行政院所屬各機關因公出國人員出國報告

(出國類別：其他)

參加第十屆健康建築物國際研討會

服務機關：行政院勞工委員會勞工安全衛生研究所

姓名職稱：洪粕宸 副研究員

派赴國家：澳大利亞

出國期間：101 年 7 月 7 日至 7 月 13 日

報告日期：101 年 9 月 20 日

摘 要

第十屆健康建築物國際研討會，在 2012 年 7 月 8 日至 12 日於澳大利亞布利斯班舉辦，今年會議主軸主要涵蓋三大面向：（一）探討節能與室內空氣品質間的平衡、（二）綠能、城市設計科技與人口成長和都市化帶來環境污染問題間的調和、（三）職場或居家環境室內生物性氣膠暴露、傳播與控制方法探討。可讓與會者在短時間內明瞭室內空氣品質相關研究及管理策略發展趨勢。會議是由 International Society of Indoor Air Quality and Climate (ISIAQ)國際室內空氣品質與氣候學會與主辦國澳大利亞昆士蘭科技大學共同主辦之國際研討會。

此次大會除了安排 6 場的開場專題演講，9 場小型的專題討論會議外，每天針對 7 個不同主題（包含 14 個 workshop）進行 3 場次的論文發表，從室內化學污染逸散、通風控制、人類對於室內環境的反應、綠能永續建築、熱舒適問題、到微生物與其他微粒影響等等相關的新知識、新技術、新資訊，內容相當多元廣泛，且從不同的面向深入剖析，相當豐富。本所發表的研究成果為：「通風管道即時殺菌單元建立與測試研究」（Development and Testing of a Real-time Sterilization Unit Using in Ventilation Duct），對於空調系統殺菌有相當成效，也獲得與會人士多所詢問。

研討會中有關微生物控制及調查的相關議題，其實本所亦有相關類似的研究，顯示本所的研究規劃多能適時與國際議題接軌，探討國際關注、

本土性職業衛生的最新議題。觀察這次研討會中有關微生物的相關研究成果，個人覺得在此研究領域仍有許多值得努力的研究方向，例如：發展並加以驗證對於高生物風險性職場微生物可行的例行監測技術；較長遠的目標是否能建立職場微生物 TLV 建議值等等，應是目前仍需努力的方向。

目　次

會議簡介

2012 年「第十屆健康建築物國際研討會」(Healthy Buildings 2012 10th international Conference),為 International Society of Indoor Air Quality and Climate (ISIAQ) 國際室內空氣品質與氣候學會及主辦國澳大利亞昆士蘭科技大學共同主辦之國際研討會,吸引室內空氣品質、通風空調、機械工程等領域數以千計的產官學者參加,促進創造健康、舒適、具有生產力的室內環境相關經驗與技術的交流。國際室內空氣品質與氣候學會為室內環境領域最重要之全球性學會,該學會於 1992 年由 109 位國際專家學者籌組成立,為一國際上少數跨領域之國際學會。該學會成立之重要目的有二: (1) 加強與促進室內空氣品質及氣候在室內環境設計、建築設計、人員使用、環境評估及健康等相關科學研究與合作。(2) 促進國際及跨領域間溝通及資訊交流,並以出版室內空氣品質及氣候相關科學文獻、舉辦或支持相關會議舉行、發展及制訂相關法條或規範以促進各國室內空氣品質與氣候條件,積極與世界各國政府單位及其他相關室內環境品質之團體合作以達成此目的。ISIAQ 的會員主要包含室內空氣品質各領域之專家學者、政府及相關政策與法規專家、醫學專家、職業衛生專家、建築、土木及空調工程師、建築師、環境法專家等跨領域專長,會員分佈遍及全世界,ISIAQ 在會務推動上及會員共同參與上,每年主要包含審查及出版學會科學期刊

Indoor Air（impact factor: 3.151），出版相關室內環境品質領域之新聞、組織相關研究室內環境品質新興議題之專門研究小組(Task forces)，並於 ISIAQ 相關研討會中集會討論未來發展重點。國際室內空氣品質與氣候學會 ISIAQ 固定每三年分別舉辦國際性健康建築(healthy buildings)及室內空氣(indoor air)研討會，每次會議均有上千名專家學者參與，亦是每年室內環境科學、環境工程、建築及環境醫學等跨領域的學術盛事。

今年會議從 7 月 8 日至 12 日在澳大利亞布利斯班之 Convention & Exhibition Centre 舉行，共計有多國千餘相關人員參與會議，今年的會議主軸主要涵蓋三大面向：（一）探討節能與室內空氣品質間的平衡、（二）綠能、城市設計科技與人口成長和都市化帶來環境污染問題間的調和、（三）職場或居家環境室內生物性氣膠暴露、傳播與控制方法探討，除了安全衛生相關器材用品展覽之外，並有 600 餘篇論文在特別的 workshop 及平行的 sessions 進行口頭報告及海報論文在會場輪流展出。本次研討會亦包含 6 篇專題演講，分別由大陸清華大學的 Jiang Yi 教授、紐西蘭 Otago 大學的 Phillipa Howden-Chapman 教授、澳洲 Curtin 大學的 Peter Newman 教授、亞洲 Clean Air Centre 的 Bert Fabian 經理、英國 Braford 大學的 Clive Beggs 教授及加拿大 Calgary 大學的 Raymond Tellier 教授主講，與 14 場次的專題討論會(workshops)，以及 9 場次 panel discussions。其中在發表的 600 餘篇論文中，本所及台灣學者共有 28 篇研究成果發表，在全球化的時代，此研討

會提供了探索室內職業與環境衛生問題的最佳管道之一。

目　的

目前在職場中有訂定勞工作業環境空氣中有害物容許濃度標準，廣意上我們也可以稱之為職場的室內空氣品質，然而在許多的情形中，職場環境和一般民眾的環境是互相相關的，最典型的就是醫療院所、勞工需作業或經常出入之就業場所內公共場所，因此，職場室內空氣品質之議題亦需相當重視。

