PRACTICAL STUDY ON DESICCANT AIR CONDITIONING SYSTEMS IN SUPERMARKETS

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ABSTRACT

Desiccant air conditioning systems as one of heat activated heat pumps are commercially in operation. The desiccant systems are valuable tools for waste heat utilization. This paper deals with operating experiences of the desiccant systems combined with waste heat recovery in the field of supermarket. In comfortable air conditioning and energy saving points of view, humidity is important factor. In the supermarket, low temperature zone, so called "cold aisle" remains in front of refrigerated display cases. The desiccant systems eliminate the cold aisle by controlling humidity independently. Also, frost forming on frozen products and refrigerated display cases are improved. Influences of the humidity level for energy savings are discussed. Working fluids of the desiccant systems is air, which relates to indoor air quality (IAQ). Increasing ventilation air increase the level of humidity, therefore, by using sequencer, it offers ventilation air volume control effectively. Improvement of the air quality is also examined as sanitizing effects. Since Japanese climate condition in summer is relatively higher temperature and higher humidity, the desiccant technology should be the key for optimum air conditioning.

Key Words: ***desiccant, heat activated, waste heat, air conditioning, cold isle, IAQ, supermarket***

1 INTRODUCTION

Desiccant cooling and dehumidification systems are currently used to meet saving energy, upgrading indoor air quality and comfort as well as reducing the threat to the Earth's ozone layer in industrial and commercial applications. In comparison with conventional vapor compression systems, desiccant systems do not use ozone-depleting refrigerants and they are driven by thermal energy such as natural gas and waste heat, thus lowering peak electric demand. In addition, they are particularly effective at treating the large humidity loads resulting from ventilation air. For supermarkets, the desiccant systems are the best choice to eliminate cold aisle and to reduce frost build up and dew forming on refrigerated display cases, therefore, they contribute to reduction of energy-consuming defrost cycles and dew prevention heaters as well as more comfortable environment in stores.

The following are historical review for desiccant technologies.
In the 1950, desiccant technology was invented as "Lizzy" by C. Munters in Sweden. Purpose of Lizzy was not for dehumidification but for cooling in association with hot water utilization of district heating in summer. This application was to provide small cooling through a combination of desiccant dehumidification wheel, heat recovery wheel and evaporative cooling. In the 1970s, based on the above, the desiccant technologies were developed in association with solar cooling opportunities. Desiccant systems offered the potential to utilize solar heat as a desiccant regeneration source. Silica gel was generally regarded as the most promising desiccant material. However, desiccant material properties typically dictated that a system either have high regeneration temperatures or large amounts

of desiccant material. As the regeneration temperature is reduced, there is a greater residual amount of water in the desiccant and more desiccant must be used to achieve the same dehumidification. Unfortunately, solar energy systems could not provide high regeneration temperatures economically, resulting in large and expensive system installations. In the 1980s, interest in desiccant technologies had shifted from solar to gas applications in the U.S.A.. Gas fired appliances could easily provide the high regeneration temperatures unavailable to solar technologies. The U.S. Department of Energy (DOE) initiated collaboration between government and industry to develop cost effective, marketable systems. In particular, American Gas Cooling Center (AGCC), Gas Research Institute (GRI), and Institute of Gas Technology (IGT) were dedicated to working with desiccant manufacturers. In 1984, early work of GRI showed that lower indoor humidity levels in supermarkets resulted in reduced refrigeration costs. Desiccant technologies were applied to achieve these lower humidity levels. Conventional desiccant systems in Japan are mainly based on the above gas-fired technologies with waste heat recovery.

On the other hand, the desiccant technologies using low temperature waste heat have been continued to research, both in the U.S.A. and Japan. During 1995, effective system operation could be achieved with regeneration temperatures as low as 54℃ at a New Jersey supermarket. By the early 2000s, cross-linked polyethylene adsorbent as a novel desiccant material was developed in Japan. In 2004, effective system operation could be achieved using cross-linked polyethylene adsorbent with regeneration temperatures as low as 50℃. At these temperature conditions, regeneration could be provided by waste heat from vapor-compression refrigerating condenser.

