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Thermal Audit of Ice Plant Using Ammonia (NH3) as Refrigerant

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Abstract: Industrial refrigeration places use a ton of energy these days, and its gone up a lot over the past few decades. That makes saving energy feel really important right now. Ice plants stand out because they depend so much on mechanical systems to cool things down. They are some of the biggest energy users in industry.

Ammonia gets used a lot in these plants as the refrigerant. Its got good thermodynamic stuff going for it, and zero ODP plus almost no GWP, which is why its popular. In this paper, there is a thermal audit from the Radhey Ice Plant. The goal was to figure out the refrigeration load and spot ways to cut down on energy use. They looked at heat coming in through walls, the roof, and floor. Used standards from ASHRAE and ISHRAE for that part. Also checked air sneaking in from outside and heat from lights or people inside. The current cooling load came out to 271.22 TR. That seems way too high. Mostly because there is no insulation on the walls, roof, or floor at all. Plus those big open areas let air infiltrate without control. And the way they run things is not great either, I think. To fix it, they suggest putting in elastomeric foam insulation, with a U value of 0.28. And plastic strip curtains too, as the main changes. Once those are done, the load drops to just 4.08 TR. Thats about a 98.5 percent cut. It feels drastic. Energy audits like this really help find waste in ice plants. The ideas are cheap to do, good for the environment, and could work in other places like this. Though some parts of the audit might have missed small things, it still shows a lot. The results confirm that energy audit is a highly effective tool for identifying and eliminating energy waste in ice plants. The proposed recommen-dations are economically viable, environmentally beneficial, and readily replicable in similar refrigeration facilities.

Keywords: Thermal Audit, Energy Audit, Ammonia Refrigeration, Energy Efficiency, NH_3 Refrigeration System.

I. INTRODUCTION

Over the past ten years or so, industries have been using way more energy than before. That makes saving energy a big deal to think about. Ice plants especially need a ton of electricity just to keep things cool. I mean, stuff like running things wrong or bad insulation lets energy slip away, and air sneaking in does not help either. Energy audits are basically checking how energy moves around in a place like that. The idea is to figure out how to make it all work better and waste less. For ice plants that use NH3 to cool, it matters even more because of the heat you have to pull out when ice forms. It seems kind of tricky there. This report covers a thermal audit we did at Radhey Ice Plant. The main goal was to guess the refrigeration load based on those ASHRAE and ISHRAE rules. We also wanted to spot where energy gets wasted and come up with fixes to cut down the cooling needs and running costs. NH3 works as a refrigerant since its pretty good at handling heat transfer. Plus, it has no ODP or GWP, which is zero for both. That part stands out as a smart choice, I think, though the whole setup could use some tweaks. Some inefficiencies just hang around without much notice.

II. LITERATURE REVIEW

Several researchers have investigated energy audit method-ologies and their applications in industrial refrigeration and cold storage facilities. [1] conducted an energy audit of a wheel manufacturing industry and demonstrated that systematic load analysis combined with insulation improvements can yield significant reductions in energy consumption. Their work highlights the importance of U-factor selection in minimizing heat transfer through building envelopes. [2] performed energy audits of food processing and bottling industries in Nigeria and established a direct correlation between poor thermal insulation and elevated cooling loads. They recommended the use of low-conductivity insulation materials as a primary intervention strategy. [3]presented an energy audit case study of an industrial site and emphasized the role of infiltration losses through doors and open spaces as a major contributor to refrigeration load. They proposed strip curtains and air locks as effective mitigation measures reviewed energy audit practices across multiple indus-trial sectors and concluded that a combination of building envelope improvements, operational scheduling changes, and equipment upgrades consistently delivers the highest energy savings. The Bureau of Energy Efficiency (BEE) Government of India [5], through its handbooks and ISHRAE guidelines, provides standard methodologies for cooling load estimation including solar and transmission heat gains, infiltration loads, and internal heat sources. These standard procedures form the basis of the calculations carried out in the present work. Based on the above review, it is evident that energy audit is a well-established and effective tool for identifying and eliminating energy waste in refrigeration-based industries. The present study applies these principles specifically to an ammonia-based ice plant to determine practical energy-saving opportunities.

