ADVANCEMENT OF SOLAR REFRIGERATION TECHNOLOGY AND ITS IMPACT IN SOCIETY

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Refrigeration is, presently, not a luxurious rather an essential usage in daily life. Apart from comfort, green vegetables as well as seasonal fruits, dairy products and life saving drugs spatially vaccines can be preserved even at the remote area where there is no scope for grid facility. This paper approaches to high performance and eco-friendly Refrigeration system to meet the surface demand as well as maintain of steady grown up village market economy.

Introduction

Modern refrigeration and air-conditioning technologies are also associated with environmental problems like green house gas (GHG) emissions in residential and commercial buildings. Such emissions at source contribute directly through refrigerant leakage and application of fossil fuel based electricity to power the systems. Air-conditioning (AC) at present is not considered as a luxurious item (India’s per capita income\(^1\) doubled in seven years from Rs.63.5 K to Rs.1.25 lakh) though the cost of electricity required for maintenance is gradually enhanced. Thus, it is estimated that 15 per cent of global population has provision for use refrigeration or fridge providing comfortable indoor temp. and high indoor air quality at the cost of 20 per cent of global energy\(^2\). In many regions, AC is increasingly becoming humanitarian necessity amidst increasing global temperature. In India, in 2015, for example, more than 2,300 people died due to worst heat wave circulated in air. Thus, rapid increase in social demand for AC machines globally at the present decades will cause further climate damage unless taken some steps to reduce direct and indirect impacts on AC usage. In this paper, we are to locate how new paradigm of technology be adopted into two main groups depending on the energy supply: a climate impact through increased energy efficiency. In short, solar cooling technology\(^3\) renovates as the following:

- **Thermal / Work Driven System**
  - Absorption refrigeration cycle;
  - Adsorption refrigeration cycle;
  - Desiccant cooling cycle;
  - Ejector refrigeration cycle;

- **Electricity (photovoltaic) Driven System**
  - Vapor compression refrigeration cycle;
  - Thermo-electric refrigeration cycle;
  - Stirling refrigeration cycle

**New Approach Towards Low Carbon Technology**

- Substantial use of refrigerant in the segment of refrigeration or fridge tending significantly to the sustainable ecological improvement.

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Design of Development Scenario of Solar Refrigeration Technology

The thermal fossil fuel driven refrigeration system has a general efficiency of about 35% on average and leads to large volumes of greenhouse gas emission. This review is related to advances in solar refrigeration in which Li-Br and water was the best suitable pair for absorption of refrigeration process. Also refrigerant water (H₂O) has zero ozone depletion and very low global warming potential (GWP). With a view to this context, numerous researchers have proposed solar powered air-conditioning / cooling systems which consists of two types:

a. Photovoltaic (PV) conversion;

b. Photo-thermal conversion

Similarly, we choose herein the combination of above two systems (shown Fig.1) using a green absorbent which is supposed to be economical. The advantage of photovoltaic cooling fraction standardizes to opt 12 per cent greater than the thermal cooling fraction.

Thus, the advantage of using this design is predominantly non-toxic and environmentally sound working fluids such as water or salt solution can be used as standalone system. Moreover, the process of cooling can be provided by both active and passive systems. At least 4-different established technologies are used to realize solar cooling:

- Vapor Compression;
- Absorption-based cooling;
- Evaporative cooling;
- Solar ejector cooling

Vapor Compression Refrigeration: The advantage of this system absorbs heat from the space to be cooled and subsequently dissipates that heat outside the system. Herein, solar energy is absorbed in a solar collector and use of mechanical power is to transfer to dc compressor. This system apart from energy consumption has some negative impact on the environment. As a result of their usage of chlorofluorocarbon (CFC) or hydro-fluorocarbon (HCFC) as refrigerants induce ozone depletion and consequently immerse on greenhouse effect. In search of sustainable energy utilization technologies, the absorption system considerably appears as an alternative way to reduce consumption of electricity and CFCs. Absorption cooling machines can be powered by solar energy and system waste heat to save energies.

