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Energy Performance Improvements in Indian Potato Cold Storages

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ABSTRACT

Energy conservation is crucial for sustainable development as well as for climate change issue. The Indian potato cold storages are responsible for significant energy consumption. The operation of these cold storages is very poor and their energy efficiency has always been ignored. The energy consumption in the storages can be minimized significantly only by considering simple energy saving measures. This paper presents the energy conservation opportunities in the existing cold storages by suggesting simple and appropriate measures for improving the performance of building and the refrigeration unit. A survey was conducted in a few potato cold storages in and around Indore City (22.71^{o}N, 75.91^{o}E) situated in a state Madhya Pradesh in India. The survey covered the building, refrigeration unit and operational parameters (e.g. indoor air temperature, relative humidity, building components and their construction details) as these are key parameters in the energy performance of the storage. During the survey, complete and reliable data was received only from the ten cold storages and, therefore, data has been analyzed and reported in this article. The description of the survey and methodology of data analysis have also been presented. The results objectively provide the preliminary information on the current energy consumption pattern and the energy saving potentials in the existing, and also valid for future, cold storages.

KEYWORDS: Energy conservation, Cold storage, Refrigeration, Energy efficient building

INTRODUCTION

Currently, in the light of energy crises, energy efficiency is crucial for sustainable development particularly in developing countries like India. The energy efficiency is also a key mitigation strategy for addressing climate change. With the urgency of climate change requiring both immediate and long-term actions and the volatility of energy markets, the importance of efficiently using energy throughout the world, including India, is clear. Increased prices of electricity and other fuels force industries and commercial buildings to reduce their energy consumptions and demands or to implement the means for conserving energy. Therefore, the need of the hour is to minimize the energy consumption and energy demand, which consequently reduces emissions at the thermal power generating stations.

In view of the energy conservation opportunities in industrial, commercial and residential sectors; one of important areas is cold storage industry, which needs to be addressed with immediate attention. Preservation of perishable commodities, like potato in the cold storage, is an energy intensive process and consumes significant amount of electrical energy. The proper and timely preservation of the perishable commodities is crucial for retaining their quality, natural flavor and for minimizing quantity degradations [1]. A sizeable amount (approximately 10-15%) of the total potato production is gone wastage every year due to shortage of the storage facility in the country [2]. Currently, available storage facility is sufficient only for 50% of the total potato production in the country [3]. Moreover, the poor operation of refrigeration units in the existing storage facilities not only increase the energy consumption but also responsible for poor quality of refrigerated product [4,5]. The Indian cold storages are mainly run on the grid electricity and their energy expenses account approximately 28% of the total costs [6]. However, continuous efforts are being made by researchers and engineers to improve the energy performance and indoor storage environment in the cold storages. Chourasia and Goswami have discussed a few important factors that influence the energy consumption in the potato cold storage along with possible options to improve the energy performance of the storage [7]. Hasse and Becker [8] studied the potential for energy savings by improving automation and control in the refrigeration system. Devres and Bishop [1] studied the energy consumption, using a theoretical model, in a real potato cold storage in the UK climate. Xie et al. [9] analyzed several design parameters such as corner baffle, the stack mode of foodstuffs for a minitype cold store and analyzed the parameters that affect the flow field in the storage. Marchant and coworkers [10,11]designed a part of an expert system controller by using artificial intelligent techniques to improve the indoor environment as well as the energy performance of the cold storage. Moreover, few researchers also suggested alternative refrigeration units, especially for the cold storages, which can be operated by the solar energy [12,13] and biomass energy[14].

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Despite of several advantageous studies in this area, the energy consumption pattern in the existing potato cold storages and the effects of the building parameters (e.g. aspect ratios, orientation, colour of exterior surfaces etc) and operational parameters have hardly been discussed in the literature. This article aims to present the energy consumption patterns in the existing cold storages and the impact of storages' building construction and design parameters and operation of refrigeration units on the overall energy use. The energy performance of the existing cold storages has been assessed based on the surveyed data collected from ten potato cold storages exist in and around Indore city located in central India. Furthermore, the energy conservation opportunities have been discussed considering the applicability of different passive, active and hybrid energy saving strategies.

