AIR MANAGEMENT TECHNOLOGIES, INC.

Building Energy & Environmental Services

www.airmanagement.com

CLEANROOMS FOR BAKING FACILITIES

WHITE PAPER

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Cleanrooms for Baking Facilities

There has been a significant industry push over the past several years to increase Food Safety and Quality through improvement of environmental conditions inside processing facilities. Primarily initiatives have focused on achieving proper building pressurization as a preventative measure to prevent molds and insects from infiltrating facilities in combination with improved air filter efficiency inside air handling equipment. While we agree these measures are extremely important and positive first steps - there are other variables which must to be considered. A food processing facility is a dynamic and interconnected environment. Careful analysis of environmental systems modifications are require to verify measures will be effective. An incorrectly applied measure even with the best of intentions may create some scenarios which actually decrease Food Safety and negatively impact process equipment performance. Our experience with design and construction applications for Industrial HVAC systems including Cleanrooms spans over 20-years - when a regional bakery requested an environmental system to "cool" a spiral bread cooler which was being enclosed. Conversations ensued where we discussed what the "ideal environment" to cool fresh bread would look like. From this request our Spiral Cooling System was developed - later evolving into our Spiral Product Conditioning System, a name change to better communicate it is much more than just temperature control.

Over the years enhancements have been made while the emphasis has remained the same; to provide the three "P's" consisting of a *Predictable* - *Protected* - *Performance* enhanced environment which supports your efforts in creating the perfect product. It is important to understand the terminology and application of environmental conditioning when discussing a typical baking facility. For your convenience we have provided a brief glossary immediately following this paragraph. Please note when the term "finished product" is used it refers to post-baked. From a microbial standpoint the oven in production applications in most cases represents a "kill zone".

<u>Cleanroom</u>

Cleanrooms provide the highest level of protection and standard of care for the finished product which also represents the highest financial investment. System design begins at the oven outlet or after de-panning depending on the application and extends through the cooling process all the way into packaging area product has been wrapped. When considering this a Cleanroom, entry and exit openings must to be considered for pressurization and if associate movement may cause contamination. In most layouts the packaging area is connected to the shipping dock. Frequently the shipping dock is one of the "dirtiest" environments, especially if the overall facility is not properly pressurized to the outdoors. Proper engineering analysis must analyze potential for tramp air movement through the Cleanroom between shipping and oven areas – zones which are normally maintained at a negative pressure in relationship to adjoining spaces.

<u>Spiral Product Conditioning</u>

A Spiral Product Conditioning System provides a lower level of overall protection than the Cleanroom because it cannot protect the product outside of the spiral cooler enclosure. However when you consider roughly 95% of the time from post-bake to packaging resides inside the cooler, this system provides an economical alternative which balances the Food Safety and Product Consistency benefits between an industrial Cleanroom environment and open ambient "coolers". For more than two decades the Spiral Product Conditioning System has been our most commonly installed system in wholesale bakeries. The system was significantly upgraded in 2019 to help you meet "Cleanroom" level conditions inside the cooler enclosure along with additional flexibility which can lower overall rigging and installation costs. Note while use of the word "spiral" designates a specific type of cooler, this system may be applied to overhead racetracks, step coolers, rack systems, or any system which may be enclosed. As a primary component for bakery Cleanroom systems, Spiral Product Conditioning also provides step-one in a phased approach should a full Cleanroom standard of care be required in the future.

