UNIVERSITI PUTRA MALAYSIA

NEW HUMIDITY CONTROL MATERIAL PREPARED FROM THE SINTERING OF DIATOMITE, WASTE GLASS AND COCKLE SHELLS TO BALANCE INDOOR RELATIVE HUMIDITY

HUONG PEI ZAM

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By

HUONG PEI ZAM

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

May 2022

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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HUONG PEI ZAM

May 2022

Chair : Emilia binti Zainal Abidin, PhD
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Introduction: High relative humidity (RH) in buildings leading to mould growth and exposure is a health risk. Conventionally, the buildings in Malaysia used air-conditioning and mechanical ventilation (ACMV) system to control indoor RH. However, it does not help in balancing the high RH buildup in an air-conditioned office when the efficiency of dehumidifying of ACMV system is decreased due to excessive cooling to lower the indoor temperature. This study aimed to determine the RH in 32 selected air-conditioned offices and the associated health effects among 294 office respondents located in the public university buildings. This study also aims to develop a humidity control material (HCM) and characterize the properties of the material. **Methodology:** RH of each office room was recorded using TSI Velocicalc for 30 minutes at four time slots and calculated the average. Health symptoms were accessed via modified, self-administered questionnaire from Indoor Air Quality and Work Environment Symptoms Survey, NIOSH Indoor Air Quality Survey (1991). For the material, a mixture of diatomite, waste glass and cockle shell powder with specific ratio was sintered at 1100°C for 20 minutes in the Muffle furnace. The chemical compositions of diatomite, cockle shell powder and waste glass were determined using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES). Moisture adsorption-desorption performances was tested referring to JIS A 1475-2004 procedure. Porous properties were determined through surface area analyser. Scanning Electron Microscope (SEM) Images and Energy Dispersive X-Ray (EDX) Analysis was used to assessed the surface morphology of the samples. Flexural strength of samples was tested using Universal Testing Machine. Antibacterial capability of samples was tested using disc diffusion test against Staphylococcus aureus and Pseudomonas aeruginosa. **Results:** The average relative humidity of 32 offices were 68.4% with maximum 72% and minimum 64.9%. There were five rooms with RH more than 70% does not comply with the permissible range stated in Industry Code of Practice for Indoor

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Air Quality. A total of 27.4, 28.0, 28.5, 34.2, 31.4 and 29.1% building occupants had headache, runny nose, sore throat, unusual fatigue, sleepiness, and fever respectively. The prevalence of SBS calculated was 35.6%. The results from multiple logistic regressions shows that an increase in average RH was associated with a twofold increase in the reporting of Sick Building Syndrome (SBS) (OR 2.38; 95% CI 1.21-4.69). Respondents who perceived the room temperature was too hot were 0.47 times less likely to complain about having SBS (OR 0.47: 95% CI 0.29-0.77). Likewise, respondents who were satisfied with the overall thermal comfort was 0.54 times less probably to report health symptoms (OR 0.54; 95% CI 0.34-0.85). Diatomite is mainly made up of SiO_2 (89.78%) and waste glass also have high content of SiO_2 at 68.46%. Main chemical component of cockle shell is calcium carbonate ($CaCO_3$) with 98.67%. The sintered materials have specific surface area from 5.744 m^2/g to 14.765 m^2/g, total pore volume recorded from 0.028-0.08 cm^3/g and pore size range from 39.5-67.7 nm. The moisture adsorption-desorption results indicated that the best material, manufactured by mixing 60% diatomite, 30% waste glass and 10% cockle shell powder. The 48h moisture adsorbed amount of compacted sample reached 7.95 % at 75% RH. The flexural strength of 8.23 ± 1.8 MPa satisfy the standard of those commercial porous ceramics. Moisture adsorption-desorption ability of the humidity control materials increases as diatomite content increases. The substitution of waste glass up to 30% showed a significant enhancement of strength in compacted samples till 80%. Qualitatively, all the sintered samples had inhibition on gram-positive Staphylococcus aureus and gram-negative Pseudomonas aeruginosa. **Conclusion**: The average RH of offices was within the recommended range according to Malaysian Code of Practice. The prevalence of SBS was 35.6% with unusual fatigue as the highest reported symptom. The increase in average RH over 68.4% was a significant contributor towards the occurrence of health symptoms among respondents. The compacted samples showed excellent properties and highly promising for various construction applications. There is a need to ensure regular maintenance of ventilation system coupling with innovative indoor humidity control measures to provide a safe and healthy work environment.

