Introduction

NHB Standard 01:2010 gives a summary of cooling load calculation (on page 40) for
1. 5-A: Loading and temperature pull down to 15°C per chamber.
2. 5-B: During pull down to +3°C at the rate of 0.5°C per day – fully loaded per chamber.
3. 5-C: During holding period at +3°C – fully loaded per chamber.

Pages 38 and 39 of the Standard give the assumptions for a 5000MT potato cold storage and suggest typical chamber layout.

The refrigeration load is maximum during loading and pull down to 15°C for 1000 bags/day of potatoes, each weighing 50 kg, totaling 50 tons/day per chamber (4% of 1250 tons), and the cooling load indicated is 85.32 kW or 24.37 TR per chamber. Detailed calculations arriving at these values are not given in the Standard.

The subsidy format given on page 29 of the Standard demands the load calculation summary during pull down and holding period for each new cold storage planned, and the customer or contractor needs to engage a refrigeration consultant to calculate cooling loads in order to fill up the form.

For presenting the load calculations, the assumptions mentioned on page 38 of the Standard have been considered.

Assumptions

1. Product: Potatoes
2. Location: Uttar Pradesh
3. Outside temperature: +45°C maximum DB, +30°C WB (113°F/86°F)
4. Product loading temperature: 20°C-25°C maximum
5. Weight of each bag: 50 kg (110 lbs)
6. Total storage capacity: 5000 metric ton
7. Each room storage: 1250 ton (1250x3.4 = 4250m³)
8. Chamber size (each): 21m Lx16m Wx13.7m H (volume = 4603 m³, floor area = 226 sq m)
9. Loading rate: 4% of total capacity/day = 1250x0.4 = 50 ton or 50000 kg/day
10. Pull down time: 15°C in 24 hrs
11. Compressor running hours: 20 hrs/day during pull down
12. Ventilation requirements: 2 to 6 air changes per day (page 4-2-h)
13. Insulation: PUF (32 kg/m³ density, K value = 0.023 W/m.K = 0.16 Btu/in.h.ft.°F) (ASHRAE Refrigeration Handbook 2014, page 24.1, Table 1), (Though the Standard mentions PUF density of 32 kg/cm³, it is recommended that a minimum of 38 kg/cm³ be used.)

14. Thickness (walls, roof, floor): 100 mm (NHB Standard 01:2010, page 10)


17. Loading density: 3.4 m³/metric ton = 120 cu ft/ton (NHB Standard 01:2010, page 44)

18. Safety factor of 10% has been considered, whereas diversity factor has not been considered

Load Calculations
For positive temperature cold storages, the major heat load contributors are:
- Heat gain through walls, roof and flooring
- Product load comprising of load due to the difference in product loading temperature and storage temperature
- Respiration load, as the product continues to breathe during storage for a considerable period
- Outside air load due to ventilation requirements and infiltration
- Equipment load such as air cooler fan heat gain and forklifts
- Loads contributed by human beings operating inside the room
- Lighting load

We shall now consider each factor for this typical NHB presented data on page 40, and how the values have been arrived at.

Transmission Load through Walls/Roof/Floor per day
$$ Q = U x A x TD $$
$$ = 0.023/0.1 x 2 x (21x16+2x21x13.7+16x13.7) x (45-15) $$
$$ = 0.23 x1663.4x30 $$
$$ = 11477.46 W, say 11.5 kW $$

Where 'U' is overall heat transfer coefficient in W/m².K = K/x, 'K' is thermal conductivity of insulation used in W/m.K and 'x' is insulation thickness in m,

' TD ' is the temperature difference between ambient condition and cold room temperature in K,

The correct method is to calculate individual wall loads depending on the direction each wall is facing w.r.t. the sun, and separate temperatures for roof and flooring. However, to simplify the calculations, we assume that all the six surfaces are exposed to ‘TD’. This would not make much difference to the load calculation, as the insulation has a greater influence compared to other factors.

Product Load

$$ = 4\% \times 1250 \text{ tons} \times 3.433 \text{ kJ/kg°C} \times (25-15) $$
$$ = 1716500 \times (24x3600) = 19.87 \text{ kW} $$

It is assumed that the product is loaded at 25°C and cooled to 15°C in 24 hours.