2 DESICCANT DEHUMIDIFICATION PROCESS AND MATERIALS

Method of dehumidification process is classified as shown in Figure1 The desiccant system is thermally activated physical-chemical process, and cooling-based dehumidification-reheat system is electrically operated mechanical process.

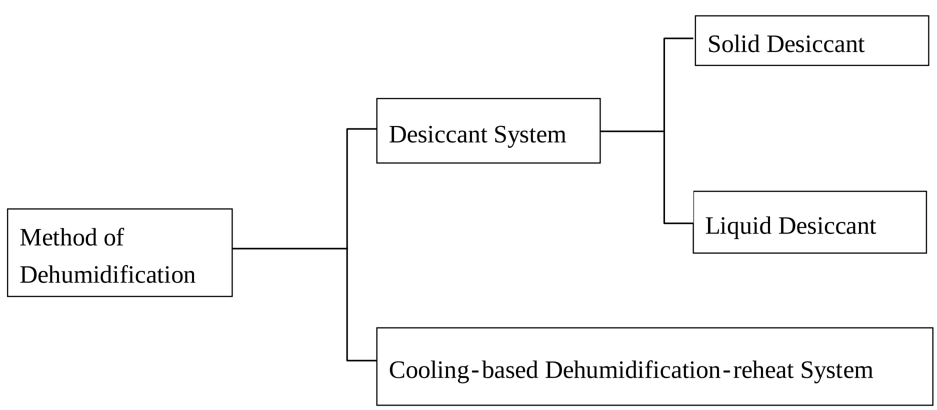

Fig.1. Classification of Dehumidification Method

Conventional vapor-compression systems for the cooling based dehumidification-reheat system are not designed to handle temperature and humidity loads separately. Consequently, oversized compressors are installed for dehumidification. In order to meet humidity requirements,

vapor-compression systems are often operated for long cycles and at low temperatures, which reduces their efficiency and requires reheating the dry, cold air to achieve comfort. Both consequences are costly. On the other hand, in the desiccant systems, a desiccant (adsorbent) material removes moisture from the air, which releases heat and increases the air temperature. This dry warm air is supplied to space to be conditioned. Pre-cooler which is an evaporator of conventional refrigerating systems may be used to obtain dehumidification capacity more. If necessary, the dry warm air is cooled using post-cooler (evaporator). The adsorbed moisture in the desiccant is then removed (the desiccant is regenerated to its original dry state) using thermal energy supplied by natural gas and waste heat.
Figure2 is a schematic diagram of typical desiccant process.