<u>Refrigerated</u>

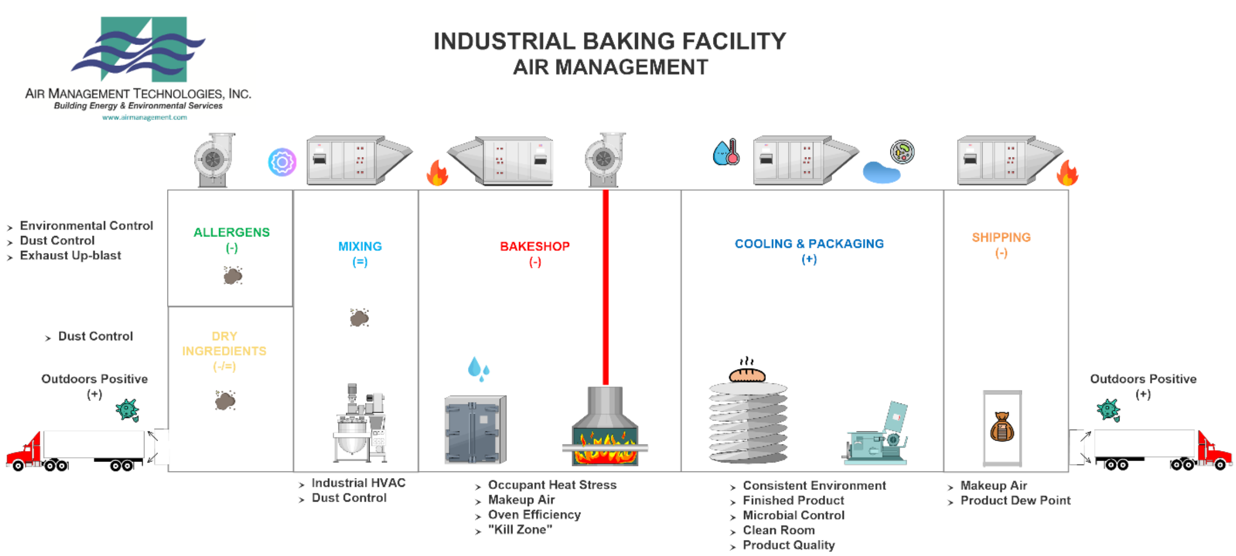
Our reference to "Refrigerated" is any mechanical cooling system with the primary objective of cooling product to a specific outlet temperature only. Refrigerated systems normally include either wall hung evaporators or fan walls installed inside the actual cooler, or air handling systems which do not incorporate other environmental control provisions such as enclosure pressurization and enhanced air filtration. Such systems may become a detriment to environmental quality when regular proper sanitation is not performed. The combination of thick cooling coils and wet surfaces combined with a nutrient (bread) is a recipe for mold growth. Frequently these systems operate at a lower air temperature than Cleanroom or Spiral Product Conditioning systems. These lower temperatures may increase product drying and surface skinning while consuming significantly higher amounts of energy.

Ambient

Our reference to "Ambient" cooling is based on systems which are designed to provide product cooling through air exchange only methods. Such ambient air exchange is subject to changes in the facilities environmental conditions that vary depending on the time of day and/or season. These systems are normally simplistic with the primary component being exhaust to remove heat and moisture released from the product. Since the coolers are not enclosed some of the heat and moisture impacts occupant comfort inside the bakery. This has been the basic standard in the baking industry for many years and are still used in many facilities. When considering the evolution of the industry with emphasis on Food Safety and Quality, ambient systems are being phased-out. Positive space pressurization requirements are replacing the "old days" where operating under a negative pressure allowed uncontained raw air infiltration from the dock areas, through gravity dampers, building cracks, or anywhere the exhaust could be made up. As a stop-gap measure to reduce uncontained air infiltration, filtered makeup air systems are incorporated into the ambient system to balance cooler exhaust loads. The associated energy costs can be extreme when considering twice the airflow must be used compared to other methods along with the required heating and/or cooling impacts associated with using 100% outside air. Additionally ambient systems require a higher overall total airflow which means more airborne particulates entering the facility.

Industrial HVAC

Industrial HVAC (Heating, Ventilation, and Air Conditioning) is a term which will be used but is a separate subject which relates to environmental systems and control for the entire facility. Industrial HVAC will be referenced but not discussed in depth to avoid potential for confusion as this document focuses on product Food Safety and Quality post-bake to packaging. It is critical facilities how Industrial HVAC impacts the direct environment product is exposed to and thus the product itself. This is especially important in the case of ambient cooling which was outlined in the prior paragraph. Extending beyond creating the perfect environment for product with *Predictable - Protected – Performance*, whole facility space pressurization control is essential for combustion and other process equipment to operate to specification. Industrial HVAC also addresses the environmental health and safety aspects of the facility with a focus on occupant heat stress and respiratory sized particulates. Certain geographic climactic zones necessitate the need for mechanical cooling in lieu of ventilation and air exchange as outdoor conditions may exceed OSHA heat stress limitations – a situation where no amount of air exchange can be beneficial. It is also important to recognize that increased air exchange increases the total amount of microbials and particles entering a facility. Consider use of filter media with about 95% particulate efficiency still allows 5% to pass into the bakery. 200,000 cfm of total outdoor air exchange will allow double the infiltration 100,000 cfm, all other factors being equal.



