A SunCam online continuing education course

Heat Load Calculations for Refrigerated Spaces

by

Jeffrey K. Welch, P.E.

Date:
Name : Joe Cool
Company : XYZ Cold Storage
From : Pete Caliente
Ref : Main Freezer Whse

REFRIGERATED SPACE HEAT LOAD ESTIMATE

CAUTION: USE ENGINEERING JUDGEMENT- GOOD DATA=GOOD ESTIMATE

Room Temperature	-10	°F

Ver. 1.0

TRANSMISSION LOAD

Wall	Length/Height	Insulation Material	Thickness	K-Value	Outside Temp	Solar Factor	ΔT	Heat Transfer
	(ft)		(in)	BTU-in/hr-ft²-F	(F)	(F)	(F)	BTU/day
North	200	Polyisocyanurate	4	0.19	95	0	105	718,200
East	225	Polyisocyanurate	4	0.19	95	4	109	838,755
South	200	Polyisocyanurate	4	0.19	95	2	107	731,880
West	225	Polyisocyanurate	4	0.19	95	4	109	838,755
Ceiling	30	Polyisocyanurate	5	0.19	40	20	70	2,872,800

Location	Area	Construction Material	Thickness	F-Factor	Ground Temp	Solar Factor	ΔT	Heat Transfer
	(ft²)		(in)	BTU/hr-ft²-F	(F)	(F)	(F)	BTU/day
Floor	45,000	8" Concrete & 6" Exp. Styrene	-	0.84	45	-	55	2,079,000
Total Transmission Load			**8,079**	**kBTU/day**	**28.05**	**Tons**	**30%**	

INFILTRATION LOAD

Properties of Moist Air	Temperature	Rel. Humidity	Enthalpy	Specific Vol.
	(°F)	%	BTU/lba	ft³/lba
Infiltrated Air	45	70	15.558	12.812
Refrigerated Room Air	-10	80	-2.012	11.343
Average Door Opening Time	23.148	min/hr		
Heat Removed per Cubic Foot of Air	1.371	BTU/ft³		
Number of Air Changes per Day	1.456	#/day		
Total Infiltration Load	**2,695**	**kBTU/day**	**25.71**	**Tons**	**27%**

PRODUCT LOAD

Product Name or Description	Chicken			
Product Loading Rate per Day	1,000,000	lbs/day		
Entering Product Temperature	0	°F		
Final Product Temperature	-10	°F		
Specific Heat above and below Freezing	0.8	BTU/lb-F	0.42	BTU/lb-F
Number of Day(s) / Hr(s) for Pulldown	1.00	days	24	hrs
Room Volume	1,350,000	ft³		
Product Loading Density	15	lbs/ft³		
No Product Respiration Heat	0	BTU/24-hr		
Total Product Load	**4,200**	**kBTU/day**	**14.58**	**Tons**	**16%**

MISCELLANEOUS LOAD

Number of People in Room	2	-		
Equivalent Heat per Person	34,178	Btu/24-hr		
Lighting Load	1	Watts/ft²	3,685,111	BTU/day
Number of Forktrucks in Room	2	-		
Horsepower per Forktruck	10	HP		
Miscellaneous Motor Load in Room (not air units)	0	HP		
Approximate Fan Horsepower from Air Units	25.000	HP		
Motor Load Equivalency	3,329	BTU/hr-HP		
Total Miscellaneous Load	**7,315**	**kBTU/day**	**25.52**	**Tons**	**27%**

TOTAL LOAD	93.87	Tons

10% Safety Factor + Total Load	103.25	Tons
Cubic Foot per Ton of Refrigeration	13,074	ft³/Ton
Square Foot per Ton of Refrigeration	436	ft²/Ton

Overview of This Course

The intent of this course is to provide the background knowledge required to calculate the heat load of a refrigerated space (typically between 40ºF to -40ºF).
It will break the heat load into four components:

Transmission Load –sensible heat gain through the floor, walls and roof from the temperature difference across these surfaces.

Infiltration Load –sensible and latent heat that carried into the refrigerated space from the air exchange through the door openings.

Product Load –heat removal required to lower the incoming product to the space temperature in a given amount of time.

Miscellaneous Load –load from lights, people and equipment in the space.
A spreadsheet will be provided with the course that will have a tab covering each of these components along with a summary tab that makes a concise presentation of the calculation results.

While the techniques in this course and the accompanying spreadsheet are used daily by refrigeration professionals, the user of these materials should seek guidance and/ or confirmation of the calculated results from an experienced professional.

Background and Need

Ever since Clarence Birdseye watched the Eskimos preserve their foodstuffs in the Arctic ice, refrigerated or frozen foods have become part of our daily life. A quick trip through today's supermarket will quickly show the importance that refrigeration has by observing the amount of lineal feet of refrigerated display cases. Refrigerated temperatures range from a high of 45ºF for fresh produce to -40ºF for sushi grade tuna and many temperature levels in between. What the retail consumer sees in the supermarket is supported by a network of refrigerated trucks, refrigerated distribution centers and food processing plants, all of which require refrigeration.

While refrigeration is a similar science to air conditioning, temperatures in the refrigerated domain are much colder and require specialized construction, equipment and design calculations. The basis of all refrigeration designs starts with the heat gain into the refrigerated space. Once this heat load is established, the appropriate refrigeration system can be designed.

Establish the Design Temperatures

Inside Temperature

The starting point for a refrigerated space design is the required temperature. As referenced in the above paragraph, this may range from a high of 45ºF to a low of -40ºF or below. The table below offers guidance for the ideal storage temperatures for a variety of products.

Room Type	Temp, ºF
Candy Storage	65
Process Areas	35-45
Coolers, General	35
Coolers, Milk	32
Coolers- Meat & Poultry	28
Shipping & Rec. Docks	35-45
Ice Storage - Non Bag	35
Ice Storage - Bag	10-20
Freezers - General	-10
Freezers - Ice Cream	-15
Blast Freezers	-30

Outside Temperature

Refer to published local climatic data to establish the design outside ambient temperature and humidity conditions. There are many sources such as; ASHRAE, NOAA, Weather Underground, the Weather Channel and others. A quick search on the internet will generally provide data for the locale in question or a nearby city with similar weather.