本所出席此次第十屆健康建築物國際研討會，除了發表本所的研究成果：「通風管道即時殺菌單元建立與測試研究」(Development and Testing of a Real-time Sterilization Unit Using in Ventilation Duct)（如附件）外，亦於會中與各國專家學者交換室內職業環境衛生研究的成果與心得，汲取新的資訊和技術。

過　程

此次第 10 屆的健康建築物國際研討會，舉辦的場所在澳洲布利斯班靠近南岸公園的 Convention & Exhibition Centre，會期有 5 天，來自全球各地的出席人員超過 1000 位。研討會召開時，同時間分 8 個場地依不同議題分頭進行，共計有 6 百多篇的室內空氣品質相關論文技術發表。呼應著會議的主軸「(一) 節能與室內空氣品質間的平衡、(二) 綠能、城市設計科技與人口成長和都市化帶來環境污染問題間的調和、(三) 職場或居家環境室內生物性氣膠暴露、傳播與控制方法探討」，會議安排 3 天的開場專題演講。第一天議題的講者分別由大陸清華大學的 Jiang Yi 教授和紐西蘭 Otago 大學的 Phillipa Howden-Chapman 教授主講；Jiang Yi 是建築系的教授，此次演講的主題是建築物能源使用與居住者行為及建築物使用模式的關聯性，在他的演講中談到目前各建築物能源使用情形的差異，主要不是在所使用的科技不同，而是在居住者行為及建築物使用模式，因此在評估建築物能源效率的時候，根據實際可能的使用模式來設定參考使用模式就顯得相當重要。Phillipa Howden-Chapman 是公共衛生系的教授，她的演講中提到在過往研究中發現，改善室內環境不僅可促進健康狀況的改善，也意外發現同時可降低能源的需求。第二天議題的講者分別由澳洲 Curtin 大學的 Peter Newman 教授和亞洲 Clean Air Centre 的 Bert Fabian 經理主講；Peter Newman 是永續發展政策研究所的教授，此次演講的主題是與時間競賽-人口、都市

成長與創新奇蹟，他談到目前在人口成長、石化燃料的消耗及車輛使用需求，看到了降低的趨勢，對於未來提供了希望，而都市的改變及創新的科技對於這些趨勢能否持續，扮演著重要的角色，且健康的問題可運用在支持都市正向改變的措施上。Bert Fabian 經理分享了在亞洲新興經濟體國家，觀察到都市化及汽車化所帶來環境空氣品質、室內空氣品質的影響，並且提供運用”都市排放快速評估方法”（Rapid Assessment of City Emissions）的實例研究讓大家了解。第三天議題與我工作上較有相關，主要談到感染性生物氣膠，講者分別由英國 Braford 大學的 Clive Beggs 教授及加拿大 Calgary 大學的 Raymond Tellier 教授主講；Clive Beggs 是工程設計與技術系的教授，此次主要談到醫療機構感染的傳播，他以英國的經驗為例，過去對於抗藥性金黃色葡萄菌感控，以手部清潔為主要對策，然而抗藥性金黃色葡萄菌的感染卻逐年上升，2007 年後改變策略增加病房深度清潔、病人篩檢等等措施，在此之後感染下降超過 50%。從英國的感控經驗中可以知道，事實上環境控制的重要性，遠比我們想像中更重要，因此建築師、工程技術人員及設施管理者在感染控制上扮演一定角色。Raymond Tellier 教授是一位醫學微生物學者，演講中藉由文獻回顧傳染性生物氣膠（部分以流感為例）傳播及感染機制、溫溼度等物理性參數、通風換氣、病毒載量、感染劑量等等的影響，最後並綜合現有對於生物氣膠物理性及生理性資料的瞭解，認為降低室內生物氣膠的傳播，最基本的介入可包含通風換氣、

溫溼度的控制、對於 upper room 利用紫外線殺菌，而且這些措施可以協同運作。

大會除了安排 3 天的開場專題演講外，也另外安排了 14 場小型的專題討論會議，包括建築物環境微生物探討-包含樣本分析技術（Microbiology of the Built environment）、通風對室內空氣品質的影響（The Role of Ventilation in Indoor Air Quality: The Need for Better Understanding, Measurement and Reporting）、探討個人控制方法與熱舒適（Personal Control and Thermal Comfort）、由全球性調查探討生活暴露對兒童氣喘、過敏的影響（Children’s Asthma and Allergy and Their Modern Life Exposure-DBH Worldwide Study）、學童教室空氣品質、健康及表現對建築物設計和管理的暗示（Indoor environmental quality in classrooms, pupils’ health and performance and its implications for school building design and management. what do we know）、室內氣膠個人暴露情形（Personal Exposure to Indoor Aerosol: how well do we understand it?）、可攜式空氣清淨機標示系統未來改進方向與需求、（Shortcomings of Current Portable Air Cleaner labeling Programs: Exploring Directions and Needs for the Future）、半揮發性有機化合物（Semi-volatile organic compounds, SVOCs: dispatches from the front）、石綿及其他潛在室內污染物（Asbestos and other potential indoor contaminants – perception versus risk from renovation, restoration, and clean-up of buildings）、揮發性有機化合

物逸散測試認證（Validation of VOC and formaldehyde emissions testing: Reference materials and analytical check standards）、睡眠時污染物暴露情形（Inhaling while Dreaming: Human Exposure to Pollutants while Sleeping）、氣候變遷對室內環境的影響（Indoor Environments and Climate Change: Priorities for ISIAQ）、綠色清潔產品效果及對室內空氣品質的影響（Defining Clean & Green in Terms of the Unseen Fraction: “Are the terms green and clean compatible?” and “How does one gauge the degree of surface contamination in buildings?”）、室內空氣揮發性有機化合物限值（All about Lowest Centration of Interest）等等議題。