Keywords: relative humidity, dampness, health symptoms, humidity control material, recyclable materials

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

BAHAN KAWALAN KELEMBAPAN BARU YANG DISEDIAKAN DENGAN BAHAN DIATOMIT, SISA KACA DAN KULIT KERANG MELALUI PROSES PENSINTERAN

By

HUONG PEI ZAM

Mei 2022

Pengerusi : **Emilia binti Zainal Abidin, PhD**
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Pengenalan: Kelembapan Relatif (RH) yang tinggi dalam bangunan mengakibatkan pertumbuhan kulat yang luar biasa dan pendedahan kepada situasi begini membawa risiko kepada kesihatan manusia yang menjalankan rutin harian dalam bangunan tersebut. Bangunan di Malaysia kebanyakan mengamalkan cara konvensional untuk kawalan RH dalam bangunan iaitu dengan aplikasi sistem pengudaraan dan penyaman udara mekanikal (Air Conditioning and Mechanical Ventilation - ACMV). Walau bagaimanpun, aplikasi sistem ini tidak mampu mengimbangi kelembapan relative yang tinggi dalam ruang tertutup pejabat kerana efektif penyahhidratan sistem ACMV berkurang dalam situasi penyejukan berlebihan dalam tempat ruang tertutup di dalam bangunan. Kajian ini bertujuan untuk menentukan RH di 32 pejabat berhawa dingin terpilih dan kesan kesihatan yang berkaitan di kalangan 294 responden pejabat yang terletak di bangunan universiti awam. Selanjutnya, kajian ini juga bertujuan untuk menghasilkan bahan kawalan kelembapan (HCM) dan menjelaskan sifat-sifat bahan tersebut. **Metodologi:** RH bagi setiap bilik pejabat direkodkan menggunakan *TSI Velocicalc* selama 30 minit pada slot empat kali dan dikira purata. Kesan kesihatan responden diakses melalui soal selidik yang diubah suai dari Kaji Selidik Kualiti Udara Dalaman dan Persekitaran Kerja, Kajian Kualiti Udara Dalaman NIOSH (1991). Penyediaan bahan melibatkan campuran diatomit, sisa kaca dan serbuk kulit kerang dengan nisbah khusus dan disinter pada suhu 1100 ° C selama 20 minit di dalam relau Muffle. Komposisi kimia bahan ini (diatomit, sisa kaca dan serbuk kulit kerang) ditentukan menggunakan *'Inductively Coupled Plasma-Optical Emission Spectrometry' (ICP-OES).* Prestasi penyerapan-penjerapan kelembapan diuji merujuk kepada prosedur JIS A 1475-2004. Sifat pori sampel ditentukan melalui penganalisis kawasan permukaan. Pengaplikasi *'Scanning Electron Microscope' (SEM)* dan *'Energy Dispersive X-Ray' (EDX)* dilaksanakan untuk menilai morfologi permukaan sampel. Kekuatan lentur sampel diuji menggunakan *'Universal Testing Machine'* manakala keupayaan antibakteria sampel diuji menggunakan