III. COLLECTED DATA

By taking actual measurements of the ice plant, the follow-ing data was recorded:

1) Weight per can: 250 kg
2) Freezing time: 72 hrs
3) Total capacity: 200 tons
4) Brine temperature range: −13.33 to −10 ◦C
5) Ice can dimensions: 183 cm × 55 cm × 27 cm
6) Number of operators: 2 (normal); 8 (during ice removal)
7) Volume of cold storage: 2285.8625 m3
8) Area of roof: 312.778 m2
9) Area of floor: 294.95 m2
10) Area of open space: 46.3 m2
11) Area of wall: 571.25 m2
12) Instruments used: Thermometer, Anemometer, Hygrom-eter
13) Number of cans: 800
14) Humidity: 51.8% (inside); 47.8% (outside)
15) Temperature: 36 ◦C (outside); 29 ◦C (inside)
16) Wind speed: 2 m/s

IV. REFRIGERATION LOAD CALCULATIONS

A. *Solar Transmission Heat Gains*

The solar radiation that falls on the exterior surface of the building also affects the refrigeration load. Heat passes through the walls, roof, and floor of the ice plant due to the temperature difference between the internal and external envi-ronment. Thus, these loads have to be taken into account when estimating the cooling load. The formula for heat transfer is:

$$Q = A \times \Delta T \times U \qquad (1)$$

where,

Q = HEAT GAIN (BTU/HR)

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where,

- Q = Heat gain (Btu/hr)

TABLE I Design Data

Factors Reference (ISHRAE Handbook)	Value
Daily Range	15˚F (Page 1.5)
Temperature Differential Correction	−2˚F (Page 1.25)
U-factor for Wall (Brick)	1.25 (Page 1.21)
U-factor for Roof (Metal Sheet)	0.667 (Page 1.21)
U-factor for Floor (Concrete)	1.098 (Page 1.21)

- A = Area of surface (ft^2)
- ΔT = Corrected temperature difference (˚F)
- U = Overall heat transfer coefficient

B. *Design Data*

TABLE II
DESIGN DATA USED FOR HEAT GAIN CALCULATION

Parameter	Value
Outside Temperature	96.8˚F
Inside Temperature	84.2˚F
Temperature Correction Factor	-2˚F
Wall U-factor	1.25
Roof U-factor	0.667
Floor U-factor	1.098

B. *HEAT GAIN THROUGH WALLS*

TABLE III
HEAT GAIN THROUGH DIFFERENT WALLS

WALL DIRECTION	HEAT GAIN (BTU/HR)
NORTH WALL	29987.91
EAST WALL	9395.29
SOUTH WALL	32694.89
WEST WALL	1697.59
TOTAL WALL HEAT GAIN	73775.69

C. *Heat Gain Through Roof and Floor*

TABLE IV
ROOF AND FLOOR HEAT GAIN

COMPONENT	HEAT GAIN (BTU/HR)
ROOF	21001.72
LOOR	36951.35

D. *Total Solar and Transmission Heat Gain*

$$Q_{TOTAL} = Q_{WALL} + Q_{ROOF} + Q_{FLOOR} \quad (2)$$

$$Q_{TOTAL} = 73775.69 + 21001.72 + 36951.35 \quad (3)$$

$$Q_{TOTAL} = 131728.76 \text{ BTU/HR} \quad (4)$$

V. INFILTRATION OF OUTSIDE AIR

Air from outside having high temperature and humidity enters the refrigerated store because of opening and closing of doors when loading and unloading is being done, leakage from the windows and cracks on the walls. This will result in increased refrigeration load. Infiltration load comprises of:

1) Sensible Heat Gain
2) Latent Heat Gain

A. *Outside Air Sensible Heat Gain*

The sensible heat gain is calculated by:

$$Q_s = (\text{CFM}) \times 1.08 \times (T_o - T_i) \quad (5)$$

where,

- CFM = Air flow rate in cubic feet per minute
- T_o = Outside temperature (˚F)
- T_i = Inside temperature (˚F)

