AN EXPLORATORY STUDY OF A LIQUID DESICCANT WATERFALL SYSTEM FOR THE MALAYSIAN HUMID CLIMATE

BY

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A dissertation submitted in fulfilment of the requirement for the degree of Master of Science in Building Services Engineering

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ABSTRACT

An exploratory study of a liquid desiccant waterfall (LDW) system was conducted as a means of achieving air dehumidification of an internal air environment. The aim is to explore an alternative technology which can reduce energy consumption, while still achieving acceptable thermal comfort conditions and achieving specific advantages when compared with conventional air conditioning systems. Some of these advantages include the pleasing aesthetics and appearance of a waterfall feature, the efficient functionality behind desiccant dehumidication technologies of the LDW system. This study and research proposed a system which harnesses hygroscopic salt of lithium chloride (desiccant) in its liquid form (45% concentration). This naturally attracts and absorbs moisture from an internal environment. Having absorbed the moist indoor air into the system, the lithium chloride then converts into a diluted form (30% concentration) and this requires the solution to be reactivated. A further advantage of the LDW system is explored representing significant potential in saving energy through the harvesting of solar thermal energy in order to expel moisture out of the system, as well as to efficiently reactivate the saline solution of lithium chloride to undertake its the cyclic nature of new dehumidification processes. To further quantify the amount of moisture to be absorbed by the LDW system and to some extent verify this exploratory study, a case study of a hypothetical space of an open plan office building in Kuala Lumpur city was proposed. The study then calculates the total amount of moisture to be eliminated by the LWD system (as specified by the common standard) was 25.4 kg/hr based on standards of thermal comfort for an office environment. Life cycle costs and energy savings were estimated. The results demonstrate and suggest a high prospect in creating an attractive financial return-on investment (ROI) including energy savings. When design optimally, this technology or system can save up to 92% of energy consumption and offer an investment rate of return of 34% per year. This was considered an attractive investment because it could offer reasonable payback period of 3 years.

ملخص البحث

يتضمن هذا البحث العلمي دراسة تصميم تفصيلية لنظام المجففات السائلة في صورة شلال مائي داخلي. وقد تم الوصل الي تصميم هذا النظام ليستخدم كوسيلة تحكم لازالة الرطوبة العالقة بالجو ,ويعتبر من الحلول المثلى لازالة والتغلب على المشاكل المتسببة من استخدام انظمة تكيف الهواء او اجهزة التبريد التقليدية و التي تشمل نسبة عالية من هدر واستهلاك للطاقة والموارد خصوصا الطاقة الكهربائية والتاثير السلبي علي مستوى جودة الهواء الداخلي .تم الجمع بين التقنية الحديثة والشكل الجمالي المميز في هذا النظام كأحد أحدث اساليب تكنولوجيا المجففات السائلة المطورة. طرح هذا النظام في صورة الشلال المائي الذي يحتوي علي المادة الكيميائية المجففة متمثلة في محلول اليثيوم كلوريد بنسبة تركيز 45% مما يجعله يجذب و يمتص بصورة طبيعية الرطوبة الموجودة في الهواء المحيط به و استيعابها في داخل النظام لمعالجتها داخليا. يعمل النظام حتي ينخفض تركيز محلول الليثيوم كلوريد الى نسبة 30%مما يخول النظام لاعادة تفعيل المحلول وذلك باستخدام الطاقة البديلة في صورة الطاقة الشمسية ليواصل دورة عمله بصورة منتظمة و فاعلة . كما تم تقديم شرح توضيحي لاستخدام و طريقة عمل هذا النظام في مبنى يشتمل علي مكاتب حديثة التصميم في مدينة كوالا لمبور .بمساحة 320 متر مربع لتحديد كمية الرطوبة المراد ازالتها من الجو بنسبة تحقق الراحة الحرارية لمستخدمي المساحة وضعا في الاعتبار كل المعايير، المقاييس والمواصفات المتعارف عليها عالميا.و قد تم قياس و تحديد كمية الرطوبة المراد ازالتها .بمقدار 25,4 كيلوجرام / ساعة للحفاظ على ظروف الراحة الحرارية حسب المقاييس المتعارف عليها. و قد اثبت هذا النظام فاعلية مالية عالية .بما انه يحقق توفيرا للطاقة بنسبة 92% كما يضمن هذا النظام معدل اعادة الاستثمار بنسبة % 34 سنويا مما يعنى اعادة الاستثمار منه فى خلال فترة ثلاث سنوات فقط.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science in Building Services Engineering.

....
Puteri Shireen Jahn kassim
Supervisor

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science in Building Services Engineering.