本所之研究成果「通風管道即時殺菌單元建立與測試研究」（Development and Testing of a Real-time Sterilization Unit Using in Ventilation Duct），被安排於大會舉辦的第 2 天進行發表，主要是以開發完成之即時殺菌單元進行醫院實地驗證，實驗以選擇中部某署立醫院兩間病房及一間護理站，先進行安裝殺菌單元前背景細菌、真菌分佈濃度測試，並接著安裝鎳篩網－紫外光殺菌單元，進行安裝後細菌、真菌分佈濃度測試。生物氣膠粒徑分佈、殺菌效率之比較方面，主要利用 AGI-30 及氣動粒徑分析儀（aerodynamic particle sizer, APS）進行採樣及培養計數。本研究選擇不同管道表面風速進行比較測量，也量測管道內濕度、溫度變化，並比較紫外光殺菌率、燈管衰減率與損耗功率，以及鎳篩網老化程度。

結果發現安裝殺菌單元的病房，鎳篩網在未披覆矽油時，在風管風速 2.4～3.5 m/s 時會造成氣膠彈跳現象，使得 4.7 μm (以六階安德森採樣器截取粒徑為例)以上大粒徑範圍氣膠捕集率下降；而在風管風速 1.4～1.9 m/s 時，反而因為機械力之過濾捕集機制無法發揮，無法針對小於 1.7 μm 以下之生物氣膠進行捕集殺菌。因此在鎳篩網未披覆矽油時，風管風速 1.4～3.5 m/s 範圍內，最佳生物氣膠捕集殺菌範圍為 1.7～4.7 μm，而 AGI-30 採樣器評估細菌殺菌率平均約為 99.3 %。本所開發之鎳篩網殺菌裝置披覆矽油後，可以防止大粒徑生物氣膠彈跳，裝載於中央空調系統之主要高速管道，可以提升鎳篩網機械力捕集過濾機制。而殺菌單元可以選擇性開啟紫外燈數分鐘進行殺菌，即可達良好殺菌效能，不必持續開啟，避免紫外光快速衰減能量，及降低鎳篩網之強度結構，也可以減少能量損耗。

因 5 天會議期間各國發表不同議題之論文眾多，雖其內容各有所長及頗具研究、實用價值，惟受限於時間，在無法兼顧情形下，除了 6 場次的專題演講外，僅就未來對單位領域研究策略或方向趨勢有所助益或啟發、個人工作領域及興趣等因素考量下擇要參加，主要接觸的主題包含通風控制、微生物控制，及熱舒適等議題。

俄羅斯學者發表了一篇結合臭氧和濾網的空間消毒技術，這項技術概念是將室內空氣先經過初級濾網除去較粗的微粒，再利用尖端放電讓生物性微粒帶電並產生臭氧，帶電的生物性微粒被濾網捕集後，再經由臭氧殺

菌如此可同時將濾網除污，而在後端設計一活性碳濾網去除 VOC 和臭氧等物質，報告中並指出經過這項裝置後，其殺菌率接近 100%，而且臭氧濃度低於 5 ppb。這項技術主要可用於一般室內空間殺菌，個人認為較不適用於空調管道，因為管道中風速較快，而本所開發之殺菌技術主要可運用於空調管道，應用性有明顯的區隔。波蘭的勞工保護國家研究機構在此次會議中提出不同通風系統對於勞工辦公環境微生物影響的研究，報告中指出自然通風系統下，辦公室環境細菌和真菌濃度介於 10-1598 CFU/m^3，而機械通風及空調系統下，辦公室環境細菌和真菌濃度介於 20-410 CFU/m^3 和 10-530 CFU/m^3，明顯較自然通風狀態下的濃度低，而其中活性細菌大約有 0.3－1%，主要菌種為革蘭式陽性球菌及桿菌，粒徑大都分布在 1.1 到 3.3 μm 和大於 7 μm 兩個區塊，有可能進入呼吸道造成刺激、過敏發炎反應，因此有效的通風換氣系統可確保勞工較佳的辦公環境空氣品質，而且在進行辦公環境廣泛性衛生評估，報告也建議應包含總細菌的部分。而在報告中個人較有興趣是有提到波蘭對於公共服務的辦公大樓有生物氣膠 TLV（threshold limit values）建議值的草案，嗜常溫細菌與真菌都訂在 5000 CFU/m^3，經詢問如何訂出建議值，才知道這個草案也是 review 學者的不同研究歸納出來，但也因為仍有爭議性所以僅止於草案。

會議中尚有多篇針對微生物控制技術的探討，例如利用微波（microwave radiation）進行表面消毒測試，波蘭學者運用不同強度的微波

強度，對不同材質表面上不同細菌、真菌孢子進行測試，結果發現細胞毒性會受到菌種特性、濃度、表面材質特性、微波強度及暴露時間等因素影響，總體來看利用微波照射確實可達到某種程度的殺菌效果，但比較值得注意的是某些菌種（例如：*T. vulgaris* 或是 *P. brevicompactum*），在經由微波照射反而有擴張增長的情形，因此應用這項技術時這些情形亦必須納入考量。此外德國的學者應用紫外線（UVC）進行表面消毒測試，紫外線消毒過去文獻已充分揭露其有效性，在此研究中提供在公共場所（例如廁所）約多久時間需使用多少強度的紫外線照射多少時間，可以維持公共場所表面微生物在一定程度之下，但是使用紫外線消毒須注意的是由於其對人的皮膚及黏膜會造成傷害，因此需要有相關的安全設計方能確保使用安全。哈佛大學的學者發表利用 Engineered Water Nanostructures (EWNS) 進行微生物控制，其是將水分子利用電灑作用（electrospraying）使其成為帶電的粒子，並產生 ROS 和 RNS 等強氧化物，可進行殺菌作用，在測試的 *Serratia marcescens.*和 *Staphyloccocus Aureus.* 兩種菌種中，可以獲得 1-2 個 order 的降低效果，但在產生內孢子的 *Bacillus subtilis.*則沒有效果，顯示仍有其限制性。在微生物控制這個領域，會議中也有其他關於利用二氧化鈦、過氧化氫、次氯酸水、氫氧自由基進行微生物控制的相關研究。總體而言，目前對於不管是室內或職場環境，對於微生物控制有各式各樣的方法，但並無一放諸四海皆可適用的準則，仍需視實場狀況再決定可行的控制方法。

