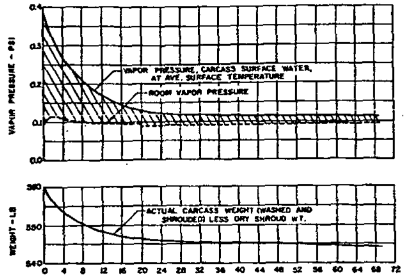

Fig. 3 .... Typical Beef Carcass Chilling-Holding Shrinkage Curves

air raises the temperature of the air immediately surrounding the carcass. The rate of transfer is increased by more rapid circulation of air against the carcass, and by lower air temperature, but this is limited by the necessity of avoiding surface-freezing.

The exposed fat of the skinned and shrouded beef carcass absorbs and carries into the cooler a large amount of wash and shroud water. This continuously vaporizes and enters the surrounding space, thereby cooling the surface. The vapor pressure of the water solution in the carcass surface is governed by the temperature and dryness of the carcass surface, and the opposing pressure of the surrounding atmospheric vapor is measured by its temperature and relative humidity. The spread between the two pressures is very large at the beginning of the chill, when the carcass is warm and wet. Evaporation proceeds rapidly and in proportion to the spread until the carcass is thoroughly chilled, causing loss of wash and shroud water and some actual shrinkage from dry carcass weight.

Estimated differences in vapor pressure between surface water (at average surface temperature) and atmospheric vapor during a typical chilling-holding cycle, and the corresponding shrinkage curve for an average carcass, are shown in Fig. 3.

Note the tremendous vapor pressure differences causing evaporation during the early part of the chill cycle, when the carcass is warm. It is reasonable to question whether the evaporative loss can be reduced by beginning the chill with room temperature high, then lowering it slowly so as to minimize at all times the pressure difference between carcass surface water and room vapor. This however, slows the chill and prolongs the period of rapid evaporation. The weight of evidence is in favor of the quick chill.

Evaporation from the *warm* carcass in cool air is to a considerable degree independent of room relative humidity, because the warmth of the carcass surface generates much higher vapor pressure than that of the cooler vapor surrounding the carcass, even when the room air is saturated. If the space surrounding a warm carcass is saturated, evaporation continues nevertheless, with the formation of a fog. This can be observed at the beginning of any chill. The existence of the fog at no time increases atmospheric vapor pressure above that at saturation.

The formation of fog in a saturated atmosphere involves a two-stage heat transfer. The warm carcass supplies the heat required to vaporize its surface water, and thereby lower carcass temperature. The freed vapor then (in condensing to fog) transfers its heat of vaporization to the cool air, thus raising air temperature. The net result is a sensible transfer of heat from the carcass to the air, and a physical movement of water out of the carcass.

Evaporation from the *well-chilled* carcass with surface temperature at or near room temperature is another matter. The spread between surface and room vapor pressures is narrowed, and approaches zero when the room air is near saturation. Evaporation proceeds slowly, without the formation of a general fog. Under these conditions, since atmospheric vapor pressure is proportional to relative humidity, an increase in relative humidity has a pronounced effect in reducing evaporation.

It is a misconception to suppose that evaporation invariably ceases when the room is saturated. This is true only if the carcass is chilled through to room temperature and no heat transfer is taking place.

The room air-vapor mixture is heated by transmission and infiltration, and by heat-producing equipment, as well as by the carcasses. Water vapor enters the space by infiltration, from personnel, and from the carcasses. The resulting mixture (air, vapor, and fog) is cooled sensibly during its passage through the refrigeration coils, typically by 1 to 3 F deg. To the extent that the temperature of the vapor is lowered below the dewpoint, water is condensed out on the coils and removed from the space. Fog is trapped physically on the coil.

The ultimate disposition of the water condensed or trapped out on the coils depends on the temperature of the coil surface and the method of coil operation. In continuous defrost (sprayed coil) operation, condensed and trapped water are picked up by the solution sprayed over the coil, resulting in its dilution. In non-frosting dry coil operation, condensed water falls to the evaporator pan and drains to sewer. Water frozen on the coil is lost to the sewer if removed by hot gas or coil spray defrost. Periodic room air defrost, however, vaporizes part of the ice and returns it to room atmosphere, while losing the remainder to sewer.

The weight changes that take place, in good current practice, may be summarized as follows for a beef carcass of average weight:

In the Chilling Cooler	Lb	Percent
Initial *dry* weight	550	
Wash water pick-up	8	
Initial *wet* weight	558	
Shroud water pick-up[a]	6	
Drip loss, not vaporized	4	
Weight at start of chill[a]	560	
Weight loss in chill cooler	13.5	
Weight at end of 20-hour chill[a]	546.5	
Net loss through chill, *wet* basis[b]	11.5	2.0
Net loss through chill, *dry* basis[c]	3.5	0.7
In the Holding Cooler		
Initial weight (shroud removed)	546.5	
Weight loss during 48-hour hold	3.5	
Weight loss per day	1.7	0.3
Final weight after 48-hour hold	543	

[a] Exclusive of 4-lb weight of the dry shroud cloth.
[b] Carcass weighed in after washing, but before shrouding.
[c] Carcass weighed in before washing and shrouding.

It should be noted again that chilling of the beef carcass is not completed in the chill cooler, but continues in the holding cooler at a reduced rate. A carcass well-chilled when it enters the holding cooler will show minimum holding shrink, and one poorly chilled will show high holding shrink.