Determining the Size

In most instances, the client has a storage requirement in pallets or, at the least, a square footage requirement. This is then factored by the room height and the possibility of tiered racking. These considerations along with an allocation for aisle space will determine the width, length and height of the refrigerated space.

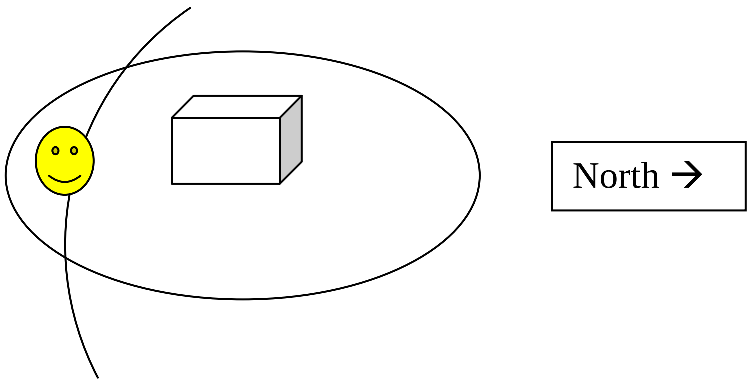
Walk in Cooler or Freezer **No Racking – Floor stacking only**

Distribution Center with Multi-tiered Pallet Racks

The above two photos represent the extremes of sizes that refrigerated spaces may be.

Determining the Ambient Solar Exposure

Refrigerated spaces may be as small as the 200 ft^2 stand-alone cooler that is found behind any fast-food restaurant, or as large as a 100,000 ft^2 free standing distribution center to something in between such as a 10,000 ft^2 refrigerated cooler within a building. In two of these examples, the solar load will have an impact. The third example will not. The East, South and West facing sides along with the roof will be affected by solar loading. The spreadsheet allows the user to account for this.



Transmission Load Calculations

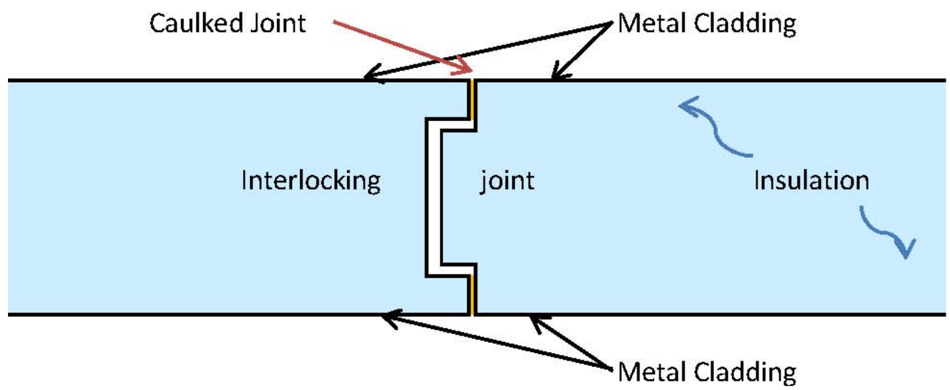
With the building envelope size and exposure established, the transmission load can be determined.

The insulation requirements of refrigerated spaces are much greater than the requirements of air conditioned spaces. This is primarily due to the greater temperature difference across the wall, roof and floor. It is also driven by the higher energy cost of a low temperature refrigeration cycle. Additionally, this greater temperature difference also creates more vapor pressure drive. This means that the water vapor pressure in the ambient air outside of the refrigerated space is much greater than the water vapor pressure inside the refrigerated space. This creates a large moisture driving force that requires a substantial vapor barrier that is much greater than the "tar paper", poly wraps or foil insulation facing used in residential or commercial construction.

H_2O Vapor, Psia	Air Temp, °F	Pressure Ratio 95	70	32
0.825	**95**	1		
0.363	**70**	2.3	1	
0.089	**32**	9.3	4.1	1
0.019	**1**	43.4	19.1	4.7
0.01	**-11**	82.5	36.3	8.9
0.001	**-50**	825.0	363.0	89.0

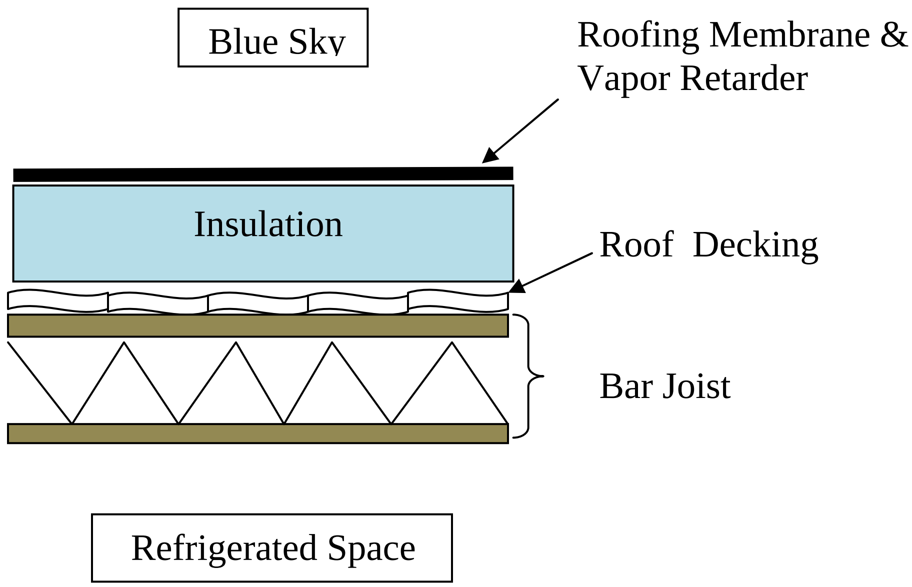
The walls of most insulated spaces today are constructed of interlocking insulated panels. These panels are constructed as a sandwich of metal – foam insulation – metal. The seams are interlocking and caulked to retard vapor flow. Smaller buildings may use interlocking panels for the roof as well.

Insulated Panel Wall Section



Larger structures will simply use un-faced sheets of foam insulation between the steel roof decking and the water tight roofing system.

