Refrigeration Room Project

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Team Members

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Chapter (1)

FREEZING METHODS & SYSTEMS

1.1 Introduction

Freezing has long been used as a method of preservation, and history reveals it was mostly shaped by the technological developments in the process. A small quantity of ice produced without using a "natural cold" in 1755 was regarded as the first milestone in the freezing process. Firstly, ice-salt systems were used to preserve fish and later on, by the late 1800's, freezing was introduced into large-scale operations as a method of commercial preservation. Meat, fish, and butter, the main products preserved in this early example, were frozen in storage chambers and handled as bulk commodities (Persson, 1993).

In the following years, scientists and researchers continuously worked to achieve success with commercial freezing trials on several food commodities. Among these commodities, fruits were one of the most important since freezing during the peak growing season had the advantage of preserving fruit for later processing into jams, jellies, ice cream, pies, and other bakery foods. Although commercial freezing of small fruits and berries first began around 1905 in the eastern part of the United States, the commercial freezing of vegetables is much more recent. Starting from 1917, only private firms conducted trials on freezing vegetables, but achieving good quality in frozen vegetables was not possible without pre-treatments due to the enzymatic deterioration. In 1929, the necessity of blanching to inactivate enzymes before freezing was concluded by several researchers to avoid deterioration and off-flavours caused by enzymatic degradation.

The modern freezing industry began in 1928 with the development of double-belt contact freezers by a technologist named Clarence Birdseye. After the revolution in the quick freezing process and equipment, the industry became more flexible, especially with the usage of multi-plate freezers. The earlier methods achieved successful freezing of fish and poultry, however with the new quick freezing system, packaged foods could be frozen between two metal belts as they moved through a freezing tunnel. This improvement was a great advantage in the commercial large-scale freezing of fruits and vegetables. Furthermore, quick-freezing of consumer-size packages helped frozen vegetables to be accepted rapidly in late 1930s.

Today, freezing is the only large-scale method that bridges the seasons, as well as variations in supply and demand of raw materials such as meat, fish, butter, fruits, and vegetables. Besides, it makes possible movement of large quantities of food over geographical distances (Persson, 1993). It is important to control the freezing process, including the pre-freezing preparation and post-freezing storage of the product, in order to achieve high-quality products. Therefore, the theory of the freezing process and the parameters involved should be understood clearly.

1.2 Freezing Methods & Quality Loss at Freezing Temperatures

Freezers must accomplish the followings:

1) **Preservation**
   - Pathogen growth is halted below –4°C.
   - Spoilage microorganisms don’t grow below –10°C.
   - Chemical reaction rates are significantly reduced.
2) **Processing aid**
   - Freezing changes the texture and viscosity for further processing, e.g. slicing meat products.
3) **Product definition**
   - Freezing defines some food products, e.g. ice-cream and frozen desserts.

1.3 Freezing Methods

There are many different types of freezer available for freezing and freezer operators are often uncertain about which type is best suited to their needs. Three factors may be initially considered when selecting a freezer; financial, functional and feasibility.

Financial considerations will take into account both the capital and running cost of the equipment and also projected losses such as product damage and dehydration. Expensive freezers should therefore justify their purchase by giving special benefits and if these benefits are not worthwhile, they need not be considered.

Functional considerations will take into account such things as whether the freezer is required for continuous or batch operation and also whether the freezer is physically able to freeze the product. For instance, a horizontal plate freezer would be inappropriate for freezing large whole tuna.

Feasibility will take into account whether it is possible to operate the freezer in tile plant location. A liquid nitrogen freezer (LNF), for instance, may be suitable in every respect for freezing the product and the high costs of using this method of freezing may be justified.

However, if the location of the plant is such that there can be no guaranteed supply of liquid nitrogen, the freezer should not be considered (Fennema, 1975).

1.3.1 Air freezing

Packaged or unpackaged no fluid foods can be frozen in air at temperatures ranging from –18° to – 40 °.

1.3.2 Sharp freezing

It consists of placing products in a very cold room, maintained at temperatures in the range of –15 °C to –29°C. Although the air within the room will circulate by convection, usually little or no provision is made for forced connection. The relatively still air is a poor conductor of heat and foods placed in even these low temperatures are frozen comparatively slow, many hours or even days being required before the products are completely solidified.

Fundamentally, sharp freezers are cold storage rooms especially constructed to operate at and maintain low temperatures. Freezing time is generally 3-72 hr or more depending on the conditions and the size of product. Sharp freezing is uncommon in modern freezing operations.

This method is extremely slow and lacks efficient design characteristics. It may also jeopardize the quality of already frozen products stored in the room because flavors may be transferred from warm products yet to be frozen. The temperature of the products already in frozen storage may rise considerably as heat is transferred from the incoming unfrozen product. And dehydration due to slow freezing rate and temperature fluctuations may be excessive (Desrosier, 1977).

1.3.3 Air blast freezing

Vigorous circulation of cold air enables freezing to proceed at a moderately rapid rate. Products are placed on trays, either loose or in packages and the trays are placed on freezing coils in a low temperature room with cold air blowing over the product. In some installations of this system, the cold air that is in the low temperature room is circulated by means of large fans, whereas in other installations the air is blown through refrigerated coils located either inside the room or in an adjoining blower room.

Tunnel freezing see Figure (1.1) is possibly the most commonly used freezing system. Tunnel freezing is substantially a system in which a long, slow moving mesh belt passes through a tunnel or enclosure containing very cold air in motion. The speed of the belt is variable according to the time necessary to freeze the product. Usually the cold air is introduced into the tunnel at the opposite end from the one where the product to be frozen enters, that is, the air flow is usually counter to the direction of the flow of the product. The temperature of the air is usually between –18° and –34°. The air velocity varies, however if rapid freezing is to be had, it is necessary to recirculate a rather large volume of the air in order to obtain a relatively small rise in the temperature of the air as it touches and leaves the product. Air has a very low specific heat and for that reason a large volume must be carefully distributed through the system.

Air velocities ranging all the way from 100 ft. per min. Up to 3500 ft. per min have been reported, and it is difficult to establish any speed as having more or less common usage. Possibly 2500 ft per min may be considered a practical and economical air velocity at –29° C.

Air blast freezing is economical and is capable of accommodating foods of a variety of sizes and shapes. It can however result in:

Excessive dehydration of unpackaged foods if condition are not carefully controlled, and this in turn necessitates frequent defrosting of equipment, or Undesirable bulging of packaged foods which are not confined between rigid surfaces during freezing (Mogons, 1984).

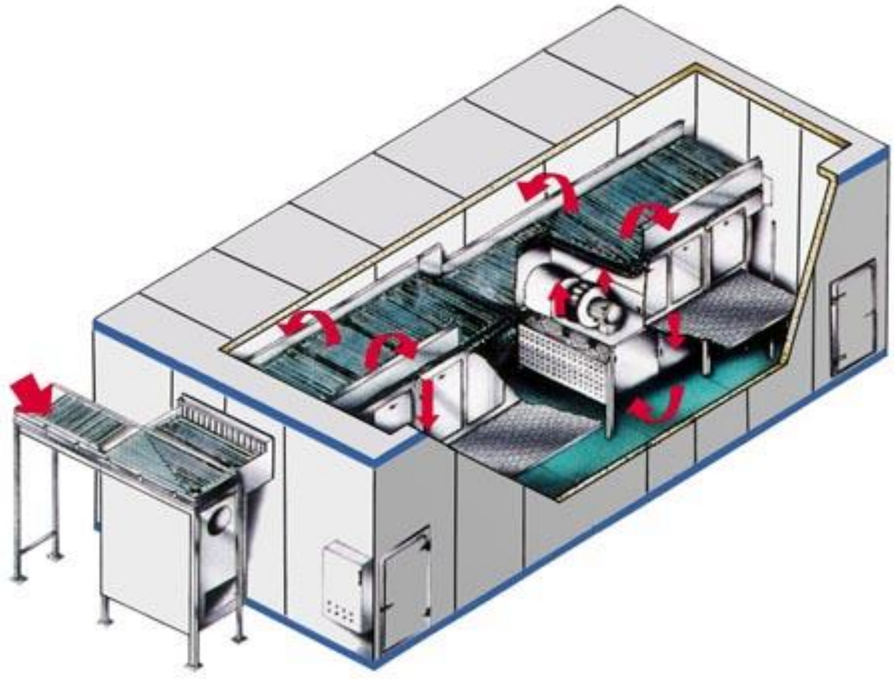


Figure (1.1) Modular Tunnel Freezer

1.3.4 Fluidized-bed freezing

Fluidized bed freezing is a modification of air-blast freezing. Solid food particles ranging in size from peas to strawberries can be fluidized by forming a bed of particles 1-5 in. Deep on a mesh belt (or mesh tray) and then forcing air upward through the bed at a rate sufficient to partially lift or suspend the particles in a manner somewhat reminiscent of a boiling liquid. If the air used for fluidization is appropriately cooled, freezing can be accomplished at a rapid rate.

An air velocity of at least 375 lineal ft/min is necessary to fluidize suitable particles, and an air temperature of about –34°C is common. Bed depth depends on the ease with which fluidization can be accomplished, and this in turn depends on size, shape, and the uniformity of particles. A depth of slightly more than 1 in. is suitable for easily fluidized particles, such as peas and whole kernel corn; a depth of 3-5 in. is used for partially fluidizable particles, such as green beans; and a depth of 8-10 in. can be used for nonfluidizable products, such as fish fillets. Although freezing time varies with conditions.

Fluidized bed freezing has proved successful for many kinds and sizes of unpackaged food tissues, although the best results are obtained with products that are relatively small and uniform in size (e.g., peas, limas, cut green beans, strawberries, whole kernel corn, brussel sprouts).

The advantages of fluidized bed freezing as compared to conventional air-blast freezing are:

- More efficient heat transfer and more rapid rates of freezing.
- Less product dehydration and less frequent defrosting of equipment.
- Short freezing time is apparently responsible for the small loss of moisture.

A major disadvantage of fluidized bed freezing is that large or nonuniform products cannot be fluidized at reasonable air velocities.

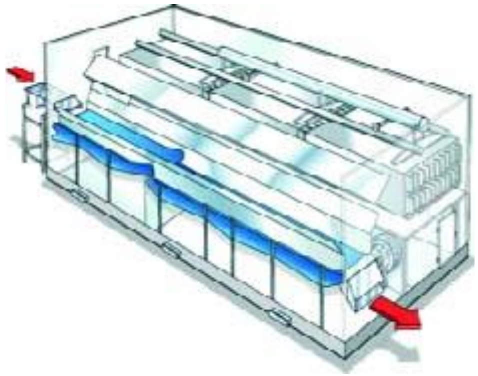


Figure (1.2) Cross Sectional View of a Fluidized Bed Freezer

1.3.5 Spiral freezers

Spiral belt freezers as shown in Figure (1.3) Spiral Freezer use a product belt that can be bent laterally. The original spiral belt design uses a spiraling rail system to carry the belt, with a central drum that drives the belt through friction at the belt edge.

The latest spiral belt design uses a self-stacking, self-enclosing stainless steel belt for compactness, greater reliability and improved air flow. This design eliminates the traditional rail system and friction drive. The number of tiers in the belt stack can be varied to accommodate different capacities. In feeds and out feeds can be located to suit most line layouts. Depending on the upstream process and capacity required this type of freezer is available in a range of models with different belt widths and may be completely factory assembled or partially assembled in modules for quick installation and future portability.

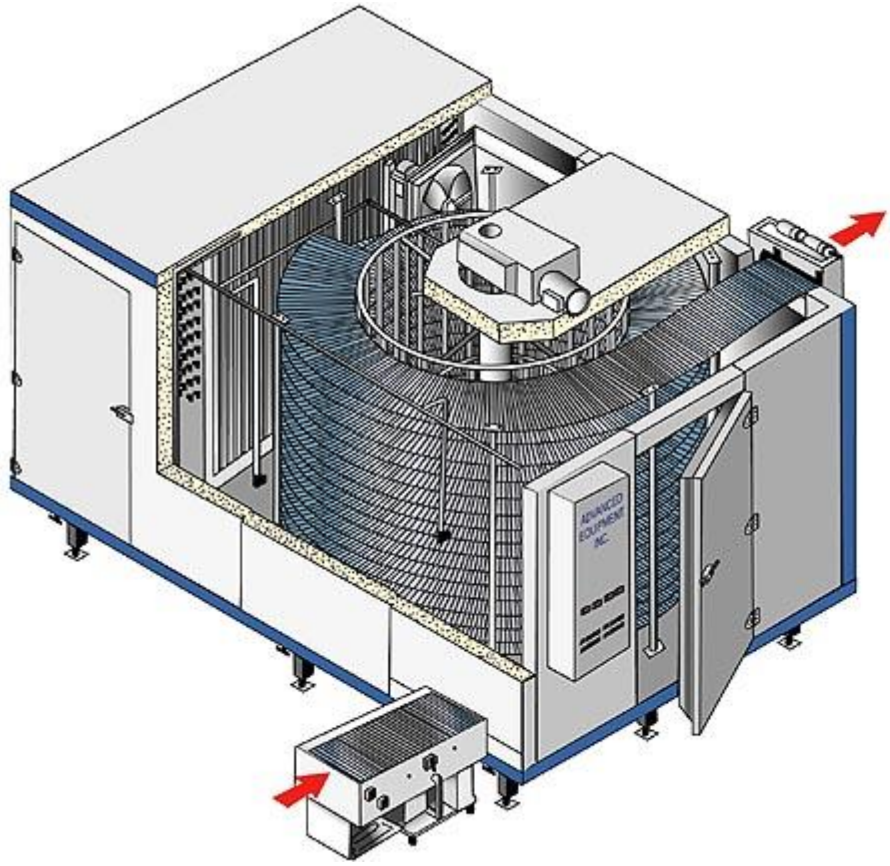


Figure (1.3) Spiral Freezer

Spiral freezers are good systems for products requiring a long freezing time (generally 10 minutes to 2 hours) and for products that require careful handling. Typical products frozen in spiral belt freezers include raw and cooked meat patties, fish fillets, chicken parts, pizza and a variety of packaged products.

1.4 Plate Freezing

Food products can be frozen by placing them in contact with a metal surface cooled either by cold brine or vaporizing refrigerants, such as refrigerant-12, 22 or ammonia. Packaged food products may rest on, slide against, or be pressed between cold metal plates.

Plate freezers consist of a series of flat hollow refrigerated metal plates. The plates are mounted parallel to each other and may be either horizontal or vertical. The spaces between the plates are variable, the plates being opened out for loading and, prior to the freezing operation, closed so that the surface of the plates is in intimate contact with the packaged or unpackaged food. Clearly the frozen product is in the form of parallel sided blocks and, during the freezing process, heat flow is perpendicular to the faces of the plates. A moderate pressure (of the order of 10-30 kNm^{-2}) is maintained between the plates and the package surfaces during freezing to promote good face to face contact.

Double contact plate freezers are commonly used for freezing foods in retail packages. This equipment, which may be batch, semi automatic, or automatic, consists of a stack of horizontal cold plates with intervening spaces to accommodate single layers of packaged product. The filled unit appears much like a multilayered sandwich containing cold plates and product in alternating layers. The plates are arranged so that they can be opened or closed in a vertical accordion-like manner, enabling product to be added or removed. When closed, the plates make firm contact with the two major surfaces of the packages, thereby facilitating heat transfer and assuring that the major surfaces of the packages do not bulge during freezing.

Contact plate freezing is an economical method that minimizes problems of product dehydration, defrosting of equipment and package bulging. Two notable disadvantages do however exist: (1). Packages must be uniform of thickness, (2). Freezing occurs at a moderately slow rate as compared to other modern methods. For example, a compact product in a well fitted package 1-1.5 in. thick, when cooled by plate's ay –33°C, requires about 1-1.5 hr to freeze. Freezing times are extended considerably when the package contains a significant volume of void space.

Figure (1.4) Plate Freezer with a two-stage compressor and a sea water condenser

1.5 Liquid Immersion Freezing

Liquid immersion freezing (usually referred to as direct immersion freezing) is accomplished when a food product, packaged or unpackaged, is frozen by immersion in or by spraying with a freezant that remains liquid throughout the process. Aqueous solutions of the following substances have been used as freezants: propylene glycol, glycerol, sodium chloride, and mixtures of salt and sugar. This technique, although not common, is used commercially for canned citrus juice concentrate (cans of juice are passed continuously through a chamber containing liquid freezant); for poultry especially during the initial stages of freezing (to impart a uniform, white color to the surface); and an occasionally for fish and shrimp.

The major advantages of liquid immersion freezing are that it results in rapid freezing (especially for foods which are unpackaged or are packaged in skin-tight films) and it is easily adapted to continuous operations. It is difficult, however, to find freezants with suitable properties.

1.6 Cryogenic Freezing

Cryogenic freezing refers to very rapid freezing achieved by exposing food items, unpackaged or thinly packaged, to an extremely cold freezant undergoing a change of state. The fact that heat removal is accomplished during a change of state by the freezant is used to distinguish cryogenic freezing from liquid-immersion freezing. The most common food grade cryogenic freezants are boiling nitrogen and boiling or subliming carbon dioxide.

The rate of freezing obtained with cryogenic methods is much greater than that obtained with air-blast or plate freezing but is only moderately greater than that obtained with fluidized bed or liquid immersion freezing.

Liquid nitrogen (LN) is used in many cryogenic freezers. The product is placed on a conveyor belt and moved into the insulated chamber, where it is cooled with moderately cold gaseous nitrogen moving counter current to the product. LN is sprayed or dribbled on the product. Following the desired exposure time, the product pass to the place where it is allowed to equilibrate to the desired final temperature (-18° to – 30°C) before it is discharged. Final product temperature is usually no different than that obtained during conventional methods of freezing.

Advantages of LN freezing are as follows:

- Dehydration loss from the product is usually much less than 1%
- Oxygen is excluded during freezing
- Individually frozen pieces of product undergo minimal freezing damage

The equipment is simple, suitable for continuous flow operations, adaptable to various production rates and product sizes, of relatively low initial cost, and capable of high production rates in a minimal space.

The only disadvantage of LN freezing is high operating cost, and this is attributable nearly entirely to the cost of LN.

1.7 Advantages & Disadvantages of Freezers

AIR BLAST (use air for heat transfer, provides the largest range of designs)

1.7.1 Batch

Advantages

- Easy and economical to build
- Can accommodate a wide range of products

Disadvantages

- Labor intensive
- Occupies a large floor space

- Poor heat transfer may occur resulting in poor product quality
- Excessive dehydration in unpacked products
- Product damage due to sticking
- Labor intensive and costly to clean

1.7.2 In-Line

Advantages

- Economical operation
- Space efficient
- Superior quality due to continuous processing flow and controlled heat transfer
- Reduced dehydration
- Easy to clean

Disadvantages

- Not as flexible as batch freezer
- Higher capital investment
- CONTACT (heat transfer occur through conduction)

1.7.3 Batch/In-Line

Advantages

- Highly efficient heat transfer
- Compact size
- Low operating cost

- Relatively low capital investment
- Minimizes package distortion
- Retains product shape
- Improved bulk product handling

Disadvantages

- In flexible: used primarily for foods in packages
- Limited package geometry
- CRYOGENIC
- BATCH/IN LINE

1.8 Quality Loss at Freezing Temperatures

Freezing is a quick and convenient way to preserve fruits and vegetables. Frozen fruits and vegetables of high quality and maximum nutritional value can be produced if the directions below are followed. These directions are based on:

- The chemical and physical reactions which take place during the freezing process.
- Scientific knowledge of the effect of freezing on the tissues of fruits and vegetables.
- Food microbiology.

The chief function of freezing is to preserve food while maintaining its high quality. This is accomplished by reducing the product temperature, thereby slowing the quality deterioration processes: the oxidation of fat, the growth of microorganisms, enzymatic reactions and the loss of surface moisture (dehydration).

1.8.1 Chemical changes during freezing

Fresh fruits and vegetables, when harvested, continue to undergo chemical changes, which can cause spoilage and deterioration of the product. This is why these products should be frozen as soon after harvest as possible and at their peak degree of ripeness.

Fresh produce contains chemical compounds called enzymes, which cause the loss of color, loss of nutrients, flavor changes, and color changes in frozen fruits and vegetables. These enzymes must be inactivated to prevent such reactions from taking place.

The blanching process inactivates enzymes in vegetables. Blanching is the exposure of the vegetables to boiling water or steam for a brief period of time. The vegetable must then be rapidly cooled in ice water to prevent it from cooking. Contrary to statements in some publications on home freezing, in most cases blanching is absolutely essential for producing quality frozen vegetables. Blanching also helps to destroy microorganisms on the surface of the vegetable and to make some vegetables, such as broccoli and spinach, more compact.

The major problem associated with enzymes in fruits is the development of brown colors and loss of vitamin C. Because fruits are usually served raw, they are not blanched like vegetables. Instead, enzymes in frozen fruit are controlled by using chemical compounds, which interfere with deteriorative chemical reactions. The most common control chemical is ascorbic acid (vitamin C). Ascorbic acid may be used in its pure form or in commercial mixtures with sugars.

Some directions for freezing fruits also include temporary measures to control enzyme-activated browning. Such temporary measures include soaking the fruit in dilute vinegar solutions or coating the fruit with sugar and lemon juice. However, these latter methods do not prevent browning as effectively as treatment with ascorbic acid.

Another group of chemical changes that can take place in frozen products is the development of rancid oxidative flavors through contact of the frozen product with air. Using a wrapping material, which does not permit air to pass into the product, can control this problem. It is also advisable to remove as much air as possible from the freezer bag or container to reduce the amount of air in contact with the product.

1.8.2 Textural changes during freezing

County extension offices frequently receive questions about whether certain fruits, vegetables, or mixtures of either may be successfully frozen. Such questions can be answered by knowing the effect of freezing on various plant tissues.

Water makes up over 90 percent of the weight of most fruits and vegetables. This water and other chemical substances are held within the fairly rigid cell walls, which give support structure, and texture to the fruit or vegetable. Freezing fruits and vegetables actually consists of freezing the water contained in the plant cells.

When the water freezes, it expands and the ice crystals cause the cell walls to rupture. Consequently, the texture of the produce, when thawed, will be much softer than it was when raw. This textural difference is especially noticeable in products, which are usually consumed raw. For example, when a frozen tomato is thawed, it becomes mushy and watery. This explains why celery, lettuce, and tomatoes are not usually frozen and is the reason for the suggestion that frozen fruits, usually consumed raw, be served before they have completely thawed. In the partially thawed state, the effect of freezing on the fruit tissue is less noticeable.

Textural changes due to freezing are not as apparent in products which are cooked before eating because cooking also softens cell walls. These changes are also less noticeable in high starch vegetables, such as peas, corn, and lima beans.

1.8.3 Rate of freezing

Freezing produce as quickly as possible can control the extent of cell wall rupture. In rapid freezing, a large number of small ice crystals are formed. These small ice crystals produce less cell wall rupture than slow freezing which produces only a few large ice crystals. This is why some home freezer manuals recommend that the temperature of the freezer be set at the coldest setting several hours before foods will be placed in the freezer. Some freezer manuals tell the location of the coldest shelves in the freezer and suggest placing unfrozen products on these shelves.

All freezer manuals give guidelines for the maximum number of cubic feet of unfrozen product, which can be frozen at one time. This is usually 2 to 3 pounds of vegetable to each cubic foot of freezer space per 24 hours. Overloading the freezer with unfrozen products will result in a long, slow freeze and a poor quality product.

1.8.4 Changes caused by fluctuating temperatures

To maintain top quality, frozen fruits and vegetables should be stored at 0°F or lower. This temperature is attainable in separate freezer units and in some combination refrigerator-freezers. A freezer thermometer can help you determine the actual temperature of your freezer. If your freezer has number temperature settings, such as from 1 to 9, check the manual to see what settings are recommended for different uses.

Storing frozen foods at temperatures higher than 0°F increases the rate at which deteriorative reactions can take place and can shorten the shelf life of frozen foods. Do not attempt to save energy in your home by raising the temperature of frozen food storage above 0°F.

Fluctuating temperatures in the freezer can cause the migration of water vapor from the product to the surface of the container. This defect is sometimes found in commercially frozen foods, which have been improperly handled.

1.8.5 Moisture loss

Dehydration is of particular interest because it is less obvious, harder to quantify and often has a large economic impact. It is the result of the inevitable loss of water vapor that occurs when a product is exposed to air or another gaseous medium. Frost accumulating on the coil surfaces provides a gross indicator of the rate of dehydration moisture loss.

Fast cooling and freezing greatly reduce dehydration for two reasons. First, the temperature of the product is reduced quickly, which minimizes the evaporation rate (the rate at which water moves from the product into the air). Second, fast freezing minimizes the length of time the product is evaporating water at a higher rate. To achieve fast cooling and freezing, cold air is not enough. It needs to be distributed efficiently over the product surface by an effective airflow design.

1.8.6 Freezer burn

Moisture loss, or ice crystals evaporating from the surface area of a product, produces freezer burn—a grainy, brownish spot where the tissues become dry and tough in frozen storage. This surface freeze-dried area is very likely to develop off flavors. Packaging in heavyweight, moisture proof wrap will prevent freezer burn.

1.8.7 Microbial growth in the freezer

The freezing process does not actually destroy the microorganisms, which may be present on fruits and vegetables. While blanching destroys some microorganisms and there is a gradual decline in the number of these microorganisms during freezer storage, sufficient populations are still present to multiply in numbers and cause spoilage of the product when it thaws. For this reason it is necessary to carefully inspect any frozen products which have accidentally thawed by the freezer going off or the freezer door being left open.

1.8.8 Nutrient value of frozen foods

Freezing, when properly done, is the method of food preservation, which may potentially preserve the greatest quantity of nutrients. To maintain top nutritional quality in frozen fruits and vegetables, it is essential to follow directions contained in this leaflet for pretreatment of the vegetables, to store the frozen product at 0° F and to use it within suggested storage times.

Chapter (2)

LOAD ESTIMATION

2.1 Cooling Load Calculation Methods

In this report five standard methods for the calculation of heat load are presented in brief. They are based on hourly calculation of the cooling load. These methods deal with the sensible heat load. However, for the latent heat, the main source is people. Heat gain from people has two components, sensible and latent. The total values and proportions of sensible and latent heat vary depending on the level of activity, age and gender. Those values are listed in tables. The latent and sensible heat gains from occupants should be computed separately until estimating the building refrigeration load, where the two components are combined. The latent heat gain is assumed to become cooling load instantly, whereas the sensible heat gain is partially delayed depending on the characteristics of the conditioned space. According to the ASHRAE regulations, the sensible heat gain from people is assumed 30% convection (instant cooling load) and 70% radiative (delayed portion).

The five methods which will be presented here are:

1) The Heat Balance Method (ASHRAE, 2001)
2) The Radiant Time Series (ASHRAE, 2001)
3) CLTD/SCL/CLF (ASHRAE, 1997)
4) The Admittance Method (CIBSE, 1986)
5) VDI Methods (VDI, 1996)

2.1.1 Heat balance method

The procedure described by this method is the most reliable mean presented by ASHRAE for estimating cooling load for a defined space. Other ASHRAE methods are simplifications of the heat balance principle. In fact, any cooling load estimate is no better than the assumptions used to define conditions and parameters such as physical makeup of the various envelope surfaces, conditions of occupancy and use, and ambient weather conditions outside the building. The ASHRAE 2001 Fundamentals mentions that the Heat balance method (HB) and the Radiant time series method (RTS) have superseded (but not invalidated) other methods including CLTD/SCL/CLF.

Main features

- Accurate method as it based on heat balance models. By this method it is possible to calculate: the cooling load assuming a constant zone air temperature, or the floating zone air temperature when there is no cooling system or zone temperature when cooling system is on.
- For heat transfer through walls, conduction transfer functions (CTF) are used which include a time-series method. The determination of the CTF coefficients is relatively

complex. To determine the CTF coefficients, two methods could be implemented: one based on using an excitation function with a known Laplace transform and transform, the second is based on matching the frequency response to the frequency response of the s-transfer function at several frequencies. The calculation of the heat transfer includes multiplication of present values of interior and exterior surface temperatures, past values of interior and exterior surface temperatures, and past values of surface heat flux.

Assumptions

Room surfaces can be treated as entities having:

- Uniform surface temperatures.
- Uniform long- and shortwave irradiation.
- One-dimensional heat conduction.

Methodology

Treatment of conduction heat transfer by a time-series method using conduction transfer functions (CTF) which relate conductive heat fluxes to the current and past surface temperatures and the past heat fluxes.

Finding cooling load

Three heat balance models are set for the outside surfaces, inside surfaces, and the zone air. The balance equations are connected with the relevant surface CTFs in order to find the surface temperatures and the zone cooling load.

Advantages

- Using a complete heat balance would give better results than simplified methods as the former balances all energy flow in each zone (which is not guaranteed for the approximate methods).
- Additional information about the component performance could be determined and not only cooling load (e.g. surface temperatures at various times).
- The zone air balance equations can be formulated to solve for cooling load assuming a constant zone air temperature, or floating zone air temperature when there is no cooling system, or to find zone temperature when cooling system is on.

Disadvantages

- A fairly complete description of the input data should be provided by this method, noting that simplified methods tend to simplify the procedure by recalculating cases and grouping the results with various correlating parameters which reduces the amount of the required input information. Typical requirements of input data will be shown later for this method.
- Iterative procedure is included because all of the heat balance equations must be solved simultaneously, and therefore, a computer program should be used.

Walls, Roof and Floor

Heat transfer balance equations are set for the outside and inside surfaces and connected with the CTF solution for the heat conduction process.

Windows

Heat balance equations are formulated for the windows taking into consideration the absorbed radiation by the window and the heat exchange at the exterior and interior surfaces to find the window surface temperatures. For the transmitted radiation, direct and diffuse radiation are calculated and summed up.

Internal heat gains

The amount of heat gains from people, lighting and equipment are estimated from tables for the specified components.

Total surface irradiance

It is calculated from summing the direct, diffuse and ground-reflected irradiance from equations (this is applicable for the method presented by (ASHRAE, 2001)), according to the location, time, solar angles for the surface, and surface, ground and sky properties.

Input data

Since the Heat Balance method requires full description of input data, here is a list of the typical required input data by this method. Global information: latitude, time zone, month, day of month, north axis of the zone, zone height. Additionally, if a variable outside heat transfer coefficient is considered, information about wind speed, wind direction and terrain roughness are required.

Wall information (for each wall): facing angle, tilt, area, solar absorptivity outside, long wave emissivity outside, shortwave absorptivity inside, long wave absorptivity inside, exterior boundary temperature code, external roughness, and layer-by-layer construction information.

Window information (for each window): The situation for windows is similar to that for walls, but windows require some additional information because of their role in the solar load. The necessary parameters include, area, normal solar transmissivity, normal SHGC, normal total absorptivity, long wave emissivity outside, long wave emissivity inside, surface-to-surface thermal conductance, reveal for solar shading, overhang width, and distance from overhang to window. Roofs and floor details: similar to walls.

Internal heat gain details: The following fractions are to be specified, sensible and latent heat gain fractions, fraction of the energy that enters as long wave and shortwave length radiation, and the fraction of the energy which enters the air as immediate convection. For lighting heat gain, the fraction of energy that goes directly to the return air. For people, the activity level of people.

Radiant distribution function: A distribution function is required that specifies the fraction of the total radiant input that is absorbed by each surface. The types of radiation that require distribution functions are; long wave radiation from equipment and lighting, shortwave radiation from lights, and transmitted solar radiation Other Required data: heat transfer coefficient/convective models, solar coefficients, and sky models.

2.1.2 Radiant time series method

This method is simpler to apply than the Heat balance method. There is no zone heat balance.

The storage and release of structure energy are approximated with predetermined zone response. The cooling load is found directly but the zone air temperature is assumed constant.

Main Features

- Zone air temperature is assumed constant.
- Periodic response factors are needed to find the conduction heat fluxes for walls. The response factors for a single pulse are composed of 24 factors for steady periodic input. A computer program on a CD-ROM can be used to generate these factors for any multilayer wall.
- Radiant time series, which is consisted of 24 radiant time factors, should be generated for the conversion of the radiative portion of heat gains into cooling

loads. A computer program for the heat balance method or a database for weighting factors has to be used to generate these factors.

Assumptions

- Sol-air temperature is assumed for the outside air. Hourly sol-air temperatures are calculated according to the location from equations for the incident solar radiation, radiant energy exchange with sky and other outdoor surroundings, and convective heat exchange with the outdoor air (ASHRAE, 2001)

- Zone air temperature is taken as a constant

- Solution is based on steady periodic conditions (where the design weather, occupancy, and heat gain conditions are identical to those for the preceding day, so that the load is repeated on a 24 hours basis)

Methodology

- Periodic response functions for the heat conduction through walls, roofs, and floors, which involves 24-hour-coefficients.

- The radiative portions of the hourly heat gains are converted into hourly cooling loads using radiative time factors (24 factors)

- The hourly cooling load is determined by summing up the loads from the convective portions and cooling loads due to radiative heat gains

Advantages

This method is a simplification of the heat balance method which can be performed step by step; therefore it does not require iterative calculations.

- Can be implemented in a computerized spreadsheet
- Can be used to find peak load

Disadvantages

- Results in small over predictions. However, significant over predictions are noticed specially for zones with large quantities of high conductance surfaces
- The sol-air temperatures for the 24 hours have to be found for each surface

- The hourly periodic response factors for the conduction heat transfer have to found for each type of wall, roof, or floor according to its layers composition, thickness, properties (computer programs are available on CD-ROM for calculating the periodic response factors for any multilayer wall)
- Similarly, a procedure should be implemented to generate the hourly factors of the radiant time series, which involves using a zone heat balance method (by a computer program) or a data base for weighting factors
- Not suitable for manual calculations because of the involved computerized calculations to find the periodic response factors for the related different walls, and the radiant time factors for the a specific construction

Walls, roof and floor

Conduction heat fluxes are found from knowing the sol-air temperature and the periodic response factors for the walls.

Internal heat gains

Heat gains from people, lighting and equipment are estimated from tables for the specified components.

Splitting the radiative and convective portions

Since this method is based on the procedure of collection of all heat gains and then splitting them into radiative and convective portions, following is a list of percentage radiative and percentage convective portions of the heat gains, respectively:

- Wall and window conduction 63%, 37%
- Roof conduction 84%, 16%
- People 70%, 30%
- Lighting 67%, 33%
- Equipment, 20%, 80%
- Transmitted solar heat gain 100%, 0%
- Absorbed solar heat gain, 63%, 37%
- Infiltration 0%, 100%

2.1.3 CLTD/SCL/CLF Method

(Cooling load temperature difference/solar cooling load factor/cooling load factor). Accurate simulation of a proposed building design without correct data is impossible.

However, the many variables required for consideration in good simulation often become tedious and force designers to spend valuable time consulting tables and performing repetitive calculations. This is especially true for the Transfer Function Method (TFM) which pertains this repetitive nature and is identified by ASHRAE as the fundamental methodology of peak cooling load calculation. Transfer function method was first introduced in 1967. This procedure is based on response factors and the interplay of heat exchange between various surfaces and sources of heat. Transfer functions are based on two concepts:

The conduction transfer factors (CTF) & the weighting factors (WF).

The CTF are used to describe the heat flux at the inside wall, roof, partition, ceiling or floor as a function of previous values of the heat flux and previous values of inside and outside temperatures. The WF is used to translate the zone heat gain into cooling loads. As a result of the TFM complexity, ASHRAE developed a method called the cooling load temperature difference/cooling load factor CLTD/CLF (1975) which was derived from the TFM. The CLTD/CLF method depends on tabulated data to simplify its operation for manual use. This method was subjected to several revisions to accommodate the problems that rose from approximations and limitations to cover more accurate tabulated data. Due to this, ASHRAE published the cooling load temperature difference/solar cooling load/cooling load factor (CLTD/SCL/CLF) method (ASHRAE 1993, 1997), which is a revised CLTD/CLF method. This method is a simplified method, simpler than the RTS method.

Main Features

- Zone air temperature is assumed constant.
- Three factors are used to deal with the conduction heat gains, solar heat gains, and internal gains, which are respectively, CLTD/SCL/CLF. Those factors are calculated using the transfer function method (TFM) which yields cooling loads for standard environmental conditions and zone types.

Assumptions

- Sol-air temperature is assumed for the outside air
- Zone air temperature is taken as a constant

Methodology

This method uses tabulated CLTD (cooling load temperature difference), SCL (solar cooling load factor), and CLF (cooling load factor) data. CLTDs, SCLs, and CLFs all include the effect of (1) time-lag in conductive heat gain through opaque exterior surfaces and (2) time delay by thermal storage in converting radiant heat gain to cooling load. This simplification allows cooling load to be calculated manually. The data are generated by weighting factors and conduction transfer coefficients, which yield cooling loads for standard environmental conditions and zone types. The cooling loads are then normalized for the specified zone conditions, so it would be possible to calculate the cooling loads for each hour with a simple multiplication.

Hourly sol-air temperature values are presented in tables for various orientations of a surface for 21 July at 40 N latitude, with standard surface absorption factor for light and dark colored surfaces. The sol-air temperatures are listed for a given air temperature cycle.

Adjustments can be introduced for other dates, latitudes and air temperature cycles.

When this method is used in conjunction with custom tables generated by appropriate Computer software, and for buildings where external shading is not significant, it can be expected that it will produce results very close to that produced by the TFM. When the Printed tables are used, some additional errors are introduced. However, in many cases the Accuracy should be sufficient.

Advantages

- A simplified method.
- More suitable to be a manual calculation method including spreadsheet use.
- The zone response can be accounted for more accurately by using ample available printed tables covering most common constructions, or using a computer program to generate a set of tables for a specific zone, latitude and month.

Disadvantages

- The adjustment for a wall or roof which is not matching one of the listed groups is one source of errors.
- The inaccuracy of correcting for other months and latitudes.

Walls, roof and floor

Hourly CLTD values for 40 N latitude are tabulated for outdoor maximum temperature of 35°C with mean temperature of 29.5°C and daily range of 11.6°C. An adjustment equation is indicated to correct for conditions other than the mentioned base case.

Windows

The absorbed and then conductive portion of the radiation through the windows is treated like the walls where CLTD values for standard glazing are available to find the cooling load. For the transmitted radiative portion, the cooling load is calculated by the solar cooling load SCL factor which accounts for both the solar heat gain and the zone response. The fraction of solar gain that is transmitted is accounted for with a shading coefficient (SC) to correct for transmittance and shading devices.

Internal heat gains

Cooling load factors CLF are used to account for the time lag of the cooling load caused by the building mass which is generated by heat from internal sources (lighting, people, appliances, etc.). The hourly heat gains for people, lights and equipment are specified.

The weighting factors equation determines the CLF factors where a CLF represents the fraction of the heat gain that is converted to cooling load. The CLF for people load is dealing with the sensible part of the occupancy heat load, where the latent part is taken as instant loads. The CLF is a function of the time people spend in the conditioned space and time elapsed since first entering the space. The appropriate CLF is selected from tables according to zone type, occupancy period, and number of hours after entering.

CLF data for lighting is tabulated also. They were calculated according to the assumptions that (1) the conditioned space temperature is continuously maintained at a constant value, and (2) the cooling load and power input to the lights eventually become equal if the lights are turned on for long enough.

For power driven equipments, the radiant part of the sensible heat gain is delayed in becoming cooling load, and CLF values from tables are used in the same manner for other components.

2.1.4 The admittance method

For climatic reasons, the application of air conditioning to office spaces in the UK in the post war period lagged behind that of the U.S. It was not the need for the calculation of cooling load, but with the need to calculate maximum temperatures in natural and mechanically ventilated buildings that the Admittance method was first developed. Unlike ASHRAE, whose methods were directed toward assuming a constant internal temperature, CIBSE primary aim was to demonstrate the role of internal mass in modifying room temperature.

Another difference between the earlier U.S. calculation methods and the U. K. methods is that the dynamic model of the room fabric is integrated with a simplified zone convection and radiant heat transfer model. The room model is known as the environmental temperature model. Two internal nodes were defined, one of which was the air node, the other being an environmental temperature node. The likely reason for this is that, the U. K. methods were originally developed for calculating heating loads and with a preponderance of hydronic radiant heating systems, a combined radiant and convective temperature was more useful than the zone air temperature. In comparison, the U. S. methods were developed for cooling, where the load was met by an air-based system. Consequently, the load at the air point was of more interest.

Main features

- The admittance method allows the calculation of overheating temperature for the room, or peak cooling load calculation for a constant (internal) environmental temperature.
- Three factors are involved in this method. The decrement factor is used to account for the heat transmission through the structure due to external excitations. For the internal heat gains, two other factors are used, the fabric admittance and the related surface factors. The values of these factors are calculated using a frequency domain solution to the unsteady conduction equation with assumed sinusoidal input fluctuations.

Assumptions

- Sol-air temperature is assumed for the outside air
- The concept of the environmental temperature t_{ei} is used to account for the combined radiant and convective heat exchange with interior room surfaces.
- Its concept is similar to that of the sol-air temperature used to define external surface heat transfer in that a combined radiant and convective conductance is used.
- Assuming sinusoidal external excitation (with a period of 24 hours) for the heat flow transmitted through the structure. Sinusoidal internal excitation is also assumed on the zone fabric.
- The thermal network is defined by three nodal temperatures (sol-air, environmental, and air temperatures).

Methodology

This method uses heat balance equations to find load components. The calculation of cooling loads with the admittance method is in two-part process in that the mean component (steady state) of the heat gains are treated separately from the fluctuating components (transient). The latter components are dealt with in three ways according to their excitations, which are: external due to variations in the sol-air temperature, internal excitation by either variations in internal environmental temperature, or radiant heat fluxes at the internal surfaces. The response to these excitations is determined by the decrement factor, admittance, and the surface factor, respectively. Each has a time lag/lead associated with it. The values of these factors are derived from thermo physical properties of the fabric layers using a frequency domain solution to the unsteady conduction equation with assumed sinusoidal input fluctuations. After the mean component and the fluctuating component of the load are calculated, they are added to give the hourly cooling load.

Advantages

- Simple.
- No iteration is needed.
- Allows the calculation in two modes: overheating calculation (floating temperature), and a peak cooling load calculation.

Disadvantages

- The environmental temperature model was lately shown to have several logical flaws.
- Tends to under predict lighter weight zones cooling loads and over predict loads for heavyweight zones.
- There are some criticisms about the treatment of solar gains because of the reliance on solar gain factors, and the treatment of the radiant part of the internal gains which causes underproductions.

Walls, roof and floor

Conduction gains are always added directly to the environmental temperature node. The main component of the conduction gains can be pre-calculated for each hour. This is because these gains are calculated based on analytical solution to sinusoidally excited conduction heat flow.

Internal heat gains and windows

The internal heat gain and the solar gain through glazing are calculated, and are then divided into radiant and convective portions, where they are added to the environmental temperature node and the air temperature node. This is done for the mean and the fluctuating components.

Treatment of solar gains

The (CIBSE, 1986) prescribes two methods of calculating solar gains using the admittance method:

1. If an overheating calculation is required (in this case zone temperature may float freely), the total incident radiation is divided into its mean and fluctuating components. A solar gain factor and an alternating solar gain factor then multiplying the mean and fluctuating components. These factors are constant and are defined for energy transfer to both air and environmental temperature points. The solar gain is then given by multiplying the glazing area by the incident irradiation by the appropriate solar gain factor. The alternating component is shifted in time by a lag associated with alternating solar gain factor. These solar gain factors are tabulated in the Guide for various windows/blind types in heavy and light buildings located in London.

2. If a peak cooling load is required, then tabulated loads due to solar gains in either a typical heavyweight or lightweight zone are given in the Guide. The tabulated loads have been calculated using a detailed model for solar transmission through and absorption by glazing. This is done for various latitudes and window/shading combinations. In either case, the solar gains are assumed to be evenly distributed over all the internal surfaces. Both of these approaches have been developed for manual calculation, but by relying on tabulated values, lack generality.