有關熱舒適的議題，丹麥的學者在熱環境下測試了幾種冷卻方式（包括對流風扇、個人通風提供新鮮空氣、輻射板、輻射板搭配風扇）對病態大樓症候群徵狀（SBS symptons）的影響，結果發現無論何種方式，暴露時間的影響最大，時間越長徵狀增加越多，而在測試的幾種方式中，相對徵狀較低的是應用個人通風提供新鮮空氣，以及輻射板搭配風扇，而徵狀增加最多的是利用對流風扇，但不論何種方式，都會增加眼睛的刺激。大陸的學者發表了關於戶外熱環境的評估方式，首先調查氣象、個人年齡、穿著、戶外空間尺寸資料等等基本資料；接著利用這些基本資料透過 CFD 和輻射計算的模式，獲得空氣溫度、相對溼度、風速、平均輻射溫度等資訊；最後再運用舒適模式計算出舒適指標 PMV（predicted mean vote），研究發現 PMV 的分布和太陽輻射、風速及人員活動有很強的相關性，因此建議 PMV 可以作為評估戶外熱舒適的重要指標。其他關於熱舒適的研究，尚有評估熱環境下人體熱感知及相關熱傳導的評估研究，以及相關職場（例如火車駕駛）熱舒適調查，另外由於氣候變遷對於室內外環境熱舒適的影響，亦有多篇研究進行。

綜觀接觸到的微生物控制及調查等議題，本所過去曾經進行過這些相關議題的職業衛生研究也相當多，例如本次發表的通風管道殺菌技術、次氯酸水殺菌技術應用、複合放電-LEDUV-金屬觸媒清淨技術，另外針對職場環境生物性暴露調查等（例如使用金屬加工液作業產生之生物氣膠濃度

特性調查，HVAC 系統中濾網細菌真菌生長情形，在此會議中亦有類似研究發表)。顯示本所的研究規劃多能即時與國際議題接軌，探討國際關注、本土性職業衛生的最新議題。

心得及建議

1. 這次參加第十屆健康建築物國際研討會，會議內容從室內化學污染逸散、通風控制、人類對於室內環境的反應、綠能永續建築、熱舒適問題、到微生物與其他微粒影響等等相關的新知識、新技術、新資訊，內容相當多元廣泛，且從不同的面向深入剖析，相當豐富，個人收穫頗多，此外研討會中有關微生物控制及調查的議題，本所過去曾經進行過這些相關議題的研究也相當多，顯示本所的研究規劃多能即時與國際議題接軌，探討國際關注、本土性職業衛生的最新議題。
2. 研討會中對於建築物室內通風控制及熱舒適等研究議題，有許多基礎及新穎的相關研究發表，建議日後相關研究同仁可持續關注及出席此類相關研討會議，藉以了解相關議題發展情形、技術及實務上可用訊息。
3. 觀察這次研討會中有關微生物的相關研究成果，個人覺得在此研究領域仍有許多值得努力的研究方向，例如：發展並加以驗證對於高生物風險性職場微生物可行的例行監測技術；職場微生物與其他化學物質或污染物之間的交互作用情形，可能影響微生物的特性及生長情形，或同時暴露於這些物質對於作業人員可能的影響；目前氣候變遷對於職場（如農牧業）微生物可能的影響；職場人員行為及作業型態對於相關暴露的影響；較長遠的目標是否能建立職場微生物 TLV 建議值等等。

附件一 本所發表之研究論文

Development and Testing of a Real-time Sterilization Unit Using in Ventilation Duct

Po-Chen Hung[1], Chane-Yu Lai[2], Yu-Hung Huang[2], Shin-Ran Wun[2], Wen-Chi Huang[2]

[1]Institute of Occupational Safety and Health, Council of Labour Affairs, Taipei, Taiwan
[2]Department of Occupational Safety and Health, Chang Shan Medical University, Taichung, Taiwan

SUMMARY

Recent study results in Taiwan have shown high concentration of microorganisms that sampled from the hospital HVAC (heating, ventilating, and air conditioning) system. As it is hard to empty the whole hospital patients and then sterilize the ventilation ducts, a real-time sterilization unit that located in the ventilation duct is a useful method to control the bioaerosol-transmitted infections in hospitals.

The objective of this research was to develop a real-time sterilization unit and evaluate the unit under wind tunnel system and in field study. The real-time sterilization unit consists of Nickel-based filters and UVGI (ultraviolet germicidal irradiation) modules. In the experiment, a Collison nebulizer was used to generate *Bacillus subtilis* spores and *Escherichia coli* as challenge aerosols. Two Andersen 6-stage samplers were used to sample bacteria concentration upstream and downstream of the real-time sterilization unit. Moreover, two hospital wards and one nurse station located in central Taiwan were recruited in the field study. The results showed the real-time sterilization unit could be used to reduce the bacteria concentration under wind tunnel conditions. In field study, the real-time sterilization unit that coating with silicone oil revealed less large size bioaerosol bounce during velocity between 1.8 to 2.5 m/s in the ventilation duct. The average bacteria disinfection rate of ward 1, ward 2 and nurse station was 88.6 %, 92.5 % and 88.8 % by using six-stage Andersen impactor, respectively. The conclusions recommended that the Nickel-filter-based real-time sterilization unit should coat with silicone oil to avoid the large bioaerosol bounce effect, and was better to use the unit in main duct under high face velocity.