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ujian resapan cakera terhadap *Staphylococcus Aureus* dan *Pseudomonas Aeruginosa.* **Hasil Kajian:** Purata bacaan RH untuk semua 32 pejabat ialah 68.4% dengan maxima 72% dan minima 64.9%. Lima pejabat mempunyai RH melebihi 70%, dimana bacaan ini tidak mematuhi piawaian yang dinyatakan dalam peraturan *'Industry Code of Practice for Indoor Air Quality'*. Sebanyak 27.4%, 28.0%, 28.5%, 34.2%, 31.4% dan 29.1% penghuni bangunan masing-masing mengalami gejala sakit kepala, hidung berair, sakit tekak, keletihan yang ganjil, mengantuk, dan demam. Kelaziman SBS yang ditaksir ialah 35.6%. Hasil dari pelbagai regresi logistik menunjukkan bahawa peningkatan purata RH dikaitkan dengan peningkatan dua kali lipat dalam laporan *'Sick Building Syndrome' (SBS)* (nisbah ganjil (OR) 2.38; 95% selang keyakinan (CI) 1.21-4.69). Responden yang merasakan suhu bilik terlebih panas adalah 0.47 kali kurang berkemungkinan mengadu tentang SBS (OR 0.47: 95% CI 0.29-0.77). Begitu juga, responden yang berpuas hati dengan keselesaan haba keseluruhan adalah 0.54 kurang berkemungkinan untuk melaporkan gejala kesihatan. (OR 0.54; 95% CI 0.34-0.85). Komponen utama dalam diatomite ialah SiO_2 (89.78%) dan sisa kaca juga mempunyai kandungan SiO_2 (68.46%). Komponen utama serbuk kerang ialah terdiri daripada 98.67% kalsium karbonat ($CaCO_3$). Sampel yang dihasilkan ini mempunyai luas permukaan khusus dalam lingkungan 5.744 m^2 / g – 14.765 m^2 / g, jumlah isipadu pori tercatat dari 0.028-0.08 cm^3/g dan mempunyai saiz pori dari 39.5 – 67.7nm. Hasil kajian daripada process penyerapan-penjerapan kelembapan menunjukkan bahawa produk terbaik ialah dengan pencampuran 60% diatomit, 30% sisa gelas dan 10% serbuk kulit kerang. Penjerapan selama 48jam oleh sampel mencapai 7.95% pada 75% RH. Kekuatan lenturan pada tahap 8.23 ± 1.8 MPa memenuhi standard seramik berliang komersial tersebut. Keupayaan penyerapan-penjerapan kelembapan sampel meningkat berikutan peningkatan kandungan diatomit. Penggantian sisa kaca sehingga 30% menunjukkan peningkatan kekuatan lenturan yang ketara dalam sampel yang dipadatkan kepada 80%. Secara kualitatif, semua sampel yang disinter mempunyai pencegahan atas *'gram-positive Staphylococcus Aureus'* dan *'gram-negative Pseudomonas Aeruginosa'*. **Kesimpulan:** Purata RH dalaman pejabat adalah dalam julat yang disyorkan mengikut Kod Amalan Malaysia. Kelaziman SBS adalah 35.6% dengan keletihan yang luar biasa sebagai gejala tertinggi yang dilaporkan. Peningkatan purata RH dalaman melebihi 68.4% merupakan penyumbang ketara kepada berlakunya gejala kesihatan dalam kalangan responden. Sampel D6W3C1 menunjukkan sifat yang amat memuaskan untuk pelbagai aplikasi dalam bangunan. Penyelenggaraan sistem pengudaraan secara berkala dengan pengawalan kelembapan dalaman yang inovatif harus dipertimbangkan untuk memastikan tempat kerja yang selamat dan sihat.