2.1.5 VDI 2078 Cooling load calculations of air-conditioned rooms

The air temperature of a room is defined by the sum of all influencing convective heat flows. Heat flows due to radiation affect the air temperature only after absorption at a room enclosure surface, delaying heat storage there, and subsequent conversion into convectively transmitted heat. Plants with high radiation heat removal (cooling ceilings) are not dealt with under the basic approach of this regulation, and require separate consideration as they change the building storage and the operative temperatures. Due to increased importance of surface cooling systems, the regulation plans to treat cooling loads under such circumstances in detail in future editions.

Two methods are presented in (VDI, 1996) for the calculation of cooling load, the abridged (short-cut) method and the Computer method. The Computer method was introduced in order to extend the scope of the application to virtually any boundary condition (variable shade, variable room temperature …etc.). In which, the room reactions can be found independent of the load by the "convolution mathematical process" using the control functions step response (transfer function)/pulse response (weighting factor). It is thus possible to register the room reactions to any boundary condition within the framework of the calculation formulation. This requires greater expense in calculation terms.

Main features

The Abridged method assumes a constant temperature inside the room, while the computer method can handle different boundary conditions.

For the Abridged method, cooling load factors are used to convert the internal heat gains to cooling loads. For the cooling load caused by the heat conduction through walls and roofs, an equivalent temperature difference is used in the basic form of the conduction heat transfer equation.

For the computerized method, weighing factors have to be found for the room reaction. With the convolution principle, the value of an output time function at a particular time is calculated by the integration of the product of the weighting function by the input time function at a previous time period. By using a recursive filter, the number of necessary weighting factors can be considerably reduced. Where the transfer function is known, the weighting factors can be determined.

Following are the mean features of the simpler method are presented, the Abridged Method:

Assumptions

- Assumes periodic internal and external daily load variation cycles
- For calculation of cooling loads for fixed boundary conditions (constant room temperature)

Methodology

The transient heat transfer through the external loads and roofs are brought together using equivalent temperature difference tables for standard loads which characterize the wall or roof by an attenuation factor and time-shift. The storage effects in the room due to the internal and external radiation loads are taken into account by the concept of the time-variant cooling load factors. The cooling load factors take into consideration the delay and attenuation of the heat transmitted to the room air in comparison with the heat load due to radiation in the room.

Advantages

- Simple.
- Involves straight forward calculations.

Disadvantages

- Data given are for Central European conditions (e.g. solar radiation at 50º latitude, true local times, mean atmospheric turbidity… etc.).
- Corrections and adjustments are required for parameters deviating from the standard conditions defined to evaluate the tables for the equivalent temperature difference and the cooling load factors which includes inside and outside temperatures, surface characteristics, constructions…etc.

Walls, roof and floor

The effects of the unsteady state heat flow through the external walls and roofs are incorporated by implementation of the equivalent temperature difference. The wall and roof structures are classified into six construction classes according to their attenuation and delay behavior. If other structures exist a time adjustment must be introduced in order to account for such deviations. Corrections for the equivalent temperature differences are introduced for external surfaces which have absorption factors and emissivities deviating from standard boundary conditions.

Internal heat gains and windows

The cooling load factors from external solar radiation through windows and internal loads due to people, lighting and machines are treated with cooling load factor. Four room classes are defined according to their thermal storage capacity (very light, light, medium, and heavy). A typical room dimensions are defined. The cooling load factor for internal gains is multiplied by the internal heat gains to find the corresponding component of the cooling load. Similar method applies for the external loads.

2.2 Refrigeration Loads

Types of refrigeration loads are shown in Figure (2.1)

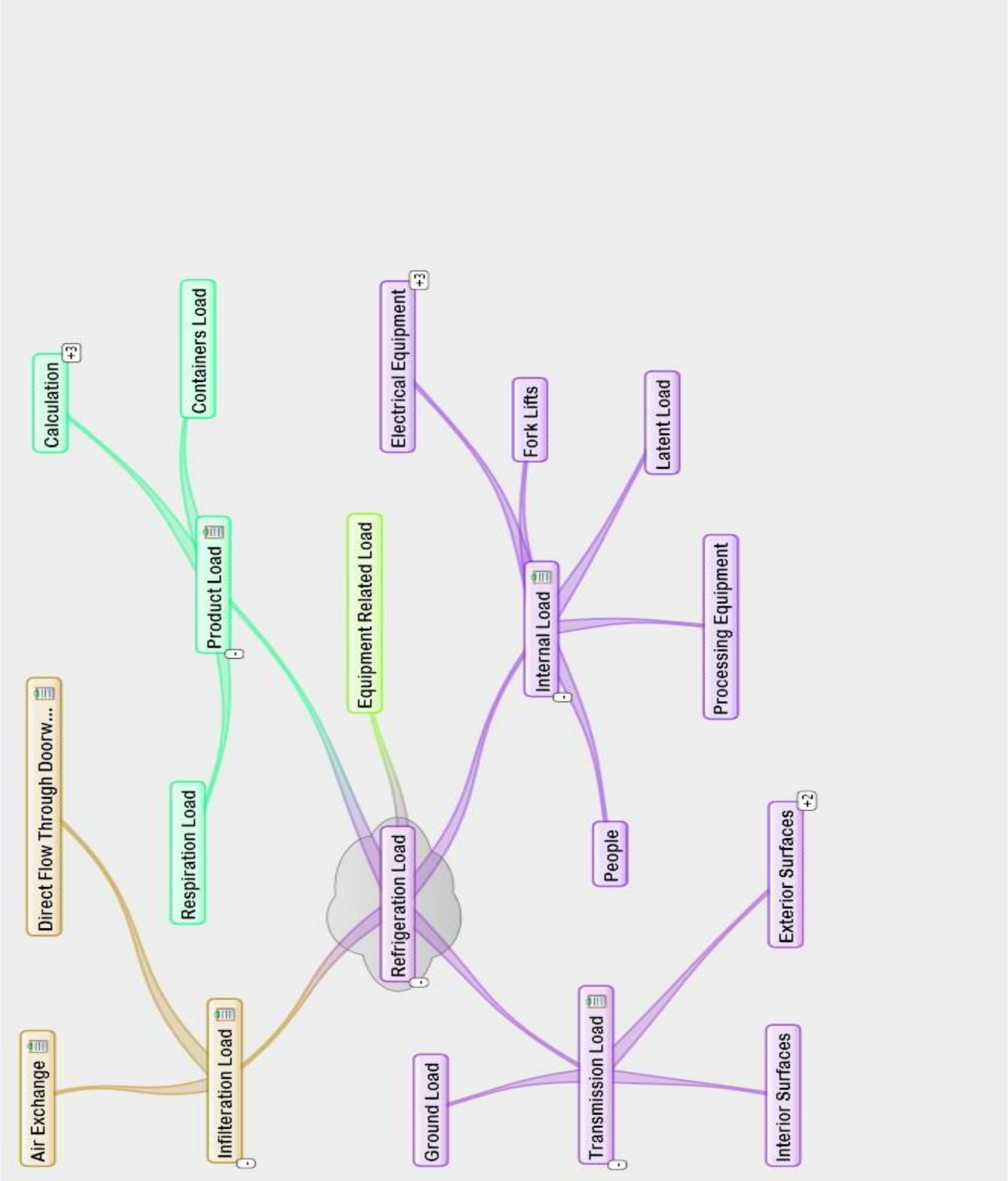


Figure (2.1) Refrigeration Load Types

2.2.1 Transmission load

Time delay effect

The energy absorbed by walls, floor, furniture, etc., contributes to space cooling load only after a time lag, with some part of this energy still present and reradiating after the heat sources have been switched off or are no longer present as shown in Figure (2.2)

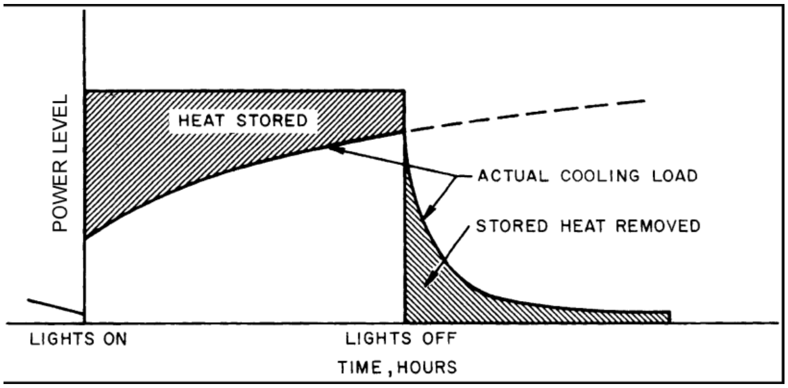


Figure (2.2) Time Delay Effect (ASHRAE, 2001)

Heat gain through exterior surfaces

Heat gain through exterior opaque surfaces is derived from the same elements of solar radiation and thermal gradient as that for fenestration areas. It differs primarily as a function of the mass and nature of the wall or roof construction, since those elements affect the rate of conductive heat transfer through the composite assembly to the interior surface.

Sol-Air temperature

Sol-Air temperature is the temperature of the outdoor air that in the absence of all radiation changes gives the same rate of heat entry into the surface as would the combination of incident solar radiation, radiant energy exchange with the sky and other outdoor surroundings, and convective heat exchange with the outdoor air.

Heat flux into exterior sunlit surfaces

The heat balance at a sunlit surface gives the heat flux into the surface q/A as:

$$\frac{q}{A} = \alpha E_t + h_\circ (t_\circ - t_s) - \varepsilon \Delta R \qquad 2.1$$

Where

α = absorptions of surface for solar radiation

E_t = total solar radqiation incident on surface, W/(m^2·K)

h_o = coefficient of heat transfer by long-wave radiation and convection at outer surface, W/(m^2·K)

t_o = outdoor air temperature, °C

t_s = surface temperature, °C

ε = hemispherical emittance of surface

ΔR = difference between long-wave radiation incident on surface from sky and surroundings and radiation emitted by blackbody at outdoor air temperature,W/m^2

Assuming the rate of heat transfer can be expressed in terms of the sol-air temperature t_e,

$$\frac{q}{A} = h_\circ \left(t_e - t_s\right) \qquad 2.2$$

And from previous equations

$$t_e = t_\circ + \frac{\alpha E_t}{h_\circ} - \frac{\varepsilon \Delta R}{h_\circ} \qquad 2.3$$

Horizontal surfaces

For horizontal surfaces that receive long wave radiation from the sky only, an appropriate value of ΔR is about 63 W/m^2,

So that if $\varepsilon = 1$ and $h_o = 17$ W/ (m^2·K), the long-wave correction term is about 4 K and the correction itself thus 4 K.

Vertical surfaces

Because vertical surfaces receive long-wave radiation from the ground and surrounding buildings as well as from the sky, accurate ΔR values are difficult to determine. When solar radiation intensity is high, surfaces of terrestrial objects usually have a higher temperature than the outdoor air; thus, their long wave radiation compensates to some extent for the sky's low emittance. Therefore, it is common practice to assume $\varepsilon \Delta R = 0$ for vertical surfaces.

Surface colors

Sol-air temperature values are given for two values of the parameter α / h_0 the value of 0.026 is appropriate for a light colored surface, while 0.052 represents the usual maximum value for this parameter (i.e., for a dark-colored surface or any surface for which the permanent lightness cannot reliably be anticipated).

2.2.2 Heat gain through interior surfaces

Whenever a conditioned space is adjacent to a space with a different temperature, transfer of heat through the separating physical section must be considered. The heat transfer rate is given by

$$q = UA(t_b - t_i) \qquad 2.4$$

Where

q = heat transfer rate, W
U = coefficient of overall heat transfer between adjacent and conditioned space, W/(m^2·K)
A = area of separating section concerned, m^2

t_b = average air temperature in adjacent space, °C
t_i = air temperature in conditioned space, °C

2.2.3 Radiant time series (RTS) method

The radiant time series (RTS) method is a simplified method for performing design cooling load calculations that is derived from the heat balance (HB) method. It effectively replaces all other simplified (non-heat-balance) methods, such as the transfer function method (TFM), the cooling load temperature difference/cooling load factor (CLTD/CLF) method, and the total equivalent temperature difference/time averaging (TETD/TA) method.

This method was developed to offer a method that is rigorous, yet does not require iterative calculations, and that quantifies each component's contribution to the total cooling load. In addition, it is desirable for the user to be able to inspect and compare the coefficients for different construction and zone types in a form illustrating their relative effect on the result. These characteristics of the RTS method make it easier to apply engineering judgment during the cooling load calculation process.

The RTS method is suitable for peak design load calculations, but it should not be used for annual energy simulations because of its inherent limiting assumptions. Although simple in concept, RTS involves too many calculations to be used practically as a manual method, although it can easily be implemented in a simple computerized spreadsheet, as illustrated in the examples. For a manual cooling load calculation method, refer to the CLTD/CLF method in Chapter 28 of (ASHRAE, 1997).

Assumptions and principles

Design cooling loads are based on the assumption of steady periodic conditions (i.e., the design day's weather, occupancy, and heat gain conditions are identical to those for preceding days such that the loads repeat on an identical 24 h cyclical basis). Thus, the heat gain for a particular component at a particular hour is the same as 24 h prior, which is the same as 48 h prior, etc. This assumption is the basis for the RTS derivation from the HB method.

Cooling load calculations must address two time-delay effects inherent in building heat transfer processes:

- Delay of conductive heat gain through opaque massive exterior surfaces (walls, roofs, or floors)
- Delay of radiative heat gain conversion to cooling loads.

Exterior walls and roofs conduct heat because of temperature differences between outdoor and indoor air. In addition, solar energy on exterior surfaces is absorbed, and then transferred by conduction to the building interior. Because of the mass and thermal capacity of the wall or roof construction materials, there is a substantial time delay in heat input at the exterior surface becoming heat gain at the interior surface.

As described in the section on Cooling Load Principles, most heat sources transfer energy to a room by a combination of convection and radiation. The convective part of heat gain immediately becomes cooling load. The radiative part must first be absorbed by the finishes and mass of the interior room surfaces, and becomes cooling load only when it is later transferred by convection from those surfaces to the room air. Thus, radiant heat gains become cooling loads over a delayed period of time. The RTS Method calculation process is shown in Figure (2.3).

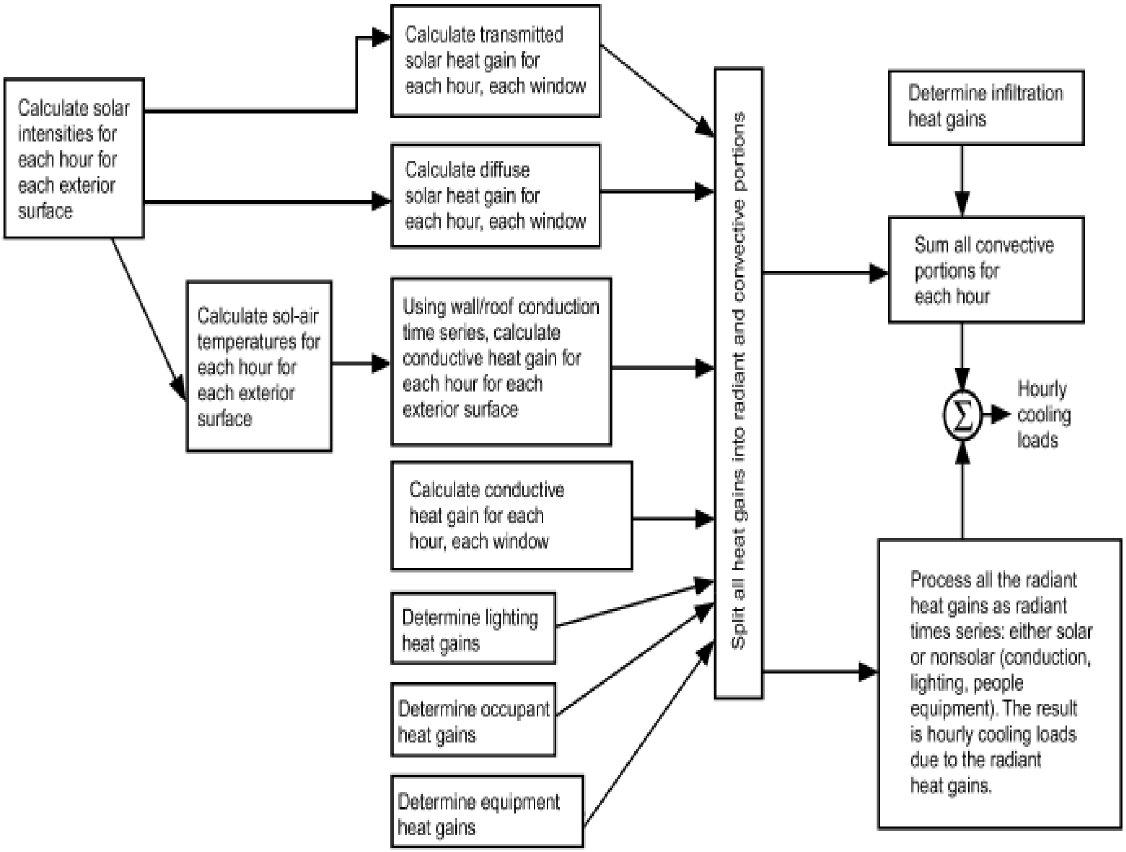


Figure (2.3) Schematic Diagram of RTS (ASHRAE, 2001)

Calculating conductive heat gain using conduction time series

In the RTS method, conduction through exterior walls and roofs is calculated using conduction time series (CTS). Wall and roof conductive heat input at the exterior is defined by the familiar conduction equation as

$$q_{i,q-n} = UA(t_{e,q-n} - t_{rc}) \qquad 2.5$$

Where

$q_{i,q-n}$ = conductive heat input for the surface n hours ago, W
U = overall heat transfer coefficient for the surface, W/(m^2·K)
A = surface area, m^2
t_e,q-n = sol-air temperature n hours ago, °C
t_{rc} = presumed constant room air temperature, °C

Conductive heat gain through walls or roofs can be calculated using conductive heat inputs for the current hours and past 23 h and conduction time series:

$$q_q = c_0 q_{i,q} + c_{1qi,q-1} + c_{2qi,q-2} + c_{3qi,q-3} + \ldots + c_{23qi,q-23} \qquad 2.6$$

Where

q_q = hourly conductive heat gain for the surface, W
q_i,q = heat input for the current hour
$q_{i,q-n}$ = heat input n hours ago
c_0, c_1, etc. = conduction time factors

Conduction time factors values were derived by first calculating conduction transfer functions for each example wall and roof construction. Assuming steady-periodic heat input conditions for design load calculations allows conduction transfer functions to be reformulated into periodic response factors. The periodic response factors were further simplified by dividing the 24 periodic response factors by the respective overall wall or roof U-factor to form the conduction time series (CTS).

The conduction time factors can then be used in previous Equation and provide a means for comparison of time delay characteristics between different wall and roof constructions.

Heat gains calculated for walls or roofs using periodic response factors (and thus CTS) are identical to those calculated using conduction transfer functions for the steady periodic conditions assumed in design cooling load calculations. The methodology for calculating periodic response factors from conduction transfer functions was originally developed as part of ASHRAE *Research Project* RP-875.

The tedious calculations involved make a simple computer spreadsheet or other computer software a useful labor saver.

2.2.4 Product load

The primary refrigeration load from products brought into and kept in the refrigerated space are the heat that must be removed to reduce the product temperature to storage temperature and the heat generated by products in storage, mainly fruits and vegetables.

The quantity of heat to be removed can be calculated based on (ASHRAE, 2002):

Heat removed to cool from the initial temperature to some lower temperature above freezing:

$$Q_1 = mc_1(t_1 - t_2) \tag{2.7}$$

Heat removed to cool from the initial temperature to the freezing point of the product:

$$Q_2 = mc_2(t_1 - t_f) \tag{2.8}$$

Heat removed to freeze the product:

$$Q_3 = mh_{if} \tag{2.9}$$

Heat removed to freeze from the freezing point to the final temperature below the freezing point:

$$Q_4 = mc_2(t_{f1} - t_3) \tag{2.10}$$

Where

Q_1, Q_2, Q_3, Q_4 = heat removed, kJ
m = mass of product, kg
c_1 = specific heat of product above freezing, kJ/(kg·K)
t_1 = initial temperature of product above freezing, °C
t_2 = lower temperature of product above freezing, °C
t_f = freezing temperature of product, °C
h_{if} = latent heat of fusion of product, kJ/kg
c_2 = specific heat of product below freezing, kJ/(kg·K)
t_3 = final temperature of product below freezing, °C

The refrigeration capacity required for products brought into storage is determined from the time allotted for heat removal and assumes that the product is properly exposed to remove the heat in that time. The calculation is

$$q = \frac{Q_2 + Q_3 + Q_4}{3600n} \tag{2.11}$$

Where

q = average cooling load, kW
n = allotted time, h

Previous Equation only applies to uniform entry of the product into storage. The refrigeration load created by non-uniform loading of a warm product may be much greater over a short period.

A product's latent heat of fusion may be estimated by multiplying the water content of the product (expressed as a decimal) by the latent heat of fusion of water, which is 334 kJ/kg. Most food products freeze in the range of −3 to −0.5°C.

When the exact freezing temperature is not known, assume that it is −2°C.

2.2.5 Internal load

Electrical equipment

All electrical energy dissipated in the refrigerated space (from lights, motors, heaters, and other equipment) must be included in the internal heat load.

Fork lifts

Forklifts in some facilities can be a large and variable contributor to the load. While many fork lifts may be in a space at one time, they do not all operate at the same energy level. For example, the energy used by a fork lift while it is elevating or lowering forks is different than when it is moving.

Processing equipment

Grinding, mixing, or even cooking equipment may be in the refrigerated areas of food processing plants. Other heat sources include equipment for packaging, glue melting, or shrink wrapping. Another possible load is the makeup air for equipment that exhausts air from a refrigerated space.

2.2.6 People

People add to the heat load, and this load varies depending on such factors as room temperature, type of work being done, type of clothing worn, and size of the person. Heat load from a person qp may be estimated as

$$q_p = 272 - 6t \tag{2.12}$$

Where t is the temperature of the refrigerated space

When people first enter storage they bring in additional surface heat. As a result, when many people enter and leave every few minutes the load is greater and must be adjusted. A conservative adjustment would be to multiply the values.

2.2.7 Latent load

The latent heat component of the internal load is usually very small compared to the total refrigeration load and is customarily regarded as all sensible heat in the total load summary.

However, the latent heat component should be calculated where water is involved in processing or cleaning.

2.2.8 Infiltration air load

Heat gain from infiltration air and associated equipment loads can amount to more than half the total refrigeration load of distribution warehouses and similar applications.

2.2.9 Infiltration by air exchange

Infiltration most commonly occurs because of air density differences between rooms. For a typical case where the air mass flowing in equals the air mass flowing out minus any condensed moisture, the room must be sealed except at the opening in question.

2.2.10 Infiltration by direct flow through doorways

A negative pressure created elsewhere in the building because of mechanical air exhaust without mechanical air replenishment is a common cause of heat gain from infiltration of warm air. In refrigerated spaces equipped with constantly or frequently open doorways or other through-the-room passageways, this air flows directly through the doorway.

2.2.11 Equipment related load

Heat gain associated with the operation of the refrigeration equipment consists essentially of the following:

Fan motor heat where forced-air circulation is used. Reheat where humidity control is part of the cooling. Heat from defrosting where the refrigeration coil operates at a temperature below freezing and must be defrosted periodically, regardless of the room temperature.

Fan motor heat must be computed based on the actual electrical energy consumed during operation. The fan motor is mounted in the airstream on many cooling units with propeller fans because the cold air extends the power range of the motor. For example, a standard motor in a −23°C freezer operates satisfactorily at a 25% overload to the rated (nameplate) power. The heat gain from the fan motors should be based on the actual run time. Generally, fans on cooling units are operated continuously except during the defrost period. But, increasingly, fans are being cycled on and off to control temperature and save energy.

(ASHRAE, 2001) Characterized and quantified the heat load associated with defrosting using hot gas. Other common defrost methods use electricity or water. Generally, the heat gain from a cooling unit with electric defrost is greater than the same unit with hot gas defrost, and heat gain from a unit with water defrost is even less. The moisture that evaporates into the space during the defrost cycle must also be added to the refrigeration load.

Some of the heat from defrosting is added only to the refrigerant and the rest is added to the space. To accurately select refrigeration equipment, a distinction should be made between those equipment heat loads that are in the refrigerated space and those that are introduced directly to the refrigerating fluid.

Equipment heat gain is usually small at space temperatures above approximately −1°C. Where reheat or other artificial loads are not imposed, total equipment heat gain is about 5% or less of the total load. However, equipment heat gain becomes a major portion of the total load at freezer temperatures. For example, at –30°C the theoretical contribution to total refrigeration load due to fan power and coil defrosting alone can exceed, for many cases, 15% of the total load. This percentage assumes proper control of defrosting so that the space is not heated excessively.

Chapter (3)

DESIGN CONDITIONS

3.1 Indoor Conditions

3.1.1 Cooling

Because products deteriorate much faster at warm than at low temperatures, rapid removal of field heat by cooling to the storage

Temperature substantially increases the market life of the product.

3.1.2 Deterioration

The environment in which harvested produce is placed may greatly influence not only the respiration rate but other changes and products formed in related chemical reactions. In fruits, these changes are described as ripening. In many fruits, such as bananas and pears, the process of ripening is required to develop the maximum edible quality. However, as ripening continues, deterioration begins and the fruit softens, loses flavor, and eventually undergoes tissue breakdown.

In addition to deterioration after harvest by biochemical changes within the product, desiccation and diseases caused by microorganisms are also important. Deterioration rate is greatly influenced by temperature and is reduced as temperature is lowered. The specific relationships between temperature and deterioration rate vary considerably among commodities and diseases.

For example, fruit that remains marketable for 12 days when stored at −1°C may last only 12/3 = 4 days when stored at 5°C. The best temperature to slow down deterioration is the lowest temperature that can safely be maintained without freezing the commodity, which is 0.5 to 1 K above the freezing point of the fruit or vegetable, some produce will not tolerate low storage temperatures. Severe physiological disorders that develop because of exposure to low but not freezing temperatures are classed as **chilling injury**. The banana is a classic example of a fruit displaying chilling injury symptoms, and storage temperatures must be elevated accordingly. Certain apple varieties exhibit this characteristic, and prolonged storage must be held at a temperature well above that usually recommended.

3.1.3 Desiccation

Water loss, which causes a product to shrivel, is a physical factor related to the evaporative potential of air, and can be expressed as follows:

$$P_D = \frac{p(100-\phi)}{100} \tag{3.1}$$

Where

P_D = vapor pressure deficit, indicating combined influence of temperature and relative humidity on evaporative potential of air

P = vapor pressure of water at given temperature

ϕ = relative humidity, percent

For example, comparing the evaporative potential of air in storage rooms at 0°C and 10°C dry bulb, with 90% RH in each room, the vapor pressure deficit at 0°C is 60 Pa, while at 0°C it is 120 Pa. Thus, if all other factors are equal, commodities tend to lose water twice as fast at 0°C dry bulb as at 0°C at the same RH values. For equal water loss at the two temperatures, the RH has to be maintained at 95% at 10°C in comparison to 90% at 0°C. These comparisons are not precise because the water in fruits and vegetables contains a sufficient quantity of dissolved sugars and other chemical materials to cause the water to be in equilibrium with water vapor in the air at 98 to 99% RH instead of 100% RH. Lowering the vapor pressure deficit by lowering the air temperature is an excellent means of reducing water loss during storage. Other important factors in desiccation include product size, surface- to-volume ratio, the kind of protective surface on the product, and air movement. Of these, the storage operator can control only the last, and this control is greatly influenced by the container, kind of pack, and stacking arrangement (i.e., the ability of the air to move past individual fruits and vegetables).

As a rule, shrivelling does not become a serious market problem until fruits lose about 5% of their mass, but any loss reduces the salable amount. Moisture losses of 3 to 6% are enough to cause a marked loss of quality for many kinds of produce. A few kinds may lose 10% moisture and still be marketable, although some trimming may be necessary, as for stored cabbage.

The vapor pressure deficit cannot be kept at a zero level, but it should be maintained as low as possible. A maximum of about 60 Pa, which corresponds to 90% RH at 0°C, is recommended. Some compromise is possible for short storage periods. In many instances, the refrigerated storage operator may find it desirable to add moisture, or, in special cases, the owner of the produce may find it desirable to use moisture barriers such as film liners.

Table 3.1, and Table 3.2, are holding the food storage conditions as recommended by (ASHRAE, 2001)

Table 3.1 Storage Requirements of Vegetables, Fresh, Fruits, and Melons (ASHRAE, 2001)

Common Name (Other Common Name)	Scientific Name	Storage Temp., °C	Rel. Humidity, %	Highest Freezing Temp., °C	Ethylene Production Rate[a]	Ethylene Sensitivity[b]	Respiration Rate[c]	Approx. Postharvest Life	Observations and Beneficial CA[d] Conditions
Acerola (Barbados cherry)	*Malpighia glabra*	0	85 to 90	–1.4				6 to 8 weeks	
African horned melon (kiwano)	*Cucumis africanus*	13 to 15	90		Low	Moderate		6 months	
Amaranth (pigweed)	*Amaranthus* spp.	0 to 2	95 to 100		Very low	Moderate		10 to 14 days	
Anise (fennel)	*Foeniculum vulgare*	0 to 2	90 to 95	–1.1				2 to 3 weeks	
Apple									
Not chilling sensitive	*Malus pumila*	–1	90 to 95	–1.5	Very high	High	Low	3 to 6 months	2 to 3% O_2 1 to 2% CO_2
Chilling sensitive	*Malus pumila* cv. Yellow Newton, Grimes golden, McIntosh	4	90 to 95	–1.5	Very high	High	Low	1 to 2 months	2 to 3% O_2 1 to 2% CO_2
Apricot	*Prunus armeniaca*	–0.5 to 0	90 to 95	–1.1	Moderate	Moderate	Low	1 to 3 weeks	2 to 3% O_2 2 to 3% CO_2
Artichokes									
Chinese	*Stachys affinia*	0	90 to 95		Very low	Very Low		1 to 2 weeks	
Globe	*Cynara acolymus*	0	95 to 100	–1.2	Very low	Low	High	2 to 3 weeks	2 to 3% O_2 3 to 5% CO_2
Jerusalem	*Helianthus tuberosus*	–0.5 to 0	90 to 95	–2.5	Very low	Low	Low	4 months	
Arugula	*Eruca vesicaria* var. *sativa*	0	95 to 100		Very low	High	Moderate	7 to 10 days	
Asian pear (nashi)	*Pyrus serotina* *P. pyrifolia*	1	90 to 95	–1.6	High	High	Low	4 to 6 months	
Asparagus, green or white	*Asparagus officinalis*	2.5	95 to 100	–0.6	Very low	Moderate	Very high	2 to 3 weeks	5 to 12% CO_2
Atemoya	*Annona squamosa* x *A. cherimola*	13	85 to 90		High	High		4 to 6 weeks	3 to 5% O_2 5 to 10% CO_2
Avocado									
Fuchs, Pollock	*Persea americana* cv. Fuchs, Pollock	13	85 to 90	–0.9	High	High	Moderate	2 weeks	
Fuerte, Hass	*Persea americana* cv. Fuerte, Hass	3 to 7	85 to 90	–1.6	High	High	Moderate	2 to 4 weeks	2 to 5% O_2 3 to 10% CO_2
Lula, Booth	*Persea americana* cv. Lula, Booth	4	90 to 95	–0.9	High	High	Moderate	4 to 8 weeks	
Babaco (mountain papaya)	*Carica candamarcensis*	7	85 to 90					1 to 3 weeks	
Banana	*Musa paradisiaca* var. *sapientum*	13 to 15	90 to 95	–0.8	Moderate	High	Low	1 to 4 weeks	2 to 5% O_2 2 to 5% CO_2
Barbados cherry	see Acerola								
Beans									
Fava (broad)	*Vicia faba*	0	90 to 95					1 to 2 weeks	
Lima	*Phaseolous lunatus*	5 to 6	95	–0.6	Low	Moderate	Moderate	5 to 7 days	
Long (yard-long)	*Vigna sesquipedalis*	4 to 7	90 to 95		Low	Moderate		7 to 10 days	
Snap (wax, green)	*Phaseolus vulgaris*	4 to 7	95	–0.7	Low	Moderate	Moderate	7 to 10 days	2 to 3% O_2 4 to 7% CO_2
Winged	*Psophocarpus tetragonolobus*	10	90					4 weeks	
Beet									
Bunched	*Beta vulgaris*	0	98 to 100	–0.4	Very low	Low	Low	10 to 14 days	
Topped	*Beta vulgaris*	0	98 to 100	–0.9	Very low	Low	Low	4 months	
Berries									
Blackberry	*Rubus* spp.	–0.5 to 0	90 to 95	–0.8	Low	Low	Moderate	3 to 6 days	5 to 10% O_2 15 to 20% CO_2

Table 3.1 Storage Requirements of Vegetables, Fresh, Fruits, and Melons (Cont.)

Common Name (Other Common Name)	Scientific Name	Storage Temp., °C	Rel. Humid-ity, %	Highest Freezing Temp., °C	Ethylene Produc-tion Rate[a]	Ethylene Sensitivity[b]	Respi-ration Rate[c]	Approx. Postharvest Life	Observations and Beneficial CA[d] Conditions
Blueberry	*Vaccinium corymbosum*	–0.5 to 0	90 to 95	–1.3	Low	Low	Low	10 to 18 days	2 to 5% O_2 12 to 20% CO_2
Cranberry	*Vaccinium macrocrpon*	2 to 5	90 to 95	–0.9	Low	Low	Low	8 to 16 weeks	1 to 2% O_2 0 to 5% CO_2
Dewberry	*Rubus* spp.	–0.5 to 0	90 to 95	–1.3	Low	Low		2 to 3 days	
Elderberry	*Rubus* spp.	–0.5 to 0	90 to 95	–0.9	Low	Low		5 to 14 days	
Loganberry	*Rubus* spp.	–0.5 to 0	90 to 95	–1.3	Low	Low		2 to 3 days	
Raspberry	*Rubus idaeus*	–0.5 to 0	90 to 95	–0.9	Low	Low	Moderate	3 to 6 days	5 to 10% O_2 15 to 20% CO_2
Strawberry	*Fragaria* spp.	0	90 to 95	–0.8	Low	Low	Low	7 to 10 days	5 to 10% O_2 15 to 20% CO_2
Bittermelon (bitter gourd)	*Momordica*	10 to 12	85 to 90		Low	Moderate	Moderate	2 to 3 weeks	2 to 3% O_2 5% CO_2
Black salsify (scorzonera)	*Scorzonera hispanica*	0 to 1	95 to 98		Very low	Low		6 months	
Bok choy	*Brassica chinensis*	0	95 to 100		Very low	High		3 weeks	
Breadfruit	*Artocarpus altilis*	13 to 15	85 to 90					2 to 6 weeks	
Broccoli	*Brassica oleracea* var. *Italica*	0	95 to 100	–0.6	Very low	High	Moderate	10 to 14 days	1 to 2% O_2 5 to 10% CO_2
Brussels sprouts	*Brassica oleracea* var. *Gemnifera*	0	95 to 100	–0.8	Very low	High	Moderate	3 to 5 weeks	1 to 2% O_2 5 to 7% CO_2
Cabbage									
Chinese (Napa)	*Brassica campestris* var. *Pekinensis*	0	95 to 100	–0.9	Very low	High	Low	2 to 3 months	1 to 2% O_2 0 to 6% CO_2
Common, early crop	*Brassica oleracea* var. *Capitata*	0	98 to 100	–0.9	Very low	High	Low	3 to 6 weeks	
Common, late crop	*Brassica oleracea* var. *Capitata*	0	95 to 100	–0.9	Very low	High	Low	5 to 6 months	3 to 5% O_2 3 to 7% CO_2
Cactus leaves (nopalitos)	*Opuntia* spp.	5 to 10	90 to 95		Very low	Moderate		2 to 3 weeks	
Cactus fruit (prickly pear fruit)	*Opuntia* spp.	5	85 to 90	–1.8	Very low	Moderate		3 weeks	
Caimito	see Sapotes								
Calamondin	see Citrus								
Canistel	see Sapotes								
Carambola (starfruit)	*Averrhoa carambola*	9 to 10	85 to 90	–1.2			Low	3 to 4 weeks	
Carrot									
Topped	*Daucus carota*	0	98 to 100	–1.4	Very low	High	Low	6 to 8 months	No CA benefit
Bunched, immature	*Daucus carota*	0	98 to 100	–1.4	Very low	High	Moderate	10 to 14 days	Ethylene causes bitterness
Cashew, apple	*Anacardium occidentale*	0 to 2	85 to 90					5 weeks	
Cassava (yucca, manioc)	*Manihot esculenta*	0 to 5	85 to 90		Very low	Low	Low	1 to 2 months	No CA benefit
Cauliflower	*Brassica oleracea* var. *Botrytis*	0	95 to 98	–0.8	Very low	High	Moderate	3 to 4 weeks	2 to 5% O_2 2 to 5% CO_2
Celeriac	*Apium graveolens* var. *Rapaceum*	0	98 to 100	–0.9	Very low	Low	Low	6 to 8 months	2 to 4% O_2 2 to 3% CO_2
Celery	*Apium graveolens* var. *Dulce*	0	98 to 100	–0.5	Very low	Moderate	Low	1 to 2 months	1 to 4% O_2 3 to 5% CO_2
Chard	*Beta vulgaris* var. *Cida*	0	95 to 100		Very low	High		10 to 14 days	
Chayote	*Sechium edule*	7	85 to 90				Low	4 to 6 weeks	
Cherimoya (custard apple)	*Annona cherimola*	13	90 to 95	–2.2	High	High	Very high	2 to 4 weeks	3 to 5% O_2 5 to 10% CO_2
Cherries									
Sour	*Prunus cerasus*	0	90 to 95	–1.7			Low	3 to 7 days	3 to 10% O_2 10 to 12% CO_2
Sweet	*Prunus avium*	–1 to 0	90 to 95	–2.1			Low	2 to 3 weeks	10 to 20% O_2 20 to 25% CO_2
Chicory	see Endive								

Table 3.1 Storage Requirements of Vegetables, Fresh, Fruits, and Melons (Cont.)

Common Name (Other Common Name)	Scientific Name	Storage Temp., °C	Rel. Humidity, %	Highest Freezing Temp., °C	Ethylene Production Rate[a]	Ethylene Sensitivity[b]	Respiration Rate[c]	Approx. Postharvest Life	Observations and Beneficial CA[d] Conditions
Chiles	see Peppers								
Chinese broccoli (gailan)	*Brassica alboglabra*	0	95 to 100		Very low	High		10 to 14 days	
Chives	*Allium schoenoprasum*	0	95 to 100		Very low	High		2 to 3 weeks	
Cilantro (Chinese parsley)	*Coriandrum sativum*	0 to 2	95 to 100		Very low	High	High	2 weeks	
Citrus									
Calamondin orange	*Citrus reticulta* x. *Fortunella* spp.	9 to 10	90	–2.0			Low	2 weeks	
Grapefruit									
CA, AZ, dry areas	*Citrus paradisi*	14 to 15	85 to 90	–1.1	Very low	Moderate	Low	6 to 8 weeks	3 to 10% O_2 5 to 10% CO_2
FL, humid areas	*Citrus paradisi*	10 to 15	85 to 90	–1.1	Very low	Moderate	Low	6 to 8 weeks	3 to 10% O_2 5 to 10% CO_2
Kumquat	*Fortunella japponica*	4	90 to 95				Low	2 to 4 weeks	
Lemon	*Citrus limon*	10 to 13	85 to 90	–1.4			Low	1 to 6 months	5 to 10% O_2 0 to 10% CO_2 Store at 0 to 4°C for < 1 mo.
Lime (Mexican, Tahitian or Persian)	*Citrus aurantifolia; C. latifolia*	9 to 10	85 to 90	–1.6			Low	6 to 8 weeks	5 to 10% O_2 0 to 10% CO_2
Orange									
CA, AZ, dry areas	*Citrus sinensis*	3 to 9	85 to 90	–0.8	Very low	Moderate	Low	3 to 8 weeks	5 to 10% O_2 0 to 5% CO_2
FL, humid areas	*Citrus sinensis*	0 to 2	85 to 90	–0.8	Very low	Moderate	Low	8 to 12 weeks	5 to 10% O_2 0 to 5% CO_2
Blood orange	*Citrus sinensis*	4 to 7	90 to 95	–0.8			Low	3 to 8 weeks	5 to 10% O_2 0 to 5% CO_2
Seville (sour)	*Citrus aurantium*	10	85 to 90	–0.8	Low		Low	12 weeks	
Pummelo	*Citrus grandis*	7 to 9	85 to 90	–1.6			Low	12 weeks	
Tangelo (minneola)	*Citrus reticulata* x *paradisi*	7 to 10	85 to 95	–0.9			Low		
Tangerine (mandarin)	*Citrus reticulata*	4 to 7	90 to 95	–1.1	Very low	Moderate	Low	2 to 4 weeks	
Coconut	*Cocos nucifera*	0 to 2	89 to 85	–0.9				1 to 2 months	
Collards and kale	*Brassica oleracea* var. *Acephala*	0	95 to 100	–0.5	Very low	High	High	10 to 14 days	
Corn, sweet and baby	*Zea mays*	0	95 to 98	–0.6	Very low	Low	High	5 to 8 days	2 to 4% O_2 5 to 10% CO_2
Cucumber	*Cucumis sativus*	10 to 12	85 to 90	–0.5	Low	High	Low	10 to 14 days	3 to 5% O_2 0 to 5% CO_2
Cucumber, pickling	*Cucumis sativus*	4	95 to 100		Low	High		7 days	3 to 5% O_2 3 to 5% CO_2
Currants	*Ribes sativum; R. nigrum; R. rubrum*	–0.5 to 0	90 to 95	–1.0	Low	Low		1 to 4 weeks	
Custard apple	see Cherimoya								
Daikon (Oriental radish)	*Raphanus sativus*	0 to 1	95 to 100		Very low	Low		4 months	
Dasheen	see Taro								
Date	*Phoenix dactylifera*	–18 to 0	75	–15.7	Very low	Low	Low	6 to 12 months	
Dill	see Herbs								
Durian	*Durio zibethinus*	4 to 6	85 to 90					6 to 8 weeks	3 to 5% O_2 5 to 15% CO_2
Eggplant	*Solanum melongena*	10 to 12	90 to 95	–0.8	Low	Moderate	Low	1 to 2 weeks	3 to 5% O_2 0% CO_2
Endive (escaraole)	*Cichorium endivia*	0	95 to 100	–0.1	Very low	Moderate	High	2 to 4 weeks	

Table 3.1 Storage Requirements of Vegetables, Fresh, Fruits, and Melons (Cont.)

