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Review of High Relative Humidity in Catheter Laboratory of a Private Hospital and a Low Energy Consuming Solution

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Abstract: The Relative Humidity in a Catheter Laboratory is desirous to be controlled within a range of 30 to 65% RH. A maximum Relative Humidity (RH) fluctuation of up to 70% is tolerated. A case study is presented whereby a high RH of up to 80% RH has been recorded in the examination room of a Catheter Laboratory (CathLab) in a local Hospital. The conditioned air to the CathLab is supplied through an existing dedicated Chilled Water Air Handling Unit. Two (2) solutions were considered and the technical and commercial comparisons carried out. The first option is an inline dehumidifier system and the second option is to install a portable standalone dehumidifier inside the CathLab examination room. Solutions to address the high Relative Humidity have to be carefully considered as the introduction of in-line dehumidifiers contribute to higher energy consumption. The latter was selected based on commercial reasons. Three (3) weeks of RH monitoring via the building's Integrated Building Management System (IBMS) was carried out. The readings measured show a drastic reduction in RH to a mean of about 60% RH which meets the end user's requirement. The cost for the second option was also found to be much lower at about 10% of the first option.

Keywords: Dry Bulb, Wet Bulb, Moisture, Relative Humidity, Energy.

1. Introduction

It is imperative to maintain good Indoor Air Quality (IAQ) in hospitals as inappropriate IAQ can encourage the growth of contaminants such as moulds and fungi [1]. In addition, communicable diseases and viral infections are further accelerated by bad IAQ. Generally, the properties of Indoor Air Quality shall be as shown in the table 1.

The optimum dry bulb temperature and Relative Humidity range in the Cathlab is 18 ℃ to 24 ℃ and 30 to 70% RH. However, specific rooms in the healthcare facility will have more stringent requirements such as Operation Theatres, Imaging Departments and Pharmacy. The Staff also spends long hours within the hospital environment and as such it is important that the IAQ is maintained within the recommended ranges at all times [2].

The ratio of the partial pressure of water vapor to the equilibrium vapor pressure of water at a given temperature is termed Relative Humidity (RH) and is normally expressed as a percentage [3].

When the percentage is high, there is high moisture content in the air and the air is termed humid [4]. At 100% RH, the air is termed to be saturated and it cannot absorb any more moisture, it has reached its dew point. Any addition of moisture will cause condensation. High RH in Hospital environment is detrimental to various functions including the operation of the Imaging Equipment and damage to the electronic components of the machine becomes a risk [5].

Psychrometry is the science of studying the thermodynamic properties of moist air [6]. The amount of moisture vapour in the air varies quite significantly under different conditions. When the air is hot, it can contain a large amount of moisture vapour. When it is cold, its capacity to hold the moisture is reduced [7]. When the temperature of warm air begins to fall, the vapour also cools and, if cooling continues, it will condense into tiny moisture droplets. In the atmosphere this results in the formation of clouds and eventually rain.

Table 1 Acceptable Range of IAQ parameters in accordance to Industry Code of Practice (ICOP) on Indoor Air Quality 2010

No	Parameters	Acceptable Range / Limit
	Physical Parameters	
1.	Air Temperature	23 – 26 ℃
2.	Relative Humidity	40 – 70%
3.	Air Movement	0.15 – 0.50 m/s
	Indoor Air Contaminants	
	Chemical Contaminants	
1.	Carbon Monoxide	10 ppm
2.	Formaldehyde	0.1 ppm
3.	Ozone	0.05 ppm
4.	Respirable Particulates	0.15 mg/m^3
5.	Total Volatile Organic Compounds (TVOC)	3 ppm
	Biological Contaminants	
1.	Total Bacterial Counts	500 cfu/m^3
2.	Total Fungal Counts	1000 cfu/m^3
	Ventilation Performance Indicator	
1.	Carbon Dioxide	1000 ppm

The psychrometric chart generally is used to determine the following five (5) parameters of the air-water vapour mixtures [8].

- Dry Bulb Temperature
- Wet Bulb Temperature
- Dewpoint Temperature
- Relative Humidity
- Humidity Ratio

By plotting any two (2) parameters, the other three (3) parameters can be determined by using the psychrometric chart. Whenever either the heat content or moisture content of air is changed, the point on the psychrometric chart that represents the initial condition of the air moves in a straight line to a position that represents the new condition of temperature and/or humidity. The objective of this study is to withdraw moisture while keeping the dry bulb temperature constant and is termed dehumidification.

Dehumidification can be achieved generally by two (2) processes:

- Desiccant Dehumidification and
- Mechanical Dehumidification [9]

Desiccant Dehumidification is also known as Chemical Dehumidification. In this process, desiccants are used to remove moisture in the supply air stream.