Kata Kunci: Kelembapan relatif, kelembapan, gejala kesihatan, bahan kawalan kelembapan, bahan kitar semula

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis were done under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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TABLE OF CONTENTS

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LIST OF TABLES

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LIST OF FIGURES

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LIST OF ABBREVIATIONS

ACMV	Air-Conditioning and Mechanical Ventilation
ASHRAE	American Society Heating, Refrigerating, and Air Conditioning Engineers
ASR	Alkali-silica Reaction
EDX	Energy Dispersive X-Ray
EPA	Environmental Protection Agency
FMHS	Faculty of Medicine and Health Sciences
GBI	Green Building Index
HCM	Humidity Control Material
HVAC	Heating, Ventilating and Air-Conditioning System
IAQ	Indoor Air Quality
ICOP	Industry Code of Practice
ICP-OES	Inductively Coupled Plasma Atomic Emission Spectroscopy
MBV	Moisture Buffer Value
MHA	Mueller-Hinton Agar
NIOSH	National Institute for Occupational Safety and Health
RH	Relative Humidity
SEM	Scanning Electron Microscope
SBS	Sick Building Syndrome
UPM	Universiti Putra Malaysia
WHO	World Health Organization

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter presents on the background of study, problem statement, significance of study and research objectives. In addition, research questions and hypotheses as well as conceptual framework are also discussed.

1.2 Background of Study

Malaysia is located in the equatorial region. The outdoor temperature can range from 23°C to 34°C with a high relative humidity (RH) reached 90% during daytime and 60% in the evening. With such climate, the usage of air-conditioning and mechanical ventilation (ACMV) system during working hours is crucial to ensure indoor temperature and relative humidity is within the thermal comfort of the workers (Jamaludin et al., 2015). Since most of the office workers spent around eight hours a day during working hours in their office, according to the Malaysia Employment Act 1955, thus the office indoor environment is crucial to ensure health, safety and well-being of the occupants (DOSH, 2016).

The equatorial climate dominated by monsoon season in Malaysia has raised multiple Indoor Air Quality (IAQ) concerns in public buildings with ACMV system. Several studies done related to the IAQ in air-conditioned buildings included Fadilah & Juliana (2012) shown prevalence of SBS recorded for new and old buildings were 47.5% and 33.8% respectively. Zamani et al (2013) assessed the relationship between IAQ and prevalence of SBS among workers in two buildings in Selangor, Malaysia. The results revealed old building had higher prevalence of SBS with 68.2% compared to new building with 25.9%.

A study by Lian et al. (2007) which determined the source of IAQ problem in a new hospital in Johor, Malaysia shows that condensation happened on numerous surfaces such as glass windowpanes, metal door frames and walls. Damp spots and noticeable microbial are observed on walls, ceiling, floor and surfaces of furniture. High indoor humidity was recorded, and it was beyond the upper limit of relative humidity of 70% and this further confirm the indoor moisture content provide conducive condition for mould growth. Wong et al. (2008) suggested that bioaerosols level such as bacteria and fungi would be associated with thermal parameters in air-conditioned spaces. Air temperature would increase when ACMV system is turned off, thus condensation happened on the

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various chilled surfaces as well as inside the ACMV system thus encourage the growth and spreading of indoor microbial.

High indoor humidity or dampness not only promote and encourage growth of microbial, causing building damage but also associated with various health effects such as sick building syndrome (SBS). Engvall et al. (2001) shows that building dampness in dwellings such as high air humidity and structural building dampness is correlated to a distinct increase of health symptoms compactible with the SBS after controlling confounding factors. Another study of Gunnbjörnsdóttir et al. (2006) shows that individuals living in damp housing with visible molds had a higher prevalence of respiratory symptoms such as breathlessness (OR 3.2; 95% CI 1.4-7.2) and long-term cough (OR 2.7; 95% CI 1.2-4.0). Moreover, Chua et al. (2016) found strong correlations between indoor temperature, humidity and illuminance with symptoms including felt stuffy, fatigue and difficulty in concentration which directly reduced work performance and productivity of employee. It said that employee working under high humidity will mostly felt stuffiness and easily tired thus affects their quality of work. There are increasing attention being paid for the effects of indoor dampness in buildings towards occupant's health and the economic lost due to building damage and recovery afterward.