Absorption Cooling: During the daytime pick hour’s solar energy eventually absorbs through collector, evaporator and condenser. The sunlight heats the collector and the absorbent thereby releases absorbed water, producing water vapor which is precipitated in the condenser due to low pressure. At night, the collector cools absorbent becomes ready to absorb water vapor again. Since the phenomenon of evaporation consumes thermal energy the temp. of cooling chamber drops. This way, absorption process allows cooling the chilling chamber at night. During the day, absorbent is regenerated by using solar radiation to safeguard cooling capacity of the machine. Sometimes back it includes LiBr-H₂O as absorbent, which increases the risk of crystallization makes it hard to be air-cooled and ammonia liquor may be replaced which is less corrosive also.

Evaporative Air-cooling: This means direct air cooling, indirect air cooling and combination of both with other technique. Indirect evaporation cooling devices undergoes water to evaporate directly from water spray component into air. The evaporation extracts thermal energy from environment, corresponds to the decreased temperature. In addition, evaporated water may humidify the environment. In case of using indirect evaporative cooling devices, water evaporates into so called heat exchanger
which cools air flowing in an air stream. Evaporative cooling devices as such do not require solar energy however; they may use solar energy for heating the surface of a pan containing water in order to increase evaporation rate.

**Solar Ejector Cooling (SEC):** This is definitely an alternative technology having good load behavior as well as high co-efficient of performance (COP). Water is used here as refrigerant which is harmlessness and good thermal conductivity. Moreover, it is used as heat transfer fluid; an ‘open’ system can be designed without hydraulic separation between solar collector, SEC and chilled water supply system. Objectives are to share experimental knowledge for changing the operational conditions, analysis of economic aspects and the possible efficiencies of the system.

At present, Solar driven Ejector Cooling (SEC) has been only studied. The SEC is assessed in operation because of its simplicity in design and in construction but it has a moderate nominal COP value. The use of conventional refrigerators enables the SEC operation with heat at a low temp. can be provided by flat plate collectors (shown in Fig. 2)

Schematic of ‘refrigeration’ depicts in Fig. 2, solar combined power/cooling is to be added with the original system so that the new system is subjected to be functioned with solar at source and alternatively with conventional source, when will be needed.

![Schematic of a PV powered refrigerator in remote village](image)

**Fig. 2:** Symmetric Configuration for a PV powered refrigerator in remote village

![Graph of solar radiation intensity vs. daytime](image)

**Fig. 3:** Curve between the solar radiation intensities and daytime

The latest understanding on technological renovation includes thermal fossil fuel driven refrigeration that has a general efficiency about 35% on average and leads to large volume of greenhouse gas emissions. But the solar driven refrigerator, in which, use of refrigerant like water (H₂O) has zero ozone depletion and very low global warming potential. Thus, solar based refrigerator system will be the best potential for well acceptance of effective technology in remote villages like Jhapandanga at Burdwan, Kaikhali at 24 Parganus (S) and Kutilpara village at Dankuni coal complex area under Hooghly where there is long absence of conventional grid system. Right from the conventional data, it may state that in India, average solar isolation is 5.5 KW/m²/day over nearly 60 per cent of landscape is most abundant for non-polluting source for the operation of such facilities. In order to satisfy the second law of Thermodynamics herein, some form of work must be performed to accomplish mechanical work which is traditionally done by applying conventional electricity or other means. However, three basic operation of heat transfer have been performed: Convection, conduction and Radiation in the process. The performance of PV module in terms of its current—voltage and power – voltage characteristics, principally depends on the solar radiation and module temperature.
Methodology

The approaches are based on as follows:

a. Data Analysis: Collection of demand data on the basis of per capita income growth, meteorological data and the hourly, monthly and annual solar radiation processed;

b. Cooling Load Calculation: Determination what kind of cooling and how much cooling are needed;

c. Design and Sizing of the AC System: Using selected design conditions the components of the system can be sized;

d. Optimization of the System: Use of least cost energy so designed system is to be optimized with that in mind;

e. Performance Evaluation and Economic Analysis: The economic effectiveness of the system will be evaluated. The lifecycle costs for solar cooling system is calculated and competitiveness with regards to price and thermal efficiency for domestic applications determined;

f. Analysis of Result and Possible Solution: The results will be analyzed and possible solution is found out. Options for improving technical effectiveness will be tentatively suggested. Ways of improving research and development (R&D) in the field were also investigated.

