and many times are not considered until an energy audit is performed. The first action that can be taken is to run as few pumps as possible when in

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[38] Berkeley National Laboratory 2005

a parallel system. The second is to restore the clearances inside the pumping mechanisms which tend to deteriorate over usage and time. For energy conservation, a machine that is working to peak efficiency is also using the least amount of energy in order to operate. Lastly, hydronic systems need to be in balance in order to operate efficiently. As they are used more, they tend to unbalance themselves so it is worthwhile to take the time to rebalance these systems.

Energy Conservation Measures

The energy conservation measures that can be done may be costly, but they can conserve a lot of resources in the long run. One of the improvements is to shorten the impeller inside the pump to fit the exact specifications necessary for the job they are being used for. (*See Equation #1*).

Installing a primary and secondary pumping arrangement will also help to reduce overall consumption of the system. This allows the primary pump to operate at the constant flow rate needed to do the system's job while the secondary pump will allow for a variable flow rate.This gives the operators the option to increase or decrease the rate in order to meet the specific needs of the system. These needs can be based on the time of day, whether or not the system is running, and the ability to meet the specifications of each process.

Replacing any three-way control valves with two-way control valves is an improvement that accomplishes the same result as the primary and secondary pump arrangement: introducing a variable flow rate to a constant flow rate system. The two-way control valves are better equipped to handle changes in both load-heat transfer and load-flow relationships.

Finally, the installation of variable speed pump drives introduces a different kind of variability to the system than the previous two improvements; this variability is for the speed drives. These mechanisms require a proportional integral derivative (PID) controller which calculates the degree of difference between both the supply and return piping of the system which will reduce the input of power to the system's motor as long as all the pumps that are setup in parallel are operating at equal speeds to ensure an even flow.

2.3.5 CHILLERS

Maintenance Improvements

There is a lot more to consider in terms of maintenance improvements in regards to chillers since they seem to be much more complicated machine than pumps. One of the things that can be done to maintain the system is to make sure that the operational controls are calibrated correctly and functioning properly.

Keeping the evaporator and condenser tubes clean is another step to peak efficiency. When covered in dirt and grime that is collected over time and usage, the abilities of the heat transfer surfaces in the system are lessened quite a bit which consequently reduces the efficiency and increases the consumption of energy. The water that runs through this system must also be properly treated with chemicals to reduce the chances of future buildup of contaminants.

When there are improper amounts of refrigerants in the system energy usage increases and heat transfer capabilities are reduced. This is why maintaining the correct charge of refrigerant in the system is important to the effectiveness of the process. The imbalance of refrigerants can be caused by leaks in the system; here is a process that can be used to eliminate these leaks in both air and refrigerant systems: [39]

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[39] Mull 2001

1. Measure the refrigerant pressure in the condenser
2. Convert the pressure to an equivalent temperature for a temperature/pressure table for the refrigerant in use.
3. Measure the temperature of the liquid refrigerant.
4. Subtract the temperature measured in step three from the temperature obtained from the table in step two.

A few other maintenance improvements that can be done to chillers are to maintain motor efficiency to make sure that there is an adequate flow of refrigerant with no restrictions of flow like a clogged refrigerant filter. Also, keeping diligent logs on each piece of equipment will provide a company with the ability to prevent possible problems ahead of time and to sample and analyze oil on a yearly basis to prevent wear and tear by finding corrosive acids and metal deposits.

Operations Improvements

In terms of operations, one must consider the involvement of cooling towers and chilled water pumping. One of the first actions that can be taken is to isolate all offline chillers when in parallel to prevent the pumps from using energy to move water through them. This can be achieved by closing the isolation valves and also turning off their adjacent pumps. Operating these chillers along with their condensers and chilled water pumps in the correct sequence for energy conservation is another step that can be taken by providing the right temperature of water to the equipment at all times. During the lighter load periods, the condensers and pumps should be programmed to operate at a lower rate that matches the current cooling loads. When operating a group of chillers in parallel, it is important to run them at their proper range of percent capacity which is between 40% and 70%. Another good practice is to turn on these chillers one at a time to lighten the overall demand charge of the company's electrical output.

It is important to know that when an improper reduced flow rate is applied to a system of chillers the energy consumption can actually increase. This decreased flow rate can be caused by partially closed valves, clogged nozzles in the cooling tower, filthy strainers and filters, scale buildup in the condenser and air in the water piping.

Resetting the temperature of chilled water to a higher temperature can decrease the compressor head which reduces the overall consumption of the equipment. The following procedure must be followed to accomplish this: [40]

1. Raise the leaving chilled water temp one degree Fahrenheit at a time and allow the system operation to achieve a steady-state condition.
2. Observe the position of each chilled water control valve supplying major cooling loads.
3. Continue to raise the chilled water temp one degree Fahrenheit at a time allowing the system to stabilize until one control valve (the one with the greatest cooling load) is wide open. If one or more than one control value is in the full open position, reduce the chilled water supply temp until only one valve is in the full open position.

The efficiency of a chiller is directly related to the temperature of the condensing refrigerant so when therefore a reduction of this temperature will result in a reduction of refrigerant pressure. With less pressure, the input power is also lessened which will save energy in the long run.

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[40] Mull 2001

2.4.6 LIGHTING

Lighting is critical throughout the pharmaceutical industry. It is used to provide overall ambient lighting throughout manufacturing, storage, and office spaces and to provide low-bay and task lighting to specific areas.[41] Energy is not only consumed to run the lights, but it is also used to run the air conditioning which offsets the heat gains that the lights produce. Savings can be found in many areas including turning off lighting systems when they aren't being used and replacing inefficient lighting systems with more energy efficient systems.

Illumination Levels

There should be reasonable amount of illumination for all working areas. Novartis defines a luminance (brightness) of 400 to 500 lux for an office environment. To achieve this with minimal operating energy, rooms should be painted light colors and have a high degree of reflection so that light is reflected around the room. Also, task lighting could allow the general area lighting to be greatly reduced, which would reduce the amount of electricity used to light an area.[42]

Turning Off Lights When Not In Use

An easy way to provide energy savings is to shut down lighting systems when they are not in use (spaces are unoccupied, or daylight levels are adequate). Normally, most systems are not in use on nights, weekends, or holidays when employees are not working in the building. One way to accomplish shutting off lights during unoccupied hours is to set up an energy management program that educates personnel about energy efficiency and encourages personnel

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[41] Berkeley National Laboratory 2005
[42] Novartis CHSE Guideline 14

to turn off lights when they are not in use.[43] The energy management program can also be applied to other electrical equipment as well such as computers, computer monitors and printers that are not being used, and have no impact if they are not on.

Occupancy Sensors

Occupancy sensors are a great way to shut off lighting when it is not in use. They are also commonly referred to as motion sensors, because they detect when there is the presence (or absence) of motion in a defined area. At all Novartis sites, occupancy sensors are required for new and existing installations in all areas with temporary utilizations (such as offices, wash rooms, warehouses, production areas, corridors, stair cases, etc.).[44] The occupancy sensor should have an override time of < fifteen minutes for employees. The two main technologies used for occupancy sensors are infrared and ultrasonic. Infrared sensors detect temperature changes in a room, and work well when the sensor has a view on an entire room. The other kind of sensor is the ultrasonic sensor, which uses high-frequency sound to detect motion.[45] A complete sensor unit consists of a motion sensor, an electronic control unit, and a controllable switch/ relay. These systems are inexpensive and can be quickly and easily installed to a current lighting system, or implemented into the design of a new lighting system. Occupancy sensors can save up to 10-20% of facility lighting costs each year.[46]

Automatic Daylight Dimming

Daylight should be used as much as possible in conjunction with electric lights to provide appropriate illumination levels for buildings. Automatic daylight dimming, or “daylighting”,

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[43] Berkeley National Laboratory 2005
[44] Novartis CHSE Guideline 14
[45] “Lighting Control Types” 2007
[46] Berkeley National Laboratory 2005

uses a light sensor to adjust the intensity of electrical lighting based on the illumination provided by the availability of daylight. If it is a bright day, the indoor electric lighting systems do not need to produce as much light as a cloudy day which saves energy. These systems are only effective in areas where there is an adequate amount of daylight, and if they are calibrated properly.[47] Novartis suggests that the daylight dimming control should be programmed at a minimum luminance of 300 lux.[48]

Automatic Time Scheduling

Electric lighting systems on automatic lighting schedules are a great way to be sure lights are turned off during unoccupied hours. These systems can be run by simple time clocks, or they can be controlled by more intricate computer systems. These systems incorporate overrides, so that a user can turn the lights on after the system has automatically shut off. The systems are programmed to shut off one to two hours after close of business, and can either be programmed to turn on automatically in the morning, or they can be turned on by the first employee who enters the building.[49]

Exit Signs

Exit signs require a significant amount of energy because they are always on due to safety regulations. Outdated exit signs that use incandescent lamps use about forty Watts. ENERGY STAR qualified exit signs that use energy efficient LEDs (Light Emitting Diodes) use less than five Watts, depending on the model. This can reduce the total amount of energy used by 80-90% which adds up over time. Although LED exit signs have a higher initial capital cost,

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[47] USDOE

[48] Novartis CHSE Guideline 14

[49] "Lighting Control Types" 2007

they have a lifetime of approximately ten years compared to incandescent exit signs which only have an expected life of one year.[50] In addition to energy savings, LED exit signs save money by reducing the need for maintenance costs from lamp replacement. ENERGY STAR qualified exit signs can save up to $24 per sign annually in electricity costs, while preventing up to 500 pounds of greenhouse gas emissions.[51]

Light Bulbs, Reflectors, and Ballasts

Incandescent light bulbs can be replaced with ENERGY STAR qualified compact fluorescent lamps (CFLs) which cost about 75% less to operate, and also last about ten times longer than incandescent bulbs. Novartis wants to phase out all traditional incandescent light bulbs because they are highly inefficient.[52]

Many industrial buildings use T-12 (1.5” diameter) fluorescent lighting tubes with magnetic ballasts. These systems consume a lot of electricity, and also have other negative aspects such as poor efficiency, short lamp life, lumen depreciation, and color rendering index which results in high energy and maintenance costs. T-12 fluorescent lighting tubes can be replaced with T-8 (1” diameter) fluorescent lighting tubes which last 60% longer, and are also 30% more energy efficient. According to case studies from several U.S. industrial facilities, it costs an estimated $0.25-$0.30/kWh-saved for replacing a T-12 lamp with a T-8 lamp with electronic ballast.[53]

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[50] Berkeley National Laboratory 2005

[51] Energy Star

[52] Novartis CSHE Guideline 14

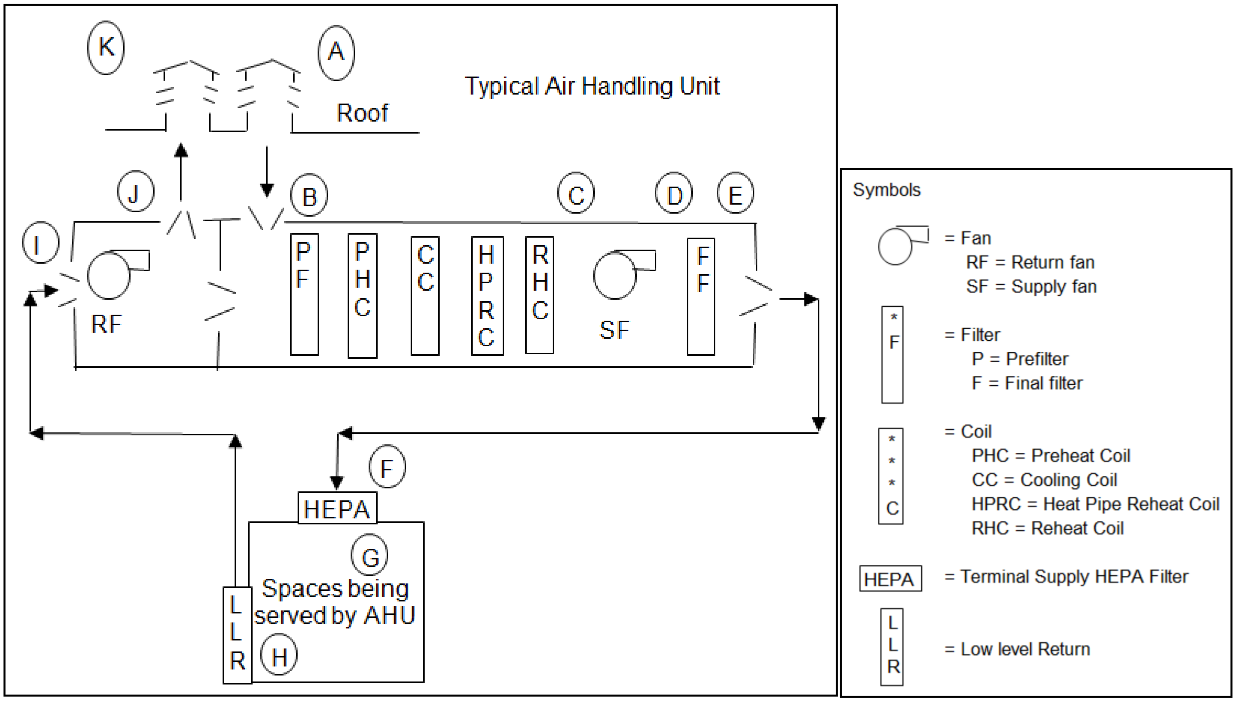
[53] Berkeley National Laboratory 2005

2.5 ENERGY USE OF A TYPICAL AIR HANDLING UNIT

There are four types of energy that are consumed by an air handling unit:

1. Fan energy to push air through air handler and all associated ductwork.
2. Heating energy to preheat and reheat air as needed to satisfy space conditions.
3. Energy to cool air as needed to meet space conditions includes cooling for heat in the air and also to remove excess moisture to limit humidity in the space.
4. Pump energy to move heating hot water and chilled water through the reheat, cooling, and reheat coils and also associated piping and water generating equipment.

Figure 2: Schematic of a Typical Air Handling Unit



2.5.1 FAN ENERGY

Fan energy is constant and does not vary so it does not matter what the outdoor conditions are. The brake horsepower for the fan needs to be calculated then converted to kilowatts of power, the power then needs to be multiplied by the number of hours in a year to determine energy used in kilowatt-hours. The kilowatt-hours are then multiplied by the blended electric cost to determine annual fan energy operating cost. Energy is dependent on:

1. The mass of air being pushed through the system.
2. The volume of air being pushed through the system.
3. The amount of pressure drop needed to push the air through the system.

The density of air at atmospheric conditions and temperature relatively close to this condition is close enough to 13.5 cubic feet per pound of air that calculations have the combined density and volume together so only volume is used in calculations, density is also taken into account (*See Equation #2*).

The fan energy will be calculated by the program is in units of Brake Horsepower which is the actual horsepower needed at the fan shaft; this is not dependent on the actual size of the motor (Assumes motor is not grossly oversized, which is typically a good assumption. If way oversized then HP just to turn the shaft and motor makes the system more inefficient). Volume is volume of air going through the fan and will be equal to input supply and return air flows input by model user. The electric power cost per kWh is manually inputted into the program by the user (*See Equation #3*).

Fan Side Pressure Losses

Here, pressure equals the sum of all the pressure drops in the entire system. For the supply fan, the drops in pressure occur from the intake of outside air through the roof, through all coils and filters (including HEPA filters) and any ductwork losses. The return fan pressure drops include the low level return and ductwork losses for both the return and the exhaust systems. In a more advanced model, it would most likely take into account each of these drops individually but instead we have the user input one pressure drop for the entire system: the range for the entire system drop is three to nine inches in our program.

2.5.2 AIRSIDE CONDITIONS

It is necessary for us to calculate the airside conditions in order to calculate the energy that is consumed by the unit's coils. The user will be required to input a large amount of data for the program to be able to produce an accurate result. The required inputs are:

- Outdoor air volume (CFM)
- Supply air volume (CFM)
- Return air volume (CFM)
- Space set point temperature (°F)
- Maximum space humidity (%RH)
- Temperature off cooling coil (°F)
- Bin data conditions
- Heating energy cost per therm (one therm = 100,000 BTU)
- Cooling energy cost per ton of cooling

The first calculation necessary for finding the airside conditions is to find the air temperature off of the return fan (*See Equation #4*). The next step is to find the mixed air conditions inside the unit which is the combination of the air off the return fan and the outdoor air (*See Equation #5).* The air in the unit has now reached the entrance to the preheat coil (if the unit has a preheat coil, not every air handling unit has one) and it now becomes necessary to evaluate the energy input through the coil. This equation is the same as the one used to find the temperature of the return fan with few modifications and substitutions (*See Equation #6*).

The value of Q is converted into therms and multiplied by the number of hours to determine the total amount of energy is used by the coil in this way. The next mechanism in the unit is the cooling coil where we must determine the enthalpy of the air as it is entering and leaving the coil. For the enthalpy equation we created a macro that will calculate the result automatically with the appropriate inputs which are described later in the report. The situation becomes complicated when determining the amount of power consumed by the coil itself because there are three possible situations that could happen:

1. If the dew point entering the coil is greater than the dry bulb temperature leaving the coil then use the enthalpy equation.
2. If the dry bulb temperature leaving the coil is greater than the dew point entering the coil and the dry bulb temperature entering the coil is greater than the dry bulb temperature leaving the coil then enthalpy is found by using the humidity ratio (another macro).
3. If the dry bulb temperature entering the coil is less than the desired dry bulb temperature leaving the coil, then the dry bulb temperature entering the coil is equal to the dry bulb temperature leaving the coil. Therefore, there is no energy or power consumed through the coil.

The last device that the air passes through is the reheat coil that repeats the same process as the one applied to the preheat coil aside from the temperature leaving the reheat coil which is dependent on the zone that the air handling unit is servicing. This input is plugged in by the user and the recommended settings are:

Table 2: Normal Range for Air Temperature Leaving Reheat Coil

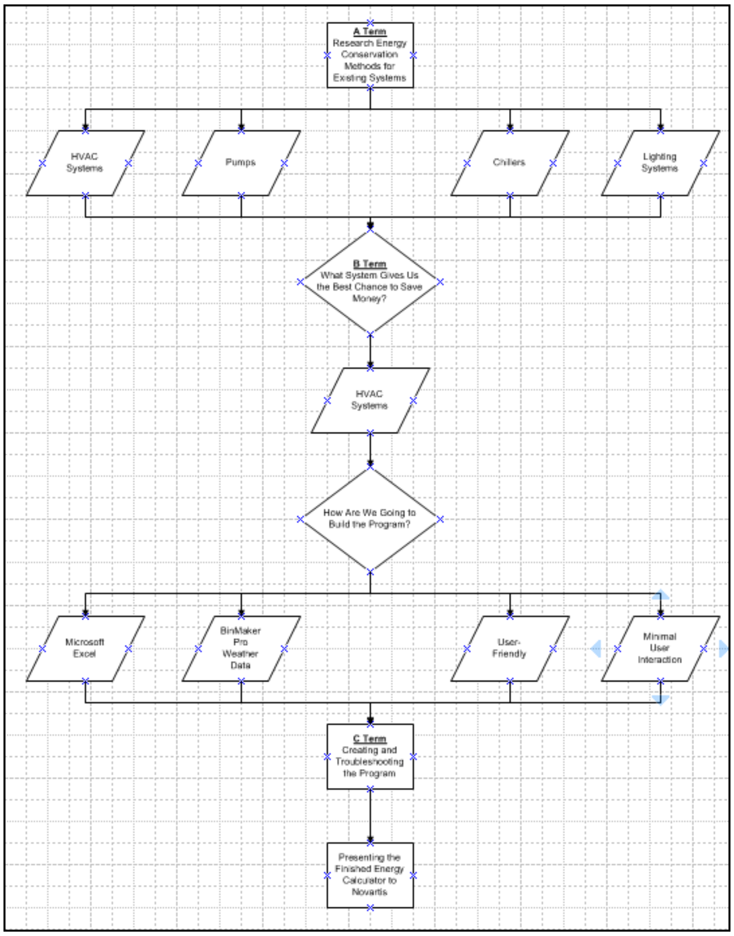
Unclassified	13 to 17 below room set point
Zone D	6 to 10 below room set point
Zone C	2 to 6 below room set point
Zone B	0 to 2 below room set point
Zone A	0 to 1 below room set point

2.5.3 PUMP ENERGY

The first step to finding the energy usage of a pump in an air handling unit is to find the brake horsepower of the device. To do this, the program must first calculate the flow of water through the pump in gallons per minute (*See Equation #7*). Once the flow is determined, the value is plugged into the equation for finding the brake horsepower of the pump (*See Equation #8*). Through simple conversion, it is easy to find the kW and kWh from the BHP. These equations are run for each temperature bin hour in the program and the cumulative energy and cost savings are calculated.

3. METHODOLOGY

Figure 3: Flowchart of Our Project Process



The overall goal of this study is to create a user-friendly model in which the company, Novartis Vaccines & Diagnostics, will be able to evaluate their HVAC systems and determine the amount of energy used, amount of money spent on a yearly basis, and how much money they would be able to save if they were to change a part of the system. The changes could be made to the number of air changes per hour, temperature, relative humidity, and the overall number of hours that the system is in operation.

Constraints

As a pharmaceutical company, Novartis must adhere to many strict codes and specifications that protect their products from damage and contamination from outside sources. The HVAC systems involved in their production process are constantly operating in order to ensure that the threat of contamination is minimal by controlling clean room air change rate, relative humidity, temperature, and pressure. Refer to Tables 3, 4, 5, 6 and 7 for the specifications of these with respect to their clean room class.

The Method

We began our first term of work on this project by simply researching energy conservation methods for existing mechanical systems such as HVAC systems, pumps, chillers and lighting systems. After collecting all of this data and several discussions we decided to only pursue building an energy calculator for just an individual air handling unit since we believed that this was the greatest opportunity for saving energy and money and this is a system that incorporates the use of fans, pumps, cooling and heating coils. We spent our last term building and troubleshooting the program to ensure that it was working properly and fits the specifications of the Novartis employees who will be using it.

The model that we created uses Microsoft Excel which will allow the user to easily change the specifications of a room and immediately observe the amount of energy conserved and the savings that the company can receive per year given that the changes are made to the system. The method of equations that we used to determine the outdoor air conditions are called the Bin Method which is used in conjunction with fluid mechanics, heat transfer and basic mechanical engineering equations to estimate energy consumption of the heating and cooling system of a room or building. Bin hours are normally grouped in 2°F bins so this is the interval that we have chosen to use for the program (1°C for countries that measure in °C).

Obtaining the information that we need is relatively simple; we must analyze the Airflow and Instrumentation Diagrams (AFIDs) of each air handling unit from the Holly Springs, North Carolina and enter the specification for every room that is connected to that particular system and apply the necessary equations to determine the overall savings when certain settings are decreased or increased. The temperature bin data information was collected from a program called Weather Data Viewer by ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers).

4. NOVARTIS VACCINES & DIAGNOSITICS QUALITY MANUAL

Cleanliness Zoning Manual

One of the most vital parts of producing a product in the medical field is to establish the purity requirements for the product along with its production process. Products in this field that are used to heal and protect the human body from sickness, disease and infection must be of the highest quality to ensure that they fulfill their purpose. The impurities that can reduce their effectiveness and safe use can originate from many sources:

- Materials used in the manufacturing process
- Contact surfaces
- Products themselves (drug substances, intermediates or raw materials)
- The surrounding environment
- Utilities (water, steam, nitrogen, compressed air, heating/cooling systems, etc.)
- People (employees, managers, etc.)

