出國報告（出國類別：其他-視訊會議）

參加「2021 國際建築物理環境研討會 (8th International Building Physics Conference Copenhagen Denmark, IBPC2021)」視訊會議報告

服務機關：內政部建築研究所
姓名職稱：王家瑩　副研究員
派赴國家：視訊會議
出國期間：110 年 8 月 25 日至 8 月 27 日
報告日期：110 年 11 月 19 日

摘要

關鍵字：聯合國永續發展目標、建築物理、節能減碳、室內環境

全球暖化問題日益嚴重，為減緩氣候變化，地球環境保護之相關政策已成為全球重要的議題。為使國人有更優質、舒適及健康之居住環境，內政部建築研究所長期推動「生態」、「節能」、「減廢」、「健康」之綠建築，並與內政部「建構永續宜居環境」之施政目標整合，辦理「創新循環綠建築環境科技計畫(108-111)」，發展符合臺灣亞熱帶及熱帶高溫高濕氣候條件與生態環境之綠建築科技與技術，已成功帶動我國綠建築、綠建材相關產業的蓬勃發展與良性競爭，然而面對全球能源結構與經濟情勢的快速變動，永續建築及永續基礎建設的發展策略仍須不斷滾動調整。

另一方面，全球自 2019 年受到嚴重特殊傳染性肺炎(COVID-19)肆虐，各國經濟與生活都受到顯著的衝擊影響，且目前從全球國際政策與策略顯示，未來將與疾病共存，因此為因應疫情衝擊與後疫情環境改變，建築物、社區或整體都市發展都將因應健康與防疫需要而有所改變。為瞭解國際間相關發展現況及未來趨勢，爰參加 110 年 8 月 25 日至 27 日於丹麥哥本哈根召開之 IBPC 2021 國際研討會(8th International Building Physics Conference Copenhagen Denmark)。

本報告係彙整發表於 IBPC 2021 國際研討會，且與本所業務相關之研究主題，包括：美國住宅建築減碳策略、澳洲 NABERS 室內環境評估工具、土耳其營建業的永續認知、韓國火害後混凝土補強研究等，提出國際間相關研究趨勢之說明，期能作為本所規劃未來科技計畫(112-115)研究課題發展方向之參考，以確保我國永續健康綠建築等政策之發展符合國際發展趨勢。最後，本文亦提出本次會議之心得及建議。

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壹、出國目的

為因應氣候與社會環境變遷、減緩地球暖化，本所「創新循環綠建築環境科技計畫(108-111)」整合內政部「建構永續宜居環境」之施政目標，本於「生態、節能、減廢、健康」的綠建築基本概念，積極研發適用於臺灣亞熱帶及熱帶氣候條件與生態環境之綠建築科技與技術，以科技創新打造永續宜居環境，提升生活環境與居住品質。