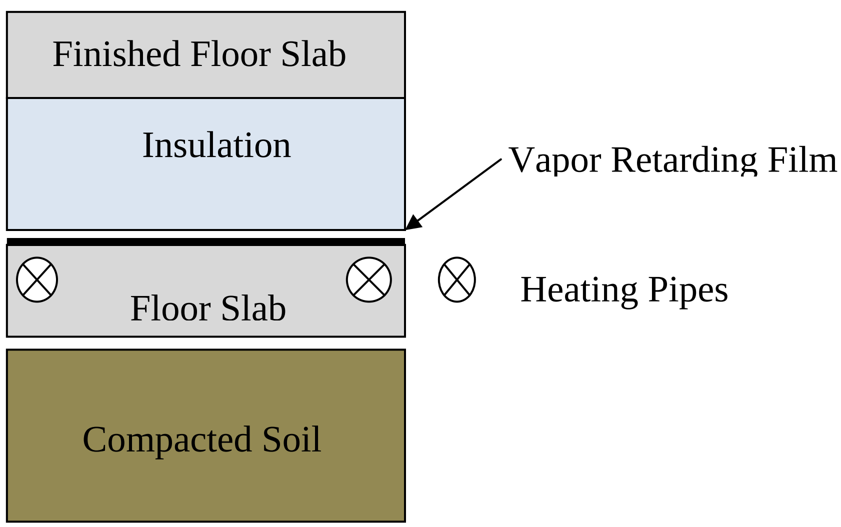
Roof Section



The floor in a high temperature cooler may be an uninsulated concrete slab. Lower, below freezing, room temperatures require insulation under the finished floor slab. In addition to insulation and a poly vapor retarder, there is a need for underfloor heat. The purpose of this heat is to ensure that the soil under the freezer floor does not freeze. The thermal conductivity of the soil alone is not sufficient to offset the heat loss through the freezer floor, resulting in ever colder temperatures over time. It is not the soil that freezes, but rather, the water in the soil. Water expands when it freezes. This expansion force is enough to buckle the floor and raise the concrete. The author has seen floors that were heaved up in excess of 6” due to a lack of underfloor heat.

55ºF to 60ºF is a commonly used soil temperature range under a floor slab. If the floor slab has underfloor heating, then the soil temperature is kept between 40ºF to 45ºF. This is warm enough to stay above freezing for a few days heating system loss, yet cold enough to minimize heat transfer through the floor. This heat may be supplied with heating cables inserted in buried pipes or warm glycol circulating though loops of poly tubing. A less dependable and therefore, less popular way is for 4" PVC air ventilation pipes spanning the building underground to allow the ambient air to be drafted or forced through them.

Typical Freezer Floor Construction



Insulation Materials

The most commonly used insulation materials used in refrigerated space construction are:

- Polyisocyanurate foam (commonly referred to as urethane, it is a light brown, open cell foam)
  - Insulating value R=5.3 per 1" of thickness
- Extruded Polystyrene (typically a blue, open cell foam)
  - Insulating value R=5.0 per 1" of thickness
- Expanded Polystyrene (a white, beaded, closed cell foam, similar to a coffee cup)
  - Insulating value R=4.8 per 1" of thickness

In the past, a variety of insulating materials have been used for cold storage construction. These include, saw dust filled walls, cork sheets and fiberglass batts. These choices quickly failed because they had insufficient vapor retarders and quickly saturated with water, destroying their R value

The Load Estimating Spreadsheet

The spreadsheet opens on the "Cover Sheet" tab which is a one page summary of the other tabs. It also has a place (the blue cells) to enter the people and project for this particular calculation.

WELCH ENGINEERING CORPORATION

REFRIGERATED SPACE HEAT LOAD ESTIMATE

CAUTION: USE ENGINEERING JUDGEMENT- GOOD DATA=GOOD ESTIMATE

Date:	
Name :	Joe Cool
Company :	XYZ Cold Storage
From :	Pete Caliente
Ref :	Main Freezer Whse

Room Temperature	-10	°F

Ver. 1.0

TRANSMISSION LOAD

Wall	Length/Height	Insulation Material	Thickness	K-Value	Outside Temp	Solar Factor	ΔT	Heat Transfer
	(ft)		(in)	BTU-in/hr-ft²-F	(F)	(F)	(F)	BTU/day
North	200	Polyisocyanurate	4	0.19	95	0	105	718,200
East	225	Polyisocyanurate	4	0.19	95	4	109	838,755
South	200	Polyisocyanurate	4	0.19	95	2	107	731,880
West	225	Polyisocyanurate	4	0.19	95	4	109	838,755
Ceiling	30	Polyisocyanurate	5	0.19	40	20	70	2,872,800

Location	Area	Construction Material	Thickness	F-Factor	Ground Temp	Solar Factor	ΔT	Heat Transfer
	(ft²)		(in)	BTU/hr-ft²-F	(F)	(F)	(F)	BTU/day
Floor	45,000	8" Concrete & 6" Exp. Styrene	-	0.84	45	-	55	2,079,000
Total Transmission Load			**8,079**	**kBTU/day**	**28.05**	**Tons**	**30%**	

INFILTRATION LOAD

Properties of Moist Air	Temperature	Rel. Humidity	Enthalpy	Specific Vol.
	(°F)	%	BTU/lba	ft³/lba
Infiltrated Air	45	70	15.558	12.812
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Number of Air Changes per Day	1.456	#/day		
Total Infiltration Load	**2,695**	**kBTU/day**	**25.71**	**Tons**	**27%**

PRODUCT LOAD

Product Name or Description	**Chicken**			
Product Loading Rate per Day	1,000,000	lbs/day		
Entering Product Temperature	0	°F		
Final Product Temperature	-10	°F		
Specific Heat above and below Freezing	0.8	BTU/lb-F	0.42	BTU/lb-F
Number of Day(s) / Hr(s) for Pulldown	1.00	days	24	hrs
Room Volume	1,350,000	ft³		
Product Loading Density	15	lbs/ft³		
No Product Respiration Heat	0	BTU/24-hr		
Total Product Load	**4,200**	**kBTU/day**	**14.58**	**Tons**	**16%**

MISCELLANEOUS LOAD

Number of People in Room	2	-		
Equivalent Heat per Person	34,178	Btu/24-hr		
Lighting Load	1	Watts/ft²	3,685,111	BTU/day
Number of Forktrucks in Room	2	-		
Horsepower per Forktruck	10	HP		
Miscellaneous Motor Load in Room (not air units)	0	HP		
Approximate Fan Horsepower from Air Units	25.000	HP		
Motor Load Equivalency	3,329	BTU/hr-HP		
Total Miscellaneous Load	**7,315**	**kBTU/day**	**25.52**	**Tons**	**27%**

TOTAL LOAD	**93.87**	**Tons**

10% Safety Factor + Total Load	**103.25**	**Tons**
Cubic Foot per Ton of Refrigeration	13,074	ft³/Ton
Square Foot per Ton of Refrigeration	436	ft²/Ton

Click on the "Transmission Load" tab. This tab allows the user to place all of the temperature and size information gathered above into one place then performs the requisite math. All of the yellow cells with red text in the spreadsheet require user input. The green cells are drop-down lists, which limit the available choices.