While in a perfect world the entire food processing facility would be tightly temperature and pressurization controlled with the highest levels of filtration, as an investment it usually makes the most sense focus increased standard of care in areas where finished product exposure takes place. Focusing on the areas where baked product is exposed is similar to a hospital, where the greatest filtration, temperature, and space controls are in critical areas such as an operating rooms. It would not make much sense to control the gift shop at the same level, right? Please keep in mind if areas cannot be enclosed, for the most part it will be challenging and next to impossible to maintain a different environment from the rest of the plant.

Cleanroom System Impact

FoodTherm Inc. Food Process • Thermal & Energy Solutions

Air Management Technologies, Inc.

Customer:		**Cooling Degree Days 65F**	864	**Electric Cost kWh**	$0.060	**Date:**	3/20/2020
Location:	Chicago, IL	**Heating Degree Days 65F**	6,209	**Natural Gas $MCF**	$5.00		

Space Input Data		
Space Name	Cleanroom Bread Cooling	
System Type	Cleanroom	
Length	100.0	Ft
Width	60.0	Ft
Height	26.0	Ft
Gross Floor Area	6,000	Ft^2
Gross Volume	156,000	Ft^3
Fixed Opening(s)	10	Ft^2
Variable Opening(s)	100	Ft^2
	5%	% Open
Space Pressure Differential	0.030	InWC
Space Internal Heat Gains	900,000	SBTUH
	315,000	LBTUH
	101	Tons

Space Airflow Design Data		
Supply Air Conditions	40,000	SCFM
	65	°F
	95%	RH
	15.4	ACH
Outside Air Conditions	100%	%
	40,000	SCFM
	15.4	ACH
Space/Return Air Conditions	0	SCFM
	86	°F
	47%	RH
	63.0	DP °F
Exhaust Airflow	(29,595)	SCFM
Space Relief/Intake Airflow	(10,405)	SCFM

System Air Filtration Levels						
Filtration MERV Ratings	Stage 1	8	Stage 2	15	Stage 3	0
Energy & Maintenance		$4,015		$15,075		$0

1. Filter replacement based on Stage 1 (12x), Stage 2 (6x) and Stage 3 (2x) per year.

Particulate Loading Raw						
Location	0.3 micron (ug/m^3)	0.5 micron (ug/m^3)	1.0 micron (ug/m^3)	2.5 micron (ug/m^3)	5.0 micron (ug/m^3)	10.0 micron (ug/m^3)
Outside Air Conditions	8.40	2.58	2.30	12.65	49.92	31.43
Space Generation Rate Hr.	0.00	0.00	0.00	0.00	0.00	0.00
Neighboring Spaces	4.81	2.64	6.32	15.87	13.65	8.32

System Air Filtration & Dilution Impact						
Location	0.3 micron (ug/m^3)	0.5 micron (ug/m^3)	1.0 micron (ug/m^3)	2.5 micron (ug/m^3)	5.0 micron (ug/m^3)	10.0 micron (ug/m^3)
	E1		E2		E3	
	Virus & Smoke		Milled Flour		Mold Spores	
Mixed Air Conditions	8.40	2.58	2.30	12.65	49.92	31.43
System Air Filtration Impact	1.26	0.39	0.18	1.01	0.75	0.47
	85.0%	85.0%	92.0%	92.0%	98.5%	98.5%
Space Air Content Lbs.[1]	1.26	0.39	0.18	1.01	0.75	0.47

1. Space Air Loading is based on loading dilution due to air exchange rate.

Finished Product Exposure (Molds E3)							
Oven/Depanner		Cooling		Packaging		Total	
Time	(ug/m^3)	Time	(ug/m^3)	Time	(ug/m^3)	Time	(ug/m^3)
1.0	0.61	60.0	0.61	1.0	0.61	62.0	0.61