Use and Abuse of Types of Inorganic Sample as Refrigerant

i) Uses of ammonia in refrigeration and heat pumps are generally safe and profitable refrigerant. This is rare compared to risk in the society which pronounce ammonia as very dangerous and frightening as ammonia has very pungent smell. As a refrigerant, ammonia is unsurpassed and it has excellent thermodynamic qualities that also have environmental advantages. In other sides, all life is dependent on recirculation of nitrogen in which the breaking down of natural substances to ammonia (NH₃). However, ammonia in anhydrous form uses as refrigerant.

ii) Carbon dioxide based refrigeration is currently the best option for the global needs. Our coolers and AC machines, CO₂ is safe and non-hazardous and its Global Warming Potential (GWP) is dramatically less than hydro-fluro carbon (HFC). They are more better than hydro chloro-fluoro carbon (HCFC) as they do not deplete the ozone layer.

Phasing Out Harmful HFCs: Refrigeration is a significant and growing source of GHGs. According to the European Parliament Directive 517/2014 the use of refrigerants with high Global Warming potential (GWP) has to be reduced. Among the Hydrofluoro carbons the use of R152a seems to be a promising choice because of the low GWP which is lower than 150. Only the flammability problems have to be faced in order to establish it. The use of CO₂ seems to be a promising choice for the future, especially with the modified system with parallel compression, sub-cooling and Ejector devices. In 2010, the growing climate impact of the refrigeration system used the low carbon technology to replace HFCs were unproven and so the new approaches to refrigeration from 2015 onwards. With this orientation towards sustainability and the necessary innovation dynamics, we succeeded in seeing new-technological standards in the segment of commercial market of refrigeration and freeze which have contributed significantly to the substantial ecological improvement of the various foods in retail sector. The existing studies show high performance and good compatibility with the existing installations. Therefore, there is a need for deeper investigation of this working fluid. In this direction, this study is a detailed analysis of a cooling system with R152a in order to determine its performance.
and its cooling capacity in different operating conditions. The novelty of this investigation is based on the different examined operating scenarios and on the development of a regression model for the prediction of the system performance.

To save the cost and bring down the AC prices sometimes back aluminum condenser is preferred to use which was though cheaper but corrosive faster and difficult to repair. In time and then it is needed to change which replaces to copper condenser. Next comes to the dynamics of inverter which needs compressor to change the magnitude of power. With this technology, compressor always on but draws less power or more power, depending on temp. of incoming air and level set of thermostat. R-410 refrigerant is thus eco-friendly. Even, R-410A can use which absorb and release more than conventional refrigerant reducing more risk of compressors.

We are proposed to develop a more cost and power efficient solar power based thermolectric refrigeration system which can store vaccine at a temp. range of 2 to 8°C.

**Economic and Social Impact**

Ongoing consumer demand for new fruits and vegetables in developed countries has contributed to an increase in trade volume of fresh production in developing countries. This, in turn, has promoted the growth of small farms and the addition of new products, creating more rural and urban jobs and reduced the disparities in income levels among farms of different sizes. As countries like ours become wealthier, their demand for high-valued commodities increases. The effect of income growth on consumption is more pronounced in developing countries. Thus, the paper reveals as the promising future in the coming decades. This is only possible for upgrading the cooling technology that is circulated air uniformly in multi-directional vents. Thus, stored food items remain fresh longer with the said designed airflow system.

**Environmental Impact**

In the recent studies, solar panel produces solar power which is stored in underground reservoir and then pumped out to the over head water tank so that kinetic energy is transformed to potential energy. To generate power micro-hydel machine with high pressure will be switch on by solar radiation thus water will be turned into electricity which will also be low-impact refrigerants blends as well as cost- effective. In addition, using of ammonia is better for the climate and more energy efficient and less leakage.

The properties of refrigerant, use of inverter and compressor in clean and eco-friendly absorbent may be used in nature. The demand and the supply of solar radiation are almost in phase with each other. But the intensity of solar radiation changes periodically and even becomes none at night, then the solar refrigeration cycles to be able to steadily run is of great importance. Dennis proposed a solution which installed a cold storage indoors for the solar cooling system which cannot provide nocturnal refrigeration. In order to relieve the impact of short-period cloudy weather, Henrik thought that it might be useful to store part of the regenerated solution and the refrigerant separately. Xu presented a new solar powered absorption refrigeration (SPAR) system with advanced energy storage technology. The energy collected from the solar radiation was first transformed into the chemical potential of the working fluid and stored in the system. The proposed system can solve the problem of the unconformity between solar radiation and cooling demand. Liu presented an innovative concept for a long-term energy storage system. The solar energy is absorbed and stored in the summer through the analytic function, and release heat in winter through the adsorption.