There are many different sources from which contamination can originate from and there are also various types of contamination that can occur:

- Cross contamination
- Non-microbial particulate contamination
- Biological/microbiological contamination

Avoiding contamination completely is impossible, but it is possible to attain a purity level that is acceptable for human use by influencing the relevant factors which include:

- The process

- Air purity
- Employees personnel hygiene and clothing
- Employee interference during work
- Material design (material construction, surface finishes, room finishes, equipment, open system/enclosed system, utensils, etc.)
- Material cleanliness
- Material flow
- Waste flow

Description of Cleanliness Zones

Table 3: Cleanliness Zones for Manufacturing of Sterile Drug Products and Sterile Drug Substances

Cleanliness Zone	Typical Applications of Cleanliness Zones
A	- Critical Area for filling and sealing of sterile drug products or sterile drug substances without terminal sterilization. [(a)] (drug products belonging to category 1 [(b)]) - Filling of terminally sterilized products when at unusual risk of contamination from the environment. - Critical area for dispensing and compounding of non filterable materials and products for aseptic preparation. - Handling and filling of aseptically prepared products. - Transfer of partially closed containers as used in freeze-drying. - Preparation and filling of sterile ointments, creams, suspensions and emulsions which cannot be subsequently filtered or terminally sterilized. - Preparation of Master and Working Cell Bank and Inoculum for biotechnical production
B	- Background environment for class A cleanliness zones as described above (drug products belonging to category 1 [(b)]). - Filling / dispensing of biotech drug substances
C	- Dispensing and compounding areas for terminally sterilized products where there is an unusual risk to the product [(c)]. - Filling of products for terminal sterilization [(a)]. - Dispensing and compounding areas for solutions which are to be sterile filtered for aseptic preparations (drug products belonging to category 1 [(b)]).
D	- Dispensing and compounding areas for terminally sterilized drug products (drug products belonging to category 1 [(b)]). - Open handling and manufacturing of dried drug substances to be used in the

	manufacturing of sterile drug products. - Final purification steps in open biotechnological processes. - Product final filling / dispensing in biotechnical processes (destined to drug products belonging to category 1 [(b)]). - Washing rooms for equipment and utensils used for manufacturing of sterile drug products (drug products belonging to category 1 [(b)]).
E	- Ancillary production rooms in which product is not handled in open containers and not exposed to the surrounding environment. - Optical control. - Corridors. - Technical rooms inside production areas.
4	Warehouses, infrastructure, solvent recovery, tank farm, etc.

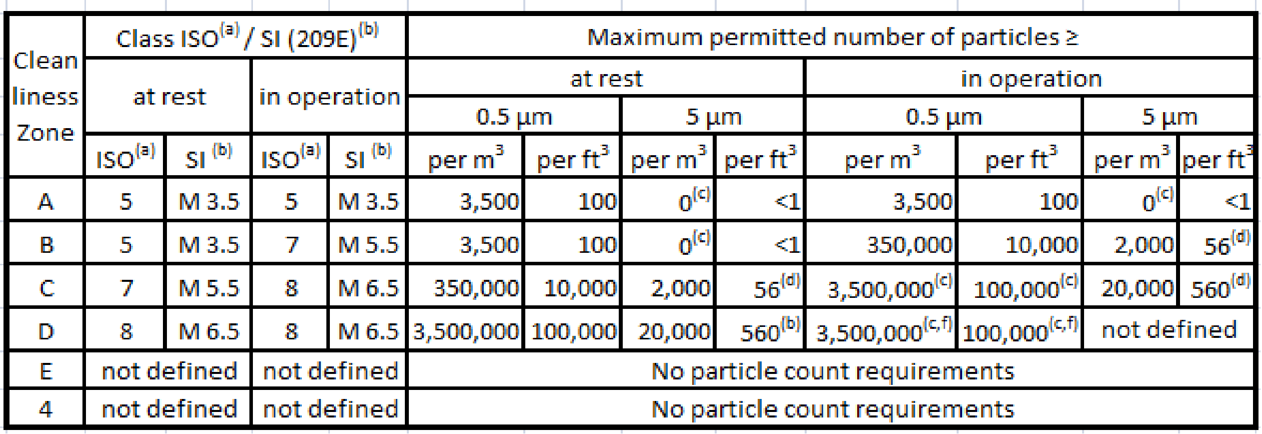
Note (a): Filling or products for terminal sterilization should be done in at least a grade C environment. Where the product is at unusual risk of contamination from the environment for example because the filling operation is slow, or the containers are wide-necked or are necessarily exposed for more than a few seconds before sealing, the filling should be done in a grade A zone with at least a grade C environment before terminal sterilization.

Note (b): According to Table 1: Product Categories

Note (c): Preparation of components and most products should be done in at least a grade D environment in order to give a low risk of microbial and particulate contamination, suitable for filtration and sterilization. Where there is an unusual risk to the product because of microbial contamination for example because the product actively supports microbial growth or must be held for a long period before sterilization or is necessarily processed mainly in open vessels, the preparation should be done in a grade C environment.

The number of particulate allowed in a specified volume of air is also very closely regulated by Novartis. The amounts of particulate allowed are determined by the cleanliness zone of the space which are detailed in Table 3. The units are in both standard (IP) and Metric (SI). The size of the particles also determines how many are permitted in a specified volume of air. The values can be seen in Table 4 below.

Table 4: Requirements for Particles



Cleanliness Zone	Class ISO[a] / SI (209E)[b]				Maximum permitted number of particles ≥							
	at rest		in operation		at rest				in operation			
					0.5 µm		5 µm		0.5 µm		5 µm	
	ISO[a]	SI [b]	ISO[a]	SI [b]	per m^3	per ft^3	per m^3	per ft^3	per m^3	per ft^3	per m^3	per ft^3
A	5	M 3.5	5	M 3.5	3,500	100	0[c]	<1	3,500	100	0[c]	<1
B	5	M 3.5	7	M 5.5	3,500	100	0[c]	<1	350,000	10,000	2,000	56[d]
C	7	M 5.5	8	M 6.5	350,000	10,000	2,000	56[d]	3,500,000[c]	100,000[c]	20,000	560[d]
D	8	M 6.5	8	M 6.5	3,500,000	100,000	20,000	560[b]	3,500,000[c,f]	100,000[c,f]	not defined	
E	not defined		not defined		No particle count requirements							
4	not defined		not defined		No particle count requirements							

Note [a]: these ISO classes are defined in the ISO/DIS 14644-1 Standard
Note [b]: the SI classes are defined in the US Federal Standard 209E
Note [c]: "0" is given in the EU guide, but 0 in one m^3 is not practicable, even to test one m^3 is not reasonable. If several measurements of 1 ft^3 are made, the average must be < 1 per ft^3. If a limit has to be indicated per m^3, 20 particles per m^3 would be adequate. (The US Fed std 209E determines no concentration limits for 5µ particles and bigger for air cleanliness class M 3.5).
Note [d]: These figures per ft^3 are derived from the figures given in the EU guide.
Note [e]: Except for those processes which by their nature generates particles.
Note [f]: Not applicable for the manufacture of non sterile drug substances.

HVAC Requirements

It is important to define all the necessary requirements for the quality of air that an HVAC system must maintain to meet its cleanliness zone standards. In order for the requirements to be met, the following should be defined:

- The significant parameters of the room that could affect any of the materials used like temperature, humidity, etc and their limits of acceptability.
- Indentify process operations that could allow for contamination.
- Identify all operations that will not be affected by the parameters of the room like closed systems.
- Potential sources of contamination like outdoor air, floor drains, etc.

- Processes that will be undertaken due to mechanical failures of fans, interlocks, and user action.

Temperature

A crucial constraint to any type of operations is the temperature of the air in the room which will affect quality, efficiency, and stability of the process and the product produced. One exception to this is any drugs produced by synthesis. The finished product of production will normally be stored at "room temperature", between 68-77°F but in some cases can be an interval as large as from 59-86°F. A final constraint that must be taken into consideration are the fact that workers will normally sweat heavily in temperatures greater than 82°F increasing the possibility of human contamination. The following are the temperature design requirements recognized as the industry standard for the ranges of temperatures that each cleanliness zone must be operated at:

Table 5: Novartis Temperature Design Requirements (°F)

Cleanliness Zone	Class ISO/SI (in operation)		Room Temp in °F
	ISO	SI	
A	Class 5	M 3.5	71.6 ± 7.2°F
B	Class 7	M 5.5	71.6 ± 7.2°F
C	Class 8	M 6.5	71.6 ± 7.2°F
D	Class 8	M 6.5	71.6 ± 7.2°F
E	N/A	N/A	68 ± 14.4°F

These ranges are defined by the industry and changing the temperature specifications is acceptable as long as the quality of the product is not affected and the room's class requirements are executed.

Relative Humidity

Controlling the humidity will protect products that are sensitive to moisture. The following are some facts to consider when controlling the humidity of any room that is being using during the production of a product:

- Product sensitive to moisture must commonly be kept between 30-50% humidity.
- For growing moulds, spores, etc. a maximum of 40-80% humidity must be kept in the air.
- If the controlled air is coming in has contact with the product then the air must not have any impurities beyond that of the water used in the process.
- Condensed water produced by the cooling coils of the HVAC system must be kept out of the controlled air so that no impurities can evaporate into the air.

Table 6: Novartis Relative Humidity Design Requirements

Cleanliness Zone	Class ISO/SI (in operation)		Relative Humidity in %
	ISO	SI	
A	Class 5	M 3.5	40 ± 10%
B	Class 7	M 5.5	45 ± 15%
C	Class 8	M 6.5	45 ± 15%
D	Class 8	M 6.5	45 ± 15%
E	N/A	N/A	N/A

As long as the class specifications are met and the product quality is preserved then the relative humidity can be set differently.

Particles and Micro-Organisms

HVAC systems used for clean rooms must be designed with the notion of keeping particles and micro-organisms out of the ductworks to prevent them from entering the sterile system. One of the best ways to accomplish this is to install coarse-filters for the larger particles followed closely by fine filters for the smaller particulates at all the exhaust points in the room.

Air Change Rates

The air change rate of a room should be decided by the required cooling, heating, relative humidity, pressurization, particulate control, dilution ventilation, recovery time from production interruptions and clean up time.

Table 7: Novartis Air Change Rates

Cleanliness Zone	Class ISO/SI (in operation)		Air Changes (AC/HR)
	ISO	SI	
A	Class 5	M 3.5	240 – 500
B (displacement)	Class 7	M 5.5	240 – 500
B (turbulent)	Class 7	M 5.5	30 – 90
C	Class 8	M 6.5	20 – 50
D	Class 8	M 6.5	5 – 30
E	N/A	N/A	4 – 10 (optional)

In Zones A and B (displacement), the driving factor for displacement airflows is to provide a homogeneous air speed of 0.45 ± 0.09 m/s which causes very high air change rates.

Relative Pressure

The relative pressure of a clean room needs to be controlled so that lower classification spaces don’t contaminate the higher classification spaces. The only space which doesn’t have a defined relative pressure in the Novartis Quality Manuel is a Class E room because there is no product involved that can be contaminated.

Monitoring

The question here is not whether or not the systems associated with the overall particle cleanliness should be closely controlled and watched; the real question is how they should be monitored. One way that they can be controlled is to have a system in place that will warn the operators of a failure in air supply. Important features to this system include alarms and a program which documents the pressure differentials in the room.

Air Flow

When considering the air flow in a space, one must take a few factors into account in order to produce an optimum flow:

- The best number of terminal units needed to attain good air distribution while not spending too much on installing unnecessary terminals.
- Standardizing terminal size and air volume for each unit to reduce cost on spare parts, filer replacements, and minimizing differential blinding.
- Finding the best position to install extraction point for both intake and outtake for air to increase the effectiveness of the system.

Safety

Precautions must always be taken when employees and working with dangerous chemicals and in climate-controlled areas. There will be positions in the production process where the product itself threatens the safety of those working on the line so the company should always take special measures to ensure safety for all:

- Ensure that there is not any risk of contamination of employees or the environment by the product.
- Ensure the product is always protected for any contamination.

5. METHODS OF OUTDOOR AIR DATA COLLECTION

Calculating building energy consumption for heating and cooling systems is a more complicated task than the average person would think. It is not like a TV, computer, or any other electric household appliance where you can just plug in a Kill-A-Watt meter (http://www.degreedays.net/kill-a-watt-meter) to measure how many kW are used in a specified period of time. It is much more complicated than that because the outside weather conditions are constantly changing, which varies how much energy is being used. Essentially, the colder the outside air temperature is, the more energy it takes to heat a building, and the warmer the outdoor air temperature is, the more energy it takes to cool the building.

There are two main methods used to calculate energy and utility usage based on outside temperatures and conditions. The first method is the temperature degree day (TDD) method which uses heating degree day (HDD) and cooling degree day (CDD) calculations. The TDD method only takes into account the outdoor temperatures, and not the relative humidity (RH) which is a term used to describe the amount of water vapor that exists in a gaseous mixture of air and water vapor.[54] The second and more accurate method for calculating energy consumption is the Bin Data method, which we used to do the calculations in the Novartis Energy and Utility Usage Calculator.

5.1 TEMPERATURE DEGREE DAY METHOD

Temperature Degree Days are a simplified representation of outside air-temperature data. They are used throughout the energy industry for calculating building energy consumption based on the affect of outside air temperature on the building. The two different kinds of Temperature

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[54] "Relative Humidity"

Degree Days are Heating Degree Days which are used to calculate energy consumption required for heating buildings and Cooling Degree Days, which calculate the energy consumption required for cooling buildings.

Heating Degree Days are a measure of how much (in degrees), and for how long (in days), outside air temperature was lower than a specific “base temperature”. The “base temperature” is a value that varies from building to building. It depends on two main things, the temperature that the building is heated to (normally 68°F (20°C) for an office building), and the average internal heat gain from the people and equipment within the building. The base temperature is usually calculated to be about 6°F (~3°C) below the building temperature set point. In the case of the base temperature being set at 62°F (~16.6°C), the building would not need to use any energy for heating if the outside temperature is above the base temperature.

Cooling Degree Days are very similar to Heating Degree Days, except that they are used for calculations relating to the cooling energy of buildings. These calculations are used to calculate energy consumption of buildings with air conditioning. Cooling Degree Days also have a base temperature, which calculates energy usage used by air conditioning when the outside temperature is above the base temperature.[55]

Temperature Degree Days are calculated using lots and lots of temperature data. To get a precise value, there would need to be infinite quantities. TDD data can be found for free at lots of different websites including <http://www.degreedays.net/> and <http://www.worldclimate.com/>. In order for the data to be accurate, the site needs to have uninterrupted temperature data for at least one year. There are complex computer algorithms that do the

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[55] “Degree Days”

calculations, but there is a simple way to explain how the calculations are done. Let's take a quick look at how TDD are calculated. In this example I will be using HDD, even though CDD are a very similar calculation based on the base temperature.

For example:

Let's say that the outside temperature is consistently one degree below the base temperature for an entire day. The HDD would look like: [56]

1 degree * 1 day = 1 heating degree day

Now let's say the outside temperature is consistently one degree below the base temperature for half a day, and is two degrees below the base temperature for the other half of the day. The HDD would look like:

1 degree * 0.5 days + 2 degrees * 0.5 days = 1.5 heating degree days

One last example showing when the outside temperature is above the base temperature:

0 degrees * 1 day = 0 heating degree days

5.2 BIN DATA METHOD

The Bin Data Method refers to a procedure where monthly or yearly weather data is sorted into discrete groups (bins) of weather conditions. Each bin contains the number of average hours of occurrence during a year of a particular range of weather condition.[57] The bin

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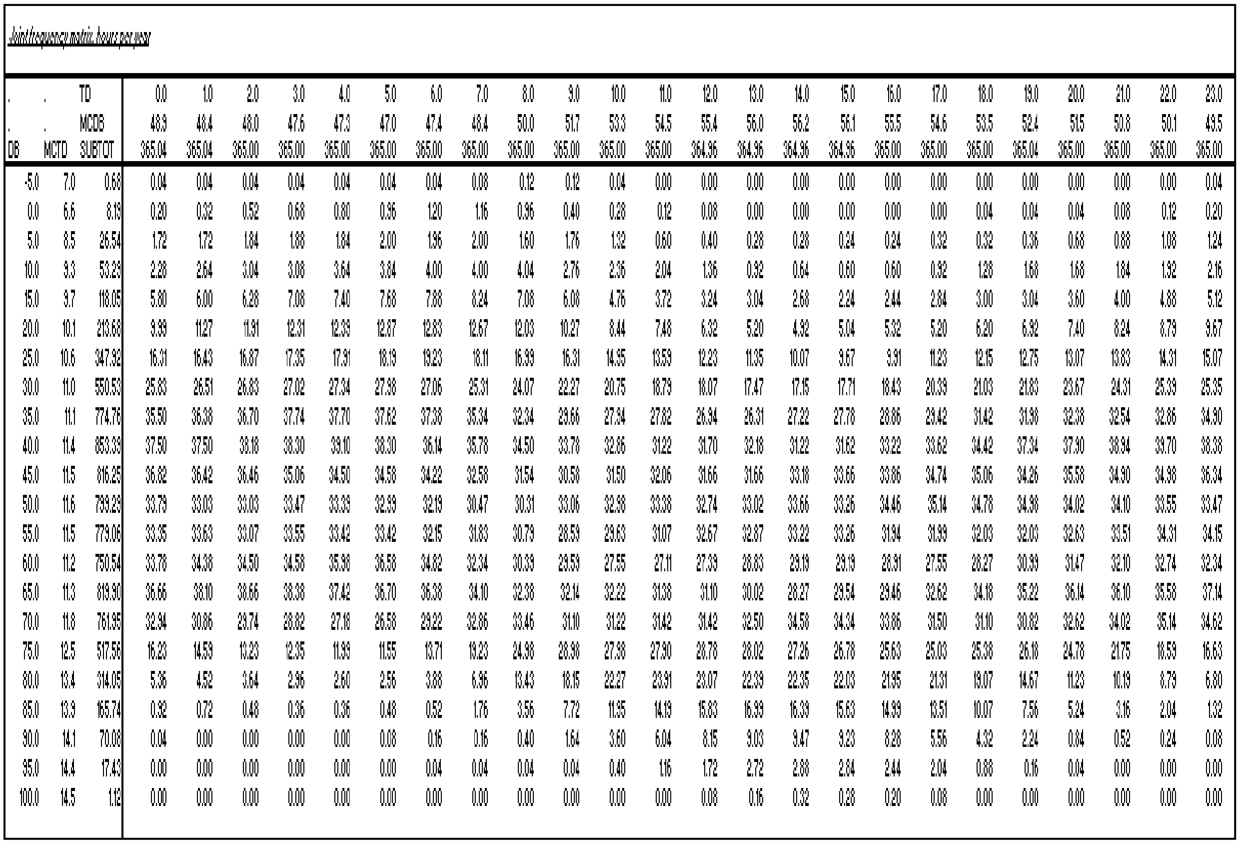
[56] Heating and Cooling Degree Days

[57] "Energy Calculations of Large Buildings"

data for the United States are based on long-term weather measurements from National Weather Service. Some of the other parameters that are collected from these weather stations are wet bulb temperature, enthalpy, wind speed, wind direction, solar insulation, and rainfall. Figure 4 shows an example of a dry bulb temperature / time of day joint frequency matrix from Logan Airport. The top row is the time of day (TD) and the far left column is the dry bulb temperature. From the table below, it can be determined that it was -5.0 °F for 0.58 hours in a whole year (8760 hours).

Figure 4: Dry Bulb Temperature/ Time of Day Frequency Matrix from Logan Airport



Joint frequency matrix, hours per year

.	.	TD	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.0	22.0	23.0
.	.	MCDB	48.9	48.4	48.0	47.6	47.3	47.0	47.4	48.4	50.0	51.7	53.3	54.5	55.4	56.0	56.2	56.1	55.5	54.6	53.5	52.4	51.5	50.8	50.1	49.5
DB	MCTD	SUBTOT	365.04	365.04	365.00	365.00	365.00	365.00	365.00	365.00	365.00	365.00	365.00	365.00	364.96	364.96	364.96	364.96	365.00	365.00	365.00	365.04	365.00	365.00	365.00	365.00
-5.0	7.0	0.68	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.08	0.12	0.12	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
0.0	6.6	8.19	0.20	0.32	0.52	0.68	0.80	0.96	1.20	1.16	0.96	0.40	0.28	0.12	0.08	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.04	0.08	0.12	0.20
5.0	8.5	26.54	1.72	1.72	1.84	1.88	1.84	2.00	1.96	2.00	1.60	1.76	1.32	0.60	0.40	0.28	0.28	0.24	0.24	0.32	0.32	0.36	0.68	0.88	1.08	1.24
10.0	9.3	53.29	2.28	2.64	3.04	3.08	3.64	3.84	4.00	4.00	4.04	2.76	2.36	2.04	1.36	0.92	0.64	0.60	0.60	0.92	1.28	1.68	1.68	1.84	1.92	2.16
15.0	9.7	118.05	5.80	6.00	6.28	7.08	7.40	7.68	7.88	8.24	7.08	6.08	4.76	3.72	3.24	3.04	2.68	2.24	2.44	2.84	3.00	3.04	3.60	4.00	4.88	5.12
20.0	10.1	213.68	9.99	11.27	11.91	12.31	12.39	12.87	12.83	12.67	12.03	10.27	8.44	7.48	6.32	5.20	4.92	5.04	5.32	5.20	6.20	6.92	7.40	8.24	8.79	9.67
25.0	10.6	347.92	16.31	16.43	16.87	17.35	17.91	18.19	19.23	18.11	16.99	16.31	14.95	13.59	12.23	11.35	10.07	9.67	9.91	11.23	12.15	12.75	13.07	13.83	14.31	15.07
30.0	11.0	550.53	25.83	26.51	26.83	27.02	27.34	27.98	27.06	25.31	24.07	22.27	20.75	18.79	18.07	17.47	17.15	17.71	18.43	20.39	21.03	21.83	23.67	24.31	25.39	25.35
35.0	11.1	774.76	35.50	36.38	36.70	37.74	37.70	37.62	37.38	35.34	32.34	29.66	27.94	27.82	26.94	26.31	27.22	27.78	28.86	29.42	31.42	31.98	32.38	32.54	32.86	34.90
40.0	11.4	853.39	37.50	37.50	38.18	38.30	39.10	38.30	36.14	35.78	34.50	33.78	32.86	31.22	31.70	32.18	31.22	31.62	33.22	33.62	34.42	37.34	37.90	38.94	39.70	38.38
45.0	11.5	816.25	36.82	36.42	36.46	35.06	34.50	34.58	34.22	32.58	31.54	30.58	31.50	32.06	31.66	31.66	33.18	33.66	33.86	34.74	35.06	34.26	35.58	34.90	34.98	36.34
50.0	11.6	799.29	33.79	33.03	33.03	33.47	33.39	32.99	32.19	30.47	30.31	33.06	32.98	33.38	32.74	33.02	33.66	33.26	34.46	35.14	34.78	34.98	34.02	34.10	33.55	33.47
55.0	11.5	779.06	33.35	33.63	33.07	33.55	33.42	33.42	32.15	31.83	30.79	28.59	29.63	31.07	32.67	32.87	33.22	33.26	31.94	31.99	32.03	32.03	32.63	33.51	34.31	34.15
60.0	11.2	750.54	33.78	34.38	34.50	34.58	35.98	36.58	34.82	32.34	30.39	29.59	27.55	27.11	27.39	28.83	29.19	29.19	28.91	27.55	28.27	30.99	31.47	32.10	32.74	32.34
65.0	11.3	819.90	36.66	38.10	38.66	38.38	37.42	36.70	36.38	34.10	32.38	32.14	32.22	31.38	31.10	30.02	28.27	29.54	29.46	32.62	34.18	35.22	36.14	36.10	35.58	37.14
70.0	11.8	761.95	32.94	30.86	29.74	28.82	27.18	26.58	29.22	32.86	33.46	31.10	31.22	31.42	31.42	32.50	34.58	34.34	33.86	31.50	31.10	30.82	32.62	34.02	35.14	34.62
75.0	12.5	517.56	16.23	14.59	13.23	12.35	11.99	11.55	13.71	19.23	24.98	28.38	27.38	27.90	28.78	28.02	27.26	26.78	25.63	25.03	25.38	26.18	24.78	21.75	18.59	16.63
80.0	13.4	314.05	5.36	4.52	3.64	2.96	2.60	2.56	3.88	6.96	13.43	18.15	22.27	23.91	23.07	22.39	22.35	22.03	21.95	21.31	19.07	14.67	11.23	10.19	8.79	6.80
85.0	13.9	165.74	0.92	0.72	0.48	0.36	0.36	0.48	0.52	1.76	3.56	7.72	11.95	14.19	15.83	16.99	16.39	15.63	14.99	13.51	10.07	7.56	5.24	3.16	2.04	1.32
90.0	14.1	70.08	0.04	0.00	0.00	0.00	0.00	0.08	0.16	0.16	0.40	1.64	3.60	6.04	8.15	9.03	9.47	9.23	8.28	5.56	4.32	2.24	0.84	0.52	0.24	0.08
95.0	14.4	17.43	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.04	0.04	0.40	1.16	1.72	2.72	2.88	2.84	2.44	2.04	0.88	0.16	0.04	0.00	0.00	0.00
100.0	14.5	1.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.16	0.32	0.28	0.20	0.08	0.00	0.00	0.00	0.00	0.00	0.00

Bin Data calculations are much more accurate than TDD calculations because an engineer or plant manager can calculate loads for each bin condition, multiply the bin load by the hours of occurrence for that bin, and then sum the load for each bin to get the total load. This is much more accurate than TDD calculations because it calculates the load based on hourly data rather than TDD which calculates based on daily averages.