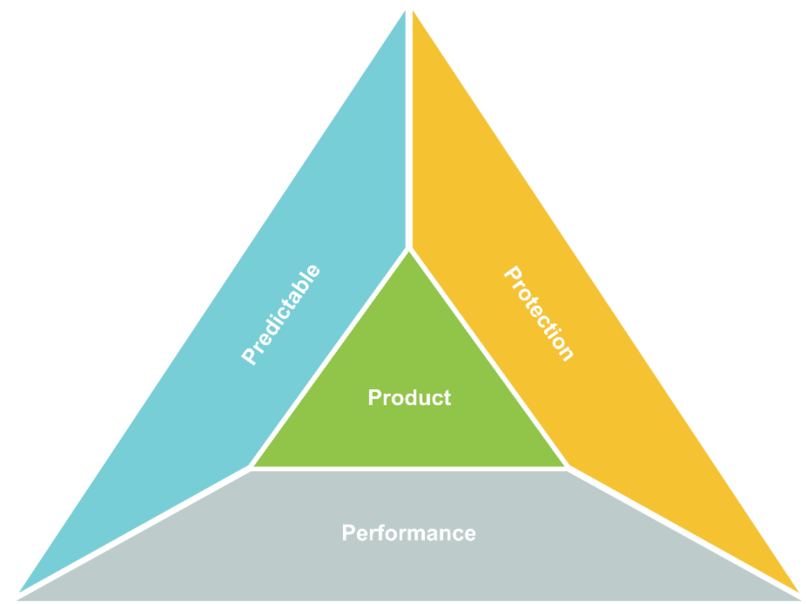
Sustainability & Energy Cost Impact							
Fan		Cooling		Heating		Total	
Energy	Carbon	Energy	Carbon	Energy	Carbon	Energy	Carbon
$9,179	161	$9,692	170	$35,929	420	$54,800	751

Cleanroom ISO pressurization requirements of 0.03" WC or (700 FPM) are normally the low standard between points of separation. In the example above which assumes the enclosure has an open man door associates are moving through and a variably open high speed door, approximately 19,000 cfm would be rushing through the openings which must be made up to maintain pressurization. Even a single open man door would require an additional 15,000cfm of filtered and conditioning makeup air to maintain goal pressurization. It is simply not practical for large openings in a Cleanroom enclosure. One of the reasons why our Spiral Product Conditioning systems have been so popular is only inlet and outlet conveyor openings need to be considered for pressurization losses.

Cleanrooms and Spiral Product Conditioning systems share similar benefits. Both have primary objectives focused on managing the 3-P's of *Predictable - Protected - Performance* to create the perfect environment for Food Safety and Quality. While evaluating the difference between Cleanrooms and Spiral Product Conditioning systems, risk tolerances in relation to finished product exposure time and particulate concentrations should be a primary consideration.

Exposure Rate $= ((C^t/T^t) \times C^e) + ((O^t/T^t) \times O^e) + ((P^t/T^t) \times P^e)$

C^t = Cooling Time Minutes
O^t = Oven Time to Cooler Minutes
P^t = Packaging to Cooler Minutes
T^t = Total Time from Oven to Packaging
C^e = Cooler Ambient Exposure
O^e = Oven Area Ambient Exposure
P^e =Packaging Area Ambient Exposure



Product

Intelligent design of environmental control systems should begin with the product and focus on how to provide the optimum solution to meet the time / temperature requirements while also enhancing food safety. Frequently the process starts with a discussion regarding throughputs and how much refrigeration to "cool" it. Instead the design criteria should be based on macronutrients, moisture percentages, and product geometry. Twenty plus year of bakery product cooling experience has provided us the tools to accurately calculate how a specific product will respond to different environments. When a new product is unique to our data base an onsite visit or testing in our environmental chamber is required to verify our provided Guaranteed Solution. It is critical to understand how outside air conditions may impact product quality - especially in colder winter climates where humidity can be almost non-existent. Low humidity may cause increased moisture removal and crusting. In colder, drier climates the ability to directly or indirectly manage cooler humidity is essential to maintaining product quality.