TRANSMISSION LOAD		Ver. 1.0	Date:	
			Name :	Joe Cool
Room Temperature (F)	-10		Company :	XYZ Cold Storage
			From :	Pete Caliente
			Ref :	Main Freezer Whse

WALL CALCULATIONS

Description	North Wall	East Wall	South Wall	West Wall	Units
Outside Temperature	95	95	95	95	^oF
Wall Surface Type	-	LIGHT	LIGHT	LIGHT	-
Solar Radiation Temp Allowance	0	4	2	4	^oF
ΔT Across the Wall	105	109	107	109	^oF
Wall Height	30	30	30	30	ft
Wall Length	200	225	200	225	ft
Area Normal to Heat Flow	6000	6750	6000	6750	ft^2
Isulation Material	Polyisocyanurate	Polyisocyanurate	Polyisocyanurate	Polyisocyanurate	-
K-Factor	0.19	0.19	0.19	0.19	BTU-in/ft^2-hr-F
Insulation Thickness	4	4	4	4	in
Transmission Loads ====>	718,200	838,755	731,880	838,755	BTU/24-hrs
Sum Total of Wall Loads	3,127,590				

CEILING CALCULATIONS

Description	Ceiling	Units
Outside Temperature	40	^oF
Ceiling Surface Type	DARK	-
Solar Radiation Temp Allowance	20	^oF
ΔT Across the Ceiling	70	^oF
Area Normal to Heat Flow	45000	ft^2
Isulation Material	Polyisocyanurate	-
K-Factor	0.19	BTU-in/ft^2-F-hr
Insulation Thickness	5	in
Transmission Load ====>	2,872,800	BTU/24-hr

FLOOR CALCULATION

Description	Floor	Units
Underfloor Temperature	45	^oF
ΔT Across the Floor	55	^oF
Area Normal to Heat Flow	45000	ft^2
Building Material	8" Concrete & 6" Exp. Styrene	
F-Factor	0.8	BTU/ft^2-F-24hr
Transmission Loads ====>	2,079,000	BTU/24-hr

TOTAL TRANSMISSION LOAD	**8,079,390**	BTU/24-hr
TOTAL TRANSMISSION LOAD	**28.05**	**Tons**

The heat transfer through the wall, roof and floor is calculated with the following equation:

$$Q = UA\Delta T$$

Where:
Q = Heat transfer quantity or load, BTU/hr
U = Overall heat transfer coefficient, BTU/hr ft^2 ºF
A = Floor, wall or roof area perpendicular to the heat flow, ft^2
ΔT = Outside temperature minus the inside temperature, ºF
The total heat load is calculated in BTU/hr. however, most refrigeration equipment sold in North America is rated in Tons. A ton of refrigeration is 12,000 BTU/hr which is the amount of refrigeration required to make a ton (2,000 lb) of ice in 24 hours.

$$1Ton = \frac{2000\ lb\ 144\frac{BTU}{lb}}{24hrs} = 12{,}000\ BTU/hr$$

While the heat load for a Ton of refrigeration will always be 12,000 BTU/hr. An equipment rating in Tons ALWAYS must be accompanied with a set of operating temperatures to accurately define the actual capacity. This is because the base capacity of all equipment is proportional to the air flow, the refrigerant mass flow, or the cooling fluid flow rates, all of which change with the operating temperature.
The overall U factor is the inverse of the sum of the individual conductance values. The equation for a built up wall is:

$$\frac{1}{U} = \frac{1}{h_i} + \frac{X_i}{K_m} + \frac{X_{ins}}{K_{ins}} + \frac{X_o}{K_o} + \frac{1}{h_o}$$

Where:
h_i = Inside still air film coefficient, BTU/hr ft^2 (1.6 in the example below)
X_m = Metal facing thickness, ft (0.1” in the example below)
X_{ins} = Insulation thickness, in (4” in the example below)
K_m = Metal thermal conductivity, BTU ft/hr ft ºF (26.2 in the example below)
K_{ins} = Insulation thermal conductivity, BTU in/hr ft ºF (0.19 in the example below)
h_o = Outside turbulent air film coefficient, BTU/hr ft^2 (6.0 in the example below)

Working through a typical wall panel:

$$\frac{1}{U} = \frac{1}{1.6} + \frac{\frac{0.1}{12}}{26.2} + \frac{4}{0.19} + \frac{\frac{0.1}{12}}{26.2} + \frac{1}{6.0} = 21.8$$

$$U = 0.0457$$

For heavily insulated structures, this equation is generally reduced to the insulation value only. The following example shows the calculation of U without the metal facings and air films.

$$\frac{1}{U} = \frac{4}{.19} = 21.05$$

$$U = 0.0475$$

In this example for a 4" isocyanurate panel wall, the difference is less than 4% in the conservative direction.

It should be noted at this point that R, the total resistance of a wall panel is the inverse of U, the total conductance.

$$R = \frac{1}{U}$$

Solar gains, if applicable, are accounted for by a simple elevation of the outside surface temperature. This correction factor is based upon the direction the wall is facing and the color of its surface. Darker surfaces will have a greater correction factor. These correction factors can range from 2ºF for a light colored South facing wall to 20ºF for a black tarred roof. The correction factors are preloaded into the spreadsheet.
For insulation materials, there are a variety of types listed, some of these are no longer used, but may be of value when analyzing older, existing buildings. A direct input of the wall's R value may also be entered. In which case, the thickness is defaulted to 1.

Because of the solar loads, exposed roofs generally have an inch or two of extra insulation
Insulation guidelines are historically represented by the following formula, which should be higher in areas with a high energy cost or where the owner is striving for a high efficiency building.