According to Kamaluddin (2010), sources of humidity in a building includes ventilation from outside air, infiltration from outdoor through enclosure cracks, air exchange through door or window operation, wet surfaces, people, air permeation through walls, equipment and materials generating moisture and leakages. Besides usage of ACMV system in the building to regulate indoor air temperature and RH, the architectural features of a building will also affect the indoor thermal condition. For instance, a building in Malaysia has brick wall with 115 mm thick and built in 15 mm cement plaster on both sides (Aziz and Adnan, 2008). Moisture ingress from outdoor towards indoor is prevented by positioned a vapour barrier on the outmost layer of the exterior wall (Zainal Abidin, 2012). However, it does not help in balancing the high indoor relative humidity buildup in an air-conditioned office when the efficiency of dehumidifying of ACMV system is decrease due to excessive cooling to lower the indoor temperature.

The increasing awareness towards green building and healthy indoor environment has raised the interest in indoor humidity control technologies both in developed and developing countries including Malaysia. The government has encouraged greener building developments and opportunities through various initiatives such as the energy audit in government buildings, green tax incentives and the introductory of Green Building Index (GBI). To reiterate an earlier point, humidity control materials (HCM) such as activated carbon or zeolite, calcium chloride, and silica-gel incorporated into wall surfaces or tiles can be used to regulate indoor relative humidity through autonomous adsorption-desorption of water vapour in the air by the different of humidity gradient inside and outside the HCM. Therefore, incorporation of HCM in building materials for old or new

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buildings in order to increase energy efficiency, improve indoor environmental quality and sustainable building management is favorable. Nevertheless, the HCM made of organic materials can be flammable, frail and non-durable, while inorganic materials are luxurious, exhibit deprived water adsorption and even potentially hazardous to human (Vu et al., 2011).

Development of HCM with favorable humidity regulating capabilities by merging diverse elements is under research and widely discussed such as in European Countries (Karaky et al., 2019; Chennouf et al., 2018; De Rossi et al., 2018) and in China (Liu et al., 2019; Wang et al., 2009; Zhang et al., 2009; Kang et al., 2007). The flexibility of HCM development is demonstrated by raw materials including lime mortars, amorphous fumed silica, bio-composites, pulverized limestone with inorganic salts, thermoplastic strengthened with sawdust and zeolite-cement (Tsutomu et al., 2007; Martin et al., 2009). However, these solutions are not readily available due to the costly production process with the use of expensive starting materials and high sintering temperature.

1.3 Problem Statement

Building dampness exposure and related-health symptoms among inhabitants is caused by insufficient knowledge and understanding of the seriousness of dampness problems among building designers, developers, landlords, proprietors, and building users (NIOSH, 2013). Fisk et al. (2011) conducted a study in the stock of U.S. office buildings estimating the costs and benefits of implementing scenarios maintaining ventilation rates at above 10 or 15 l/s per person, reducing dampness and mould problem which could improve indoor environment. The collective yearly economic advantage from the settings is approximately USD$20 billion comprised of increased work productivity, lesser SBS symptoms, decreased absenteeism, and better thermal comfort.

There were also several studies in Malaysia conducted to assess the relationship between IAQ and SBS among inhabitants in various settings. Norhidayah et al., (2013) found the main factors for prevalence of SBS were ventilation and accumulated indoor air pollutants in three public buildings. Saad et al., (2016) study the association between SBS among laboratory workers and indoor air quality and found that prevalence of SBS among occupants in dry laboratories (20%) was significantly lower compared to wet laboratories (45.4%). Fauzan et al., (2016) investigate the relationship between IAQ and SBS reported by workers in two different buildings that are retrofitting and purpose-built building. Pollutants such as carbon dioxide, PM_{10} and bacteria count in retrofit building exceeded the standard level. These results of studies showed the indoor air quality as a risk factor for occurrence of SBS but the remedial action is limited such as maintenance or improve of the ventilation and housekeeping to reduce indoor air pollutants. This urges for effective intervention to ensure worker's health and wellbeing to sustain their work performances in the workplaces.