Predictable

Climatic Design

Understanding geographic climatic conditions is extremely important when designing conditioning systems since it may be a detriment or benefit depending on dwell time and product mix. Predictable performance regardless of seasonal temperature and humidity variabilities along with understanding of how these variables impact performance is highly significant to finished product quality. This is especially important for companies that have a national or worldwide footprint with a desire to produce the same product in different locations using the same standards and formulations.

Consistency

Since a large percentage of product cooling is based on time and temperature requirements, conditioning systems must be designed to limit variability that can result with different product loading and types. Intelligent design incorporates discharge air control with reset based on product loading is used rather than typical strategies of trying to maintain space temperature - which are commonly subject to variability. Humidity also plays a large part in product heat loss and is one of the reasons why product temperatures can actually be reduced in some cases even below the ambient dry bulb conditions as moisture loss in the air stream has an evaporative cooling impact on the product.

Humidity Control

Humidity control is typically controlled through indirect means by recycling a portion of the moisture released from the product during the cooling process during the colder months. This prevents excessive moisture removal and product quality issues. In unique circumstances, direct humidity control can be provided when an added degree of precision is required. Direct humidification in coolers may utilize adiabatic or isothermal humidification sources.

Air Exchange

Enclosure air exchange rates are maintained to minimize stratification between the various levels of the cooler. This is accomplished by maintaining an air pathway which promotes supply air around the perimeter of the cooler while returning/exhausting air from the upper middle. The air exchange rate can be adjusted depending on loading and different product types. Additionally a certain percentage of outside air is always exchanged to maintain pressurization requirements and dilute air conditions.

Air Velocity

Supply air distribution is equipped with air deflectors which provide air velocity management. In most bakery applications, low air velocities are desired around the perimeter to prevent excessive surface moisture removal – a concern as it can cause crusting and product quality issues. When increased velocities are desired for additional moisture and / or heat removal the deflectors may be adjusted accordingly.

Protection

Enclosures

Enclosures provide security and demonstrate you are serious about Food Safety and Quality. Without an enclosure product cannot be protected nor have sufficient environmental control to maintain consistency regardless of external conditions. Construction is typically Insulated Metal Panels (IMP). In difficult applications where it's not practical to construct a room, fabric enclosures and other methods may be used. A sufficiently pressurized enclosures will also protect the product by preventing airborne particulates and insects is from entering the exposed product zone. Care should be taken to limit the number of both variable and fixed enclosure openings required for space access, and how any occupants, materials and equipment will impact the protected space zone.

In cases where building constraints may require using the existing facility envelope as part of the enclosure, extreme care must be taken - especially in colder climates. If air temperatures cause surfaces to fall below dew Point, condensation may result in molds and building envelope damage. It is also important to control exfiltration from these spaces since the air may contain some compounds which are corrosive along with undesirable humidity impacts.

Space Pressurization

The protected space is typically managed under a positive pressure which protects the environment from molds, insects and unwanted particulates from the general facility. This is carefully managed to prevent infiltration from the plant but not to the extent where product handling issues may arise.

Space Pressure Differrential Airflow							
Inches Water Column Differential	0.01	0.03	0.05	0.07	0.09	0.11	0.13
Feet Per Minute Velocity (FPM)	401	694	896	1,060	1,202	1,328	1,444
Cubic Feet Per Minute Per 10Ft^2	4,005	6,937	8,955	10,596	12,015	13,283	14,440
Mile Per Hour Wind Velocity (MPH)	4.6	7.9	10.2	12.0	13.7	15.1	16.4

Air Filtration

Air filtration should be enhanced where it is needed most to protect the finished product. The table below provides an overview of the typical particulate sizes and Minimum Efficiency Reporting Values (MERV). Mold size particles are normally in the 2.5-10-micron range. This is important since the cost of increased air filtration is more than just the direct cost – there are also significant initial capital and energy consequences. In most cases, MERV-13 or higher filtration is used and prefilters are recommended on outside air intake filtration. This works to prevent entry of outdoors airborne contaminants and insects from entering the mixing box sections and making their way into the facility.