Mechanical dehumidification utilises the air conditioning processes by cooling the air beyond the saturation temperature of the supply air.

Cooling beyond this temperature, will make the moisture condense out of the air stream thus lowering the absolute humidity. Subsequently, the air is heated to room temperature when the dehumidified air absorbs the various internal and external room heat loads. The effect is a low Relative Humidity in the room [10].

2. Problem Statement

The Cathlab in the private Hospital was experiencing high maximum RH up to 80%. The Client's requirement is between 30% and 70%. This high RH is not conducive for a Cathlab environment and the staff working there [11]. Whether it is about proper handling and storage of drug-eluting stents, plasma supplies, or protecting anticoagulants from humidity-caused deterioration, there is a wide range of drugs and other supplies in the typical Cathlab that need to be protected from adverse temperature and/or humidity effects [12]. The existing airconditioned supply air is supplied via a Chilled Water Air Handling Unit. The initial dry bulb temperature and RH during the Testing & Commissioning stage recorded temperatures below 22 ^{o}C and RH of between 60 to 70%. After about 5 years in operation, the dry bulb temperature maintained but the RH began to rise. As it is imperative to generally maintain the RH between 30 to 65% RH, the Client is keen to review the Chilled Water system architecture with a view of retrofit to ensure the RH is maintained within the range.

3. Methods

The retrofit was to be designed with a low commercial impact and to be implemented with minimum disruption to the operation of the Cathlab. To do this, two (2) Options were studied namely Inline Dehumidifier System and Portable Dehumidifiers (Table 2).

3.1 Option 1 – Inline Dehumidifier System

3.1.1 Technical proposal

An inline dehumidifier system was proposed to be installed in the existing Chilled Water Supply System [10]. Figure 1 shows the system flow diagram. Psychrometry is used to determine the dry bulb temperature, relative humidity and absolute humidity at each stage. 10% Fresh air amounting to 510 cmh was introduced through a pre-cooling Chilled Water Fan Coil Unit (FCU). The outdoor conditions are 35^{0}C Dry Bulb and 27^{0}C Wet Bulb. Moisture content of the outside air is 20.3 g/kg. This air is run through a pre-cooling Chilled Water Fan Coil Unit of capacity 30,196 Btu/Hr to condition the air to 12.8^{0}C Dry Bulb temperature and 12.2^{0}C wet bulb temperature and a reduced moisture content of 8.5 g/kg. Subsequently, the fresh air is passed through a Desiccant type dehumidifier where the Relative Humidity is further reduced to 3.7% RH. This fresh air is mixed with the return air from the Cathlab room. The 90% return air characteristics is 19^{0}C Dry Bulb temperature and moisture content of 7.4 g/kg.

The mixed return air is computed to achieve 21.2^{0}C Dry Bulb temperature and moisture content of 6.8 g/kg. This mixed air is conditioned in the centralized chilled water AHU to achieve off-coil condition of 12.8^{0}C Dry Bulb temperature and moisture content of 6.8 g/kg and supplied to the space. In the conditioned space, the Cathlab room, the supply air picks up the heat and the resultant condition is 19^{0}C Dry Bulb temperature, RH of 55 to 70% and Absolute humidity of 7.4 g/kg. This satisfies the requirement of the Client.

3.1.2 Commercial proposal

The estimated cost is given in table 3.

Table 3 Estimated Cost of Supply and Installation of Equipment

No	Description	Estimated Cost (RM)
1	Chilled water FCU and accessories	20,000.00
2	Modification to existing ductwork and new ductwork	6,000.00
3	Desiccant Dehumidifier	30,000.00
4	Power supply	3,000.00
	Total	**59,000.00**

Table 2 Specifications of Inline Dehumidifier

COMPACT DEHUMIDIFER - FFB SERIES - SPECIFICATIONS

MODEL	FFB 600
Process Air Flow (cmh)	600
Process ESP (Pa)	200
Processs Motor (kW)	0.37
React Air Flow (cmh)	200
React ESP (Pa)	150
React Motor (kW)	0.37
React Heater (kW)	7.2
Power Required (V/Ph/Hz)	415/3/50
Approx Weight (kg)	109
Dimensions (LxDxH) mm	890x630x494

3.1.3 Encumbrances

The various encumbrances envisaged are as follows:

i) The existing ductwork need to be modified and new ductwork and equipment installed. This requires the Cathlab to be shut down for at least 2 weeks.

ii) The power supply requirement is 7.9 kW for the new equipment amounting to an additional RM 10,000 per annum.

iii) The capital cost is RM 59,000.