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From the benefits of controlling ventilation rates, reduces dampness and mould exposure mentioned above, Malaysia who have high temperature and humidity throughout the year needs to consider approaches for regulating indoor humidity emphasized on the operative, amenities, and costs of energy. Apart from the conventional thermal regulation by ACMV system, the currently common practices for humidity control are either through electric dehumidifier or moisture absorber in container form with limited capacity such as the famous brand Thirsty Hippo. The disadvantages of the usage of the electric dehumidifier are the obvious costs of energy as it required electricity to run even though some dehumidifier have energy-efficient functions, specific water reservoir capacity that requires draining of the tank and also cleaning of the air filter and the price can range from few hundreds to few thousands. Moisture absorber such as calcium chloride is used in the Thirsty Hippo Dehumidifier, that is suitable for cupboards and small spaces, needs frequent changing which can be within 4 weeks or less depends on the different environment, and need to be placed away from heat and children.

Humidity control materials in various form such as paint, wall board, coating on walls, porous ceramic tiles, composite materials and etc have been produced and studied by researchers from China, Korea, Taiwan and etc. The application of humidity controlling material has the advantages of no addition energy consumption, environmental-friendly, easy to handle and recyclable (Karaky et al., 2019; Liu et al., 2019 and De Rossi et al., 2018). Application of HCM is most recommended in indoor environment with specific humidity ranges from 30% to 80%. Silica gel, volcanic ash, diatomaceous earth and sepiolite, were some of the porous materials that were used as raw materials for fabrication of HCM. The effectiveness of HCM in regulate humid conditions is enhanced by these materials with large surface area and porosity, as well as mesopore structure. However, some of the raw materials used are costly due to the sourcing of numerous starting materials and the fabrication procedure, flammable, fragile and perishable organic materials. Meanwhile, the selection of inorganic matter as initial materials may be harmful to health and possessed low water absorption.

Therefore, the compositions of the raw materials selected to produce the HCM which is applicable in Malaysia air-conditioned buildings is essential. This is because the pore structure, pore volume, adsorptive and desorptive performances and flexural strength of final product are affected by the interaction between the selected raw materials. As such, this study will provide a method of preparation and characterization of diatomite, recycled glass and cockle shell powder composite that studied the properties of the initial materials and samples fabricated, the optimal preparation condition, humidity controlling performance and antibacterial ability. The final product is expected to show outstanding capabilities as a HCM with sufficient flexural strength, antibacterial characteristics as well as utilized for walling materials at economic cost.

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1.4 Significance of Study

Relative humidity levels less than 25% can cause chapping, irritation and discomfort due to dry skin and mucous membranes. Low level of humidity also impedes the processing of computers and paper-operating equipment through increases static electricity. All these symptoms of discomfort can cause workers to take medical leave and thus lower productivity. Conversely, high indoor humidity leads to condensation either on interior or exterior surfaces and between building envelope thus result in development of harmful microbials. Fungi such as *Stachybotrys* and *Penicilium* grown due to high level of humidity, produce myotoxins which causes eyes irritation, cough, airway contagions, headache, and lethargy. In addition, extra maintenance work must be carried out to remove the wall of building with moulds or fungi lead to monetary loss. Thus, regulate and maintaining indoor RH in the acceptable range is crucial for health and well-being of the inhabitants.

Humidity control materials (HCM) as an innovative way of controlling indoor relative humidity gained interests from various researchers and have been widely studied. According to Vu et al. (2013), HCM is capable to adsorb water vapour from air and release back into the ambient air. This product has been promoted for dwelling and air tight seal of buildings and replace the usage of mechanical moisture absorber, air purifier and air-condition system in long term. Bo & Qian (2016) stated that HCM does not required any equipment or power source to operate due to its sensitivity towards gradient difference in ambient humidity and temperature. Although the humidity control materials have gained increasingly attention, the production and the possible raw materials involved is still less reported in Malaysia.