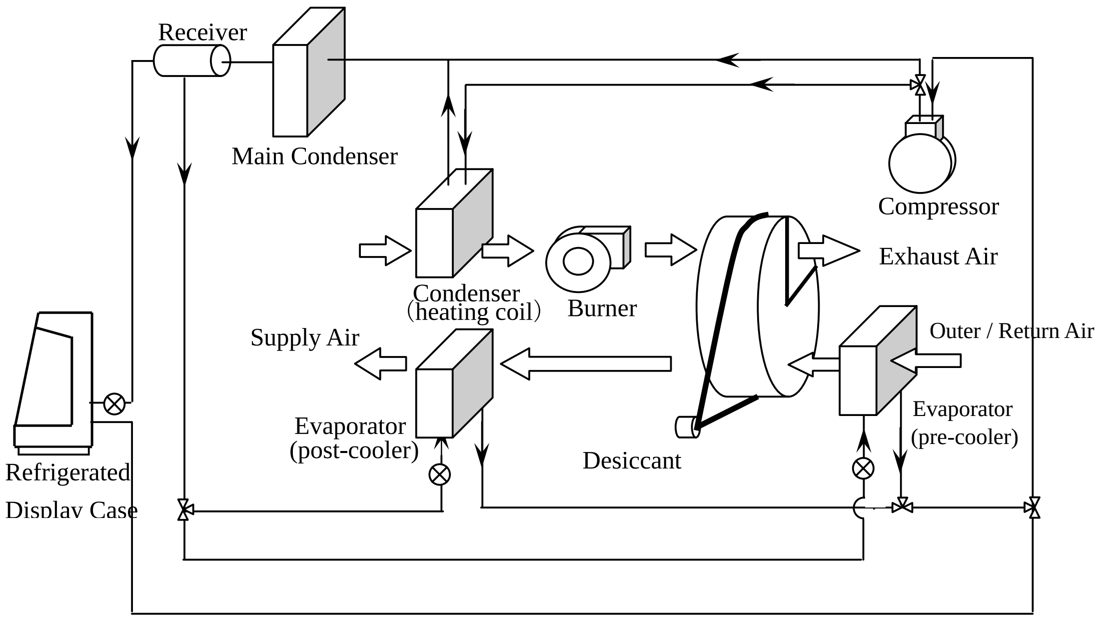

Fig. 2. Schematic Diagram of Typical Desiccant Process

In Figure2, combination of waste heat from vapor-compression refrigerating condenser and gas burner, or exhaust gas from micro-gas turbine (MGT), which temperature is higher than 120℃ is used for regeneration because of providing high temperature easily. The desiccant material is Titanium-reinforced silica gel which allows high temperature regeneration. As a quarter of the desiccant wheel surface is used for high temperature regeneration, it results in cost effective and high performance.
The high temperature regeneration desiccant systems are mainly applied to combined heat and power systems for the supermarkets in Japan. In 2004, all electric desiccant air conditioning system was developed. In the system, waste heat of 50℃ around from vapor-compression refrigerating condenser (heating coil) is only used for regeneration.
The cross-linked polyethylene adsorbent as the novel desiccant material is applied to this low temperature regeneration system. A half of the desiccant wheel surface is used for low temperature regeneration.

Figure3 shows the chemical structure of polymer adsorbent as the novel desiccant material which is developed for low temperature waste heat recovery.

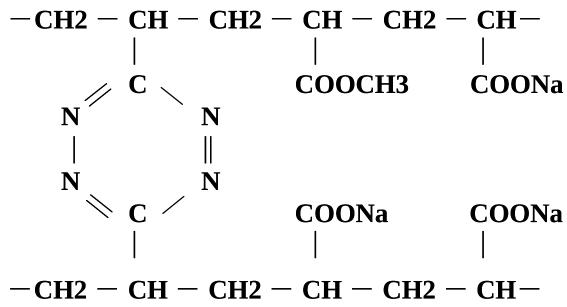

Fig. 3. Chemical Structure of Polymer Adsorbent

Honeycomb type desiccant wheel is formed by advanced polymer adsorbent which is composed of the cross-linked polymer of sodium polyacrylate. The advanced polymer adsorbent which is a high molecular compound dehumidifies by a water vapor molecules adhering to the circumference by relatively weak bounding strength, while the cross-linked polymer changes unlike the phenomenon which zeolite and silica gel of an inorganic sorbent adsorb water vapor molecules on the solid surface, and is dehumidified. (This phenomenon is termed the “sorption”.) Also, since the bounding strength of water vapor adhesion is weak, regeneration of the adsorbent can also be performed at 50-80 degree C.

Furthermore, since the advanced polymer adsorbent does not have performance degradation by sorption and desorption operation, a long-life of dehumidifying wheel is attained.

Figure4 shows dehumidification performance of desiccant materials. The dehumidification performance of the desiccant wheels, which are advanced polymer adsorbent and conventional silicagel, was measured in summertime outdoor air condition. The advanced polymer adsorbent is more efficient in dehumidifying performance by 20-30% compared with conventional one at low regenerating temperature of 50-60 degree C.