The specifications of the equipment is listed below:

3.2 Option 2 – Portable Dehumidifiers

The Cathlab is being operated full time and any downtime will be detrimental to the operation of the Cathlab. Thus, an Option 2 is considered, whereby a portable standalone dehumidifier is proposed to be installed within the room. The design of this system is shown below:

A Standalone Dehumidifier was selected based on the moisture removal capacity required (Table 4 &5).

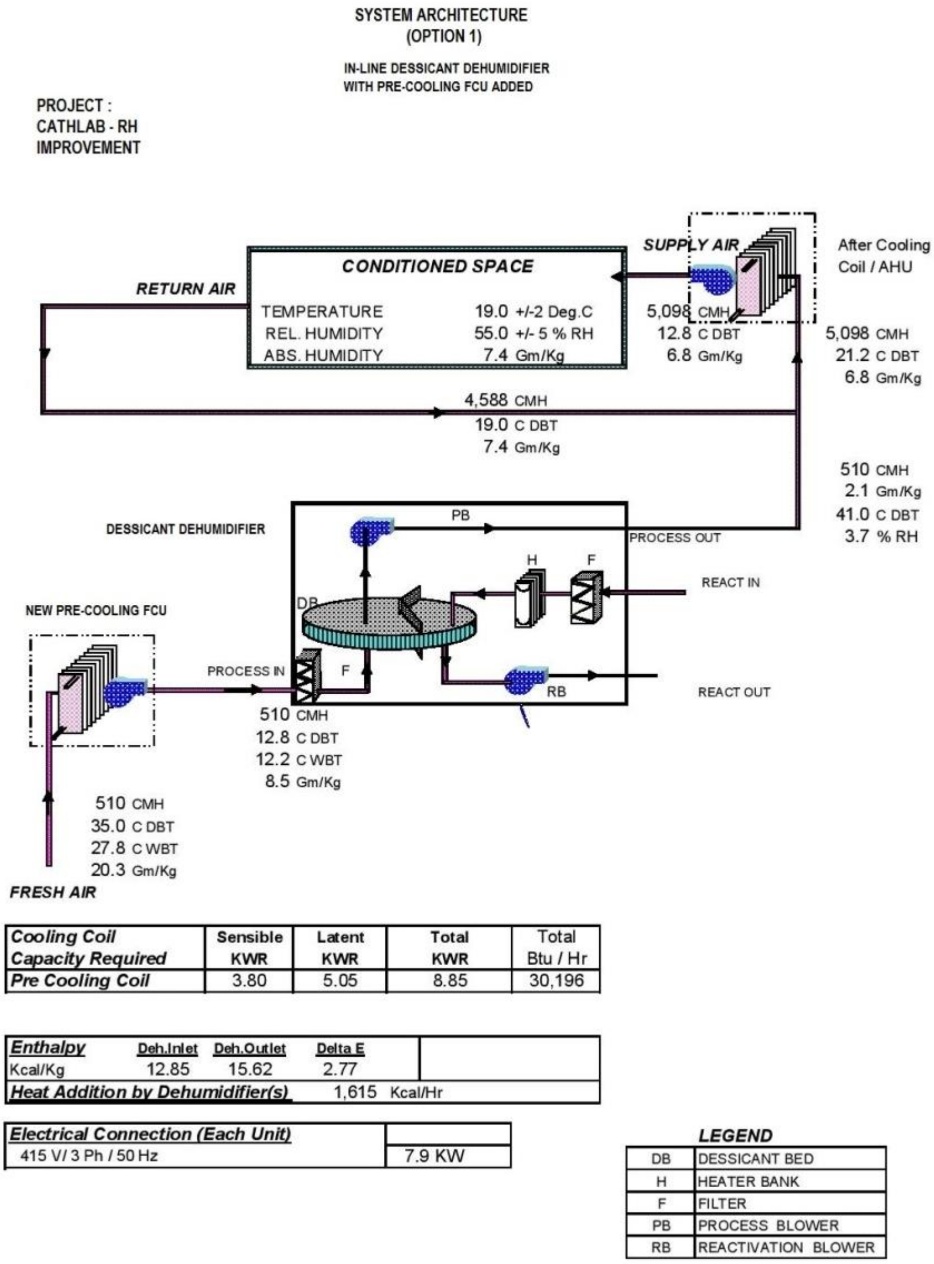

Figure 1 System Architecture of Inline Dehumidifier Installation System (Option 1)