....
Noor Aziah Mohd Ariffin
Examiner

This dissertation was submitted to the Kulliyyah of Architecture and Environmental Design and is accepted as a fulfilment of the requirement for the degree of Master of Science in Building Services Engineering.

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Nurul Hamiruddin Salleh
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This dissertation was submitted to the Kulliyyah of Architecture and Environmental Design and is accepted as a fulfilment of the requirement for the degree of Master of Science in Building Services Engineering.

…...
Khairuddin Abdul Rashid
Dean, Kulliyyah of
Architecture and
Environmental Design

DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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Ihab Faisal Ibrahim Ahmed

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LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers.
$CaCl_2$	Calcium chloride.
CFM	Cubic feet per minute.
COP	Coefficient of performance.
DH-5	Molecular sieve.
DH-7	Molecular sieve.
KCOOH	Potassium formate.
LCIX	Artificial silicate.
LDW	Liquid desiccant waterfall.
LiBr	Lithium bromide.
LiCl	Lithium chloride.
$MgCl_2$	Magnesium chloride.
MS	Malaysian Standard.
MSDS	Material safety data sheet.
TEG	Triethylene glycol.
TRY	Test reference year.
13X	Zeolite molecular sieve.

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

For the past decades, conventional air conditioning systems have ensured thermal comfort in hot humid regions. However, this enhancement does not come without a high amount of energy consumption. From a luxury to a necessity, the air conditioning system has increased air pollution levels, mainly because of higher carbon dioxide levels of fossil fuels used to generate energy for the system. In the long run, this can influence global warming and climate change.

Traditional air conditioning system is ideally required to counterbalance between two load components termed as latent loads and sensible loads in order to attain feasible thermal comfort condition. For instance, to handle a latent load and dehumidify moist air, the system must initially cool the humid air down to its saturation point in order to condense the moisture out of the atmospheric air. This cooling is more than what is necessary for human thermal comfort. The dry air is then reheated to a feasible room temperature for comfort. These processes of overcooling and reheating consume a large sum of energy and this can only be fulfilled by an excessive use of electricity. Figure 1.1 indicates the complete dehumidification process in a conventional air cooling system.

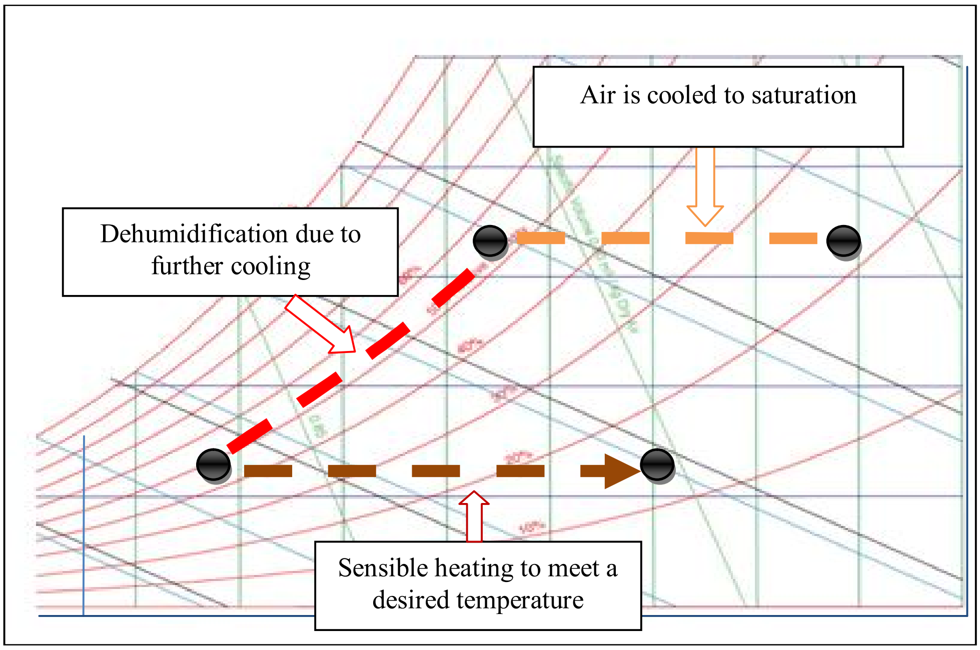

Figure 1.1 Air dehumidification in conventional air conditioning system

In humid climate regions, the conventional air conditioning system is no longer sufficient to meet the requirements of occupants, who are concerned about indoor air quality. One such example is the Sick Building Syndrome phenomenon. Adequate ventilation can eliminate such occurrence, but it will increase indoor moisture to a level unhealthy and uncomfortable to the occupants.