Common Name (Other Common Name)	Scientific Name	Storage Temp., °C	Rel. Humidity, %	Highest Freezing Temp., °C	Ethylene Production Rate^a	Ethylene Sensitivity^b	Respiration Rate^c	Approx. Postharvest Life	Observations and Beneficial CA^d Conditions
Belgian endive (Witloof chicory)	*Cichorium intybus*	2 to 3	95 to 98		Very low	Moderate		2 to 4 weeks	Light causes greening 3 to 4% O_2 4 to 5% C_2
Feijoa (pineapple guava)	*Feijoa selloiana*	5 to 10	90		Moderate	Low		2 to 3 weeks	
Fennel	see Anise								
Fig, fresh	*Ficus carica*	–0.5 to 0	85 to 90	–2.4	Moderate	Low	Low	7 to 10 days	5 to 10% O_2 15 to 20% CO_2
Garlic	*Allium sativum*	0	65 to 70	–0.8	Very low	Low	Low	6 to 7 months	0.5% O_2 5 to 10% CO_2
Ginger	*Zingiber officinale*	13	65		Very low	Low		6 months	No CA benefit
Gooseberry	*Ribes grossularia*	–0.5 to 0	90 to 95	–1.1	Low	Low	Low	3 to 4 weeks	
Granadilla	see Passionfruit								
Grape^e									
Table grape	*Vitis vinifera*	–0.5 to 0	90 to 95	–2.7	Very low	Low	Low	2 to 8 weeks	2 to 5% O_2 1 to 3% CO_2 to 4 weeks: 5 to 10% O_2 10 to 15% CO_2
American grape	*Vitis labrusca*	–1 to –0.5	90 to 95	–1.4	Very low	Low	Low	1 to 6 months	
Grapefruit	see Citrus						Low		
Guava	*Psidium guajava*	5 to 10	90		Low	Moderate	Moderate	2 to 3 weeks	
Herbs, fresh culinary									5 to 10% O_2 5 to 10% CO_2
Basil	*Ocimum basilicum*	10	90		Very low	High		7 days	
Chives	*Allium schoenorasum*	0	95 to 100	–0.9	Low	Moderate			
Dill	*Anethum graveolens*	0	95 to 100	–0.7	Very low	High		1 to 2 weeks	
Epazote	*Chenopodium ambrosioides*	0 to 5	90 to 95		Very low	Moderate		1 to 2 weeks	
Mint	*Menta* spp.	0	95 to 100		Very low	High		2 to 3 weeks	
Oregano	*Origanum vulgare*	0 to 5	90 to 95		Very low	Moderate		1 to 2 weeks	
Parsley	*Petroselinum crispum*	0	95 to 100	–1.1	Very low	High	Very high	1 to 2 months	
Perilla (shiso)	*Perilla frutescens*	10	95		Very low	Moderate		7 days	
Sage	*Salvia officinalis*	0	90 to 95					2 to 3 weeks	
Thyme	*Thymus vulgaris*	0	90 to 95					2 to 3 weeks	
Horseradish	*Amoracia rusticana*	–1 to 0	98 to 100	–1.8	Very low	Low		10 to 12 months	
Husk tomato	see Tomatillo								
Jaboticaba	*Myrciaria cauliflora = Eugenia cauliflora*	13 to 15	90 to 95					2 to 3 days	
Jackfruit	*Artocarpus heterophyllus*	13	85 to 90		Moderate	Moderate		2 to 6 weeks	
Jerusalem artichoke	see Artichoke								
Jicama (yambean)	*Pachyrrhizus erosus*	13 to 18	85 to 90		Very low	Low	Low	1 to 2 months	
Jujube (Chinese date)	*Ziziphus jujuba*	2.5 to 10	85 to 90	–1.6	Low	Moderate		1 month	
Kaki	see Persimmon								
Kale	see Collards and kale								
Kiwano	see African horned melon								
Kiwifruit (Chinese gooseberry)	*Actinidia chinensis*	0	90 to 95	–0.9	Low	High	Low	3 to 5 months	1 to 2% O_2 3 to 5% CO_2
Kohlrabi	*Brassica oleracea* var. *Gongylodes*	0	98 to 100	–1.0	Very low	Low	Low	2 to 3 months	
Lo Bok	see Daikon								
Langsat (lanzone)	*Aglaia* sp.; *Lansium* sp.	11 to 14	85 to 90					2 weeks	

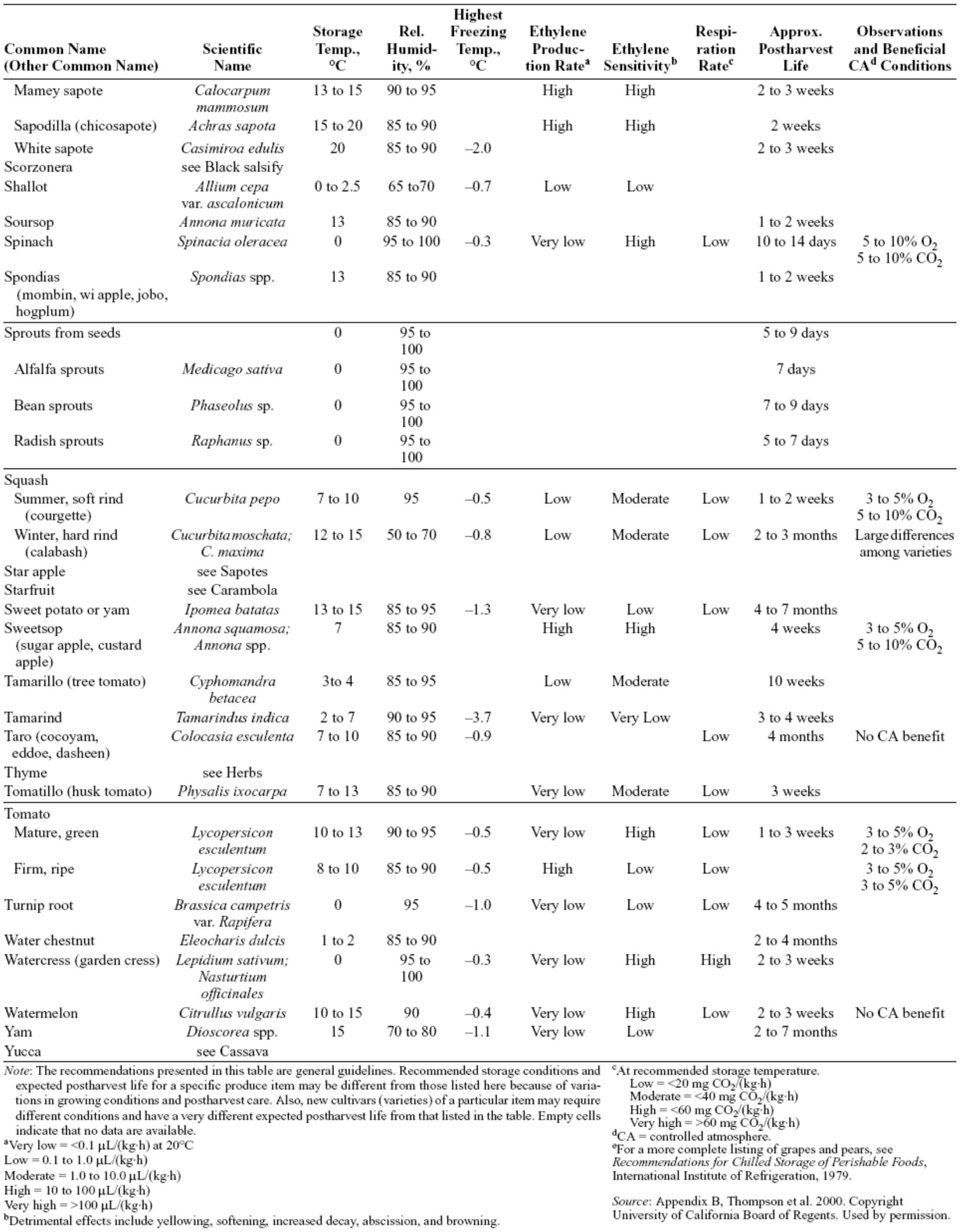
Table 3.1 Storage Requirements of Vegetables, Fresh, Fruits, and Melons (Cont.)

Common Name (Other Common Name)	Scientific Name	Storage Temp., °C	Rel. Humidity, %	Highest Freezing Temp., °C	Ethylene Production Rate[a]	Ethylene Sensitivity[b]	Respiration Rate[c]	Approx. Postharvest Life	Observations and Beneficial CA[d] Conditions
Leafy greens									
Cool-season	various	0	95 to 100	–0.6	Very low	High		10 to 14 days	
Warm-season	various	7 to 10	95 to 100	–0.6	Very low	High		5 to 7 days	
Leek	*Allium porrum*	0	95 to 100	–0.7	Very low	Moderate	Moderate	2 months	1 to 2% O_2 2 to 5% CO_2
Lemon	see Citrus								
Lettuce	*Lactuca sativa*	0	98 to 100	–0.2	Very low	High	Low	2 to 3 weeks	2 to 5% O_2 0% CO_2
Lime	see Citrus								
Longan	*Dimocarpus longan* = *Euphoria longan*	1 to 2	90 to 95	–2.4				3 to 5 weeks	
Loquat	*Eriobotrya japonica*	0	90	–1.9				3 weeks	
Luffa (Chinese okra)	*Luffa* spp.	10 to 12	90 to 95		Low	Moderate		1 to 2 weeks	
Lychee (litchi)	*Litchi chinensis*	1 to 2	90 to 95		Moderate	Moderate	Low	3 to 5 weeks	3 to 5% O_2 3 to 5% CO_2
Malanga (tania, new cocoyam)	*Xanthosoma sagittifolium*	7	70 to 80		Very low	Low		3 months	
Mamey	see Sapotes								
Mandarin	see Citrus								
Mango	*Mangifera indica*	13	85 to 90	–1.4	Moderate	Moderate	Moderate	2 to 3 weeks	3 to 5% O_2 5 to 10% CO_2
Mangosteen	*Garcinia mangostana*	13	85 to 90		Moderate	High		2 to 4 weeks	
Melons									
Cantaloupes and other netted melons	*Cucurbita melo* var. *reticulatus*	2 to 5	95	–1.2	High	Moderate	Low	2 to 3 weeks	3 to 5% O_2 10 to 15% CO_2
Casaba	*Cucurbita melo*	7 to 10	85 to 90	–1.0	Low	Low		3 to 4 weeks	3 to 5% O_2 5 to 10% CO_2
Crenshaw	*Cucurbita melo*	7 to 10	85 to 90	–1.1	Moderate	High		2 to 3 weeks	3 to 5% O_2 5 to 10% CO_2
Honeydew, orange-flesh	*Cucurbita melo*	5 to 10	85 to 90	–1.1	Moderate	High	Low	3 to 4 weeks	3 to 5% O_2 5 to 10% CO_2
Persian	*Cucurbita melo*	7 to 10	85 to 90	–0.8	Moderate	High		2 to 3 weeks	3 to 5% O_2 5 to 10% CO_2
Mint	see Herbs								
Mombin	see Spondias								
Mushrooms	*Agaricus*, other genera	0	90	–0.9	Very low	Moderate	High	7 to 14 days	3 to 21% O_2 15 to 15% CO_2
Mustard greens	*Brassica juncea*	0	90 to 95		Very low	High		7 to 14 days	
Nashi	see Asian pear								
Nectarine	*Prunus persica*	–0.5 to 0	90 to 95	–0.9	Moderate	Moderate	Low	2 to 4 weeks	1 to 2% O_2 3 to 5% CO_2 Internal breakdown at 3 to 10°C
Okra	*Abelmoschus esculentus*	7 to 10	90 to 95	–1.8	Low	Moderate	High	7 to 10 days	Air 4 to 10% CO_2
Olives, fresh	*Olea europea*	5 to 10	85 to 90	–1.4	Low	Moderate	Low	4 to 6 weeks	2 to 3% O_2 0 to 1% CO_2
Onion									
Mature bulbs, dry	*Allium cepa*	0	65 to 70	–0.8	Very low	Low	Low	1 to 8 months	1 to 3% O_2 5 to 10% CO_2
Green	*Allium cepa*	0	95 to 100	–0.9	Low	High	Moderate	3 weeks	2 to 4% O_2 10 to 20% CO_2
Orange	see Citrus								
Papaya	*Carica papaya*	7 to 13	85 to 90	–0.9			Low	1 to 3 weeks	2 to 5% O_2 5 to 8% CO_2
Parsley	see Herbs								

Table 3.1 Storage Requirements of Vegetables, Fresh, Fruits, and Melons (Cont.)

Common Name (Other Common Name)	Scientific Name	Storage Temp., °C	Rel. Humid- ity, %	Highest Freezing Temp., °C	Ethylene Produc- tion Rate[a]	Ethylene Sensitivity[b]	Respi- ration Rate[c]	Approx. Postharvest Life	Observations and Beneficial CA[d] Conditions
Parsnips	*Pastinaca sativa*	0	95 to 100	–0.9	Very low	High	Low	4 to 6 months	Ethylene causes bitterness
Passionfruit	*Passiflora* spp.	10	85 to 90		Very high	Moderate	Very high	3 to 4 weeks	
Peach	*Prunus persica*	–0.5 to 0	90 to 95	–0.9	High	Moderate	Low	2 to 4 weeks	1 to 2% O_2 3 to 5% CO_2 Internal breakdown at 3 to 10°C
Pear, American[e]	*Pyrus communis*	–1.5 to –0.5	90 to 95	–1.7	High	High	Low	2 to 7 months	Cultivar variations 1 to 3% O_2 0 to 5% CO_2
Peas									
In pods (snow, snap, and sugar peas)	*Pisum sativum*	0 to 1	90 to 98	–0.6	Very low	Moderate	Very high	1 to 2 weeks	2 to 3% O_2 2 to 3% CO_2
Southern peas (cowpeas)	*Vigna sinensis = V. unguiculata*	4 to 5	95					6 to 8 days	
Pepino (melon pear)	*Solanum muricatum*	5 to 10	95		Low	Moderate		4 weeks	
Peppers									
Bell pepper or paprika	*Capsicum annuum*	7 to 10	95 to 98	–0.7	Low	Low	Low	2 to 3 weeks	2 to 5% O_2 2 to 5% CO_2
Hot peppers (chiles)	*Capsicum annuum* and *C. frutescens*	5 to 10	85 to 95	–0.7	Low	Moderate		2 to 3 weeks	3 to 5% O_2 5 to 10% CO_2
Persimmon (kaki)	*Dispyros kaki*								3 to 5% O_2 5 to 8% CO_2
Fuyu	*Dispyros kaki* var. *Fuyu*	0	90 to 95	–2.2	Low	High	Low	1 to 3 months	
Hachiya	*Dispyros kaki* var. *Hachiya*	0	90 to 95	–2.2	Low	High	Low	2 to 3 months	
Pineapple	*Ananas comosus*	7 to 13	85 to 90	–1.1	Low	Low	Low	2 to 4 weeks	2 to 5% O_2 5 to 10% CO_2
Plantain	*Musa paradisiaca* var. *paradisiaca*	13 to 15	90 to 95	–0.8	Low	High		1 to 5 weeks	
Plums and prunes	*Prunus domestica*	–0.5 to 0	90 to 95	–0.8	Moderate	Moderate	Low	2 to 5 weeks	1 to 2% O_2 0 to 5% CO_2
Pomegranate	*Punica granatum*	5	90 to 95	–3.0			Low	2 to 3 months	3 to 5% O_2 5 to 10% CO_2
Potato									
Early crop	*Solanum tuberosum*	10 to 15	90 to 95	–0.8	Very low	Moderate	Low	10 to 14 days	No CA benefit
Late crop	*Solanum tuberosum*	4 to 12	95 to 98	–0.8	Very low	Moderate	Low	5 to 10 months	No CA benefit
Pumpkin	*Cucurbita maxima*	12 to 15	50 to 70	–0.8	Very low	Moderate	Low	2 to 3 months	
Quince	*Cydonia oblonga*	–0.5 to 0	90	–2.0	Low	High		2 to 3 months	
Raddichio	*Cichorium intybus*	0 to 1	95 to 100					3 to 4 weeks	
Radish	*Raphanus sativus*	0	95 to 100	–0.7	Very low	Low	Low	1 to 2 months	1 to 2% O_2 2 to 3% CO_2
Rambutan	*Nephelium lappaceum*	12	90 to 95		High	High		1 to 3 weeks	3 to 5% O_2 7 to 12% CO_2
Rhubarb	*Rheum rhaponticum*	0	95 to 100	–0.9	Very low	Low	Low	2 to 4 weeks	
Rutabaga	*Brassica napus* var. *Napobrassica*	0	98 to 100	–1.1	Very low	Low	Low	4 to 6 months	
Sage	see Herbs								
Salsify (vegetable oyster)	*Trapopogon porrifolius*	0	95 to 98	–1.1	Very low	Low	Low	2 to 4 months	
Sapotes									
Black sapote	*Diospyros ebenaster*	13 to 15	85 to 90	–2.3				2 to 3 weeks	
Caimito (star apple)	*Chrysophyllum cainito*	3	90	–1.2				3 weeks	
Canistel (eggfruit)	*Pouteria campechiana*	13 to 15	85 to 90	–1.8				3 weeks	

Table 3.1 Storage Requirements of Vegetables, Fresh, Fruits, and Melons (Cont.)



Common Name (Other Common Name)	Scientific Name	Storage Temp., °C	Rel. Humidity, %	Highest Freezing Temp., °C	Ethylene Production Rate[a]	Ethylene Sensitivity[b]	Respiration Rate[c]	Approx. Postharvest Life	Observations and Beneficial CA[d] Conditions
Mamey sapote	*Calocarpum mammosum*	13 to 15	90 to 95		High	High		2 to 3 weeks	
Sapodilla (chicosapote)	*Achras sapota*	15 to 20	85 to 90		High	High		2 weeks	
White sapote	*Casimiroa edulis*	20	85 to 90	–2.0				2 to 3 weeks	
Scorzonera	see Black salsify								
Shallot	*Allium cepa* var. *ascalonicum*	0 to 2.5	65 to70	–0.7	Low	Low			
Soursop	*Annona muricata*	13	85 to 90					1 to 2 weeks	
Spinach	*Spinacia oleracea*	0	95 to 100	–0.3	Very low	High	Low	10 to 14 days	5 to 10% O_2 5 to 10% CO_2
Spondias (mombin, wi apple, jobo, hogplum)	*Spondias* spp.	13	85 to 90					1 to 2 weeks	
Sprouts from seeds		0	95 to 100					5 to 9 days	
Alfalfa sprouts	*Medicago sativa*	0	95 to 100					7 days	
Bean sprouts	*Phaseolus* sp.	0	95 to 100					7 to 9 days	
Radish sprouts	*Raphanus* sp.	0	95 to 100					5 to 7 days	
Squash									
Summer, soft rind (courgette)	*Cucurbita pepo*	7 to 10	95	–0.5	Low	Moderate	Low	1 to 2 weeks	3 to 5% O_2 5 to 10% CO_2
Winter, hard rind (calabash)	*Cucurbita moschata; C. maxima*	12 to 15	50 to 70	–0.8	Low	Moderate	Low	2 to 3 months	Large differences among varieties
Star apple	see Sapotes								
Starfruit	see Carambola								
Sweet potato or yam	*Ipomea batatas*	13 to 15	85 to 95	–1.3	Very low	Low	Low	4 to 7 months	
Sweetsop (sugar apple, custard apple)	*Annona squamosa; Annona* spp.	7	85 to 90		High	High		4 weeks	3 to 5% O_2 5 to 10% CO_2
Tamarillo (tree tomato)	*Cyphomandra betacea*	3to 4	85 to 95		Low	Moderate		10 weeks	
Tamarind	*Tamarindus indica*	2 to 7	90 to 95	–3.7	Very low	Very Low		3 to 4 weeks	
Taro (cocoyam, eddoe, dasheen)	*Colocasia esculenta*	7 to 10	85 to 90	–0.9			Low	4 months	No CA benefit
Thyme	see Herbs								
Tomatillo (husk tomato)	*Physalis ixocarpa*	7 to 13	85 to 90		Very low	Moderate	Low	3 weeks	
Tomato									
Mature, green	*Lycopersicon esculentum*	10 to 13	90 to 95	–0.5	Very low	High	Low	1 to 3 weeks	3 to 5% O_2 2 to 3% CO_2
Firm, ripe	*Lycopersicon esculentum*	8 to 10	85 to 90	–0.5	High	Low	Low		3 to 5% O_2 3 to 5% CO_2
Turnip root	*Brassica campetris* var. *Rapifera*	0	95	–1.0	Very low	Low	Low	4 to 5 months	
Water chestnut	*Eleocharis dulcis*	1 to 2	85 to 90					2 to 4 months	
Watercress (garden cress)	*Lepidium sativum; Nasturtium officinales*	0	95 to 100	–0.3	Very low	High	High	2 to 3 weeks	
Watermelon	*Citrullus vulgaris*	10 to 15	90	–0.4	Very low	High	Low	2 to 3 weeks	No CA benefit
Yam	*Dioscorea* spp.	15	70 to 80	–1.1	Very low	Low		2 to 7 months	
Yucca	see Cassava								

Note: The recommendations presented in this table are general guidelines. Recommended storage conditions and expected postharvest life for a specific produce item may be different from those listed here because of variations in growing conditions and postharvest care. Also, new cultivars (varieties) of a particular item may require different conditions and have a very different expected postharvest life from that listed in the table. Empty cells indicate that no data are available.

[a] Very low = <0.1 μL/(kg·h) at 20°C
Low = 0.1 to 1.0 μL/(kg·h)
Moderate = 1.0 to 10.0 μL/(kg·h)
High = 10 to 100 μL/(kg·h)
Very high = >100 μL/(kg·h)

[b] Detrimental effects include yellowing, softening, increased decay, abscission, and browning.

[c] At recommended storage temperature.
Low = <20 mg CO_2/(kg·h)
Moderate = <40 mg CO_2/(kg·h)
High = <60 mg CO_2/(kg·h)
Very high = >60 mg CO_2/(kg·h)

[d] CA = controlled atmosphere.

[e] For a more complete listing of grapes and pears, see *Recommendations for Chilled Storage of Perishable Foods*, International Institute of Refrigeration, 1979.

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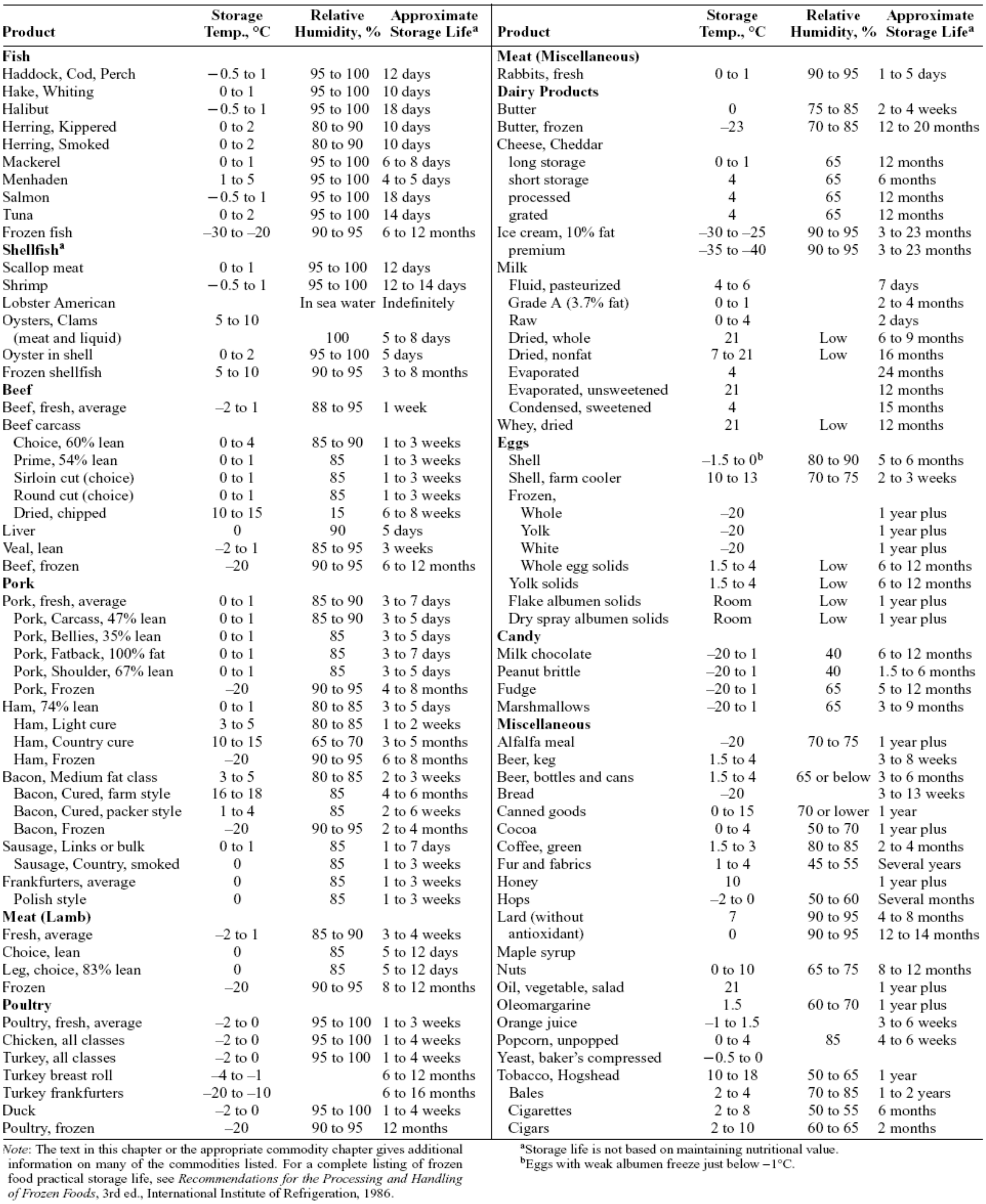
Table 3.2 Storage Requirements of Other Perishable Products (ASHRAE, 2001)



Product	Storage Temp., °C	Relative Humidity, %	Approximate Storage Life[a]
Fish			
Haddock, Cod, Perch	−0.5 to 1	95 to 100	12 days
Hake, Whiting	0 to 1	95 to 100	10 days
Halibut	−0.5 to 1	95 to 100	18 days
Herring, Kippered	0 to 2	80 to 90	10 days
Herring, Smoked	0 to 2	80 to 90	10 days
Mackerel	0 to 1	95 to 100	6 to 8 days
Menhaden	1 to 5	95 to 100	4 to 5 days
Salmon	−0.5 to 1	95 to 100	18 days
Tuna	0 to 2	95 to 100	14 days
Frozen fish	–30 to –20	90 to 95	6 to 12 months
Shellfish[a]			
Scallop meat	0 to 1	95 to 100	12 days
Shrimp	−0.5 to 1	95 to 100	12 to 14 days
Lobster American		In sea water	Indefinitely
Oysters, Clams	5 to 10		
(meat and liquid)		100	5 to 8 days
Oyster in shell	0 to 2	95 to 100	5 days
Frozen shellfish	5 to 10	90 to 95	3 to 8 months
Beef			
Beef, fresh, average	–2 to 1	88 to 95	1 week
Beef carcass			
Choice, 60% lean	0 to 4	85 to 90	1 to 3 weeks
Prime, 54% lean	0 to 1	85	1 to 3 weeks
Sirloin cut (choice)	0 to 1	85	1 to 3 weeks
Round cut (choice)	0 to 1	85	1 to 3 weeks
Dried, chipped	10 to 15	15	6 to 8 weeks
Liver	0	90	5 days
Veal, lean	–2 to 1	85 to 95	3 weeks
Beef, frozen	–20	90 to 95	6 to 12 months
Pork			
Pork, fresh, average	0 to 1	85 to 90	3 to 7 days
Pork, Carcass, 47% lean	0 to 1	85 to 90	3 to 5 days
Pork, Bellies, 35% lean	0 to 1	85	3 to 5 days
Pork, Fatback, 100% fat	0 to 1	85	3 to 7 days
Pork, Shoulder, 67% lean	0 to 1	85	3 to 5 days
Pork, Frozen	–20	90 to 95	4 to 8 months
Ham, 74% lean	0 to 1	80 to 85	3 to 5 days
Ham, Light cure	3 to 5	80 to 85	1 to 2 weeks
Ham, Country cure	10 to 15	65 to 70	3 to 5 months
Ham, Frozen	–20	90 to 95	6 to 8 months
Bacon, Medium fat class	3 to 5	80 to 85	2 to 3 weeks
Bacon, Cured, farm style	16 to 18	85	4 to 6 months
Bacon, Cured, packer style	1 to 4	85	2 to 6 weeks
Bacon, Frozen	–20	90 to 95	2 to 4 months
Sausage, Links or bulk	0 to 1	85	1 to 7 days
Sausage, Country, smoked	0	85	1 to 3 weeks
Frankfurters, average	0	85	1 to 3 weeks
Polish style	0	85	1 to 3 weeks
Meat (Lamb)			
Fresh, average	–2 to 1	85 to 90	3 to 4 weeks
Choice, lean	0	85	5 to 12 days
Leg, choice, 83% lean	0	85	5 to 12 days
Frozen	–20	90 to 95	8 to 12 months
Poultry			
Poultry, fresh, average	–2 to 0	95 to 100	1 to 3 weeks
Chicken, all classes	–2 to 0	95 to 100	1 to 4 weeks
Turkey, all classes	–2 to 0	95 to 100	1 to 4 weeks
Turkey breast roll	–4 to –1		6 to 12 months
Turkey frankfurters	–20 to –10		6 to 16 months
Duck	–2 to 0	95 to 100	1 to 4 weeks
Poultry, frozen	–20	90 to 95	12 months
Meat (Miscellaneous)			
Rabbits, fresh	0 to 1	90 to 95	1 to 5 days
Dairy Products			
Butter	0	75 to 85	2 to 4 weeks
Butter, frozen	–23	70 to 85	12 to 20 months
Cheese, Cheddar			
long storage	0 to 1	65	12 months
short storage	4	65	6 months
processed	4	65	12 months
grated	4	65	12 months
Ice cream, 10% fat	–30 to –25	90 to 95	3 to 23 months
premium	–35 to –40	90 to 95	3 to 23 months
Milk			
Fluid, pasteurized	4 to 6		7 days
Grade A (3.7% fat)	0 to 1		2 to 4 months
Raw	0 to 4		2 days
Dried, whole	21	Low	6 to 9 months
Dried, nonfat	7 to 21	Low	16 months
Evaporated	4		24 months
Evaporated, unsweetened	21		12 months
Condensed, sweetened	4		15 months
Whey, dried	21	Low	12 months
Eggs			
Shell	–1.5 to 0[b]	80 to 90	5 to 6 months
Shell, farm cooler	10 to 13	70 to 75	2 to 3 weeks
Frozen,			
Whole	–20		1 year plus
Yolk	–20		1 year plus
White	–20		1 year plus
Whole egg solids	1.5 to 4	Low	6 to 12 months
Yolk solids	1.5 to 4	Low	6 to 12 months
Flake albumen solids	Room	Low	1 year plus
Dry spray albumen solids	Room	Low	1 year plus
Candy			
Milk chocolate	–20 to 1	40	6 to 12 months
Peanut brittle	–20 to 1	40	1.5 to 6 months
Fudge	–20 to 1	65	5 to 12 months
Marshmallows	–20 to 1	65	3 to 9 months
Miscellaneous			
Alfalfa meal	–20	70 to 75	1 year plus
Beer, keg	1.5 to 4		3 to 8 weeks
Beer, bottles and cans	1.5 to 4	65 or below	3 to 6 months
Bread	–20		3 to 13 weeks
Canned goods	0 to 15	70 or lower	1 year
Cocoa	0 to 4	50 to 70	1 year plus
Coffee, green	1.5 to 3	80 to 85	2 to 4 months
Fur and fabrics	1 to 4	45 to 55	Several years
Honey	10		1 year plus
Hops	–2 to 0	50 to 60	Several months
Lard (without	7	90 to 95	4 to 8 months
antioxidant)	0	90 to 95	12 to 14 months
Maple syrup			
Nuts	0 to 10	65 to 75	8 to 12 months
Oil, vegetable, salad	21		1 year plus
Oleomargarine	1.5	60 to 70	1 year plus
Orange juice	–1 to 1.5		3 to 6 weeks
Popcorn, unpopped	0 to 4	85	4 to 6 weeks
Yeast, baker's compressed	−0.5 to 0		
Tobacco, Hogshead	10 to 18	50 to 65	1 year
Bales	2 to 4	70 to 85	1 to 2 years
Cigarettes	2 to 8	50 to 55	6 months
Cigars	2 to 10	60 to 65	2 months

Note: The text in this chapter or the appropriate commodity chapter gives additional information on many of the commodities listed. For a complete listing of frozen food practical storage life, see *Recommendations for the Processing and Handling of Frozen Foods*, 3rd ed., International Institute of Refrigeration, 1986.

[a] Storage life is not based on maintaining nutritional value.

[b] Eggs with weak albumen freeze just below −1°C.

3.2 Outdoor Conditions

The outdoor conditions are required to make an accurate design for the cooling storage room. The conditions should be known for every hour in every month of the year. The weather condition is used to in knowing the highest temperatures.

The following tables (Table 3.3, and Table 3.4) are sample tables from (ASHRAE, 2001) which have Egypt in their listings.

Table 3.3 Heating and Wind Design Condition - World Location Table (ASHRAE, 2001)

Station	WMO#	Lat.	Long.	Elev., m	StdP, kPa	Dates	Heating Dry Bulb		Extreme Wind Speed, m/s			Coldest Month				MWS/PWD to DB				Extr. Annual Daily			
												0.4%		1%		99.6%		0.4%		Mean DB		StdD DB	
							99.6%	99%	1%	2.5%	5%	WS	MDB	WS	MDB	MWS	PWD	MWS	PWD	Max.	Min.	Max.	Min.
1a	1b	1c	1d	1e	1f	1g	2a	2b	3a	3b	3c	4a	4b	4c	4d	5a	5b	5c	5d	6a	6b	6c	6d
Zhangjiakou	544010	40.78N	114.88E	726	92.90	8293	−17.0	−15.4	7.7	6.6	5.6	7.3	−9.5	6.4	−8.9	3.1	340	2.5	140	34.8	−19.5	0.6	2.0
Zhanjiang	596580	21.22N	110.40E	28	100.99	8293	7.6	8.9	7.1	5.9	5.2	6.2	12.4	5.4	13.4	3.6	340	3.5	250	36.2	5.7	1.7	2.2
Zhengzhou	570830	34.72N	113.65E	111	100.00	8293	−7.4	−5.9	9.3	7.4	6.2	10.5	4.5	8.6	3.6	1.2	180	3.4	160	37.7	−10.6	1.4	2.3
COLOMBIA																							
Bogota	802220	4.70N	74.13W	2548	74.23	8293	2.2	3.9	9.4	8.0	6.4	10.3	17.6	8.5	17.4	0.2	320	4.5	90	28.0	−0.9	4.7	1.5
COOK ISLANDS																							
Rarotonga Island	918430	21.20S	159.82W	7	101.24	8293	16.8	17.8	11.1	9.8	8.9	11.5	21.9	10.3	22.2	0.5	150	4.9	80	31.5	14.6	1.7	1.4
CROATIA																							
Pula	132090	44.90N	13.92E	63	100.57	8293	−4.1	−2.8	11.5	9.4	7.7	11.8	1.8	9.6	3.5	3.3	20	2.8	270	33.5	−6.2	1.1	2.0
Split	133330	43.53N	16.30E	21	101.07	8293	−1.9	−0.1	10.6	8.4	7.0	10.4	4.9	8.5	6.6	3.9	340	3.7	230	34.6	−7.1	3.9	9.3
Zagreb	131310	45.73N	16.07E	107	100.05	8293	−13.2	−10.0	8.5	7.2	5.9	7.7	4.0	6.3	3.9	1.0	240	2.9	230	33.5	−16.5	3.2	4.6
CUBA																							
Guantanamo	783670	19.90N	75.15W	17	101.12	8293	19.2	20.1	10.0	8.9	7.9	9.3	29.2	8.4	29.0	3.5	360	5.2	130	37.6	16.0	2.6	4.6
CYPRUS																							
Akrotiri	176010	34.58N	32.98E	23	101.05	8293	4.6	6.0	11.1	10.0	9.0	12.9	11.4	11.5	12.3	2.3	350	4.3	260	35.2	2.4	1.7	2.4
Larnaca	176090	34.88N	33.63E	2	101.30	8293	3.0	4.6	11.9	10.2	8.9	12.5	12.2	10.8	12.2	3.2	310	5.5	200	36.9	0.8	1.2	1.9
Paphos	176000	34.72N	32.48E	8	101.23	8293	4.0	5.4	10.6	9.2	8.0	13.2	12.9	11.3	13.0	3.9	30	4.0	280	33.5	2.1	1.8	1.9
CZECH REPUBLIC																							
Brno	117230	49.15N	16.70E	246	98.40	8293	−14.4	−10.9	10.6	9.2	8.2	11.5	−1.0	9.5	−0.7	3.4	60	4.5	180	32.6	−15.8	1.6	4.0
Cheb	114060	50.08N	12.40E	471	95.79	8293	−15.6	−12.4	7.1	6.1	5.3	7.6	2.8	6.4	2.1	1.0	40	2.3	220	32.1	−17.1	2.1	3.5
Ostrava	117820	49.68N	18.12E	256	98.29	8293	−17.1	−12.9	10.1	9.1	8.3	11.5	−0.1	10.3	0.6	2.3	20	4.6	190	32.3	−19.6	1.7	5.5
Plzen	114480	49.65N	13.27E	364	97.03	8293	−16.7	−12.8	9.4	8.3	7.4	10.7	5.0	9.1	3.5	1.0	20	3.5	120	33.3	−18.2	2.2	5.1
Praded Mountain	117350	50.07N	17.23E	1492	84.64	8293	−19.0	−16.4	21.0	18.2	16.1	22.6	−6.9	19.0	−5.4	8.4	20	5.2	180	22.1	−20.2	1.7	4.3
Prague	115180	50.10N	14.28E	366	97.00	8293	−16.1	−12.4	12.4	10.4	9.0	13.9	4.0	11.9	2.3	1.9	10	3.5	160	32.8	−18.0	2.0	4.9
Pribyslav	116590	49.58N	15.77E	536	95.05	8293	−16.2	−13.0	12.8	11.2	9.8	13.3	1.1	12.1	−0.7	2.1	360	3.9	130	30.4	−18.9	2.7	4.0
DENMARK																							
Alborg	60300	57.10N	9.87E	3	101.29	8293	−13.1	−9.2	13.0	11.4	10.2	14.3	7.0	12.5	5.8	2.6	220	4.7	100	28.0	−14.1	2.2	6.9
Copenhagen	61800	55.63N	12.67E	5	101.26	8293	−11.1	−8.0	13.0	11.6	10.5	13.2	4.3	12.0	3.1	5.1	360	4.7	160	27.5	−10.3	1.8	4.5
Hammerodde	61930	55.30N	14.78E	11	101.19	8293	−6.7	−5.3	19.5	16.7	15.0	20.2	1.1	18.5	1.0	8.9	70	5.2	230	26.7	−5.6	1.9	3.3
Mon Island	61790	54.95N	12.55E	15	101.14	8293	−8.0	−5.7	19.1	15.8	14.3	20.4	2.8	18.2	1.9	6.2	320	4.0	70	25.4	−7.2	2.2	4.3
Odense	61200	55.47N	10.33E	17	101.12	8293	−10.2	−7.7	13.1	11.5	10.2	13.5	5.5	12.2	4.2	3.4	40	4.9	120	29.0	−12.6	2.3	5.3
Skagen	60410	57.77N	10.65E	7	101.24	8293	−9.3	−6.4	18.4	16.0	14.4	18.3	2.0	16.2	3.2	7.4	40	4.6	360	24.5	−8.8	1.9	4.4
Tirstrup	60700	56.30N	10.62E	25	101.03	8293	−13.0	−9.1	12.0	10.5	9.4	12.3	4.6	10.9	3.7	2.4	20	4.8	280	27.8	−14.0	1.9	6.1
ECUADOR																							
Guayaquil	842030	2.15S	79.88W	9	101.22	8293	19.7	19.9	7.3	6.5	6.0	7.7	23.2	7.1	23.1	3.6	210	3.2	40	34.9	10.5	1.3	6.3
Quito	840710	0.15S	78.48W	2812	71.80	8293	7.0	7.9	7.8	6.6	5.9	6.6	17.6	6.0	17.8	0.3	350	4.1	150	28.8	4.7	4.3	1.8
EGYPT																							
Alexandria	623180	31.20N	29.95E	7	101.24	8293	6.8	7.8	10.7	9.2	8.1	13.0	13.6	11.3	14.6	2.1	190	4.3	340	39.0	2.9	1.8	2.1
Cairo	623660	30.13N	31.40E	74	100.44	8293	7.0	8.0	9.5	8.3	7.3	10.3	14.6	8.7	16.4	2.6	210	5.6	350	42.1	3.1	1.6	2.7
Luxor	624050	25.67N	32.70E	88	100.27	8293	4.4	5.7	7.2	6.1	5.2	6.8	17.8	5.8	17.7	0.9	180	2.6	330	46.1	0.9	1.7	1.0
ESTONIA																							
Kopu/Cape Ristna	261150	58.92N	22.07E	9	101.22	8293	−15.1	−11.9	13.2	11.1	9.4	12.9	3.2	10.7	2.9	2.3	80	2.7	70	26.4	−14.1	2.3	6.7
Tallinn	260380	59.35N	24.80E	44	100.80	8293	−19.8	−16.0	9.2	8.1	7.3	9.8	0.9	8.6	0.0	2.9	140	3.6	40	28.0	−19.6	2.4	4.8
FAEROE ISLANDS																							
Torshavn	60110	62.02N	6.77W	39	100.86	8293	−3.2	−2.3	18.2	15.3	13.7	21.5	5.7	19.2	6.2	5.8	320	4.8	210	18.1	−5.4	1.9	1.4
FIJI																							
Nadi	916800	17.75S	177.45E	18	101.11	8293	16.0	17.1	8.9	7.8	7.0	8.7	25.8	7.7	26.0	1.6	120	5.8	350	34.9	13.1	2.0	3.3
Nausori	916830	18.05S	178.57E	7	101.24	8293	16.9	17.9	9.1	8.2	7.3	8.9	23.8	8.1	23.5	0.3	320	4.7	60	32.9	15.0	1.1	1.0
FINLAND																							
Helsinki	29740	60.32N	24.97E	56	100.65	8293	−23.7	−19.5	10.0	8.8	7.9	10.9	1.5	9.7	−0.1	2.4	340	4.8	210	28.4	−24.7	1.7	5.3
Jyvaskyla	29350	62.40N	25.68E	145	99.60	8293	−29.2	−24.8	8.9	7.7	6.8	10.2	−2.2	8.4	−3.4	0.7	330	3.8	180	28.5	−30.2	2.4	4.2
Kauhava	29130	63.10N	23.03E	44	100.80	8293	−29.0	−25.6	9.4	8.3	7.4	10.4	−0.5	9.3	−0.6	0.8	80	3.8	230	27.6	−29.6	1.3	4.5
Kuopio	29170	63.02N	27.80E	102	100.11	8293	−29.7	−25.6	8.4	7.4	6.7	9.3	−1.2	8.3	−2.0	0.6	140	3.3	170	27.5	−29.5	1.4	4.4
Lahti	29650	60.97N	25.63E	84	100.32	8293	−26.3	−21.9	6.3	5.4	4.8	6.9	0.8	6.0	−0.3	0.6	350	2.7	150	28.5	−28.1	1.5	4.0
Pello	28440	66.80N	24.00E	84	100.32	8293	−31.4	−29.1	6.4	5.6	5.0	6.3	−3.7	5.4	−4.4	0.4	300	3.0	340	27.6	−34.7	2.7	3.0
Pori	29520	61.47N	21.80E	17	101.12	8293	−24.3	−20.2	11.1	9.8	8.7	13.2	2.7	11.3	1.7	2.3	90	5.0	140	27.5	−24.8	1.4	4.4
Suomussalmi	28790	64.90N	29.02E	224	98.66	8293	−29.7	−27.2	7.4	6.4	5.8	7.9	−1.2	6.9	−3.0	0.5	360	3.1	270	28.2	−32.1	5.6	3.7
Tampere	29440	61.42N	23.58E	112	99.99	8293	−26.2	−22.2	8.4	7.5	6.8	9.5	1.2	8.4	0.2	0.8	10	4.0	10	28.8	−27.2	1.4	4.8
Turku	29720	60.52N	22.27E	59	100.62	8293	−23.1	−19.6	9.5	8.3	7.4	11.1	0.5	9.4	−0.1	2.7	40	4.0	230	28.4	−23.9	1.2	5.4
FRANCE																							
Bordeaux	75100	44.83N	0.70W	61	100.59	8293	−5.8	−3.0	9.9	8.3	7.1	10.6	10.3	9.0	10.4	1.6	40	3.3	80	35.9	−7.4	1.5	4.1
Clermont-Ferrand	74600	45.78N	3.17E	330	97.42	8293	−9.1	−6.8	10.7	8.9	7.5	11.4	9.4	9.7	9.2	1.4	360	3.4	20	36.2	−11.8	1.6	3.9
Dijon	72800	47.27N	5.08E	227	98.63	8293	−9.8	−6.8	10.2	8.7	7.6	11.0	7.0	9.7	6.0	3.1	20	4.6	170	33.5	−11.3	1.9	4.5
Brest	71100	48.45N	4.42W	103	100.09	8293	−2.8	−1.0	11.8	10.4	9.3	12.7	8.7	11.4	8.0	3.4	120	4.0	40	29.5	−4.4	2.2	2.4
Lyon	74810	45.73N	5.08E	240	98.47	8293	−8.5	−5.1	11.4	9.6	8.2	11.8	6.6	10.0	7.2	1.4	20	5.2	180	34.8	−9.7	1.5	4.1
Marseille	76500	43.45N	5.23E	36	100.89	8293	−3.9	−2.0	16.8	14.4	12.4	17.1	6.7	14.4	6.5	3.8	360	5.6	280	35.1	−5.6	1.8	3.1
Montpellier	76430	43.58N	3.97E	6	101.25	8293	−3.8	−1.8	12.7	11.0	9.6	12.2	9.6	10.6	10.2	3.3	340	5.6	180	35.7	−5.9	1.4	3.0