**Conclusion**

At the outset, solar energy is no doubt, an ideal source for low temp. application due to sustainability prospective. This source is attractive because of its universal availability of low environmental impact and no ongoing fuel cost. The use of solar energy is absorbed on a surface providing a heating potential on refrigeration system. The Peltier effect uses electricity to pump heat directly. Thus, refrigerators allows to keep food products, milk and fruit products, vegetables and drugs like vaccines etc. can be kept refrigerated long from poisoning. Thus, the temp minimization under restricted conditions is done that total entropy of the system and its environment is maximized in equilibrium. This leads to increase in power consumption which in turn leads to more PV cells, more thermo-electrics for obtaining the desired temperature range thereby increasing overall cost of the system. It is also endeavouer to solve this problem by working on a high efficiency, low cost thermoelectric refrigeration system. Also it is being tried to bring down the size of solar PV used thus making system more portable. The LED (consume 20 times less power) in place of GI bulb may be used to emit 10
Table -1: Per Capita National Income Growth

<table>
<thead>
<tr>
<th>Financial Year</th>
<th>Annual Growth (%)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013-14</td>
<td>11.9</td>
<td>India’s per capita income will cross $1800 where China’s is over $ 8,000</td>
</tr>
<tr>
<td>2014-15</td>
<td>11.5</td>
<td></td>
</tr>
<tr>
<td>2015-16</td>
<td>9.5</td>
<td></td>
</tr>
<tr>
<td>2016-17</td>
<td>9.3</td>
<td></td>
</tr>
<tr>
<td>2017-18</td>
<td>9.6</td>
<td>Per capita income is double in seven years from Rs. 63.5 K to Rs. 1.25 Lacs.</td>
</tr>
<tr>
<td>2018-19</td>
<td>8.6</td>
<td></td>
</tr>
<tr>
<td>2019-20</td>
<td>11.1</td>
<td></td>
</tr>
</tbody>
</table>

(NSSO data, G.O.I, 2018)

It depicts from Table-1 that per capita national income is high up means life happy index (LHI) improves gradually. Thus, the demand for comfort life like use of Refrigeration/ Air-conditioning has been increasing. This phenomenon is alike with other developing countries like China, Brazil and Middle-East countries in particular where possibly hot and humid climates exist, Gross domestic product (GDP) is also increasing in those nations and thus, increasing demand of AC to millions of people who may afford the system. By 2050, an estimated data under business-as-usual scenario highlights AC demands in non-OECD countries will increase global AC energy consumption by 2.5 times.