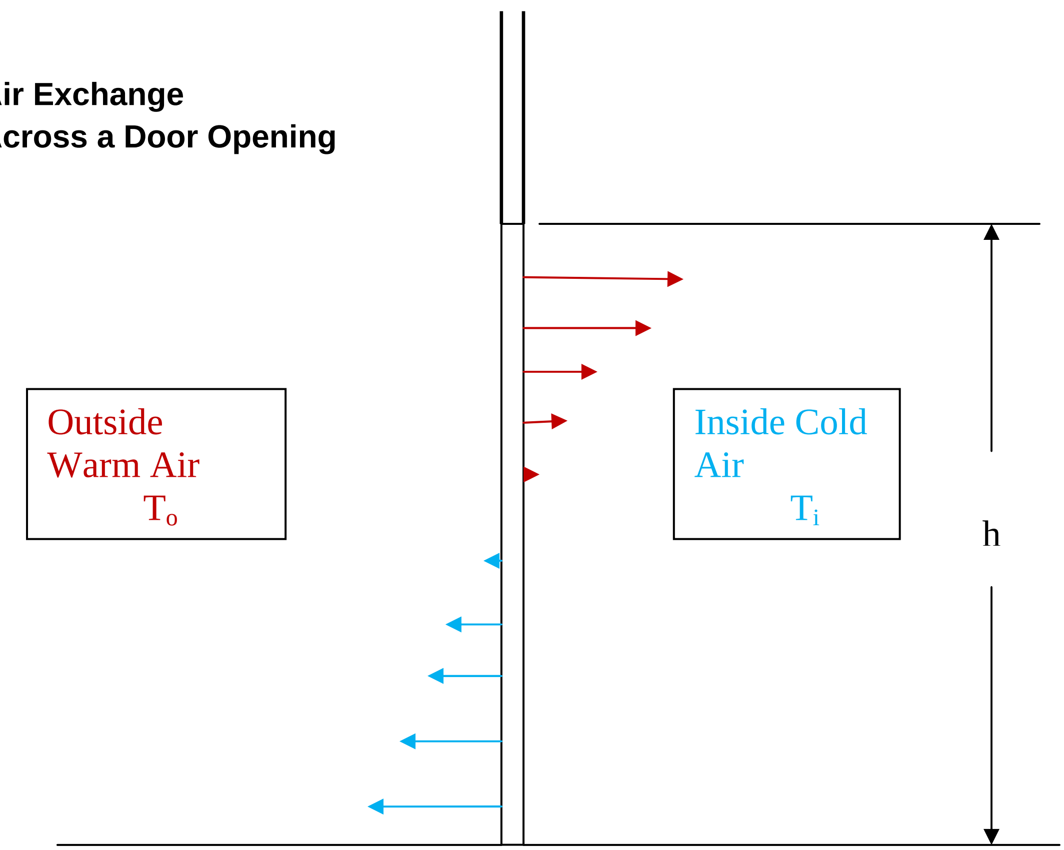
$$R = .3\Delta T - 3.5$$

Where:
R = Wall insulation, 1/BTU/hr °F ft^2
ΔT = Design outside ambient temperature minus the inside room temperature, °F

Infiltration Load

As discussed above, there is a large water vapor pressure drive from the outside ambient to the inside of a refrigerated space. In addition, when the door is closed and the internal air is cooled, it will decrease in volume. This creates a lower pressure in the refrigerated space, increasing the importance of tightly sealed construction with a proper vapor retarder.
When the door is opened to a refrigerated space, the cold dense air in the space literally flows out the lower half of the door opening and warm outside air flows in through the upper half of the door opening to replace the exiting cold air.

Air Exchange
Across a Door Opening



This interchange is proportional to the temperature difference and the door opening size. One simple, empirically derived formula to represent this is:

$$V = 4.88\sqrt{h}\sqrt{\Delta T}$$

Where:
V = Average velocity through the upper or lower half of the door opening, ft/min
h = Door opening height, ft
ΔT = Temperature outside the door opening minus the inside room temperature, ^{o}F

Other, more complex formulas have been developed to predict the amount of air exchange in a door opening and are used in the spreadsheet. Strip curtains, air curtains and vestibules will slow the full development of this air exchange.
From these velocity equations and the size of the door opening, an instantaneous air volume exchange rate can be calculated, which, when multiplied by the amount of door opening time, will produce the volume rate of air exchange.
This can be expressed with the equation:

$$W = \frac{Vhw}{2}$$

Where:
W = Volume flow rate of air entering the refrigerated space, ft^3/min
h = Door opening height, ft
w = Door opening width, ft

The spreadsheet uses psychrometric property equations to calculate the air properties on each side of the door opening. Refrigerated spaces typically have a relative humidity range of 70-80%. If the infiltrating air is ambient, refer to the historical local climate data to establish the dry bulb temperature and relative humidity. If the refrigerated space opens to another room, enter the air temperature and relative humidity for that room. It should be noted, that the colder and drier, the infiltrating air is, the lower the infiltration load will be.

The product loading and unloading rate is directly proportional to the amount of door open time. There is no difference between 2 doors opening frequently or 10 doors opening at 1/5 of that rate, so the spreadsheet does not ask for a door count.

The spreadsheet then breaks the loading rate into trips, with each round trip comes a calculated amount of air exchange. The psychrometric properties of the two air streams are then used to calculate the daily heat load. Both sensible and latent heat components are included in this calculation.

With the volume flow rate, the air conditions and door open time known, the heat gain can be calculated with the following formula:

$$Q = W\rho_{ca}t_o\Delta h_a$$

Where:

Q = Heat transfer quantity or load, BTU/hr

W = Volume flow rate of air entering the refrigerated space, ft^3/min

ρ_{ca} = Density of the cold air, lb/ft^3

t_o = time of door opening, min/hr

Δh_a = enthalpy of the warm air minus the enthalpy of the cold air, BTU/lb

In the refrigeration industry, there are many historical "Rules of Thumb" that are used to spot check detailed calculations. One of those is the number of air changes per 24 hours in a refrigerated space. The spreadsheet allows a choice between the calculated or rule of thumb method. The number of air changes per 24 hours can range from 20-30 for a small, 1,000 ft^3 walk in cooler to less than 1 for a large, 250,000 ft^3 distribution center. The addition of vestibules and the layout of shipping and receiving docks can have a significant impact on the amount of infiltration.