WMO# = World Meteorological Organization number
Elev. = elevation, m
PWD = prevailing wind direction, ° True
DB = dry-bulb temperature, °C
Lat. = latitude °
Long. = longitude °
StdP = standard pressure at station elevation, kPa
WS = wind speed, m/s

Table 3.4 Cooling and Dehumidifaction Design Conditions - World Locations (ASHRAE, 2001)

	Cooling DB/MWB						Evaporation WB/MDB						Dehumidification DP/MDB and HR									Range of DB
	0.4%		1%		2%		0.4%		1%		2%		0.4%			1%			2%			
Station	DB	MWB	DB	MWB	DB	MWB	WB	MDB	WB	MDB	WB	MDB	DP	HR	MDB	DP	HR	MDB	DP	HR	MDB	
1	2a	2b	2c	2d	2e	2f	3a	3b	3c	3d	3e	3f	4a	4b	4c	4d	4e	4f	4g	4h	4i	5
Zhangjiakou	31.9	18.4	30.5	18.2	29.1	18.0	22.4	27.4	21.5	26.8	20.7	25.9	20.9	17.0	25.3	19.7	15.8	24.6	18.8	14.9	24.1	9.5
Zhanjiang	33.9	26.5	33.1	26.6	32.3	26.6	28.0	31.4	27.7	30.9	27.4	30.6	27.2	23.1	29.8	26.9	22.6	29.5	26.6	22.2	29.4	4.7
Zhengzhou	34.7	23.6	33.4	23.5	32.1	23.5	27.4	31.5	26.6	30.4	25.8	29.4	26.3	22.0	30.1	25.5	21.0	28.9	24.8	20.1	28.4	8.1
COLOMBIA																						
Bogota	21.1	13.3	20.2	13.5	20.0	13.5	15.3	18.9	14.9	18.6	14.6	18.2	14.1	13.8	17.5	13.8	13.5	17.0	13.1	12.9	16.5	11.5
COOK ISLANDS																						
Rarotonga Island	29.7	25.5	29.3	25.3	28.9	25.1	26.5	28.7	26.2	28.4	25.9	28.1	25.9	21.2	28.0	25.6	20.9	27.8	25.2	20.3	27.6	4.6
CROATIA																						
Pula	31.8	21.4	30.2	20.6	29.1	20.2	23.3	27.9	22.5	27.8	21.5	27.1	21.9	16.7	26.0	20.8	15.6	25.1	19.9	14.7	24.1	10.6
Split	32.8	21.2	31.7	20.4	30.2	20.0	22.5	29.9	21.7	29.3	21.1	28.7	20.1	14.8	25.9	19.1	13.9	25.3	18.2	13.1	24.7	10.3
Zagreb	31.1	21.3	29.5	21.0	28.1	20.1	22.5	29.4	21.6	28.1	20.8	26.9	20.2	15.1	25.6	19.2	14.2	24.9	18.5	13.5	23.6	12.3
CUBA																						
Guantanamo	34.2	25.8	34.0	25.7	33.2	25.4	27.6	32.8	27.1	32.6	26.7	32.3	26.1	21.5	31.5	25.6	20.9	31.3	25.1	20.2	30.8	8.5
CYPRUS																						
Akrotiri	32.7	21.7	31.4	22.2	30.3	22.6	25.6	29.2	25.1	28.7	24.6	28.1	24.6	19.6	27.7	24.0	18.9	27.6	23.4	18.2	27.3	7.2
Larnaca	33.8	21.7	32.7	22.1	31.6	22.4	25.7	29.9	25.1	29.5	24.6	29.1	24.2	19.1	28.5	23.8	18.7	28.2	23.1	17.9	27.7	9.9
Paphos	30.9	24.7	30.1	24.6	29.2	24.3	26.2	29.8	25.7	29.2	25.1	28.5	25.1	20.2	29.2	24.6	19.6	28.8	24.0	18.9	28.2	8.6
CZECH REPUBLIC																						
Brno	29.5	19.1	27.7	18.5	26.1	17.6	20.2	27.5	19.3	26.2	18.5	24.3	17.7	13.1	23.2	17.0	12.5	21.9	16.2	11.9	21.3	10.8
Cheb	28.4	18.5	26.6	17.5	24.8	16.7	19.3	26.6	18.3	24.7	17.4	23.2	16.8	12.7	21.8	16.0	12.0	20.2	15.2	11.4	19.5	10.8
Ostrava	29.5	19.3	27.6	18.3	25.8	17.7	20.3	27.6	19.4	26.1	18.5	24.2	17.9	13.3	22.6	17.1	12.6	21.5	16.3	12.0	21.2	11.5
Plzen	29.0	19.4	27.1	18.5	25.3	17.7	20.3	27.5	19.3	25.5	18.4	24.0	17.9	13.4	23.6	17.0	12.7	22.6	16.1	12.0	20.8	11.3
Praded Mountain	18.6	13.0	17.0	12.3	15.6	11.7	14.1	17.3	13.2	15.8	12.3	14.7	13.1	11.3	15.0	12.1	10.6	14.1	11.3	10.0	13.3	5.4
Prague	28.8	18.4	26.8	17.8	25.0	17.1	19.7	26.2	18.7	24.7	17.8	23.4	17.3	12.9	22.1	16.4	12.2	20.6	15.8	11.7	20.3	11.1
Pribyslav	27.0	18.1	25.2	17.5	23.5	16.7	19.1	25.4	18.1	23.5	17.2	22.4	16.8	12.8	21.7	16.0	12.1	20.6	15.2	11.5	19.7	10.3
DENMARK																						
Alborg	25.0	17.1	23.1	16.3	21.5	15.5	18.1	23.7	17.2	21.8	16.2	20.3	16.0	11.4	20.2	15.1	10.7	19.3	14.2	10.1	18.1	8.4
Copenhagen	25.0	17.2	23.2	16.4	21.9	15.8	18.2	23.2	17.4	21.7	16.5	20.4	16.2	11.5	20.0	15.5	11.0	19.4	14.8	10.5	18.9	8.1
Hammerodde	22.8	17.8	21.3	17.4	20.1	16.8	18.8	21.3	18.0	20.5	17.2	19.5	17.9	12.9	20.2	17.0	12.1	19.2	16.2	11.5	18.7	3.9
Mon Island	23.1	18.2	21.6	17.4	20.4	16.7	19.0	21.9	18.1	20.9	17.2	19.7	17.8	12.8	20.8	16.8	12.0	20.0	16.0	11.4	19.1	5.6
Odense	25.8	17.8	24.1	17.0	22.3	16.2	18.8	23.7	17.8	22.9	16.9	21.2	16.9	12.1	21.1	15.9	11.3	20.1	15.0	10.7	19.1	9.6
Skagen	22.1	18.9	20.7	17.9	19.4	17.1	19.5	21.3	18.4	20.3	17.5	18.9	18.7	13.5	20.7	17.6	12.6	19.4	16.8	12.0	18.5	5.3
Tirstrup	25.2	17.5	23.7	16.8	22.0	15.9	18.6	23.5	17.6	21.8	16.6	20.5	17.0	12.2	19.8	16.0	11.4	19.0	15.0	10.7	18.2	9.9
ECUADOR																						
Guayaquil	33.2	24.5	32.9	24.6	32.1	24.4	26.7	31.2	26.2	30.4	25.9	29.6	25.8	21.1	29.3	25.2	20.4	28.2	25.0	20.1	27.9	7.4
Quito	22.0	12.5	21.2	12.3	20.8	12.1	14.6	19.4	14.1	19.0	13.7	18.4	13.0	13.3	16.1	12.2	12.6	15.1	12.1	12.5	14.8	10.2
EGYPT																						
Alexandria	32.5	21.6	30.9	22.9	29.9	23.1	25.0	29.7	24.4	28.8	24.0	28.5	23.5	18.3	27.9	23.0	17.8	27.5	22.5	17.2	27.4	6.3
Cairo	38.0	20.3	36.2	20.5	35.1	20.8	24.1	31.5	23.6	30.4	23.1	30.1	22.2	17.0	26.0	21.9	16.7	25.8	21.2	16.0	25.6	13.3
Luxor	43.1	22.2	42.0	21.9	40.9	21.7	24.0	39.4	23.3	38.7	22.7	38.2	18.9	13.8	33.4	17.8	12.9	32.6	16.9	12.2	32.5	17.0
ESTONIA																						
Kopu/Cape Ristna	22.6	17.5	21.1	17.0	19.8	16.3	18.7	21.6	17.7	20.1	16.9	19.2	17.6	12.6	20.4	16.7	11.9	19.4	15.8	11.2	18.4	4.8
Tallinn	24.9	17.6	23.3	16.9	21.6	16.0	19.0	23.0	17.9	21.9	16.9	20.6	17.4	12.5	20.8	16.3	11.7	20.0	15.2	10.8	18.7	8.2
FAEROE ISLANDS																						
Torshavn	14.3	12.4	13.5	11.8	12.7	11.5	13.0	13.9	12.4	13.1	11.9	12.5	12.6	9.1	13.3	12.0	8.8	12.7	11.5	8.5	12.2	3.0
FIJI																						
Nadi	32.3	25.0	31.7	25.0	31.2	24.8	26.6	30.4	26.2	30.0	25.9	29.7	25.6	20.9	28.5	25.2	20.4	28.2	24.9	20.0	28.0	7.9
Nausori	31.2	25.8	30.6	25.7	30.0	25.4	26.7	29.8	26.3	29.3	26.0	28.9	25.9	21.2	28.2	25.6	20.9	28.0	25.2	20.3	27.7	6.1
FINLAND																						
Helsinki	25.9	17.6	24.1	16.3	22.7	15.9	18.7	23.6	17.6	22.4	16.7	20.8	17.0	12.2	19.6	15.9	11.4	19.2	14.9	10.7	18.4	9.8
Jyvaskyla	25.4	16.8	23.8	16.2	21.9	15.3	18.4	23.0	17.2	22.0	16.1	20.3	16.5	12.0	20.5	15.3	11.1	18.5	14.3	10.3	17.6	9.8
Kauhava	25.0	16.7	23.2	16.1	21.2	15.1	18.2	22.9	17.0	21.3	16.0	20.1	16.5	11.8	20.2	15.3	10.9	18.5	14.3	10.2	17.7	10.0
Kuopio	25.4	16.9	23.7	16.2	21.9	15.7	18.6	23.3	17.4	21.7	16.4	20.5	16.7	12.0	20.7	15.7	11.3	19.1	14.6	10.5	18.1	7.1
Lahti	26.1	17.8	24.5	17.0	22.8	16.2	19.1	24.2	17.9	23.2	16.9	21.6	17.0	12.3	21.2	15.8	11.3	20.0	14.9	10.7	18.8	10.6
Pello	24.2	16.0	22.2	15.4	20.3	14.3	17.4	22.0	16.2	20.4	15.1	18.8	15.5	11.1	19.1	14.4	10.3	17.9	13.3	9.6	16.8	8.8
Pori	24.8	16.9	23.2	15.9	21.5	15.1	18.2	22.8	17.1	21.6	16.1	20.0	16.6	11.8	19.7	15.3	10.9	18.5	14.4	10.3	17.5	9.0
Suomussalmi	24.3	16.1	22.3	15.4	20.4	14.3	17.4	22.6	16.2	20.9	15.2	19.1	15.3	11.2	19.0	14.3	10.4	17.7	13.4	9.8	16.8	8.4
Tampere	26.1	16.8	24.4	16.3	22.8	15.4	18.5	23.7	17.3	22.4	16.2	21.1	16.4	11.8	19.6	15.2	10.9	18.9	14.2	10.2	17.6	10.4
Turku	25.9	17.3	24.1	15.9	22.5	15.3	18.4	23.6	17.4	22.2	16.3	20.4	16.7	12.0	20.6	15.4	11.0	19.0	14.6	10.4	18.1	9.1
FRANCE																						
Bordeaux	32.1	21.2	30.0	20.8	28.1	20.0	23.0	29.6	21.8	27.5	20.9	26.1	21.1	15.9	25.9	20.0	14.8	24.0	19.1	14.0	23.1	11.3
Clermont-Ferrand	31.9	20.9	29.8	20.0	27.9	19.6	22.0	29.5	21.0	28.1	20.0	26.5	19.5	14.8	25.0	18.6	14.0	24.3	17.8	13.3	23.2	12.6
Dijon	30.4	20.2	28.8	19.8	27.0	19.2	21.9	27.6	20.9	26.8	19.9	25.5	20.0	15.1	25.1	18.9	14.1	23.3	18.0	13.3	22.2	11.6
Brest	25.8	18.5	23.5	18.3	21.7	17.2	19.7	24.4	18.6	22.1	17.7	20.1	18.2	13.3	20.6	17.5	12.7	19.5	16.9	12.2	18.9	7.6
Lyon	32.0	20.7	30.0	20.3	28.1	19.6	22.2	29.1	21.1	27.9	20.2	26.5	19.9	15.0	25.7	18.9	14.1	24.1	18.0	13.3	22.9	11.9
Marseille	32.0	21.6	30.7	21.2	29.2	20.6	23.7	28.7	22.8	27.9	21.9	27.0	22.1	16.8	26.2	21.1	15.8	25.8	20.1	14.9	24.9	10.4
Montpellier	32.1	21.7	30.3	21.0	29.0	20.5	24.6	27.8	23.7	27.0	22.8	26.4	23.8	18.7	26.0	22.8	17.5	25.3	21.8	16.5	24.7	10.3

MDB = mean coincident dry-bulb temp., °C
MWB = mean coincident wet-bulb temp., °C
MWS = mean coincident wind speed, m/s
StdD = standard deviation, °C
HR = humidity ratio, grams of moisture per kilogram of dry air
A = airport
DP = dew-point temperature, °C

Chapter (4)

THERMAL & MOISTURE INSULATIONS

4.1 Introduction

Thermal insulating material is a porous material these materials are content of fibrous or granular or cellular and have gabs between them.

The basic work of insulating materials is decrease the leakage rate of heat to 10w/m2 that for keeping the temperature constant inside the refrigeration store and decrease the power of refrigeration unit.

The insulating material used for decrease the temperature deference through the layer which near the store wall that's decrease the speed of air at these area ,and used to decrease the dryness rate for object were put near the inside wall of the store .

The prefabricated thermal insulating walls allow more space in the store and have a small cost, speed assembly so preferred to use it.

4.2 Selection of Thermal Insulating Material

It must be Cheap, available .have a stable property and dimension ,have a mechanical hardness, have a reaction resist with other materials, easy to cut, have a resist of bugs, easy to form, doesn't absorb the water vapor, have a constant properties at deferent temperature, have no smile, doesn't absorb the smiles, flame resists .

The Selection of thermal insulating material depends on the price only see Figure (4.1) but also:

- Decrease heat & vapor leakage.
- Decrease the change in temperature inside the refrigerator.
- Increase the hardness of inside wall to use it as the guide to concrete.
- Absorb & decrease the vibration & noise level.
- Resist the bacteria.

4.2.1 The relation between the cost and the insulation thickness

Increasing the insulation thickness, the insulation material cost (c_f) increase but the cooling coil operation cost (c_m) decrease (Mahmoud, 1988).

(Fixed cost) obtained by:

$$c_f = (A\ L_{ins}\ c_{ins}) / z \qquad 4.1$$

Where:

C_f: fixed cost, (L.E).

A: surface area, (m^2).

L_{ins}: insulation thickness, (m).

C_{ins}: insulation cost, (L.E/m^3).

Z: insulation life time, (Years).

(Running cost) or lost energy cost obtained by:

$$C_R = P_{elec}\ H\ \ C_{elec} \qquad 4.2$$

Where:

C_r: Running cost, (L.E).

H: Working hours per year, (hr).

C_{elec}: Electricity cost per, kW.hr (L.E/ W.hr)

P_{elec}: Power of compressor, (kW)

The annual total cost can be obtained by:

$$C_m = C_f + C_R \qquad 4.3$$

The optimum thickness of thermal insulation can be obtained at point A from Figure (4.1)

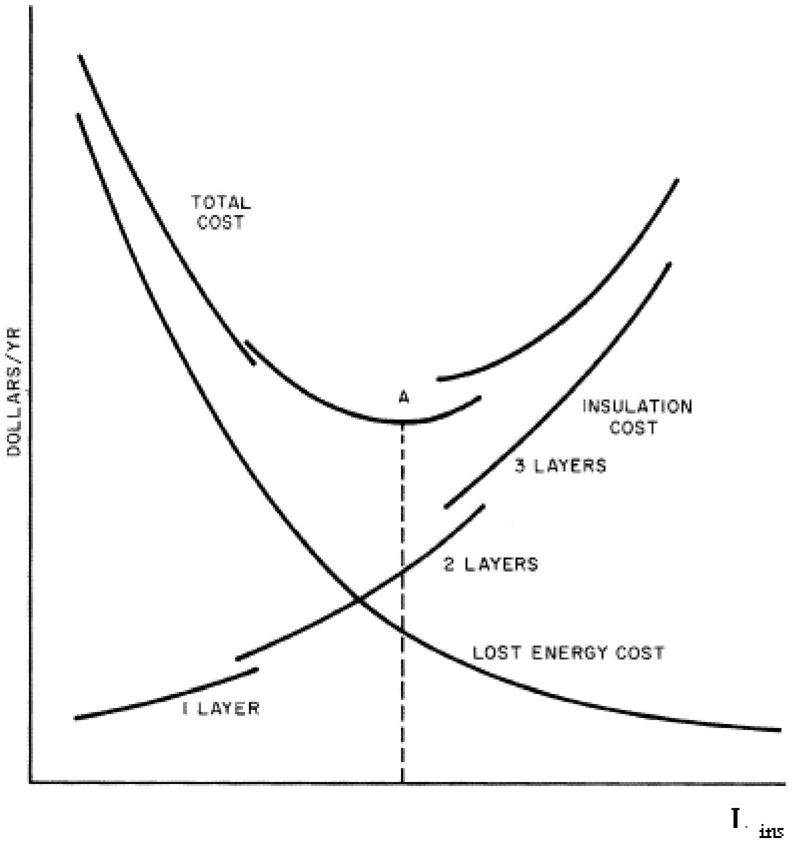


Figure (4.1) Relation between Insulation Thickness & Annual Cost (ASHRAE, 2001)

4.3 Properties of Thermal Insulation Materials

1- Safe & Health Properties

- It must be resist for insect, empty from dust, resist for, smell absorption flame resist.

2- Humidity Properties

- The absorption of insulating material for water vapor make water condensate & freezing inside the insulation to increase the insulation size to 10% that make conduction rate increase so the properties of absorption , absorption hygroscopic, capillarity for insulating material is too small .

3- Mechanical Properties

- The most important mechanical properties for insulation material is to be easier for fabricated & hard to use as supports ,so hardness of insulation depend on it's density it must be not less than 20 kg/m^3 (Mahmoud, 1988).

4- Thermal Properties

- The most important property for insulating material is conductivity rate & density .we found that increasing in density the conductivity decrease in small value & increase after that.

4.4 Classification of Thermal Insulating Materials

The installation materials can be classified according to:

4.4.1 Heat transfer

Thermal conductivity material as concrete wood, polystyrene, and most insulation materials

Reflected heat material like aluminum sheets

4.4.2 Material origin

Animal like horse's hair or wool minerals like glass wool, aluminum sheets industrial like polystyrene and polyerssan vegetables like straw, cotton and feline.

4.4.3 Material structure

1- Loose fill

It's about powder or grains used for fill the spaces between layers like glass wool and cork.

2- Formed in place

It's about liquid chemical material filled to form rigid foams or have rigid like poly- aresan

3- Flexible

It's flexible material as sheets forms or organic material or non-organic material with or without like mineral wool

4- Rigid

It's about sheets, half pipes, elbows, or specific shapes according to the propose or cork or polystyrene.

4.4.4 Material nature

- Organic material consist of carbon like cork
- Non-organic material like glass wool.

4.4.5 Temperature range

Thermal insulation material classified to low temperature insulating material (80 to -40 ^{o}c) and high temperature insulating material (1000 to 80 ^{o}c) like heat block.

4.4.6 Values of thermal properties

1- High effective insulating material

natural organic material like hydrophytes industrial organic material like plastic foam non organic material like glass wool or aluminum sheet non compressed material like polystyrene foam compressed material at high pressure &high temperature like poly aresan Insulation material used for house refrigerator, moving refrigerator and light heavy equipment.

2- Effective insulating material

Some examples for effective insulating material:

- natural organic material like cork
- non organic like glass wool and mineral wool

The effective insulating material used for refrigeration store .pipes

3- Medium effective insulating material

Example for this group are non organic materials like concrete foam and used for isolate building

4- Low effective insulating material

Examples for this group are:

- natural organic like wood
- industrial non-organic like concrete
- natural non-organic like block

Low effective insulating material used for butcher, ice storage.

4.5 Used Insulating Material

The insulating material classify to tow groups

4.5.1 Agglomerated materials

Examples in that

- Cork as standard insulation and prefer for floor insulation freezing storage
- Polystyrene which used cense 1954. It used for freezing and refrigeration
- Pb- Foam materials
    - Unimat it's one of polystyrene types by heating pressured welding way.
    - Unimat properties better than extended polystyrene

  - Styrofoamit has the same chemical structure for polystyrene and used for floor insulation and wall for its prefect mechanical properties

- Polystyrene produced from chemical reaction between polyol and polycyanate in a foamed material like R-11, R-12 and non flammable material as a result of it's small thermal conductivity it need small thickness for thermal insulation. We can use polystyrene in sites by spray gun.

- Glass foam it's about net of glass non–organic have better properties in insulation material and we can use it for walls and building.

4.6 Moisture Insulation

4.6.1 Understanding vapor barriers

The function of a vapor barrier is to retard the migration of water vapor. Where it is located in an assembly and its permeability is a function of climate, the characteristics of the materials that comprise the assembly and the interior conditions. Vapor barriers are not typically intended to retard the migration of air. That is the function of air barriers.

Confusion on the issue of vapor barriers and air barriers is common. The confusion arises because air often holds a great deal of moisture in the vapor form. When this air moves from location to location due to an air pressure difference, the vapor moves with it. This is a type of migration of water vapor. In the strictest sense air barriers are also vapor barriers when they control the transport of moistureladen air.

Vapor barriers are also cold climate artifacts that have diffused into other climates more from ignorance than need. The history of cold climate vapor barriers itself is a story based more on personalities than physics.

The problem

Incorrect use of vapor barriers is leading to an increase in moisture related problems. Vapor barriers were originally intended to prevent assemblies from getting wet. However, they often prevent assemblies from drying. Vapor barriers installed on the interior of assemblies prevent assemblies from drying inward. This can be a problem in any air-conditioned enclosure. This can be a problem in any below grade space. This can be a problem when there is also a vapor barrier on the exterior. This can be a problem where brick is installed over building paper and vapor permeable sheathing.

Solution

Two seemingly simple requirements for building enclosures bedevil engineers and architects almost endlessly:

- keep water out.
- let water out if it gets in.

Water can come in several phases: liquid, solid, vapor and adsorbed. The liquid phase as rain and ground water has driven everyone crazy for hundreds of years but can be readily understood – drain everything and remember the humble flashing. The solid phase also drives everyone crazy when we have to shovel it or melt it, but at least most professionals understand the related building problems (ice damming, frost heave, freeze-thaw damage). But the vapor phase is in a class of craziness all by itself. We will conveniently ignore the adsorbed phase and leave it for someone else to deal with.

Note that adsorbed water is different than absorbed water (Kumaran, et al., M.T., 1994).

The fundamental principle of control of water in the liquid form is to drain it out if it gets in – and let us make it perfectly clear – it will get in if you build where it rains or if you put your building in the ground where there is water in the ground. This is easy to understand, logical, with a long historical basis.

The fundamental principle of control of water in the solid form is to not let it get solid and if it does – give it space or if it is solid not let it get liquid and if it does drain it away before it can get solid again. This is a little more difficult to understand, but logical and based on solid research. Examples of this principle include the use of air entrained concrete to control freeze-thaw damage and the use of attic venting to provide cold roof decks to control ice damming.

The fundamental principle of control of water in the vapor form is to keep it out and to let it out if it gets in. Simple right? No chance. It gets complicated because sometimes the best strategies to keep water vapor out also trap water vapor in. This can be a real problem if the assemblies start out wet because of rain or the use of wet materials.

It gets even more complicated because of climate. In general water vapor moves from the warm side of building assemblies to the cold side of building assemblies. This is simple to understand, except we have trouble deciding what side of a wall is the cold or warm side. Logically, this means we need different strategies for different climates. We also have to take into account differences between summer and winter.

Finally, complications arise when materials can store water. This can be both good and bad. A cladding system such as a brick veneer can act as a reservoir after a rainstorm and significantly complicate wall design. Alternatively, wood framing or masonry can act as a hygric buffer absorbing water lessening moisture shocks.

What is required is to define vapor control measures on a more regional climatic basis and to define the vapor control measures more precisely.

4.7 Vapor Retarders

OBJECTIVES: The movement of water vapor through vapor diffusion is another major factor of water vapor problems in storages, along with high indoor RH and air leakage. The objective of this section is to provide best practice recommendations for the correct use of vapor retarders in the above-grade portion of storage's thermal envelope (ARES, 2006).

Vapor retarders are used to control or slow the diffusion of moisture vapor through storages envelope materials. Vapor retarders, when used correctly; prevent high levels of humidity inside storages envelope assemblies that can result in condensation. When used incorrectly, vapor retarders can trap moisture, slow the normal drying process, and contribute to moisture damage.

PRECAUTIONS: All materials exhibit some amount of vapor retardance – that is – they have some impact on allowing moisture vapor to pass through them. So when considering vapor retarder requirements, it is important to consider the vapor permeability characteristics of all materials used in the wall assembly, not just those that are designated as a “vapor retarder.” References like the 2005 ASHRAE Fundamentals Handbook have permeance data that can give a sense of how breathable different types of construction materials are.

The recognition that all materials play some role in water vapor migration can lead to a host of complex design issues – especially as wall assemblies begin to include new or additional materials. A few examples of this are mentioned in this section, but these are specialized design issues that do not have a well established set of best practice guidance and thus are not discussed in detail here. More generic recommendations for vapor retarders are discussed here, and when followed in conjunction with the previous best practices for indoor RH and air leakage, should address the major causes of many water vapor problems in storages.

Best practices

Design walls to dry towards the inside in hot/humid climates In hot/humid climates.

Exterior wall systems should dry towards the interior by locating vapor retarding materials on the outside of the wall assembly and keeping interior materials vapor permeable. Providing some resistance to outdoor moisture vapor from diffusing into the wall assembly limits moisture problems during hot and humid periods of the year. And by keeping the interior side of the assembly vapor permeable, any moisture within the wall system can migrate to the cool and dry building interior. If a vapor retarding material like polyethylene or even vinyl wallpaper is used towards the inside of the wall assembly, it could block vapor migration on its cool surface and cause condensation problems. Instead, materials towards the interior of the wall assembly should be semi-permeable or permeable, like unfaced fiberglass batts with permeable interior paint on the gypsum.

Design walls to dry towards the outside in cold climates

In cold climates exterior wall systems should dry towards the outside by locating vapor retarding materials on the inside of the wall assembly and keeping exterior materials vapor permeable. Along with providing this type of wall design, control of indoor humidity levels and air leakage are also very important considerations. To establish resistance to moisture vapor diffusing into the wall from inside the house, widely accepted materials include kraft-faced insulation batts and semi-permeable interior paints.

Along with vapor retarder materials like kraftfaced batts towards the inside of cold region wall assemblies, vapor permeable materials towards the outside of the assembly will facilitate outward drying. This allows any moisture in the wall to dry outward towards the colder and drier outdoor environment. However, several common sheathing materials like wood structural panels and foam insulating panels have fairly low perm ratings, which in theory could impede drying and possibly even create a cold surface for condensation. Given that this guide is intended to present established best practices and these issues are still being researched by the building science community.

Various types of insulation are shown in Figs.(4.2 – 4.17). The figures are illustrating the formation of some of the vapor retarders.

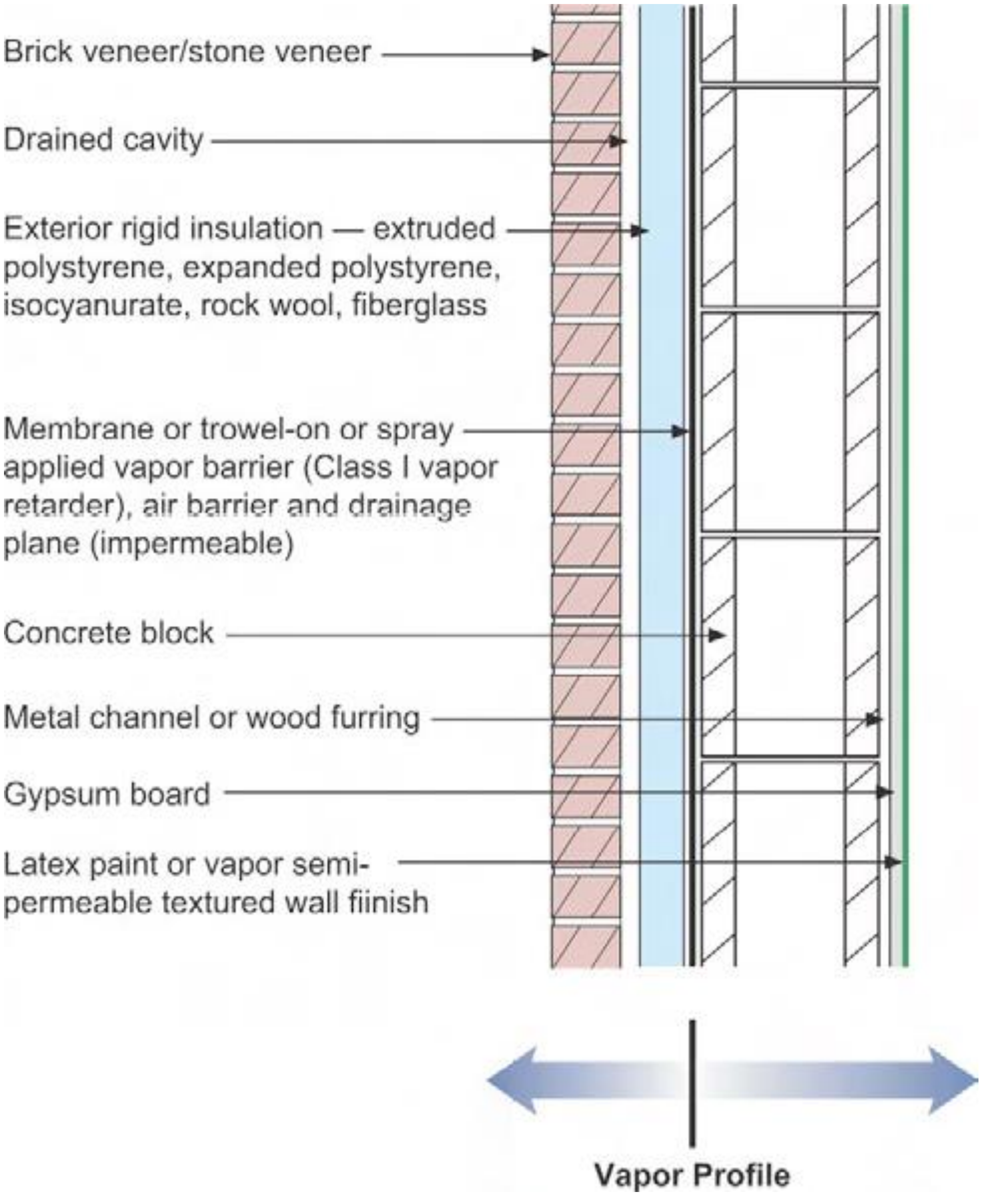


Figure (4.2) Concrete Block with Exterior and Brick or Stone Veneer (Joseph, 2005)

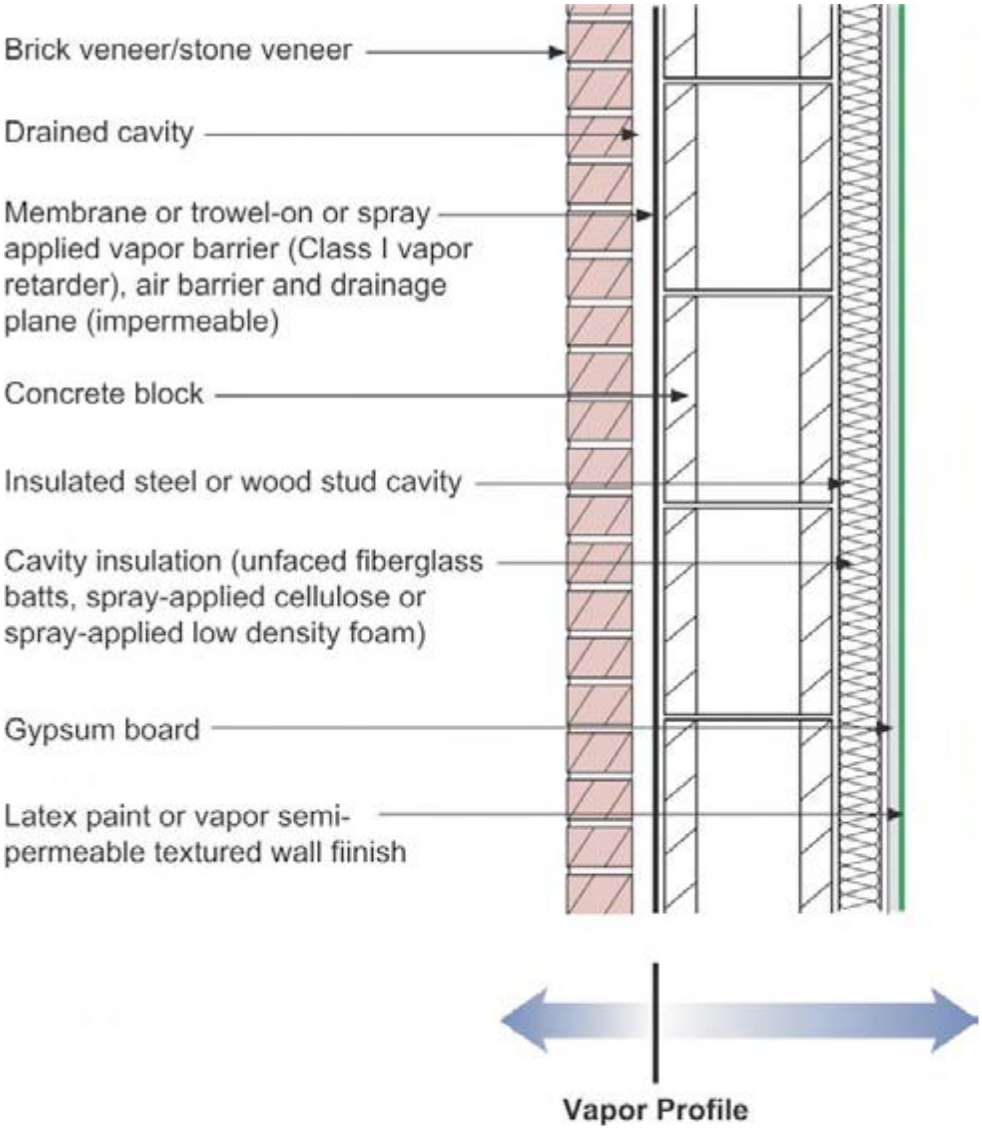


Figure (4.3) Concrete Block with Interior Frame Wall Cavity Insulation and Brick or Stone Veneer (Joseph, 2005)

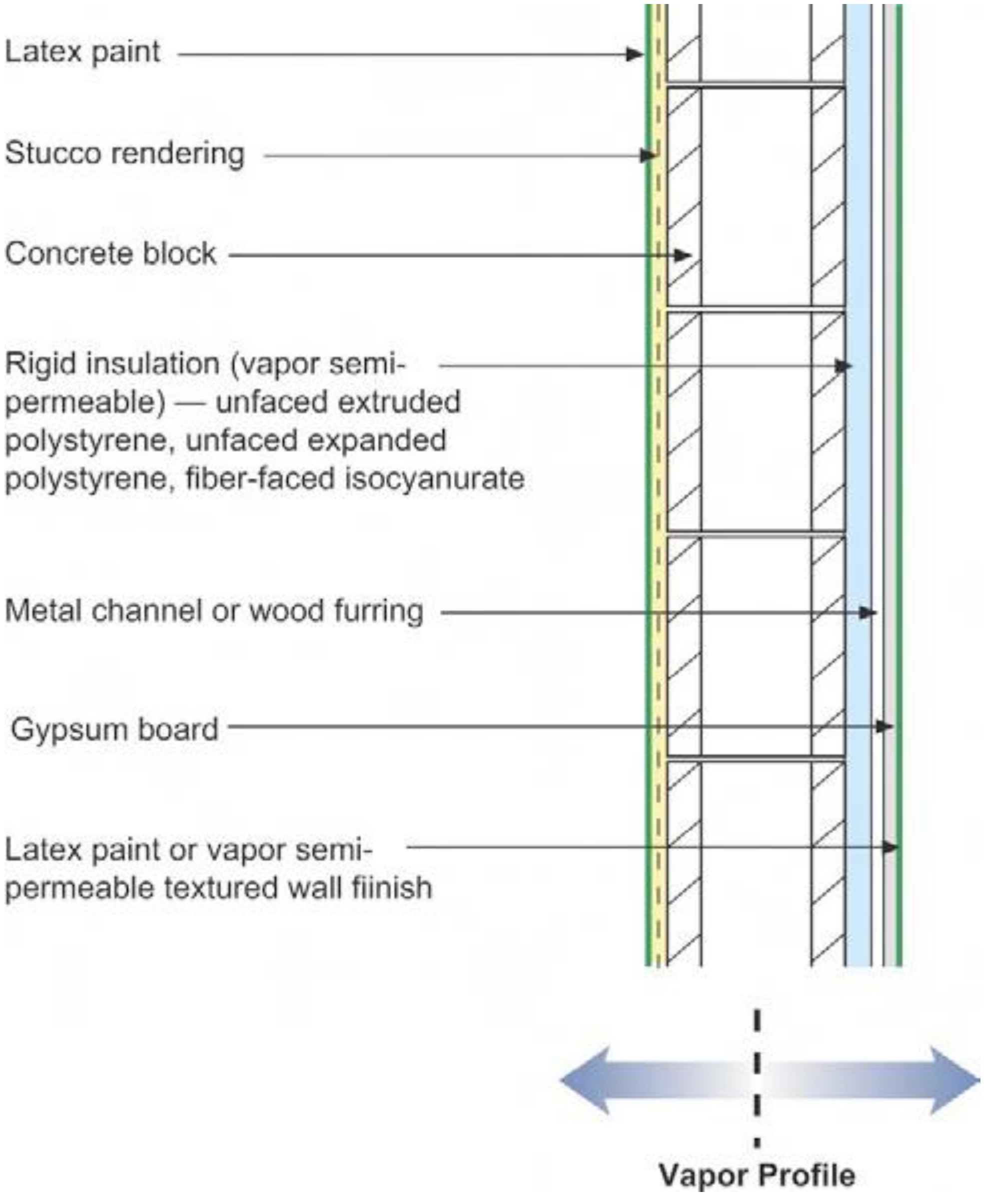


Figure (4.4) Concrete Block with Interior Rigid Insulation and Stucco (Joseph, 2005)

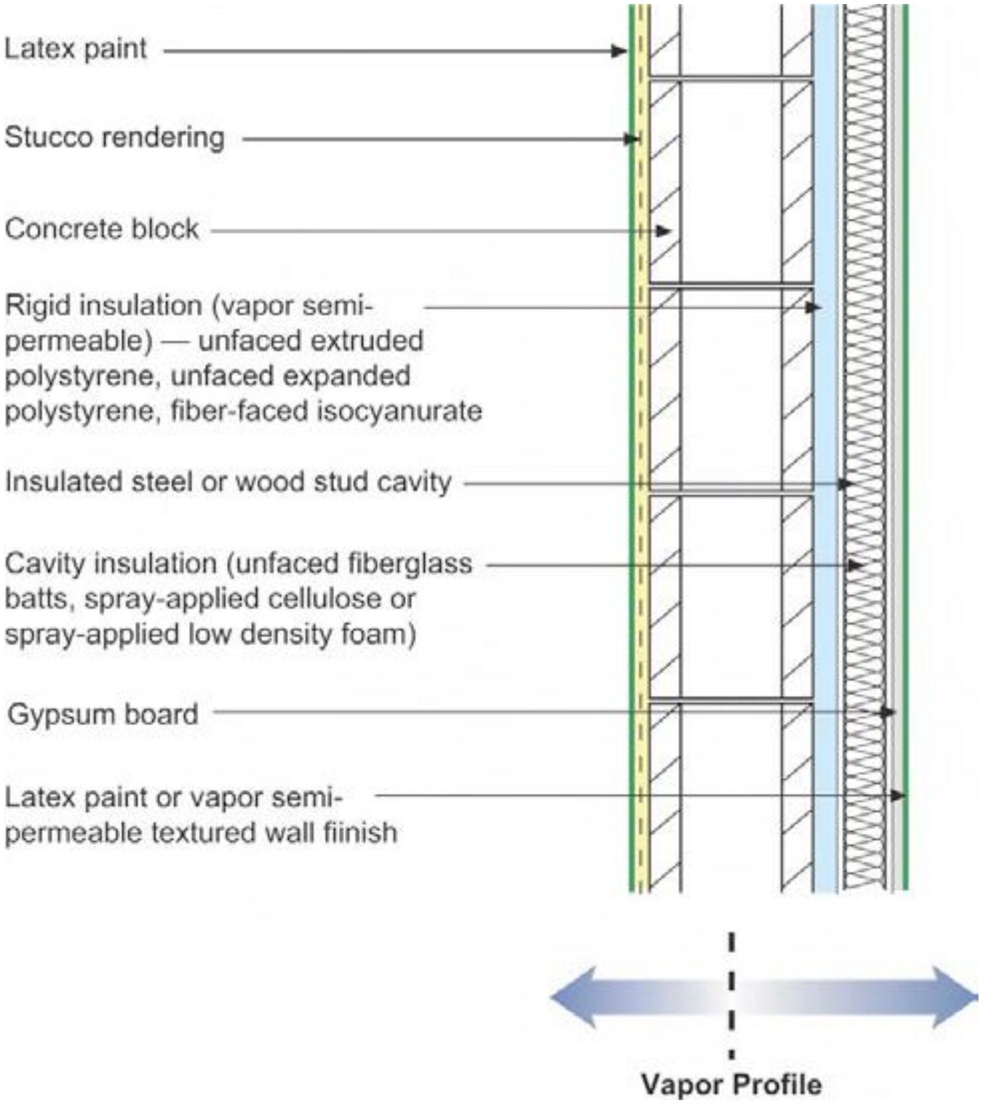


Figure (4.5) Concrete Block with Interior Rigid Insulation/Frame Wall with Cavity Insulation and Stucco (Joseph, 2005)