Table -2: Mean Daily Duration of Sunshine Hours in Metro Cities

<table>
<thead>
<tr>
<th>Station</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tiruvananthapurum</td>
<td>9.0</td>
<td>9.3</td>
<td>9.3</td>
<td>8.4</td>
<td>8.1</td>
<td>7.5</td>
<td>7.0</td>
<td>7.7</td>
<td>7.9</td>
<td>8.1</td>
<td>8.2</td>
<td>9.1</td>
</tr>
<tr>
<td>Bangalore</td>
<td>9.4</td>
<td>10.4</td>
<td>10.1</td>
<td>10.1</td>
<td>9.5</td>
<td>8.3</td>
<td>7.5</td>
<td>7.2</td>
<td>7.5</td>
<td>8.3</td>
<td>8.6</td>
<td>8.8</td>
</tr>
<tr>
<td>Chennai</td>
<td>9.3</td>
<td>10.3</td>
<td>9.8</td>
<td>10.3</td>
<td>10.1</td>
<td>9.3</td>
<td>8.9</td>
<td>8.7</td>
<td>8.9</td>
<td>7.6</td>
<td>8.3</td>
<td>8.2</td>
</tr>
<tr>
<td>Hyderabad</td>
<td>9.9</td>
<td>10.2</td>
<td>9.4</td>
<td>10.4</td>
<td>10.5</td>
<td>9.3</td>
<td>7.9</td>
<td>7.8</td>
<td>8.3</td>
<td>8.9</td>
<td>9.8</td>
<td>9.4</td>
</tr>
<tr>
<td>Mumbai</td>
<td>10.0</td>
<td>10.3</td>
<td>10.3</td>
<td>10.3</td>
<td>9.9</td>
<td>8.7</td>
<td>6.0</td>
<td>6.2</td>
<td>8.0</td>
<td>9.3</td>
<td>10.2</td>
<td>9.7</td>
</tr>
<tr>
<td>Kolkata</td>
<td>8.4</td>
<td>9.0</td>
<td>8.1</td>
<td>8.8</td>
<td>9.1</td>
<td>8.5</td>
<td>7.3</td>
<td>7.0</td>
<td>7.4</td>
<td>8.4</td>
<td>8.8</td>
<td>7.9</td>
</tr>
<tr>
<td>Ahmedabad</td>
<td>10.0</td>
<td>10.7</td>
<td>10.1</td>
<td>11.2</td>
<td>11.4</td>
<td>10.0</td>
<td>7.6</td>
<td>6.9</td>
<td>8.6</td>
<td>10.1</td>
<td>10.1</td>
<td>9.7</td>
</tr>
<tr>
<td>Varanasi</td>
<td>8.9</td>
<td>8.6</td>
<td>8.4</td>
<td>9.0</td>
<td>9.0</td>
<td>8.9</td>
<td>6.2</td>
<td>8.2</td>
<td>8.3</td>
<td>8.2</td>
<td>8.0</td>
<td>7.4</td>
</tr>
<tr>
<td>New Delhi</td>
<td>8.7</td>
<td>8.7</td>
<td>9.0</td>
<td>9.7</td>
<td>9.7</td>
<td>9.4</td>
<td>8.4</td>
<td>7.8</td>
<td>8.6</td>
<td>9.6</td>
<td>9.7</td>
<td>8.1</td>
</tr>
<tr>
<td>Patna</td>
<td>6.5</td>
<td>8.2</td>
<td>8.1</td>
<td>8.7</td>
<td>8.6</td>
<td>6.4</td>
<td>4.2</td>
<td>4.5</td>
<td>5.0</td>
<td>7.1</td>
<td>7.3</td>
<td>6.4</td>
</tr>
</tbody>
</table>

(Source: MNRE, Govt. of India)

Table -2 indicates the solar isolation to different major metro cities of which Tiruvananthapurum in South India is too some extent high while Patna is comparatively low. Thus the provision for using solar powered refrigeration system will be beneficial for remote places of Ahmedabad, Varanasi, Mumbai, Hyderabad, Channai etc. This paper will bring much social impact to those areas as proven technological advantage.

Table- 3: Data Analysis Solar Refrigerator Versus Conventional Refrigerator

<table>
<thead>
<tr>
<th>Year</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yr.</td>
<td>(0)</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
</tr>
<tr>
<td>Initial System Cost; for Refrigerator (Rs.)</td>
<td>30,950</td>
<td>Running Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Running Cost for conventional Refrigerator(Rs.)</td>
<td>4,818</td>
<td>5,083</td>
<td>5,363</td>
<td>5658</td>
<td>5970</td>
<td>6299</td>
<td></td>
</tr>
<tr>
<td>Cumulative Running Cost (Rs.)</td>
<td>4,818</td>
<td>9901</td>
<td>15,264</td>
<td>20,922</td>
<td>26,892</td>
<td>33,191</td>
<td></td>
</tr>
<tr>
<td>Payback Cost (Rs.)</td>
<td>26,132</td>
<td>21,049</td>
<td>15,686</td>
<td>10,028</td>
<td>4,058</td>
<td>2,241</td>
<td></td>
</tr>
</tbody>
</table>

Note: Calculation of Payback Cost of Solar Refrigeration System
times lesser heat means food items would remain much more immune to temp. swing owing to this lighting arrangement. Thus, cooling need is one of the appealing in refrigeration technology. With the above purview, we can conclude that ACs are now perceived as an essential appliance even in the middle and low income families.

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References

1. N.S.S.O., Statistical Data, Govt. of India, 2014
2. R. Ciconkov, Refrigerants. There is still no vision for sustainable solutions. Int. J. Refrig., 86, 441–448. [Google Scholar] [CrossRef], 2018.