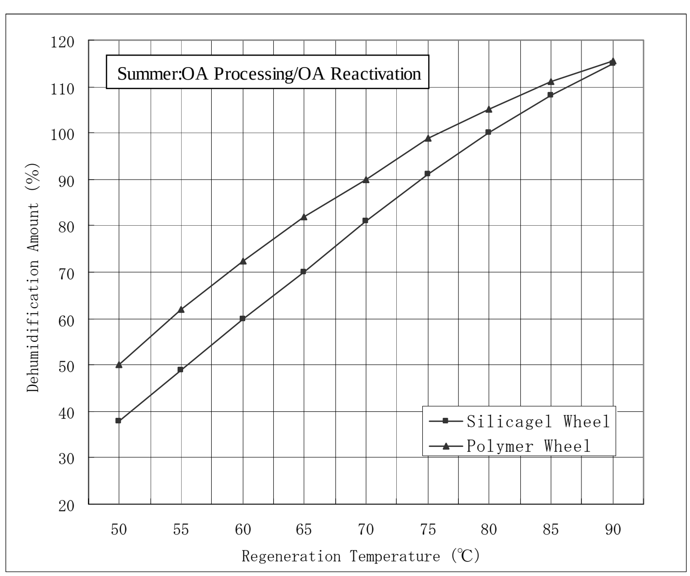

Fig. 4. Dehumidification Performance of Desiccant Materials

3 HUMIDITY REVELATION

Regarding air conditioning factors, main factor for desiccant systems is not temperature but humidity. Figure5 shows effective temperature chart modified which is based on ASHRAE Handbook 1995 in Munters' technical bulletin.

According to Figure5, it is found that lowering humidity can raise temperature without causing uncomfortable. Therefore, keeping 40% of relative humidity results in 28℃ of temperature as recommended energy efficient cooling conditions in Japan.

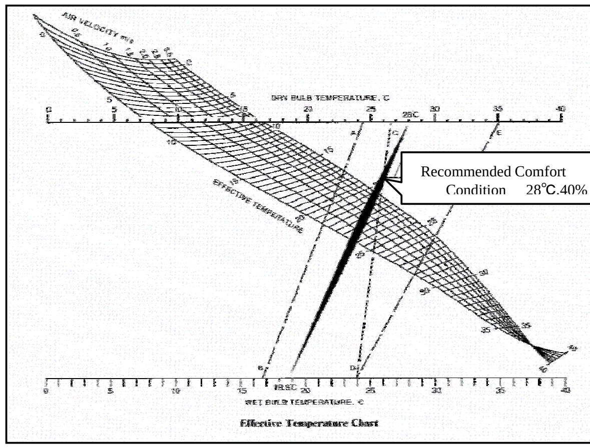

Fig. 5. Effective Temperature Chart

Figure 6 shows climate of representing Japanese city. Japan is located northern latitudes between 24 and 47 degree, and eastern longitudes between 124 and 148 degree. Therefore, climate conditions differ greatly from Sapporo in the north and Naha in the south. Tokyo is considered central Japan.