It is important to use air filtration which is resistant to high moisture levels and will not support microbial growth. Linked air filtration should be used when possible in lieu of standard air filters to prevent the bypass of air between filters. When this is not possible, filters should be sealed with adhesives or a similar food safe technique to prevent air bypass. In most cases, HEPA filtration (MERV-18/19) is not required for most Food applications but when it is desired it is important to have appropriate pre-filtration to minimize particulate loading.

TECHNICAL INFORMATION SERIES

FILTER SELECTION GUIDE

Modified Table E-1 from ASHRAE 52.2-2017 APPLICATION GUIDELINES

Standard 52.2 Minimum Efficiency Reporting Value (MERV)	Approx. Std 52.1 Results		Application Guidelines	
	Dust Spot Efficiency	Arrestance	Typical Controlled Containment	Typical Applications and Limitations
	n/a	n/a	**≤0.30 μm Particle Size** Virus (unattached) Carbon dust Sea salt All combustion smoke Radon progeny	Cleanrooms Radioactive materials Pharmaceutical manufacturing Carcinogenic materials Orthopedic surgery
16 15 14 13	n/a >95% 90-95% 80-90%	n/a n/a >98% >98%	**0.30-1.0 μm Particle Size** All bacteria Most tobacco smoke Droplet nuclei (sneeze) Cooking oil Most smoke Insecticide dust Copier toner Most face powder Most paint pigments	Hospital inpatient care General surgery Smoking lounges Superior commercial buildings
12 11 10 9	70-75% 60-65% 50-55% 40-45%	>95% >95% >95% >90%	**1.0-3.0 μm Particle Size** Legionella Humidifier dust Lead dust Milled flour Coal dust Auto emissions Nebulizer drops Welding fumes	Superior residential Better commercial buildings Hospital laboratories
8 7 6 5	30-35% 25-30% <20% <20%	>90% >90% 85-90% 80-85%	**3.0-10.0 μm Particle Size** Mold Spores Hair spray Fabric protector Dusting aids Cement dust Pudding mix Snuff Powdered milk	Commercial buildings Better residential Industrial workplaces Paint booth inlet air

UVC Lighting

Our systems normally incorporate Ultraviolet Lighting to protect the cooling coils and drain pans inside air handling units from microbial growth. Growth can occur in as little as 24-hours and unit sanitation periods may not be that frequent. For mold to grow it requires three primary ingredients which include moisture-absence of light-nutrient. UV-Lighting cuts off a key element by providing light and by blanketing this section reduces the potential for mold growth. UV Space Mounted Germicidal Lighting can also be applied inside enclosures for direct product contact although it has some limited impact and inherent pitfalls which need to be considered.

Post-Wrap

What happens before wrap has a major impact on how the finished product will respond after wrapping. Finished product temperature and moisture content management is important to product quality and shelf life. “Warm” product may represent product with higher moisture content and when placed inside packaging, it can become like a “Greenhouse” and not in a good way! This condition becomes even more of a concern during Fall periods when molds may be high and cold delivery trucks and loading docks may approach dew Point inside of the wrapper.

Performance

Equipment Design

Sanitary Design is the first requirement which needs to be considered when selecting air handling equipment. In food processing applications equipment must have enough access provisions to allow proper sanitation in a timely manner along with and water management to prevent molds growth. Stainless Steel interior liner wall panels provide a sanitary finish and the insulated metal panel walls must provide enough thermal break to prevent condensation of the moist airstream. Curbs and penetrations must have voids filled with foam to prevent any harborage areas and to manage the positive pressure and potential impact to adjoining structures.

Air Distribution

Space air distribution is available in several forms, but all options consider sanitary design elements for the application. When ducting is required every effort is made to avoid flat surfaces (round duct). In cases where enough space exists over the top of the cooler, a pressurized plenum is used to facilitate ease of air balance and access where a team member can enter and clean like wiping down a wall with no special tools. Stainless steel air distribution is also an option when enough space does not exist on top the cooler but there is room around the sides of the cooler. When mechanical cooling is required, double wall construction is used to prevent condensation. Fabric Duct is another option with the advantage of that it may be exchanged with a spare set during a typical down day, the “dirty” cleaned through a commercial laundry. Additionally fabric duct fits in tight spaces for cooler access and can be deflated to gain access.