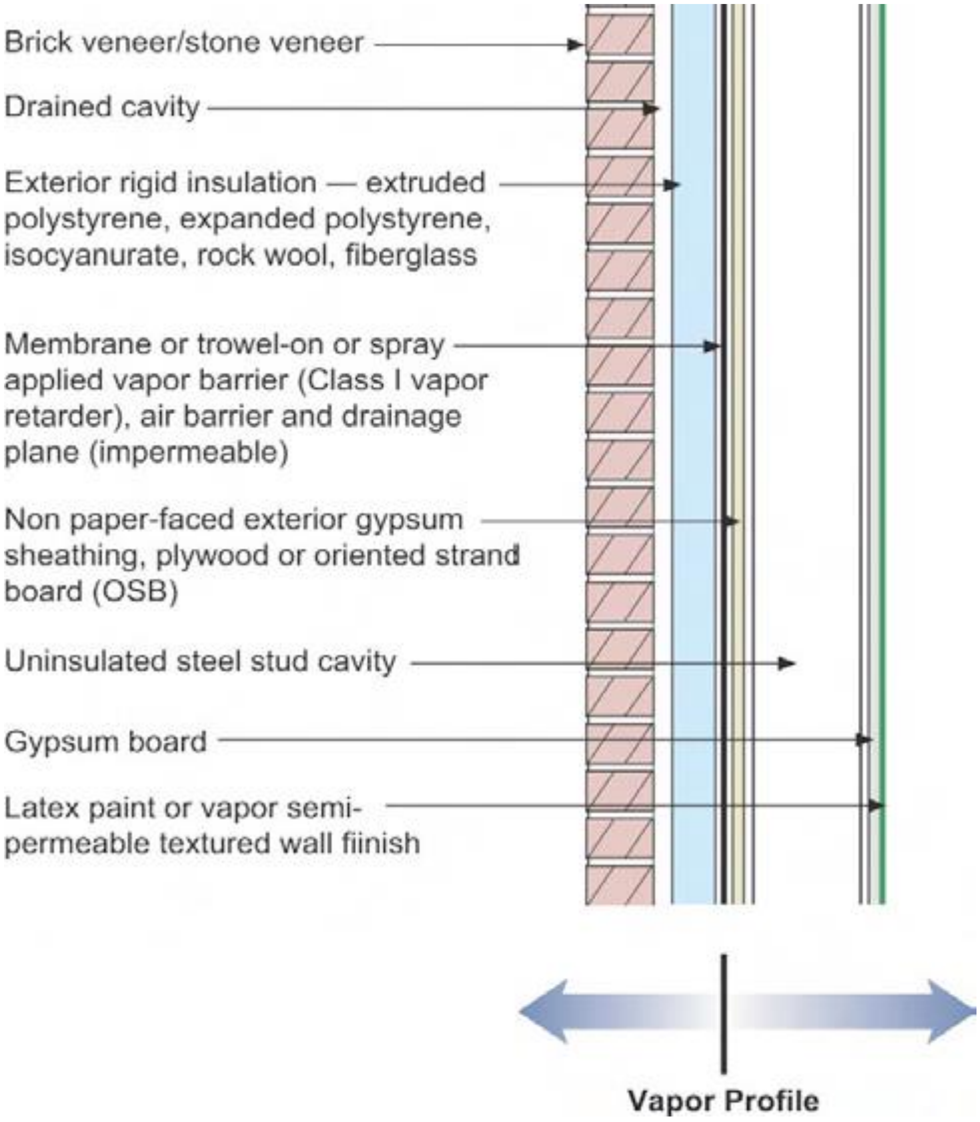


Figure (4.6) Frame Wall with Exterior Insulation and Brick or Stone Veneer (Joseph, 2005)

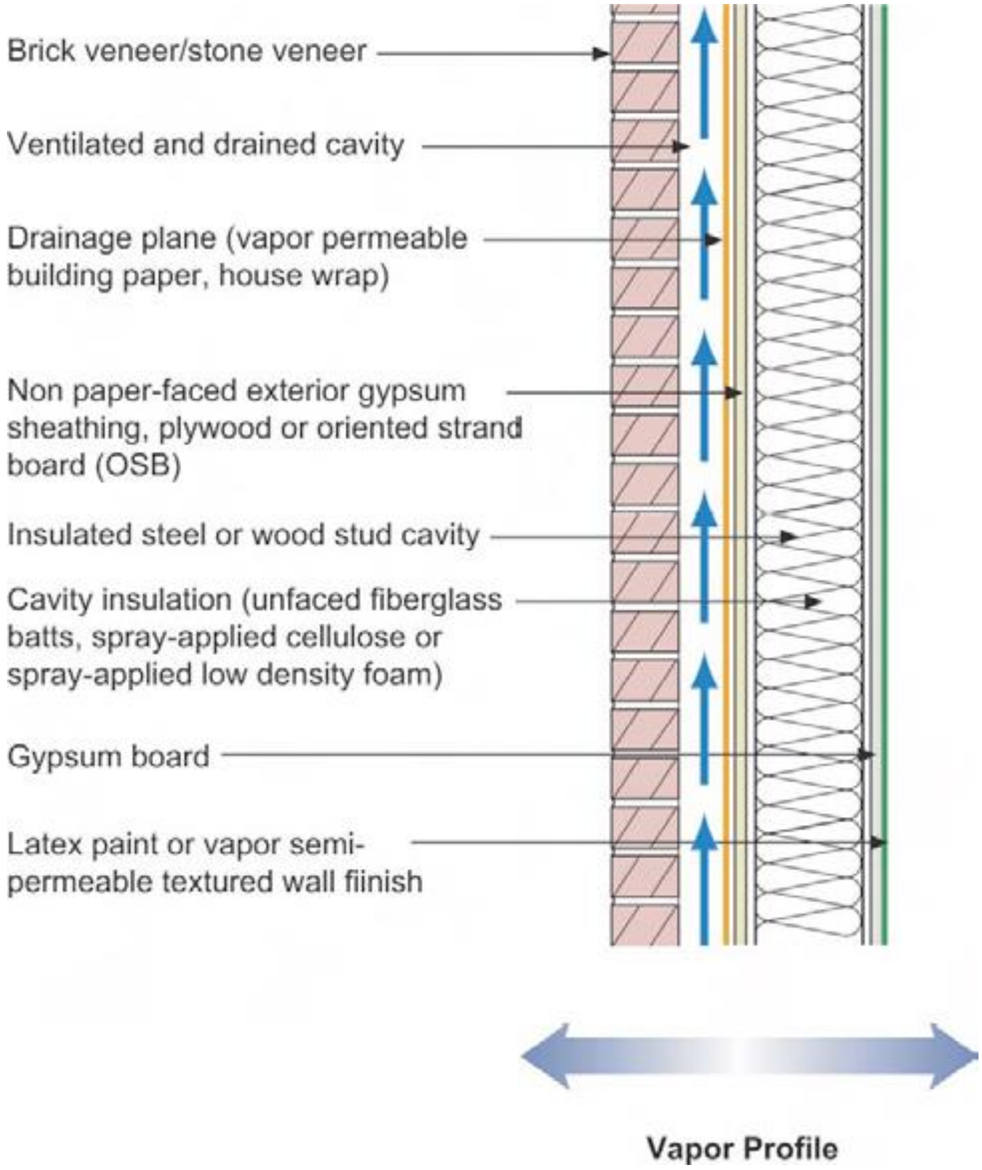


Figure (4.7) Frame Wall with Cavity Insulation and Brick or Stone Veneer (Joseph, 2005)

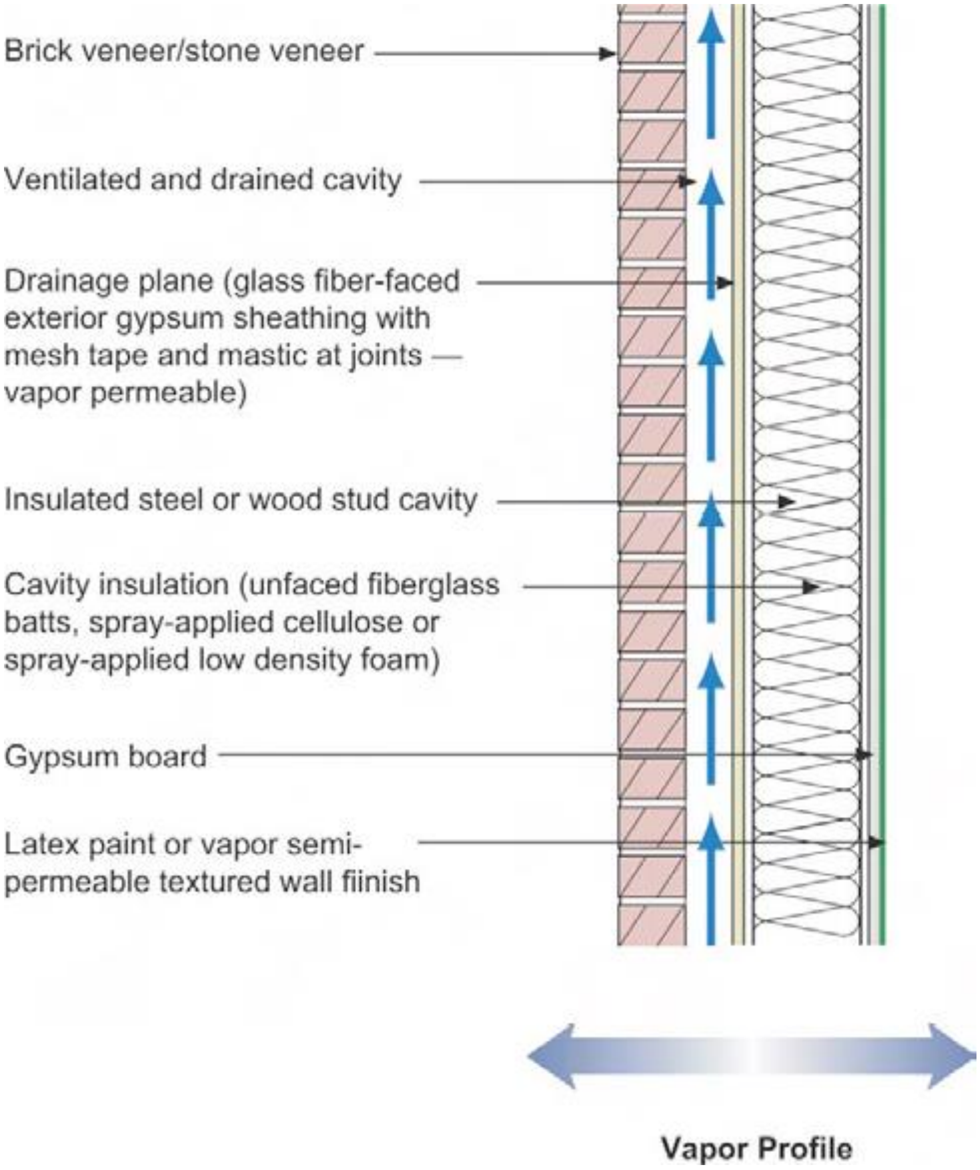


Figure (4.8) Frame Wall with Cavity Insulation and Brick or Stone Veneer (Joseph, 2005)

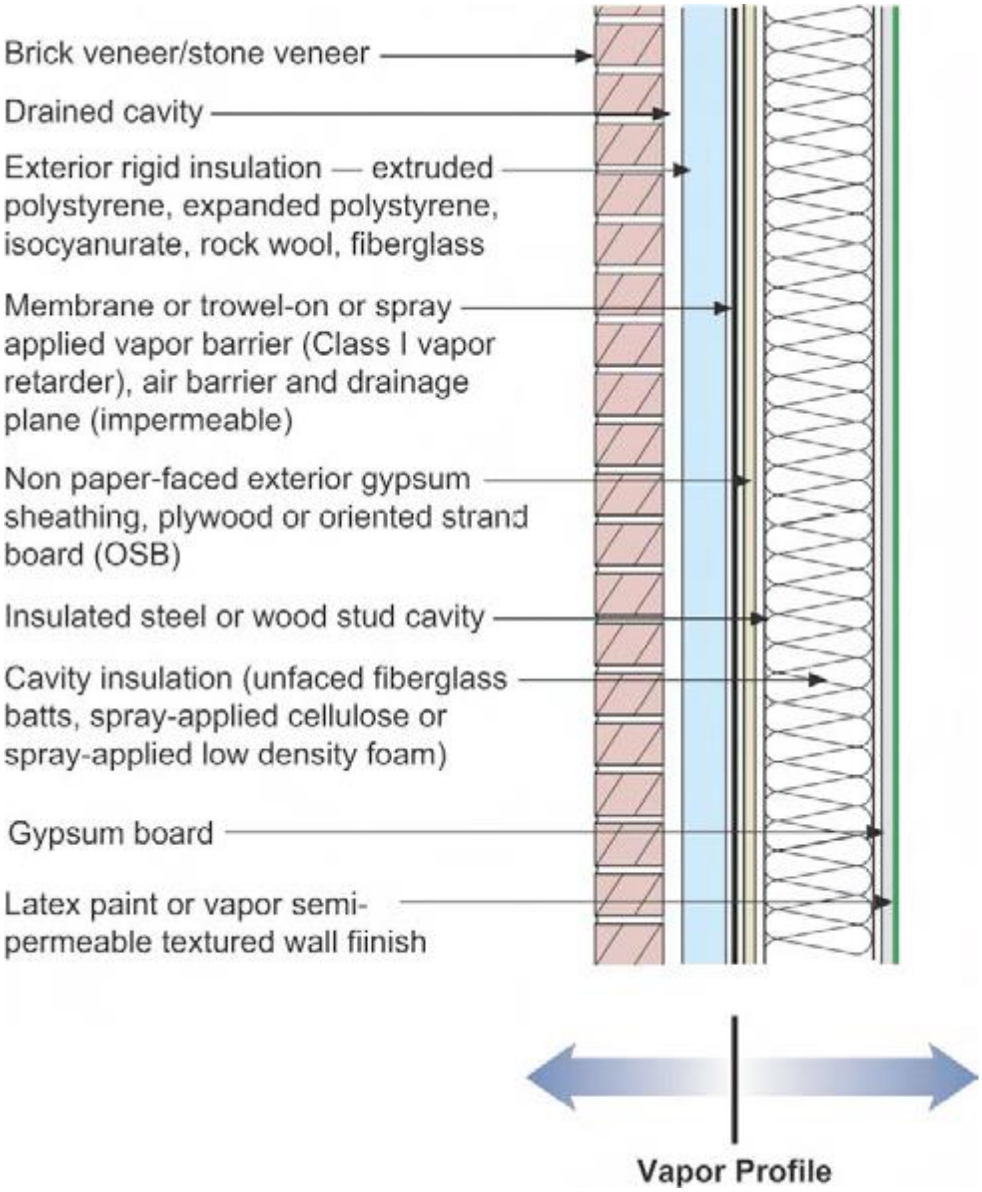


Figure (4.9) Frame Wall with Cavity Insulation and Brick or Stone Veneer (Joseph, 2005)

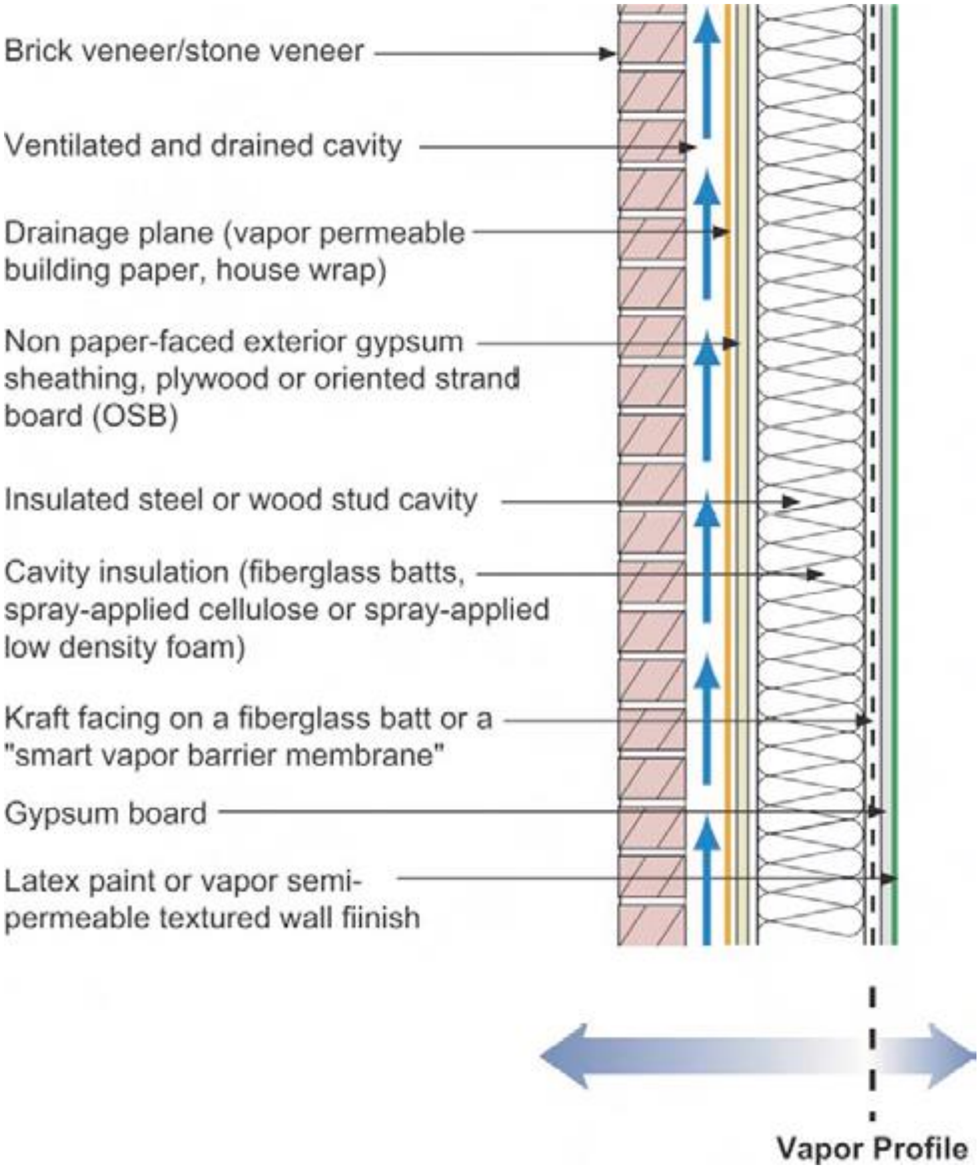


Figure (4.10) Frame Wall with Exterior Rigid Insulation With Cavity Insulation and Brick or Stone Veneer (Joseph, 2005)

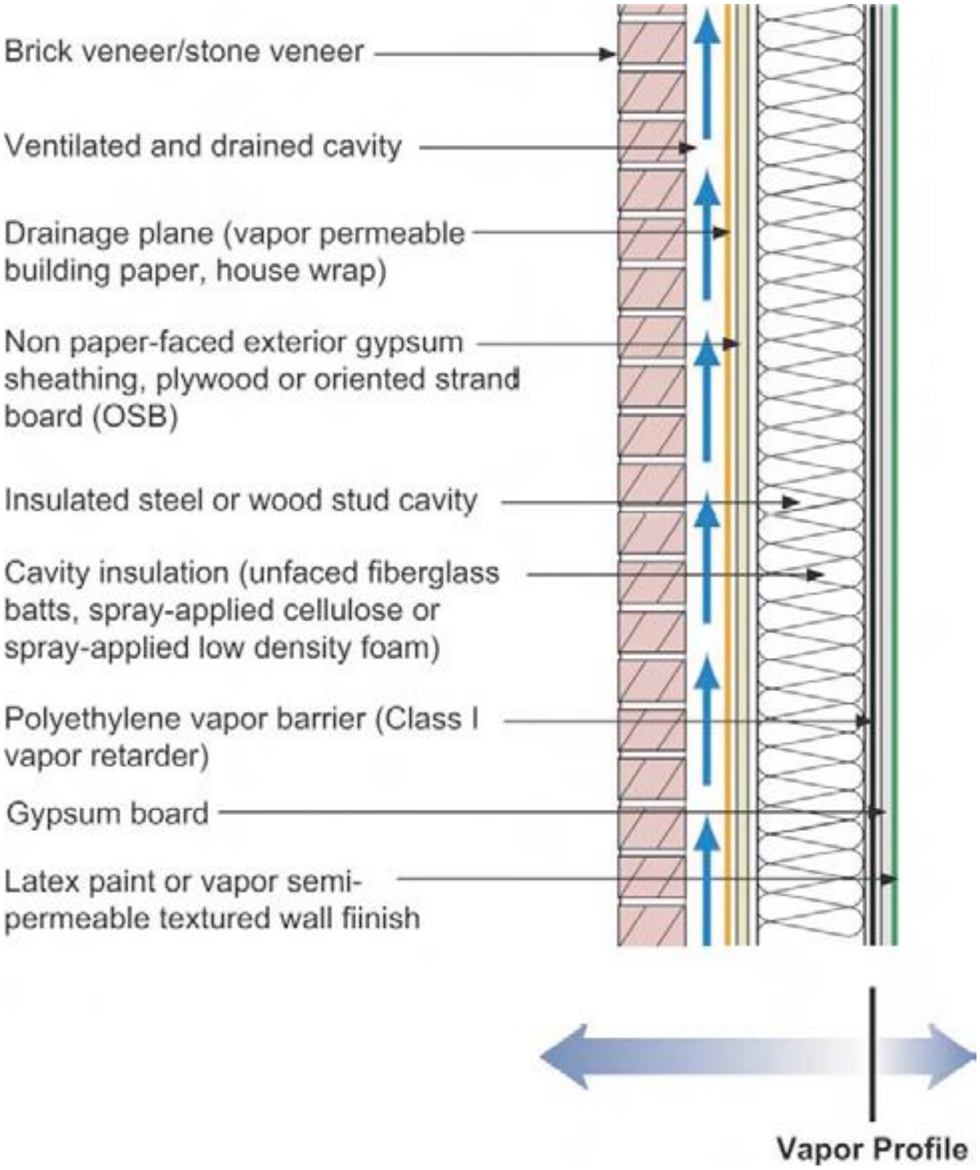


Figure (4.11) Frame Wall with Cavity Insulation and Brick or Stone Veneer With Interior Vapor (Joseph, 2005)

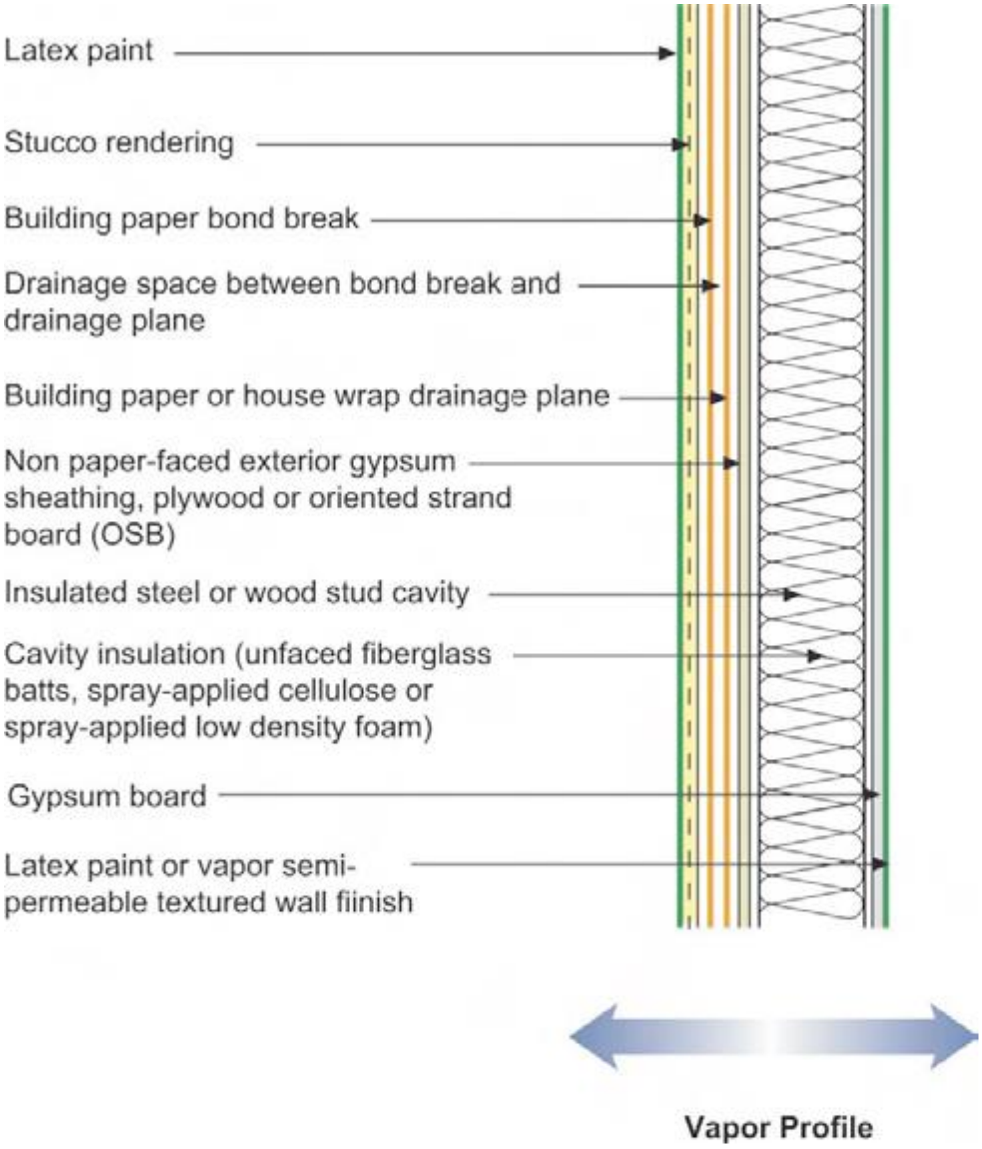


Figure (4.12) Frame Wall with Cavity Insulation and Brick or Stone Veneer With Interior Vapor (Joseph, 2005)

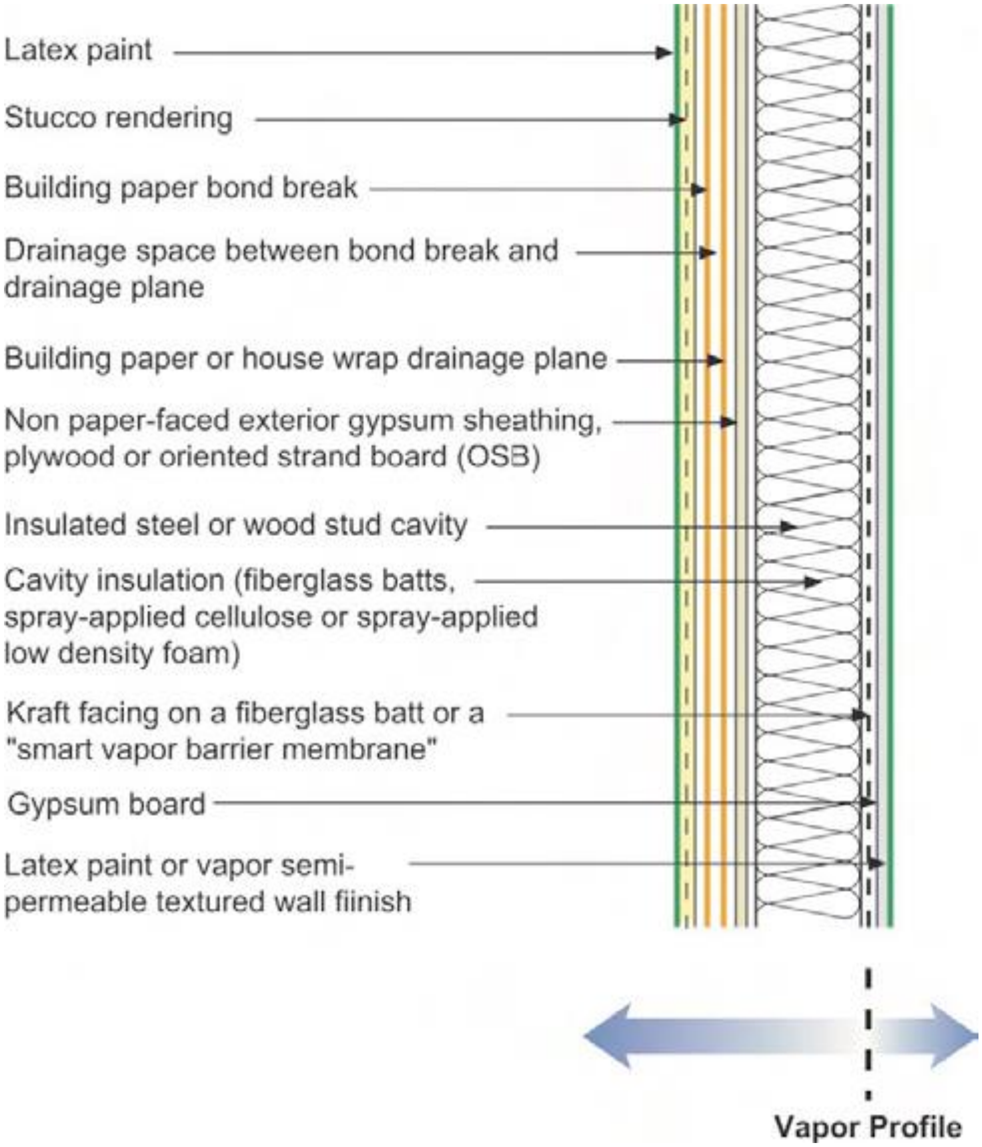


Figure (4.13) Wall with Cavity Insulation and Stucco (Joseph, 2005)

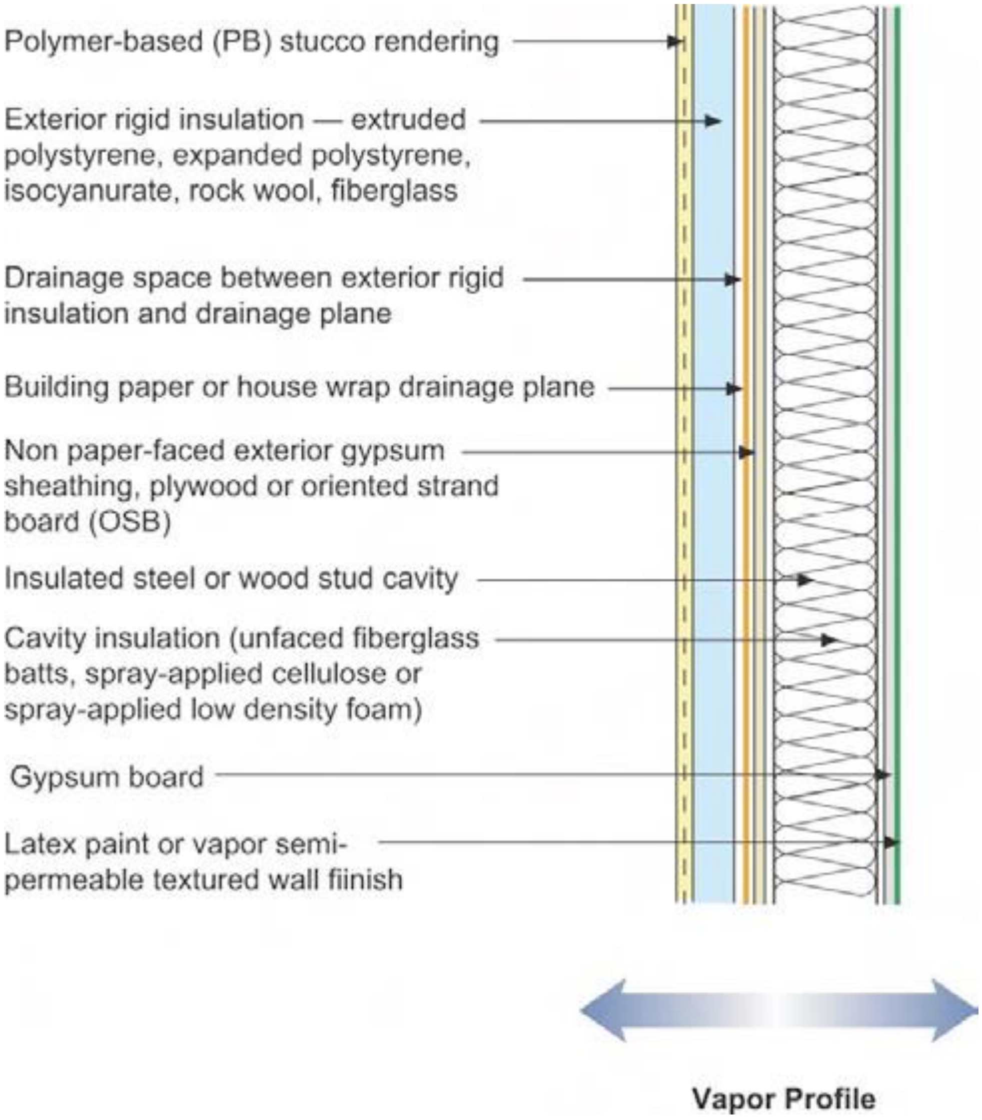


Figure (4.14) Frame Wall with Cavity Insulation and Stucco With Interior Vapor Retarder (Joseph, 2005)

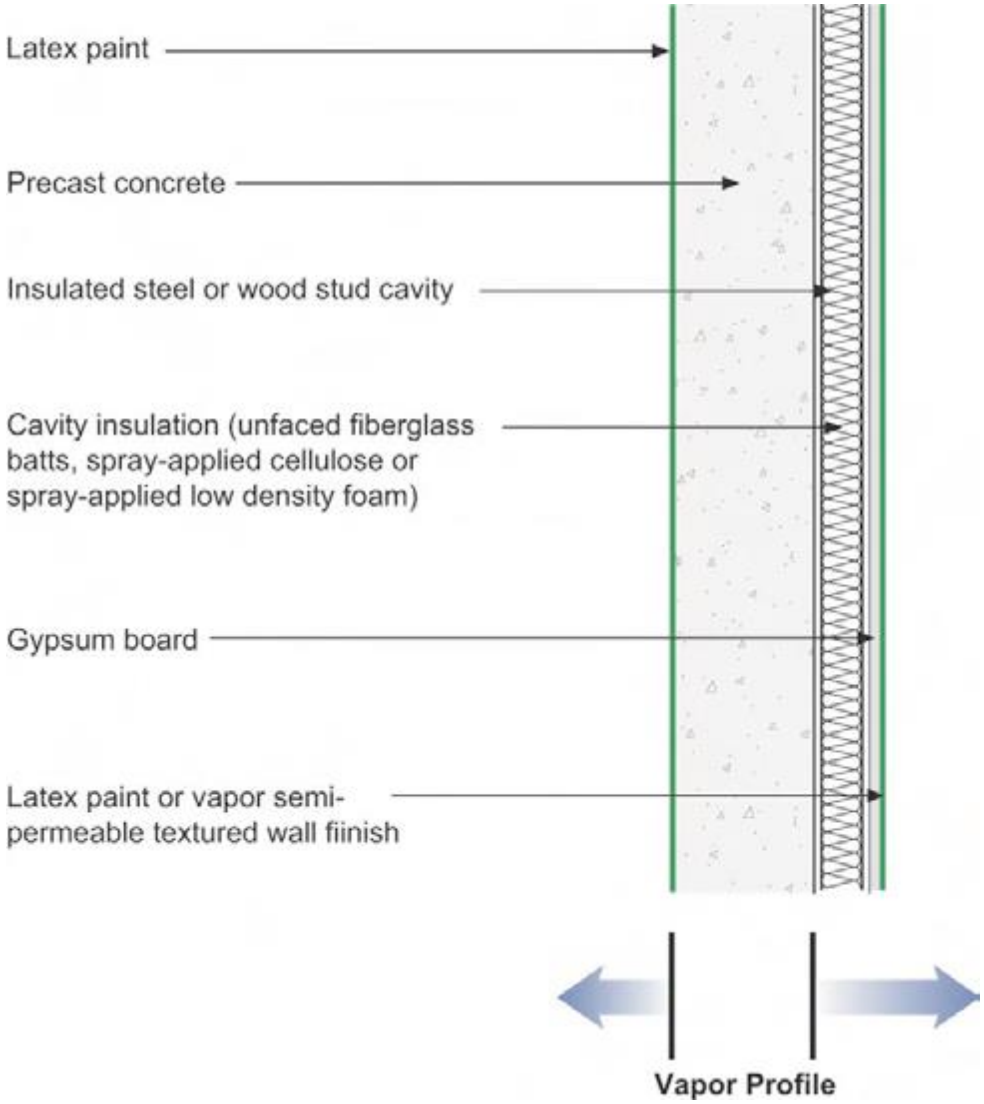


Figure (4.15) Frame Wall with Exterior Rigid Insulation With Cavity Insulation and Stucco (Joseph, 2005)

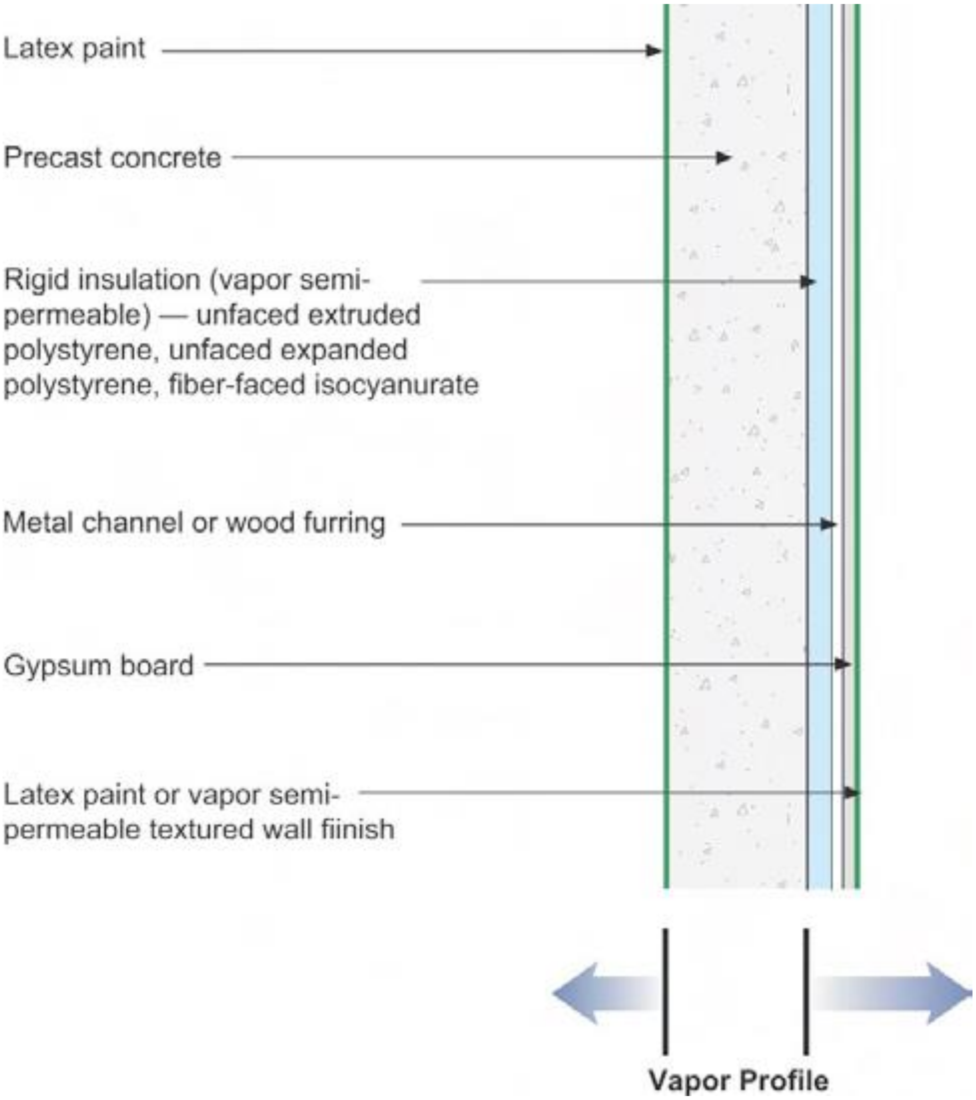


Figure (4.16) Precast Concrete with Interior Frame Wall Cavity Insulation (Joseph, 2005)

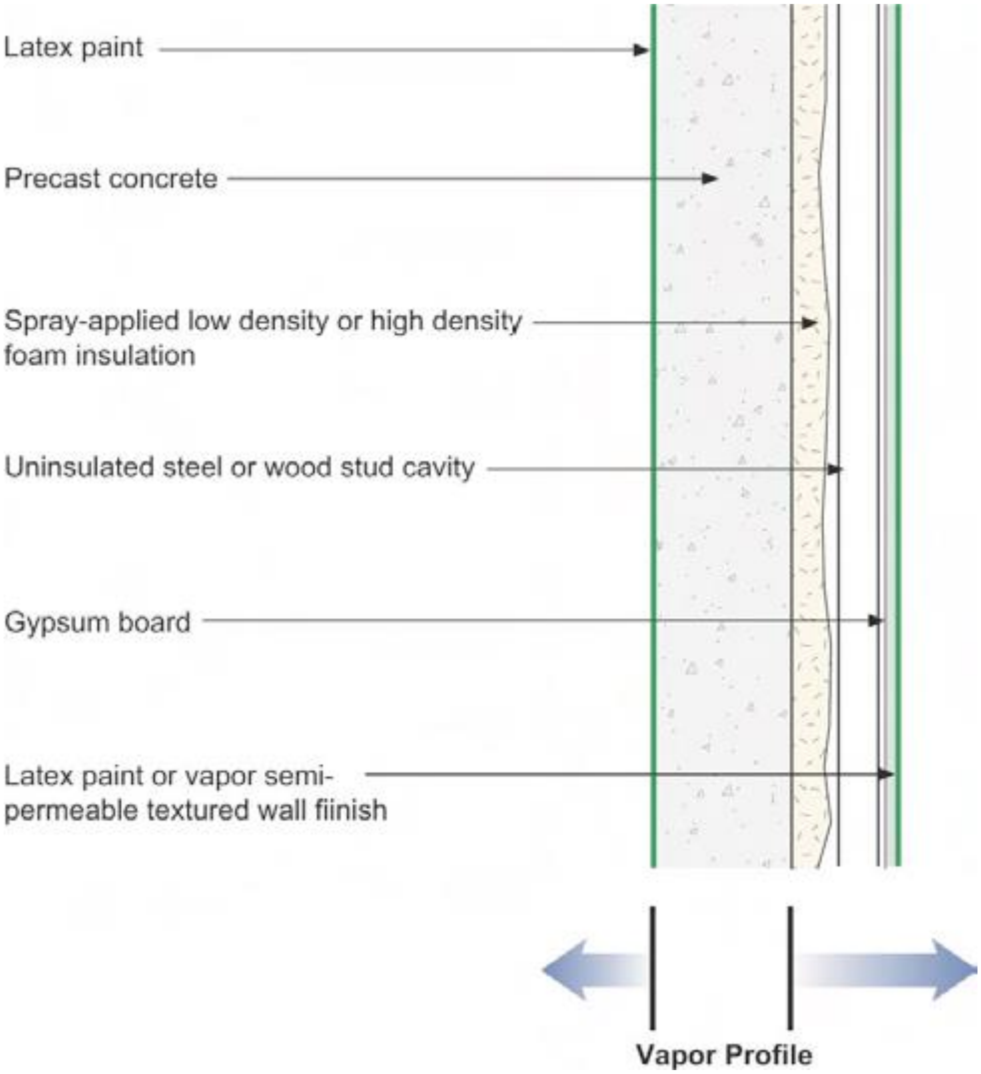


Figure (4.17) Precast Concrete with Interior Rigid Insulation (Joseph, 2005)

The air vapor usually condensate on the hot surface not on the cold surface of insulation because the out surface temperature lower than dew point of the air.