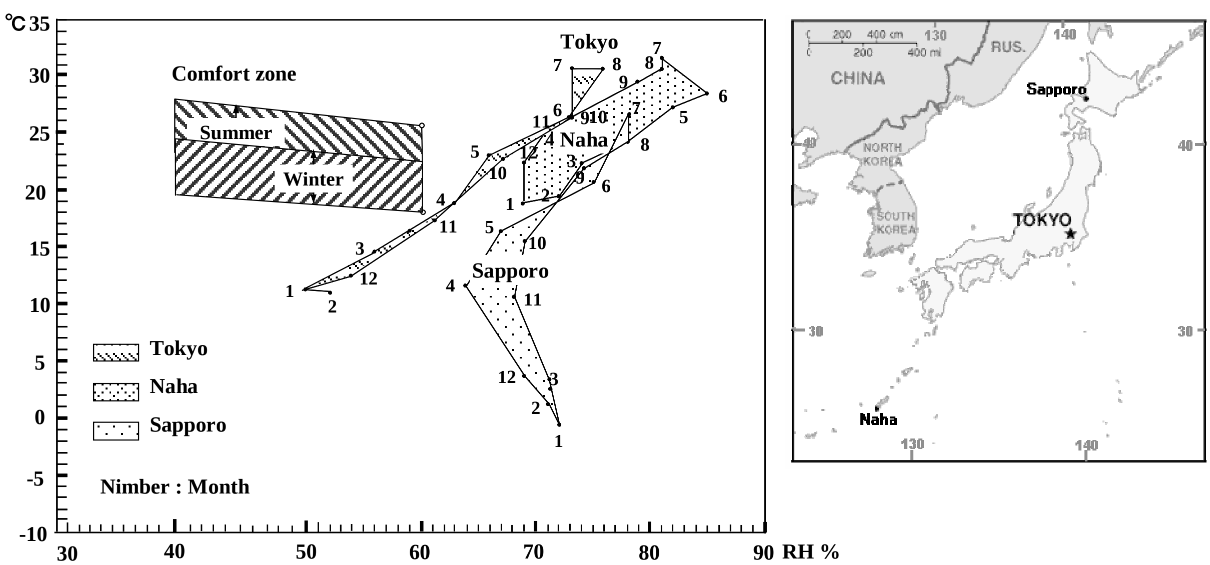

Fig. 6. Climate of Representing Japanese city

Importance of humidity level is closed up in Figure6. The desiccant systems working together with conventional air conditioning systems can treat the temperature and humidity loads separately and more efficiently.

4 OPERATING EXPERIENCES

As show in Figure1 typical desiccant systems are classified in association with regeneration temperatures. Figure7 shows application example of desiccant system combined with refrigerated display cases in supermarket.

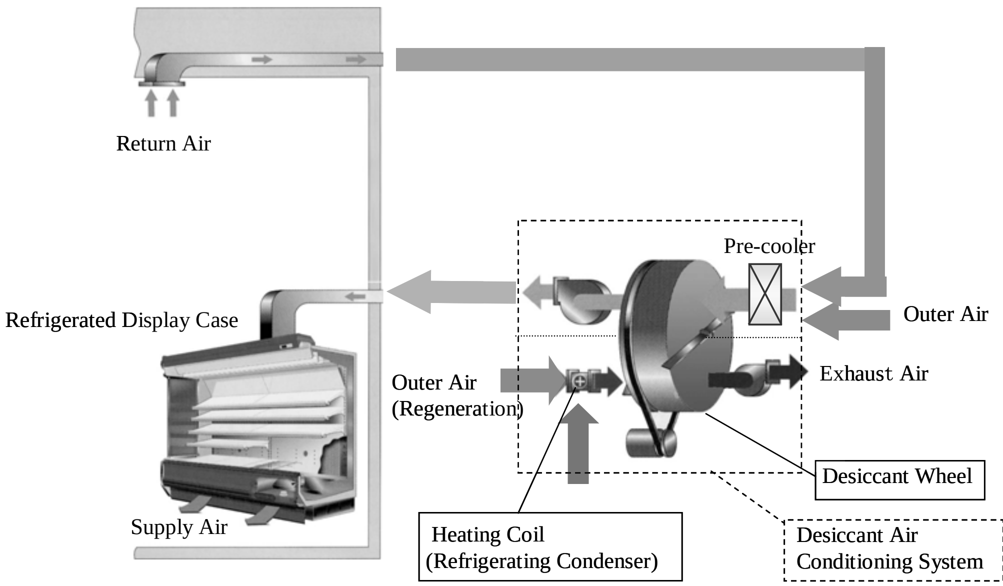

Fig. 7. Typical Schematic of Desiccant combined with Refrigerated Display Case

Based on the modified comfort zone, relative humidity of 40% and temperature of 28℃ are specified for food shopping area of the supermarket in summer. The system effectively eliminates the cold aisle by dry warm air that is sent from the lower portion of refrigerated display cases through the desiccant wheel. Accordingly, the system provides both customer and employees comfort. Representative data of low regenerating temperature system are shown in Table1.