METHODOLOGY

Study location

A survey was conducted in a few potato cold storages in and around Indore City (22.71^{o}N, 75.91^{o}E) situated in a state Madhya Pradesh in India. The city was considered as one of the special economic zones (SEZs) and has highest cold storage facilities in the region [3, 15]. Also, the demand of perishable products in the region is mainly regulated by the city. The city and close by area has approximately 52 cold storages and roughly 50% of the existing storage facility is used for potato storage only [3].

Data collection and analysis

A sample survey technique was adopted to evaluate the energy consumption pattern as well as energy conservation potential in the cold storages. A questionnaire was prepared and supplied randomly to a number of potato cold storages. A few responsible people at each of the surveyed cold storages were asked to answer all the questions stated in the questionnaire. The information was asked in the questionnaire specifically was on design and construction features of the storage buildings, potato storage patterns, monthly energy consumption and fuel type, frequency of use and capacity of refrigeration units. Also, the surveyed cold storages were visited physically a number of times for validating the information obtained in the questionnaire. Moreover, a few selected people for example owner, manager and operator were also interviewed for collecting information on technical, economic and social challenges in running the storages. However, only relevant information has been presented in this article.

All of the received questionnaires were examined carefully and only ten questionnaires, which had most of the desirable information and covers complete range of storage capacity, were analyzed. The storage capacities of the selected cold storages vary between 6000 tones and 15000 tones. The compiled data for the storages was analyzed qualitatively and quantitatively mainly in terms of electrical and building parameters. Results of the analysis have been presented and discussed separately in the following section.

RESULTS AND DISCUSSION

The selected cold storages for the analysis are used for potato storage only. The results have been presented and discussed in two following sub-sections:

Electrical parameters:

The cold storages are mainly run on electricity, which is supplied by the regional power distribution company. The power distribution company is paid for the total monthly supplied electricity. Therefore, at this stage, the monthly total energy usage in the storages seems to be appropriate parameter for analysis instead of component-wise energy usage. The annual average specific energy consumption in the surveyed cold storages were estimated and presented in Figure 1. One can easily observed from the figure 1 that the specific energy consumption in the storages varies between 9 kWh/tone and15 kWh/tone. The variation is significant and it can be appropriate to mention here that few of the cold storages are being operated energy efficiently and others are most inefficiently. Hence, a significant energy can be saved in the energy inefficient storages by considering appropriate energy conservation measures and their energy usage can be brought down in the level of the efficient one.

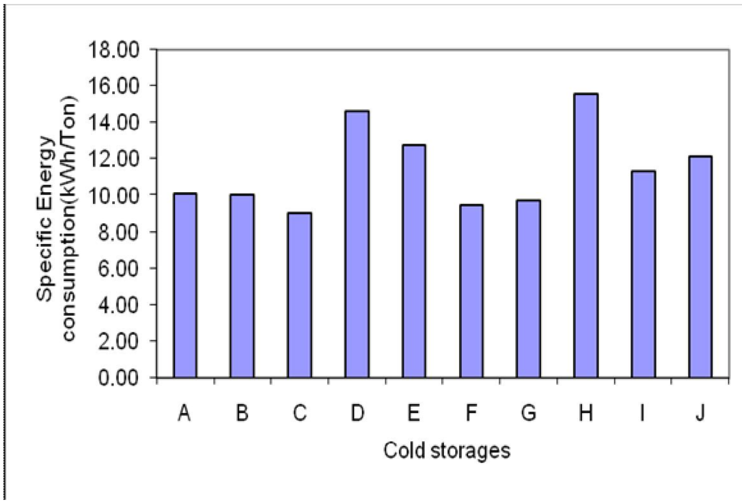

Figure 1 Annual average specific energy consumption

Contract Demand:

Besides total electrical energy consumption, demand and demand charges, power factor and surcharge for low power factor have also been considered in the analysis. A fix and significant amount of monthly electricity bills is charged for the consumer's contract demand. The contract demand basically is nothing else but the peak demand of the power. With an idea of expending the storage capacity in future, a few cold storages owners have acquired a higher contract demand than they actually needed. But, due to some financial and/or other constraints, they could not extend the storage capacities and are still operating the storages without reducing the contract demand to a desirable level. From the analysis it has been found that the consumers are supposed to pay for a minimum of 75% of their electricity contract demand whether they have not run the facility even for a single day in a month. .Also, the consumers those are having higher contract demand than the requirement obviously needs to pay more. For example, the needed contract demand of a consumer is only 100 kVA and actually he/she has contracted for 150 kVA. Now the consumer needs to pay for at least 112.5 kVA instead of 75 kVA. The analysis results show that a 50% of the surveyed cold storages falls under the higher contract demand category. It was suggested to the owners of this category to modify their contract demand to avoid the regular loss. Monetary saving potentials for the different cold storages on modifying contract demand are shown in Figure 2. The analysis can also be useful for the similar cold storages in the other regions.

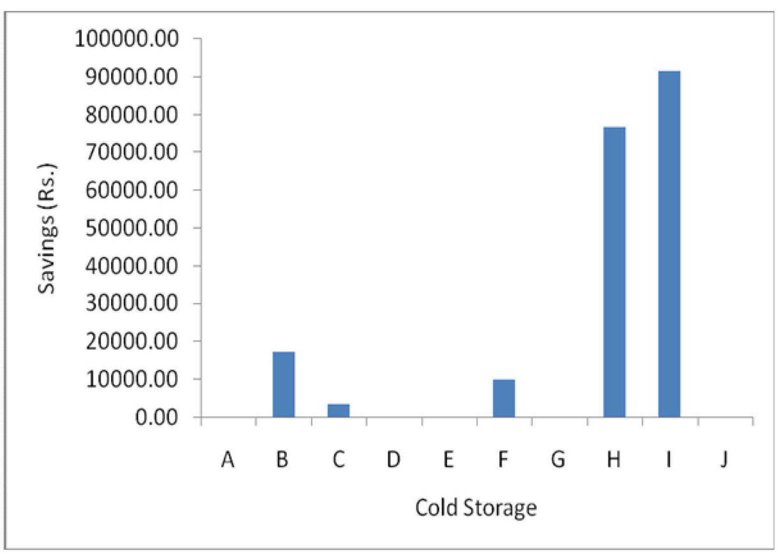

Figure 2 Monetary savings (Rs.) on modifying the contract demand.

Power factor:

Power factor (PF) is another important parameter for electrical energy efficiency. PF indicates the energy efficiency of reactive loads, such as induction motor. Most of the connected load in the cold storages is reactive type in the form of electric motors used to drive compressors, AHU fans and humidifiers and pumps. Therefore, PF upholding is most attentive in the operation. The power distribution companies provide incentives for high value of PF and a penalty is laid for lower PF value. Moreover, a higher PF save significant electrical energy directly.

Interestingly, analysis of the survey indicates that 90% of the cold storages are being operated with sufficiently high PFs. Only 10% storages have a lower PF value, which can be improved easily by installing desirable capacitors. Table 1 shows annual monetary saving potential and economic analysis for improving PF to a recommended level.

Table 1 Economic analysis for improving the Power Factor of cold storage

Code	Real Power	Existing P.F.	Improved P.F	Investment (Rs.)	Saving Rs/Year
E	82.06	0.84	0.91	400.00	22551.19

Building parameters:

Solar thermal load through the building envelop affect the energy consumption in the potato cold storage significantly. In general, factors that affect cooling energy demand in the cold storage building include thermal gain through conduction and infiltration through cracks and openings in the buildings. The heat gain into the building depends on aspect ratio of length, width and height, envelop orientation, exterior colour, construction patterns of opaque components and construction materials as well as shape of the buildings [16-20]. All of these parameters have been covered in the survey. The aspect ratios and orientations of the surveyed cold storages are given in Table 2.