5.3 BIN DATA PROGRAM SELECTION

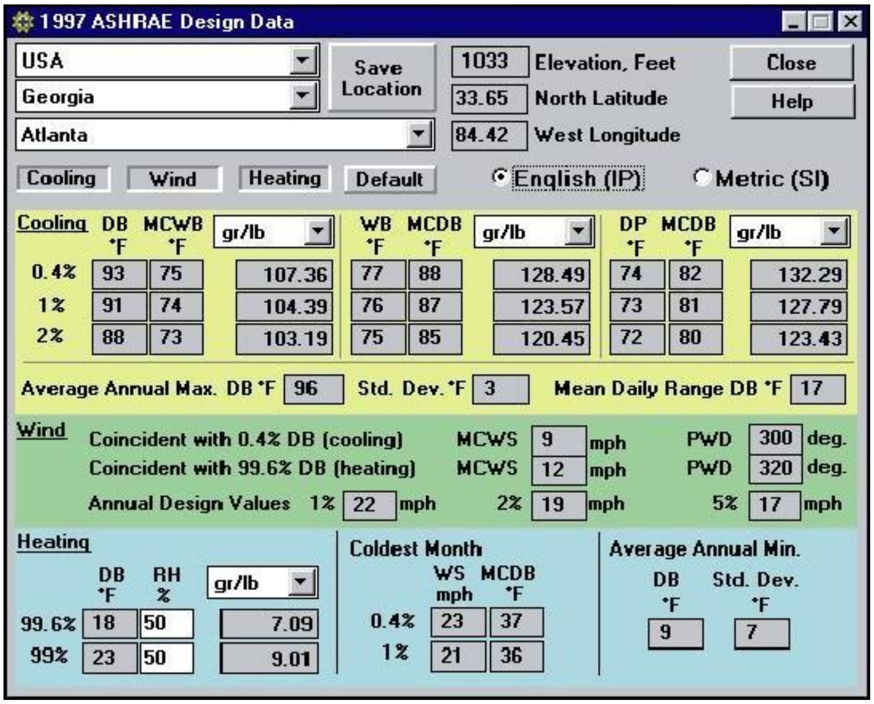
In order to calculate heating and cooling loads, we require data that is a good representation of the outdoor temperature. That is why we chose to do the calculations based on Weather Bin Data and not the TDD method. We found that the best way to determine the temperature outside for a production site based on its geographical location, altitude, and time of year is to obtain bin data for the nearest major city. Bin data gives the number of hours that the dry-bulb temperature outside is in a specified degree range, and also gives the Mean Coincident Wet Bulb (MCDB). We decided to use 2° F intervals ranging from -6.5°F to 103.5°F for U.S locations, and for the international locations, the bin data is in 1.8°F intervals ranging from -2.2°F to 109.4°F. The reason the international bin data is in 1.8°F bins is because the values were recorded in 1°C bins and we converted all of the values into °F. This will allow us to do all of the calculations in our program in Inch-Pounds (IP) instead of making a program for both IP and Metric (SI). The Bin Data calculations will determine the ton-hrs of cooling and therms of heating used by the cooling, preheat, and reheat coils in the air handling unit. This is important in determining the overall energy cost of each individual AHU because it gives the outdoor air conditions.

We found three possible programs that we could order to receive this information from major cities around the globe. We did a cost-benefit analysis for each to determine which program would best suit or needs.

Option #1: BinMaker® PRO 2.01 Weather Data

This program would give us weather data and bin data for 239 domestic locations in the United States, and ASHRAE's (American Society of Heating, Refrigerating and Air-Conditioning Engineers) design weather data for 1459 domestic and international locations. The user will have the option of defining a specific operating schedule, with different hours for each day of the week, or it can summarize all 8760 hours of the year. In addition to creating Bin summaries by dry bulb temperature, BinMaker Pro creates Bin summaries based on wet bulb temp, humidity ratio, and wind speed. Also, it allows the user to create joint frequency tables (hours occurring at each temperature and moisture). It provides all this information in an Excel file and costs $149.99 for one copy. The program has the option of working in I-P or SI units.[58]

Figure 5: Screenshot of BinMaker® Pro 2.01 Weather Data



1997 ASHRAE Design Data

USA
Georgia
Atlanta

1033 Elevation, Feet
33.65 North Latitude
84.42 West Longitude

● English (IP) ○ Metric (SI)

Cooling	DB °F	MCWB °F	gr/lb	WB °F	MCDB °F	gr/lb	DP °F	MCDB °F	gr/lb
0.4%	93	75	107.36	77	88	128.49	74	82	132.29
1%	91	74	104.39	76	87	123.57	73	81	127.79
2%	88	73	103.19	75	85	120.45	72	80	123.43

Average Annual Max. DB °F 96 Std. Dev. °F 3 Mean Daily Range DB °F 17

Wind
Coincident with 0.4% DB (cooling) MCWS 9 mph PWD 300 deg.
Coincident with 99.6% DB (heating) MCWS 12 mph PWD 320 deg.
Annual Design Values 1% 22 mph 2% 19 mph 5% 17 mph

Heating	DB °F	RH %	gr/lb
99.6%	18	50	7.09
99%	23	50	9.01

Coldest Month	WS mph	MCDB °F
0.4%	23	37
1%	21	36

Average Annual Min.	
DB °F	Std. Dev. °F
9	7

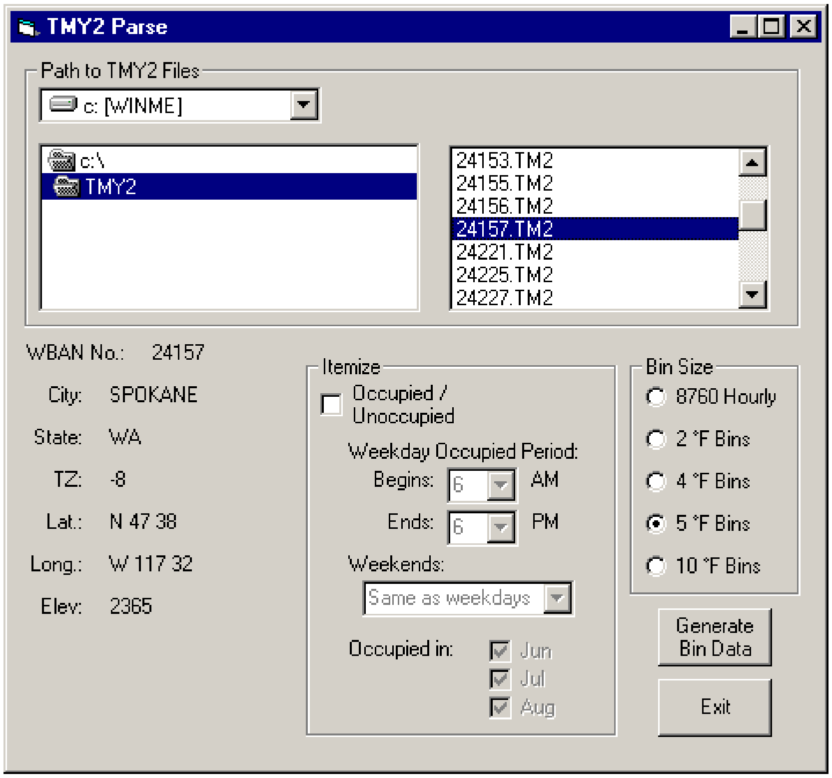
---

[58] BinMaker Pro

Option #2: TMY2BIN

True to its name, TMY2BIN obtains its data from the Typical Metrological Year (TMY2) data as well as converting the hourly weather files directly into dry-bulb temperatures and allows for the use of 2, 4, 5, and 10 degree bin intervals. Produced is a .csv file that needs to be reorganized by hand into an Excel file spreadsheet and can also give the relative humidity. This program would only cost $25.

Figure 6: Screenshot of TMY2BIN



Path to TMY2 Files: c: [WINME]

c:\
TMY2

24153.TM2
24155.TM2
24156.TM2
24157.TM2
24221.TM2
24225.TM2
24227.TM2

WBAN No.: 24157
City: SPOKANE
State: WA
TZ: -8
Lat.: N 47 38
Long.: W 117 32
Elev: 2365

Itemize
☐ Occupied / Unoccupied
Weekday Occupied Period:
Begins: 6 AM
Ends: 6 PM
Weekends: Same as weekdays
Occupied in: ☑ Jun ☑ Jul ☑ Aug

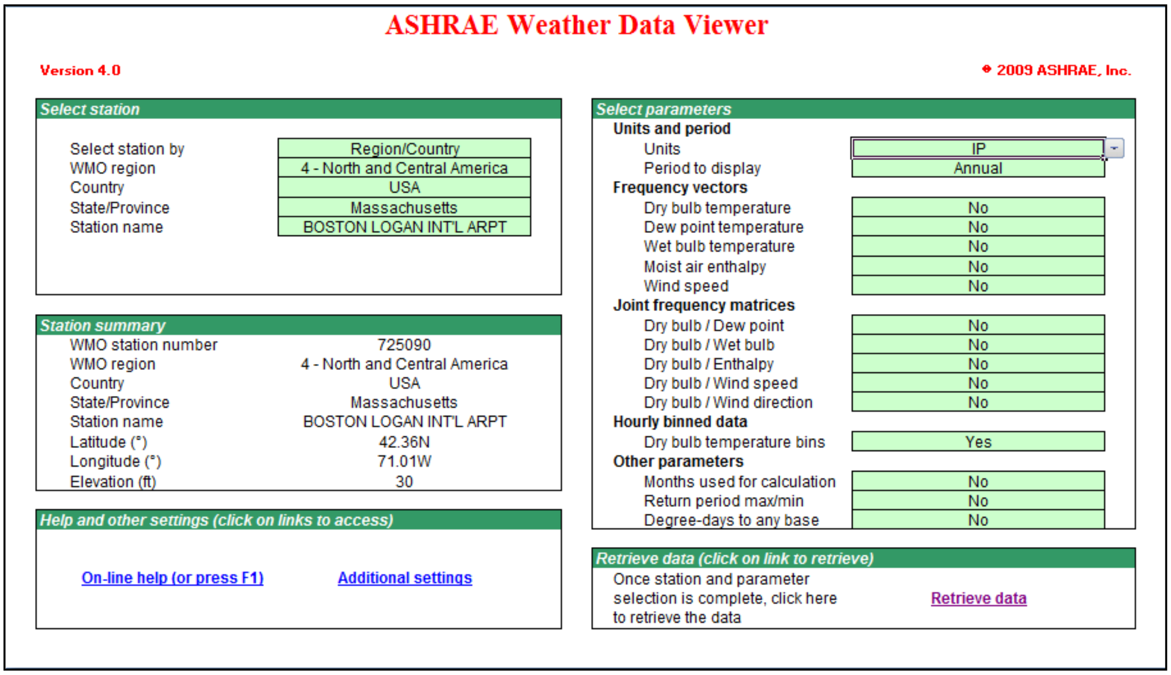
Bin Size
○ 8760 Hourly
○ 2 °F Bins
○ 4 °F Bins
● 5 °F Bins
○ 10 °F Bins

Option #3: ASHRAE Weather Data Viewer

Much more versatile than the other two, ASHRAE provides bin data for 509 United States, 134 Canadian, 339 European, 293 Asian cities along with 169 other locations across the rest of the globe (1444 locations total). It calculates the dry and wet-bulb temperatures and the humidity ratio and takes the data from the climatic design information chapter of the 1997

ASHRAE Handbook – Fundamentals. It produces in bin intervals of two, five, or ten degrees in a space or comma delimited format that we need to be manually inserted into Excel while costing $99.

Figure 7: Screenshot of ASHRAE Weather Data Viewer



ASHRAE Weather Data Viewer

Version 4.0

© 2009 ASHRAE, Inc.

Select station

Select station by	Region/Country
WMO region	4 - North and Central America
Country	USA
State/Province	Massachusetts
Station name	BOSTON LOGAN INT'L ARPT

Station summary

WMO station number	725090
WMO region	4 - North and Central America
Country	USA
State/Province	Massachusetts
Station name	BOSTON LOGAN INT'L ARPT
Latitude (°)	42.36N
Longitude (°)	71.01W
Elevation (ft)	30

Help and other settings (click on links to access)

On-line help (or press F1)   Additional settings

Select parameters

Units and period	
Units	IP
Period to display	Annual
Frequency vectors	
Dry bulb temperature	No
Dew point temperature	No
Wet bulb temperature	No
Moist air enthalpy	No
Wind speed	No
Joint frequency matrices	
Dry bulb / Dew point	No
Dry bulb / Wet bulb	No
Dry bulb / Enthalpy	No
Dry bulb / Wind speed	No
Dry bulb / Wind direction	No
Hourly binned data	
Dry bulb temperature bins	Yes
Other parameters	
Months used for calculation	No
Return period max/min	No
Degree-days to any base	No

Retrieve data (click on link to retrieve)

Once station and parameter selection is complete, click here to retrieve the data   Retrieve data

Final Decision

What we need is the bin data for major locations in both the United States and Europe that will give the dry and wet-blub temperatures in two degree intervals in an easy to use format. The best representation of this would be Option #3, the ASHRAE Weather Data Viewer since it includes not only European but Canadian and Asian locations would allow us to allow the model to apply to any Novartis sites on the planet. It will be difficult to manually insert every bin and its corresponding data into the Excel file, but the value that all this supplementary information will provide to the company is enormous.

5.4 NOVARTIS BIN DATA SITE LOCATIONS

Figure 8: Novartis Vaccines and Diagnostics World-Wide Locations

Novartis Vaccines and Diagnostics Division has ten sites worldwide, located on four continents and both hemispheres; their locations starting from the left moving to the right are:

- Emeryville, CA, USA
- Holly Springs, NC, USA
- Cambridge, MA, USA
- Pernambuco, Brazil
- Liverpool, England, UK
- Rosia, Italy
- Siena, Italy
- Marburg, Germany
- Ankleshwar, India
- Linping, China

Emeryville, California, USA

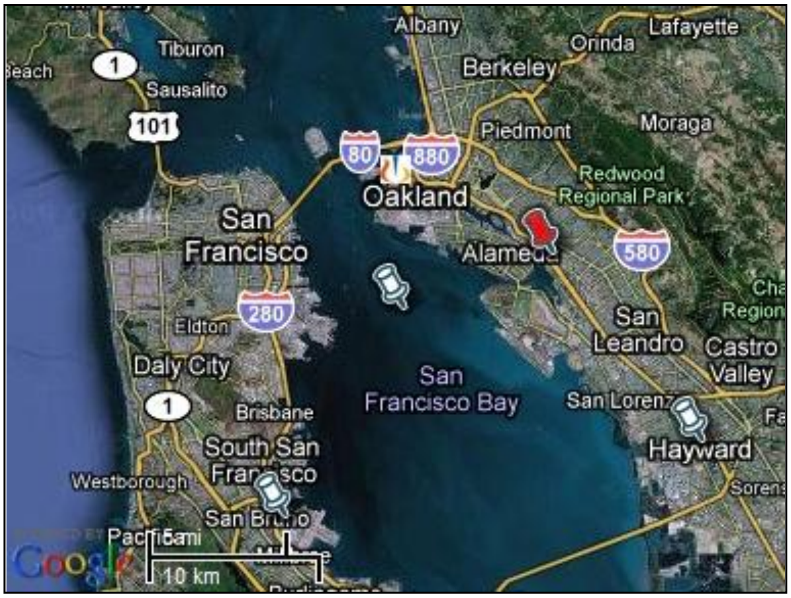


Figure 9: Emeryville, California, USA Bin Data Location

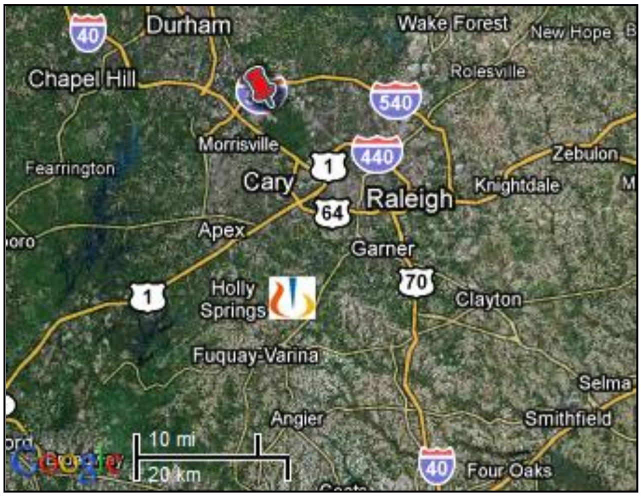
Emeryville, California, USA Bin Data WMO Information
Site Name: Oakland Metropolitan Airport, California, USA
Site WMO ID: 724930
Latitude: 37.76°N
Longitude: 122.22°W
Elevation: 27m / 89ft
Approximate Distance to Site: 5 miles

Table 8: Oakland Metropolitan Airport Yearly Temperature Bin Data

Oakland Metropolitan Airport, California, USA											
DB	MCWB	Hours	DB	MCWB	Hours	DB	MCWB	Hours	DB	MCWB	Hours
23.5	19.5	0.0	41.5	39.5	88.4	59.5	56.0	921.4	79.5	64.5	27.6
25.5	21.8	0.3	43.5	41.1	146.5	61.5	57.0	811.8	81.5	64.9	25.2
27.5	23.8	0.7	45.5	43.0	306.9	63.5	57.7	742.7	83.5	65.5	11.3
29.5	26.6	0.9	47.5	44.8	349.1	65.5	59.4	446.3	85.5	66.6	5.6
31.5	28.6	2.1	49.5	46.7	420.8	67.5	60.5	285.0	87.5	66.6	4.7
33.5	31.1	5.2	51.5	48.5	602.2	69.5	61.3	230.3	89.5	66.8	3.1
35.5	33.7	13.5	53.5	50.5	789.5	71.5	62.1	138.7	91.5	67.9	1.4
37.5	35.4	30.1	55.5	52.4	1,012.7	73.5	62.8	92.5	93.5	69.3	0.5
39.5	37.5	60.7	57.5	54.2	1,090.6	75.5	63.6	59.8	95.5	69.5	0.4
						77.5	64.1	31.2	97.5	70.3	0.2

Holly Springs, North Carolina, USA

Figure 10: Holly Springs, North Carolina, USA Bin Data Location



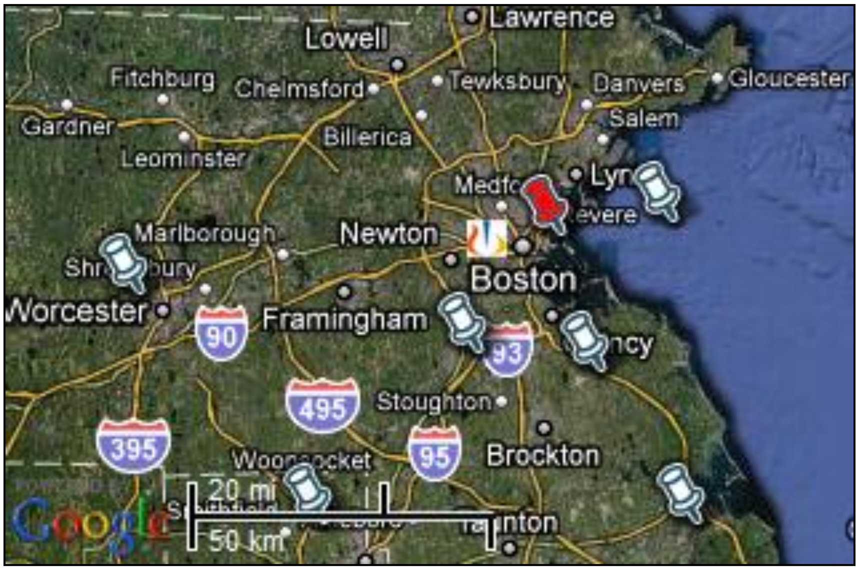
Holly Springs, North Carolina, USA Bin Data WMO Information
Site Name: Raleigh Durham International Airport, North Carolina, USA
Site WMO ID: 723060
Latitude: 35.87°N
Longitude: 78.79°W
Elevation: 133m / 436ft
Approximate Distance to Site: 20 miles

Table 9: Raleigh Durham International Airport Yearly Temperature Bin Data

Raleigh Durham International Airport, North Carolina, USA											
DB	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**
-6.5	-8.1	0.2	21.5	19.0	24.8	49.5	44.5	299.9	77.5	69.3	286.6
-4.5	-6.5	0.1	23.5	20.8	39.1	51.5	46.4	280.2	79.5	70.0	252.6
-2.5	-4.5	0.1	25.5	22.7	58.9	53.5	48.3	284.5	81.5	70.8	223.3
-0.5	-1.5	0.1	27.5	24.6	99.8	55.5	50.1	282.1	83.5	71.7	193.8
1.5	0.2	0.2	29.5	26.4	124.6	57.5	52.2	303.4	85.5	72.7	165.8
3.5	1.5	0.4	31.5	28.6	156.8	59.5	54.1	308.4	87.5	73.6	128.7
5.5	3.5	1.1	33.5	30.4	176.8	61.5	56.3	319.7	89.5	74.6	95.7
7.5	5.9	1.3	35.5	32.1	190.4	63.5	58.1	355.5	91.5	75.5	61.4
9.5	7.9	2.0	37.5	33.9	213.8	65.5	60.1	359.1	93.5	75.8	36.7
11.5	9.3	3.1	39.5	35.7	234.8	67.5	62.3	388.2	95.5	76.1	18.0
13.5	11.2	5.5	41.5	37.5	238.8	69.5	64.4	414.9	97.5	76.4	7.8
15.5	13.2	7.2	43.5	39.2	251.3	71.5	66.6	447.0	99.5	76.9	2.3
17.5	15.0	11.4	45.5	40.9	282.2	73.5	68.1	447.4	101.5	75.5	0.6
19.5	17.1	19.9	47.5	42.7	283.9	75.5	68.8	367.4	103.5	73.1	0.2

Cambridge, Massachusetts, USA

Figure 11: Cambridge, Massachusetts, USA Bin Data Location



Cambridge, Massachusetts, USA Bin Data WMO Information
Site Name: Boston Logan International Airport, Massachusetts, USA
Site WMO ID: 725090
Latitude: 42.36°N
Longitude: 71.01°W
Elevation: 9m / 30ft
Approximate Distance to Site: 5 miles

Table 10: Boston Logan International Airport Yearly Temperature Bin Data

Cambridge, MA											
DB	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**
-6.5	-7.8	0.2	19.5	16.4	87.7	45.5	41.1	335.2	73.5	65.5	242.1
-4.5	-6.5	0.2	21.5	18.1	95.5	47.5	43.0	322.7	75.5	66.5	191.4
-2.5	-3.8	0.7	23.5	20.0	115.9	49.5	44.7	334.7	77.5	67.5	155.8
-0.5	-2.1	2.0	25.5	21.9	145.0	51.5	46.6	299.6	79.5	68.2	133.1
1.5	-0.4	5.7	27.5	23.8	183.7	53.5	48.6	309.3	81.5	69.1	109.2
3.5	1.5	9.5	29.5	25.8	209.6	55.5	50.7	311.7	83.5	70.0	84.7
5.5	3.5	10.4	31.5	27.7	243.1	57.5	52.5	302.7	85.5	71.0	59.8
7.5	5.3	14.5	33.5	29.8	294.6	59.5	54.7	304.3	87.5	71.9	41.6
9.5	7.1	18.5	35.5	31.7	311.5	61.5	56.5	301.8	89.5	72.5	29.7
11.5	8.7	27.0	37.5	33.7	325.3	63.5	58.3	332.7	91.5	73.7	20.1
13.5	10.6	37.3	39.5	35.6	351.9	65.5	60.0	331.3	93.5	74.4	10.0
15.5	12.6	50.5	41.5	37.4	344.9	67.5	61.4	320.7	95.5	75.4	5.6
17.5	14.4	61.0	43.5	39.2	324.0	69.5	63.0	320.9	97.5	76.2	2.7
						71.5	64.5	276.3	99.5	75.7	0.4