Table 1. Representative Data of Low Regenerating Temperature system

	Outer air	Supply air			Inlet of heating coil	Exhaust air
		Inlet of pre-cooler	Inlet of desiccant wheel	Outlet of desiccant wheel		
Summer	34.3℃ 56.1%	29.3℃ 44.7%	18.5℃ 82.7%	33.3℃ 26.1%	50.0℃ 24.6%	36.6℃ 56.2%
Tsuyu (Rainy Season)	21.8℃ 90.0%	27.4℃ 55.7%	19.3℃ 86.4%	36.2℃ 22.2%	50.0℃ 19.1%	34.4℃ 54.1%
Spring /Autumn	21.8℃ 75.0%	27.4℃ 48.8%	26.4℃ 57.6%	38.9℃ 19.2%	50.0℃ 15.9%	38.7℃ 34.9%

More than 50% of total electric power is used for refrigeration energy in typical supermarkets. Cooling load of refrigerated display eases is affected by surrounding environment. Because of the customer count in a supermarket, outdoor air must be brought into the store to provide for the proper ventilation rate as determined. Many supermarkets do not have this problem, because the makeup air requirement for exhaust systems will usually exceed ventilation requirements of the customer count. By lowering the store's humidity low enough, this can affect the load on the display cases and lower electric power consumption required to operate the cases.

Table2 shows relationship among indoor temperature, relative humidity and cooling load of open multi-deck type refrigerated display cases (OMC) for medium and low temperature.

Table 2. Cooling Load of Refrigerated Display Case

	27℃･70% RH	25℃･60% RH	25℃･50% RH	25℃･40% RH
Midium temp. OMC	144	100	93.8	87.6
Low temp. OMC	112	100	94.8	89.7

* Evaporative Temperature : －10℃ for Medium Temperature. OMC
: －20℃ for Low Temperature. OMC

The decreased refrigerated display case cooling load increases suction pressure and decreases compressor load. Operation results of typical supermarket indicate that relative humidity impacts on the performance of refrigerated display cases than temperature. The dew prevention heaters or anti-sweat heaters are used to prevent dew forming on refrigerated display cases. Decreasing indoor relative humidity reduces dew forming. Table3 shows capability of electric power reduction for the dew prevention heater per 6 feet type refrigerated display case and Figure8 shows control example of the dew prevention heaters as relationship between humidity and energized ratio.

Table 3. Reduction possibility of Electric Power Consumption

	output (W)		reduction possibility	
	existing	25℃･50%	W	%
Midium temp･OMC	22	16	6	27
Chilled OMC	628	440	188	30
Low temp･OMC	955	670	285	30
Low temp･flat	340	240	100	29