KEYWORDS
Decontamination and disinfection, field studies, filtration

1 INTRODUCTION

Recent research results in Taiwan indicated that there were various bacteria and fungi survive inside the hospitals' ventilation ducts (Li & Hou, 2003). Two medical centres and one local community hospital were included in the research conducted by Yu et al. (2006). In these hospitals, two wards of airborne transmission-related departments at the end and head of the ventilation system were selected as the sampling locations. Sampling was performed at the ceilings of room supply air outlets and the breathing area 1.0~1.2 meter above the sickbeds. The same sampling method was also performed at the clinics of Pulmonary Care Department, Dental Department and Emergency Room. The highest bacterial concentration located at the ceiling of an air outlet was observed at the end of the clinic's ventilation system with an average of 2330.0 CFU/m^3, with the lowest at the head of the ward's ventilation system with an average of 57.3 CFU/m^3. The highest fungus concentration was observed at the end of the clinic's ventilation system with an average of 1383.3 CFU/m^3. For the breathing samples, the highest bacterial concentration was observed at the end of the ward's ventilation system with an average of 1227.9 CFU/m^3, with the lowest at the head of the clinic's ventilation system with an average of 160.2 CFU/m^3. The highest fungus concentration was observed at the head of the emergency room's ventilation system with an average of 1957.6 CFU/m^3. These results show that there were various bacteria and fungi inside the ventilation ducts of hospitals. Although high efficiency particulate air filters (HEPA) were mounted in the ambient air inlet of ventilation ducts, a great number of bacteria and fungi were still found at room supply air outlets due to contamination occurring in the long and dark ventilation ducts. Nevertheless, it was difficult to carry out sterilization procedures in the ventilation ducts since there were outpatients and in-patients in the hospitals all the time.

Conventional germicidal techniques include: using a general filter to collect aerosols in the air, using ultraviolet germicidal irradiation (UVGI) or combining photo-catalytic coating filter and UVGI to eliminate germs (Lee, 2003; Lin & Li, 2003; Lin & Li, 2003). However, the aerosol collection efficiency of a general filter is lower than HEPA due to its larger porosity and smaller packing density. Since air resistance affects the consumption of energy resource, a good filter should be equipped with efficient particulate collection as well as low pressure drop. Therefore, it is necessary to develop a filtration and sterilization device for ventilation ducts, which can significantly reduce the bounce-off phenomenon of bioaerosols, can effectively collect and eliminate bioaerosols at low maintenance cost. In addition, it should be applicable to the HVAC system with high airflow rate and wind velocity.

Consequently, porous filter media (made of foam or Nickel) and UVGI modules were used in this research to meet the requirement of "effectively collecting bioaerosols, and preventing bounce-off of aerosols, with sufficient time for sterilization".

2 MATERIALS/METHODS

A real-time sterilization unit developed recently was able to carry out real-time sterilization in ventilation ducts (Lai, et al., 2007). It combined 80 ppi foam filters and UVGIs to proceed with the sterilization. However, the foam-base sterilization unit would suffer from UV ageing, so a "nickel porous filter-UVGI" module was used in this research to evaluate the feasibility of routine duct-sterilization in hospitals. Besides evaluating the function of the sterilization unit, it was also tested in a wind tunnel system.

2.1 Real-time sterilization unit

The real-time sterilization unit combines 80 ppi foam filters and UVGI to proceed with sterilization. The constitution of the module is "joint foam (12 mm) — UVGI — joint foam (12 mm) — UVGI — joint foam (12 mm) — UVGI". With such constitution, the total filtration thickness of the foam is 36 mm (12 mm x 3). The UVGIs between the foam filters can effectively destroy the germs collected by the filters. The foam can be coated with silicon oil, thereby effectively reducing the aerosol bounce effect. Moreover, the overall filtration resistance will be reduced, as the filtration pressure drop is lower than HEPA. However, the weakness of the real-time sterilization unit is that the foam would suffer from UV ageing.

2.2 Other porous material: nickel filter

Other porous material, such as nickel filter, was used in this research in the expectation of preventing the disadvantage of foam ageing under UV irradiation as well as to extend the service life of the real-time sterilization unit. To consider filtration efficiency and pressure drop, 94 ppi nickel (similar to the porosity of foam), was selected. The average thickness of nickel filter was 1.7 mm. In addition, to conform to the design of previous tests of foam-based real-time sterilization units, 6 nickel filters were put together with thickness of 10.2 mm, and the constitution was: "joint nickel filters (10.2 mm) — UVGI—joint nickel filters (10.2 mm) — UVGI —joint nickel filters (10.2 mm) — UVGI". In such constitution, the total filtration thickness of the nickel filters was 30.6 mm (10.2 mm x 3).

2.3 Methods

Before evaluating the foam and nickel filters in a wind tunnel system, testing of the penetration rate was conducted to ensure that the filtration efficiency. In the wind tunnel testing experiment, an Andersen Single Stage Microbial Sampler (Model 10-890) and

Andersen Six Stage Microbial Sampler (Model 10-800) were used to sample the bioaerosols. An Aerodynamic Particle Sizer (APS, Model 3321, TSI Inc., St. Paul, MN, USA) and PORTACOUNT (Model 8020, TSI PORTACOUNT® Plus Respirator Fit Tester, TSI Inc., St. Paul, MN, USA) was used to measure the concentration of the particles.Trypticase soy agar (TSA, Difco, Detroit MI, USA) was used as the bacteria culture medium. As for the preparation of challenge aerosol suspension, *Escherichia coli* and *Bacillus subtilis* spores were selected. Both *Escherichia coli* (C.C.R.C.17320) and *Bacillus subtilis* (C.C.R.C.12145) were purchased from Food Industry Research and Development Institute (Hsinchu, Taiwan). The preparation of bioaerosol suspension was put into Refluxing 6-jet modified MRE-type short-form Collison nebulizer (Model NSF CN-31/1) and then the bioaerosols were generated. A radioactive source, Am-241, was used to neutralize the challenge particles to the Boltzmann charge equilibrium. The real-time sterilization system was mounted in the test wind tunnel. An Andersen 1-stage sampler or 6-stage sampler was used to sample bioaerosols at the upstream and downstream of the tunnel. The sample was then incubated for 24 hours at 37 ℃ in an oven. The test is required to be repeated at least three times. The range of steady wind velocity of the wind tunnel was 0.5~15 m/s. The total length of the tunnel was 700 cm. The volume of the test section was 30*30*200 cubic centimetre, as illustrated in Figure 1.