Table 2 Aspect ratios and orientations of building envelope of cold storages

Cold storage	Chamber	W/L	H/L	Orientation
A	1	0.44	0.10	E-W
	2	1.06	0.75	E-W
B	1	0.63	0.43	E-W
	2	0.77	0.46	N-S
C		1.00	0.64	N-S
D		0.40	0.20	N-S
E		0.91	0.59	E-W
F	1	0.68	0.27	E-W
	2	1.00	0.42	E-W
G	1	0.18	0.09	E-W
	2	0.43	0.24	N-S
	3	0.60	0.44	N-S
	4	0.65	0.25	E-W
H		0.37	0.21	E-W
I		0.80	0.33	E-W
J		0.80	0.33	N-S

Results indicate that there are no any specific criteria for selecting the optimum aspect ratio and orientation of the cold storages for least thermal load. The optimization of the cold storage building in terms of the aspect ratio and the respective orientation needs to be done for lowest solar thermal load. The colours of exterior surfaces, which directly exposed to the outdoor environmental conditions, influence the solar heat absorbed by the surface and total heat transfer to the indoor depending on their reflectance and absorptance. The buildings of the surveyed cold storages have been found either painted mainly by white, light yellow colours or left unpainted. However, none of the clear cut observation could be made. The buildings have either been painted fully by a single colour or surfaces of different storage chambers of a cold storage have been painted by different colours. Percentage-wise distribution of the storages painted by different colours is summarized in Figure 3. The first three storages (A, B and C) were found painted white, F was partially yellow and partially white, H was partially painted and rests of the buildings were painted yellow. A similar construction pattern of the building walls and roof in all cold storages have been observed. The buildings have mainly been constructed by bricks, and RCC. The walls and roof consist a number of layers with varying thicknesses of different construction materials. A common construction pattern and thicknesses of different construction materials in the walls and roof are given in Table 3.

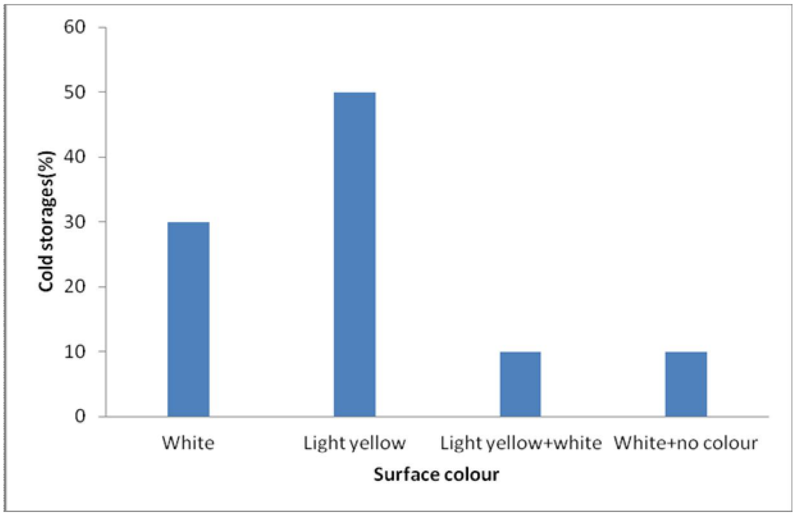

Figure 3 Summary of exterior colour of the surveyed cold storages

Table 3 Thickness of construction material and layers arrangement for roofs and walls

	Thickness(in meters)								
	Plaster	**Wood powder**	**Brick**	**Tarcol sheet**	**Plaster**	**Thermocole**	**Iron net**	**Plaster**	**Wood**
Roof	-	0.2032	-	0.004	-	0.1016	0.003	0.038	0.038
Walls	0.0254	-	0.356	-	0.0254	0.0762	0.003	0.038	-

A cheaper and easily available insulating material has been used in the building. It has been observed from the survey data that the thicknesses of different layers of construction materials and their arrangement in walls and roof are almost similar for all the chosen cold storages. Only conventional construction materials have been used in the construction. However, various new energy efficient construction materials are available in the market that can be used to reduce the energy consumption in the storages.

Energy conservation options in buildings:

The energy conservation in the building sector is now getting more attention throughout the world in regards to protect earth's environment. Building's energy efficiency is highly dependent on various building parameters described previously in this article. Various energy saving options have been observed in the analysis of surveyed data. A few options can be implemented immediately and other can only be incorporated effectively at the time of planning and development stage.