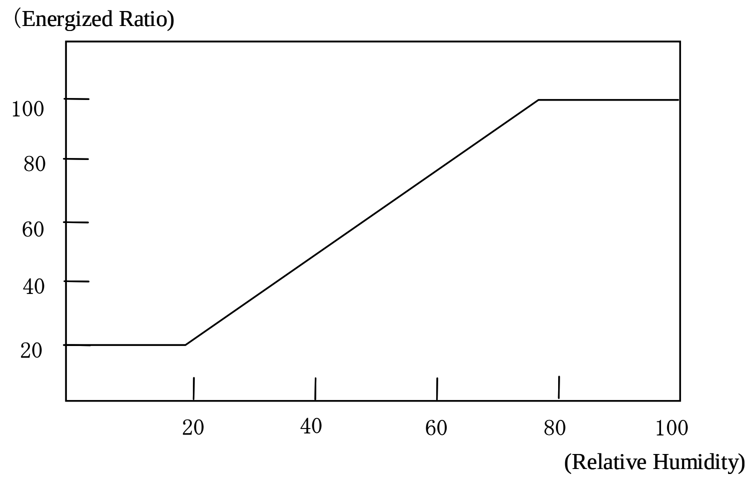

Fig. 8. Energized Ratio of Dew Prevention Heater

Dry warm air is supplied to aisles through ducts behind refrigerated display cases, therefore, “cold isles” are eliminated. Figure9 shows temperature and humidity distributions in typical food shopping area of supermarket.

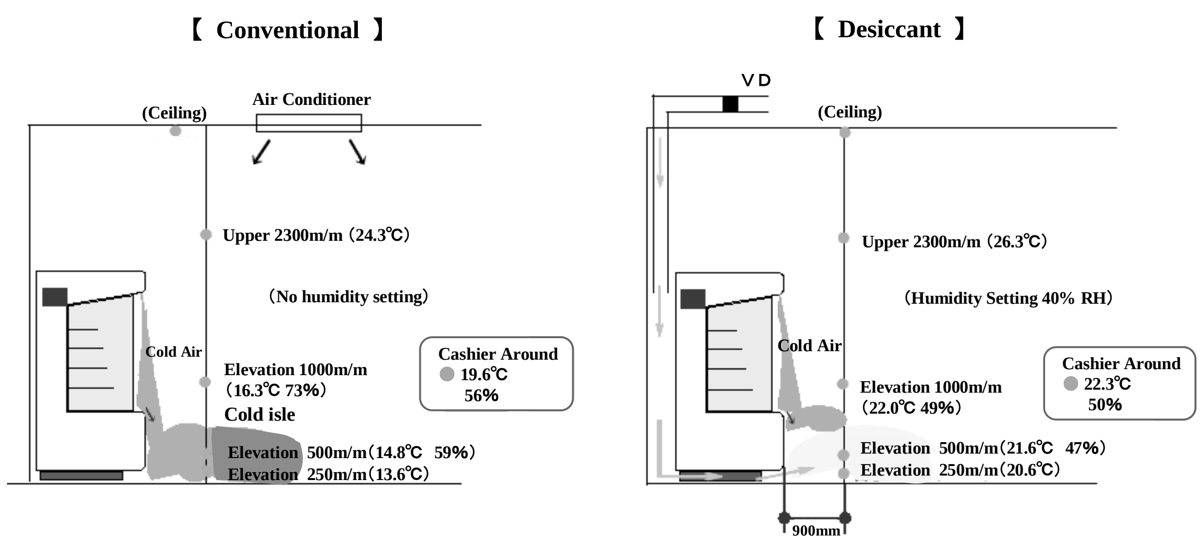

Fig. 9. Temperature and Humidity Distributions

For example when the desiccant system is used, at 500mm of floor level, 21.6℃ and 47% RH are measured. On the contrary 14.8℃ and 59% RH is measured without the desiccant system. Cleary, results shown in Figure9 indicate improvement of comfort.

Dehumidified dry warm air by the desiccant systems is associated with indoor air quality (IAQ). IAQ investigations show that air borne micro-organisms (bioaerosols) are a primary link to sick building syndromes, infections and hyper-sensitivity diseases. Recently, it is reported that bioaerosols are responsible in as many as problem buildings regarding IAQ issues. Many studies identify insufficient ventilation or re-circulated air as a primary cause of IAQ problems. However, increasing the amount of fresh air without pre-conditioning can also increase the level of humidity. Excess moisture above 60% RH provides conditions which allow mold to proliferate as shown in Figure10.