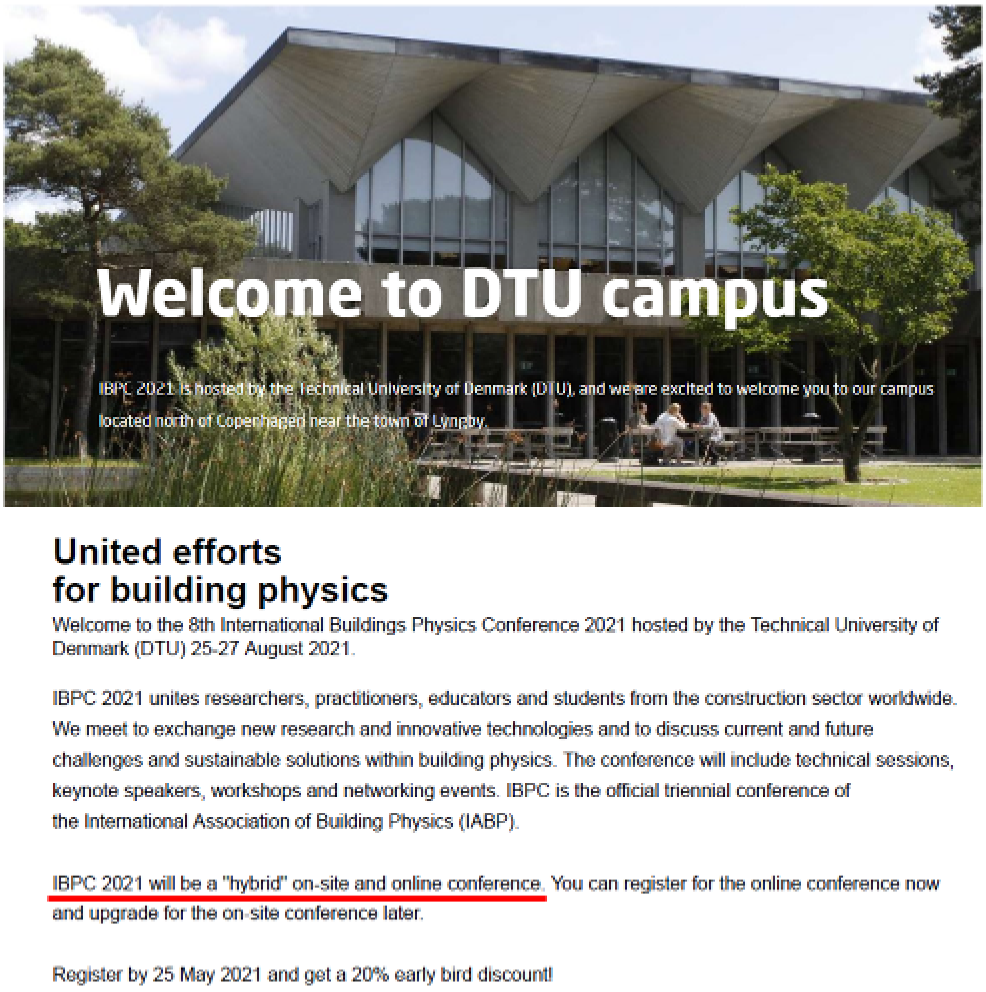
而在國際間，全球暖化與氣候變遷的議題持續受到全球關注，聯合國氣候變化綱要公約（UNFCCC）的歷次會議均確認全球必須努力把溫度上升控制在 1.5~2℃的範圍以內，各國也透過相關協議與自願性的減碳承諾，共同推動溫室氣體減量，在此背景下，各國對於永續與智慧建築所能發揮的減碳效益，均予高度重視，催化了永續與智慧建築的快速發展。

本次以線上會議方式參加 IBPC 2021 國際研討會之目的，即是希望藉由國際研討會平臺的交流，廣泛蒐集國際最新永續建築、能源效率、建築物耐久、循環及室內物理環境相關技術及研究成果等最新資料，擷取其中值得參考或借鏡之處，作為本所未來科技計畫研究課題發展或綠建築相關政策推動之參考。

貳、 視訊會議議程

一、 國際研討會改以視訊方式參加

2021 年第 8 屆國際建築物理環境研討會(8th International Building Physics Conference Copenhagen Denmark)定於 110 年 8 月 25 日至 27 日，在丹麥首都-哥本哈根辦理，鑒於新冠肺炎(COVID-19)疫情肆虐全球，該會議主辦單位於網站上公告，改採以線上與實體會議併行的方式辦理(圖 1)，本所評估線上參與研討會議之方式，仍可達成蒐集資料之目的，尚無於防疫期間派員出國之必要，因此依據「行政院及所屬各級機關因公派員出國案件編審要點」第 4 點及「內政部及所屬各級機關因公派員出國案件處理要點」第 4 點相關規定，報陳上級機關同意變更計畫，改以派員 1 人於國內參加線上會議之方式執行。



Welcome to DTU campus

IBPC 2021 is hosted by the Technical University of Denmark (DTU), and we are excited to welcome you to our campus located north of Copenhagen near the town of Lyngby.

United efforts
for building physics

Welcome to the 8th International Buildings Physics Conference 2021 hosted by the Technical University of Denmark (DTU) 25-27 August 2021.

IBPC 2021 unites researchers, practitioners, educators and students from the construction sector worldwide. We meet to exchange new research and innovative technologies and to discuss current and future challenges and sustainable solutions within building physics. The conference will include technical sessions, keynote speakers, workshops and networking events. IBPC is the official triennial conference of the International Association of Building Physics (IABP).

IBPC 2021 will be a "hybrid" on-site and online conference. You can register for the online conference now and upgrade for the on-site conference later.

Register by 25 May 2021 and get a 20% early bird discount!