Pernambuco, Brazil

Figure 12: Pernambuco, Brazil Bin Data Location

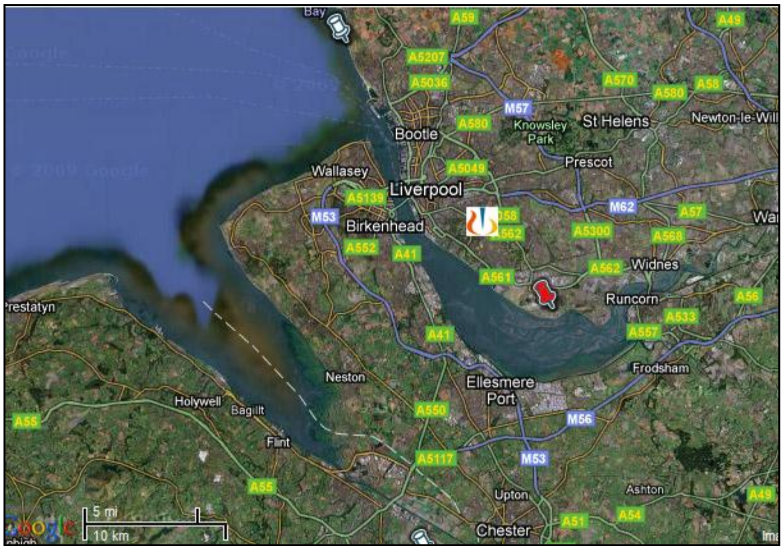
Pernambuco, Brazil Bin Data WMO Information
Site Name: Maceio Airport, Brazil
WMO ID: 829930
Latitude: 9.52°S
Longitude: 35.78°W
Elevation: 117m / 384ft
Approximate Distance to Site: 100 miles

Table 11: Maceio Airport Yearly Temperature Bin Data

Pernambuco, Brazil											
DB	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**
60.8	60.2	0.1	69.8	68.7	379.1	80.6	74.8	738.2	91.4	77.7	46.1
62.6	61.9	0.6	71.6	70.3	783.5	82.4	75.1	653.6	93.2	78.6	11.7
64.4	63.9	6.7	73.4	71.9	1,189.9	84.2	75.5	571.6	95.0	79.2	2.9
66.2	65.5	44.0	75.2	73.2	1,269.1	86.0	76.0	505.2	96.8	79.6	1.0
68.0	67.1	164.3	77.0	74.3	1,089.2	87.8	76.3	312.9	98.6	77.6	0.3
			78.8	74.7	832.6	89.6	77.0	157.1	100.4	80.1	0.2

Liverpool, England, United Kingdom

Figure 13: Liverpool, England, United Kingdom Bin Data Location



Liverpool, England, United Kingdom Bin Data WMO Information:
Site Name: Liverpool, England
Site WMO ID: 033233
Latitude: 53.33°N
Longitude: 2.85°W
Elevation: 25m / 82ft
Approximate Location to Site: 5 miles

Table 12: Liverpool, England, United Kingdom Yearly Temperature Bin Data

Liverpool, England, United Kingdom											
DB	MCWB	Hours	DB	MCWB	Hours	DB	MCWB	Hours	DB	MCWB	Hours
14.0	14.0	0.2	33.8	32.2	174.4	53.6	49.8	546.9	73.4	62.3	42.4
15.8	15.8	1.0	35.6	33.8	221.6	55.4	51.5	568.6	75.2	63.3	27.5
17.6	17.2	1.0	37.4	35.4	314.0	57.2	53.0	506.7	77.0	64.2	19.7
19.4	18.6	2.7	39.2	37.1	358.4	59.0	54.6	487.4	78.8	64.7	12.9
21.2	20.2	4.3	41.0	38.7	462.0	60.8	55.9	384.4	80.6	66.0	10.2
23.0	22.3	7.2	42.8	40.5	480.9	62.6	57.3	333.9	82.4	65.9	5.5
24.8	24.3	13.2	44.6	42.1	566.4	64.4	58.0	227.9	84.2	65.6	2.9
26.6	25.8	26.9	46.4	43.8	545.2	66.2	59.0	170.7	86.0	66.0	1.4
28.4	27.5	40.2	48.2	45.5	598.6	68.0	60.0	113.7	87.8	66.6	0.8
30.2	29.1	78.5	50.0	46.9	556.6	69.8	61.2	84.0	89.6	67.5	0.4
32.0	30.9	110.2	51.8	48.2	588.9	71.6	61.7	59.3	91.4	68.4	0.4

Siena and Rosia, Italy

Figure 14: Siena and Rosia, Italy Bin Data Locations

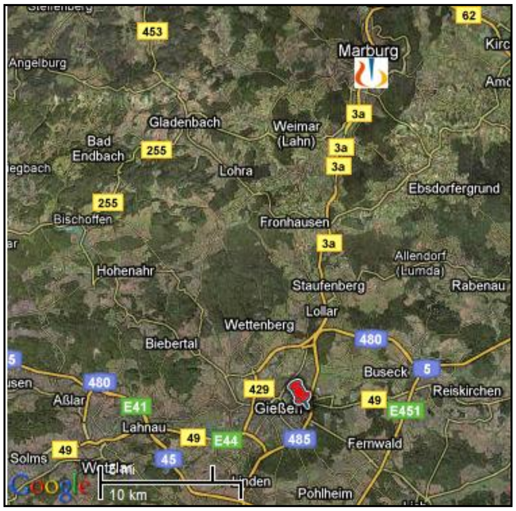
Siena and Rosia, Italy Bin Data WMO Information:
Site Name: Firenze/ Peretola, Italy
Site WMO ID: 161700
Latitude: 43.8°N
Longitude: 11.2°E
Elevation: 38m / 125ft
Approximate Distance to Site: 40 miles (Siena), 55 miles (Rosia)

Table 13: Firenze/ Peretola, Italy Yearly Temperature Bin Data

Firenze/ Peretola, Italy											
DB	MCWB	Hours	DB	MCWB	Hours	DB	MCWB	Hours	DB	MCWB	Hours
17.6	17.6	0.4	39.2	35.6	180.1	60.8	55.6	346.3	82.4	68.3	153.4
19.4	18.3	1.6	41.0	37.5	220.7	62.6	57.2	341.5	84.2	68.9	136.8
21.2	19.9	4.2	42.8	39.2	261.9	64.4	58.5	341.7	86.0	69.8	119.1
23.0	21.6	9.2	44.6	41.0	307.7	66.2	60.0	343.0	87.8	70.7	95.9
24.8	23.2	12.0	46.4	42.6	332.8	68.0	61.4	338.3	89.6	71.2	81.4
26.6	24.8	23.3	48.2	44.4	355.4	69.8	62.8	331.6	91.4	72.2	56.3
28.4	26.3	34.8	50.0	46.2	376.7	71.6	63.9	314.5	93.2	73.0	38.4
30.2	27.9	49.9	51.8	47.7	392.9	73.4	64.7	288.2	95.0	73.4	25.2
32.0	29.4	70.9	53.6	49.2	374.7	75.2	65.6	266.6	96.8	73.3	13.8
33.8	30.9	105.1	55.4	50.8	378.3	77.0	66.3	233.8	98.6	74.8	7.3
35.6	32.4	129.3	57.2	52.3	366.6	78.8	67.0	201.1	100.4	74.4	2.8
37.4	33.9	152.8	59.0	54.0	357.4	80.6	67.8	182.9	102.2	74.4	1.0
									104.0	77.4	0.5

Marburg, Germany

Figure 15: Marburg, Germany Bin Data Location



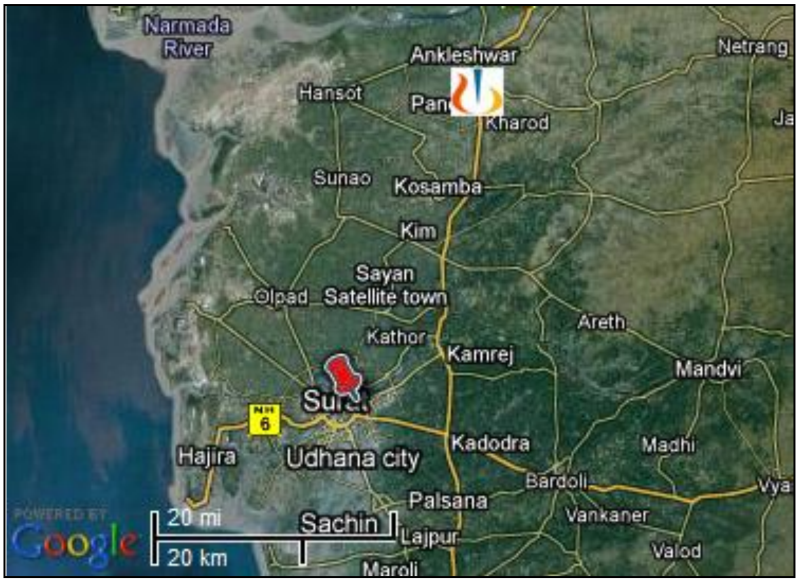
Marburg, Germany Bin Data WMO Information:
Site Name: Giessen, Germany
Site WMO ID: 105320
Latitude: 50.58°N
Longitude: 8.7°E
Elevation: 186m / 610ft
Approximate Distance to Site: 20 miles

Table 14: Geissen, Germany Yearly Temperature Bin Data

Geissen, Germany											
DB	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**
-2.2	-2.2	0.3	21.2	19.9	48.1	46.4	43.8	383.4	71.6	60.4	119.3
-0.4	-1.3	0.2	23.0	21.7	65.1	48.2	45.4	384.5	73.4	60.8	116.4
1.4	1.4	2.2	24.8	23.5	88.8	50.0	47.1	400.8	75.2	61.6	93.0
3.2	2.8	3.7	26.6	25.3	109.1	51.8	48.4	381.8	77.0	62.3	81.6
5.0	4.5	5.3	28.4	27.1	159.2	53.6	50.0	375.3	78.8	63.3	63.5
6.8	6.3	6.6	30.2	28.8	196.1	55.4	51.5	371.6	80.6	64.1	52.4
8.6	8.0	9.9	32.0	30.8	286.6	57.2	52.9	373.5	82.4	64.9	37.5
10.4	9.7	13.0	33.8	32.6	325.8	59.0	54.0	349.2	84.2	66.1	26.4
12.2	11.4	17.0	35.6	34.1	362.4	60.8	55.4	298.7	86.0	66.8	17.0
14.0	13.1	21.7	37.4	35.8	371.1	62.6	56.4	279.3	87.8	67.3	11.8
15.8	15.0	26.7	39.2	37.4	362.6	64.4	57.4	246.5	89.6	67.0	4.3
17.6	16.6	31.8	41.0	38.9	401.6	66.2	58.2	212.5	91.4	67.8	3.0
19.4	18.4	46.8	42.8	40.4	390.0	68.0	58.9	186.7	93.2	69.6	1.4
			44.6	42.1	380.2	69.8	59.5	156.4	95.0	70.4	0.5

Ankleshwar, India

Figure 16: Ankleshwar, India Bin Data Location



Ankleshwar, India Bin Data WMO Information
Site Name: Surat, India
Site WMO ID: 428400
Latitude: 21.2°N
Longitude: 72.83°E
Elevation: 12m / 39ft
Approximate Location to Site: 30 miles

Table 15: Surat, India Yearly Temperature Bin Data

Surat, India											
DB	MCWB	Hours	DB	MCWB	Hours	DB	MCWB	Hours	DB	MCWB	Hours
48.2	46.2	0.2	62.6	56.3	88.2	78.8	71.3	627.4	95.0	73.6	114.1
50.0	48.3	0.4	64.4	57.8	123.0	80.6	73.7	942.6	96.8	73.4	68.1
51.8	50.4	1.5	66.2	59.0	168.4	82.4	75.1	1,139.5	98.6	72.8	39.9
53.6	49.8	3.1	68.0	60.3	209.5	84.2	75.8	1,056.5	100.4	72.5	21.9
55.4	51.4	9.1	69.8	61.5	241.5	86.0	76.2	898.0	102.2	71.6	12.5
57.2	52.8	22.3	71.6	62.7	269.2	87.8	75.8	593.8	104.0	72.1	6.2
59.0	53.7	41.5	73.4	64.0	290.6	89.6	75.6	444.0	105.8	71.0	1.6
60.8	55.1	60.7	75.2	65.4	331.9	91.4	75.5	317.3	107.6	73.3	0.9
			77.0	67.8	409.1	93.2	74.9	205.4	109.4	74.0	0.2

Linping, China

Figure 17: Linping, China Bin Data Location

Linping, China Bin Data WMO Information:
Site Name: Hangzhou, China
Site WMO ID: 584570
Latitude: 30.23°N
Longitude: 120.17°E
Elevation: 43m / 141 ft
Approximate Distance to Site: 20 miles

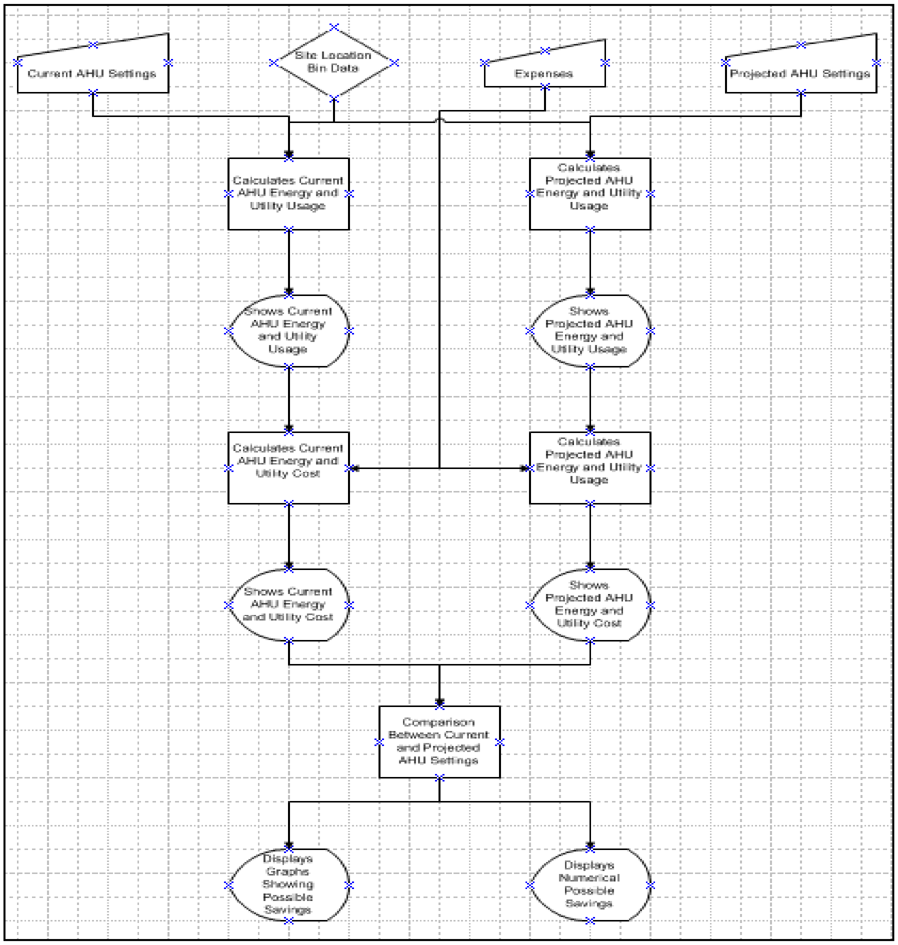
Table 16: Hangzhou, China Yearly Temperature Bin Data

Hangzhou, China											
DB	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**
15.8	15.8	0.1	37.4	34.7	194.3	59.0	54.8	250.7	80.6	74.7	309.8
17.6	15.8	0.1	39.2	36.4	224.0	60.8	56.7	254.3	82.4	75.7	262.9
19.4	18.1	0.6	41.0	38.2	263.4	62.6	58.4	263.5	84.2	76.4	215.3
21.2	19.8	0.8	42.8	40.1	289.4	64.4	60.1	283.7	86.0	77.2	176.7
23.0	21.4	2.9	44.6	41.7	299.1	66.2	61.8	287.2	87.8	77.9	140.5
24.8	22.5	7.6	46.4	43.4	292.9	68.0	63.6	303.3	89.6	78.4	113.6
26.6	24.5	16.2	48.2	45.0	284.8	69.8	65.4	319.9	91.4	79.2	94.0
28.4	26.1	30.6	50.0	46.6	265.5	71.6	67.0	336.5	93.2	79.8	70.6
30.2	27.8	58.7	51.8	47.8	245.6	73.4	68.6	328.6	95.0	80.1	58.3
32.0	30.0	101.7	53.6	49.5	228.0	75.2	70.4	343.9	96.8	80.2	39.4
33.8	31.3	135.1	55.4	51.3	236.1	77.0	72.2	347.2	98.6	80.7	18.2
35.6	33.0	161.2	57.2	53.1	247.9	78.8	73.7	348.1	100.4	81.1	6.3
									102.2	80.2	0.8

6. HVAC EXCEL PROGRAM

Our group decided that the best way to evaluate the HVAC systems of any site in the Vaccines & Diagnosis Division while ensuring that it will be compatible to most PCs and user friendly would be to create a program in Microsoft Excel$^{©}$. In order to cover the full scope of any HVAC system, several factors need to be taken into account including fan power, pump power, coil heat transfer and the temperature bin data for the location of the site. It was obvious that several sheets of an Excel workbook would need to be utilized to make sure that the user would not need to scroll around and possibly lose track of what they are trying to accomplish. An unexpected factor that came into play while trying to create the program was the involvement of macros which are created and run via Microsoft Visual Basic$^{©}$. Macros are used when simply writing equations, if-then statements, and values into cells are not sophisticated enough to run the program. In the workbook there are a total of five sheets that make up the program.

Figure 18: Excel Program Flowchart



6.1 HOW THE PROGRAM WORKS

Supply and Return Fans

Incorporating fans into the program was probably the simplest of all the features to create since the equations are relatively simple to understand and use. They also require the least amount of user inputs. The inputs that are required to calculate the power of a fan being used in an HVAC system are airflow, mechanical efficiency, and static pressure. The first step to evaluating amount of energy being used and the cost of running them is to compute the fan's brake horsepower (*See Equation #9*).[59]

A problem arises when observing this particular equation, it will be impossible to solve on the off chance that the mechanical efficiency of the fan is zero. The denominator in a division problem cannot equal zero because then the answer is undefined so it became necessary to include an if-then statement in the cell that would calculate the brake horsepower. This statement would make the cell produce a value of zero if the user were to input a value of zero as the fan's mechanical efficiency. The next step is to calculate the amount of money that it takes to run the fan for an entire year nonstop which means that the brake horsepower must be converted into kilowatt-hours then multiplied by the number of hours in operation and the cost per kilowatt-hour (*See Equation #10*).

A typical HVAC unit will have one supply fan and one return fan so these equations must be used separately from each one and the end results are added together to get the overall electric cost of the fan systems in the unit for one year. All of these results, along with the results for all the cost calculations, are found in the Summary worksheet of the program.

Current and Proposed Outputs

Both of these sheets contain a 60 by 24 table that calculates the amount of energy and water that is used by the air handling unit and its respective pumps that are being evaluated. Each of the 24 columns has its own function tailored to solve its title's description and could use either a simple equation, an if-then statement, or a macro designed in Microsoft Visual Basic© to accomplish its task. The table is so large because the method that we chose to use, the bin hour

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[59] Energy Efficiency Guide, 9

method, requires us to run each calculation for every degree bin followed by summing the entire column to find the total amount of energy used. The leftmost column represents each column in the table, the center column gives the name of the variable being solved for and the rightmost column explains what each lettered variable represents in the function.

Table 17: Current and Projected Outputs Functions

Column	Title and Function Contents	Explanation
E	*Temperature Off Return Fan (DB)* A+IF(B=0,0,((0.39084*C)/B))	A = Area Temperature (DB) B = Return Fan Mechanical Efficiency C = Return Fan Static Pressure
F	*Temperature Off Return Fan (WB)* WetBulbTemp(A,HumRatio2(B,C,D),D)	A = Temp Off Return Fan (DB) B = Area Temperature (DB) C = Area Temperature (WB) D = Site Elevation
G	*Mixed Air Temperature (DB)* A*(100%-B)+C*B	A = Temp Off Return Fan (DB) B = Outdoor Air % C = Outside Temperature (DB)
H	*Mixed Air Temperature (WB)* A*(100%-B)+C*B	A = Temp Off Return Fan (WB) B = Outdoor Air % C = Outside Temperature (WB)
I	*Mixed Air Enthalpy* Enthalpy(A,HumRatio2(A,B,C))	A = Mixed Air Temperature (DB) B = Mixed Air Temperature (WB) C = Site Elevation
J	*Air Temp Leaving Cooling Coil (DB)* IF(A>B,B,A)	A = Mixed Air Temperature (DB) B = Temperature Off Cooling Coil
K	*Air Temp Leaving Cooling Coil* (WB) IF(A>B,B,A)	A = Mixed Air Temperature (WB) B = Temperature Off Cooling Coil
L	*Air Temp Leaving Cooling Coil Enthalpy* Enthalpy(A,HumRatio2(A,B,C))	A=Air Temp Leaving Cooling Coil (DB) B=Air Temp Leaving Cooling Coil (WB) C = Site Elevation
M	*Air Temp Leaving AHU (DB)* A+IF(B=0,0,((0.39084*C)/B))	A=Air Temp Leaving Cooling Coil (DB) B = Supply Fan Mechanical Efficiency C = Supply Fan Static Pressure
N	*Cooling Load in Tons* IF((A*60/13.5*(B-C))/12000>=0,(A*60/13.5*(B-C))/12000,IF(D<E,(1.085*A*(D-E))/12000,0))	A = Supply Fan Airflow B = Mixed Air Enthalpy C=Air Temp Leaving Cooling Coil Enthalpy D = Air Temp Leaving Cooling Coil (DB) E = Air Temp Leaving Cooling Coil (WB)
O	*Cooling Load in Ton-Hours* A*B	A = Bin Hours B = Cooling Load in Tons
P	*Preheat Load in BTU/hr* IF(1.085*A*(B-C)<0,0,1.085*A*(B-C))	A = Supply Fan Airflow B = Max Allowable Area Temp (DB) C = Air Temp Leaving AHU (DB)
Q	*Preheat Load in Therms* A*B/100000	A = Preheat Load in BTU/hr B = Bin Hours
R	*Reheat Load in BTU/hr* IF(1.085*A*(B-C)<0,0,1.085*A*(B-C))	A = Supply Fan Airflow B = Max Allowable Area Temp (DB)