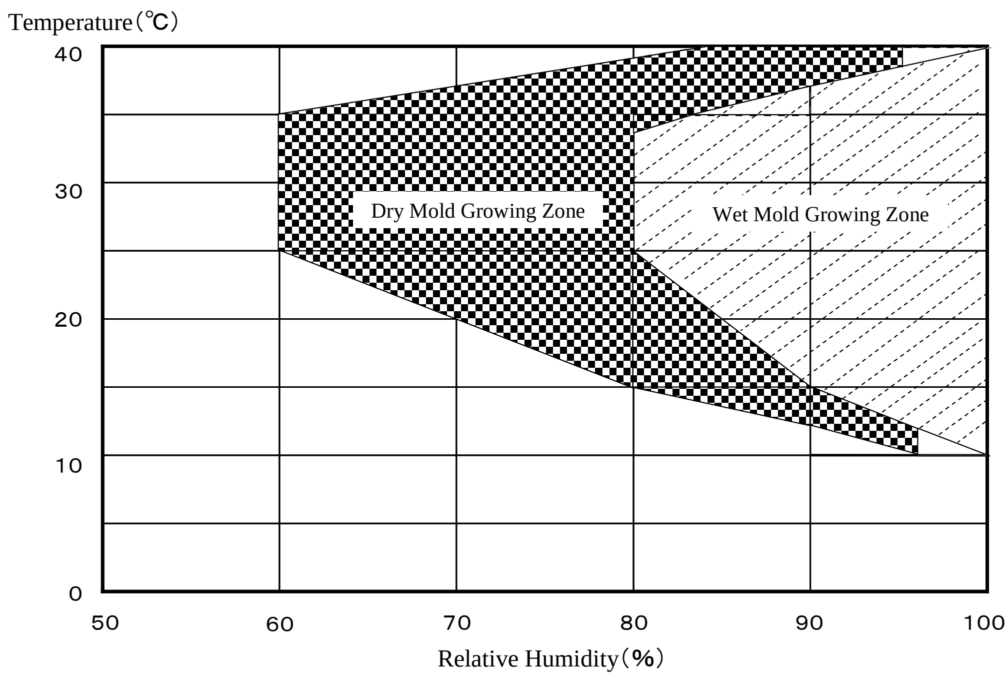

Fig. 10. Mold Proliferation Conditions

Since bioearosols are associated with moisture, maintaining relative humidity below 60% RH in their control. Table4 shows Desiccant air conditioning systems reduced air-borne levels of bacteria and fungi. These data point to the desiccant wheel as the primary source of these reductions.

Table 4. Reduction of air-borne levels of bacteria by desiccants

	Bacteria (cfu)	Fungi (cfu)
Inlet air	38.9	31.2
Outlet air	6.4	0.7

cfu : Bacterium amount in cubic feet

According to studies conducted by Kovak et al. (1997), the desiccant air conditioning systems have the ability to remove pollutants from indoor air in the presence of water vapor.

It is known that reducing the level of humidity, indirectly reduces the concentrations of bioaerosols. Since, microbial contaminants thrive in high humidity environments, the use of the desiccant system may reduce the numbers of bioaerosols in indoor air both; directly, through desiccation and, indirectly, through dehumidification. The desiccant air conditioning systems can remove particulates from the air as well as to kill microorganisms through desiccation. The desiccants have possibility in reducing airborne microbial contamination and should be considered for use in hospitals, health care, and clean room environments where airborne microorganisms are a significant problem. In addition, humidity forms frost and ice on the frozen foods. Frost on the food packages spoils their appearance and hastens product deterioration.

5 CONCLUSIONS

The desiccant systems as described in this paper could greatly contribute to saving energy, improving comfort and upgrading indoor air quality at supermarket. Also, the desiccant systems, working together with conventional systems, could achieve higher quality of air conditioning level. Therefore, we have realized humidity is the key for the supermarkets by operating experiences. However, further improvements are necessary to be accepted widely in the air conditioning market.

Before ending the paper, great thanks should be acknowledged to Munters Japan Co., Ltd. for providing information related, particularly high temperature regeneration desiccant systems and to Kubota Corporation for low temperature regeneration ones.

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