圖 1 IBPC 2021 改以線上與實體會議併行的方式辦理

二、 會議及主辦單位簡介

IBPC 2021(圖 2) 召集國際間建築行業的研究人員、從業人員、教育工作者和學生，共同交流創新的研究和技術，並討論建築物理學領域當前問題與未來挑戰，並提出永續解決方案。IBPC 2021 包括技術會議、主題演講、研討會和交流活動。

圖 2 IBPC 2021 國際建築物理研討會

IBPC 2021 為國際建築物理協會 (IABP)每三年舉辦一屆的官方國際會議，今(110)年為第八屆辦理，並由丹麥技術大學、奧爾堡大學、奧胡斯大學、南丹麥大學和隆德大學共同合作辦理(圖 3)，同時也預定了 2024 的第九屆會議，將會在加拿大多倫多的瑞爾森大學辦理。

圖 3 IBPC 2021 共同協辦單位

三、 線上會議時間與議程

本屆會議定於丹麥哥本哈根當地時間 110 年 8 月 25 日至 8 月 27 日召開，會議主題針對循環經濟、建築防疫與室內環境等建築物永續發展理之最新國際趨勢，並從設計手法、施工構造、設施設備等回應永續循環之執行策略，共約發表了 297 篇研討會論文，研討會議程與各分項主題如下表 1 至表 3 所示：

表 1 IBPC 2021 國際建築物理環境研討會議程表(110 年 8 月 25 日星期三)

時間 (110年8月25日)	**議程**
08:30-08:40	開場致詞
08:40-10:00	會議講座 I：循環經濟與再生材料 Plenary session I: Circular economy and reuse of materials
10:30-11:15	議程 01：CLT 和水分 02：健康、績效和環境 20：建築圍護結構 04：建築中使用的 PCM 05：人工神經網絡（ANN）
11:15-11:40	發表簡介 01：建築結構中的水分 02: 室內環境品質與污染物 15：建築外殼 04：創新建材 16：CFD 模擬、機器學習
11:40-12:00	發表簡介 05：熱濕傳遞數值 10：COVID-19 和感染風險 20：建築外殼 09：生命週期，永續 08：聲學
13:00-14:00	問與答
14:00-15:30	議程 06：木結構中的水分轉移 11：Covid-19 和室內環境 10：建築圍護結構優化 08: 熱性能和絕緣 09：通風、傳熱和 CFD
16:00-17:30	議程 13：濕熱評估建築構件 12：風驅降雨、冰和霜 07：氣候變遷的適應與影響 15：RES（可再生能源系統） 14：建築聲學和噪音控制

表 2 IBPC 2021 國際建築物理環境研討會議程表(110 年 8 月 26 日星期四)

時間 (110年8月26日)	議程
08:30-10:00	會議講座 II：COVID-19 疫情下如何重塑建築環境 Plenary session II: How the COVID-19 pandemic will reshape the built environment
10:30-11:15	議程 17：吸濕材料 03：熱舒適和生理模型 18：日光和視覺舒適度 16：寒冷和北極氣候 19：能源靈活性和需求管理
11:15-11:35	發表簡介 12：熱量和水分傳遞(實驗) 03：熱舒適 13：日光、窗戶、玻璃和遮陽 11：極端氣候和氣候適應 14：能耗與優化
11:35-12:00	發表簡介 17：熱量和水分傳遞(實驗) 07：室內空氣質量、健康、睡眠質量 18：太陽輻射和能量 06：城市環境、戶外環境 19：能耗與優化
13:00-14:00	問與答
14:00-15:30	議程 22：黴菌生長及相關問題 23：ZEB（零能耗建築） 21：上光和遮陽技術 24：建築模擬 工作坊二：健康、耐用和可持續的建築——建築物理學的補充
16:00-17:30	議程 26：建築物中的水分及其風險 27：熱舒適性研究 25：能源性能和消耗 29：濕度控制

表 3 IBPC 2021 國際建築物理環境研討會議程表(110 年 8 月 27 日星期五)

時間 (110年8月27日)	議程
08:30-10:00	會議講座 III：生物基解決方案-好處和挑戰 Plenary session III: Bio-based solutions - benefits and challenges
10:30-12:00	議程 30：翻新和能源改造 34：室內空氣質量、通風和污染物 32：城市環境、戶外環境 33：歷史建築和遺產保護 31：創新的冷卻系統
13:00-14:30	議程 35：能源需求建模和預測 37：健康與環境 36：基準測試和環境影響 28：濕度、HAM(熱、空氣、濕度)