INFILTRATION LOAD

Ver. 1.0

Date:	
Name :	Joe Cool
Company :	XYZ Cold Storage
From :	Pete Caliente
Ref :	Main Freezer Whse

PROPERTIES OF ROOM AIR

Room Air Temperature, T_a	-10	°F
Room Air Pressure, P	14.697	PSIA
Water Saturation Pressure, P_s	0.01083	PSIA
Relative Humidity, ϕ	80	%
Humidity Ratio, ω^+	0.000367	lbw/lba
Specific Volume, v^+	11.343	ft³/lba
Enthalpy, h^+	-2.012	BTU/lba
Dew Point Temperature, T_{dp}	-15.17	°F

PROPERTIES OF OUTSIDE AIR

Outside Air Temperature, T_o	45	°F
Outside Air Pressure, P	14.697	PSIA
Water Saturation Pressure, P_s	0.147553	PSIA
Relative Humidity, ϕ	70	%
Humidity Ratio, ω^+	0.004402	lbw/lba
Specific Volume, v^+	12.812	ft³/lba
Enthalpy, h^+	15.558	BTU/lba
Dew Point Temperature, T_{dp}	35.82	°F

Height of Doorway	8	ft	
Width of Doorway	7	ft	
Area of Doorway	56	ft²	
Volumetric Air Flow through Doorway	65.236	ft³/sec	
Mass Flow Rate through Doorway	5.751	lb/sec	
Doorway Flow Factor, D_f	0.8	-	(Percent of Fully-Developed Flow)
Heat Removed per Cubic Foot of Air	1.3713	BTU/ft³	

Pounds/Day of Product Turn Around	1,000,000	lb/day	
Pounds/Hr of product Turn Around	41666.67	lb/hr	
Pounds per Forktruck Load	1200	lb	
Number of Trips (in + out) of Room	1666.7	trips/day	
Average Door Opening Frequency	20	sec/trip	(15-25 sec is about average)
Door Opening Time Factor, D_f	0.38580	-	
Average Door Opening Time	23.148	min/hr	

Room Volume	1350000	ft³
Volumetric Air Flow through Doorway	3914.18	ft³/min
Number of Air Changes per Day	1.456	-

Total Infiltration Load	2694799	BTU/day
Total Infiltration Load	**9.357**	**Tons**

To adjust the number of air changes per day, choose YES or NO. -->	NO

Adjusting the Number of Air Changes

Enter the Number of Air Changes per Day	4	-
Average Door Opening Time	63.611	min/hr
Total Infiltration Load	7405277	BTU/day
Total Infiltration Load	**25.713**	**Tons**

Product Load

Temperature Reduction

All refrigerated spaces have a turnover of stored product. It may be as infrequently as once every 9 months for seasonal operations, such as storing up turkeys for the Thanksgiving rush or every 12 hours for a blast freezer or a distribution center that consolidates and picks products for daily store deliveries.

In most cases, the incoming product arrives at a higher temperature than the refrigerated space. This may be by design if the product came from a production facility, or inadvertently if the delivery truck has refrigeration issues. The cooling load of this warmer product must be incorporated into the overall load calculation.

Cooling food products or other materials in a cooler that operates above freezing is represented with the following equation:

$$H = M(Cp_A \Delta T_A)$$

Where:

H = Heat removal, BTU

M=Product loading, lbs

Cp_A = Specific heat of the product above freezing, BTU/lb °F

ΔT = Incoming product temperature minus the cooler temperature, °F

If the incoming product to a freezer is already frozen, then there is no latent load and the equation that expresses this is:

$$H = M(Cp_B \Delta T_B)$$

Where:

H = Heat removal, BTU

M=Product loading, lbs

Cp_B = Specific heat of the product below freezing, BTU/lb °F

ΔT = Incoming product temperature minus the freezer temperature, °F

Product Freezing

In many instances, product is placed in a room specifically to be frozen. These rooms are typically called blast cells. Their design is very compact with an extremely high air velocity that is directed through the product for rapid heat transfer. There are some instances where a slower freezing time is acceptable or preferred.

To freeze a product is a 3 step process

1. Removing the sensible heat above freezing
2. Freezing or crystallizing the product, which is removal of the latent heat
3. Removing the sensible heat below freezing.

The equation that calculates this is a combination of the above two equations plus the latent heat of freezing:

$$H = M((Cp_A \Delta T_A) + L + (Cp_B \Delta T_B))$$

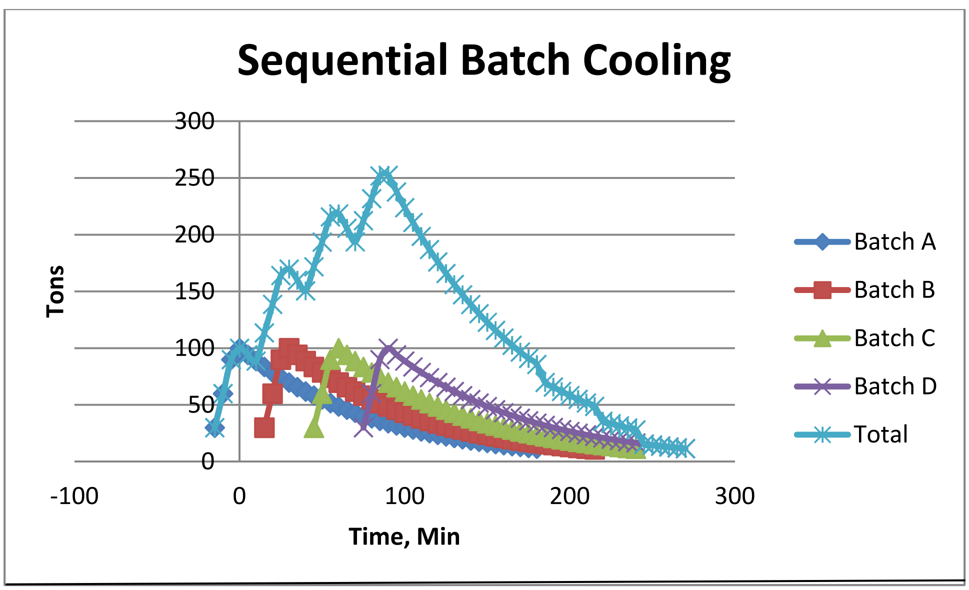
Where all of the terms are as above plus:
L = Latent heat of freezing, BTU/lb

The spreadsheet has a drop down list of the most common foods and their thermal properties. A portion of that list is shown below. For different foods or materials, the thermal properties can be estimated with the percent water content, if known. Reference cell M42.