This study uses natural porous material, diatomite which has large reserved and abundant mesopore structure, blended with powdered recycle glass and cockle shells powder to develop novel humidity control material suitable for Malaysian's air-conditioned building application to regulate indoor humidity. This humidity control material may provide alternative for indoor environment improvement application economically, energy-free and safe. The final product also aims to exhibit antibacterial properties derived from the chemical compositions of cockle shell powder thus avoid being the new breeding ground for microorganisms. The ability to maintain the indoor humidity using humidity control material within the range of 40-70% as recommended in the Industrial Code of Practise on Indoor Air Quality (ICOP) (2010) will safeguard health, safety and well-being of the workers as well as increase morale and productivity.

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1.5 Research Aim and Objectives

Research aim:

Humidity control materials development using natural porous substances and recyclable matter has not been widely reported in Malaysia. The aim of this study was to produce a composite compact from diatomite, powdered waste glass and cockle shells powder that is suitable for indoor humidity controlling and is antibacterial. A range of factors that affect the feasibility of the production of humidity control material and the various testing to characterize the performances of the material were assessed.

Research objectives:

1. To determine the relative humidity of the selected office rooms and Sick Building Syndrome experienced by building occupants.

2. To identify chemical compositions of diatomite, clear recycled glass and Anadara granosa shell powder.

3. To develop a humidity regulator made of diatomite, recycled glass and shell powder blended at specific ratio and sintered at high temperature.

4. To determine the moisture regulating ability, surface morphology, pore structure, strength of samples and antibacterial properties of samples on *Pseudomonas Aeruginosa* and *Staphylococcus Aureus*.

1.6 Research Questions

1. What is the range of relative humidity measured in 32 selected office workplace and does it within the acceptable range and what symptoms of Sick Building Syndrome most experienced by building occupants?

2. What are the chemical compositions of diatomite, clear recycled glass and Anadara granosa shell?

3. Is it feasible to develop a prototype of humidity control material by mixing diatomite, glass and cockle shell powder at different ratio and sinter at high temperature?

4. What is the water vapour adsorption-desorption capability, pore structure, surface morphology, flexural strength and antimicrobial performances of samples?

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1.7 Research Hypotheses

1. The mean of relative humidity for 32 selected office rooms is within the acceptable range of 40-70% and building occupants experienced some Sick Building Syndrome (SBS).

2. Diatomite and waste glass has high contents of silicon dioxide and cockle shells powder mainly consists of calcium carbonate.

3. The particle size of diatomite and waste glass are homogeneous, suggesting the homogeneity of the mixture to improve the mechanical milling and chemical processing of porous formation and co-precipitation processes of products. The addition of cockle shell powder enhanced the antibacterial characteristics of the final products.

4. The final products show excellent humidity controlling abilities, with fine flexural strength satisfying the standard of porous ceramic and will have antibacterial properties.

1.8 Conceptual Framework

Figure 1.1 is the conceptual outline of this research. Indoor humidity not only is the main parameter for thermal comfort but is also an important determinant for the survival and spreading of biological contaminants including bacteria, fungi, spores, virus and others. There are well-establish association between excessive moisture and the growth and spreading of biological contaminants in indoor environment. Moreover, indoor dampness and mould exposure can jeopardy the health of the inhabitants. Thus, SBS among office workers was assessed and the indoor relative humidity in selected offices was measured. The association between indoor RH and health symptoms reported among respondents was determined.

The high indoor relative humidity needs immediate intervention apart from the usage of ACMV system which will increase the energy consumption. Humidity control materials incorporated in walls as building material is worth exploring as it does not require any energy in regulating the RH, environmentally friendly and less maintenance needed. Therefore, samples were prepared from the sintering of diatomite, waste glass and cockle shells powder and their properties were examined. The sintered samples were tested for their moisture adsorption-desorption abilities, porous and mechanical properties as well as the bactericidal effects on Pseudomonas aeruginosa and Staphylococcus aureus.