參、會議參與過程

一、 會議開幕致詞

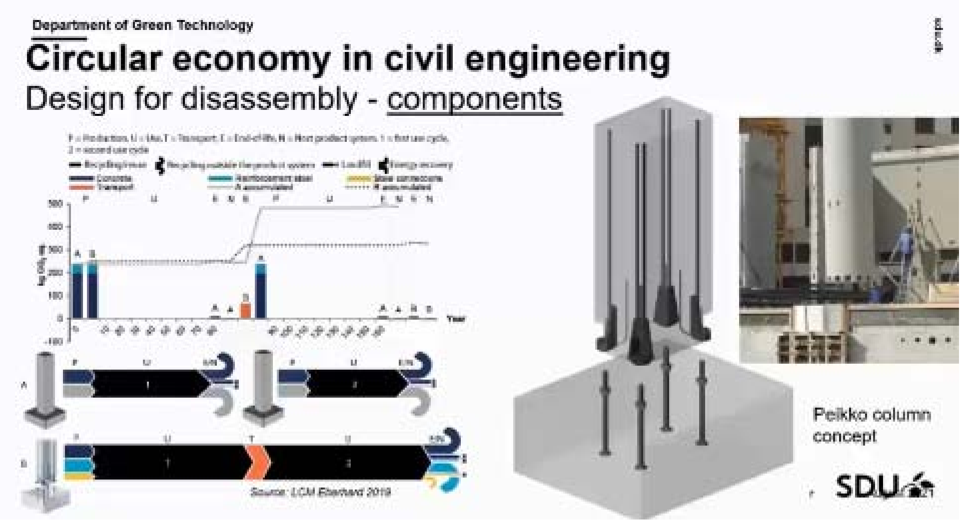
會議開幕式係由本會議主席 Carsten Rode 教授進行開場致詞與演講，他同時也是主辦方丹麥技術大學土木工程系教授，專攻建築物室內環境和建築能源性能領域，對於建築材料和建築外殼結構的實驗研究有豐富的經驗，同時也曾參與國際能源署(International Energy Agency,IEA) 的多項國際合作項目。致詞中 Carsten Rode 教授簡單敘述了各個國家因為氣候不同，對於建築外殼設計的要求與性能，也會受到實際物理環境的熱溼氣候條件影響。因此，需要藉由 IBPC 2021 國際建築物理環境研討會的舉辦，蒐集各國在不同氣候區的建築外殼節能設計手法與策略，透過學術交流與資訊學習，創造更好的建築環境，共同維護人類生存環境永續發展，並祝大會圓滿順利。

二、 會議重要內容概述

本屆研討會研究論文主題廣泛且多達 297 篇，為因應國際間永續發展、循環經濟以及 COVID-19 健康防疫等發展趨勢，本報告摘錄其中與本所業務相關之研究內容說明如下：

(一) 循環經濟與再生建築材料

丹麥技術大學土木工程系 Carsten Rode 教授針對循環經濟與再生建築材料進行主題演講，說明歐盟在落實營建產業循環經濟上強調前端資源的設計使用、著重省能低碳化，發展可逆式設計等相關手法，並針對待拆除之建築物則推行「拆除、去污染與再利用」的政策與施工規範(圖 4)。



Department of Green Technology

Circular economy in civil engineering

Design for disassembly - components

Source: LCM Eberhard 2019

Peikko column concept

SDU

圖 4 循環建築設計的建築構件組成與拆解之方式

同時運用循環建築設計手法，將可降低對環境的衝擊，從圖 5 可發現，可拆卸的建築構造設計模型(開放建築-灰線)，相較於其他傳統構造形式，對於長年的氣候暖化潛力(二氧化碳排放量)，是平穩未增加的。