1.2 DESICCANT DEHUMIDIFICATION TECHNOLOGY

In order to eradicate shortcomings of the traditional air cooling systems, more energy saving technologies were innovated. This causes the emergence of various dehumidification techniques and applications, which are becoming the main part of the air conditioning system's function in buildings and spaces that require humidity control.

In recent years, dehumidification technology applications based on desiccant materials have attracted considerable public attention with regards to their energy saving characteristics and precise humidity control. These features prevent major problems faced by industrial applications such as moisture regimes, protection against condensation and protection against corrosion.

In contrast to the conventional air conditioning systems, a desiccant dehumidification system utilizes a highly absorbent material called desiccant to capture and absorb water vapor naturally from the ambient air, due to the difference of water vapor pressure between the desiccant - air interfaces. Expelling the absorbed moisture out of the desiccant as well as reactivating the desiccant material can be accomplished by introducing heat from any energy source, such as solar thermal energy, natural gas, electricity or wasted heat source.

For dehumidification task, generating heat is much easier and less costly than consuming electricity for sophisticated machineries. Therefore, the desiccant dehumidification system is particularly functional in the case where a latent load is high since such system can eliminate moisture more economically than the traditional air conditioning system.

1.3 THE LIQUID DESICCANT WATERFALL (LDW) SYSTEM

The liquid desiccant waterfall (LDW) system aids in removing water vapor from the air without the burden of conventional air conditioning system's excessive energy consumption. The functionality behind desiccant dehumidification technologies along with the aesthetic appearance of the waterfall feature are combined to create the LDW system.

The critical notion that drives the LDW system's operation is the harnessing of hygroscopic salt of lithium chloride (desiccant) in its liquid form (45% concentration). This naturally attracts and absorbs moisture from the atmosphere. Subsequent to having the indoor moist air absorbed in the LDW, the working fluid of the lithium chloride converts to be diluted (30% concentration). Another advantageous characteristic of the LDW system is in harvesting solar thermal energy to expel moisture; this efficiently reactivates the saline solution of the lithium chloride to undertake new dehumidification tasks.

The LDW system proposes a variety of advantages — dehumidification, cooling, particle elimination, purifying, energy conservation — over the conventional air conditioning system. Hence, it can be implemented and adapted to numerous applications such as in residential, healthcare, office, and commercial buildings.

1.4 PROBLEM STATEMENT

The liquid desiccant waterfall (LDW) system eradicates moisture out of the air with an extremely low energy consumption. It can also eliminate the necessity of conventional air-conditioner in humid climate. There is a lack of research on the applications and energy saving impacts of the combination between this waterfall feature and the desiccant dehumidification technologies. Most previous studies harnessed the desiccant dehumidification technology to solely the air conditioning system applications.

1.5 RESEARCH AIM AND OBJECTIVES

The research aims to explore, using variable standards and design assumptions, the liquid desiccant waterfall (LDW) system as a mean of space dehumidification, which aids to eliminate the potential pitfalls associated with conventional an air conditioning system.

The following are the objectives of the study:

1- To review related aspects and concepts of liquid desiccant waterfall (LDW) system and recent advancement of the dehumidification technologies applied.
2- To identify and analyze air ventilation requirements in order to accomplish feasible thermal comfort conditions according to the air conditioning standards related to the subject in applicable climates.
3- To apply the standard environmental parameters to a proposed case study space in Malaysia in order to quantify the total amount of moisture to be removed from the space.
4- To investigate the optimum properties of desiccant materials in order to select the best desiccant solution to the LDW system.
5- To establish the selection and sizing of the proposed system components to demonstrate maximum efficiency with respect to air ventilation requirements.
6- To conduct a life cycle cost analysis of the LDW system with a corresponding air conditioning system at the specific space.

1.6 RESEARCH STRUCTURE

The thesis outlines the premises and methodological approach adopted to explore the proposed system as a dehumidification means under a humid and tropical climate. This thesis is structured in seven main chapters in order to meet the problem statement, objectives and the aims presented. The research structure of this research is illustrated n Figure 1.2.