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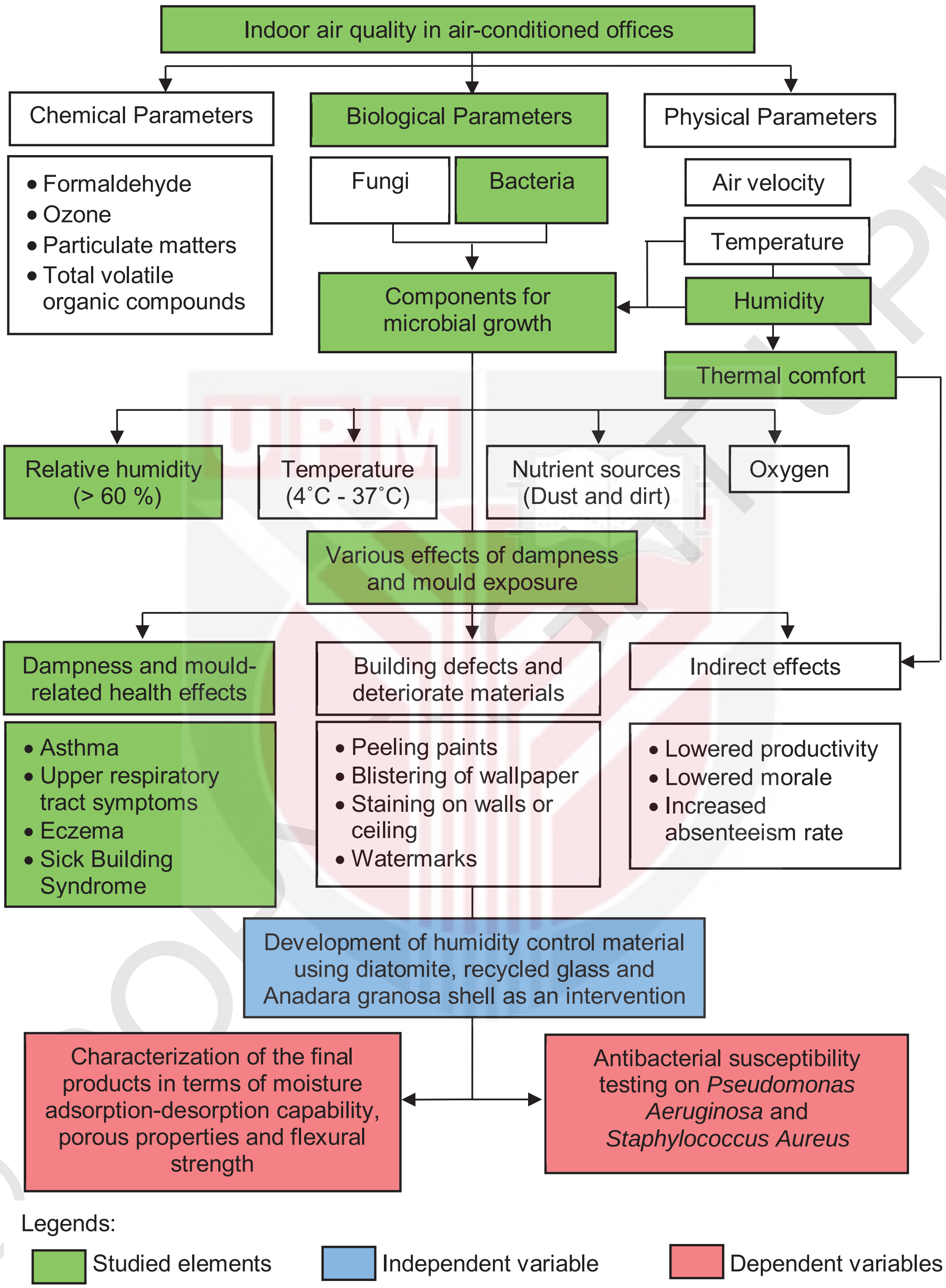

Figure 1.1: Conceptual framework of research

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