The vapor insulation thickness can be obtained by:

$$q= (1/R_o)\,(t_o-t_s) = (1/R_{all})\,(t_o-t_i) \qquad 4.1$$

Where:

q: Heat transfer rate, (W/m^2).

t_o, t_i: Indoor & outdoor temperature, (^{o}C).

t_s: outer surface temperature, usually equal to dew point of the outer air, (^{o}C).

R_o: outer surface thermal resistance, (m^2.^{o}C/W).

R_{all}: overall thermal resistance of the wall materials, (m^2. ^{o}C/W).

Chapter (5)

FREEZING STORAGE DESIGN

5.1 Introduction

Implementing the strategy of refrigeration & air condition diploma which is aiming to educate the postgraduate students' different techniques to estimate thermal loads, equipment selection & refrigeration and air condition maintenance issues, this project takes place in order to attend these needs.

5.1.1 Overall duration of the project

About 8 months starting at 2008-Nov-07.

5.1.2 Aim of the project

To design a freezing storages dimensions & selecting of the suitable equipments for the estimated considerable loads.

5.1.3 Added values

- The different techniques of estimates the thermal loads.
- Use the different software programs to calculate thermal loads.
- How to select the equipments required for the design.

5.2 Project Goals

In order to achieve the aim this project…the team implement a plan to archive the below goals:

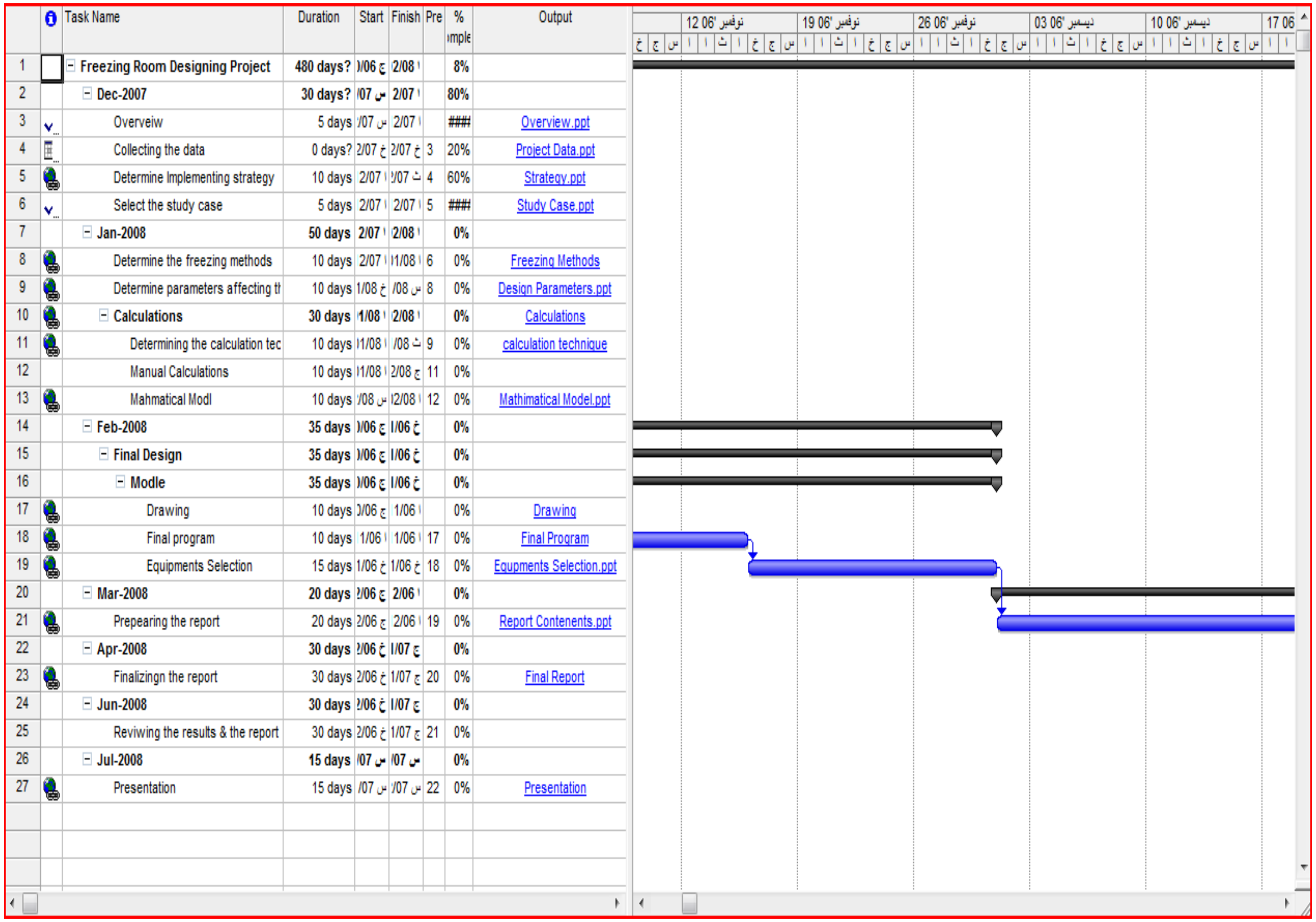
To design a cooling storages for a specific products. The different techniques of estimates the thermal loads. Use the different software programs to calculate thermal loads. How to select the equipments required for the design.

5.3 Project Plan

A preliminary plan was putted based on some main points:

- Custom Program for calculating the refrigeration load.
- Select the product type
- Determine the storage specification.
- Determine the assumption.
- State the design equations.
- Get the results.
- Select the system.
- Present the design.

The detailed plan was presented by Microsoft project see Fig. (5.1).



	Task Name	Duration	Start	Finish	Pre	% omple	Output
1	**Freezing Room Designing Project**	**480 days?**	**0/06 ع**	**2/08**		**8%**	
2	**Dec-2007**	**30 days?**	**/07 س**	**2/07**		**80%**	
3	Overveiw	5 days	/07 س	2/07		####	Overview.ppt
4	Collecting the data	0 days?	2/07 خ	2/07 خ	3	20%	Project Data.ppt
5	Determine Implementing strategy	10 days	2/07	/07 ث	4	60%	Strategy.ppt
6	Select the study case	5 days	2/07	2/07	5	####	Study Case.ppt
7	**Jan-2008**	**50 days**	**2/07**	**2/08**		**0%**	
8	Determine the freezing methods	10 days	2/07	1/08	6	0%	Freezing Methods
9	Determine parameters affecting tl	10 days	1/08 خ	/08 س	8	0%	Design Parameters.ppt
10	**Calculations**	**30 days**	**1/08**	**2/08**		**0%**	Calculations
11	Determining the calculation tec	10 days	1/08	/08 ث	9	0%	calculation technique
12	Manual Calculations	10 days	1/08	2/08 ج	11	0%	
13	Mahmatical Modl	10 days	/08 س	2/08	12	0%	Mathimatical Model.ppt
14	**Feb-2008**	**35 days**	**0/06 ع**	**1/06 خ**		**0%**	
15	**Final Design**	**35 days**	**0/06 ع**	**1/06 خ**		**0%**	
16	**Modle**	**35 days**	**0/06 ع**	**1/06 خ**		**0%**	
17	Drawing	10 days	0/06 ع	1/06		0%	Drawing
18	Final program	10 days	1/06	1/06	17	0%	Final Program
19	Equipments Selection	15 days	1/06 خ	1/06 خ	18	0%	Equpments Selection.ppt
20	**Mar-2008**	**20 days**	**2/06 ع**	**2/06**		**0%**	
21	Prepearing the report	20 days	2/06 ج	2/06	19	0%	Report Contenents.ppt
22	**Apr-2008**	**30 days**	**2/06 خ**	**1/07 ع**		**0%**	
23	Finalizngn the report	30 days	2/06 خ	1/07 ج	20	0%	Final Report
24	**Jun-2008**	**30 days**	**2/06 خ**	**1/07 ع**		**0%**	
25	Reviwing the results & the report	30 days	2/06 خ	1/07 ج	21	0%	
26	**Jul-2008**	**15 days**	**/07 س**	**/07 س**		**0%**	
27	Presentation	15 days	/07 س	/07 س	22	0%	Presentation

Figure (5.1) Project Planning Sheet

5.4 Project Assumptions

- One floor.
- One room.
- The room in the last floor of the building.
- The dimensions of the room is 3 * 4 * 3 meters
- Product type is beef.
- The activity of the storage is supplying for small traders.

5.5 Project Calculations and Mathematical Model

The refrigeration load calculation was calculated based on ASHRAE cooling load mathematical model.

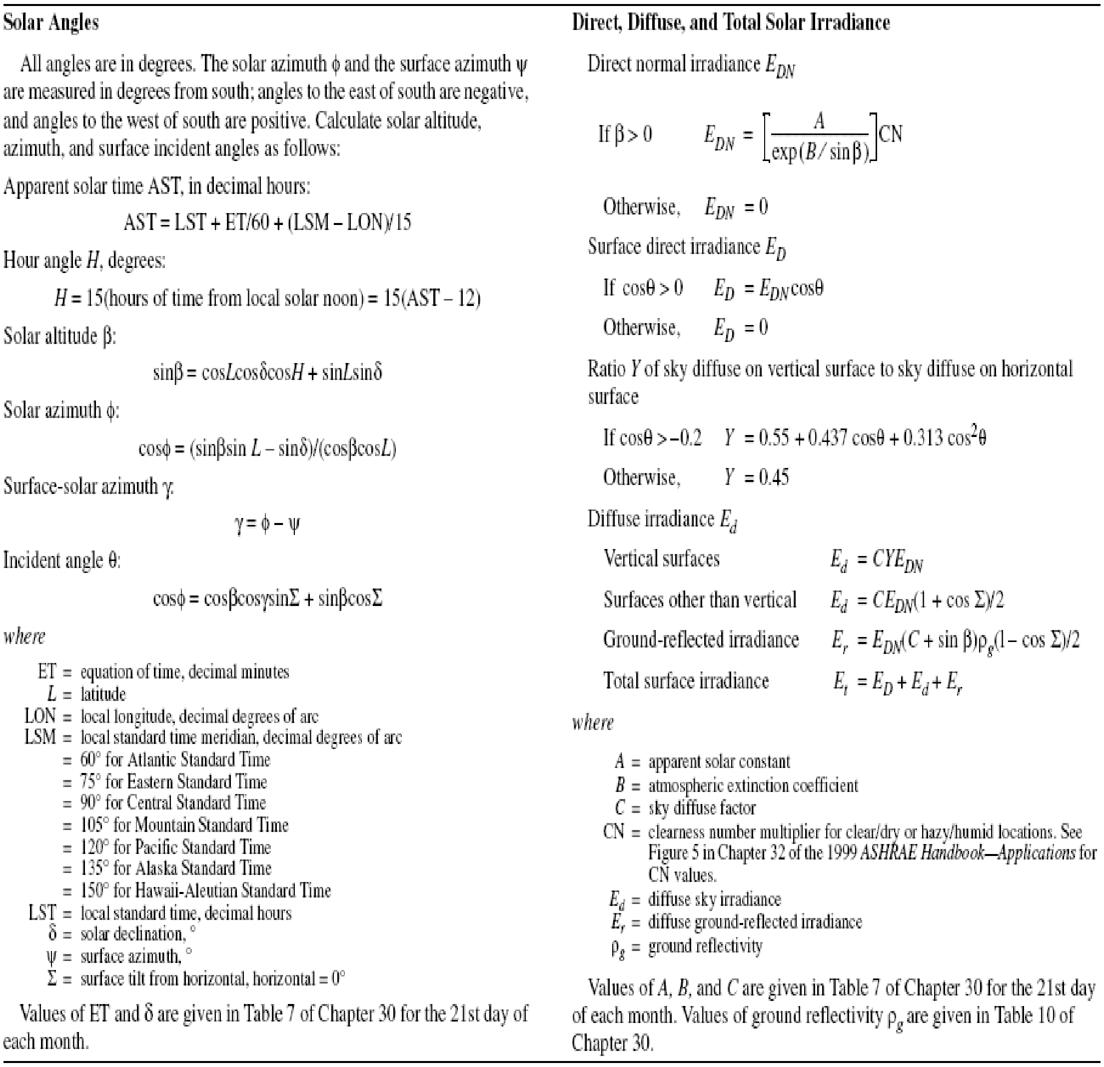
The step of calculations includes the following steps:

- Calculating Sol-Air temperature.
- Calculating Walls Heat Gain.
- Conduction Time Series Method.
- Calculating Heat Input 24 hour Profile.
- Calculating Heat Gain by Applying CTS Factors to the Heat Input.
- Selecting the maximum heat gain for every surface to be summed.
- Calculating Product Load.
- Calculating Person Load.
- Calculating Lights Load.

5.6 Refrigeration Load Calculation

5.6.1 Sol-Air temperature calculation

Table 5.1 Sol-Air Equations



Solar Angles

All angles are in degrees. The solar azimuth ϕ and the surface azimuth ψ are measured in degrees from south; angles to the east of south are negative, and angles to the west of south are positive. Calculate solar altitude, azimuth, and surface incident angles as follows:

Apparent solar time AST, in decimal hours:

$$AST = LST + ET/60 + (LSM - LON)/15$$

Hour angle H, degrees:

$$H = 15(\text{hours of time from local solar noon}) = 15(AST - 12)$$

Solar altitude β:

$$\sin\beta = \cos L \cos\delta \cos H + \sin L \sin\delta$$

Solar azimuth ϕ:

$$\cos\phi = (\sin\beta \sin L - \sin\delta)/(\cos\beta \cos L)$$

Surface-solar azimuth γ:

$$\gamma = \phi - \psi$$

Incident angle θ:

$$\cos\phi = \cos\beta \cos\gamma \sin\Sigma + \sin\beta \cos\Sigma$$

where

ET = equation of time, decimal minutes
L = latitude
LON = local longitude, decimal degrees of arc
LSM = local standard time meridian, decimal degrees of arc
= 60° for Atlantic Standard Time
= 75° for Eastern Standard Time
= 90° for Central Standard Time
= 105° for Mountain Standard Time
= 120° for Pacific Standard Time
= 135° for Alaska Standard Time
= 150° for Hawaii-Aleutian Standard Time
LST = local standard time, decimal hours
δ = solar declination, °
ψ = surface azimuth, °
Σ = surface tilt from horizontal, horizontal = 0°

Values of ET and δ are given in Table 7 of Chapter 30 for the 21st day of each month.

Direct, Diffuse, and Total Solar Irradiance

Direct normal irradiance E_{DN}

If $\beta > 0$ $\quad E_{DN} = \left[\dfrac{A}{\exp(B/\sin\beta)}\right]CN$

Otherwise, $\quad E_{DN} = 0$

Surface direct irradiance E_D

If $\cos\theta > 0 \quad E_D = E_{DN}\cos\theta$

Otherwise, $\quad E_D = 0$

Ratio Y of sky diffuse on vertical surface to sky diffuse on horizontal surface

If $\cos\theta > -0.2 \quad Y = 0.55 + 0.437\cos\theta + 0.313\cos^2\theta$

Otherwise, $\quad Y = 0.45$

Diffuse irradiance E_d

Vertical surfaces $\quad E_d = CYE_{DN}$

Surfaces other than vertical $\quad E_d = CE_{DN}(1 + \cos\Sigma)/2$

Ground-reflected irradiance $\quad E_r = E_{DN}(C + \sin\beta)\rho_g(1 - \cos\Sigma)/2$

Total surface irradiance $\quad E_t = E_D + E_d + E_r$

where

A = apparent solar constant
B = atmospheric extinction coefficient
C = sky diffuse factor
CN = clearness number multiplier for clear/dry or hazy/humid locations. See Figure 5 in Chapter 32 of the 1999 *ASHRAE Handbook—Applications* for CN values.
E_d = diffuse sky irradiance
E_r = diffuse ground-reflected irradiance
ρ_g = ground reflectivity

Values of A, B, and C are given in Table 7 of Chapter 30 for the 21st day of each month. Values of ground reflectivity ρ_g are given in Table 10 of Chapter 30.

5.6.2 Heat input

Whenever a conditioned space is adjacent to a space with a different temperature, transfer of heat through the separation physical section must be considered. The heat transfer rate is given by the equation

$$Q = UA(T_b - T_i) \tag{5.1}$$

Where

Q = heat transfer rate (*W*)

U = Coefficient of overall heat transfer between adjacent and conditioned space $W/m^2.K$

A = Area of separating section connected, m^2

T_b = Average air temperature in adjacent space, degree

5.6.3 Heat gain

Calculation of heat gain can be presented by

$$q_{i,\theta-n} = UA(t_{e,\theta-n} - t_{rc}) \tag{5.2}$$

Where

$q_{i,\theta-n}$ = Conductive heat input for the surface n hours ago, W

U= Overall heat transfer coefficient for the surface, W/(m2.K)

A = Surface area, m^2

$t_{e,\theta-n}$ = Sol-air temperature n hours ago, degree C

t_{rc} = Presumed constant room air temperature

Conductive heat gain through walls or roofs can be calculated using conductive heat inputs for the current hours and past 23 h and conduction time series:

$$q_\theta = c_0 q_{i,\theta} + c_1 q_{i,\theta-1} + c_2 q_{i,\theta-2} + c_3 q_{i,\theta-3} + \ldots + c_{23} q_{i,\theta-23} \quad 5.3$$

Where

q_θ = hourly conductive heat gain for the surface, W

$q_{i,\theta}$ = heat input for the current hour, W

$q_{i,\theta-n}$ = heat input n hours age, W

5.6.4 Product load

The primary refrigeration load from products brought into and kept in the refrigerated space are:

- The heat that must be removed to reduce the product temperature to storage temperature.
- The heat generated by products in storage, mainly fruits and vegetables.
- The quantity of heat to be removed can be calculated as follows:

1. Heat removed to cool from the initial temperature to some lower temperature above freezing:

$$Q_1 = mc_1(t_1 - t_2) \quad 5.4$$

2. Heat removed to cool from the initial temperature to the freezing point of the product:

$$Q_2 = mc_1(t_1 - t_f) \quad 5.5$$

3. Heat removed to freeze the product:

$$Q_3 = mh_{if} \quad 5.6$$

4. Heat removed to cool from the freezing point to the final temperature below the freezing point:

$$Q_4 = mc_2(t_f - t_3) \quad 5.7$$

Where

Q_1, Q_2, Q_3, Q_4 = heat removed, kJ

m = mass of product, kg

c_1 = specific heat of product above freezing, kJ/(kg·K)

t_1= initial temperature of product above freezing, °C

t_2 = lower temperature of product above freezing, °C

t_f = freezing temperature of product, °C

h_{if} = latent heat of fusion of product, kJ/kg

c_2 = specific heat of product below freezing, kJ/(kg·K)

t_3= final temperature of product below freezing, °C

The refrigeration capacity required for products brought into storage is determined from the time allotted for heat removal and assumes that the product is properly exposed to remove the heat in that time. The calculation is

$$q = \frac{Q_2 + Q_3 + Q_4}{3600n} \tag{5.8}$$

Where

q = average cooling load, kW

n = allotted time, h

Previous Equation only applies to uniform entry of the product into storage. The refrigeration load created by non-uniform loading of a warm product may be much greater over a short period.

5.6.5 People load

$$q_p = 272 - 6t \tag{5.9}$$

Where t is the temperature of refrigerated space in °C.

5.6.6 Lights load

$$q_{et} = WF_{ul}F_{sa} \tag{5.10}$$

Where

q_{el} = heat gain, W

W = total light wattage

F_{ul} = lighting use factor

F_{sa} = lighting special allowance factor

5.7 Program Architecture

The program is written in C# 3 with .net framework 3.5. Visual Studio 2008 Professional were used in making the program, however Visual C# 2008 express edition is free to use for students and academic institutions which don't target the commercial applications.

5.7.1 Class diagrams

Solar System

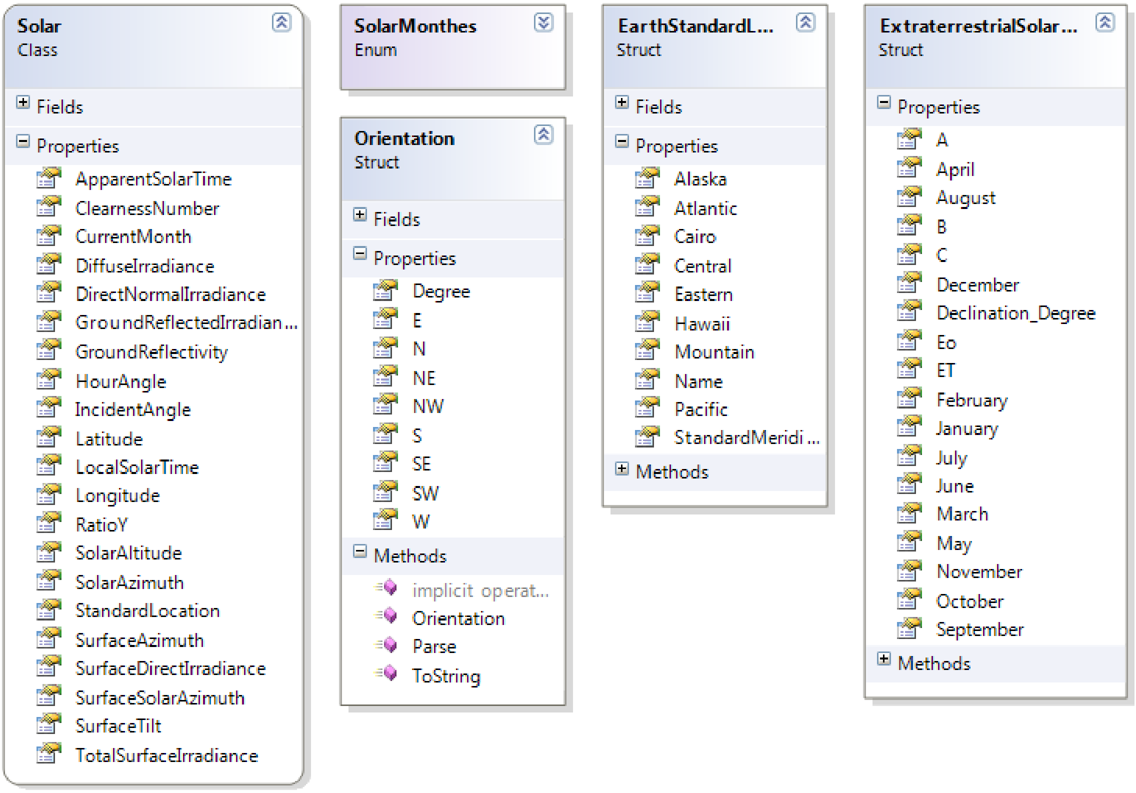


Figure (5.2) UML Class Diagram of Solar Calculation

Refrigeration load

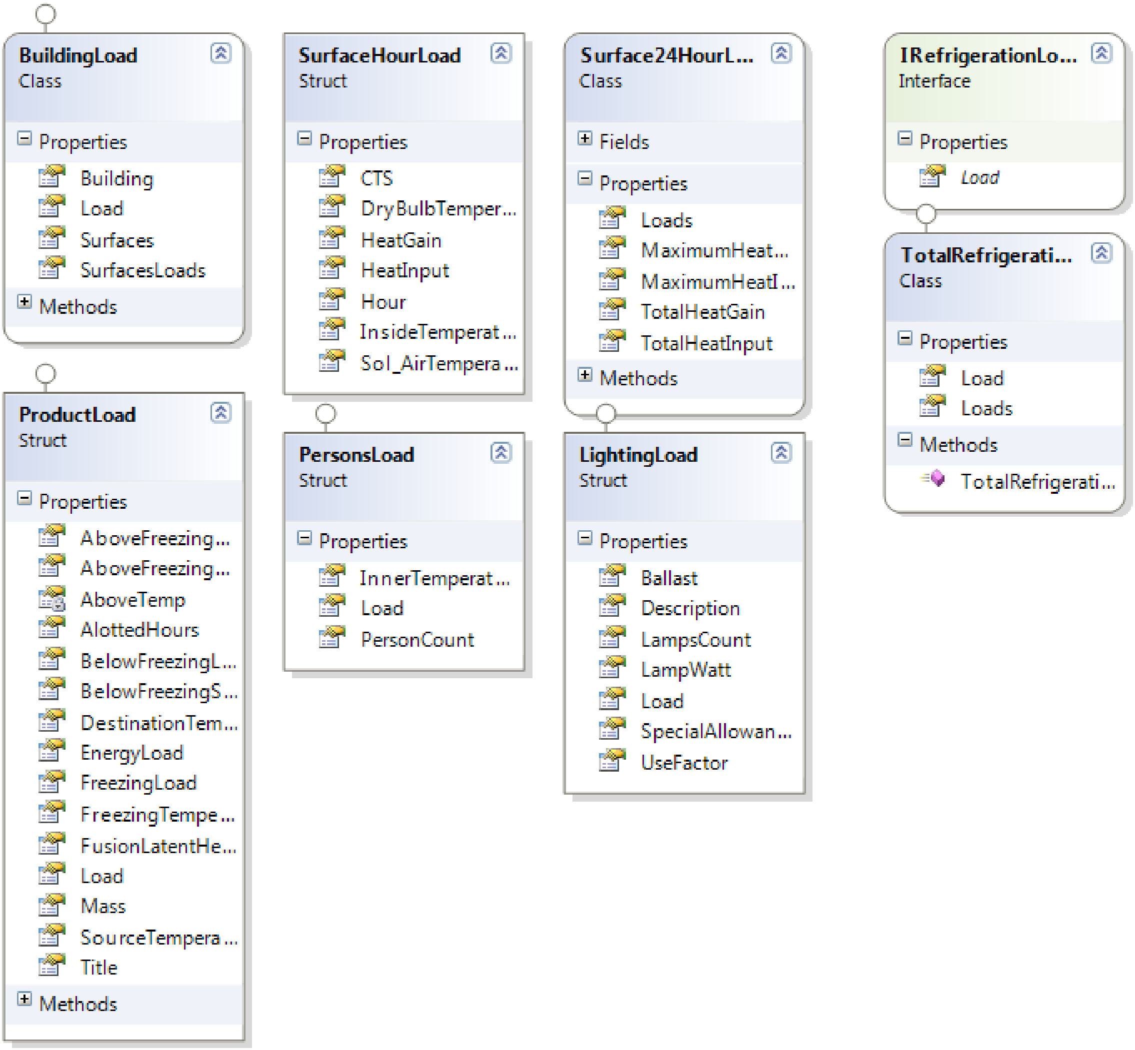


Figure (5.3) UML Class Diagram for Various Refrigeration Load Types

5.7.2 Program source code

The following Source code is selective code from the program for specific calculation. This is not the complete program nor should it be ready to be executed however for any average programmer the code will be clear enough to make his own program easily.

The program source code will be available on the internet at http://www.lostparticles.net

- Solar calculation

- Solar data

From Solar.cs see Table 5.1

```
#region Solar Data
public bool UseGivenSolarTime = false;
private double _ASM;
[Category("Solar Data")]
public double ApparentSolarTime
{
    get
    {
        if (UseGivenSolarTime)
        {
            return _ASM;
        }
        else
        {
```

```
                    double ET = ExtraterrestrialSolarIrradiance.Get_Extraterrestrial_Solar_Data(CurrentMonth).ET;
                    double L = Latitude;
                    double LON = Longitude;
                    double LSM = StandardLocation.StandardMeridian;
                    double LST = LocalSolarTime;
                    return LST + ET / 60 + (LSM - LON) / 15;
                }
            }
        }

        [Category("Solar Data")]
        public double HourAngle
        {
            get
            {
                return (15 * (ApparentSolarTime - 12));
            }
        }
        [Category("Solar Data")]
        public double SolarAltitude
        {
            get
```

```
          {
            double L = Latitude * Math.PI / 180;

            double dcg = ExtraterrestrialSolarIrradiance.Get_Extraterrestrial_Solar_Data(CurrentMonth).Declination_Degree * Math.PI / 180;

            double H = HourAngle * Math.PI / 180;

            double sinBeta = Math.Cos(L) * Math.Cos(dcg) * Math.Cos(H) + Math.Sin(L) * Math.Sin(dcg);

            double Beta = Math.Asin(sinBeta) * 180 / Math.PI;

            return (double)Beta;

          }

        }


        [Category("Solar Data")]

        public double SolarAzimuth

        {

          get

          {

            double Beta = SolarAltitude * Math.PI / 180;

            double L = Latitude * Math.PI / 180;

            double dcg = ExtraterrestrialSolarIrradiance.Get_Extraterrestrial_Solar_Data(CurrentMonth).Declination_Degree * Math.PI / 180;

            double cosFie = (Math.Sin(Beta) * Math.Sin(L) - Math.Sin(dcg)) / (Math.Cos(Beta) * Math.Cos(L));
```

```
                double Fie = Math.Acos(cosFie) * 180 / Math.PI;

                //The solar azimuth is positive for afternoon hours and negative for morning hours.

                if (LocalSolarTime < 12) Fie = Fie * -1;

                return (double)Fie;

            }

        }


        [Category("Solar Data")]

        public double SurfaceSolarAzimuth

        {

            get

            {

                return SolarAzimuth - SurfaceAzimuth;

            }

        }


        [Category("Solar Data")]

        public double IncidentAngle

        {

            get

            {
```

```
                double Beta = SolarAltitude * Math.PI / 180;

                double ssa = SurfaceSolarAzimuth * Math.PI / 180;

                double lnt = SurfaceTilt * Math.PI / 180;

                double cosTheta = Math.Cos(Beta) * Math.Cos(ssa) * Math.Sin(lnt) + Math.Sin(Beta) * Math.Cos(lnt);

                double Theta = Math.Acos(cosTheta) * 180 / Math.PI;

                return (double)Theta;

            }

        }

        #endregion

        #region Irradiance Data

        [Category("Irradiance Data")]

        public double DirectNormalIrradiance

        {

            get

            {

                double A = ExtraterrestrialSolarIrradiance.Get_Extraterrestrial_Solar_Data(CurrentMonth).A;

                double B = (double)ExtraterrestrialSolarIrradiance.Get_Extraterrestrial_Solar_Data(CurrentMonth).B;

                double sinBeta = Math.Sin(SolarAltitude * Math.PI / 180);


                double EDN = new double();

                if (SolarAltitude > 0)
```

```
            {

                EDN = (A / Math.Exp(B / sinBeta)) * ClearnessNumber;
            }
            else
                EDN = 0;
            return EDN;
        }
    }

    [Category("Irradiance Data")]
    public double RatioY
    {
        get
        {
            double cosTheta = Math.Cos(IncidentAngle * Math.PI / 180);
            double Y = 0;
            if (cosTheta > -0.2)
                Y = 0.55 + 0.437 * cosTheta + 0.313 * cosTheta * cosTheta;
            else
                Y = 0.45;
```

```
            return (double)Y;
        }
    }

    [Category("Irradiance Data")]
    public double SurfaceDirectIrradiance
    {
        get
        {
            double ED = new double();
            double cosTheta = Math.Cos(IncidentAngle * Math.PI / 180);
            if (cosTheta > 0)
                ED = DirectNormalIrradiance * cosTheta;
            else
                ED = 0;
            return ED;
        }
    }

    [Category("Irradiance Data")]
    public double DiffuseIrradiance
    {
```

```
            get
            {
                double                                              C                                                =
ExtraterrestrialSolarIrradiance.Get_Extraterrestrial_Solar_Data(CurrentMonth).C;
                double Y = RatioY;
                double EDN = (double)DirectNormalIrradiance;


                double Ed = new double();
                if (SurfaceTilt == 90)
                    Ed = C * Y * EDN;
                else
                    Ed = C * EDN * (1 + Math.Cos(SurfaceTilt * Math.PI / 180)) / 2;
                return Ed;
            }
        }


        [Category("Irradiance Data")]
        public double GroundReflectedIrradiance
        {
            get
            {
                double EDN = DirectNormalIrradiance;
                double                                              C                                                =
```

```
(double)ExtraterrestrialSolarIrradiance.Get_Extraterrestrial_Solar_Data(CurrentMonth).C;
                double sinBeta = Math.Sin(SolarAltitude * Math.PI / 180);
                double gr = (double)GroundReflectivity;
                double cos_Int = Math.Cos(SurfaceTilt * Math.PI / 180);

                double Er = new double();
                Er = EDN * (C + sinBeta) * gr * (1 - cos_Int) / 2;
                return Er;
              }
            }

            [Category("Irradiance Data")]
            public double TotalSurfaceIrradiance
            {
              get
              {
                double total = SurfaceDirectIrradiance + DiffuseIrradiance +
GroundReflectedIrradiance;
                return total;

              }
            }
            #endregion
```

```
            #endregion
```

Building Calculation

Sol-Air Temperature see Table 5.1

```
            /// <summary>
            /// Calculate sol-air at specified hour.
            /// </summary>
            /// <param name="hour">local hour</param>
            /// <returns>sol-air temperature</returns>
            public double SolAirTemperature(int hour)
            {
              this.Building.SolarData.LocalSolarTime = (double)hour;
              this.Building.SolarData.SurfaceAzimuth = new SolarSystem.Orientation(this.Building.Orientation + this.Orientaion);
              this.Building.SolarData.SurfaceTilt = this.Tilt;
              double Et = this.Building.SolarData.TotalSurfaceIrradiance;
              double To = this.Building.GetDryBulbTemperature(hour);
              double alpha_h = this.OutsideSolarAbsoptivity / this.SurfaceAirFilmCoefficient;
              double emmitance = (this.OutsideLWEmmesivity * DeltaR / this.SurfaceAirFilmCoefficient);
```

```
    double value = To + alpha_h * Et - emmitance;

    return value;

}
```

Heat Input

$$Q = UA(T_b - T_i)$$

```
/// <summary>

/// Calculate the heat input to the wall.

/// </summary>

/// <param name="solarAirTemperature"></param>

/// <param name="innerTemperature"></param>

/// <returns></returns>

public double ConductionHeatInput(int hour)

{

   return U * Area * (SolAirTemperature(hour) - Building.InsideTemperature);

}
```

Heat Gain

$$q_\theta = c_0 q_{i,\theta} + c_1 q_{i,\theta-1} + c_2 q_{i,\theta-2} + c_3 q_{i,\theta-3} + \cdots + c_{23} q_{i,\theta-23}$$

```
/// <summary>
/// The Heat Gain by Applying the CTS Factor for this hour to the Heat Input of This hour
/// </summary>
/// <param name="hour"></param>
/// <returns></returns>
public double HeatGain(int hour)
{
   int Before = hour; //begin from specified hour to hour =1.
   int CTSCounter = 1;  //alwayis increase.
   double TotalWatt = 0;
   while (Before > 0)
   {
      double c = GetCTSFactor(CTSCounter);
      double q = ConductionHeatInput(Before);
      TotalWatt += c * q;
      Before--;
      CTSCounter++;
```

```
    }
    int AfterZero = 24; //begin from 24 to the specified hour
    while (AfterZero > hour)
    {
        double c = GetCTSFactor(CTSCounter);
        double q = ConductionHeatInput(AfterZero);
        TotalWatt += c * q;
        AfterZero--;
        CTSCounter++;
    }
    return TotalWatt;
}
```

Surface Hourly Load

```
/// <summary>
/// properties of surface at specific hour.
/// </summary>
public struct SurfaceHourLoad
{
    /// <summary>
    /// Solar Hour From 1 to 24
    /// </summary>
    public int Hour { get; set; }

    /// <summary>
    /// External Temperature.
    /// </summary>
    public double DryBulbTemperature { get; set; }

    /// <summary>
    /// Inside Temperature the surface is exposed to
    /// </summary>
    public double InsideTemperature { get; set; }
```

```
/// <summary>
/// Solar-Air Temperature that was calculated due to ASHRAE
/// </summary>
public double Sol_AirTemperature { get; set; }


/// <summary>
/// Heat Input from sol-air to inside temperature.
/// </summary>
public double HeatInput { get; set; }


/// <summary>
/// Conduction Time Series Coeffecient that modifies the Heat input
/// to Heat gain
/// this factor depends on the surface material
/// and varies for every hour.
/// </summary>
public double CTS { get; set; }


/// <summary>
/// the heat gain in this hour
/// it should be noted that the heat gain is different
/// than heat input and we calculate it to get the maximum
```

```
        /// heat gain {which obviously lower than the heat input}
        /// </summary>
        public double HeatGain { get; set; }

    }

    public class Surface24HourLoad
    {
        string title;
        public override string ToString()
        {
            return title;
        }

        public Surface24HourLoad(string title)
        {
            this.title = title;
            Loads = new List<SurfaceHourLoad>(24);
        }

        public List<SurfaceHourLoad> Loads
        {
```

```
  get;
  private set;
}
public double MaximumHeatInput
{
  get
  {
    var HeatInputs = from ld in Loads
                select ld.HeatInput;
    return HeatInputs.Max();
  }
}
public double MaximumHeatGain
{
  get
  {
    var HeatGains = from ld in Loads
                select ld.HeatGain;
    return HeatGains.Max();
  }
}
```

```
        public double TotalHeatInput
        {
            get
            {
                var HeatInputs = from ld in Loads
                                 select ld.HeatInput;

                return HeatInputs.Sum();
            }
        }
        public double TotalHeatGain
        {
            get
            {
                var HeatGains = from ld in Loads
                                select ld.HeatGain;
                return HeatGains.Sum();
            }
        }
    }
```

Building Load

```
namespace RefrigerationLoad
{
    /// <summary>
    /// holds the building refrigeration load.
    /// </summary>
    public class BuildingLoad:IRefrigerationLoad
    {
        public BuildingLoad(BuildingSystem.Building building)
        {
            Building = building;
            Surfaces = building.GetAllSurfaces();
            SurfacesLoads = new List<Surface24HourLoad>(24);
            PrepareValues();
        }

        public BuildingSystem.Building Building
        {
            get;
            private set;
        }
```

```
public List<BuildingSystem.Surface> Surfaces
{
    get;
    private set;
}
public List<Surface24HourLoad> SurfacesLoads
{
    get;
    private set;
}

private void PrepareValues()
{
    //create container for all surfaces calculation.
    foreach (BuildingSystem.Surface surface in Surfaces)
    {
        Surface24HourLoad shl = new Surface24HourLoad(surface.Title);
        for (int h = 1; h <= 24; h++)
        {
            SurfaceHourLoad rd = new SurfaceHourLoad();
            rd.Hour = h;
            rd.DryBulbTemperature = surface.Building.GetDryBulbTemperature(h);
```

```
            rd.InsideTemperature = surface.Building.InsideTemperature;

            rd.Sol_AirTemperature = surface.SolAirTemperature(h);

            rd.HeatInput = surface.ConductionHeatInput(h);

            rd.CTS = surface.GetCTSFactor(h);

            rd.HeatGain = surface.HeatGain(h);

            shl.Loads.Add(rd);

        }

        SurfacesLoads.Add(shl);

    }

}

#region IRefrigerationLoad Members

public double Load

{

    get

    {

        //return sum of all maximum heat gain

        var MaxHeatGains = from SurfaceLoad in SurfacesLoads

                           select SurfaceLoad.MaximumHeatGain;

        return MaxHeatGains.Sum();

    }

}

#endregion
```

```
        }

    }
```

Product Load

Product Load

```
    namespace RefrigerationLoad

    {

        public struct ProductLoad : IRefrigerationLoad

        {

            public ProductLoad(string title)

                :this()

            {

                Title = title;

            }

            public string Title

            {

                get;

                set;

            }


            public double Mass { get; set; }
```

```
public double AboveFreezingSpecificHeat { get; set; }
public double BelowFreezingSpecificHeat { get; set; }
public double FusionLatentHeat { get; set; }

/// <summary>
/// the temperature that the product change phase
/// in celecuis
/// </summary>
public double FreezingTemperature { get; set; }

/// <summary>
/// the source temperature of the product.
/// </summary>
public double SourceTemperature { get; set; }

/// <summary>
/// destination temperature we want to reach
/// </summary>
public double DestinationTemperature { get; set; }
```

```
private double AboveTemp
{
    get
    {
        if (DestinationTemperature <= FreezingTemperature)
            return FreezingTemperature;
        else
            return DestinationTemperature;
    }
}

public double AboveFreezingLoad
{
    get
    {
        return Mass * AboveFreezingSpecificHeat * (SourceTemperature - AboveTemp);
    }
}

public double FreezingLoad
{
    get
```

```
            {
                if (DestinationTemperature <= FreezingTemperature)
                    return Mass * FusionLatentHeat;
                else
                    return 0;
            }
        }

        public double BelowFreezingLoad
        {
            get
            {
                if (DestinationTemperature < FreezingTemperature)
                    return Mass * BelowFreezingSpecificHeat * (FreezingTemperature - DestinationTemperature);
                else
                    return 0;
            }
        }

        /// <summary>
        /// Kilo Joule
        /// </summary>
```

```
public double EnergyLoad

{

   get

   {

      return AboveFreezingLoad + FreezingLoad + BelowFreezingLoad;

   }

}


/// <summary>

/// Time required for heat removal in hours.

/// </summary>

public double AlottedHours

{

   get;

   set;

}


#region IRefrigerationLoad Members


public double Load

{

   get
```

```
                {
                    return (EnergyLoad / (3600 * AlottedHours)) * 1000;
                    //I multiplied by 1000 to convert it from kilo watt to watt
                }
            }
            #endregion
        }
    }
```

Persons Load

$$q_p = 272 - 6t$$

```
        public struct PersonsLoad: IRefrigerationLoad
        {
            public int PersonCount { get; set; }
            public double InnerTemperature { get; set; }
            #region IRefrigerationLoad Members
            public double Load
            {
                get
```

```
            {
                return PersonCount * (272 - 6 * InnerTemperature);
            }
        }
        #endregion
    }
```

Lights Load

$$q_{et} = W F_{ul} F_{sa}$$

```
    public struct LightingLoad : IRefrigerationLoad
    {
        /// <summary>
        /// lamp description.
        /// </summary>
        public string Description { get; set; }

        public string Ballast { get; set; }
```

```
/// <summary>
/// lamp wattage
/// </summary>
public double LampWatt { get; set; }

/// <summary>
/// <= 1
/// </summary>
public double UseFactor { get; set; }



/// <summary>
/// <= 1
/// </summary>
public double SpecialAllowanceFactor { get; set; }

/// <summary>
/// number of lamps with the same characteristics.
/// </summary>
public int LampsCount { get; set; }
```

```
#region IRefrigerationLoad Members

public double Load

{

   get

   {

      return LampsCount * LampWatt * UseFactor * SpecialAllowanceFactor;

   }

}

#endregion
```

5.8 Program Functionality and Usage Brief

To calculate the heat gain, certain information needed to accomplish the task.

- Solar Data information.
- Wall Construction.
- Overall heat transfer coefficient (U).
- CTS Factors for 24 hour profile.
- Applying the calculation.