For immediate implementation:

- The exterior surfaces are painted by different colours without taking the advantage of high reflection properties of the colours. The energy consumption can be reduced significantly by selecting the colour of exterior surface appropriately [21]. Nearby plantation and other shading of building might be effective options for immediate improvement in energy efficiency as well as for minimizing the worst environmental effect [22].

For planning time considerations:

- It has been observed from the analysis results that none of the building have been found optimally designed and constructed in terms of the aspect ratios and the orientation for least solar thermal load. As discussed by some authors, the aspect ratios and the respective orientation play major role in the energy efficiency of the building. The overall energy consumption can be minimized significantly by choosing the optimum aspect ratios and the respective orientation [20].
- The construction materials have been used in the cold storages are conventional and have not been arranged in any specific manner. The thickness different materials needs to be optimized [17].
- It has also been observed during the survey that none of the passive features were incorporated in the building for minimizing the energy consumption. However, many building researchers have explored the energy conservation potential of the passive cooling techniques in different types of buildings and a significant energy consumption has been reduced by implementing them in the building envelops [23-29].

Refrigeration unit*:*

Refrigeration units are installed to provide the desirable indoor environment (temperature and humidity) for the potato preservation in the cold storage. In Indian cold storages, a vapour compression refrigeration system is used mainly for refrigeration. The vapour-compression refrigeration system includes a reciprocating compressor, a condenser, a receiver, an expansion valve and an evaporator. The nominal cooling capacities were installed in the surveyed cold storages for the extended hours of operation. Two types of air handling units i.e. i) bunker type and ii) fan coil units (FCUs), have been installed for supplying cold air in the storage space (Figure 4). About 80% of the storages have the bunker type units and 20% have the fan coil units. The air handling unit is placed just below the ceiling in the storages chambers. The AHU cools and re-circulates the indoor air continuously. Besides heat, the stored potato releases CO2 in the respiration process and needs to be removed after a certain interval. Therefore, the indoor air is replaced completely by fresh outdoor air every day in the morning hours (at the time of minimum outdoor ambient air temperature) [30].

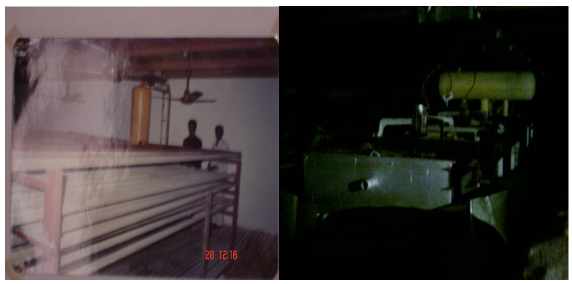

Figure 4 Air handling unit a) Banker type b) Fan coil unit

Energy conservation options in refrigeration units:

In the literature, various energy-saving measures for refrigeration have been presented, however, only a few of them can be applied in the Indian cold storage industry. Some of the important energy saving measures are presented below:

1) It was observed that the temperature and the humidity measurements and the compressors on-off system are maintained manually in most of the cold storages. The manual control might be inefficient and inaccurate, which may result in higher energy use and significant weight loss of the stored produce. Also, the control system usually may impair the performance of the machine, reduce the effective life of the compressor and other attached components and also increase the power consumption. Therefore, automatic and adequately operation controlling of the refrigeration system and other environmental parameters can be helpful to reduce the energy consumption significantly [31].
2) Use of sub-cooling system: Sub-cooling of the refrigerant in a simple vapor-compression refrigeration system may improve the coefficient of performance (COP) of the system and eventually lower the energy use [32].

Conclusion:

A survey of the 10 potato cold storages has been conducted to explore the energy saving potentials. The analysis of the survey data indicates that the specific energy consumption in the cold storages vary between 9 kWh/tone and 15kWh/tone. The variation in the specific energy consumption is significant and could be a results of unlike and poor operation of the refrigeration system, and variation in the building aspect ratios, orientation and other parameters. Based on the literature, a few most effective energy saving measures have been suggested to be made for immediate as well as for long term improvements in the energy performance of the cold storages.

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