Respiration Load
Assuming that the remaining (1250-50 = 1200 ton or 1200000 kg) potatoes are already in store, and refrigeration load on the last day of loading is considered, the respiration load would be:

$$ \text{Respiration load} = 1200000 \times 0.018 = 21600W = 21.6 \text{ kW} $$

Total product load would be 19.87+21.6 = 41.47 kW, say 42 kW

Infiltration Load
Based on 4 air changes/day, outside enthalpy 99.173kJ/kg at 45°C DB and 30°C WB, inside enthalpy 13.62 kJ/kg at 3°C and 90% RH, Δh = 85.553. (These values have been taken from Psychrometric property tables for moist air.)

Amount of ventilation air for 4603 (volume of room, m³) x 4 air changes ÷ (24x3.6) = 213 litre/second.

And using the standard formula for total heat load as 1.2 x l/s x (Δh),

$$ = 1.2x213x85.53/1000 = 21.86 \text{ kW}. \text{With 70% recovery, it would be} $$

15.3 kW

Internal Load due to Fan Motors
Assuming 4 coolers per room, each with 2 fans of 0.75 kW, total motor power is 6 kW. Power contributed to heat load at the rate of 993W per motor = 8x0.933 = 7.94 kW

Lighting Load
At 10 W/sq m during loading = 336 sq ft floor area x10 W/1000

= 3.6 kW

Occupancy Load
Assuming 4 persons working inside the cold room during loading, each person would be contributing 250 W. Total occupancy load = 250 Wx4 = 1 kW

Total Internal Load = 7.94 + 3.6 + 1 = 12.54 kW

Total Load = Transmission+ product + infiltration + fan motor + lighting + occupancy

= 11.5+42+15.3+12.54 = 81.34 kW x 1.1 safety factor = 89.47 kW

kW per chamber

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Description</th>
<th>Refrigeration Load, kW/24 hr as Per NHB Standard 01:2010, pg 40</th>
<th>Calculated as Above</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Transmission load</td>
<td>12.12</td>
<td>11.5</td>
</tr>
<tr>
<td>2</td>
<td>Product load</td>
<td>43.16</td>
<td>42</td>
</tr>
<tr>
<td>3</td>
<td>Internal load</td>
<td>5.25</td>
<td>4.6</td>
</tr>
<tr>
<td>4</td>
<td>Infiltration and ventilation air load</td>
<td>16.14</td>
<td>15.3</td>
</tr>
<tr>
<td>5</td>
<td>Equipment load</td>
<td>8.65</td>
<td>7.94</td>
</tr>
<tr>
<td>6</td>
<td>Total load</td>
<td>85.32 (24.37 TR)</td>
<td>81.34x1.1 safety factor = 89.47 kW</td>
</tr>
</tbody>
</table>

Considering the compressor running time of 20 hours, the total capacity required would be 89.47x4x24/20 = 107.36 kW per room. The Standard is for 5000 tons with 4 rooms. Hence, total plant capacity required during loading is 429.47 kW.

Refrigeration system capacity recommended in NHB Standard 01:2010 at +2°C SST and 38°C SCT is 234.85x2 = 469.7 kW (page 42-6-ii).
Conclusion

Depending upon individual requirements, the assumptions

determined visually or with a pair of calipers. Individual fingers
should be between light three-quarter and full three-quarter
size. Over-sized fruit ripens rapidly and should be handled with
great care because the peel can easily split during handling, while
under-sized fruit will not ripen normally.

After determining the maturity, pallets are placed in the
ripening room and the air circulation system turned on. The
fruit is heated or cooled to the desired ripening temperature
(14°C-18°C; do not exceed 20°C pulp temperature during the
ripening cycle). Temperature controls the rate of ripening and
high temperatures will result in ‘green’ ripening, i.e. softening
of the pulp without de-greening of the peel. As soon as the
pulp has reached the set temperature, ethylene is introduced
into the ripening room with an ethylene generator or bottled
ethylene to maintain the levels at 100 ppm for a duration of 24
hours. After ethylene treatment, the room should be vented to
get rid of excess ethylene and CO₂. Thereafter, the rooms should
be vented at least twice per day for 20 minutes or continuously
with exhaust fans to keep the CO₂ levels below 1%. CO₂ levels
above 1% will inhibit the ripening process.