3 RESULTS

As illustrated in Figure 1, the major wavelength and the power of the 9W UVGI (model: Philips UV-C Germicidal Sterilamp® TUV PL-L 9W/4P 2G11) used in this research was about: 252.9 nm vs.13.5 mWatt/cm^2, and 257.5 nm vs. 21.5 mWatt/cm^2. An Ocean Optics UV spectrometer (model: USB2000- UV-VIS Spectrometer, Dunedin, Florida, USA.) was used in the study.

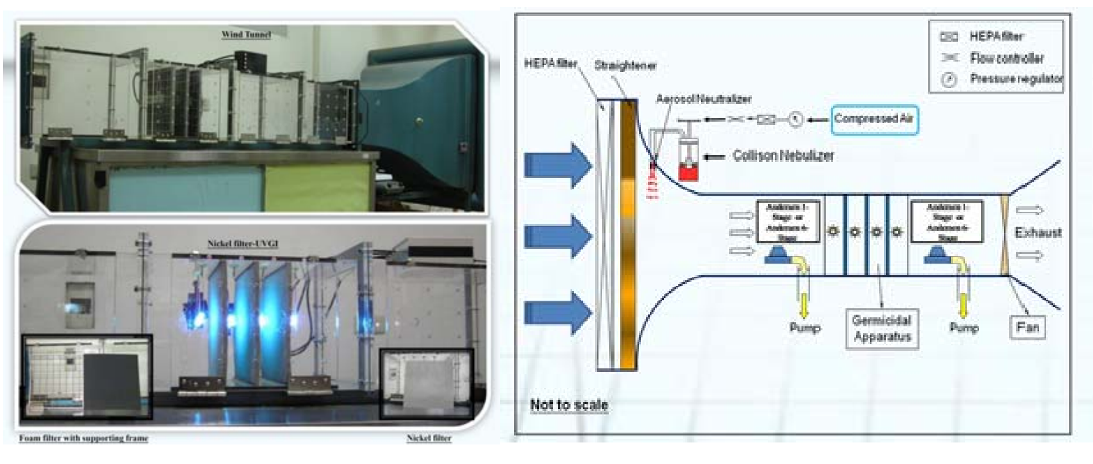


Figure 1: The schematic setup of wind tunnel system.

When the face velocity was 1 m/s, the pressure drop of the real-time sterilization unit alone, the unit combined with 45 ppi foam filter, the unit combined with 80 ppi foam filter and the unit combined with 94 ppi nickel filter were very close to each other: 2.89, 3.08, 3.40, 3.56 mmH_2O, respectively. When the face velocity was 8 m/s, the pressure drop of real-time sterilization unit alone was 28.43 mmH_2O, while the unit combined with 45 ppi foam filter was 36.00 mmH_2O, the unit combined with 80 ppi foam filter was 40.17 mmH_2O, and the unit combined with 94 ppi nickel filter was 42.67 mmH_2O. When the pleated HEPA of M brand used, and the face velocity was 1 m/s, the pressure drop of single layer HEPA (0.69 mm thickness) reached as high as 92 mmH_2O, as illustrated in Fig. 2.

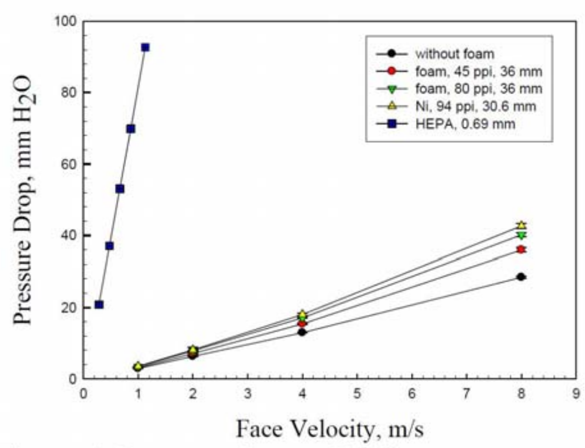


Figure 2: Pressure drops of different combinations of sterilization unit and filters at different face velocities.

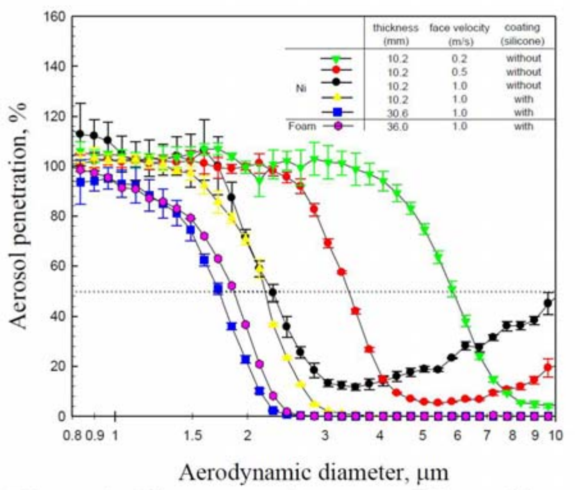


Figure 3: The penetration rate of foam filter and nickel filter when challenge with PST particles.