Table 4 RH Load Estimation for Standalone Portable Dehumidifier

LEAKAGE & INFILTRATION LOAD		**0.15**	**kg/Hr**
Formula: LOAD = (C-B)x0.0012xAxDxExFxG			
A = VOLUME OF CONDITION SPACE (m3)	165.25		
B = DESIGNED HUMIDITY (g/kg)	10.29		
C = SURROUNDING HUMIDITY (g/kg)	13.98		
D = VOLUME FACTOR	0.4		
E = PRESSURE FACTOR	1.0		
F = CONSTRUCTION FACTOR	1.0		
G= Delta g/kg factor	0.5		
HUMAN LOAD		**0.6**	**kg/Hr**
Formula: LOAD = G x H x 0.15			
G = NUMBER OF PEOPLE	4		
H = Work Load Coeff (0.5 Light to 1.6 Heavy)	1		
MAKE UP AIR LOAD		**0**	**kg/Hr**
Formula: LOAD = (K- B) x J x 0.0012			
J = Air volume in cmh	0		
K = MAKE UP AIR HUMIDITY (g/kg)	0.000		
DOOR OPENING LOAD		**0.01**	**kg/Hr**
Formula: LOAD = (M- B) x 0.0012 x N x P x L x 0.3			
L = TOTAL DOOR X-SECTION AREA	5		
M = NEXT DOOR AIR HUMIDITY (g/kg)	13.98		
N = EACH OPENING TIME (seconds)	2		
P = NUMBER OF OPENING /HOUR	1		
HYGROSCOPIC MATERIAL LOAD		**0**	**kg/Hr**
EXPOSED WATER SURFACE LOAD		**0**	**kg/Hr**
TOTAL HUMIDITY LOAD		**0.76**	**kg/Hr**
SAFETY MARGIN 10% OTHER LOAD		**0.08**	**kg/hr**
TOTAL HUMIDITY LOAD		**0.84**	**kg/Hr**
TOTAL MOISTURE REMOVAL FOR 24 HRS		20.06	lit/day

Table 5 Specifications of Standalone Dehumidifier

Capacity	
Moisture Removal capacity (30°C/ 80%RH)	**90 liters/Day**
Water Tank Capacity	n/a
Operating Temperature	5°C-35°C
Features	
Compressor Type	Rotary
Refrigerant	R410A
Front Mount Reservoir	Direct
Water level Indicator	Direct
Continuous drain out option	Yes
Drain hose connection	Yes
Washable air Filter	Yes
Casters	Yes
Convenient handle	No
Automatic defrost when reservoir full	Yes
Electronic control	Yes
Soft Key button	Yes
Display Screen	LED
Microprocessor self check at startup	Yes
Adjustable dehumidifier control display	Yes
Fan Speed	2
Auto timer ON-OFF	Yes
Energy	
Power Supply	230V/1Ph/50Hz
Power Consumption (W)	1350
Maximum current (A)	5.9
Dimension	
Dimension (W x H x D) mm	480 x 440 x 970
Ney Weight (kg)	45
** Warranty 1 year against manufacturing defects*	

3.2.1 Advantages

The various advantages for using Option 2 are listed as follows:

i. The existing ductwork need not be modified. This does not require the Cathlab to be shut down. No downtime.
ii. The power supply requirement is 1.5 kW for the new equipment amounting to an additional RM 1,200 per annum.
iii. The capital cost is RM 6,000.

4 Testing and commissioning of the equipment

The standalone portable dehumidifier was installed in the premises for a period of 3 weeks and the RH data log recorded by the centralised Building Management System was reviewed. The log is as listed below.

By plotting a chart of average RH value by date, the difference made by the portable dehumidifier can be very clearly seen.

6. Conclusion

This study presents a review of two (2) options of different dehumidification systems adopted to lower the RH in a CathLab. The first Option is a more costly option whereas the second option is a much cheaper option. The capital cost and operation cost of the two (2) options is presented below

Options	Capital Cost (RM)	Operation Cost (RM per annum)
Inline Dehumidifier System	59,000.00	10,000.00
Portable Dehumidifiers	6,000.00	1,200.00

Based on the cost, the second option was adopted and the equipment installed at site. It can also be seen from the data log that the RH for Option 2 has reduced to below 70 % and meets the Client's requirement at an economical cost. This solution is a low capital cost and low energy consuming answer to the problem statement. In the era of global financial constraint, it is pertinent that capital expenses be kept low albeit not compromising on system performance. System designers have to be innovative and explore various options to ensure the end performance criteria is met at a competitive cost. In this case study, it can be seen that a simple low-cost solution can meet the same requirements as a comprehensive system.

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Conflict of interest

The authors have no conflicts of interest to declare that they are relevant to the content of this article.

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