5.8.1 Conduction time series

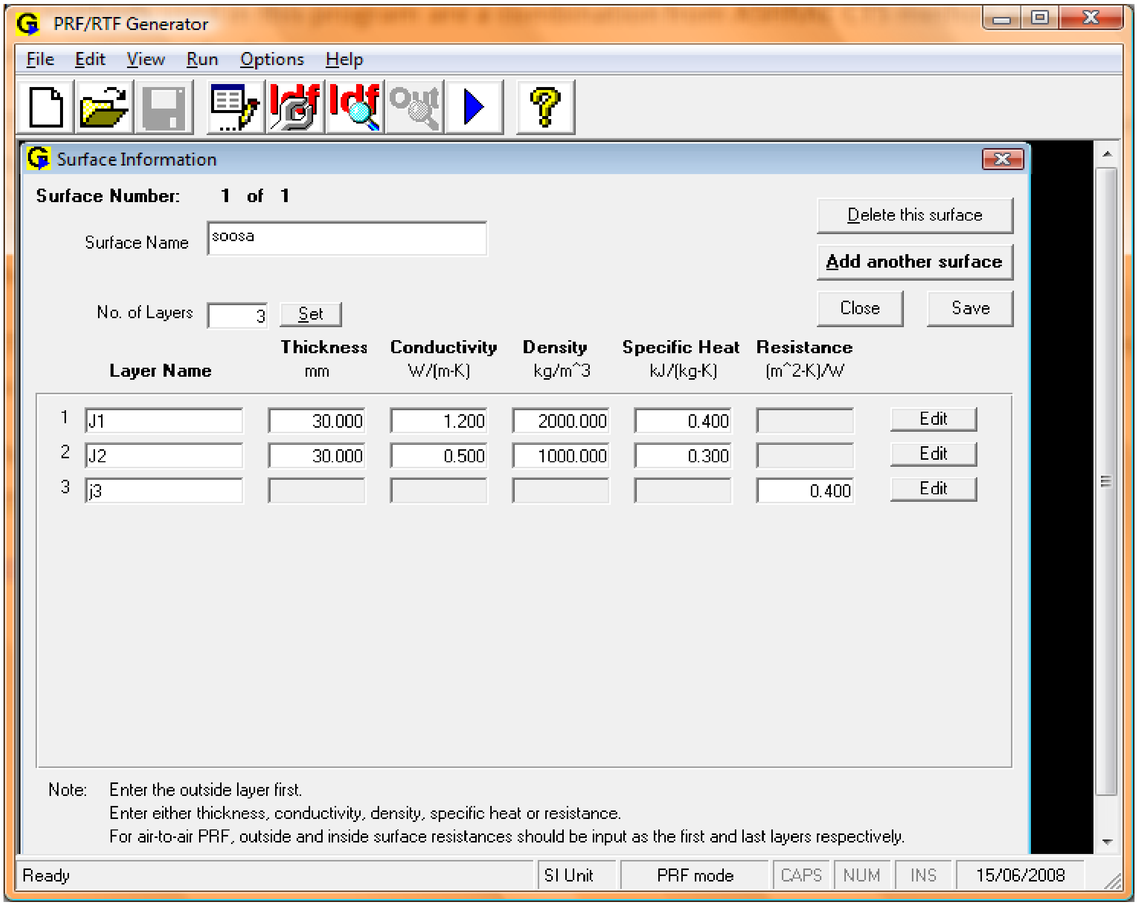
CTS Factors or (Conduction Time Series) are numbers generated based on the wall construction.

Conduction Time Series mentioned in ASHRAE 2001 is the subset of RTS method of calculating cooling load.

In the custom program we used the CTS part of the RTS method to calculate the heat gain through the walls instead of the direct calculation to the heat input.

Using the CTS method is making more accurate calculations and less error.

CTS (Conduction Time Series) are the process of calculating heat gain by applying CTS factor to the Heat Input calculated in direct way. CTS factors are generated using the PRF/RTF Generator program which take the wall layers as inputs and then output their CTS Values to an output file. This program is based on the ASHRAE refrigeration toolkit and it is available in the web site of Oklahoma University http://www.hvac.okstate.edu/resources.html



Surface Number: 1 of 1

Surface Name: soosa

No. of Layers: 3

	Layer Name	Thickness mm	Conductivity W/(m-K)	Density kg/m^3	Specific Heat kJ/(kg-K)	Resistance (m^2-K)/W
1	J1	30.000	1.200	2000.000	0.400	
2	J2	30.000	0.500	1000.000	0.300	
3	j3					0.400

Note: Enter the outside layer first.
Enter either thickness, conductivity, density, specific heat or resistance.
For air-to-air PRF, outside and inside surface resistances should be input as the first and last layers respectively.

Ready | SI Unit | PRF mode | CAPS | NUM | INS | 15/06/2008

Figure (5.4) Response Factor and Periodic Response Factor Generator Software

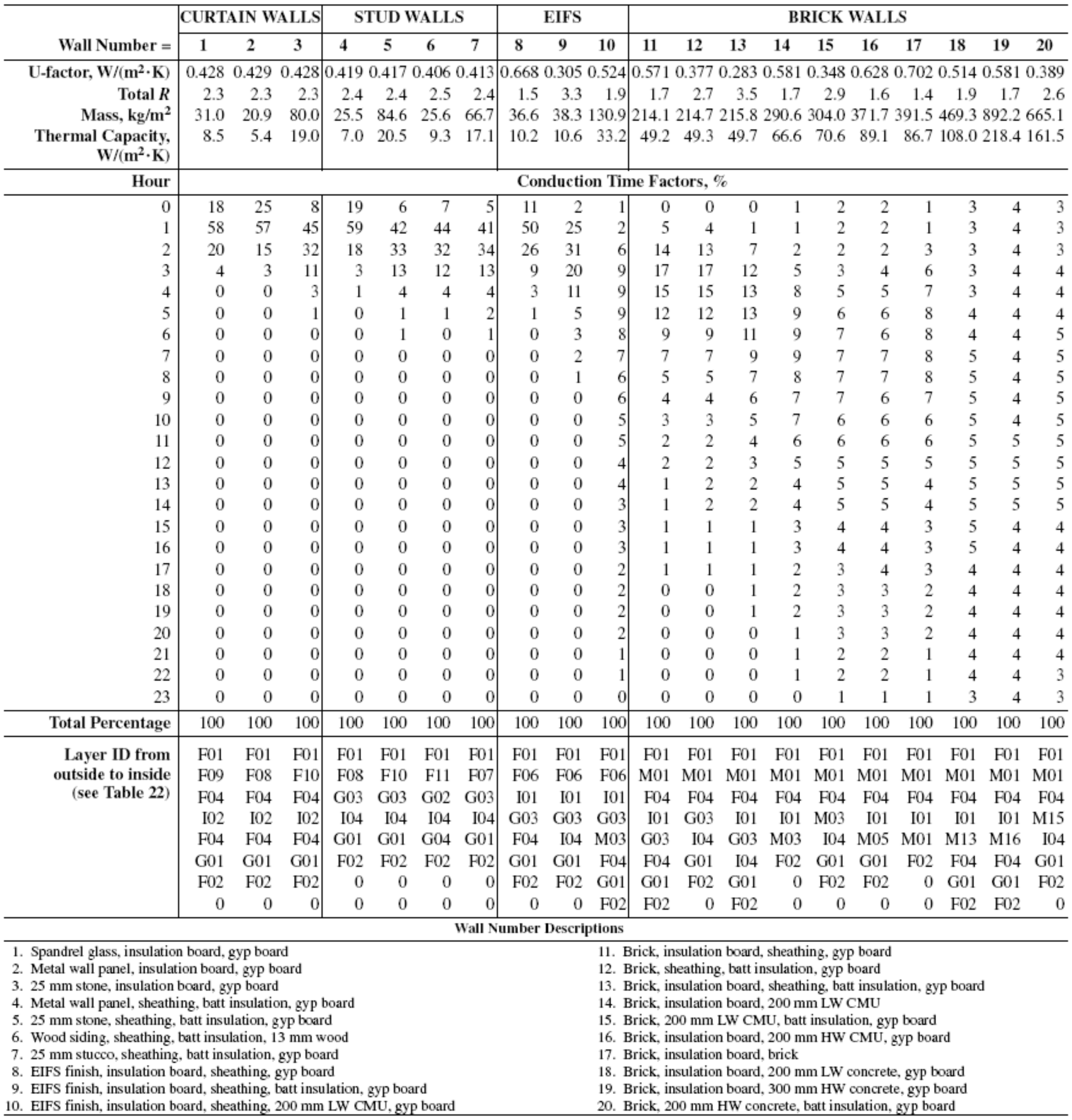
5.8.2 Wall construction

For simplicity the room was assumed to be single room exposed to the sun from all of its sides this type of room can be easily found on the roof of buildings.

The wall construction is the same for all each wall in the room and corresponding to the wall type {Wall: 14} From Table 20 in ASHRAE 2001 Chapter 29

However for any custom wall construction using the PRF/RTF Generator will be sufficient to get the CTS Factors for any combination of any wall assembly.

Table 5.2 Wall Conduction Time Series (CTS)



	CURTAIN WALLS			STUD WALLS				EIFS			BRICK WALLS									
Wall Number =	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
U-factor, W/(m²·K)	0.428	0.429	0.428	0.419	0.417	0.406	0.413	0.668	0.305	0.524	0.571	0.377	0.283	0.581	0.348	0.628	0.702	0.514	0.581	0.389
Total *R*	2.3	2.3	2.3	2.4	2.4	2.5	2.4	1.5	3.3	1.9	1.7	2.7	3.5	1.7	2.9	1.6	1.4	1.9	1.7	2.6
Mass, kg/m²	31.0	20.9	80.0	25.5	84.6	25.6	66.7	36.6	38.3	130.9	214.1	214.7	215.8	290.6	304.0	371.7	391.5	469.3	892.2	665.1
Thermal Capacity, W/(m²·K)	8.5	5.4	19.0	7.0	20.5	9.3	17.1	10.2	10.6	33.2	49.2	49.3	49.7	66.6	70.6	89.1	86.7	108.0	218.4	161.5
Hour	**Conduction Time Factors, %**																			
0	18	25	8	19	6	7	5	11	2	1	0	0	0	1	2	2	1	3	4	3
1	58	57	45	59	42	44	41	50	25	2	5	4	1	1	2	2	1	3	4	3
2	20	15	32	18	33	32	34	26	31	6	14	13	7	2	2	2	3	3	4	3
3	4	3	11	3	13	12	13	9	20	9	17	17	12	5	3	4	6	3	4	4
4	0	0	3	1	4	4	4	3	11	9	15	15	13	8	5	5	7	3	4	4
5	0	0	1	0	1	1	2	1	5	9	12	12	13	9	6	6	8	4	4	4
6	0	0	0	0	1	0	1	0	3	8	9	9	11	9	7	6	8	4	4	5
7	0	0	0	0	0	0	0	0	2	7	7	7	9	9	7	7	8	5	4	5
8	0	0	0	0	0	0	0	0	1	6	5	5	7	8	7	7	8	5	4	5
9	0	0	0	0	0	0	0	0	0	6	4	4	6	7	7	6	7	5	4	5
10	0	0	0	0	0	0	0	0	0	5	3	3	5	7	6	6	6	5	4	5
11	0	0	0	0	0	0	0	0	0	5	2	2	4	6	6	6	6	5	5	5
12	0	0	0	0	0	0	0	0	0	4	2	2	3	5	5	5	5	5	5	5
13	0	0	0	0	0	0	0	0	0	4	1	2	2	4	5	5	4	5	5	5
14	0	0	0	0	0	0	0	0	0	3	1	2	2	4	5	5	4	5	5	5
15	0	0	0	0	0	0	0	0	0	3	1	1	1	3	4	4	3	5	4	4
16	0	0	0	0	0	0	0	0	0	3	1	1	1	3	4	4	3	5	4	4
17	0	0	0	0	0	0	0	0	0	2	1	1	1	2	3	4	3	4	4	4
18	0	0	0	0	0	0	0	0	0	2	0	0	1	2	3	3	2	4	4	4
19	0	0	0	0	0	0	0	0	0	2	0	0	1	2	3	3	2	4	4	4
20	0	0	0	0	0	0	0	0	0	2	0	0	0	1	3	3	2	4	4	4
21	0	0	0	0	0	0	0	0	0	1	0	0	0	1	2	2	1	4	4	4
22	0	0	0	0	0	0	0	0	0	1	0	0	0	1	2	2	1	4	4	3
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3	4	3
Total Percentage	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Layer ID from outside to inside (see Table 22)	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01
	F09	F08	F10	F08	F10	F11	F07	F06	F06	F06	M01	M01	M01	M01	M01	M01	M01	M01	M01	M01
	F04	F04	F04	G03	G03	G02	G03	I01	I01	I01	F04	F04	F04	F04	F04	F04	F04	F04	F04	F04
	I02	I02	I02	I04	I04	I04	I04	G03	G03	G03	I01	G03	I01	I01	M03	I01	I01	I01	I01	M15
	F04	F04	F04	G01	G01	G04	G01	F04	I04	M03	G03	I04	G03	M03	I04	M05	M01	M13	M16	I04
	G01	G01	G01	F02	F02	F02	F02	G01	G01	F04	F04	G01	I04	F02	G01	G01	F02	F04	F04	G01
	F02	F02	F02	0	0	0	0	F02	F02	G01	G01	F02	G01	0	F02	F02	0	G01	G01	F02
	0	0	0	0	0	0	0	0	0	F02	F02	0	F02	0	0	0	0	F02	F02	0

Wall Number Descriptions

1. Spandrel glass, insulation board, gyp board
2. Metal wall panel, insulation board, gyp board
3. 25 mm stone, insulation board, gyp board
4. Metal wall panel, sheathing, batt insulation, gyp board
5. 25 mm stone, sheathing, batt insulation, gyp board
6. Wood siding, sheathing, batt insulation, 13 mm wood
7. 25 mm stucco, sheathing, batt insulation, gyp board
8. EIFS finish, insulation board, sheathing, gyp board
9. EIFS finish, insulation board, sheathing, batt insulation, gyp board
10. EIFS finish, insulation board, sheathing, 200 mm LW CMU, gyp board
11. Brick, insulation board, sheathing, gyp board
12. Brick, sheathing, batt insulation, gyp board
13. Brick, insulation board, sheathing, batt insulation, gyp board
14. Brick, insulation board, 200 mm LW CMU
15. Brick, 200 mm LW CMU, batt insulation, gyp board
16. Brick, insulation board, 200 mm HW CMU, gyp board
17. Brick, insulation board, brick
18. Brick, insulation board, 200 mm LW concrete, gyp board
19. Brick, insulation board, 300 mm HW concrete, gyp board
20. Brick, 200 mm HW concrete, batt insulation, gyp board

Table 5.2 Wall Conduction Time Series (CTS) (Cont.)

	CONCRETE BLOCK WALL						PRECAST AND CAST-IN-PLACE CONCRETE WALLS								
Wall Number =	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**
U-factor, W/(m²·K)	0.383	0.335	0.414	1.056	0.834	0.689	0.673	0.418	0.434	0.650	0.387	0.467	0.434	0.266	3.122
Total *R*	2.6	3.0	2.4	0.9	1.2	1.5	1.5	2.4	2.3	1.5	2.6	2.1	2.3	3.8	0.3
Mass, kg/m²	108.8	108.8	224.3	94.3	107.1	168.9	143.9	144.6	262.5	291.8	274.7	488.1	469.9	698.9	683.2
Thermal Capacity, W/(m²·K)	27.4	27.4	57.0	23.1	26.9	42.0	34.5	34.6	61.3	68.9	64.9	122.7	118.3	175.7	171.0
Hour	**Conduction Time Factors, %**														
0	0	1	0	1	1	0	1	2	1	3	1	2	1	0	1
1	2	11	3	1	10	8	1	2	2	3	2	2	2	2	11
2	8	21	12	2	20	18	3	3	3	4	5	3	4	8	21
3	12	20	16	5	18	18	6	5	6	5	8	3	7	12	20
4	12	15	15	7	14	14	8	6	7	6	9	5	8	12	15
5	11	10	12	9	10	11	9	6	8	6	9	5	8	11	10
6	9	7	10	9	7	8	9	6	8	6	8	6	8	9	7
7	8	5	8	8	5	6	9	6	7	5	7	6	8	8	5
8	7	3	6	8	4	4	8	6	7	5	6	6	7	7	3
9	6	2	4	7	3	3	7	6	6	5	6	6	6	6	2
10	5	2	3	6	2	2	7	5	6	5	5	6	6	5	2
11	4	1	3	6	2	2	6	5	5	5	5	5	5	4	1
12	3	1	2	5	1	2	5	5	5	4	4	5	4	3	1
13	2	1	2	4	1	1	4	5	4	4	4	5	4	2	1
14	2	0	1	4	1	1	4	4	4	4	3	4	4	2	0
15	2	0	1	3	1	1	3	4	3	4	3	4	3	2	0
16	1	0	1	3	0	1	2	4	3	4	3	4	3	1	0
17	1	0	1	2	0	0	2	3	3	4	2	4	3	1	0
18	1	0	0	2	0	0	1	3	2	4	2	4	2	1	0
19	1	0	0	2	0	0	1	3	2	3	2	3	2	1	0
20	1	0	0	2	0	0	1	3	2	3	2	3	2	1	0
21	1	0	0	2	0	0	1	3	2	3	2	3	1	1	0
22	1	0	0	1	0	0	1	3	2	3	1	3	1	1	0
23	0	0	0	1	0	0	1	2	2	2	1	3	1	0	0
Total Percentage	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Layer ID from outside to inside (see Table 22)	F01 F07 M05 I04 G01 F02	F01 M08 F02 — — —	F01 M08 F04 G01 F02 —	F01 M09 F04 G01 F02 —	F01 M11 I01 F04 G01 F02	F01 M11 I04 G01 F02 —	F01 M11 I02 M11 F02 —	F01 F06 I01 M13 G01 F02	F01 M13 I04 G01 F02 —	F01 F06 I02 M15 G01 F02	F01 M15 I04 G01 F02 —	F01 M16 I05 G01 F02 —	F01 M16 F02 — — —	F01 F07 M05 I04 G01 F02	F01 M08 F02 — — —

Wall Number Descriptions

21. 200 mm LW CMU, batt insulation, gyp board
22. 200 mm LW CMU with fill insulation, batt insulation, gyp board
23. 25 mm stucco, 200 mm HW CMU, batt insulation, gyp board
24. 200 mm LW CMU with fill insulation
25. 200 mm LW CMU with fill insulation, gyp board
26. 300 mm LW CMU with fill insulation, gyp board
27. 100 mm LW concrete, board insulation, gyp board
28. 100 mm LW concrete, batt insulation, gyp board
29. 100 mm LW concrete, board insulation, 100 mm LW concrete
30. EIFS finish, insulation board, 200 mm LW concrete, gyp board
31. 200 mm LW concrete, batt insulation, gyp board
32. EIFS finish, insulation board, 200 mm HW concrete, gyp board
33. 200 mm HW concrete, batt insulation, gyp board
34. 300 mm HW concrete, batt insulation, gyp board
35. 300 mm HW concrete

Table 5.2 Wall Conduction Time Series (CTS) (Cont.)

	SLOPED FRAME ROOFS						WOOD DECK		METAL DECK ROOFS					CONCRETE ROOFS					
Roof Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
U-factor, W/(m²·K)	0.249	0.227	0.255	0.235	0.239	0.231	0.393	0.329	0.452	0.370	0.323	0.206	0.297	0.304	0.296	0.288	0.315	0.313	0.239
Total *R*	4.0	4.4	3.9	4.2	4.2	4.3	2.5	3.0	2.2	2.7	3.1	4.9	3.4	3.3	3.4	3.5	3.2	3.2	4.2
Mass, kg/m²	26.7	21.0	14.0	34.7	55.5	34.9	48.9	55.9	23.9	30.9	25.0	27.2	57.6	149.2	214.3	279.3	360.7	474.5	362.3
Thermal Capacity, W/(m²·K)	7.3	4.6	3.5	12.9	20.2	13.0	21.0	22.1	7.8	8.9	8.1	8.9	15.7	37.6	52.8	67.9	92.8	121.3	91.8
Hour	**Conduction Time Factors, %**																		
0	6	10	27	1	1	1	0	1	18	4	8	1	0	1	2	2	2	3	1
1	45	57	62	17	17	12	7	3	61	41	53	23	10	2	2	2	2	3	2
2	33	27	10	31	34	25	18	8	18	35	30	38	22	8	3	3	5	3	6
3	11	5	1	24	25	22	18	10	3	14	7	22	20	11	6	4	6	5	8
4	3	1	0	14	13	15	15	10	0	4	2	10	14	11	7	5	7	6	8
5	1	0	0	7	6	10	11	9	0	1	0	4	10	10	8	6	7	6	8
6	1	0	0	4	3	6	8	8	0	1	0	2	7	9	8	6	6	6	7
7	0	0	0	2	1	4	6	7	0	0	0	0	5	7	7	6	6	6	7
8	0	0	0	0	0	2	5	6	0	0	0	0	4	6	7	6	6	6	6
9	0	0	0	0	0	1	3	5	0	0	0	0	3	5	6	6	5	5	5
10	0	0	0	0	0	1	3	5	0	0	0	0	2	5	5	6	5	5	5
11	0	0	0	0	0	1	2	4	0	0	0	0	1	4	5	5	5	5	5
12	0	0	0	0	0	0	1	4	0	0	0	0	1	3	5	5	4	5	4
13	0	0	0	0	0	0	1	3	0	0	0	0	1	3	4	5	4	4	4
14	0	0	0	0	0	0	1	3	0	0	0	0	0	3	4	4	4	4	3
15	0	0	0	0	0	0	1	3	0	0	0	0	0	2	3	4	4	4	3
16	0	0	0	0	0	0	0	2	0	0	0	0	0	2	3	4	3	4	3
17	0	0	0	0	0	0	0	2	0	0	0	0	0	2	3	4	3	4	3
18	0	0	0	0	0	0	0	2	0	0	0	0	0	1	3	3	3	3	2
19	0	0	0	0	0	0	0	2	0	0	0	0	0	1	2	3	3	3	2
20	0	0	0	0	0	0	0	1	0	0	0	0	0	1	2	3	3	3	2
21	0	0	0	0	0	0	0	1	0	0	0	0	0	1	2	3	3	3	2
22	0	0	0	0	0	0	0	1	0	0	0	0	0	1	2	3	2	2	2
23	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	2	2
	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Layer ID from outside to inside (see Table 22)	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01	F01
	F08	F08	F08	F12	F14	F15	F13	F13	F13	F13	F13	F13	M17	F13	F13	F13	F13	F13	F13
	G03	G03	G03	G05	G05	G05	G03	G03	G03	G03	G03	G03	F13	G03	G03	G03	G03	G03	M14
	F05	F05	F05	F05	F05	F05	I02	I02	I02	I02	I03	I02	G03	I03	I03	I03	I03	I03	F05
	I05	I05	I05	I05	I05	I05	G06	G06	F08	F08	F08	I03	I03	M11	M12	M13	M14	M15	I05
	G01	F05	F03	F05	F05	F05	F03	F05	F03	F05	F03	F08	F08	F03	F03	F03	F03	F03	F16
	F03	F16	—	G01	G01	G01	—	F16	—	F16	—	—	F03	—	—	—	—	—	F03
	—	F03	—	F03	F03	F03	—	F03	—	F03	—	—	—	—	—	—	—	—	—

Roof Number Descriptions

1. Metal roof, batt insulation, gyp board
2. Metal roof, batt insulation, suspended acoustical ceiling
3. Metal roof, batt insulation
4. Asphalt shingles, wood sheathing, batt insulation, gyp board
5. Slate or tile, wood sheathing, batt insulation, gyp board
6. Wood shingles, wood sheathing, batt insulation, gyp board
7. Membrane, sheathing, insulation board, wood deck
8. Membrane, sheathing, insulation board, wood deck, suspended acoustical ceiling
9. Membrane, sheathing, insulation board, metal deck
10. Membrane, sheathing, insulation board, metal deck, suspended acoustical ceiling
11. Membrane, sheathing, insulation board, metal deck
12. Membrane, sheathing, plus insulation boards, metal deck
13. 50 mm concrete roof ballast, membrane, sheathing, insulation board, metal deck
14. Membrane, sheathing, insulation board, 100 mm LW concrete
15. Membrane, sheathing, insulation board, 150 mm LW concrete
16. Membrane, sheathing, insulation board, 200 mm LW concrete
17. Membrane, sheathing, insulation board, 150 mm HW concrete
18. Membrane, sheathing, insulation board, 200 mm HW concrete
19. Membrane, 150 mm HW concrete, batt insulation, suspended acoustical ceiling

Table 5.3 Thermal Properties and Code Numbers of Layers Used in Wall and Roof Descriptions

Layer ID	Description	Thickness, mm	Conductivity, W/(m·K)	Density, kg/m³	Specific Heat, kJ/(kg·K)	Resistance, m²·K/W	*R*	Mass, kg/m²	Thermal Capacity, W·h/(m²·K)	Notes
F01	Outside surface resistance	—	—	—	—	0.04	0.04	—	—	1
F02	Inside vertical surface resistance	—	—	—	—	0.12	0.12	—	—	2
F03	Inside horizontal surface resistance	—	—	—	—	0.16	0.16	—	—	3
F04	Wall air space resistance	—	—	—	—	0.15	0.15	—	—	4
F05	Ceiling air space resistance	—	—	—	—	0.18	0.18	—	—	5
F06	EIFS finish	9.5	0.72	1856	0.84	—	0.01	17.7	4.12	6
F07	25 mm stucco	25.4	0.72	1856	0.84	—	0.04	47.2	10.98	6
F08	Metal surface	0.8	45.28	7824	0.50	—	0.00	6.0	0.83	7
F09	Opaque spandrel glass	6.4	0.99	2528	0.88	—	0.01	16.1	3.39	8
F10	25 mm stone	25.4	3.17	2560	0.79	—	0.01	65.1	14.39	9
F11	Wood siding	12.7	0.09	592	1.17	—	0.14	7.5	2.45	10
F12	Asphalt shingles	3.2	0.04	1120	1.26	—	0.08	3.6	1.24	
F13	Built-up roofing	9.5	0.16	1120	1.46	—	0.06	10.7	4.35	
F14	Slate or tile	12.7	1.59	1920	1.26	—	0.01	24.4	8.52	
F15	Wood shingles	6.4	0.04	592	1.30	—	0.17	3.8	1.36	
F16	Acoustic tile	19.1	0.06	368	0.59	—	0.31	7.0	1.14	11
F17	Carpet	12.7	0.06	288	1.38	—	0.22	3.7	1.41	12
F18	Terrazzo	25.4	1.80	2560	0.79	—	0.01	65.1	14.39	13
G01	16 mm gyp board	15.9	0.16	800	1.09	—	0.10	12.7	3.85	
G02	16 mm plywood	15.9	0.12	544	1.21	—	0.14	8.6	2.92	
G03	13 mm fiberboard sheathing	12.7	0.07	400	1.30	—	0.19	5.1	1.83	14
G04	13 mm wood	12.7	0.15	608	1.63	—	0.08	7.7	3.51	15
G05	25 mm wood	25.4	0.15	608	1.63	—	0.17	15.5	7.01	15
G06	50 mm wood	50.8	0.15	608	1.63	—	0.33	30.9	14.03	15
G07	100 mm wood	101.6	0.15	608	1.63	—	0.66	61.8	28.05	15
I01	25 mm insulation board	25.4	0.03	43	1.21	—	0.88	1.1	0.37	16
I02	50 mm insulation board	50.8	0.03	43	1.21	—	1.76	2.2	0.74	16
I03	75 mm insulation board	76.2	0.03	43	1.21	—	2.64	3.3	1.11	16
I04	89 mm batt insulation	89.4	0.05	19	0.96	—	1.94	1.7	0.46	17
I05	154 mm batt insulation	154.4	0.05	19	0.96	—	3.34	3.0	0.79	17
I06	244 mm batt insulation	243.8	0.05	19	0.96	—	5.28	4.7	1.25	17
M01	100 mm brick	101.6	0.89	1920	0.79	—	0.11	195.2	43.16	18
M02	150 mm LW concrete block	152.4	0.49	512	0.88	—	0.31	78.1	19.08	19
M03	200 mm LW concrete block	203.2	0.50	464	0.88	—	0.41	94.3	23.06	20
M04	300 mm LW concrete block	304.8	0.71	512	0.88	—	0.43	156.2	38.16	21
M05	200 mm concrete block	203.2	1.11	800	0.92	—	0.18	162.7	41.65	22
M06	300 mm concrete block	304.8	1.40	800	0.92	—	0.22	244.0	62.47	23
M07	150 mm LW concrete block (filled)	152.4	0.29	512	0.88	—	0.53	78.1	19.08	24
M08	200 mm LW concrete block (filled)	203.2	0.26	464	0.88	—	0.78	94.3	23.06	25
M09	300 mm LW concrete block (filled)	304.8	0.29	512	0.88	—	1.04	156.2	38.16	26
M10	200 mm concrete block (filled)	203.2	0.72	800	0.92	—	0.28	162.7	41.65	27
M11	100 mm lightweight concrete	101.6	0.53	1280	0.84	—	0.19	130.1	30.29	
M12	150 mm lightweight concrete	152.4	0.53	1280	0.84	—	0.29	195.2	45.43	
M13	200 mm lightweight concrete	203.2	0.53	1280	0.84	—	0.38	260.3	60.58	
M14	150 mm heavyweight concrete	152.4	1.95	2240	0.90	—	0.08	341.6	85.47	
M15	200 mm heavyweight concrete	203.2	1.95	2240	0.90	—	0.10	455.5	113.96	
M16	300 mm heavyweight concrete	304.8	1.95	2240	0.90	—	0.16	683.2	170.94	
M17	50 mm LW concrete roof ballast	50.8	0.19	640	0.84	—	0.27	32.5	7.57	28

5.9 The Program Sample Data

The following data describe the data entered used in the program

5.9.1 Walls

4 perpendicular walls with one roof, windows, and doors have been neglected for the simplicity of calculation.

The orientation of the building is South orientation

5.9.2 Solar data information

Location have been chosen to be Egypt July month

Latitude = 30

Longitude = 30

Ground reflectivity approximated to 0.2

Clearness Number = 1.0, indicating clear sky model

The inside temperature is –20 for storing meat applications.

The dry bulb temperatures for calculation of sol-air temperatures should be selected according to the weather data of Egypt.

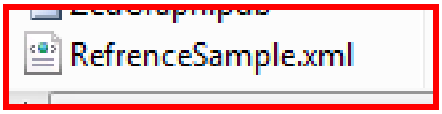
Table 5.4 Dry Bulb Temperatures for 24 Hours

Hour	Dry bulb Temperature °C
1	24.4
2	24.4
3	23.9
4	23.9
5	23.3
6	23.3
7	23.3
8	23.9
9	25
10	26.7
11	28.3
12	30.6
13	32.2
14	33.9
15	34.4
16	35
17	34.4
18	33.9
19	32.8
20	30.6
21	29.4
22	28.3
23	27.2
24	26.1

5.10 Using the Program

5.10.1 The input data

The program in current state is taking the building and location information data based on xml file called RefrenceSample.xml found in the same folder of the executable program.



The program when starting will locate this file to load the initial building data

The file is a standard xml file and should be modified to to reflect the required calculations

The sample included with the program

RefrenceSample.xml

```
<?xml version="1.0" encoding="utf-8" ?>


<Building

 U="0.581"


 Height="3"


 CTS="1, 1, 2, 5, 8, 9, 9, 9, 8, 7, 7, 6, 5, 4, 4, 3, 3, 2, 2, 2, 1, 1, 1, 0"
```

```
        InsideTemperature="-20"

        DryBulbTemperature="24.4, 24.4, 23.9, 23.3, 23.3, 23.3, 23.9, 25, 26.7, 28.3, 30.6, 32.2, 33.9, 34.4, 35, 34.4, 33.9, 32.8, 30.6, 29.4, 28.3, 27.2, 26.1, 25"

        Orientation="S"
        >

        <SolarData
          StandardLocation="Cairo"
          CurrentMonth="July"
          Latitude="30"
          Longitude="31"
          GroundReflectivity="0.2"
          ClearnessNumber="1.0"
          />

        <RefrencePoints>
          <Point x="0" y="0" />
          <Point x="4" y="0" />
          <Point x="4" y="3" />
          <Point x="0" y="3" />
```

```
        </RefrencePoints>




        <Walls>

          <Wall Point1="0" Point2="1"  />

          <Wall Point1="1" Point2="2" />

          <Wall Point1="2" Point2="3" />

          <Wall Point1="3" Point2="0" />

        </Walls>

</Building>
```

5.10.2 XML file explanation

The first line is "<?xml version="1.0" encoding="utf-8" ?>"

This indicates that this is a valid xml file.

Building information

<Building

U="0.581"

Height="3"

CTS="1, 1, 2, 5, 8, 9, 9, 9, 8, 7, 7, 6, 5, 4, 4, 3, 3, 2, 2, 2, 1, 1, 1, 0"

InsideTemperature="-20"

DryBulbTemperature="24.4, 24.4, 23.9, 23.3, 23.3, 23.3, 23.9, 25, 26.7, 28.3, 30.6, 32.2, 33.9, 34.4, 35, 34.4, 33.9, 32.8, 30.6, 29.4, 28.3, 27.2, 26.1, 25"

```
Orientation="S"
>
```

The Building Node has attributes to tell the program about the construction of the room walls, CTS Factors, inside temperature, Dry Bulb Temperatures, and the building orientation.

Solar data input

```
<SolarData
  StandardLocation="Cairo"
  CurrentMonth="July"
  Latitude="30"
  Longitude="31"
  GroundReflectivity="0.2"
  ClearnessNumber="1.0"
  />
```

Solar Data node is for specifying the solar data values

Plan points

```
<RefrencePoints>
  <Point x="0" y="0" />  <!-- index 0 -->
  <Point x="4" y="0" />  <!-- index 1 -->
  <Point x="4" y="3" />  <!-- index 2 -->
  <Point x="0" y="3" />  <!-- index 3 -->
</RefrencePoints>
```

Reference points are used to specify the room corners which will serve as wall joint points which specify the room walls to the program.

Walls

```
<Walls>
  <Wall Point1="0" Point2="1"  />
  <Wall Point1="1" Point2="2" />
  <Wall Point1="2" Point2="3" />
  <Wall Point1="3" Point2="0" />
 </Walls>
```

The walls step is to specify walls according to the points

Points indexing start from 0

So Point1="0" ➔ `<Point x="0" y="0" />   <!-- index 0 -->`

Which in return will make a room with 4 walls forming a square if viewed from the plan.

Note:

The roof is automatically generated for you by the program

Note:

The program in current state don't have a building modeling screen and is not supporing complex building geometries as this program is only for the academic research.

5.10.3 Program usage

After opening the program the first screen appeared

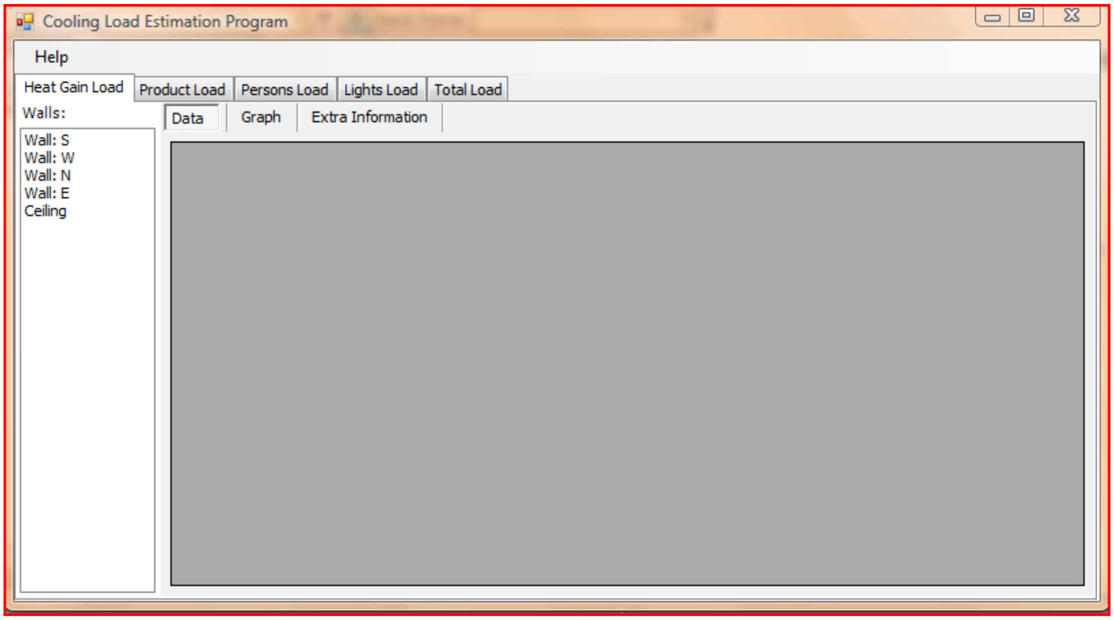
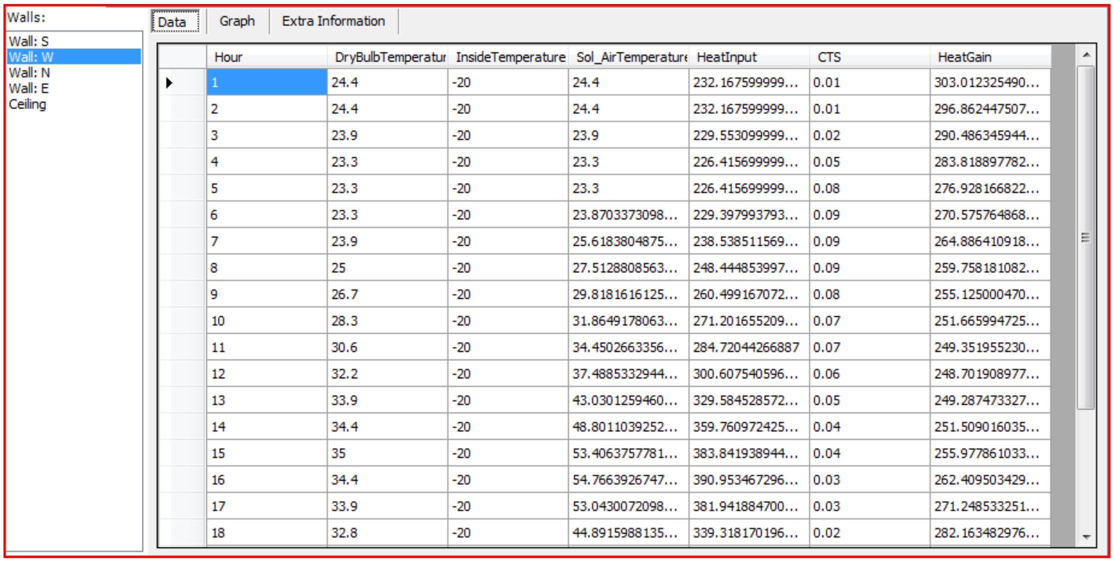


Figure (5.5) Main Program Screen

With the walls list at the left selecting a wall in the left will result in the data appears in the right pane



Hour	DryBulbTemperatur	InsideTemperature	Sol_AirTemperature	HeatInput	CTS	HeatGain
1	24.4	-20	24.4	232.167599999...	0.01	303.012325490...
2	24.4	-20	24.4	232.167599999...	0.01	296.862447507...
3	23.9	-20	23.9	229.553099999...	0.02	290.486345944...
4	23.3	-20	23.3	226.415699999...	0.05	283.818897782...
5	23.3	-20	23.3	226.415699999...	0.08	276.928166822...
6	23.3	-20	23.8703373098...	229.397993793...	0.09	270.575764868...
7	23.9	-20	25.6183804875...	238.538511569...	0.09	264.886410918...
8	25	-20	27.5128808563...	248.444853997...	0.09	259.758181082...
9	26.7	-20	29.8181616125...	260.499167072...	0.08	255.125000470...
10	28.3	-20	31.8649178063...	271.201655209...	0.07	251.665994725...
11	30.6	-20	34.4502663356...	284.72044266887	0.07	249.351955230...
12	32.2	-20	37.4885332944...	300.607540596...	0.06	248.701908977...
13	33.9	-20	43.0301259460...	329.584528572...	0.05	249.287473327...
14	34.4	-20	48.8011039252...	359.760972425...	0.04	251.509016035...
15	35	-20	53.4063757781...	383.841938944...	0.04	255.977861033...
16	34.4	-20	54.7663926747...	390.953467296...	0.03	262.409503429...
17	33.9	-20	53.0430072098...	381.941884700...	0.03	271.248533251...
18	32.8	-20	44.8915988135...	339.318170196...	0.02	282.163482976...

Figure (5.6) Wall Calculated Data

Data shown in the data view is showing the calculated Sol-Air Temperature, Heat Input, and Heat Gain for every hour in the day

The calculating has been validated by the sample data in the ASHRAE Handbook 2001 chapter 29.

Later in this chapter the mathematical model of these calculations will be discussed in more details.

There is another view in the right view which called Graph

Clicking this view will result in displaying the heat input versus the hear gain in time profile graph.

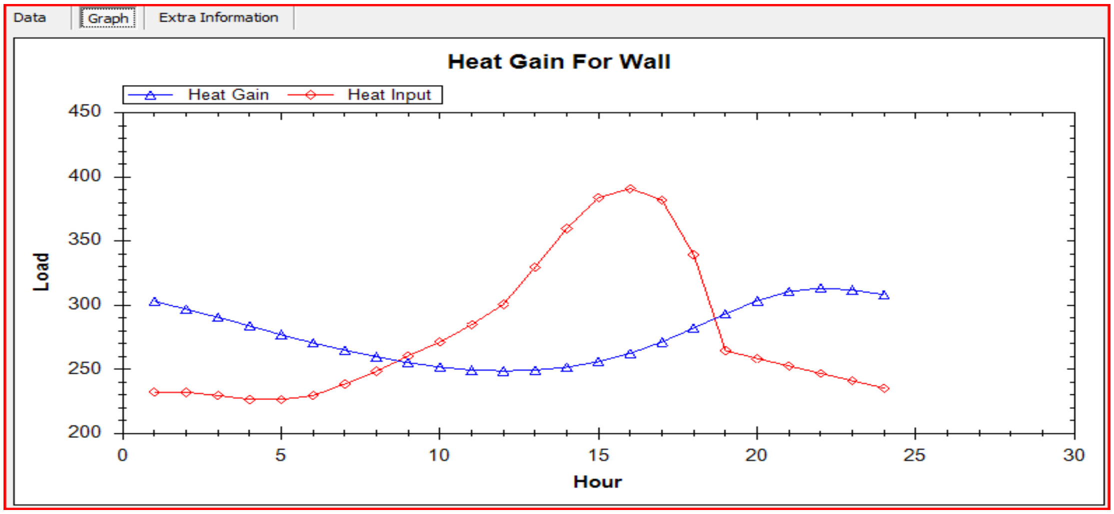
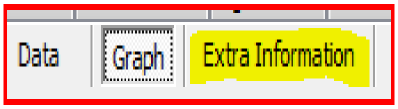


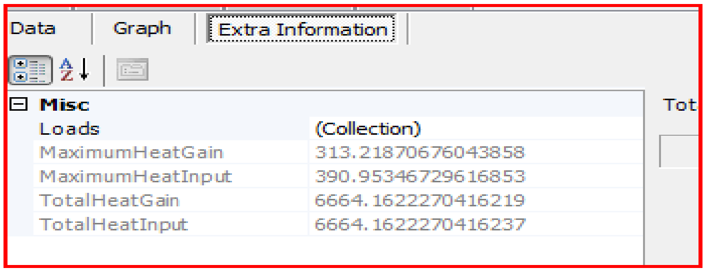
Figure (5.7) Heat Gain vs Heat Input For The Wall

It should be noted the big difference between the Heat Gain and the Heat Input

To get the exact values in the graph please click the Extra Information button



The extra information appeared



Misc	
Loads	(Collection)
MaximumHeatGain	313.218706760443858
MaximumHeatInput	390.953467296 16853
TotalHeatGain	6664.1622270416219
TotalHeatInput	6664.1622270416237

Maximum heat input for this wall is 390.954 watt

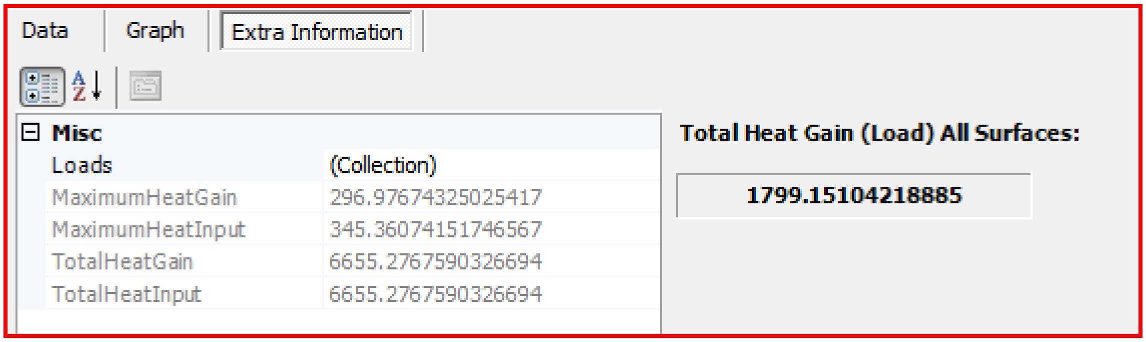
Where maximum heat gain is 313.219 watt

The error percentage of this = *100 - (313.219/390.954) * 100 = 20%* error percentage.