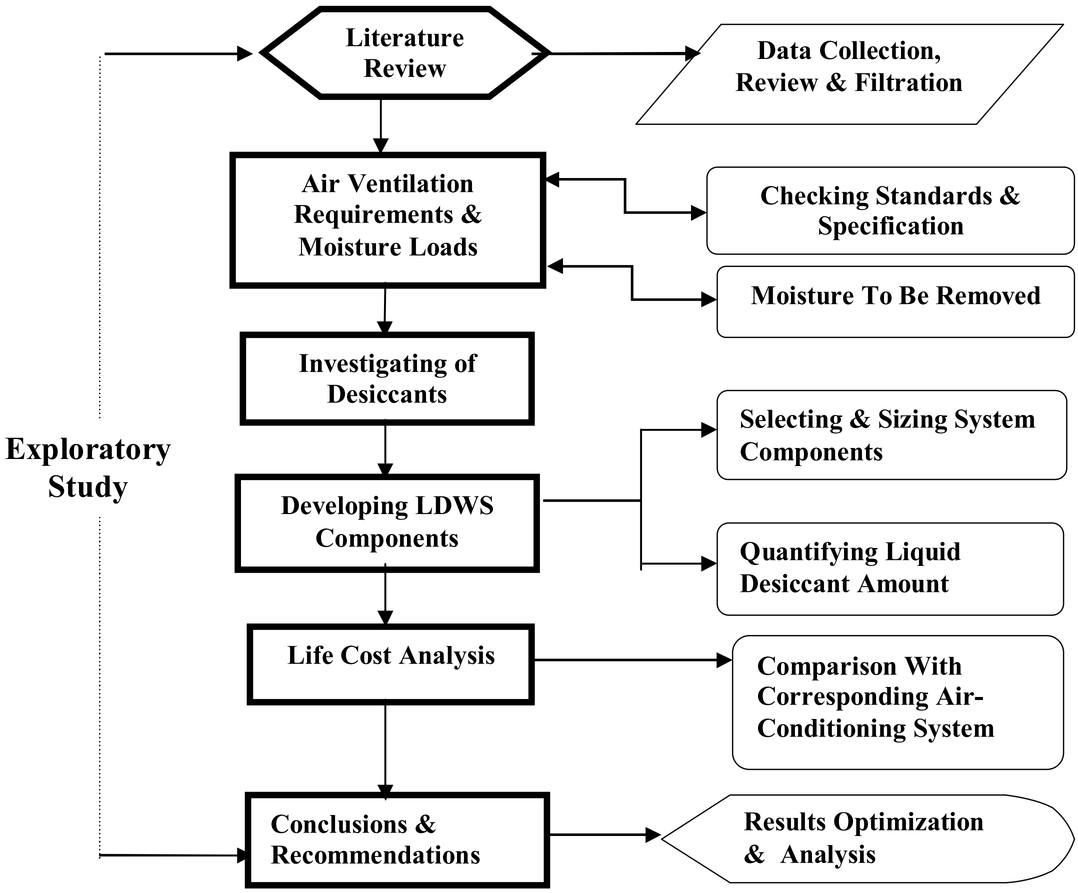

Figure 1.2 The research's structure

The second chapter highlights related literature on desiccant dehumidification technologies. This includes desiccant materials classification, their performance, the applicable climate to adapt such technology and the potential of cost and energy saving obtainable from applying the dehumidification technology. The literatures are sources from both international and national. Relevant books, scientific papers, journals and websites were also extensively reviewed to obtain an understanding of this technology.

In Chapter Three, air ventilation and humidity removal requirements were identified and presented as the foundation for developing the exploratory study. It will also be determined and calculated, the total amount of moisture to be absorbed by the

LWD system in order to attain a feasible thermal comfort condition in the Malaysian climate.

To achieve such goals, this thesis proposes a hypothetical case study of an open plan office located in Kuala Lumpur. The office has an area of 320 m^2. Secondly, the building comfort set points specified by the Malaysian Standards (MS1525-2009) along with the extreme and actual Malaysian weather data conditions were obtained. Lastly, all the sources of moisture were identified in the proposed space.

Chapter Four presents a comparative study of the desiccant material specification in order to select the optimum desiccant solution for the LDW system based on the desired properties and the advance performance. Lithium chloride, lithium bromide, calcium chloride and magnesium chloride were the four proposed desiccant solutions.

Each candidate saline solution was investigated through a screening process based on the eight properties required to be satisfied such as vapor pressure, corrosion rate, safety and cost. Whereas, the importance of the properties to the LDW system was assigned as the maximum weight factor and the relative weight was assigned as the objective of merits for the properties that were investigated. The optimum desiccant solution is then to be chosen as the one with the highest weight factor.

After obtaining the exact amount of moisture to be removed with the optimum desiccant solution, the configuration and sizing of the system components were addressed in Chapter Five. The sizing was a reflection of the system requirement to operate efficiently in the proposed space. Each component was sized separately to accomplish maximum clearance on its different parts, functions and roles in the LDW system's operation.

Chapter Six provides the development of life cycle cost analysis for the LDW system's different components, as well as clarifies the economical value this system can offer in the long run. The engineering estimation method was taken as the most appropriate approach for the cost analysis of the proposed system. This is because an exact system specification does not exist in the current markets, and this study was established based on design guidelines for the system's potential implementation.