Cooling Coil Design

In applications which mechanical cooling, the evaporator “cooling” coils are a common area for failure in the baking industry due to the corrosive properties released from bread cooling. Some designs may require stainless steel construction to prolong coil life. In most cases however, when operating with our proprietary logic, copper coils with copper fins can be installed which have greatly increased heat transfer capabilities which reduces initial capital and long-term operating cost. In most cases, Standard HVAC equipment cooling coils are not capable of handling the large moisture loads which are part of the cooling process. This results in molds and substandard operation. Equipment must be designed to manage this high transfer of latent heat.

Control

Temperature control is the basis of design although when dealing with moisture sensitive processes airstream humidity ratio is used for process control. Systems are available with both Honeywell and Allen Bradley Controls and have graphic interfaces, alarm outputs, and remote communications. Filtration and motor status outputs are provided. Space particulate measurement communicates the air filtration system is operating properly and is recommended for performance verification requirements.

Energy Savings

Since sustainability and energy savings are part of our very core, our system uses special control logic which provides operation with energy cost at only a fraction of refrigerated and ambient cooling systems. This design considers the impact of product moisture loss which is a significant load. Often the air stream is exhausted rather than recirculated for energy savings and decreased equipment requirements which results in electrical energy savings as well. Fan energy is reduced using variable frequency drives adjusting speed based on product load and environmental factors.

In many cases the cooling requirements for Cleanrooms and Spiral Conditioning Systems can be satisfied by existing glycol refrigeration systems that serve mixers and other process requirements. This is accomplished with Thermal Energy Storage which transfers unused capacity from the glycol mixer refrigeration system and stores it in an “ice bank”. This energy can then be drawn as needed to satisfy mechanical cooling requirements without the need for additional equipment. For over 25-years we have applied this technology in various business sectors including the baking industry with excellent results. In many cases utility rebates may be available to offset cost as part of a demand side management strategy.

Food Safety & Quality Benefit Assessments

Food Safety and Quality benefits are achieved through Cleanrooms and Spiral Conditioning Systems may differ for each application and organization. For this reason, we have provided a comparative analysis to assist in this assessment. Our Guaranteed Solutions Comparative Analysis is based on a Breadline located in Chicago that has a production rate of 10,000 lbs./hr. and product investment is estimated at $0.50 per lb. Utility cost are based on $.06kWh and $5.00 per MCF of Natural Gas.

Guaranteed Solutions Comparative Snapshot

	Cleanroom	Spiral Conditioning	Refrigerated	Ambient
Sustainability Impact				
Emissions GHG/Tons	63	50	50	94
Refrigerant GWP/Tons	171	114	379	0
Stewardship Allowance	$0	$0	$0	$0
Energy Cost				
Fan	$4,770	$3,816	$3,816	$7,156
Cooling	$4,430	$2,954	$56,000	$0
Heating	$0	$0	$0	$2,385
Operating Cost				
Production Efficiency	$0	$0	$0	$0
Sanitation & Maintenance	$10,000	$7,500	$10,000	$5,000
Food Safety & Quality				
Predictiable & Protective	Best	Better	Good-Fair	Fair
Quality-Waste-Value Benefit	0.30%	0.20%	0.10%	0.00%
Financial Impact Annual Benefit[1]	($120,000)	($80,000)	($40,000)	$0
Financial				
Capital Investment	$1,075,000	$775,000	$575,000	$300,000
Capital Avoidance	$300,000	$300,000	$300,000	$0
Incentives	$0	$0	$0	$0
Capital Comparison	$775,000	$475,000	$275,000	$300,000
Cost Bias				
First Year Investment	$674,201	$409,270	$304,816	$314,541
Annual Operating Cost	($100,799)	($65,730)	$29,816	$14,541
Simple Return on Investment %	15%	16%	-10%	-5%
Life Cycle Years	15	15	15	15
Life Cycle Investment	($736,987)	($510,950)	$722,246	$518,115
Investment Impact Cost Lb.	($0.0006)	($0.0004)	$0.0006	$0.0004

We want to thank you for taking the time to examine our White Paper on Cleanrooms for Food Processing and hope that the information was beneficial. We look forward to hearing from you and please feel free to contact us with any questions or comments.

THANK YOU!

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