B. Calculation of Infiltration Air Quantity

Air quantity entering through open space:

$$Q = A \times V \tag{6}$$

where,

- A = Open space area = 46.3 m^2 = 498.369 ft^2
- V = Air velocity = 2 m/s = 393.72 ft/min

$$Q = 498.369 \times 393.72 \tag{7}$$

$$Q = 196217.84 \text{ CFM} \tag{8}$$

C. Sensible Heat Gain

$$Q_s = 196217.84 \times 1.08 \times (98.6 - 84.2) \tag{9}$$

$$Q_s = 3051579.89 \text{ Btu/hr} \tag{10}$$

D. Outside Air Latent Heat Gain

Latent heat gain is calculated by:

$$Q_l = (\text{CFM}) \times 0.68 \times (W_o - W_i) \tag{11}$$

where,

- W_o = Outside humidity ratio = 0.0175
- W_i = Inside humidity ratio = 0.013

$$Q_l = 196217.84 \times 0.68 \times (0.0175 - 0.013) \tag{12}$$

$$Q_l = 600.42 \text{ Btu/hr} \tag{13}$$

E. Total Infiltration Load

$$Q_{total} = Q_s + Q_l \tag{14}$$

$$Q_{total} = 3051579.89 + 600.42 \tag{15}$$

$$Q_{total} = 3052180.31 \text{ Btu/hr} \tag{16}$$

VI. INTERNAL LOADS

Internal loads are the heat gains generated inside the ice plant due to lighting systems, workers, motors, and other equipmer operating within the refrigerated space. These loads increase the refrigeration requirement and must be considered during c load estimation.

The major internal loads considered in this project are:

1) Lighting Load
2) Occupancy Load

A. Lighting Load

The heat produced by electric lights inside the plant is converted into sensible heat.

Typical lighting requirement for industrial areas:

- 1 to 1.5 W/ft^2
- 10 to 15 W/m^2

The lighting heat gain is calculated as:

$$Q_L = (kW) \times N \times F \times 3410 \tag{17}$$

where,

- *kW = Power rating of each tube light*
- *N = Number of light*
- *F* = Load factor

Given:

1) Power of tube light = 18 W = 18 $\times 10^{-3}$ kW
2) Number of tubelights = 27
3) Load factor = 0.8

$$Q_L = (18 \times 10^{-3}) \times 27 \times 0.8 \times 3410 \quad (18)$$

$$Q_L = 1325.81 \text{ Btu/hr} \quad (19)$$

4) *Occupancy Load*

Workers present inside the plant release both sensible and latent heat.

For normal room temperature (approximately 27°C or 82°F):

a. Sensible heat/person = 450 Btu/hr
b. Latent heat/person = 1000 Btu/hr

Total workers during ice removal = 8 persons

Heat gain due to occupancy:

$$Q_O = (450 + 1000) \times 8 \quad (20)$$

$$Q_O = 11600 \text{ Btu/hr} \quad (21)$$

5) *Total Internal Load*

$$Q_{internal} = Q_L + Q_O \quad (22)$$

$$Q_{internal} = 1325.81 + 11600 \quad (23)$$

$$Q_{internal} = 12925.81 \text{ Btu/hr} \quad (24)$$

TABLE V

Internal Heat Loads

Source	**Heat Gain (Btu/hr)**
Lighting Load	1325.81
Occupancy Load	11600.00
Total Internal Load	12925.81

VII. SAFETY FACTOR FOR TOTAL REFRIGERATION LOAD

A safety factor is added to the calculated refrigeration load to account for uncertainties in operating conditions, unexpected future load variations, and system inefficiencies. It ensures reliable and continuous operation of the refrigeration sy practical working conditions.

For this project, a safety factor of **5%** is considered.

A. *Calculated Heat Loads*

The total refrigeration load before adding safety factor consists of:

Table VI

Calculated Heat Loads

A. Load Component	*B.* Heat Gain (Btu/hr)
C. Solar and Transmission Heat Gain	*D.* 189681.83
E. Infiltration of Outside Air	*F.* 3052180.31
G. Internal Loads	*H.* 12925.81
I. Subtotal Load	*J.* 3254787.95

B. Safety Factor Calculation

Safety Factor = 5% of Total Load (25)

Q_s = 0.05 × 3254787.95 (26)

Q_s = 162739.40 Btu/hr (27)

C. Total Refrigeration Load

Q_{total} = 3254787.95 + 162739.40 (28)

Q_{total} = 3417527.35 Btu/hr (29)

D. Conversion into Tons of Refrigeration

$1\ TR = 12000$ Btu/hr

TR = 3417527.35 / 12000

TR = 284.79 *TR* (32)

E. Recommended Practical Load

Based on plant conditions and operational assumptions, the working refrigeration load may be considered approximately:

271.22 *TR* (33)

F. Present Condition

Based on the site survey and calculated refrigeration load, the following observations were made regarding the condition of the ice plant:

1) The calculated cooling load is significantly high due to large open areas in the ice plant, which allow heat to enter continuously.
2) There is no insulation layer on the walls, roof, and floor. This results in high heat transfer from surroundings to the refrigerated space.
3) Ice cans are placed between two storeys without thermal insulation, causing additional heat gain from the surrounding structure.
4) A higher number of workers inside the plant contributes to increased internal heat load due to body heat and movement.
5) Water filling inside ice cans is generally carried out during noon hours, when water temperature is comparatively high.
6) Water storage tanks are constructed below ground level, but they are exposed to direct sunlight because proper shading is not provided.