Tests on the filter penetration rate with challenge PST aerosols were performed to determine the filtration efficiency. As illustrated in Fig. 3, if a coating of silicon oil of 700 μm thickness were applied to the nickel filter, when the face velocity was 1m/s, the bounce-off phenomenon of PST particles can be restrained, leading to a more efficient collection.

4 DISCUSSION

For the experiment of disinfection rate test of the nickel filter-UVGI sterilization unit, three Andersen 1-stage samplers were used. The humidity of the test ranged from 42 %～45 %, and the temperature ranged from 21~25 ℃. When the face velocity was 0.5 m/s and 1 m/s, the nickel filter alone could not effectively collect the *Escherichia coli*. The collection rate was only 32 % at a face velocity of 0.5 m/s. However, when the UVGI was turned on, the disinfection rate rose to 100 %. Few *Escherichia coli* with large aerodynamic diameter experienced bounce-off and re-entrainment. On the other hand, the nickel filter alone could collect *Bacillus subtilis* spores up to 72 %. The collection rate would increase to

88 % when the face velocity increased to 1 m/s. After turning on the UVGI, the disinfection rate of *Bacillus subtilis* spores increased to 82 %. When the face velocity increased to 1 m/s, the disinfection rate rises to 96 %.

Moreover, three Andersen 6-stage samplers were used to best understand the bioaerosol size distribution. In the nickel filter-UVGI sterilization unit, *Escherichia coli* or *Bacillus subtilis* spores were used as the challenge aerosols. While the UVGI was turned off, the aerodynamic diameter of the challenge aerosol concentration sampled in the upstream of nickel filter － UV sterilization unit by using an Andersen 6-stage sampler at face velocity of 0.5～1 m/s, had higher concentration distribution between aerodynamic diameter of 1.1～2.1 μm. When UVGI was turned on, most *Escherichia coli* or *Bacillus subtilis* spores would be killed or deactivated, so no colony would be cultured by the media of Andersen 6-stage sampler. However, *Escherichia coli* with large aerodynamic diameter would experience bounce-off and re-entrainment, especially with the aerodynamic diameter of 3.3～7 μm. While applying a silicon oil coating of 700 μm thickness, it might restrain the bounce-off and improve the collection efficiency of the nickel filter. The poor collection efficiency for some *Bacillus subtilis* spores with small aerodynamic diameter might be the cause of the higher penetration rate. The collection of particles with small diameter depended on diffusion, when the face velocity increased, the collection efficiency of nickel filter was reduced.

The disinfection rate of *Escherichia coli* by using an Andersen 6-stage sampler is illustrated in Fig. 4a shows that when the UVGI was turned off, the average disinfection rate was less than 88 %, but after the UVGI was turned on, the disinfection rate reached 100 %. Actually, the nickel filter-UV sterilization unit could not effectively collect *Escherichia coli* with diameter smaller than 0.65 μm. However, after turning on the UVGI, the disinfection rate reached 100 %; it might be that the *Escherichia coli* with diameters smaller than 0.65 μm were killed directly by the UVGI at low face velocity.

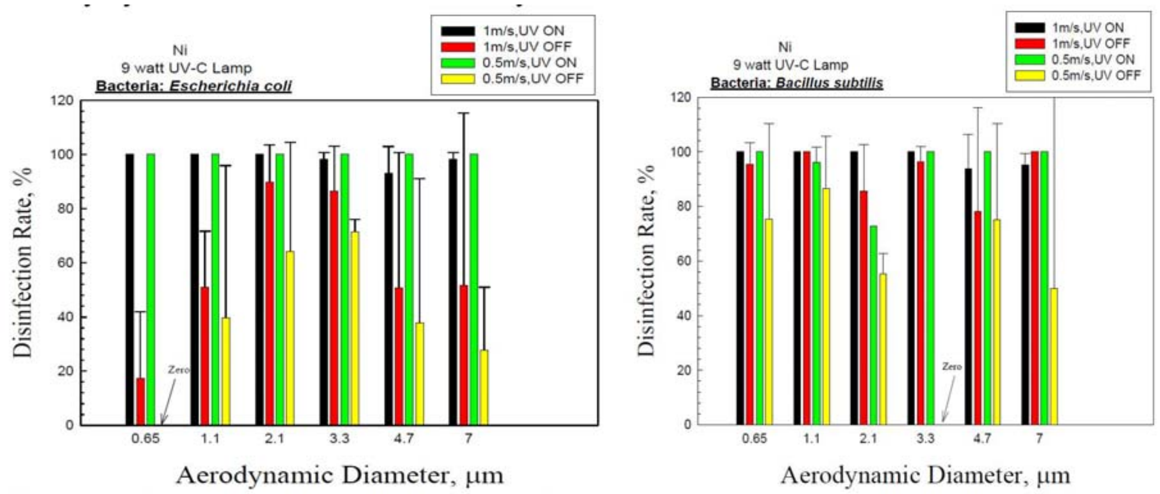


Figure 4a & 4b: The disinfection rate of the nickel filter–UV sterilization unit for *Escherichia coli* and *Bacillus subtilis* spores at face velocities of 0.5 m/s and 1m/s.

Fig. 4b shows that the disinfection rate of *Bacillus subtilis* spores at face velocity of 1 m/s was higher than that at 0.5 m/s. At a face velocity of 0.5 m/s, when the UVGI was turned off, there was no collection and disinfection effect on the *Bacillus subtilis* spores at diameter of 3.3 µm. When the UVGI was turned on, the disinfection rate was close to 100 % at face velocity between 0.5~1 m/s. However, the disinfection rate of the *Bacillus subtilis* spore at aerodynamic diameter of 2.2 µm was only 72 % at a face velocity of 0.5 m/s. The main reason was that few *Bacillus subtilis* spores with an aerodynamic diameter of 2.2 µm could penetrate the nickel filter.