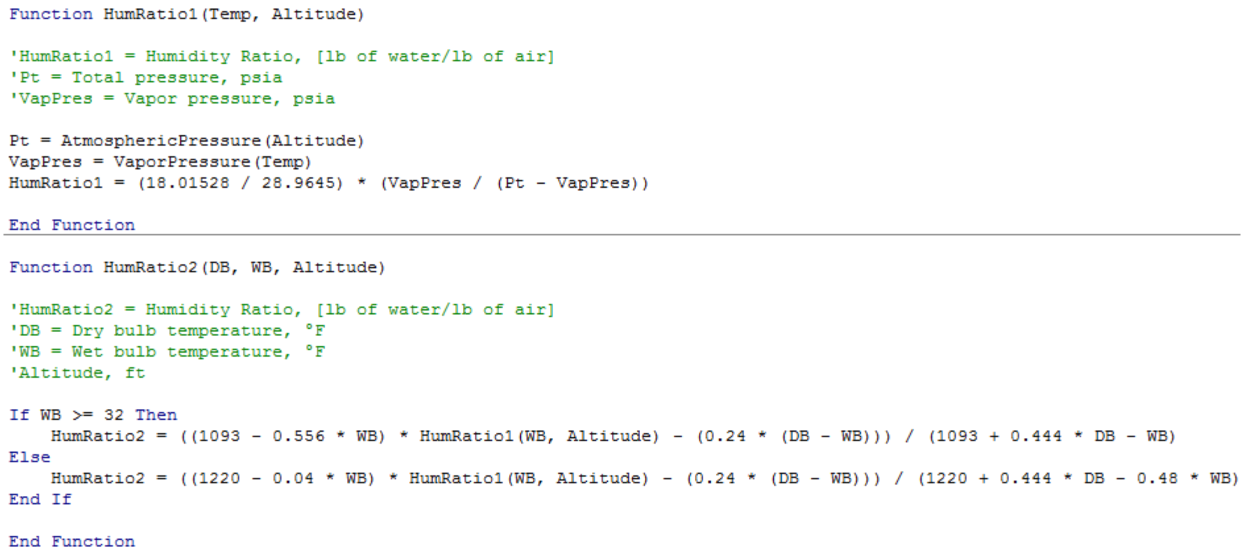
		C = Air Temp Leaving AHU (DB)
S	*Reheat Load in Therms* A*B/100000	A = Reheat Load in BTU/hr B = Bin Hours
T	*Cooling Coil Flow in GPM* (A*12000)/(500*(B-C))	A = Cooling Load in Tons B = Water Temp from Cooling Coil C = Water Temp to Cooling Coil
U	*Cooling Coil Pump BHP* (A*B*1)/(3960*C)	A = Cooling Coil Flow in GPM B = Pressure Drop in Cooling Coil C = Cooling Coil Pump Efficiency
V	*Cooling Coil Pump kWh* A*0.7457*B*60	A = Pump BHP B = Bin Hours
W	*Preheat Coil Flow in GPM* (A*10000)/(500*(B-C))	A = Preheat Load in Therms B = Water Temp from Preheat Coil C = Water Temp to Preheat Coil
X	*Preheat Coil Pump BHP* (A*B*1)/(3960*C)	A = Preheat Coil Flow in GPM B = Pressure Drop in Preheat Coil C = Preheat Coil Pump Efficiency
Y	*Preheat Coil Pump kWh* A*0.7475*B*60	A = Preheat Coil Pump BHP B = Bin Hours
Z	*Reheat Coil Flow in GPM* (A*10000)/(500*(B-C))	A = Reheat Load in Therms B = Water Temp from Reheat Coil C = Water Temp to Reheat Coil
AA	*Reheat Coil Pump BHP* (A*B*1)/(3960*C)	A = Reheat Coil Flow in GPM B = Pressure Drop in Reheat Coil C = Reheat Coil Pump Efficiency
AB	*Reheat Coil Pump kWh* A*0.7475*B*60	A = Reheat Coil Pump BHP B = Bin Hours
AC	*Cooling Coil Water Usage in GPH* A*60*B	A = Cooling Coil Flow in GPM B = Bin Hours
AD	*Preheat Coil Water Usage in GPH* A*60*B	A = Preheat Coil Flow in GPM B = Bin Hours
AE	*Reheat Coil Water Usage in GPH* A*60*B	A = Reheat Coil Flow in GPM B = Bin Hours

DB = Dry Bulb
WB = Wet Bulb
kWh = Kilowatt-hours
BHP = Brake Horsepower
GPM = Gallons per Minute
GPH = Gallons per Hour

The beginning of an if-then statement is represented by the symbol “IF”, but this is not always at the very beginning of a function. The most important symbol to pay attention to in an if-then statement in an excel worksheet is the commas because they provide separation between each part of the statement. The first part of the statement begins immediately after the first open parenthesis and ends at the first comma, this is the “if” part of the function and will always have an equals sign, a less than sign or a greater than sign followed by a value that is either a numerical value or a variable. If the statement is proven to be true then the function will produce the second part of the statement as the result, but if the statement is proven to be false then the function will produce the third part of the statement as the result. An example of this type of function would be for a division equation that has variables in the denominator and there is a possibility that the entire denominator could equal zero. This is of course an impossible equation to solve so an if-then statement is used so the function can circumvent the equation and allow the function to produce an adequate result to be used in the rest of the model.

For some of the functions we managed to write code in visual basic that would produce the result without forcing us to write complex equations in an individual cell's function. Writing complex equations in excel function bars are tricky since they are difficult to read and therefore are hard to troubleshoot. Having an intricate equation that involves division and/or multiple if-then statements in one straight line that cannot all be viewed at the same time is hard to change and manipulate. There are a total of three macros being used in the outputs tables, they are called WetBulbTemp, HumRatio2, and Enthalpy and the variables that they require to be solved can be found immediately following them in the parenthesis. The coding for all three of these is as follows:

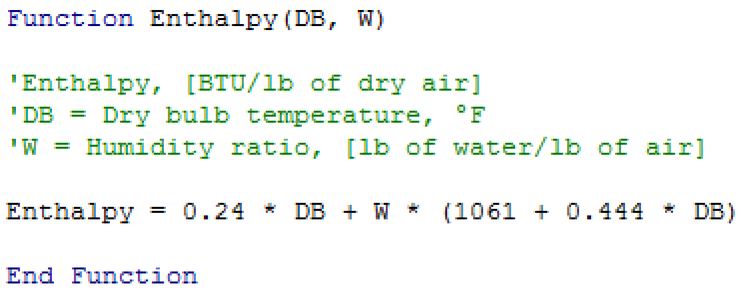
Function HumRatio2 and all subsequent coding required:



```
Function HumRatio1(Temp, Altitude)

'HumRatio1 = Humidity Ratio, [lb of water/lb of air]
'Pt = Total pressure, psia
'VapPres = Vapor pressure, psia

Pt = AtmosphericPressure(Altitude)
VapPres = VaporPressure(Temp)
HumRatio1 = (18.01528 / 28.9645) * (VapPres / (Pt - VapPres))

End Function
```

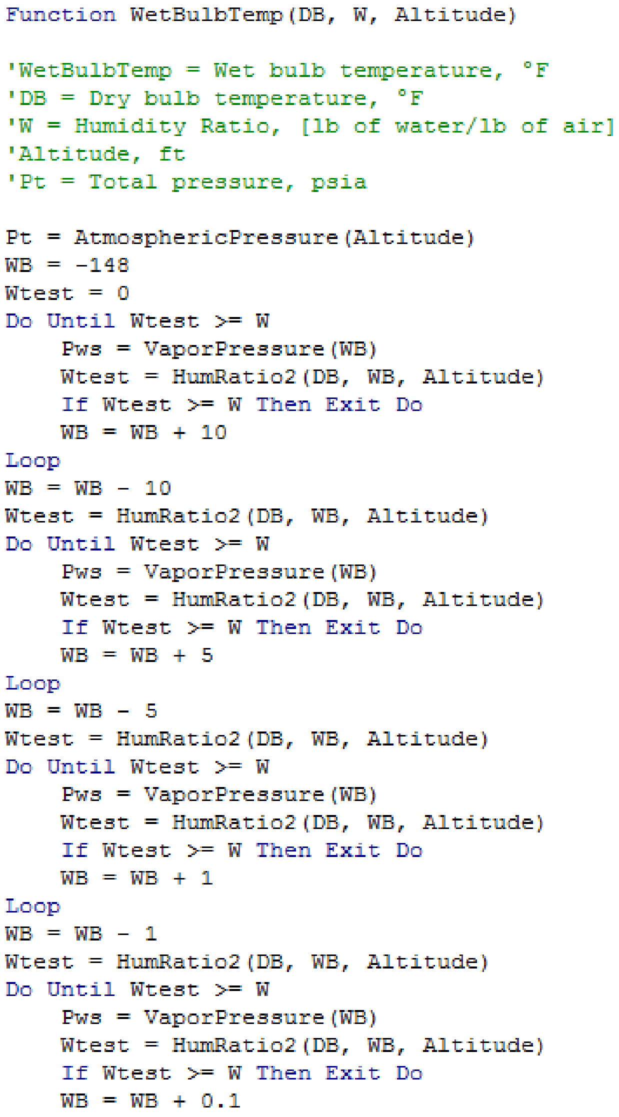
```
Function HumRatio2(DB, WB, Altitude)

'HumRatio2 = Humidity Ratio, [lb of water/lb of air]
'DB = Dry bulb temperature, °F
'WB = Wet bulb temperature, °F
'Altitude, ft

If WB >= 32 Then
    HumRatio2 = ((1093 - 0.556 * WB) * HumRatio1(WB, Altitude) - (0.24 * (DB - WB))) / (1093 + 0.444 * DB - WB)
Else
    HumRatio2 = ((1220 - 0.04 * WB) * HumRatio1(WB, Altitude) - (0.24 * (DB - WB))) / (1220 + 0.444 * DB - 0.48 * WB)
End If

End Function
```

Function Enthalpy:

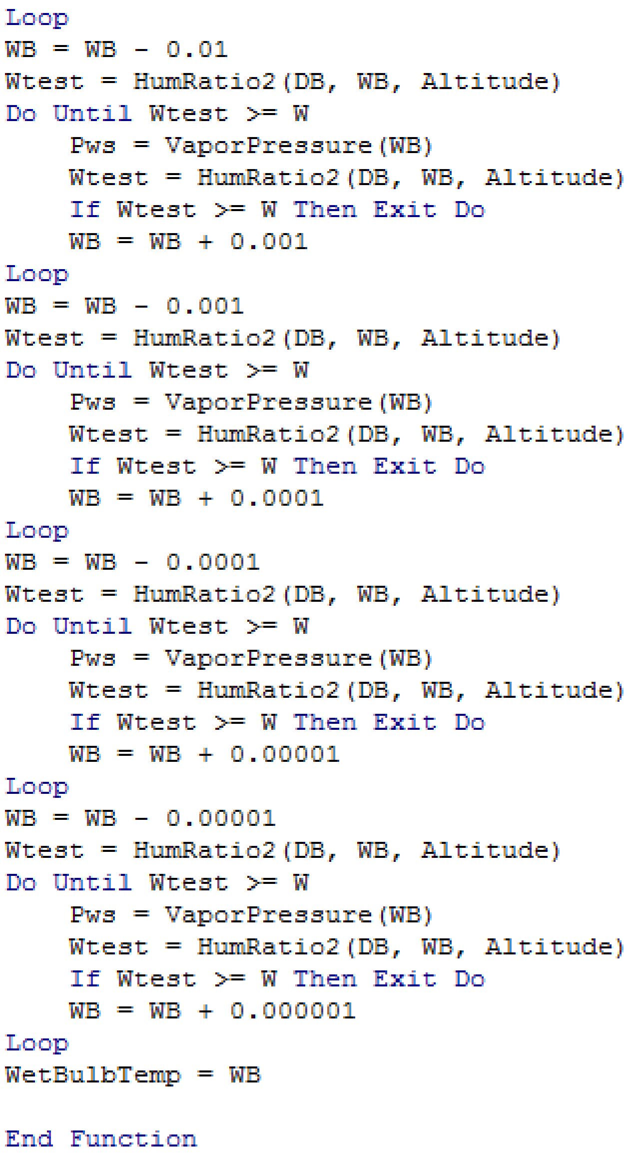


```
Function Enthalpy(DB, W)

'Enthalpy, [BTU/lb of dry air]
'DB = Dry bulb temperature, °F
'W = Humidity ratio, [lb of water/lb of air]

Enthalpy = 0.24 * DB + W * (1061 + 0.444 * DB)

End Function
```

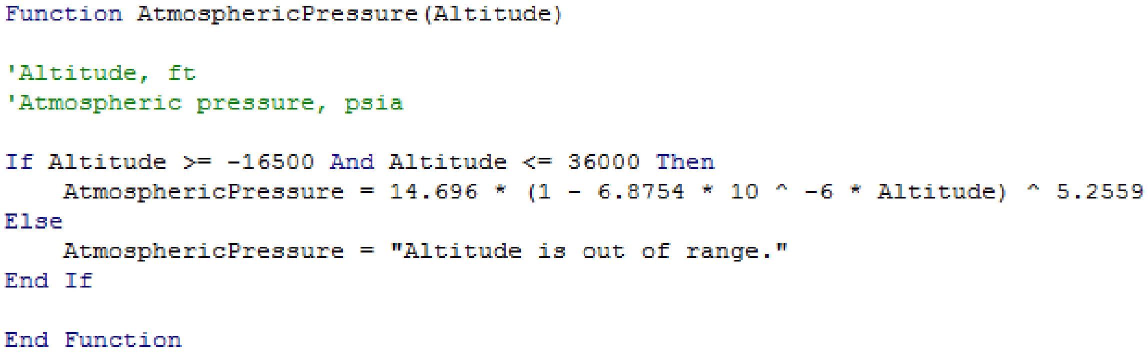
Function WetBulbTemp and all subsequent coding required:



```
Function WetBulbTemp(DB, W, Altitude)

'WetBulbTemp = Wet bulb temperature, °F
'DB = Dry bulb temperature, °F
'W = Humidity Ratio, [lb of water/lb of air]
'Altitude, ft
'Pt = Total pressure, psia

Pt = AtmosphericPressure(Altitude)
WB = -148
Wtest = 0
Do Until Wtest >= W
    Pws = VaporPressure(WB)
    Wtest = HumRatio2(DB, WB, Altitude)
    If Wtest >= W Then Exit Do
    WB = WB + 10
Loop
WB = WB - 10
Wtest = HumRatio2(DB, WB, Altitude)
Do Until Wtest >= W
    Pws = VaporPressure(WB)
    Wtest = HumRatio2(DB, WB, Altitude)
    If Wtest >= W Then Exit Do
    WB = WB + 5
Loop
WB = WB - 5
Wtest = HumRatio2(DB, WB, Altitude)
Do Until Wtest >= W
    Pws = VaporPressure(WB)
    Wtest = HumRatio2(DB, WB, Altitude)
    If Wtest >= W Then Exit Do
    WB = WB + 1
Loop
WB = WB - 1
Wtest = HumRatio2(DB, WB, Altitude)
Do Until Wtest >= W
    Pws = VaporPressure(WB)
    Wtest = HumRatio2(DB, WB, Altitude)
    If Wtest >= W Then Exit Do
    WB = WB + 0.1
```



```
Loop
WB = WB - 0.01
Wtest = HumRatio2(DB, WB, Altitude)
Do Until Wtest >= W
    Pws = VaporPressure(WB)
    Wtest = HumRatio2(DB, WB, Altitude)
    If Wtest >= W Then Exit Do
    WB = WB + 0.001
Loop
WB = WB - 0.001
Wtest = HumRatio2(DB, WB, Altitude)
Do Until Wtest >= W
    Pws = VaporPressure(WB)
    Wtest = HumRatio2(DB, WB, Altitude)
    If Wtest >= W Then Exit Do
    WB = WB + 0.0001
Loop
WB = WB - 0.0001
Wtest = HumRatio2(DB, WB, Altitude)
Do Until Wtest >= W
    Pws = VaporPressure(WB)
    Wtest = HumRatio2(DB, WB, Altitude)
    If Wtest >= W Then Exit Do
    WB = WB + 0.00001
Loop
WB = WB - 0.00001
Wtest = HumRatio2(DB, WB, Altitude)
Do Until Wtest >= W
    Pws = VaporPressure(WB)
    Wtest = HumRatio2(DB, WB, Altitude)
    If Wtest >= W Then Exit Do
    WB = WB + 0.000001
Loop
WetBulbTemp = WB

End Function
```



```
Function AtmosphericPressure(Altitude)

'Altitude, ft
'Atmospheric pressure, psia

If Altitude >= -16500 And Altitude <= 36000 Then
    AtmosphericPressure = 14.696 * (1 - 6.8754 * 10 ^ -6 * Altitude) ^ 5.2559
Else
    AtmosphericPressure = "Altitude is out of range."
End If

End Function
```

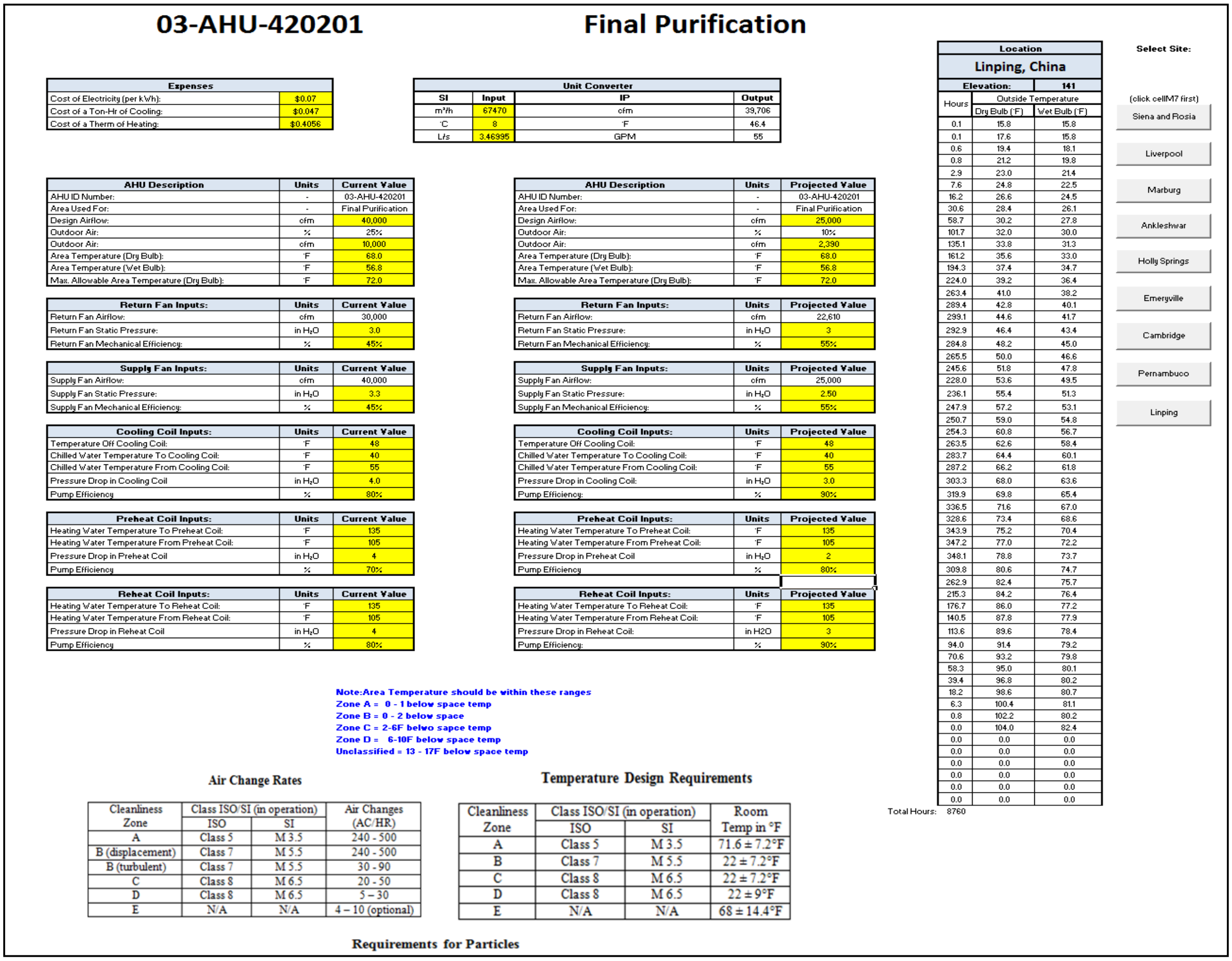
Site Bin Hour Selection

When creating a program as complex as ours in a spreadsheet format, it became necessary for us to use visual basic in cooperation with excel to simplify the more sophisticated parts. One of the parts was when we were trying to find an easy way to generate the appropriate bin data for the site that the user is evaluating in the input sheet. After much experimentation with list boxes, combo boxes, and buttons we found that the best way would be to have each site in the division represented by a button located in a column directly to the right of the data box that contains the bin data. The best way to accomplish this programming feat would be to record an individual macro for each site that would take the bin data, stored together on another sheet in the workbook, and insert them into their appropriate column on the input sheet. The last step was to ensure that each macro is properly assigned to its appropriate site button.

6.1 HOW TO USE THE PROGRAM

Inputs

Figure 19: Screenshot of Inputs Worksheet



03-AHU-420201

Final Purification

Expenses	
Cost of Electricity (per kWh):	$0.07
Cost of a Ton-Hr of Cooling:	$0.047
Cost of a Therm of Heating:	$0.4056

Unit Converter			
SI	Input	IP	Output
m^3/h	67470	cfm	39,706
°C	8	°F	46.4
L/s	3.46995	GPM	55

AHU Description	Units	Current Value
AHU ID Number:	-	03-AHU-420201
Area Used For:	-	Final Purification
Design Airflow:	cfm	40,000
Outdoor Air:	%	25%
Outdoor Air:	cfm	10,000
Area Temperature (Dry Bulb):	°F	68.0
Area Temperature (Wet Bulb):	°F	56.8
Max. Allowable Area Temperature (Dry Bulb):	°F	72.0

Return Fan Inputs:	Units	Current Value
Return Fan Airflow:	cfm	30,000
Return Fan Static Pressure:	in H_2O	3.0
Return Fan Mechanical Efficiency:	%	45%

Supply Fan Inputs:	Units	Current Value
Supply Fan Airflow:	cfm	40,000
Supply Fan Static Pressure:	in H_2O	3.3
Supply Fan Mechanical Efficiency:	%	45%

Cooling Coil Inputs:	Units	Current Value
Temperature Off Cooling Coil:	°F	48
Chilled Water Temperature To Cooling Coil:	°F	40
Chilled Water Temperature From Cooling Coil:	°F	55
Pressure Drop in Cooling Coil	in H_2O	4.0
Pump Efficiency	%	80%

Preheat Coil Inputs:	Units	Current Value
Heating Water Temperature To Preheat Coil:	°F	135
Heating Water Temperature From Preheat Coil:	°F	105
Pressure Drop in Preheat Coil	in H_2O	4
Pump Efficiency	%	70%

Reheat Coil Inputs:	Units	Current Value
Heating Water Temperature To Reheat Coil:	°F	135
Heating Water Temperature From Reheat Coil:	°F	105
Pressure Drop in Reheat Coil	in H_2O	4
Pump Efficiency	%	80%

AHU Description	Units	Projected Value
AHU ID Number:	-	03-AHU-420201
Area Used For:	-	Final Purification
Design Airflow:	cfm	25,000
Outdoor Air:	%	10%
Outdoor Air:	cfm	2,390
Area Temperature (Dry Bulb):	°F	68.0
Area Temperature (Wet Bulb):	°F	56.8
Max. Allowable Area Temperature (Dry Bulb):	°F	72.0

Return Fan Inputs:	Units	Projected Value
Return Fan Airflow:	cfm	22,610
Return Fan Static Pressure:	in H_2O	3
Return Fan Mechanical Efficiency:	%	55%

Supply Fan Inputs:	Units	Projected Value
Supply Fan Airflow:	cfm	25,000
Supply Fan Static Pressure:	in H_2O	2.50
Supply Fan Mechanical Efficiency:	%	55%

Cooling Coil Inputs:	Units	Projected Value
Temperature Off Cooling Coil:	°F	48
Chilled Water Temperature To Cooling Coil:	°F	40
Chilled Water Temperature From Cooling Coil:	°F	55
Pressure Drop in Cooling Coil:	in H_2O	3.0
Pump Efficiency:	%	90%

Preheat Coil Inputs:	Units	Projected Value
Heating Water Temperature To Preheat Coil:	°F	135
Heating Water Temperature From Preheat Coil:	°F	105
Pressure Drop in Preheat Coil	in H_2O	2
Pump Efficiency	%	80%

Reheat Coil Inputs:	Units	Projected Value
Heating Water Temperature To Reheat Coil:	°F	135
Heating Water Temperature From Reheat Coil:	°F	105
Pressure Drop in Reheat Coil:	in H2O	3
Pump Efficiency:	%	90%

