Heat Load Calculation

Factors to be considered in determining refrigeration required for a cold-storage plant. Examples are simplified to illustrate steps necessary to calculate heat load of a refrigerated storage area during cooling and normal storage operation. More information on load calculations can be found in ASHRAE (1981), Bartsch and Blanpied (1984), Patchen (1971) and Ryall and Lipton (1979). The information presented here is adapted from pages 14 to 16 of the previous USDA Agriculture Handbook Number 66 (Hardenberg et al., 1986). Examples are shown in metric units for pears in storage at -1.1 ºC (30 ºF). To convert respiration rate of fruits and vegetables expressed in mg CO_2 kg^{-1} h^{-1} to heat production in kJ, multiply mg CO_2 kg^{-1} h^{-1} by 61 to get kcal $tonne^{-1}$ day^{-1} (1 kcal = 4,186 kJ).

Conditions	**Example**
Storage size	15 x 15 x 4.5 m
Outside surface area (including floor)	720 m^2
Inside dimensions	14.7 x 14.7 x 4.2 m
Volume	908 m^3
Insulation	7.6 cm of polyurethane with a conductivity value (k) = 1.3 kJ per m^2 per cm thickness per ºC Coefficient of transmission (U) = 1.1 kJ per h per m^2 per ºC
Ambient conditions at harvest	30 ºC and 50% RH
Fruit temperature	At harvest, 21 ºC; In storage, -1.1 ºC
Storage capacity	600 bins at 500 kg fruit per bin = 300,000 kg of fruit
Bin weight	63.5 kg; total weight of bins = 38,100 kg
Loading weight and time	200 bins (100,000 kg fruit per day); 3 days to fill
Cooling rate	1st day, 21 to 4.5 ºC; 2nd day, 4.5 to -1.1 ºC
Air changes from door openings during cooling	Six per day
Air changes from door openings during storage	1.8 per day
Specific heat	Pears, 0.86; Wood bins, 0.5
Heat load to lower air from 30 to -1.1 ºC (50% RH)	74.5 kJ per m^3
Heat load to lower air from 7.2 to to -1.1 ºC (70% RH)	15.3 kJ per m^3
Miscellaneous heat loads	Lights, 2,400 W per h (3.6 kJ per W) Fans at 3,112 kJ per HP Electric forklifts, 36,920 kJ each for 8 h Workers, 1,000 kJ per h for each person

A. Load during cooling and filling storage: temperature difference (TD) from 30 ºC to -1.1 ºC = 31.1 ºC, assuming 31.1 ºC TD on all surfaces:

	kJ per 24 h
1. Building-transmission load: area (720 m^2) x U (1.1 kJ) x TD (31.1 ºC) x h (24) =	591,149
2. Air-change load from door openings: volume (908 m^3) x heat load (74.5 kJ) x air changes (6) =	405,876
3. Product cooling (field heat removal) -	
First day	
Fruit weight (100,000 kg) x specific heat (0.86) x TD (21 to 4.5 ºC) x kJ factor (4.186) =	5,939,934
Bin weight (12,700 kg) x specific heat (0.5) x TD (21 to 4.5 ºC) x kJ factor (4.186) =	438,588
Second day	
Fruit weight (100,000 kg) x specific heat (0.86) x TD (4.5 to -1.1 ºC) x kJ factor (4.186) =	2,015,977
Bin weight (12,700 kg) x specific heat (0.5) x TD (4.5 to -1.1 ºC) x kJ factor (4.186) =	148,854
4. Heat of respiration during cooling (vital heat) -	
First day	
Average temperature of 13EC; respiration rate of 12,206 kJ per tonne per 24 h; Tonne of fruit (100) x rate (12,206) =	1,220,600
Second day	

Average temperature of 1.7EC; respiration rate of 1,741 kJ per tonne per 24 h; Tonne of fruit (100) x rate (1,741) =	174,100
Maximum heat accumulated in storage before cooling completed: Total fruit weight of 300,000 kg - 2 day loading weight of 200,000 kg = 100,000 kg (100 tonnes); respiration rate at - 1.1 ºC is 812 kJ per tonne per 24 h; tonne of fruit (100) x respiration rate (812) =	81,200
5. Miscellaneous heat loads:	
Lights - W (2,400) x kJ per W (3.6) x h (8) =	69,120
Fans - HP (3) x kJ per HP (3,112) x h (24) =	224,064
Forklifts - 2 x 36,920 kJ per forklift for 8 h =	73,840
Labor - workers (2) x kJ per h (1,000) x h (8)	16,000

Total heat load during cooling:

1. Building transmission		519,149
2. Air change		405,876
3. Product cooling		8,543,353
4. Production respiration		1,475,900
5. Miscellaneous		383,024
	Subtotal	11,399,302
	Add 10% to be cautious	1,139,930
	Total required refrigeration	12,539,232

Assuming that refrigeration equipment operates 18 h per day: 12,539,232 ÷ 18 h = 696,624 kJ per h. Since a tonne of refrigeration absorbs 12,660 kJ per 24 h: 696,624 ÷ 12,660 = 55 tons of peak refrigeration capacity is required.

B. Load during normal storage operation (average outside ambient conditions, 7.2EC at 70% RH; storage temperature, -1.1EC; TD = 7.2E to -1.1EC = 8.3EC.)

	kJ per 24 h
1. Building-transmission load: area (720 m^2) x U (1.1 kJ) x TD (8.3 ºC) x h (24) =	157,766
2. Air-change load from door openings: volume (908 m^3) x heat load (15.3 kJ) x air changes (1.8) =	25,006
Product load (respiration, no cooling):	
3. Respiration rate at - 1.1 ºC is 812 kJ per tonne per 24 h; tonne of fruit (300) x rate (812) =	243,600
4. Miscellaneous head loads:	
Lights - W (2,400) x kJ per W (3.6) x h (4) =	34,560
Fans - HP (3) x kJ per HP (3,112) x h (24) =	224,064
Labor - people (1) x kJ per h (1,000) x h (4) =	4,000

Total load during storage:

1. Building transmission		157,766
2. Air change		25,006
3. Product load (respiration)		243,600
4. Miscellaneous		262,624
	Subtotal	688,996
	Add 10% to be cautious	68,899
	Total required refrigeration	757,895

Assuming refrigeration equipment operates 18 h per day: 757,895 ÷ by 18 h = 42,105 kJ per h and 42,105 ÷ 12,660 = 3.3 tonnes of refrigeration capacity is needed during normal storage.

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