Which indicates how the direct calculation makes is a large source of error when not taking the time delay effect in consideration

However the total load coming from walls are calculated based on the maximum load from each wall plus ceiling

The total load will appear in the extra information tab



Loads	(Collection)
MaximumHeatGain	296.97674325025417
MaximumHeatInput	345.36074151746567
TotalHeatGain	6655.2767590326694
TotalHeatInput	6655.2767590326694

Total Heat Gain (Load) All Surfaces: 1799.15104218885

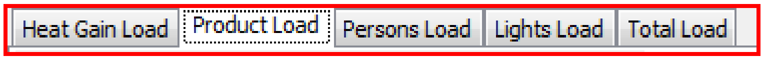
Figure (5.8) Extra Information Tab

Total heat gain = 1800 watt approximately

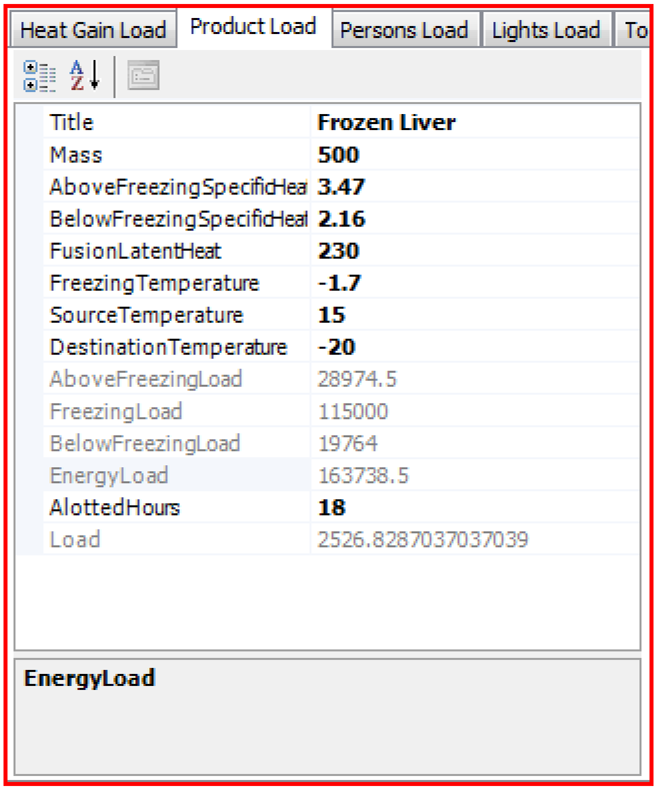
5.10.4 Product load

The program is accepting the data of the product based on ASHRAE refrigeration handbook 2002

When clicking Product tab



The panel will change showing the current data of the product which were selected as a sample data to be evaluated in the program as a sample.



Title	**Frozen Liver**
Mass	**500**
AboveFreezingSpecificHea	**3.47**
BelowFreezingSpecificHeat	**2.16**
FusionLatentHeat	**230**
FreezingTemperature	**-1.7**
SourceTemperature	**15**
DestinationTemperature	**-20**
AboveFreezingLoad	28974.5
FreezingLoad	115000
BelowFreezingLoad	19764
EnergyLoad	163738.5
AlottedHours	**18**
Load	2526.8287037037039

EnergyLoad

Figure (5.9) Product Load Screen

Thermal properties are based on ASHRAE Refrigeration Handbook 2002 Table 3 of Chapter 8

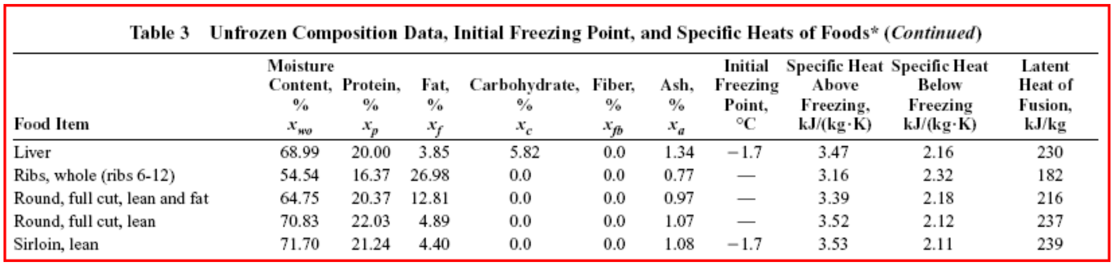


Table 3 Unfrozen Composition Data, Initial Freezing Point, and Specific Heats of Foods* (*Continued*)

Food Item	Moisture Content, % x_{wo}	Protein, % x_p	Fat, % x_f	Carbohydrate, % x_c	Fiber, % x_{fb}	Ash, % x_a	Initial Freezing Point, °C	Specific Heat Above Freezing, kJ/(kg·K)	Specific Heat Below Freezing kJ/(kg·K)	Latent Heat of Fusion, kJ/kg
Liver	68.99	20.00	3.85	5.82	0.0	1.34	−1.7	3.47	2.16	230
Ribs, whole (ribs 6-12)	54.54	16.37	26.98	0.0	0.0	0.77	—	3.16	2.32	182
Round, full cut, lean and fat	64.75	20.37	12.81	0.0	0.0	0.97	—	3.39	2.18	216
Round, full cut, lean	70.83	22.03	4.89	0.0	0.0	1.07	—	3.52	2.12	237
Sirloin, lean	71.70	21.24	4.40	0.0	0.0	1.08	−1.7	3.53	2.11	239

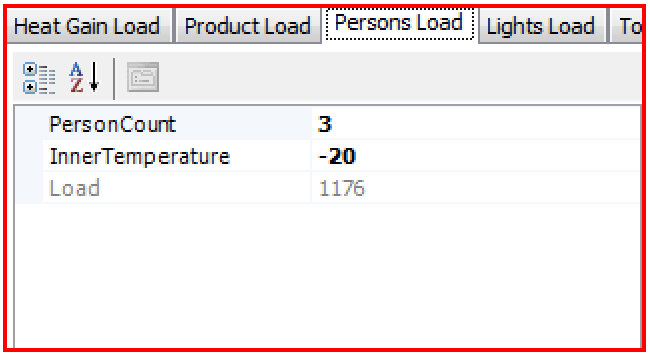
Figure (5.10) Part of thermal properties table (ASHRAE, 2001)

Please review the Table 3.1 in design condition chapter.

For the purpose of the selected we've selected 500 kg of Beef, Liver to be stored in -20 degree Celsius.

The load was *2526.828* watt, and refrigeration time taken for 18 hour to reach -20 from 15 degree will require 2527 Watt

5.10.5 Persons load

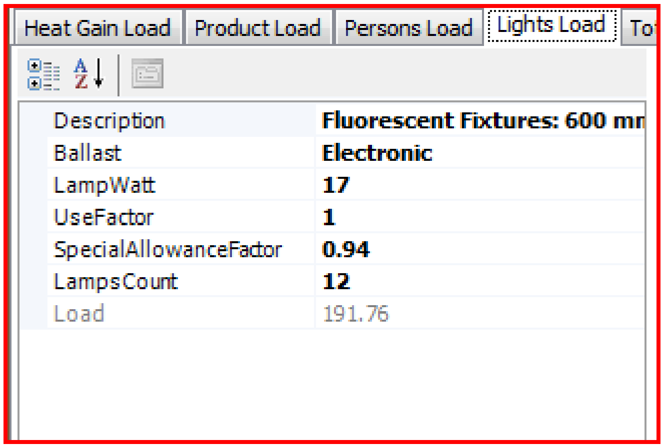


PersonCount 3
InnerTemperature -20
Load 1176

Figure (5.11) Persons Load Screen

Persons load is calculated based on simple equation from ASHRAE refrigeration

5.10.6 Lights load

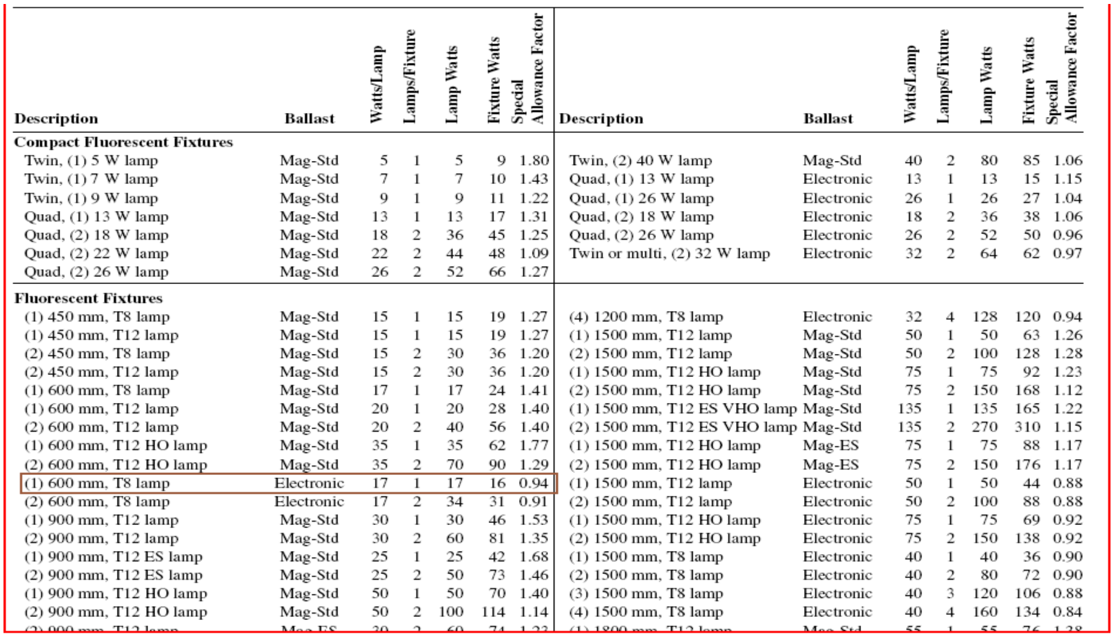


Description	Fluorescent Fixtures: 600 mn
Ballast	Electronic
LampWatt	17
UseFactor	1
SpecialAllowanceFactor	0.94
LampsCount	12
Load	191.76

Figure (5.12) Lights Load Tab

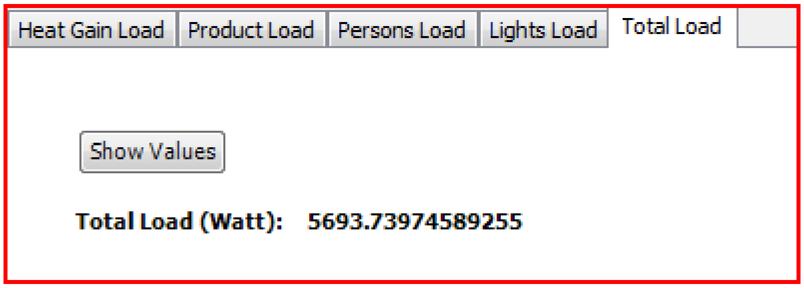
Lights load are calculated also based on ASHRAE method in calculating light load in AHSRAE fundamentals 2001 in chapter 29.

Light data were selected from Table 2 in (ASHRAE, 2001)



Description	Ballast	Watts/Lamp	Lamps/Fixture	Lamp Watts	Fixture Watts	Special Allowance Factor	Description	Ballast	Watts/Lamp	Lamps/Fixture	Lamp Watts	Fixture Watts	Special Allowance Factor
Compact Fluorescent Fixtures													
Twin, (1) 5 W lamp	Mag-Std	5	1	5	9	1.80	Twin, (2) 40 W lamp	Mag-Std	40	2	80	85	1.06
Twin, (1) 7 W lamp	Mag-Std	7	1	7	10	1.43	Quad, (1) 13 W lamp	Electronic	13	1	13	15	1.15
Twin, (1) 9 W lamp	Mag-Std	9	1	9	11	1.22	Quad, (1) 26 W lamp	Electronic	26	1	26	27	1.04
Quad, (1) 13 W lamp	Mag-Std	13	1	13	17	1.31	Quad, (2) 18 W lamp	Electronic	18	2	36	38	1.06
Quad, (2) 18 W lamp	Mag-Std	18	2	36	45	1.25	Quad, (2) 26 W lamp	Electronic	26	2	52	50	0.96
Quad, (2) 22 W lamp	Mag-Std	22	2	44	48	1.09	Twin or multi, (2) 32 W lamp	Electronic	32	2	64	62	0.97
Quad, (2) 26 W lamp	Mag-Std	26	2	52	66	1.27							
Fluorescent Fixtures													
(1) 450 mm, T8 lamp	Mag-Std	15	1	15	19	1.27	(4) 1200 mm, T8 lamp	Electronic	32	4	128	120	0.94
(1) 450 mm, T12 lamp	Mag-Std	15	1	15	19	1.27	(1) 1500 mm, T12 lamp	Mag-Std	50	1	50	63	1.26
(2) 450 mm, T8 lamp	Mag-Std	15	2	30	36	1.20	(2) 1500 mm, T12 lamp	Mag-Std	50	2	100	128	1.28
(2) 450 mm, T12 lamp	Mag-Std	15	2	30	36	1.20	(1) 1500 mm, T12 HO lamp	Mag-Std	75	1	75	92	1.23
(1) 600 mm, T8 lamp	Mag-Std	17	1	17	24	1.41	(2) 1500 mm, T12 HO lamp	Mag-Std	75	2	150	168	1.12
(1) 600 mm, T12 lamp	Mag-Std	20	1	20	28	1.40	(1) 1500 mm, T12 ES VHO lamp	Mag-Std	135	1	135	165	1.22
(2) 600 mm, T12 lamp	Mag-Std	20	2	40	56	1.40	(2) 1500 mm, T12 ES VHO lamp	Mag-Std	135	2	270	310	1.15
(1) 600 mm, T12 HO lamp	Mag-Std	35	1	35	62	1.77	(1) 1500 mm, T12 HO lamp	Mag-ES	75	1	75	88	1.17
(2) 600 mm, T12 HO lamp	Mag-Std	35	2	70	90	1.29	(2) 1500 mm, T12 HO lamp	Mag-ES	75	2	150	176	1.17
(1) 600 mm, T8 lamp	Electronic	17	1	17	16	0.94	(1) 1500 mm, T12 lamp	Electronic	50	1	50	44	0.88
(2) 600 mm, T8 lamp	Electronic	17	2	34	31	0.91	(2) 1500 mm, T12 lamp	Electronic	50	2	100	88	0.88
(1) 900 mm, T12 lamp	Mag-Std	30	1	30	46	1.53	(1) 1500 mm, T12 HO lamp	Electronic	75	1	75	69	0.92
(2) 900 mm, T12 lamp	Mag-Std	30	2	60	81	1.35	(2) 1500 mm, T12 HO lamp	Electronic	75	2	150	138	0.92
(1) 900 mm, T12 ES lamp	Mag-Std	25	1	25	42	1.68	(1) 1500 mm, T8 lamp	Electronic	40	1	40	36	0.90
(2) 900 mm, T12 ES lamp	Mag-Std	25	2	50	73	1.46	(2) 1500 mm, T8 lamp	Electronic	40	2	80	72	0.90
(1) 900 mm, T12 HO lamp	Mag-Std	50	1	50	70	1.40	(3) 1500 mm, T8 lamp	Electronic	40	3	120	106	0.88
(2) 900 mm, T12 HO lamp	Mag-Std	50	2	100	114	1.14	(4) 1500 mm, T8 lamp	Electronic	40	4	160	134	0.84

Total load for all previous loads is in the last tab



Total Load (Watt): 5693.73974589255

Figure (5.13) Total Load Screen

By clicking Show Values button the sum of loads appear in watt unit

5.11 Selecting the System

5.11.1 Input data

- One room.
- The room in the last floor of the building.
- The dimensions of the room is 3 * 4 * (3 height) meters
- Product type is beef stored in boxes (box can carry 100 kg/Box approximately)
- The room capacity is about 50 Box approximately.
- The activity of the storage is supplying for small traders.
- The amount of storage product is 5 *Ton* = 5000 *kg*.
- The condensation unit is outdoor, evaporating is indoor.
- The time required is 18 *Hour per day* for condenser.

5.11.2 Selection parameters

- q_{gain} = 1800 watt
- $q_{persons}$ = 1176 watt
- $q_{products}$ = 25269 watt
- q_{lights} = 192 watt
- Q_{total} = 28436 watt

5.11.3 Selected refrigerant

R404A (R502 alternative)

5.11.4 Selected system

Steps for selecting the system (from DWM Copland catalogs)

1. Estimate the evaporator load (Q total)

2. Determining the ambient temperature T_{amb}=35 ^oC

3. Selection will be above this temperature the Condenser Temperature will be 40 ^oC

   - Note: if the exact temperature is not available in the catalogs, the selection will be the near high temp. Value.

4. Determining the required evaporator temp (-20 ^oC)

5. Determining the refrigerant type (R404A)

   By entering the tables with the above data At R404A, T_{evap}, T_{amb},

6. Allocate the corresponding condenser capacity *kw*.

7. Allocate the required power input in *kw*.

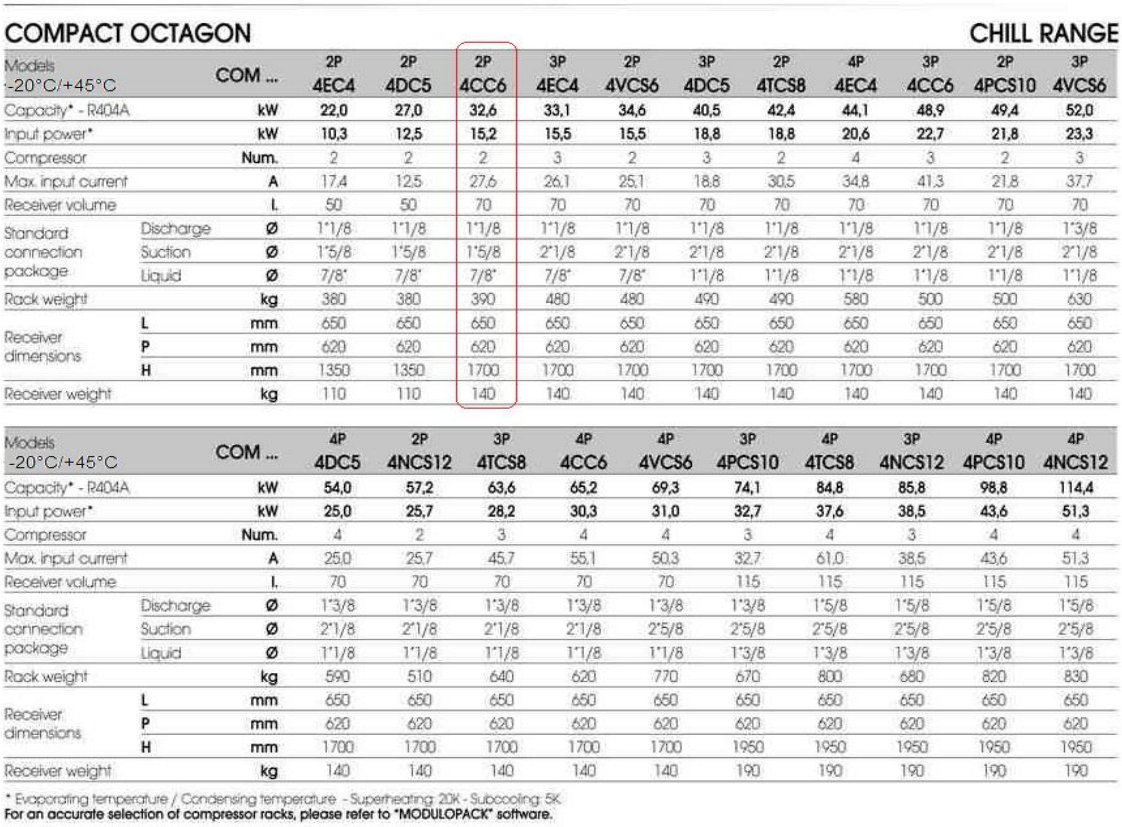
8. Allocate the corresponding suitable condensing system code (W99-6DH-350X) So…according to the system code:

   - Required power = 22.9 *kw*

   - Standard code of the condensation unit is (W99-6DH-350X)

   - The specifications of the selected system from the tables below

Table 5.5 HeatCraft Catalogue of Evaporating Unit



COMPACT OCTAGON **CHILL RANGE**

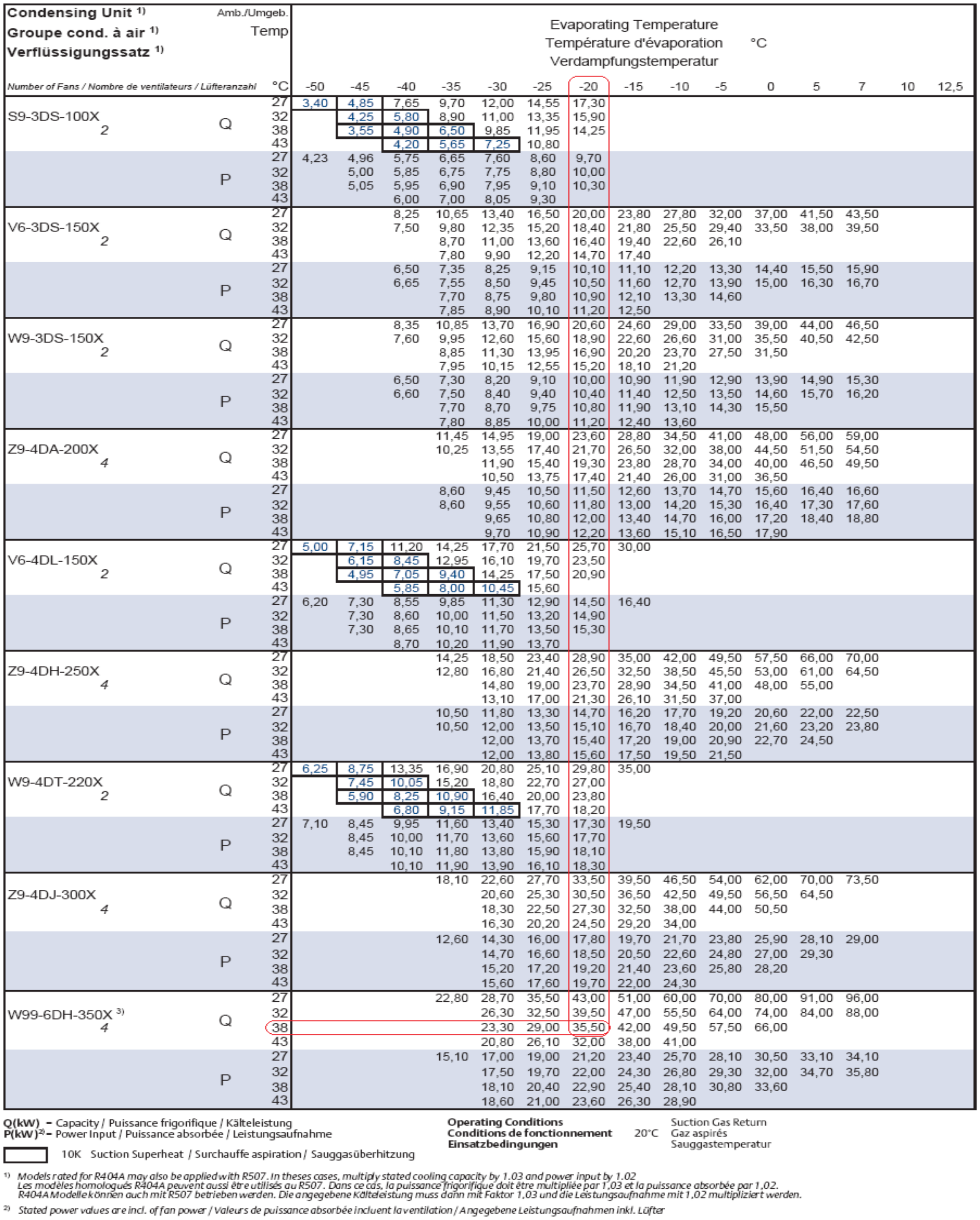
Models -20°C/+45°C		COM ...	2P 4EC4	2P 4DC5	2P 4CC6	3P 4EC4	2P 4VCS6	3P 4DC5	2P 4TCS8	4P 4EC4	3P 4CC6	2P 4PCS10	3P 4VCS6
Capacity* - R404A		kW	22,0	27,0	32,6	33,1	34,6	40,5	42,4	44,1	48,9	49,4	52,0
Input power*		kW	10,3	12,5	15,2	15,5	15,5	18,8	18,8	20,6	22,7	21,8	23,3
Compressor		Num.	2	2	2	3	2	3	2	4	3	2	3
Max. input current		A	17,4	12,5	27,6	26,1	25,1	18,8	30,5	34,8	41,3	21,8	37,7
Receiver volume		l.	50	50	70	70	70	70	70	70	70	70	70
Standard connection package	Discharge	Ø	1"1/8	1"1/8	1"1/8	1"1/8	1"1/8	1"1/8	1"1/8	1"1/8	1"1/8	1"1/8	1"3/8
	Suction	Ø	1"5/8	1"5/8	1"5/8	2"1/8	2"1/8	2"1/8	2"1/8	2"1/8	2"1/8	2"1/8	2"1/8
	Liquid	Ø	7/8"	7/8"	7/8"	7/8"	7/8"	1"1/8	1"1/8	1"1/8	1"1/8	1"1/8	1"1/8
Rack weight		kg	380	380	390	480	480	490	490	580	500	500	630
Receiver dimensions	L	mm	650	650	650	650	650	650	650	650	650	650	650
	P	mm	620	620	620	620	620	620	620	620	620	620	620
	H	mm	1350	1350	1700	1700	1700	1700	1700	1700	1700	1700	1700
Receiver weight		kg	110	110	140	140	140	140	140	140	140	140	140

Models -20°C/+45°C		COM ...	4P 4DC5	2P 4NCS12	3P 4TCS8	4P 4CC6	4P 4VCS6	3P 4PCS10	4P 4TCS8	3P 4NCS12	4P 4PCS10	4P 4NCS12
Capacity* - R404A		kW	54,0	57,2	63,6	65,2	69,3	74,1	84,8	85,8	98,8	114,4
Input power*		kW	25,0	25,7	28,2	30,3	31,0	32,7	37,6	38,5	43,6	51,3
Compressor		Num.	4	2	3	4	4	3	4	3	4	4
Max. input current		A	25,0	25,7	45,7	55,1	50,3	32,7	61,0	38,5	43,6	51,3
Receiver volume		l.	70	70	70	70	70	115	115	115	115	115
Standard connection package	Discharge	Ø	1"3/8	1"3/8	1"3/8	1"3/8	1"3/8	1"3/8	1"5/8	1"5/8	1"5/8	1"5/8
	Suction	Ø	2"1/8	2"1/8	2"1/8	2"1/8	2"5/8	2"5/8	2"5/8	2"5/8	2"5/8	2"5/8
	Liquid	Ø	1"1/8	1"1/8	1"1/8	1"1/8	1"1/8	1"3/8	1"3/8	1"3/8	1"3/8	1"3/8
Rack weight		kg	590	510	640	620	770	670	800	680	820	830
Receiver dimensions	L	mm	650	650	650	650	650	650	650	650	650	650
	P	mm	620	620	620	620	620	620	620	620	620	620
	H	mm	1700	1700	1700	1700	1700	1950	1950	1950	1950	1950
Receiver weight		kg	140	140	140	140	140	190	190	190	190	190

* Evaporating temperature / Condensing temperature - Superheating: 20K - Subcooling: 5K

For an accurate selection of compressor racks, please refer to "MODULOPACK" software.

Table 5.6 DWM Copland Catalogue for R404A Discus *50HZ*



Condensing Unit [1] Groupe cond. à air [1] Verflüssigungssatz [1]	Number of Fans / Nombre de ventilateurs / Lüfteranzahl		Amb./Umgeb. Temp °C	Evaporating Temperature Température d'évaporation Verdampfungstemperatur °C														
				-50	-45	-40	-35	-30	-25	-20	-15	-10	-5	0	5	7	10	12,5
S9-3DS-100X	2	Q	27	3,40	4,85	7,65	9,70	12,00	14,55	17,30								
			32		4,25	5,80	8,90	11,00	13,35	15,90								
			38		3,55	4,90	6,50	9,85	11,95	14,25								
			43			4,20	5,65	7,25	10,80									
		P	27	4,23	4,96	5,75	6,65	7,60	8,60	9,70								
			32		5,00	5,85	6,75	7,75	8,80	10,00								
			38		5,05	5,95	6,90	7,95	9,10	10,30								
			43			6,00	7,00	8,05	9,30									
V6-3DS-150X	2	Q	27			8,25	10,65	13,40	16,50	20,00	23,80	27,80	32,00	37,00	41,50	43,50		
			32			7,50	9,80	12,35	15,20	18,40	21,80	25,50	29,40	33,50	38,00	39,50		
			38				8,70	11,00	13,60	16,40	19,40	22,60	26,10					
			43				7,80	9,90	12,20	14,70	17,40							
		P	27			6,50	7,35	8,25	9,15	10,10	11,10	12,20	13,30	14,40	15,50	15,90		
			32			6,65	7,55	8,50	9,45	10,50	11,60	12,70	13,90	15,00	16,30	16,70		
			38				7,70	8,75	9,80	10,90	12,10	13,30	14,60					
			43				7,85	8,90	10,10	11,20	12,50							
W9-3DS-150X	2	Q	27			8,35	10,85	13,70	16,90	20,60	24,60	29,00	33,50	39,00	44,00	46,50		
			32			7,60	9,95	12,60	15,60	18,90	22,60	26,60	31,00	35,50	40,50	42,50		
			38				8,85	11,30	13,95	16,90	20,20	23,70	27,50	31,50				
			43				7,95	10,15	12,55	15,20	18,10	21,20						
		P	27			6,50	7,30	8,20	9,10	10,00	10,90	11,90	12,90	13,90	14,90	15,30		
			32			6,60	7,50	8,40	9,40	10,40	11,40	12,50	13,50	14,60	15,70	16,20		
			38				7,70	8,70	9,75	10,80	11,90	13,10	14,30	15,50				
			43				7,80	8,85	10,00	11,20	12,40	13,60						
Z9-4DA-200X	4	Q	27				11,45	14,95	19,00	23,60	28,80	34,50	41,00	48,00	56,00	59,00		
			32				10,25	13,55	17,40	21,70	26,50	32,00	38,00	44,50	51,50	54,50		
			38					11,90	15,40	19,30	23,80	28,70	34,00	40,00	46,50	49,50		
			43					10,50	13,75	17,40	21,40	26,00	31,00	36,50				
		P	27				8,60	9,45	10,50	11,50	12,60	13,70	14,70	15,60	16,40	16,60		
			32				8,60	9,55	10,60	11,80	13,00	14,20	15,30	16,40	17,30	17,60		
			38					9,65	10,80	12,00	13,40	14,70	16,00	17,20	18,40	18,80		
			43					9,70	10,90	12,20	13,60	15,10	16,50	17,90				
V6-4DL-150X	2	Q	27	5,00	7,15	11,20	14,25	17,70	21,50	25,70	30,00							
			32		6,15	8,45	12,95	16,10	19,70	23,50								
			38		4,95	7,05	9,40	14,25	17,50	20,90								
			43			5,85	8,00	10,45	15,60									
		P	27	6,20	7,30	8,55	9,85	11,30	12,90	14,50	16,40							
			32		7,30	8,60	10,00	11,50	13,20	14,90								
			38		7,30	8,65	10,10	11,70	13,50	15,30								
			43			8,70	10,20	11,90	13,70									
Z9-4DH-250X	4	Q	27				14,25	18,50	23,40	28,90	35,00	42,00	49,50	57,50	66,00	70,00		
			32				12,80	16,80	21,40	26,50	32,50	38,50	45,50	53,00	61,00	64,50		
			38					14,80	19,00	23,70	28,90	34,50	41,00	48,00	55,00			
			43					13,10	17,00	21,30	26,10	31,50	37,00					
		P	27				10,50	11,80	13,30	14,70	16,20	17,70	19,20	20,60	22,00	22,50		
			32				10,50	12,00	13,50	15,10	16,70	18,40	20,00	21,60	23,20	23,80		
			38					12,00	13,70	15,40	17,20	19,00	20,90	22,70	24,50			
			43					12,00	13,80	15,60	17,50	19,50	21,50					
W9-4DT-220X	2	Q	27	6,25	8,75	13,35	16,90	20,80	25,10	29,80	35,00							
			32		7,45	10,05	15,20	18,80	22,70	27,00								
			38		5,90	8,25	10,90	16,40	20,00	23,80								
			43			6,80	9,15	11,85	17,70	18,20								
		P	27	7,10	8,45	9,95	11,60	13,40	15,30	17,30	19,50							
			32		8,45	10,00	11,70	13,60	15,60	17,70								
			38		8,45	10,10	11,80	13,80	15,90	18,10								
			43			10,10	11,90	13,90	16,10	18,30								
Z9-4DJ-300X	4	Q	27				18,10	22,60	27,70	33,50	39,50	46,50	54,00	62,00	70,00	73,50		
			32					20,60	25,30	30,50	36,50	42,50	49,50	56,50	64,50			
			38					18,30	22,50	27,30	32,50	38,00	44,00	50,50				
			43					16,30	20,20	24,50	29,20	34,00						
		P	27				12,60	14,30	16,00	17,80	19,70	21,70	23,80	25,90	28,10	29,00		
			32					14,70	16,60	18,50	20,50	22,60	24,80	27,00	29,30			
			38					15,20	17,20	19,20	21,40	23,60	25,80	28,20				
			43					15,60	17,60	19,70	22,00	24,30						
W99-6DH-350X [3]	4	Q	27				22,80	28,70	35,50	43,00	51,00	60,00	70,00	80,00	91,00	96,00		
			32					26,30	32,50	39,50	47,00	55,50	64,00	74,00	84,00	88,00		
			38					23,30	29,00	35,50	42,00	49,50	57,50	66,00				
			43					20,80	26,10	32,00	38,00	41,00						
		P	27				15,10	17,00	19,00	21,20	23,40	25,70	28,10	30,50	33,10	34,10		
			32					17,50	19,70	22,00	24,30	26,80	29,30	32,00	34,70	35,80		
			38					18,10	20,40	22,90	25,40	28,10	30,80	33,60				
			43					18,60	21,00	23,60	26,30	28,90						

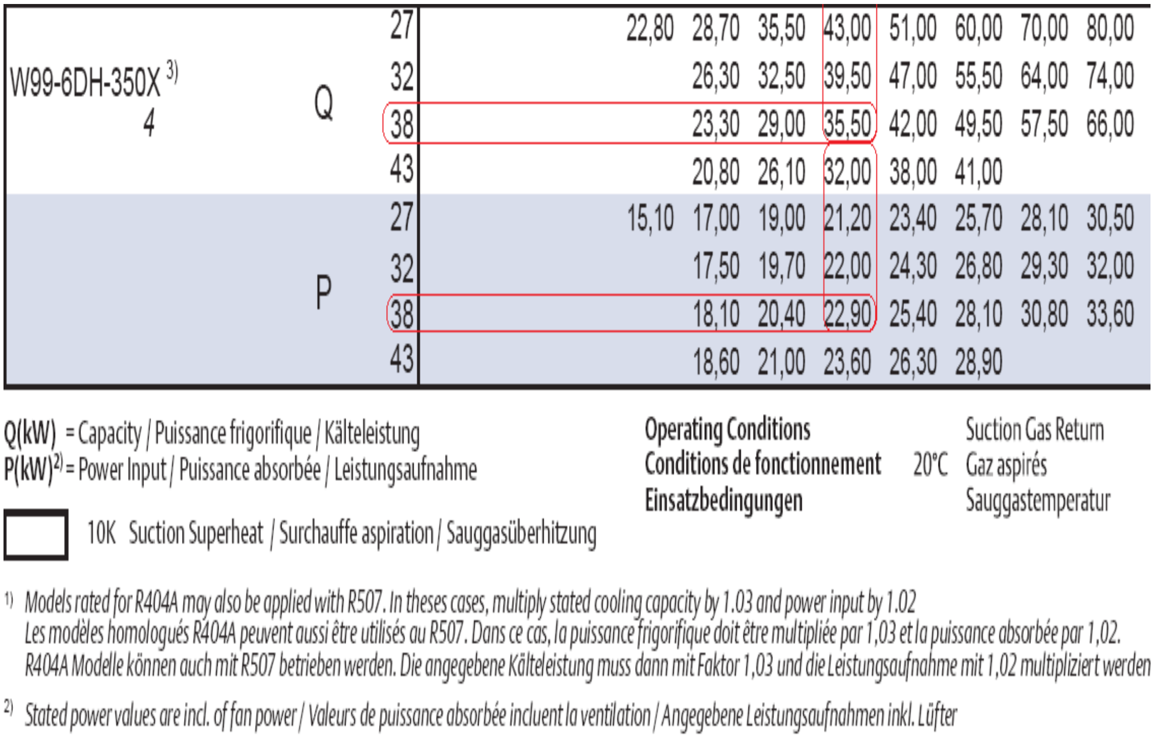
Q(kW) – Capacity / Puissance frigorifique / Kälteleistung
P(kW)[2] – Power Input / Puissance absorbée / Leistungsaufnahme

▭ 10K Suction Superheat / Surchauffe aspiration / Sauggasüberhitzung

Operating Conditions **Conditions de fonctionnement** **Einsatzbedingungen**	20°C	Suction Gas Return Gaz aspirés Sauggastemperatur

[1] *Models rated for R404A may also be applied with R507. In theses cases, multiply stated cooling capacity by 1.03 and power input by 1.02*
Les modèles homologués R404A peuvent aussi être utilisés au R507. Dans ce cas, la puissance frigorifique doit être multipliée par 1,03 et la puissance absorbée par 1,02.
R404A Modelle können auch mit R507 betrieben werden. Die angegebene Kälteleistung muss dann mit Faktor 1,03 und die Leistungsaufnahme mit 1,02 multipliziert werden.

[2] *Stated power values are incl. of fan power / Valeurs de puissance absorbée incluent la ventilation / Angegebene Leistungsaufnahmen inkl. Lüfter*



W99-6DH-350X[3] 4	Q	27	22,80	28,70	35,50	43,00	51,00	60,00	70,00	80,00
		32		26,30	32,50	39,50	47,00	55,50	64,00	74,00
		38		23,30	29,00	35,50	42,00	49,50	57,50	66,00
		43		20,80	26,10	32,00	38,00	41,00		
	P	27	15,10	17,00	19,00	21,20	23,40	25,70	28,10	30,50
		32		17,50	19,70	22,00	24,30	26,80	29,30	32,00
		38		18,10	20,40	22,90	25,40	28,10	30,80	33,60
		43		18,60	21,00	23,60	26,30	28,90		

Q(kW) = Capacity / Puissance frigorifique / Kälteleistung
P(kW)[2] = Power Input / Puissance absorbée / Leistungsaufnahme

☐ 10K Suction Superheat / Surchauffe aspiration / Sauggasüberhitzung

Operating Conditions **Conditions de fonctionnement** **Einsatzbedingungen**	20°C	Suction Gas Return Gaz aspirés Sauggastemperatur

[1] *Models rated for R404A may also be applied with R507. In theses cases, multiply stated cooling capacity by 1.03 and power input by 1.02*
Les modèles homologués R404A peuvent aussi être utilisés au R507. Dans ce cas, la puissance frigorifique doit être multipliée par 1,03 et la puissance absorbée par 1,02.
R404A Modelle können auch mit R507 betrieben werden. Die angegebene Kälteleistung muss dann mit Faktor 1,03 und die Leistungsaufnahme mit 1,02 multipliziert werden

[2] *Stated power values are incl. of fan power / Valeurs de puissance absorbée incluent la ventilation / Angegebene Leistungsaufnahmen inkl. Lüfter*

Figure (5.14) Snapshot for the Selected Condensation unit

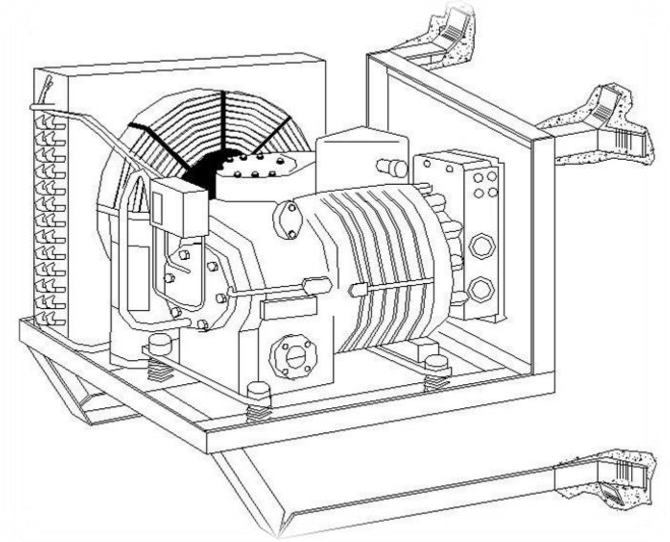


Figure (5.15) Selected Compensating Unit of the Project

5.11.5 General specifications

Walls and ceiling

Prefabricated sandwich panel polyurethane injected density 40 Kg/m^3 the interior and exterior cladding-made of pre-painted white coating steel with 0.5 mm thickness.

Panel thickness 100 mm for wall and ceiling. Panels connected together (by Male/Female or Lock system.

Floor:

Traditional insulation floor (10 cm polyurethane with 40 Kg/m^3).

Manual hinged doors:

100mm thick polyurethane injected density 40 Kg/m3

Exterior and interior cladding made of pre painted white coating steel with 0.5*mm* thickness with opening dim. (90*cm* width X 220*cm* height.) Heavy duty door lock and accessories made in Italy. The door will be fitted with rubber gasket (according to the drawings).

Provide Safety unlock from inside the cooling room. All dimensions in meters.

No of Rooms	Room dimensions	out Panel height	Panel Thickness	Floor Area(m2)	No of Floors
1	4 x 3	3	10 cm	12	1

Cooling unit

1- Condensing unit

Copeland Type (based on Copeland catalogues).

Model	W99-6DH-350X
Compressor Capacity	22.9 *kw*
Room Temperature	-20˚C
REFRIGERANT	R404A
Power Input	15.2

2-Evaporator

FRIGA BOHN Type. (Based on FRIGA BOHON catalogues)

Model	COMPACT OCTAGON 2P 4CC6
Total capacity	32.6 *kw*
Room Temperature	-20˚C
REFRIGERANT	R404A
Power Input	15.2

3-Accessories

Sight glass

Filter

Suction flexible joint

H.L.P Protection

Hand valves

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