G. Proposed Modifications to Reduce Cooling Load

To improve plant efficiency and reduce refrigeration load, the following modifications are recommended:

1) Thermal insulation should be provided on walls, roof, and floor from both sides using **Elastomeric Foam**.
2) The thermal conductivity of Elastomeric Foam is low, and its overall U-factor is:

$$U = 0.28 \quad (34)$$

3) Elastomeric foam resists moisture absorption, prevents condensation, and is easy to install and maintain.
4) Plastic strip curtains should be installed at doors and open spaces to reduce outside air infiltration.
5) Water filling inside cans should preferably be done during night hours or early morning to reduce initial water temperature
6) Proper roof shading or shelter should be provided above underground storage tanks to avoid direct solar heating.
7) Worker movement inside refrigerated zones should be minimized by proper planning and faster handling methods.

H. Expected Benefits

TABLE VII
Expected Benefits of Proposed Modifications

Modification	Expected Benefit
Wall/Roof/Floor Insulation	Lower heat gain
Plastic Strip Curtains	Reduced infiltration load
Night Water Filling	Faster ice formation
Tank Roof Shading	Lower water temperature
Reduced Worker Exposure	Lower internal load

VIII. MODIFIED HEAT LOAD CALCULATIONS AFTER

Improvements

After providing insulation and reducing infiltration losses, the refrigeration load is recalculated.

A. Heat Gain Through Walls

Heat gain through walls is calculated using:

$$Q = A \times \Delta T \times U \quad (35)$$

where improved insulation material is Elastomeric Foam with:

$$U = 0.28 \quad (36)$$

TABLE VIII
Modified Heat Gain Through Walls

Wall Direction	Heat Gain (Btu/hr)
North Wall	6717.29
East Wall	2104.54
South Wall	7323.66
West Wall	380.26
Total Wall Heat Gain	16525.75

B. Heat Gain Through Roof

$$Q_{roof} = 8816.315 \text{ Btu/hr} \quad (37)$$

C. Heat Gain Through Floor

$$Q_{floor} = 9422.93 \text{ Btu/hr} \quad (38)$$

D. Total Solar and Transmission Heat Gain

$$Q_{surface} = Q_{wall} + Q_{roof} + Q_{floor} \quad (39)$$

$$Q_{surface} = 16525.75 + 8816.315 + 9422.93 \quad (40)$$

$$Q_{surface} = 34764.99 \text{ Btu/hr} \quad (41)$$

E. Infiltration of Outside Air

By installing plastic strip curtains of suitable thickness at doors and open spaces, outside air entry can be minimized. Hence, infiltration load is considered negligible.

$$Q_{infiltration} \approx 0 \quad (42)$$

F. Internal Loads

1) Lighting Load:

$Q_L = (18 \times 10^{-3}) \times 27 \times 0.8 \times 3410$ (43)

Q_L = 1325.808 Btu/hr (44)

2) Occupancy Load: For 8 workers:

Q_O = (450 + 1000) × 8 (45)

Q_O = 11600 Btu/hr (46)

3) Internal Load:

$Q_{internal}$ = 1325.808 + 11600 (47)

$Q_{internal}$ = 12925.808 Btu/hr (48)

G. 6. Safety Factor

A safety margin of 5% is considered.

H. Total Refrigeration Load

Qtotal = Qsurface + Qinfiltration + Qinternal + 5% (49)

Q_{total} = 49016.665 Btu/hr (50)

TR =49016.665 / 12000 (51)

TR = 4.08 TR (52)

IX. RESULTS

TABLE IX
Cooling Load Comparison

Condition	Cooling Load (TR)
Current Cooling Load	271.22
Estimated Cooling Load After Improvements	4.08

1) After installation of insulation and curtains, cooling load is considerably reduced.
2) Ice formation time will reduce from 72 hours.
3) Use of skilled labour can improve plant productivity.
4) Covering storage tanks with roof or shelter reduces in-coming water temperature.
5) Filling water into ice cans during night hours further reduces cooling time.