Location		
Linping, China		
Elevation:	141	
Hours	Outside Temperature	
	Dry Bulb (°F)	Wet Bulb (°F)
0.1	15.8	15.8
0.1	17.6	15.8
0.6	19.4	18.1
0.8	21.2	19.8
2.9	23.0	21.4
7.6	24.8	22.5
16.2	26.6	24.5
30.6	28.4	26.1
58.7	30.2	27.8
101.7	32.0	30.0
135.1	33.8	31.3
161.2	35.6	33.0
194.3	37.4	34.7
224.0	39.2	36.4
263.4	41.0	38.2
289.4	42.8	40.1
299.1	44.6	41.7
292.9	46.4	43.4
284.8	48.2	45.0
265.5	50.0	46.6
245.6	51.8	47.8
228.0	53.6	49.5
236.1	55.4	51.3
247.9	57.2	53.1
250.7	59.0	54.8
254.3	60.8	56.7
263.5	62.6	58.4
283.7	64.4	60.1
287.2	66.2	61.8
303.3	68.0	63.6
319.9	69.8	65.4
336.5	71.6	67.0
328.6	73.4	68.6
343.9	75.2	70.4
347.2	77.0	72.2
348.1	78.8	73.7
309.8	80.6	74.7
262.9	82.4	75.7
215.3	84.2	76.4
176.7	86.0	77.2
140.5	87.8	77.9
113.6	89.6	78.4
94.0	91.4	79.2
70.6	93.2	79.8
58.3	95.0	80.1
39.4	96.8	80.2
18.2	98.6	80.7
6.3	100.4	81.1
0.8	102.2	80.2
0.0	104.0	82.4
0.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0

Total Hours: 8760

Note:Area Temperature should be within these ranges
Zone A = 0 - 1 below space temp
Zone B = 0 - 2 below space
Zone C = 2-6F belwo sapce temp
Zone D = 6-10F below space temp
Unclassified = 13 - 17F below space temp

Air Change Rates

Cleanliness Zone	Class ISO/SI (in operation)		Air Changes (AC/HR)
	ISO	SI	
A	Class 5	M 3.5	240 - 500
B (displacement)	Class 7	M 5.5	240 - 500
B (turbulent)	Class 7	M 5.5	30 - 90
C	Class 8	M 6.5	20 - 50
D	Class 8	M 6.5	5 – 30
E	N/A	N/A	4 – 10 (optional)

Temperature Design Requirements

Cleanliness Zone	Class ISO/SI (in operation)		Room Temp in °F
	ISO	SI	
A	Class 5	M 3.5	71.6 ± 7.2°F
B	Class 7	M 5.5	22 ± 7.2°F
C	Class 8	M 6.5	22 ± 7.2°F
D	Class 8	M 6.5	22 ± 9°F
E	N/A	N/A	68 ± 14.4°F

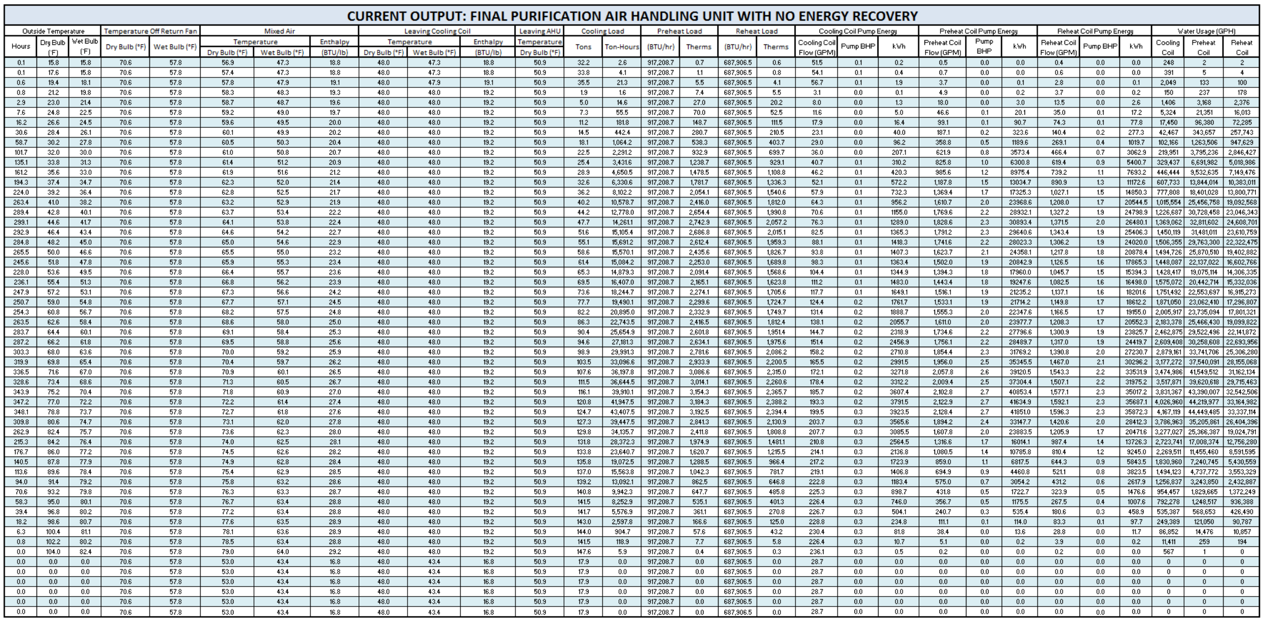
Requirements for Particles

The first worksheet is the only one that the end user will be able to enter in values. The other four worksheets are locked and protected from any unwanted changes that could occur while being used. This worksheet is comprised of twelve tables in two columns of six. The leftmost column of tables calculates the cost of using the air handling unit using the settings that it is currently running on and the other is the proposed settings that the user wants to evaluate. Each column of tables has the same titles running from top to bottom; AHU description, return fan inputs, supply fan inputs, cooling coil inputs, preheat coil inputs, and reheat coil inputs. Inside all of these tables are cells that have been highlighted with the color yellows, which are the cells that the user inputs numbers into. Some of these cells have limitations on them which are explained below the two columns in blue text. If the user inputs a value that is outside the normal range for that value an automated warning appears informing the user of their mistake and gives them the option of changing or keeping the number that they have entered. Above these columns are two smaller tables, the one on the left is the expenses table used for inputting the costs per kWh, cost per ton of cooling, and cost per therm of heating. The other table is for converting metric values into standard values so that users from sites outside of the United States can input their values and receive the proper numerical values to input into the program since all the calculations use standard (IP) units.

The last table is very long vertically and is how the user informs the program of the location of the air handling unit on the planet. Simply by highlighting cell M7 and then selecting the button corresponding to the Novartis V&D division site the user will have the correct bin data with hours, dry blub temperature, wet blub temperature, and the site elevation. This feat was accomplished via individual recorded macros, one per site, and simply takes the values from the last worksheet in the workbook where the bin data for every site in the division is saved. The sites are as follows: Holly Springs, Cambridge, Emeryville, Liverpool, Marburg, Ankleshwar, Linping, Pernambuco, Siena and Rosia. With all of the information entered into the program on this worksheet, the rest of the program runs automatically on the rest of the worksheets and the user may now observe the expenses and possible savings of the air handling unit.

Current and Proposed Outputs

Figure 20: Screenshot of Current/Proposed Outputs Worksheet



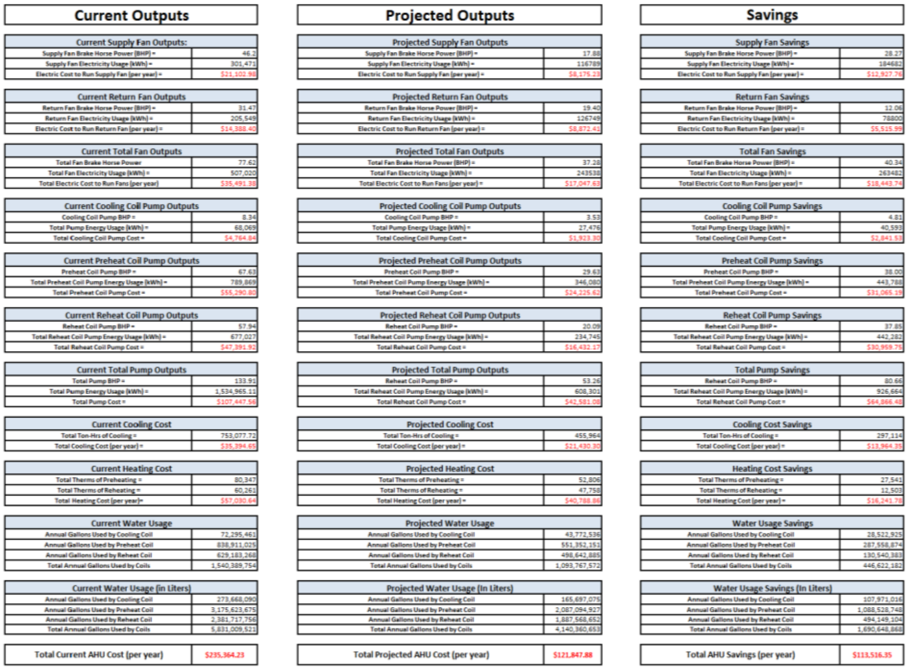
CURRENT OUTPUT: FINAL PURIFICATION AIR HANDLING UNIT WITH NO ENERGY RECOVERY

Outside Temperature			Temperature Off Return Fan		Mixed Air			Leaving Cooling Coil			Leaving AHU	Cooling Load		Preheat Load		Reheat Load		Cooling Coil Pump Energy			Preheat Coil Pump Energy			Reheat Coil Pump Energy			Water Usage (GPH)		
Hours	Dry Bulb (°F)	Wet Bulb (°F)	Dry Bulb (°F)	Wet Bulb (°F)	Temperature		Enthalpy	Temperature		Enthalpy	Temperature	Tons	Ton-Hours	(BTU/hr)	Therms	(BTU/hr)	Therms	Cooling Coil Flow (GPM)	Pump BHP	kWh	Preheat Coil Flow (GPM)	Pump BHP	kWh	Reheat Coil Flow (GPM)	Pump BHP	kWh	Cooling Coil	Preheat Coil	Reheat Coil
					Dry Bulb (°F)	Wet Bulb (°F)	(BTU/lb)	Dry Bulb (°F)	Wet Bulb (°F)	(BTU/lb)	Dry Bulb (°F)																		
0.1	15.8	15.8	70.6	57.8	56.9	47.3	18.8	48.0	47.3	18.8	50.9	32.2	2.6	917,208.7	0.7	687,906.5	0.6	51.5	0.1	0.2	0.5	0.0	0.0	0.4	0.0	0.0	248	2	2
0.1	17.6	15.8	70.6	57.8	57.4	47.3	18.8	48.0	47.3	18.8	50.9	33.8	4.1	917,208.7	1.1	687,906.5	0.8	54.1	0.1	0.4	0.7	0.0	0.0	0.6	0.0	0.0	391	5	4
0.6	19.4	18.1	70.6	57.8	57.8	47.9	19.1	48.0	47.9	19.1	50.9	35.5	21.3	917,208.7	5.5	687,906.5	4.1	56.7	0.1	1.9	3.7	0.0	0.1	2.8	0.0	0.1	2,049	133	100
0.8	21.2	19.8	70.6	57.8	58.3	48.3	19.3	48.0	48.0	19.2	50.9	1.9	1.6	917,208.7	7.4	687,906.5	5.5	3.1	0.0	0.1	4.9	0.0	0.2	3.7	0.0	0.2	150	237	178
2.9	23.0	21.4	70.6	57.8	58.7	48.7	19.6	48.0	48.0	19.2	50.9	5.0	14.6	917,208.7	27.0	687,906.5	20.2	8.0	0.0	1.3	18.0	0.0	3.0	13.5	0.0	2.6	1,406	3,168	2,376
7.6	24.8	22.5	70.6	57.8	59.2	49.0	19.7	48.0	48.0	19.2	50.9	7.3	55.5	917,208.7	70.0	687,906.5	52.5	11.6	0.0	5.0	46.6	0.1	20.1	35.0	0.1	17.2	5,324	21,351	16,013
16.2	26.6	24.5	70.6	57.8	59.6	49.5	20.0	48.0	48.0	19.2	50.9	11.2	181.8	917,208.7	148.7	687,906.5	111.5	17.9	0.0	16.4	99.1	0.1	90.7	74.3	0.1	77.8	17,450	96,380	72,285
30.6	28.4	26.1	70.6	57.8	60.1	49.9	20.2	48.0	48.0	19.2	50.9	14.5	442.4	917,208.7	280.7	687,906.5	210.5	23.1	0.0	40.0	187.1	0.2	323.6	140.4	0.2	277.3	42,467	343,657	257,743
58.7	30.2	27.8	70.6	57.8	60.5	50.3	20.4	48.0	48.0	19.2	50.9	18.1	1,064.2	917,208.7	538.3	687,906.5	403.7	29.0	0.0	96.2	358.8	0.5	1189.6	269.1	0.4	1019.7	102,166	1,263,506	947,629
101.7	32.0	30.0	70.6	57.8	61.0	50.8	20.7	48.0	48.0	19.2	50.9	22.5	2,291.2	917,208.7	932.9	687,906.5	699.7	36.0	0.0	207.1	621.9	0.8	3573.4	466.4	0.7	3062.9	219,951	3,795,236	2,846,427
135.1	33.8	31.3	70.6	57.8	61.4	51.2	20.9	48.0	48.0	19.2	50.9	25.4	3,431.6	917,208.7	1,238.7	687,906.5	929.1	40.7	0.1	310.2	825.8	1.0	6300.8	619.4	0.9	5400.7	329,437	6,691,982	5,018,986
161.2	35.6	33.0	70.6	57.8	61.9	51.6	21.2	48.0	48.0	19.2	50.9	28.9	4,650.5	917,208.7	1,478.5	687,906.5	1,108.8	46.2	0.1	420.3	985.6	1.2	8975.4	739.2	1.1	7693.2	446,444	9,532,635	7,149,476
194.3	37.4	34.7	70.6	57.8	62.3	52.0	21.4	48.0	48.0	19.2	50.9	32.6	6,330.6	917,208.7	1,781.7	687,906.5	1,336.3	52.1	0.1	572.2	1,187.8	1.5	13034.7	890.9	1.3	11172.6	607,733	13,844,014	10,383,011
224.0	39.2	36.4	70.6	57.8	62.8	52.5	21.7	48.0	48.0	19.2	50.9	36.2	8,102.2	917,208.7	2,054.1	687,906.5	1,540.6	57.9	0.1	732.3	1,369.4	1.7	17325.3	1,027.1	1.5	14850.3	777,808	18,401,028	13,800,771
263.4	41.0	38.2	70.6	57.8	63.2	52.9	21.9	48.0	48.0	19.2	50.9	40.2	10,578.7	917,208.7	2,416.0	687,906.5	1,812.0	64.3	0.1	956.2	1,610.7	2.0	23968.6	1,208.0	1.7	20544.5	1,015,554	25,456,758	19,092,568
289.4	42.8	40.1	70.6	57.8	63.7	53.4	22.2	48.0	48.0	19.2	50.9	44.2	12,778.0	917,208.7	2,654.4	687,906.5	1,990.8	70.6	0.1	1155.0	1,769.6	2.2	28932.1	1,327.2	1.9	24798.9	1,226,687	30,728,458	23,046,343
299.1	44.6	41.7	70.6	57.8	64.1	53.8	22.4	48.0	48.0	19.2	50.9	47.7	14,261.1	917,208.7	2,742.9	687,906.5	2,057.2	76.3	0.1	1289.0	1,828.6	2.3	30893.4	1,371.5	2.0	26480.1	1,369,062	32,811,602	24,608,701
292.9	46.4	43.4	70.6	57.8	64.6	54.2	22.7	48.0	48.0	19.2	50.9	51.6	15,105.4	917,208.7	2,686.8	687,906.5	2,015.1	82.5	0.1	1365.3	1,791.2	2.3	29640.6	1,343.4	1.9	25406.3	1,450,119	31,481,011	23,610,759
284.8	48.2	45.0	70.6	57.8	65.0	54.6	22.9	48.0	48.0	19.2	50.9	55.1	15,691.2	917,208.7	2,612.4	687,906.5	1,959.3	88.1	0.1	1418.3	1,741.6	2.2	28023.3	1,306.2	1.9	24020.0	1,506,355	29,763,300	22,322,475
265.5	50.0	46.6	70.6	57.8	65.5	55.0	23.2	48.0	48.0	19.2	50.9	58.6	15,570.1	917,208.7	2,435.6	687,906.5	1,826.7	93.8	0.1	1407.3	1,623.7	2.1	24358.1	1,217.8	1.8	20878.4	1,494,726	25,870,510	19,402,882
245.6	51.8	47.8	70.6	57.8	65.9	55.3	23.4	48.0	48.0	19.2	50.9	61.4	15,084.2	917,208.7	2,253.0	687,906.5	1,689.8	98.3	0.1	1363.4	1,502.0	1.9	20842.9	1,126.5	1.6	17865.3	1,448,087	22,137,022	16,602,766
228.0	53.6	49.5	70.6	57.8	66.4	55.7	23.6	48.0	48.0	19.2	50.9	65.3	14,879.3	917,208.7	2,091.4	687,906.5	1,568.6	104.4	0.1	1344.9	1,394.3	1.8	17960.0	1,045.7	1.5	15394.3	1,428,417	19,075,114	14,306,335
236.1	55.4	51.3	70.6	57.8	66.8	56.2	23.9	48.0	48.0	19.2	50.9	69.5	16,407.0	917,208.7	2,165.1	687,906.5	1,623.8	111.2	0.1	1483.0	1,443.4	1.8	19247.6	1,082.5	1.6	16498.0	1,575,072	20,442,714	15,332,036
247.9	57.2	53.1	70.6	57.8	67.3	56.6	24.2	48.0	48.0	19.2	50.9	73.6	18,244.7	917,208.7	2,274.1	687,906.5	1,705.6	117.7	0.1	1649.1	1,516.1	1.9	21235.2	1,137.1	1.6	18201.6	1,751,492	22,553,697	16,915,273
250.7	59.0	54.8	70.6	57.8	67.7	57.1	24.5	48.0	48.0	19.2	50.9	77.7	19,490.1	917,208.7	2,299.6	687,906.5	1,724.7	124.4	0.2	1761.7	1,533.1	1.9	21714.2	1,149.8	1.7	18612.2	1,871,050	23,062,410	17,296,807
254.3	60.8	56.7	70.6	57.8	68.2	57.5	24.8	48.0	48.0	19.2	50.9	82.2	20,895.0	917,208.7	2,332.9	687,906.5	1,749.7	131.4	0.2	1888.7	1,555.3	2.0	22347.6	1,166.5	1.7	19155.0	2,005,917	23,735,094	17,801,321
263.5	62.6	58.4	70.6	57.8	68.6	58.0	25.0	48.0	48.0	19.2	50.9	86.3	22,743.5	917,208.7	2,416.5	687,906.5	1,812.4	138.1	0.2	2055.7	1,611.0	2.0	23977.7	1,208.3	1.7	20552.3	2,183,378	25,466,430	19,099,822
283.7	64.4	60.1	70.6	57.8	69.1	58.4	25.3	48.0	48.0	19.2	50.9	90.4	25,654.9	917,208.7	2,601.8	687,906.5	1,951.4	144.7	0.2	2318.9	1,734.6	2.2	27796.6	1,300.9	1.9	23825.7	2,462,875	29,522,496	22,141,872
287.2	66.2	61.8	70.6	57.8	69.5	58.8	25.6	48.0	48.0	19.2	50.9	94.6	27,181.3	917,208.7	2,634.1	687,906.5	1,975.6	151.4	0.2	2456.9	1,756.1	2.2	28489.7	1,317.0	1.9	24419.7	2,609,408	30,258,608	22,693,956
303.3	68.0	63.6	70.6	57.8	70.0	59.2	25.9	48.0	48.0	19.2	50.9	98.9	29,991.3	917,208.7	2,781.6	687,906.5	2,086.2	158.2	0.2	2710.8	1,854.4	2.3	31769.2	1,390.8	2.0	27230.7	2,879,161	33,741,706	25,306,280
319.9	69.8	65.4	70.6	57.8	70.4	59.7	26.2	48.0	48.0	19.2	50.9	103.5	33,096.6	917,208.7	2,933.9	687,906.5	2,200.5	165.5	0.2	2991.5	1,956.0	2.5	35345.5	1,467.0	2.1	30296.2	3,177,272	37,540,091	28,155,068
336.5	71.6	67.0	70.6	57.8	70.9	60.1	26.5	48.0	48.0	19.2	50.9	107.6	36,197.8	917,208.7	3,086.6	687,906.5	2,315.0	172.1	0.2	3271.8	2,057.8	2.6	39120.5	1,543.3	2.2	33531.9	3,474,986	41,549,512	31,162,134
328.6	73.4	68.6	70.6	57.8	71.3	60.5	26.7	48.0	48.0	19.2	50.9	111.5	36,644.5	917,208.7	3,014.1	687,906.5	2,260.6	178.4	0.2	3312.2	2,009.4	2.5	37304.4	1,507.1	2.2	31975.2	3,517,871	39,620,618	29,715,463
343.9	75.2	70.4	70.6	57.8	71.8	60.9	27.0	48.0	48.0	19.2	50.9	116.1	39,910.1	917,208.7	3,154.3	687,906.5	2,365.7	185.7	0.2	3607.4	2,102.8	2.7	40853.4	1,577.1	2.3	35017.2	3,831,367	43,390,007	32,542,506
347.2	77.0	72.2	70.6	57.8	72.2	61.4	27.4	48.0	48.0	19.2	50.9	120.8	41,947.5	917,208.7	3,184.3	687,906.5	2,388.2	193.3	0.2	3791.5	2,122.9	2.7	41634.9	1,592.1	2.3	35687.1	4,026,960	44,219,977	33,164,982
348.1	78.8	73.7	70.6	57.8	72.7	61.8	27.6	48.0	48.0	19.2	50.9	124.7	43,407.5	917,208.7	3,192.5	687,906.5	2,394.4	199.5	0.3	3923.5	2,128.4	2.7	41851.0	1,596.3	2.3	35872.3	4,167,119	44,449,485	33,337,114
309.8	80.6	74.7	70.6	57.8	73.1	62.0	27.8	48.0	48.0	19.2	50.9	127.3	39,447.5	917,208.7	2,841.3	687,906.5	2,130.9	203.7	0.3	3565.6	1,894.2	2.4	33147.7	1,420.6	2.0	28412.3	3,786,963	35,205,861	26,404,396
262.9	82.4	75.7	70.6	57.8	73.6	62.3	28.0	48.0	48.0	19.2	50.9	129.8	34,135.7	917,208.7	2,411.8	687,906.5	1,808.8	207.7	0.3	3085.5	1,607.8	2.0	23883.5	1,205.9	1.7	20471.6	3,277,027	25,366,387	19,024,791
215.3	84.2	76.4	70.6	57.8	74.0	62.5	28.1	48.0	48.0	19.2	50.9	131.8	28,372.3	917,208.7	1,974.9	687,906.5	1,481.1	210.8	0.3	2564.5	1,316.6	1.7	16014.1	987.4	1.4	13726.3	2,723,741	17,008,374	12,756,280
176.7	86.0	77.2	70.6	57.8	74.5	62.6	28.2	48.0	48.0	19.2	50.9	133.8	23,640.7	917,208.7	1,620.7	687,906.5	1,215.5	214.1	0.3	2136.8	1,080.5	1.4	10785.8	810.4	1.2	9245.0	2,269,511	11,455,460	8,591,595
140.5	87.8	77.9	70.6	57.8	74.9	62.8	28.4	48.0	48.0	19.2	50.9	135.8	19,072.5	917,208.7	1,288.5	687,906.5	966.4	217.2	0.3	1723.9	859.0	1.1	6817.5	644.3	0.9	5843.5	1,830,960	7,240,745	5,430,559
113.6	89.6	78.4	70.6	57.8	75.4	62.9	28.5	48.0	48.0	19.2	50.9	137.0	15,563.8	917,208.7	1,042.3	687,906.5	781.7	219.1	0.3	1406.8	694.9	0.9	4460.8	521.1	0.8	3823.5	1,494,123	4,737,772	3,553,329
94.0	91.4	79.2	70.6	57.8	75.8	63.2	28.6	48.0	48.0	19.2	50.9	139.2	13,092.1	917,208.7	862.5	687,906.5	646.8	222.8	0.3	1183.4	575.0	0.7	3054.2	431.2	0.6	2617.9	1,256,837	3,243,850	2,432,887
70.6	93.2	79.8	70.6	57.8	76.3	63.3	28.7	48.0	48.0	19.2	50.9	140.8	9,942.3	917,208.7	647.7	687,906.5	485.8	225.3	0.3	898.7	431.8	0.5	1722.7	323.9	0.5	1476.6	954,457	1,829,665	1,372,249
58.3	95.0	80.1	70.6	57.8	76.7	63.4	28.8	48.0	48.0	19.2	50.9	141.5	8,252.9	917,208.7	535.1	687,906.5	401.3	226.4	0.3	746.0	356.7	0.5	1175.5	267.5	0.4	1007.6	792,278	1,248,517	936,388
39.4	96.8	80.2	70.6	57.8	77.2	63.4	28.8	48.0	48.0	19.2	50.9	141.7	5,576.9	917,208.7	361.1	687,906.5	270.8	226.7	0.3	504.1	240.7	0.3	535.4	180.6	0.3	458.9	535,387	568,653	426,490
18.2	98.6	80.7	70.6	57.8	77.6	63.5	28.9	48.0	48.0	19.2	50.9	143.0	2,597.8	917,208.7	166.6	687,906.5	125.0	228.8	0.3	234.8	111.1	0.1	114.0	83.3	0.1	97.7	249,389	121,050	90,787
6.3	100.4	81.1	70.6	57.8	78.1	63.6	28.9	48.0	48.0	19.2	50.9	144.0	904.7	917,208.7	57.6	687,906.5	43.2	230.4	0.3	81.8	38.4	0.0	13.6	28.8	0.0	11.7	86,852	14,476	10,857
0.8	102.2	80.2	70.6	57.8	78.5	63.4	28.8	48.0	48.0	19.2	50.9	141.5	118.9	917,208.7	7.7	687,906.5	5.8	226.4	0.3	10.7	5.1	0.0	0.2	3.9	0.0	0.2	11,411	259	194
0.0	104.0	82.4	70.6	57.8	79.0	64.0	29.2	48.0	48.0	19.2	50.9	147.6	5.9	917,208.7	0.4	687,906.5	0.3	236.1	0.3	0.5	0.2	0.0	0.0	0.2	0.0	0.0	567	1	0
0.0	0.0	0.0	70.6	57.8	53.0	43.4	16.8	48.0	43.4	16.8	50.9	17.9	0.0	917,208.7	0.0	687,906.5	0.0	28.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
0.0	0.0	0.0	70.6	57.8	53.0	43.4	16.8	48.0	43.4	16.8	50.9	17.9	0.0	917,208.7	0.0	687,906.5	0.0	28.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
0.0	0.0	0.0	70.6	57.8	53.0	43.4	16.8	48.0	43.4	16.8	50.9	17.9	0.0	917,208.7	0.0	687,906.5	0.0	28.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
0.0	0.0	0.0	70.6	57.8	53.0	43.4	16.8	48.0	43.4	16.8	50.9	17.9	0.0	917,208.7	0.0	687,906.5	0.0	28.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
0.0	0.0	0.0	70.6	57.8	53.0	43.4	16.8	48.0	43.4	16.8	50.9	17.9	0.0	917,208.7	0.0	687,906.5	0.0	28.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
0.0	0.0	0.0	70.6	57.8	53.0	43.4	16.8	48.0	43.4	16.8	50.9	17.9	0.0	917,208.7	0.0	687,906.5	0.0	28.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0

These two worksheets are identical in format but different in inputs used from the inputs worksheet and are comprised almost completely of one rather large table that starts from the leftmost column and calculates many different equations and if-then statements as it travels to the last column on the right. Here the program is taking the proper values that it needs from the inputs worksheet and plugs them into the necessary equations to calculate the energy required to operate this air handling unit and it’s corresponding pumps at each degree bin that has hours under it. The output and comparisons from these tables is shown in the Summary worksheet along with the results from the fan’s calculations of the workbook.