For the experiment of disinfection rate test of the foam filter-UVGI sterilization unit, the ranges of face velocity, humidity and temperature tested in this research were: 0.5-2 m/s, 48.4 %～62.7 % and 24.7~28.3 ℃. *Escherichia coli* and *Bacillus subtilis* spores were the challenge bioaerosols with aerodynamic diameter of 0.65 μm～7 μm tested in the research. When the UVGI was turned on, the total disinfection rate exceeded 85 % within the ranges of face velocity, humidity, and temperature as mentioned above.

The field study result showed that the nickel filter-UVGI sterilization unit coating with silicone oil revealed less large size aerosol bounce during air duct velocity between 1.8 to 2.5 m/s. The average bacteria disinfection rate of ward 1, ward 2 and nurse station was 88.6 %, 92.5 % and 88.8 % using six-stage Andersen impactor, respectively.

5 CONCLUSIONS

Although the total cost of the nickel-based sterilization unit is more expensive (20～30 % higher than foam-based sterilization unit), it was recommended for use after considering the factors of the operation time and durability as well as the disadvantages of foam-based sterilization unit's UV ageing and the extra cost of a foam-filter support frame. So the nickel-based real-time sterilization unit was finally recommended for use in routine duct-sterilization after comparing the total disinfection rate, filtration quality and economic factors.

The conclusions recommended that the nickel filter-UVGI sterilization unit should coat with silicone oil to avoid the large aerosol bounce effect, and was better to use the unit in main ducts under high face velocity.

6 REFERENCES

Lai, C.Y., Hung, P.C., Yu, T.S., and Chang, J.P.: Evaluation on Disinfection Methods Used in Hospital Ventilation Ducts, Report of Institute of Occupational Safety & Health, 2007.

Yu, T.S., Lin, W.H., Chang, J.P.: A Study on the Characteristics of Bioaerosols Concentration in the Hospital Air-Conditioning Systems, Report of Institute of Occupational Safety & Health, 2006.

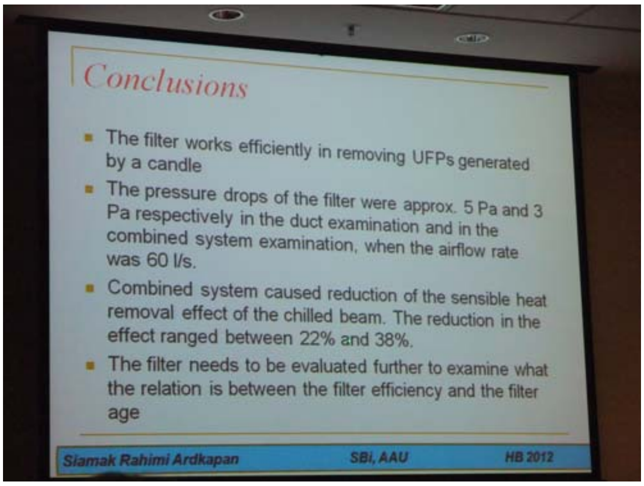
Li, C. S., and Hou, P. A.: Bioaerosol Characteristics in Hospital Clean Rooms. The Science of the Total Environment; 305: 169-176, 2003.

Lee, S.H.: Development of Photocatalyst Plasma Air Cleaning Filter Used in Air Conditioner, J. AOTs 6(1):66-69, 2003.

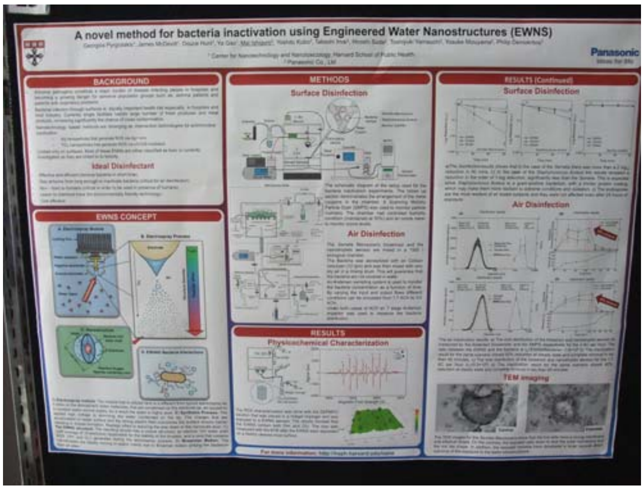
Lin, C.Y, and Li, C.S.: Effectiveness of Titanium Dioxide Photocatalyst Filters for Controlling Bioaerosols, Aerosol Sci. Technol. 37:162-170, 2003.

Lin, C.Y, and Li, C.S.: Inactivation of Microorganisms on the Photocatalytic Surfaces in Air, Aerosol Sci. Technol. 37:939-946, 2003.

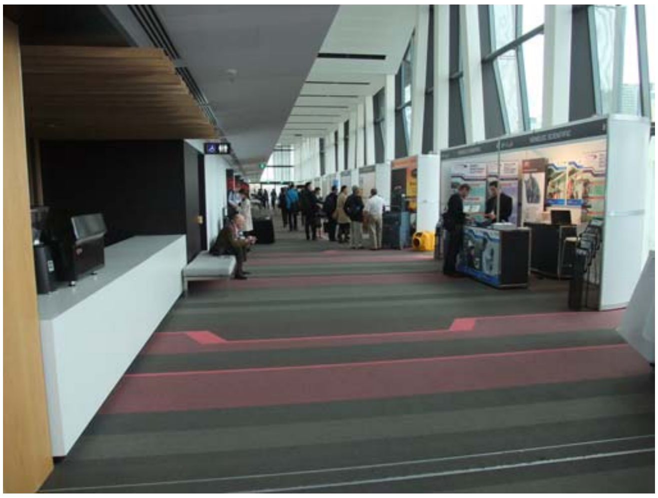
附件二 會場照片



通風控制相關論文發表



微生物控制相關海報論文發表



會場參展廠商