Product	Specific Heat		Latent	Freeze	Resp. HT
Name	Above	Below	Heat	Point	BTU/LB/24Hr
Butter	0.64	0.34	15	30	
Cheese	0.7	0.4	86	19	
Cream	0.85	0.4	90	28	
Ice Cream	0.75	0.42	89	28	
Whole Milk	0.92	0.48	125	31	
Margerine	0.32	0.25	22	0	
Apples	0.87	0.45	121	29.3	0.72
Green Bananas	0.8	0.42	108	30.6	0.17
Cranberries	0.9	0.46	124	30.4	0.48
Grapefruit	0.91	0.46	126	30	0.48
Grapes	0.86	0.44	1116	28.1	0.48
Oranges	0.9	0.46	124	30.6	0.72
Peaches	0.9	0.46	124	30.3	0.96
Pears	0.86	0.45	118	29.2	0.72

It may have been noticed that the above equations provided a heat value in BTU. However, the heat transfer rate must have a time coefficient. To convert the above change in heat content to a load in BTU/hr, the time required to cool the product must be determined. For a blast freezer this time may be a defined period such as 12, 20 or 30 hours. Cased product that is sitting on a pallet in a refrigerated warehouse, may take 48 or 72 hours to equalize to the room temperature. The spreadsheet requires this estimated time. Judgment is required.

For a steady flow of product with a slight amount of temperature drop, the above heat content change divided by the cooling time will suffice for an average load.
For high instantaneous loading rates or batch operations such as a blast freezer which is quickly loaded then left to freeze the product, an average calculation will underestimate the peak load. A safety factor of up to 50% may be required to ensure that the refrigeration system can cope with the initial higher loads
The following plot shows the peak loads and the effect of diversity if there are multiple freezers.



Respiration Heat

Fresh fruits and vegetables are living things and when stored at above freezing temperatures, they respire, producing a heat load. This load is reflective of the total amount of product stored, not the loading rate. The spreadsheet allows for estimating the amount of product stored, if not known.

This is a snap shot of the Product load tab in the spreadsheet.

PRODUCT LOAD		Ver. 1.0	Date:	
			Name :	Joe Cool
			Company :	XYZ Cold Storage
Room Temperature	-10	°F	From :	Pete Caliente
			Ref :	Main Freezer Whse
Product :	**Chicken**			
Product Loading Rate	1000000	lb/day	41666.67	lb/hr
Incoming Product Temperature	0	°F		
Final Product Temperature	-10	°F		
Product Freezing Temperature	27	°F		
Product Specific Heat Above Freezing	0.8	BTU/lb-F		
Product Specific Heat Below Freezing	0.42	BTU/lb-F		
Product Latent Heat of Fusion	106	BTU/lb		
Number of Day(s) for Pulldown	1.0000	day(s)	24	hr(s)
Product Loading Daily Rate	1000000	lbs/24-hr		
Heat Removed above Freezing, Q_{above}	0	BTU/24-hr		
Heat Removed during Freezing, Q_{freeze}	0	BTU/24-hr		
Heat Removed below Freezing, Q_{below}	4200000	BTU/24-hr		
Product Load per Day	**4200000**	**BTU/24-hr**	**14.58**	**Tons**
To Account for Respiration Heat				
Room Volume	1350000	ft^3		
Percent Loading Capacity of the Room	75	%		
Loading Density	15	lb/ft^3		
Pounds of Product Respiring	15187500	lb		
Product Respiration Heat	0	BTU/lb-24hr		
Respiration Heat per Day	0.00	BTU/24-hr	**0.00**	**Tons**
Total Product Load	**4200000**	**BTU/24-hr**	**14.58**	**Tons**

Miscellaneous Load

In addition to product, all refrigerated spaces will have lights, people and equipment in them. These too, add to the overall heat load.

People give off heat. The harder they work, more heat is given off. This can range from 300 BTU/hr at rest to 1,200 BTU/hr for brisk walking. It is also influenced by the room temperature. The spreadsheet uses the following equation to estimate the heat load:

$$Q = 1295 - 11.5T$$

Where:
Q = Load, BTU/hr
T = Room temperature, ^{o}F

Since there are rarely windows in refrigerated spaces, they always require lights. 1 W/ft^2 is generally a sufficient allowance. High efficiency lighting, especially LED lighting, may be less. The spreadsheet allows this value to be changed. It then factors this into the floor area for a load.

Larger warehouses will use fork trucks and pallet jacks to move product in and out of the refrigerated spaces. They give off heat from the drive motors to the space. A typical sit down, 5,000 lb rated fork truck will have 20 HP of electric drive and steering motor capacity. This needs to be factored by the amount of time the fork trucks are actually in the freezer. 50% of the time would reflect a 10 HP estimate for the spreadsheet.

Many refrigerated spaces may have food processing equipment such as grinders, cookers and motorized conveyor belts. When determining the heat load from a motor, bear in mind that the full power load of the motor must be taken into account. For instance a 5 HP motor with an 85% efficiency rating is represented with the following formula:

$$Q = BHP * \frac{2545}{eff} + kW * 3412$$

Where:
Q = Load, BTU/hr
BHP = Nameplate power of the motor
eff = motor efficiency expressed as a decimal
kW = Electric Heater rating