A word of caution on shrink values is in order. If these are to have any significance, they must be derived with great care. Actual product loss must be determined by first weighing the dry carcass prior to washing, then out of the cooler with the shroud removed. In-motion weights are not sufficiently precise; carcasses must be weighed at rest. Scales must be accurate, and the same scale if possible used before and after chilling. If the shrinkage is to have any comparison value it must be measured on carcasses chilled to the same temperature, since the chilling occurs largely by evaporative weight loss.

Table 1 .... Load Calculations, Beef Chilling

Cooler Size (Feet) 72×108×15
Cooler Capacity: 520 carcasses
Assumed Chill Rate: 40 F in 20 hours
Assumed Air Circulation: 135,000 cfm
Loading Time: 4 hr maximum
Average Carcass Weight: 560 lb
Assumed Air to Coil: 33 F 100% rh
Assumed Fan Horsepower: 45 hp

Heat Gain—Room Load	Loads, Btuh		
	Sensible Heat	Latent Heat	Total Heat
1. Transmission, infiltration, personnel, and equipment heat	288,000	3,000	291,000
2. Product heat (average, first 4 hr):			
a. 520 × 560 × 0.75 × 40 × 0.08	700,000		
b. 520 × 13.5 × 0.08 × 1070	−620,000	620,000	700,000
3. Total heat gain (room load), Btuh (Items 1 + 2a + 2b)	368,000	623,000	991,000
Heat Removal—Coil Load	**Loads, Btuh**		
	Sensible Heat	Latent Heat	Total Heat
4. Air circulation, dry air lb/hr 135,000 × 0.08 × 60 = 650,000	—	—	—
5. Heat removed per lb dry air, Btu (Total heat Item 3)/(Item 4) = 1.525	—	—	—
6. Air-vapor enthalpy, Btu/lb dry air:			
a. Air to coil, 33 F 100% rh	7.927	4.242	12.169
b. Btu removed, temp drop 3.7 F deg	0.880	0.645	1.525
c. Air from coil, 29.3 F 100% rh	7.047	3.597	10.644
7. Coil air-vapor heat removal, Btuh (Item 4) (Item 6b)	572,000	419,000	991,000
8. Room vapor condensed to fog (Item 7) − (Item 3)	204,000	−204,000	—
9. Water (ice) removed by coil 520 × 13.5 × 0.08 × 144		82,000	82,000
10. Total heat removal (coil load), Btuh (Items 3+8+9)	572,000	501,000	1,073,000

Design Conditions and Refrigeration Load

It is sound practice to base equipment selection on conditions at peak load, when product loss is greatest. Room losses, equipment heat, and carcass heat add up to a total load that varies greatly throughout the chill, not only in magnitude but also in proportion of sensible to total heat (sensible heat ratio). As the chill progresses, the vapor load decreases and the sensible load becomes more predominant.

Under peak chilling load, more water is vaporized from the warm carcass than can exist as vapor at room temperature. The excess condenses into fog—enough to warm the air-vapor-fog mixture to the sensible heat ratio of the heat removal process. The heat removal process of the coil therefore under-estimates the actual rate of water removal by the amount of vapor condensed to fog, as shown in Table 1.

Under later chilling room loads, and all holding room loads, fog does not form generally, although it may form locally and re-vaporize. Sensible heat ratios of air-vapor heat gain and air-vapor heat removal are then equal, as shown in Table 2.

It has been customary in beef chilling rooms, particularly with sprayed coil systems, to provide evaporator capacity sufficient to hold room temperature under load approximately as shown in Fig. 2. This results in a rise in room temperature to 35 to 40 F, with gradual reduction thereafter to 32 to 34 F. Many recent installations, however, provide greater capacity, particularly dry coil systems which thereby avoid excessive coil frosting. In batch-loaded coolers, room temperature may be as low as 25 F under peak load, provided it is raised to 30 F as the chill progresses, without surface-freezing of the beef. The shrink improvement effected by such lower temperatures, however, tends to be less than expected (in beef chilling) because of the relatively small part played by sensible transfer of heat.

It is standard practice in the holding room to provide evaporator capacity to hold the room temperature at 32 to 34 F at all times. Holding room coils sized at peak load, low air-vapor circulation rate, and a coil temperature 10 F below room temperature tend to maintain the 90 to 95 percent relative humidity that avoids excessive shrink while preventing surface sliming.

From the average temperature curve of Fig. 2 and the shrinkage curve of Fig. 3 certain generalizations, useful in calculating carcass chilling load, may be made:

In the chilling cooler, the average carcass temperature is reduced approximately 40 F (from 85 F average first-hour temperature to 45 F) in 20 hr. Simultaneously, about 13.5 lb of water is vaporized per carcass (of which only 3.5 lb is actual shrinkage). The loss of sensible heat and of water occur at about the same rate; averaging 8.6, 4.5, 3.5, and 3 percent of the total *per hour* during the five successive four-hour periods represented. For a chilling cooler batch-loaded over a four-hour period, the maximum rate of 8 percent should be used in design. This tallies with the old rule-of-thumb that peak load is approximately 1.5 times average load.

In the holding cooler, the average carcass temperature is reduced approximately 10 F deg (from 45 to 35 F) in 48 hours. Simultaneously, about 3.5 lb of water will be vaporized per carcass (all actual shrinkage). Here also, the loss of sensible heat and of water occur at about the same rate; averaging 5, 4, 3, 2, 2, 2, 2, 1, 1, 1, 1, and 1 percent of the total per hour during the twelve successive four-hour periods represented. Because the holding cooler is loaded at random, the