The fruit should be kept at the required temperature until
it has reached the desired stage of ripeness (firmness). Pulp
temperatures must be recorded throughout the room on a
daily basis and the relative humidity should be kept at 90-95%
throughout the ripening cycle. Once the fruit has reached the
desired ripeness, it should be cooled down to 14°C to slow down
ripening, and placed in a cold store at 14°C. Ripened fruit are
less prone to chilling injury than unripe fruit. Further ripening
after storage can be controlled by time and temperature. The
higher the pulp temperature, the shorter is the time required
to reach eat ripeness. The pulp temperature should never be
allowed to rise above 20°C during ripening. Please see Table 1.

<table>
<thead>
<tr>
<th>Ripening Schedule</th>
<th>First</th>
<th>Second</th>
<th>Third</th>
<th>Fourth</th>
<th>Fifth</th>
<th>Sixth</th>
<th>Seventh</th>
<th>Eighth</th>
<th>Ninth</th>
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<tbody>
<tr>
<td>4 days</td>
<td>18 ethylene</td>
<td>18</td>
<td>16.5</td>
<td>15.5</td>
<td>Store at 14.5</td>
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<td></td>
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<tr>
<td>5 days</td>
<td>16.5 ethylene</td>
<td>16.5</td>
<td>16.5</td>
<td>16.5</td>
<td>16.5</td>
<td>Store at 14.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 days</td>
<td>16.5 ethylene</td>
<td>16.5</td>
<td>15.5</td>
<td>15.5</td>
<td>15.5</td>
<td>14.5</td>
<td>Store at 14.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 days</td>
<td>15.5 ethylene</td>
<td>15.5</td>
<td>15.5</td>
<td>15.5</td>
<td>15.5</td>
<td>14.5</td>
<td>14.5</td>
<td>Store at 14.5</td>
<td></td>
</tr>
<tr>
<td>8 days</td>
<td>14.5 ethylene</td>
<td>14.5</td>
<td>14.5</td>
<td>14.5</td>
<td>14.5</td>
<td>14.5</td>
<td>14.5</td>
<td>14.5</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Fruit pulp temperature (°C)

Uneven Ripening

Uneven ripening in a box, pallet or load is a common
problem encountered in fruit that is ripened after harvesting.
The most common causes of uneven ripening are improper
ripening techniques, insufficient ethylene levels, incorrect
exposure time, incorrect ripening temperature, RH below
90%, temperatures above 21°C during ripening, improper air
circulation, excessive holding periods before the start of the
ripening cycle, variable fruit age, variable fruit maturity, wide
variations in pulp temperature upon arrival at the ripening
room, exposure to temperatures below 12°C prior to ripening
and exposure to extreme high temperatures prior to ripening
(heat damage).

Conclusion

Fruit ripening chambers are proliferating throughout
the country as the fruit handler community has realized the
importance of deploying a scientific method for ripening in a
cold room, exercising control over temperature, RH and gas
levels of ethylene, CO₂ and oxygen. A revolution has taken place
in this sector during last the five years, as ripening chambers
have reached even the smallest villages and farms. Refrigeration
engineers play an important role in setting up these facilities.

This sector has a vast potential for rural employment
generation. National Horticulture Board (NHB) offers handsome
incentives for setting up ripening and cold preservation chambers
for all fruits and vegetables and other agricultural produce.

Since it is a normal practice in India to hold potatoes for
considerable duration in storage, and the holding load
mentioned in the Standard (page 41) is 32.93kWx4 = 131.72
kW, I recommend selecting one compressor to meet the holding
load and a second compressor to meet the initial loading and
pull down load of 297.75 kW (429.47-131.72 = 297.75) instead of
selecting two compressors of equal capacity. Running one base
compressor at full load and the second with variable capacity
depending on the load, with capacity control arrangement
of either cylinder unloading or VFD, would give better power
 savings compared to two compressors of equal capacity.