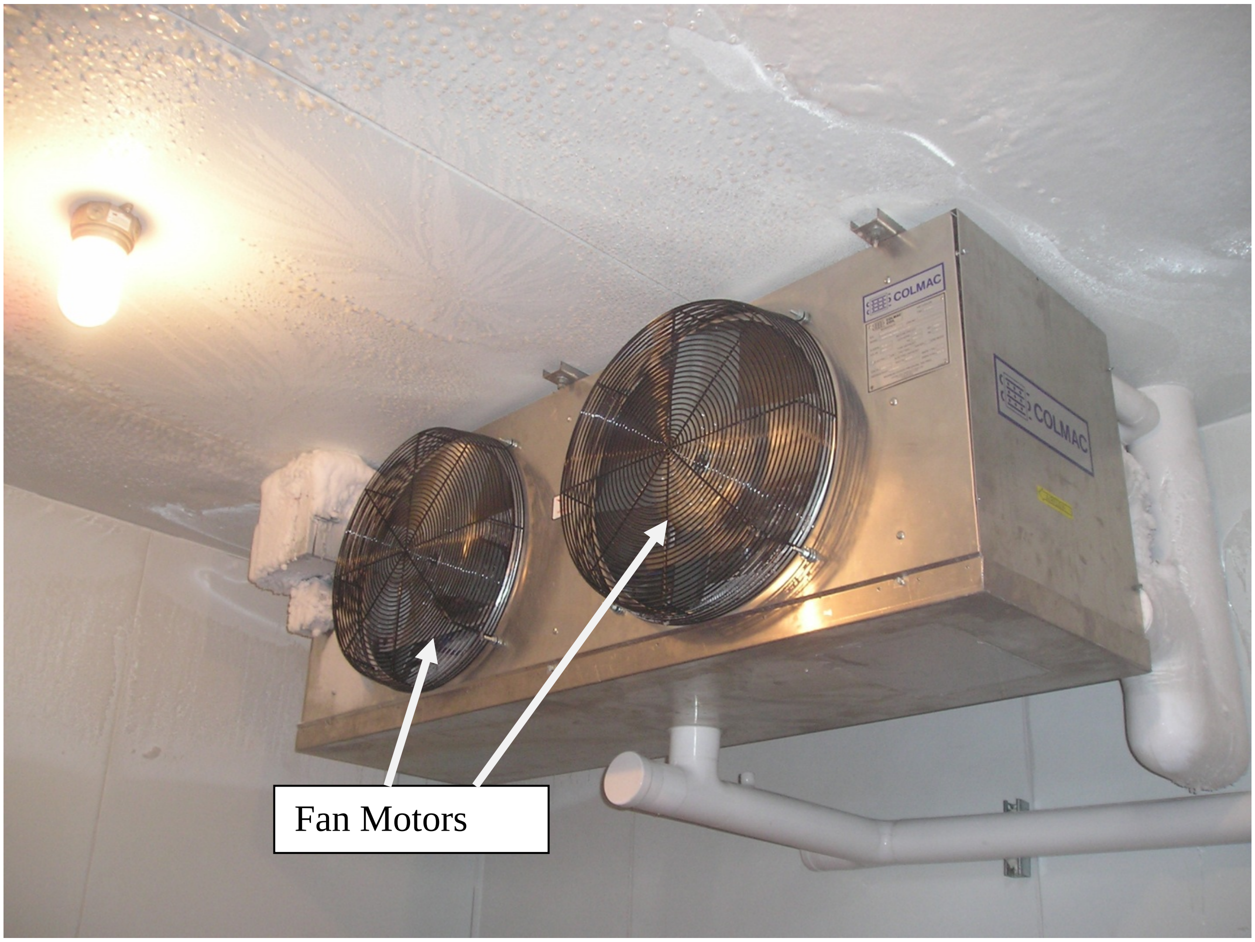
Once the gross Q is determined from above, a decision must be made on how much of this heat remains in the refrigerated space. For instance a motorized conveyor overcomes friction and all of the motor energy is eventually dissipated into the space as heat. Whereas a grinder may only liberate 50% of its power as heat to the room, while the remainder of the motor's work goes into the product which may leave the room before liberating it's heat. Remember, *energy is neither, created or destroyed*. It is the design engineer's place to determine what fraction of that energy remains in the refrigerated space!

These loads must be approximated and entered in cell D20.

Typical refrigerated food processing room with motorized conveyors

Finally, all refrigerated spaces are cooled with a fan and coil evaporator. The capacity ratings of these units do not take the fan power into account. The manufacturers publish a gross, rather than net, capacity rating. Therefore the fan power must be added to the space load.

Typical Ceiling Hung Fan & Coil Evaporator



Arriving at the correct fan power value is an iterative process, as the total space load must be determined in order to select the evaporators, then the fan power must be adjusted top match. A good starting point is to estimate 0.25 HP/Ton.

MISCELLANEOUS LOAD			Ver. 1.0	Date:	
				Name :	Joe Cool
				Company :	XYZ Cold Storage
				From :	Pete Caliente
				Ref :	Main Freezer Whse
Room Temperature	-10	°F			
Number of People in Room	2	-			
Average Heat per Person	1424.1	BTU/hr	34178	Btu/24-hr	
Occupancy Load	**0.237**	**Tons**			
Enter the Light Load	1	Watt/ft^2			
Load due to Storage Room Lighting	3.412	BTU/hr-ft^2			
Room Area	45000	ft^2			
Total Load due to Lighting	153546	BTU/hr	3685111	BTU/day	
Total Load due to Lighting	**12.796**	**Tons**			
Number of Forktrucks	2	-			
Motor Horsepower per Forktruck	10	HP			
Other Motor power (heat) to the room	0	HP			
(not including air units)	-	-			
Total Air Unit Fan Horsepower	25.00	HP			
Average Motor Efficiency, all Motors	85	%			
Connected + Motor Load Equivalency	3329	BTU/hr-HP			
Total Motor Load in the Room	149824	BTU/hr	3595765	BTU/day	
Total Motor Load in the Room	**12.49**	**Tons**			
Total Miscellaneous Load	**7315054**	**BTU/day**	**25.52**	**Tons**	

This completes the calculation process and the spreadsheet has already reflected all of these calculations to the “Cover” tab. The four load segments are totaled and a safety factor is applied.

At this point, it is time for one more Rule of Thumb gut check. These typical estimated values for ft^2/Ton are provided.

Room Type	Estimated* Ft^2/Ton
Candy Storage	400
Process Areas	100-125
Coolers, General	250-350
Coolers, Milk	200-300
Coolers- Meat & Poultry	250-300
Shipping & Rec. Docks	125-150
Ice Storage - Non Bag	300
Ice Storage - Bag	300
Freezers - General	250-400
Freezers - Ice Cream	200-350
Blast Freezers	Calc.

* These are estimated ranges. There are many site specific details that could dramatically change these ranges. Such as front and rear shipping docks, large processing equipment loads, unknown construction details, etc.