Heat Load Calculation

Some factors need 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 Patchen (1971), Ryall and Lipton (1979), ASHRAE (1981), and Bartsch and Blanpied (1984). 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	15×15×4.5 m
Outside surface area (including floor)	720 m^2
Inside dimensions	14.7×14.7×4.2 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 h^{-1} m^{-2} $ºC^{-1}$
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	6 per day
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 m^{-3}
from 7.2 to -1.1 ºC (70% RH)	15.3 kJ m^{-3}
Miscellaneous heat loads	lights, 2,400 W per h (3.6 kJ W^{-1}) fans at 3,112 kJ per HP electric forklifts, 36,920 kJ each for 8 h workers, 1,000 kJ per h per 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) × U (1.1 kJ) × TD (31.1 ºC) × h (24) =	591,149
2. Air-change load from doors: vol (908 m^3) × heat load (74.5 kJ) × air changes (6) =	405,876

3. Product cooling (field heat removal):

First day

Fruit (100,000 kg) × specific heat (0.86) × TD (21 to 4.5 ºC) × kJ factor (4.186) =	5,939,934
Bin weight (12,700 kg) × specific heat (0.5) × TD (21 to 4.5 ºC) × kJ factor (4.186) =	438,588

Second day

Fruit weight (100,000 kg) × specific heat (0.86) × TD (4.5 to -1.1 ºC) × kJ factor (4.186) =	2,015,977
Bin weight (12,700 kg) × specific heat (0.5) × TD (4.5 to -1.1 ºC) × kJ factor (4.186) =	148,854

4. Heat of respiration during cooling (vital heat):

First day

Average temperature of 13 ºC; respiration rate of 12,206 kJ per tonne per 24 h; tons of fruit (100) × rate (12,206) =	1,220,600

Second day

Average temperature of 1.7 ºC; respiration rate of 1,741 kJ per tonne per 24 h; tonnes of fruit (100) × 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; tonnes of fruit (100) × respiration rate (812) =	81,200

5. Miscellaneous heat loads:

Lights: W (2,400) × kJ per W (3.6) × h (8) =	69,120
Fans: HP (3) × kJ per HP (3,112) × h (24) =	224,064
Forklifts: 2 × 36,920 kJ per forklift for 8 h =	73,840
Labor: workers (2) × kJ per h (1,000) × h (8) =	16,000

Total heat load during cooling:

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

Assuming refrigeration equipment operates 18 h per day: 12,539,232 ÷ 18 h = 696,624 kJ h^{-1}. Since a tonne of refrigeration absorbs 12,660 kJ per 24 h: 696,624 ÷ 12,660 = 55 tonnes of peak refrigeration capacity is required.

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

	kJ per 24 h
1. Building-transmission load: area (720 m^2) × U (1.1 kJ) × TD (8.3 ºC) × h (24) =	157,766
2. Air-change load from doors: vol (908 m^3) × heat load (15.3 kJ) × 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 fruit (300) × rate (812) =	243,600
4. Miscellaneous head loads:	
Lights: W (2,400) × kJ per W (3.6) × h (4) =	34,560
Fans: HP (3) × kJ per HP (3,112) × h (24) =	224,064
Labor: people (1) × kJ per h (1,000) × h (4) =	4,000

Total load during storage:

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

Assuming refrigeration equipment operates 18 hours per day: 757,895 ÷ 18 h = 42,105 kJ h^{-1} and 42,105 ÷ 12,660 = 3.3 tonnes of refrigeration capacity is needed during normal storage.

References

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