Summary

Figure 21: Screenshot of Summary Worksheet



Current Outputs	
Current Supply Fan Outputs:	
Supply Fan Brake Horse Power (BHP) =	46.2
Supply Fan Electricity Usage (kWh) =	301,471
Electric Cost to Run Supply Fan (per year) =	$21,102.98
Current Return Fan Outputs	
Return Fan Brake Horse Power (BHP) =	31.47
Return Fan Electricity Usage (kWh) =	205,549
Electric Cost to Run Return Fan (per year) =	$14,388.40
Current Total Fan Outputs	
Total Fan Brake Horse Power	77.62
Total Fan Electricity Usage (kWh) =	507,020
Total Electric Cost to Run Fans (per year)	$35,491.38
Current Cooling Coil Pump Outputs	
Cooling Coil Pump BHP =	8.34
Total Pump Energy Usage (kWh) =	68,069
Total Cooling Coil Pump Cost =	$4,764.84
Current Preheat Coil Pump Outputs	
Preheat Coil Pump BHP =	67.63
Total Preheat Coil Pump Energy Usage (kWh) =	789,869
Total Preheat Coil Pump Cost =	$55,290.80
Current Reheat Coil Pump Outputs	
Reheat Coil Pump BHP =	57.94
Total Reheat Coil Pump Energy Usage (kWh) =	677,027
Total Reheat Coil Pump Cost =	$47,391.92
Current Total Pump Outputs	
Total Pump BHP =	133.91
Total Pump Energy Usage (kWh) =	1,534,965.11
Total Pump Cost =	$107,447.56
Current Cooling Cost	
Total Ton-Hrs of Cooling =	753,077.72
Total Cooling Cost (per year) =	$35,394.65
Current Heating Cost	
Total Therms of Preheating =	80,347
Total Therms of Reheating =	60,261
Total Heating Cost (per year)=	$57,030.64
Current Water Usage	
Annual Gallons Used by Cooling Coil	72,295,461
Annual Gallons Used by Preheat Coil	838,911,025
Annual Gallons Used by Reheat Coil	629,183,268
Total Annual Gallons Used by Coils	1,540,389,754
Current Water Usage (in Liters)	
Annual Gallons Used by Cooling Coil	273,668,090
Annual Gallons Used by Preheat Coil	3,175,623,675
Annual Gallons Used by Reheat Coil	2,381,717,756
Total Annual Gallons Used by Coils	5,831,009,521
Total Current AHU Cost (per year)	$235,364.23

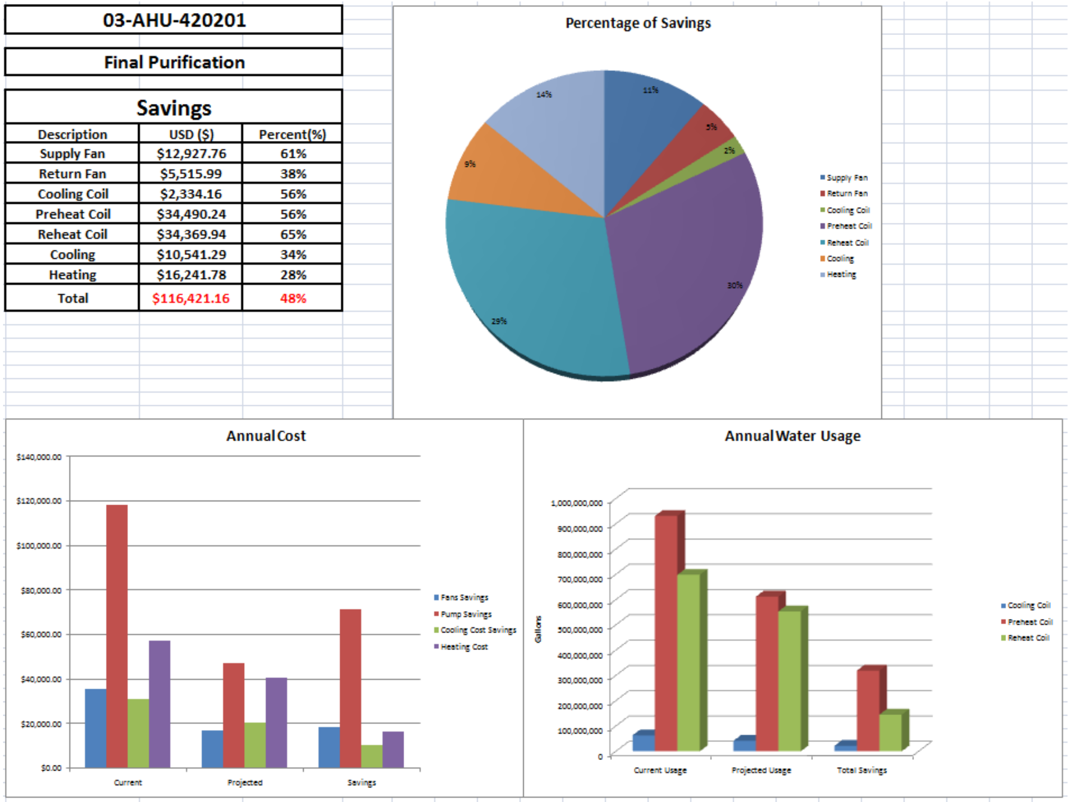
Projected Outputs	
Projected Supply Fan Outputs	
Supply Fan Brake Horse Power (BHP) =	17.88
Supply Fan Electricity Usage (kWh) =	116789
Electric Cost to Run Supply Fan (per year) =	$8,175.23
Projected Return Fan Outputs	
Return Fan Brake Horse Power (BHP) =	19.40
Return Fan Electricity Usage (kWh) =	126749
Electric Cost to Run Return Fan (per year) =	$8,872.41
Projected Total Fan Outputs	
Total Fan Brake Horse Power (BHP) =	37.28
Total Fan Electricity Usage (kWh) =	243538
Total Electric Cost to Run Fans (per year) =	$17,047.63
Projected Cooling Coil Pump Outputs	
Cooling Coil Pump BHP =	3.53
Total Pump Energy Usage (kWh) =	27,476
Total Cooling Coil Pump Cost =	$1,923.30
Projected Preheat Coil Pump Outputs	
Preheat Coil Pump BHP =	29.63
Total Preheat Coil Pump Energy Usage (kWh) =	346,080
Total Preheat Coil Pump Cost =	$24,225.62
Projected Reheat Coil Pump Outputs	
Reheat Coil Pump BHP =	20.09
Total Reheat Coil Pump Energy Usage (kWh) =	234,745
Total Reheat Coil Pump Cost =	$16,432.17
Projected Total Pump Outputs	
Reheat Coil Pump BHP =	53.26
Total Reheat Coil Pump Energy Usage (kWh) =	608,301
Total Reheat Coil Pump Cost =	$42,581.08
Projected Cooling Cost	
Total Ton-Hrs of Cooling =	455,964
Total Cooling Cost (per year) =	$21,430.30
Projected Heating Cost	
Total Therms of Preheating =	52,806
Total Therms of Reheating =	47,758
Total Heating Cost (per year) =	$40,788.86
Projected Water Usage	
Annual Gallons Used by Cooling Coil	43,772,536
Annual Gallons Used by Preheat Coil	551,352,151
Annual Gallons Used by Reheat Coil	498,642,885
Total Annual Gallons Used by Coils	1,093,767,572
Projected Water Usage (In Liters)	
Annual Gallons Used by Cooling Coil	165,697,075
Annual Gallons Used by Preheat Coil	2,087,094,927
Annual Gallons Used by Reheat Coil	1,887,568,652
Total Annual Gallons Used by Coils	4,140,360,653
Total Projected AHU Cost (per year)	$121,847.88

Savings	
Supply Fan Savings	
Supply Fan Brake Horse Power (BHP) =	28.27
Supply Fan Electricity Usage (kWh) =	184682
Electric Cost to Run Supply Fan (per year) =	$12,927.76
Return Fan Savings	
Return Fan Brake Horse Power (BHP) =	12.06
Return Fan Electricity Usage (kWh) =	78800
Electric Cost to Run Return Fan (per year) =	$5,515.99
Total Fan Savings	
Total Fan Brake Horse Power (BHP) =	40.34
Total Fan Electricity Usage (kWh) =	263482
Total Electric Cost to Run Fans (per year) =	$18,443.74
Cooling Coil Pump Savings	
Cooling Coil Pump BHP =	4.81
Total Pump Energy Usage (kWh) =	40,593
Total Cooling Coil Pump Cost =	$2,841.53
Preheat Coil Pump Savings	
Preheat Coil Pump BHP =	38.00
Total Preheat Coil Pump Energy Usage (kWh) =	443,788
Total Preheat Coil Pump Cost =	$31,065.19
Reheat Coil Pump Savings	
Reheat Coil Pump BHP =	37.85
Total Reheat Coil Pump Energy Usage (kWh) =	442,282
Total Reheat Coil Pump Cost =	$30,959.75
Total Pump Savings	
Reheat Coil Pump BHP =	80.66
Total Reheat Coil Pump Energy Usage (kWh) =	926,664
Total Reheat Coil Pump Cost =	$64,866.48
Cooling Cost Savings	
Total Ton-Hrs of Cooling =	297,114
Total Cooling Cost (per year) =	$13,964.35
Heating Cost Savings	
Total Therms of Preheating =	27,541
Total Therms of Reheating =	12,503
Total Heating Cost (per year) =	$16,241.78
Water Usage Savings	
Annual Gallons Used by Cooling Coil	28,522,925
Annual Gallons Used by Preheat Coil	287,558,874
Annual Gallons Used by Reheat Coil	130,540,383
Total Annual Gallons Used by Coils	446,622,182
Water Usage Savings (In Liters)	
Annual Gallons Used by Cooling Coil	107,971,016
Annual Gallons Used by Preheat Coil	1,088,528,748
Annual Gallons Used by Reheat Coil	494,149,104
Total Annual Gallons Used by Coils	1,690,648,868
Total AHU Savings (per year)	$113,516.35

This worksheet is where the program does a detailed numerical comparison between the current and proposed outputs. It shows the user how much energy is being used, how much money is being spent, how much energy can be saved, and how much money can be saved. The manner in which the evaluation is done by showing amount of kilowatt-hours, brake horsepower, and monetary cost that each individual mechanism involved in the air handling unit's design. Then a total fan, pump, cooling, and heating energy and monetary cost along with a water usage breakdown at the bottom for the coils are computed by simple addition between all the similar devices. A total cost for current and proposed settings is computed at the bottom of the first two columns while the third column is the savings for each row found by simple subtraction (current outputs – proposed outputs) and an overall savings box is shown in the bottom right-hand corner of the sheet.

Savings

Figure 22: Screenshot of Savings Worksheet



03-AHU-420201

Final Purification

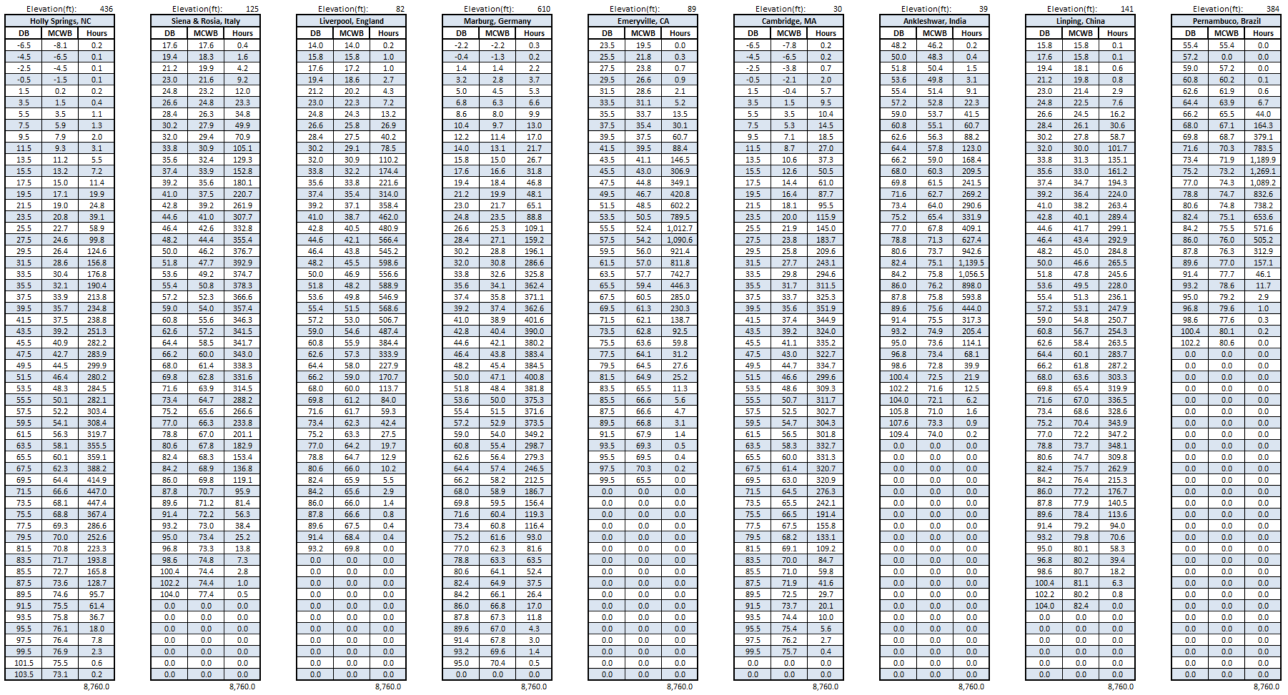
Savings

Description	USD ($)	Percent(%)
Supply Fan	$12,927.76	61%
Return Fan	$5,515.99	38%
Cooling Coil	$2,334.16	56%
Preheat Coil	$34,490.24	56%
Reheat Coil	$34,369.94	65%
Cooling	$10,541.29	34%
Heating	$16,241.78	28%
Total	$116,421.16	48%

The reason for the savings sheet is to allow the user to produce the findings of the simulation in one place and gives them the option of printing their findings out to present to the necessary people in the company. This is a valuable tool that will allow the Energy Site Managers in the Vaccines & Diagnosis Division of Novartis to justify the proposed settings changes to whomever they need to get the changes made. These simple graphs show all the information displayed on the summary worksheet in easy to understand pie and bar charts that not only stress the massive amount of energy and money spent on the air handling unit but show visually the amount of both that can be saved if the settings were changed to match that of the proposed settings.

Bin Data

Figure 23: Screenshot of Bin Data Worksheet



Elevation(ft):		436	Elevation(ft):		125	Elevation(ft):		82
Holly Springs, NC			**Siena & Rosia, Italy**			**Liverpool, England**		
DB	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**
-6.5	-8.1	0.2	17.6	17.6	0.4	14.0	14.0	0.2
-4.5	-6.5	0.1	19.4	18.3	1.6	15.8	15.8	1.0
-2.5	-4.5	0.1	21.2	19.9	4.2	17.6	17.2	1.0
-0.5	-1.5	0.1	23.0	21.6	9.2	19.4	18.6	2.7
1.5	0.2	0.2	24.8	23.2	12.0	21.2	20.2	4.3
3.5	1.5	0.4	26.6	24.8	23.3	23.0	22.3	7.2
5.5	3.5	1.1	28.4	26.3	34.8	24.8	24.3	13.2
7.5	5.9	1.3	30.2	27.9	49.9	26.6	25.8	26.9
9.5	7.9	2.0	32.0	29.4	70.9	28.4	27.5	40.2
11.5	9.3	3.1	33.8	30.9	105.1	30.2	29.1	78.5
13.5	11.2	5.5	35.6	32.4	129.3	32.0	30.9	110.2
15.5	13.2	7.2	37.4	33.9	152.8	33.8	32.2	174.4
17.5	15.0	11.4	39.2	35.6	180.1	35.6	33.8	221.6
19.5	17.1	19.9	41.0	37.5	220.7	37.4	35.4	314.0
21.5	19.0	24.8	42.8	39.2	261.9	39.2	37.1	358.4
23.5	20.8	39.1	44.6	41.0	307.7	41.0	38.7	462.0
25.5	22.7	58.9	46.4	42.6	332.8	42.8	40.5	480.9
27.5	24.6	99.8	48.2	44.4	355.4	44.6	42.1	566.4
29.5	26.4	124.6	50.0	46.2	376.7	46.4	43.8	545.2
31.5	28.6	156.8	51.8	47.7	392.9	48.2	45.5	598.6
33.5	30.4	176.8	53.6	49.2	374.7	50.0	46.9	556.6
35.5	32.1	190.4	55.4	50.8	378.3	51.8	48.2	588.9
37.5	33.9	213.8	57.2	52.3	366.6	53.6	49.8	546.9
39.5	35.7	234.8	59.0	54.0	357.4	55.4	51.5	568.6
41.5	37.5	238.8	60.8	55.6	346.3	57.2	53.0	506.7
43.5	39.2	251.3	62.6	57.2	341.5	59.0	54.6	487.4
45.5	40.9	282.2	64.4	58.5	341.7	60.8	55.9	384.4
47.5	42.7	283.9	66.2	60.0	343.0	62.6	57.3	333.9
49.5	44.5	299.9	68.0	61.4	338.3	64.4	58.0	227.9
51.5	46.4	280.2	69.8	62.8	331.6	66.2	59.0	170.7
53.5	48.3	284.5	71.6	63.9	314.5	68.0	60.0	113.7
55.5	50.1	282.1	73.4	64.7	288.2	69.8	61.2	84.0
57.5	52.2	303.4	75.2	65.6	266.6	71.6	61.7	59.3
59.5	54.1	308.4	77.0	66.3	233.8	73.4	62.3	42.4
61.5	56.3	319.7	78.8	67.0	201.1	75.2	63.3	27.5
63.5	58.1	355.5	80.6	67.8	182.9	77.0	64.2	19.7
65.5	60.1	359.1	82.4	68.3	153.4	78.8	64.7	12.9
67.5	62.3	388.2	84.2	68.9	136.8	80.6	66.0	10.2
69.5	64.4	414.9	86.0	69.8	119.1	82.4	65.9	5.5
71.5	66.6	447.0	87.8	70.7	95.9	84.2	65.6	2.9
73.5	68.1	447.4	89.6	71.2	81.4	86.0	66.0	1.4
75.5	68.8	367.4	91.4	72.2	56.3	87.8	66.6	0.8
77.5	69.3	286.6	93.2	73.0	38.4	89.6	67.5	0.4
79.5	70.0	252.6	95.0	73.4	25.2	91.4	68.4	0.4
81.5	70.8	223.3	96.8	73.3	13.8	93.2	69.8	0.0
83.5	71.7	193.8	98.6	74.8	7.3	0.0	0.0	0.0
85.5	72.7	165.8	100.4	74.4	2.8	0.0	0.0	0.0
87.5	73.6	128.7	102.2	74.4	1.0	0.0	0.0	0.0
89.5	74.6	95.7	104.0	77.4	0.5	0.0	0.0	0.0
91.5	75.5	61.4	0.0	0.0	0.0	0.0	0.0	0.0
93.5	75.8	36.7	0.0	0.0	0.0	0.0	0.0	0.0
95.5	76.1	18.0	0.0	0.0	0.0	0.0	0.0	0.0
97.5	76.4	7.8	0.0	0.0	0.0	0.0	0.0	0.0
99.5	76.9	2.3	0.0	0.0	0.0	0.0	0.0	0.0
101.5	75.5	0.6	0.0	0.0	0.0	0.0	0.0	0.0
103.5	73.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
		8,760.0			8,760.0			8,760.0