X. CONCLUSION

The proposed energy efficiency measures significantly re-duce cooling load and operating cost of the ice plant.
By implementing proper insulation, minimizing infiltration losses, and improving operating practices, the plant can oper-ate with lower refrigeration demand. This improvement is beneficial in both economic and envi-ronmental aspects. It reduces production time, lowers electric-ity bills, and increases overall plant efficiency.
Hence, the project is highly practical and can be replicated in similar ice manufacturing industries.

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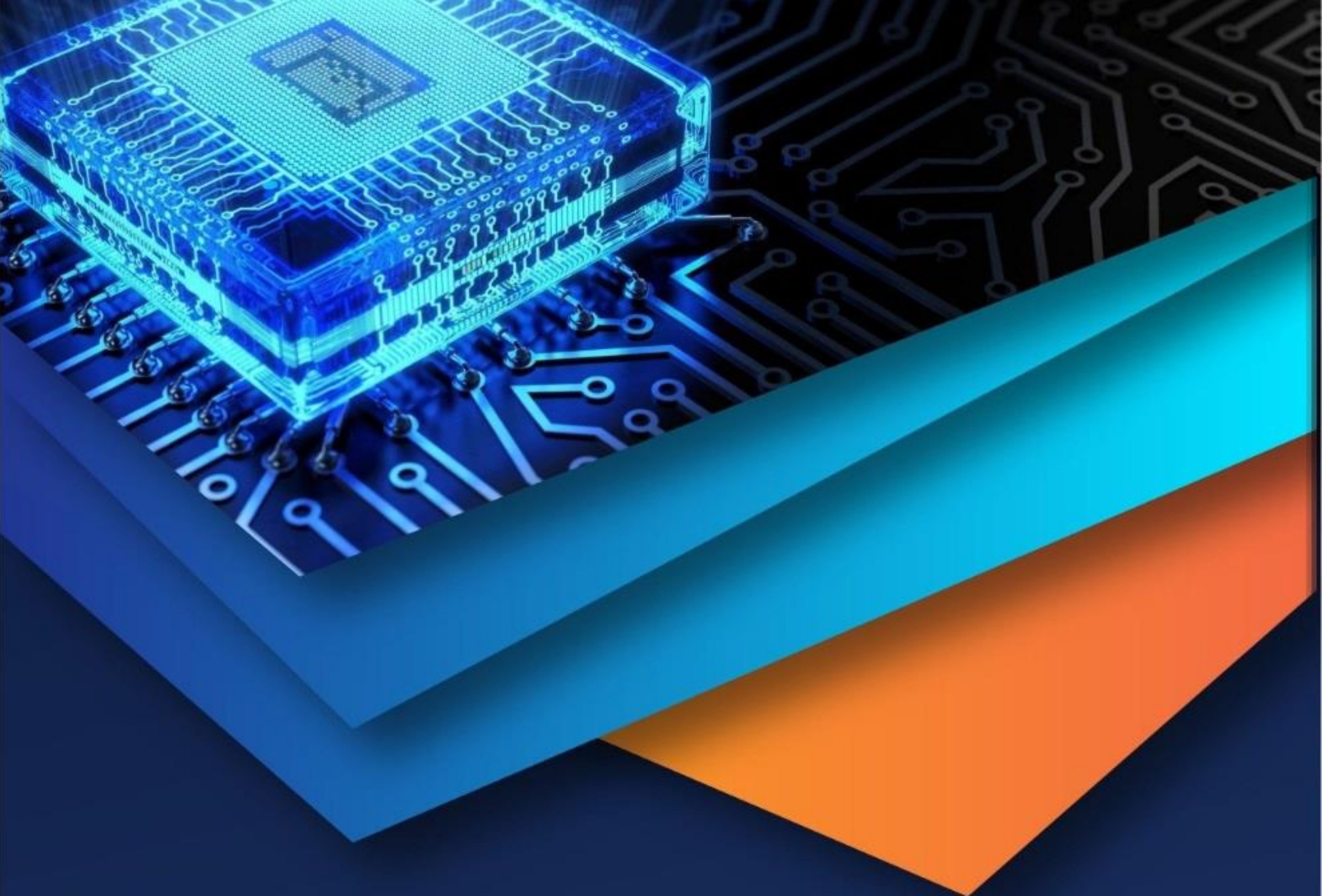

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