The pricing process of the system component was assigned based on a search for the component's supplying company in local and international markets. After the capital cost of the proposed system was determined, a simple comparative life cycle analysis was conducted for the LDW system with a corresponding air conditioning system at the proposed open plan office. In addition, investment rate of return for the system was presented to confirm the system value economically and environmentally, as well as proving that it gives much more room for additional improvements, depending on flexible adjustments possible for the components of the system.

Chapter Seven concludes the results optimization and analysis throughout the thesis both theoretically and technically. It also provides the reader with a vision of how this system can be improved, modified and implemented in order to achieve maximum efficiency.

Furthermore, this chapter summarizes all results from a different set of calculations which lead to the presenting of the LDW system to ensure the flexibility, simplicity and user-friendliness of the system. Alongside the above, it will show a great prospect for implementing the proposed system in residential, commercial and health care buildings.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter outlines a background literature on the development of desiccant dehumidification technologies throughout the last two decades including a study on the suitable criteria for the selection of the most proper desiccant for the LDW system. Furthermore, it reviews various studies on different types of desiccant materials, determining their advantages and disadvantages and how they are applied in the dehumidification technology industry. It also reviews their developments and performances under different conditions of temperature and concentration levels.

This also includes current case studies on innovative feature of the desiccant waterfall dehumidification established by the team from University of Maryland (2011), one of the most attractive ideas that leads to the concept of the LDW system's design development.

2.2 DESICCANT MATERIALS IN PERSPECTIVE

Since the early 1920's, the notion of water absorption and adsorption was initially explored as dehumidification's means of cooling, focusing on their applications in residential, commercial and industrial buildings (Anon, 1996). With respect to advanced technologies, the interest of desiccant dehumidification was renewed in the early 1990's, having the solution perceived as an alternative to eliminate new challenges associated with the conventional air cooling and heating system (Jurinak, Mitchell and Beckman, 1984). Such challenges include the significant depletion of energy resources along with escalating energy demands.

Desiccants are either natural or synthetic substances with high affinity for water vapor within the air due to the differences in vapor pressure of water between the exposed surface of the desiccant and the surrounding air. The capability of desiccant materials to capture moisture out of the air is termed as Sorption, while the process of transferring and extracting moisture from the desiccants to the surrounding environment is called Desorption (ASHRAE, 2005).

Vapor pressure is the crucial driver for transferring moisture from desiccant materials to the atmosphere and vice versa. For instance, desiccants with lower vapor pressure than that of the surrounding air will absorb moisture from the latter. In contrast, substances with higher vapor pressure will always expel moisture out to the ambient air. Figure 2.1 represents the diagram of vapor pressure role in a desiccant cycle.

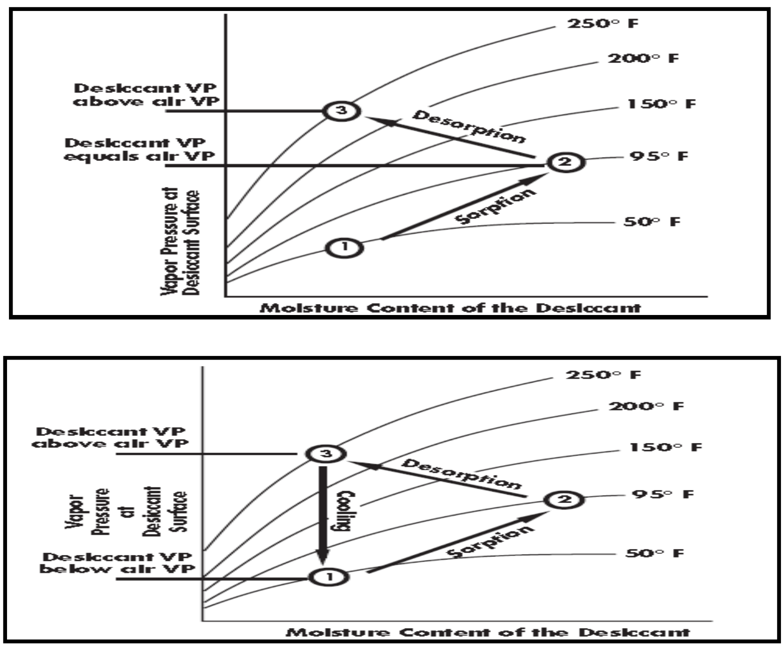

Figure 2.1 Diagrammatic representations of the vapor pressure role in desiccant cycle (Lewis and Harriman, 2002)