Elevation(ft):		610	Elevation(ft):		89	Elevation(ft):		30
Marburg, Germany			**Emeryville, CA**			**Cambridge, MA**		
DB	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**
-2.2	-2.2	0.3	23.5	19.5	0.0	-6.5	-7.8	0.2
-0.4	-1.3	0.2	25.5	21.8	0.3	-4.5	-6.5	0.2
1.4	1.4	2.2	27.5	23.8	0.7	-2.5	-3.8	0.7
3.2	2.8	3.7	29.5	26.6	0.9	-0.5	-2.1	2.0
5.0	4.5	5.3	31.5	28.6	2.1	1.5	-0.4	5.7
6.8	6.3	6.6	33.5	31.1	5.2	3.5	1.5	9.5
8.6	8.0	9.9	35.5	33.7	13.5	5.5	3.5	10.4
10.4	9.7	13.0	37.5	35.4	30.1	7.5	5.3	14.5
12.2	11.4	17.0	39.5	37.5	60.7	9.5	7.1	18.5
14.0	13.1	21.7	41.5	39.5	88.4	11.5	8.7	27.0
15.8	15.0	26.7	43.5	41.1	146.5	13.5	10.6	37.3
17.6	16.6	31.8	45.5	43.0	306.9	15.5	12.6	50.5
19.4	18.4	46.8	47.5	44.8	349.1	17.5	14.4	61.0
21.2	19.9	48.1	49.5	46.7	420.8	19.5	16.4	87.7
23.0	21.7	65.1	51.5	48.5	602.2	21.5	18.1	95.5
24.8	23.5	88.8	53.5	50.5	789.5	23.5	20.0	115.9
26.6	25.3	109.1	55.5	52.4	1,012.7	25.5	21.9	145.0
28.4	27.1	159.2	57.5	54.2	1,090.6	27.5	23.8	183.7
30.2	28.8	196.1	59.5	56.0	921.4	29.5	25.8	209.6
32.0	30.8	286.6	61.5	57.0	811.8	31.5	27.7	243.1
33.8	32.6	325.8	63.5	57.7	742.7	33.5	29.8	294.6
35.6	34.1	362.4	65.5	59.4	446.3	35.5	31.7	311.5
37.4	35.8	371.1	67.5	60.5	285.0	37.5	33.7	325.3
39.2	37.4	362.6	69.5	61.3	230.3	39.5	35.6	351.9
41.0	38.9	401.6	71.5	62.1	138.7	41.5	37.4	344.9
42.8	40.4	390.0	73.5	62.8	92.5	43.5	39.2	324.0
44.6	42.1	380.2	75.5	63.6	59.8	45.5	41.1	335.2
46.4	43.8	383.4	77.5	64.1	31.2	47.5	43.0	322.7
48.2	45.4	384.5	79.5	64.5	27.6	49.5	44.7	334.7
50.0	47.1	400.8	81.5	64.9	25.2	51.5	46.6	299.6
51.8	48.4	381.8	83.5	65.5	11.3	53.5	48.6	309.3
53.6	50.0	375.3	85.5	66.6	5.6	55.5	50.7	311.7
55.4	51.5	371.6	87.5	66.6	4.7	57.5	52.5	302.7
57.2	52.9	373.5	89.5	66.8	3.1	59.5	54.7	304.3
59.0	54.0	349.2	91.5	67.9	1.4	61.5	56.5	301.8
60.8	55.4	298.7	93.5	69.3	0.5	63.5	58.3	332.7
62.6	56.4	279.3	95.5	69.5	0.4	65.5	60.0	331.3
64.4	57.4	246.5	97.5	70.3	0.2	67.5	61.4	320.7
66.2	58.2	212.5	99.5	65.5	0.0	69.5	63.0	320.9
68.0	58.9	186.7	0.0	0.0	0.0	71.5	64.5	276.3
69.8	59.5	156.4	0.0	0.0	0.0	73.5	65.5	242.1
71.6	60.4	119.3	0.0	0.0	0.0	75.5	66.5	191.4
73.4	60.8	116.4	0.0	0.0	0.0	77.5	67.5	155.8
75.2	61.6	93.0	0.0	0.0	0.0	79.5	68.2	133.1
77.0	62.3	81.6	0.0	0.0	0.0	81.5	69.1	109.2
78.8	63.3	63.5	0.0	0.0	0.0	83.5	70.0	84.7
80.6	64.1	52.4	0.0	0.0	0.0	85.5	71.0	59.8
82.4	64.9	37.5	0.0	0.0	0.0	87.5	71.9	41.6
84.2	66.1	26.4	0.0	0.0	0.0	89.5	72.5	29.7
86.0	66.8	17.0	0.0	0.0	0.0	91.5	73.7	20.1
87.8	67.3	11.8	0.0	0.0	0.0	93.5	74.4	10.0
89.6	67.0	4.3	0.0	0.0	0.0	95.5	75.4	5.6
91.4	67.8	3.0	0.0	0.0	0.0	97.5	76.2	2.7
93.2	69.6	1.4	0.0	0.0	0.0	99.5	75.7	0.4
95.0	70.4	0.5	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		8,760.0			8,760.0			8,760.0

Elevation(ft):		39	Elevation(ft):		141	Elevation(ft):		384
Ankleshwar, India			**Linping, China**			**Pernambuco, Brazil**		
DB	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**	**DB**	**MCWB**	**Hours**
48.2	46.2	0.2	15.8	15.8	0.1	55.4	55.4	0.0
50.0	48.3	0.4	17.6	15.8	0.1	57.2	0.0	0.0
51.8	50.4	1.5	19.4	18.1	0.6	59.0	57.2	0.0
53.6	49.8	3.1	21.2	19.8	0.8	60.8	60.2	0.1
55.4	51.4	9.1	23.0	21.4	2.9	62.6	61.9	0.6
57.2	52.8	22.3	24.8	22.5	7.6	64.4	63.9	6.7
59.0	53.7	41.5	26.6	24.5	16.2	66.2	65.5	44.0
60.8	55.1	60.7	28.4	26.1	30.6	68.0	67.1	164.3
62.6	56.3	88.2	30.2	27.8	58.7	69.8	68.7	379.1
64.4	57.8	123.0	32.0	30.0	101.7	71.6	70.3	783.5
66.2	59.0	168.4	33.8	31.3	135.1	73.4	71.9	1,189.9
68.0	60.3	209.5	35.6	33.0	161.2	75.2	73.2	1,269.1
69.8	61.5	241.5	37.4	34.7	194.3	77.0	74.3	1,089.2
71.6	62.7	269.2	39.2	36.4	224.0	78.8	74.7	832.6
73.4	64.0	290.6	41.0	38.2	263.4	80.6	74.8	738.2
75.2	65.4	331.9	42.8	40.1	289.4	82.4	75.1	653.6
77.0	67.8	409.1	44.6	41.7	299.1	84.2	75.5	571.6
78.8	71.3	627.4	46.4	43.4	292.9	86.0	76.0	505.2
80.6	73.7	942.6	48.2	45.0	284.8	87.8	76.3	312.9
82.4	75.1	1,139.5	50.0	46.6	265.5	89.6	77.0	157.1
84.2	75.8	1,056.5	51.8	47.8	245.6	91.4	77.7	46.1
86.0	76.2	898.0	53.6	49.5	228.0	93.2	78.6	11.7
87.8	75.8	593.8	55.4	51.3	236.1	95.0	79.2	2.9
89.6	75.6	444.0	57.2	53.1	247.9	96.8	79.6	1.0
91.4	75.5	317.3	59.0	54.8	250.7	98.6	77.6	0.3
93.2	74.9	205.4	60.8	56.7	254.3	100.4	80.1	0.2
95.0	73.6	114.1	62.6	58.4	263.5	102.2	80.6	0.0
96.8	73.4	68.1	64.4	60.1	283.7	0.0	0.0	0.0
98.6	72.8	39.9	66.2	61.8	287.2	0.0	0.0	0.0
100.4	72.5	21.9	68.0	63.6	303.3	0.0	0.0	0.0
102.2	71.6	12.5	69.8	65.4	319.9	0.0	0.0	0.0
104.0	72.1	6.2	71.6	67.0	336.5	0.0	0.0	0.0
105.8	71.0	1.6	73.4	68.6	328.6	0.0	0.0	0.0
107.6	73.3	0.9	75.2	70.4	343.9	0.0	0.0	0.0
109.4	74.0	0.2	77.0	72.2	347.2	0.0	0.0	0.0
0.0	0.0	0.0	78.8	73.7	348.1	0.0	0.0	0.0
0.0	0.0	0.0	80.6	74.7	309.8	0.0	0.0	0.0
0.0	0.0	0.0	82.4	75.7	262.9	0.0	0.0	0.0
0.0	0.0	0.0	84.2	76.4	215.3	0.0	0.0	0.0
0.0	0.0	0.0	86.0	77.2	176.7	0.0	0.0	0.0
0.0	0.0	0.0	87.8	77.9	140.5	0.0	0.0	0.0
0.0	0.0	0.0	89.6	78.4	113.6	0.0	0.0	0.0
0.0	0.0	0.0	91.4	79.2	94.0	0.0	0.0	0.0
0.0	0.0	0.0	93.2	79.8	70.6	0.0	0.0	0.0
0.0	0.0	0.0	95.0	80.1	58.3	0.0	0.0	0.0
0.0	0.0	0.0	96.8	80.2	39.4	0.0	0.0	0.0
0.0	0.0	0.0	98.6	80.7	18.2	0.0	0.0	0.0
0.0	0.0	0.0	100.4	81.1	6.3	0.0	0.0	0.0
0.0	0.0	0.0	102.2	80.2	0.8	0.0	0.0	0.0
0.0	0.0	0.0	104.0	82.4	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		8,760.0			8,760.0			8,760.0

The last worksheet will never need to be viewed by any of the users since this is where the bin data for each site in the Novartis Vaccines & Diagnostics Division is stored for transfer onto the inputs worksheet based upon the button selected by the user. It is important to note that the bin data for each site is not calculated for that exact geographical location, but instead for the nearest weather station to the site's location.

7. RESULTS AND ANALYSIS

For the results, we analyzed the same Air Handling Unit (AHU) scenario at each Novartis Vaccines and Diagnostics site. The AHU information comes from an AHU located in Holly Spring, NC, USA called 03-AHU-421201, which is a Class C Adjuvant Production area currently with 40 Air Changes Per Hour (ACH). The information for the projected AHU scenario will be the same, except the number of ACH will be reduced from 40 to 25.

Table 18: Typical Air Handling Unit Current Information

AHU Description	Units	Current Value
AHU ID Number:	-	Sample
Area Used For:	-	Air Handling Unit
Design Airflow:	cfm	30,000
Outdoor Air:	%	50%
Outdoor Air:	cfm	15,000
Area Temperature (Dry Bulb):	°F	68.0
Area Temperature (Wet Bulb):	°F	56.8
Max. Allowable Area Temperature (Dry Bulb):	°F	72.0
Return Fan Inputs:	**Units**	**Current Value**
Return Fan Airflow:	cfm	15,000
Return Fan Static Pressure:	in H_2O	3.0
Return Fan Mechanical Efficiency:	%	60%
Supply Fan Inputs:	**Units**	**Current Value**
Supply Fan Airflow:	cfm	30,000
Supply Fan Static Pressure:	in H_2O	5.0
Supply Fan Mechanical Efficiency:	%	55%
Cooling Coil Inputs:	**Units**	**Current Value**
Temperature Off Cooling Coil:	°F	48
Chilled Water Temperature To Cooling Coil:	°F	40
Chilled Water Temperature From Cooling Coil:	°F	55
Pressure Drop in Cooling Coil	in H_2O	5.5
Pump Efficiency	%	90%
Preheat Coil Inputs:	**Units**	**Current Value**
Heating Water Temperature To Preheat Coil:	°F	135
Heating Water Temperature From Preheat Coil:	°F	105
Pressure Drop in Preheat Coil	in H_2O	4
Pump Efficiency	%	80%
Reheat Coil Inputs:	**Units**	**Current Value**
Heating Water Temperature To Reheat Coil:	°F	135
Heating Water Temperature From Reheat Coil:	°F	105

Pressure Drop in Reheat Coil	in H_2O	4
Pump Efficiency	%	90%

Table 19: Typical Air Handling Unit Proposed Information

AHU Description	**Units**	**Projected Value**
AHU ID Number:	-	Typical
Area Used For:	-	Air Handling Unit
Design Airflow:	cfm	18,750
Outdoor Air:	%	50%
Outdoor Air:	cfm	9,375
Area Temperature (Dry Bulb):	°F	68.0
Area Temperature (Wet Bulb):	°F	56.8
Max. Allowable Area Temperature (Dry Bulb):	°F	72.0
Return Fan Inputs:	**Units**	**Projected Value**
Return Fan Airflow:	cfm	9,375
Return Fan Static Pressure:	in H_2O	3
Return Fan Mechanical Efficiency:	%	60%
Supply Fan Inputs:	**Units**	**Projected Value**
Supply Fan Airflow:	cfm	18,750
Supply Fan Static Pressure:	in H_2O	5.00
Supply Fan Mechanical Efficiency:	%	55%
Cooling Coil Inputs:	**Units**	**Projected Value**
Temperature Off Cooling Coil:	°F	48
Chilled Water Temperature To Cooling Coil:	°F	40
Chilled Water Temperature From Cooling Coil:	°F	55
Pressure Drop in Cooling Coil:	in H_2O	5.5
Pump Efficiency:	%	90%
Preheat Coil Inputs:	**Units**	**Projected Value**
Heating Water Temperature To Preheat Coil:	°F	135
Heating Water Temperature From Preheat Coil:	°F	105
Pressure Drop in Preheat Coil	in H_2O	4
Pump Efficiency	%	80%
Reheat Coil Inputs:	**Units**	**Projected Value**
Heating Water Temperature To Reheat Coil:	°F	135
Heating Water Temperature From Reheat Coil:	°F	105
Pressure Drop in Reheat Coil:	in H2O	4
Pump Efficiency:	%	90%

Table 20: Yearly AHU Savings in North and South America

North and South America	
Yearly AHU Savings	
Description	USD ($)
Supply Fan	$29,430.80
Return Fan	$8,093.48
Cooling Coil	$6,919.07
Preheat Coil	$107,311.12
Reheat Coil	$60,362.29
Cooling	$42,052.07
Heating	$53,403.17
Total	$307,572.00

Table 21: Yearly AHU Savings in Europe

Europe	
Yearly AHU Savings	
Description	USD ($)
Supply Fan	$29,430.80
Return Fan	$8,093.48
Cooling Pump	$4,244.41
Preheat Pump	$68,059.25
Reheat Pump	$38,281.27
Cooling	$25,796.28
Heating	$53,314.40
Total	$227,219.89

Table 22: Yearly AHU Savings in Asia

Asia	
Yearly AHU Savings	
Description	USD ($)
Supply Fan	$14,715.40
Return Fan	$4,046.74
Cooling Coil	$4,754.90
Preheat Coil	$47,351.51
Reheat Coil	$26,634.88
Cooling	$28,898.88
Heating	$26604.21
Total	$153,006.52

Table 23: Total Yearly AHU Savings

Total Savings Comparison	
Region	Savings
North and South America	$307,572.00
Europe	$227,219.89
Asia	$153,006.52
TOTAL	$687,798.41

Figure 24: Graph of Total Savings by Region

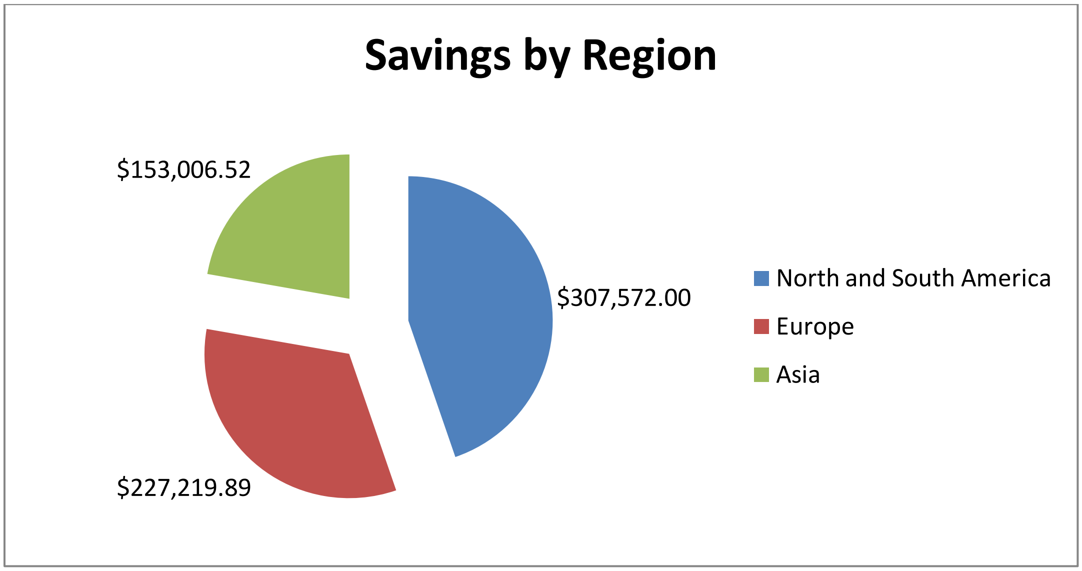


Table 24: Annual Water Savings

Annual Water Savings (In Gallons)	
Site	Total Savings
Emeryville, CA, USA	921,881,644
Holly Springs, NC, USA	397,420,991
Cambridge, MA, USA	370,801,449
Pernambuco, Brazil	1,143,376,857
Liverpool, England, UK	592,016,557
Rosia, Italy	396,874,625
Siena, Italy	396,874,625
Marburg, Germany	409,509,621
Ankleshwar, India	906,809,612
Linping, China	364,602,861
TOTAL	**4,978,287,198**

The results show amazing potential for reducing energy and utility costs in the Novartis Vaccines and Diagnostics Division based on the assumptions previously shown. On a yearly basis, the savings are approximately $69,000 per air handling unit which has the number of air changes reduced from 40 ACH to 25 ACH in Class C clean rooms. This is a very substantial figure, because there are multiple air handling units per site which this change can be applied to. On average, there are approximately five air handling units per site which this analysis can be applied to giving a rough estimate of a savings of almost $350,000 per site. If this number is applied to all ten of the Novartis Vaccines and Diagnostics sites, they can expect an annual savings of almost $3.5 million USD. This analysis can also be used for other scenarios such as reducing the number of air changes in a Class D room from 30 ACH to 20 ACH.

There is also a substantial amount of water savings that can be attributed to the same scenario, assuming the water is not reused in another part of the site for another process. On average, each site can save approximately 500 million gallons of water annually for each air handling unit. Using the same assumption as before that there are approximately 5 Class C air handling units per site, this gives a total of 2.5billion gallons of savings per site. If this change is applied across all 10 Novartis sites, that equals a total savings of over 25 billion gallons of water saved annually.

The amount of energy and utility savings for all 10 Novartis sites is a good reason for the company to pursue it further and to get the scenario approved by quality assurance. These changes can't be implemented until they are proven beyond a doubt that it won't affect production of final product.

8. CONCLUDING REMARKS

8.1 RECOMMENDATIONS

Our recommendations to Novartis when using this program are to not take the results as perfect representations of the money that can be saved given the modifications. There are a number of assumptions that we made when testing the tool. The first assumption is that we typically assumed that the air handling unit was incorporating 50% outdoor air into the system when many times it is about 100% because of the risk of cross-contamination. The amount of outdoor air used is dependent on what classification area the unit is operating on. Another assumption made for our results was that all the air handling units were the same, meaning they all had the same components and the only difference between them was the bin data representing the outdoor air conditions. Unfortunately we did not have enough time to get data for each individual site so we simply used one AHU from the Holly Springs, NC site and applied it to each site in the division. Lastly, the program does not take into account any irregularities that an AHU might have including ductwork imperfections, pressure losses, or any decrease in the mechanical systems efficiency that may have occurred do to it being constantly run since it was installed. We assumed that all the pieces of the system are working as if they were brand new, which we understand is not a good assumption to make, but it would have been nearly impossible for us to take into account since we could not travel to each site and inspect each unit. We did take a trip to visit the both the Siena and Rosia sites in Italy to receive a better understanding of the processes that they run in production and the type of HVAC systems that they were using. This was an enormous help to our project as it allowed us to see firsthand how some of the systems were run and gave us an opportunity to network with some of the employees in case we would require any information from them. This is how when came in contact with Alexander Mitrovic whose assistance in this study was invaluable.

` In conclusion, our program has great potential to save Novartis Vaccines & Diagnosis Division a lot of money on energy and utility costs. Unfortunately, the program was completed near the conclusion of the time allotted for our project so we have not had the opportunity to apply our energy calculator to more than just one air handling unit. Alexander Mitrovic, the Energy Site Manager at the Holly Springs site and one of our contacts in the company, has run some initial research regarding the money that can be saved by applying several modifications to the HVAC systems of Novartis could save $3.5 million across the entire division. With a least five Class C AHU's at each site, and our tool estimating that on average about $69,000 can be saved one just one unit, we believe that this is an attainable goal for the company. The importance of this tool lies in the graphs; with the Energy Site Managers applying the calculator to each of their respective sites and compiling their findings, we believe that convincing the proper people in the company's corporate office in Basil, Switzerland to change the settings on their divisions HVAC systems will only be the beginning of a company-wide shift in energy practices. It will be difficult for them to pass on the opportunity to save millions to use a tool that cost them nearly nothing to make.

8.2 DISCUSSIONS ON INDUSTRIAL ENGINEERING (IE) CAPSTONE REQUIREMENT

To complete the final objective of a fully-functional, user-friendly HVAC energy savings calculator, our project group used the engineering design process. ABET's definition of engineering design is:

> Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the

> basic science and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation.

Throughout the Novartis Energy and Utility Usage MQP, our group used weekly, and sometime semiweekly, teleconferences to communicate about the desired needs of the client. These meetings allowed us to present what we had researched/ learned/ completed over the past week and for Novartis employees to comment and give us feedback about what we were doing. This was very helpful because it allowed us to steer the project in the correct direction, without deviating from the final goal.

The project was initially an Energy Use Guide that would teach employees how to reduce energy and utility costs, but after researching many different energy saving topics, we learned that almost 65% of energy in the pharmaceutical industry is consumed by HVAC alone, which can be seen in Table ##. After further researching HVAC systems, we learned a way to optimize HVAC systems by reducing the number of hourly air changes (ACH). We alerted our contacts at Novartis about this and they supplied us with information about their HVAC systems and air-handling units. After communicating through teleconferences and email, we agreed the final objective of the project would be a fully-functional, user-friendly HVAC energy savings calculator for use in Microsoft Excel©.

We researched various ways to do the HVAC energy saving calculations, and the two methods that we found were the Temperature Degree Days (TDD) Method and the Temperature Bin Data Method. We proposed both ideas to the Novartis Employees and they liked the Temperature Bin Data Method because it is much more accurate for the use at multiple sites. The next step in the design process was to find a reliable source for the temperature bin data. We presented three computer programs during a teleconference and the decision was made to buy the ASHRAE program because it would be the most reliable, even though it was more expensive. All of the necessary data was then collected and we started to build the energy calculator in Excel. Every week we would present the progress to the Novartis employees and they would give us feedback on how we could improve the program and make it more user-friendly.

We faced many constraints along the engineering design process. These ranged from time constraints to location constraints to health and safety constraints to usability constraints. The MQP is very unique because it is a three term project that needs to be completed within approximately half a year. That is a very short amount of time to accomplish a project of this scale that will be used around the world. In order to meet the time constraint, proper planning and time management was needed. We used A-term mainly to research various energy and utility saving techniques. During B-term, we narrowed down the scope of our project to only HVAC systems and started to develop the energy calculator program. During winter break between B and C terms, we did minor revisions on the program, and worked mostly on getting the paper up-to-date. In C-term the program really started to come together. Every week we would have 2 teleconferences with our Novartis contacts, and each time they would give us great advice on how to improve our program which we would then present at the next teleconference. The second major constraint in our project was the location constraint because all of our Novartis contacts were spread across the globe, which made it difficult to have meetings. Eric and I were able to find time to schedule the meetings so that all necessary attendees were able to attend the meetings. Another location constraint that we had was that during C-term I was working full time from home which is approximately 30 minutes from Worcester. We had a lot of phone and email conversations, and I was able to travel to WPI on the weekends to accomplish work together. The third constraint that arose was the health and safety constraint. Novartis manufactures vaccines which are intended for human use. This means that the product must be top quality so that it doesn't make it's patients sick. The program that we created was intended to calculate the energy and utilities savings from reducing the number of air changes in clean rooms. This reduction could be very detrimental to the product quality if it is not validated and verified first that it won't affect final product. The usability was a constraint because the program would need to be usable at all Novartis V&D sites around the world. We decided to use Excel because it is a part of the Microsoft Office© package, which is widely used throughout the world. One of the constraints about this program was that we were designing it using Office 2007, and Novartis was only using Office 2003, so we had to make sure that the program would run smoothly in both the 2003 and 2007 versions.

After designing the final version of the energy calculator in Excel, we tested and implemented it to make sure there were no bugs, and that the program would run smoothly. During the testing, we asked our Novartis contacts to try the program out on their own computers which had Office 2003. The program worked very well on both Office 2003 and Office 2007 which was very good for us because Novartis was going to purchase Office 2007 in the upcoming fiscal year. One of the specific tests we did was to calculate the energy and utilities savings for each Novartis site by reducing the number of air changes in a Class C room from 40 ACH to 25 ACH. This testing is documented in the final MQP report.

This program will be a very useful tool for the Novartis V&D Global Energy Manager, Mr. Alexander Mitrovic, and for the Novartis V&D Site Energy Managers at all ten sites worldwide. Each Site Energy Manager will be able to calculate the amount of money and utilities that can be saved annually at each site by reducing the number of air changes in the clean rooms.

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