Source: LCM Eberhard 2020

圖 5 各種建築構造形式造成地球暖化的潛力

如圖 6 所示而建築物若能從建築材料、構件、空間模組，一直到整棟建築物，都採可循環再利用的設計規劃，除了可降低對環境的衝擊，提升環境價值，亦可提高經濟效益。

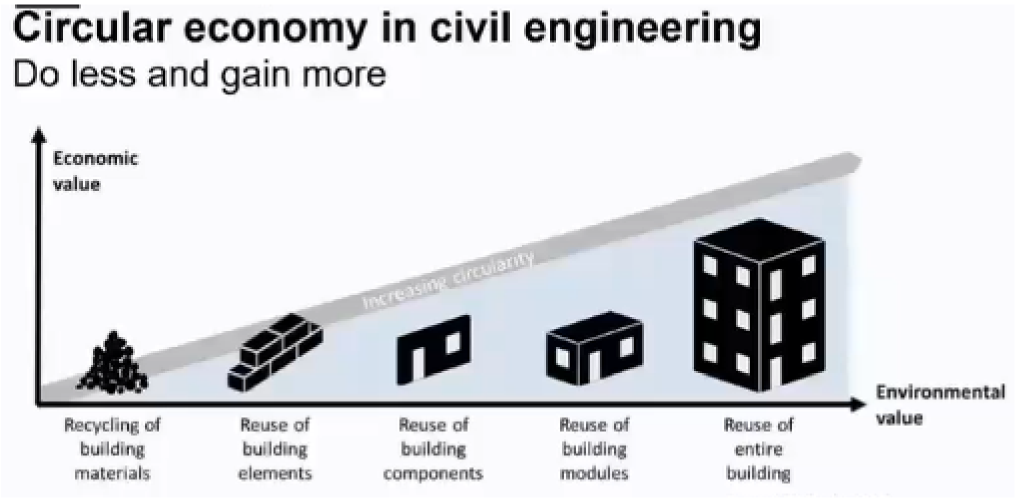


圖 6 建築物循環再利用之經濟、環境效益

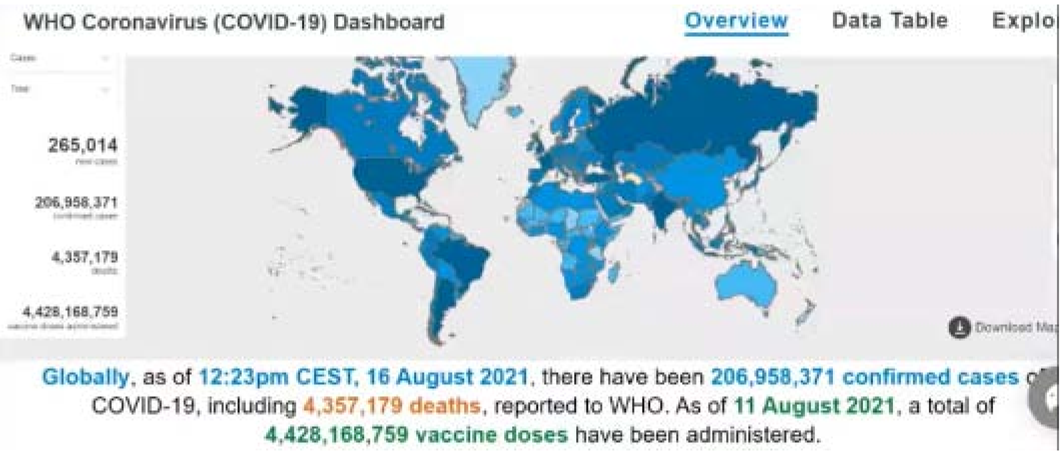
因此，本研究提出下列幾點結論：

1. 循環經濟已成為主要趨勢，導入建築規劃設計後，不同的評估目標和世界觀而具有挑戰性，亦會對未來的建築材料採購模式帶來改變。
2. 評估循環經濟實際上是可能的，但由於。
3. 循環經濟的確切環境潛力，仍需要進一步量化，對於未來建築環境發展帶來很大的不確定性。

4. 循環經濟似乎具有巨大的環境效益，可以幫助解決永續發展的挑戰。
5. 建築材料本身的循環再利用率，對於循環經濟亦是一大挑戰，像是:建築材料本身的品質與耐久度、使用過程是否受到污染等，因此除了持續使循環經濟發揮最大的環境效益，亦應避免循環建材的運用導致人類健康造成影響。

(二) 降低 SARS-CoV-2 室內空氣傳播感染風險評估策略之研究

由於嚴重急性呼吸系統綜合冠狀病毒 (SARS-CoV-2)在 2019 年引起的史無前例冠狀病毒大流行(COVID-19)，根據 WHO 統計資料顯示，全球已超過 2 億人感染 COVID-19，超過 435 萬人死亡(圖 7)。



Globally, as of 12:23pm CEST, 16 August 2021, there have been 206,958,371 confirmed cases o COVID-19, including 4,357,179 deaths, reported to WHO. As of 11 August 2021, a total of 4,428,168,759 vaccine doses have been administered.

圖 7 WHO 全球 COVID-19 疫情統計

SARS-CoV-2 屬於呼吸道疾病，其傳染路徑包括飛沫傳染及接觸傳染，而攜帶病毒的氣溶膠可以通過感染者的呼吸活動排出，並在更長的時間(數小時)和距離內(＞2 公尺)懸浮在空氣中，因此，空氣傳播被認為是新冠病毒的主要傳播途徑之一(圖 8)。為了控制病毒傳播，室內空氣品質維持成為很重要的控制手法，包括來源控制、通風控制及空氣清淨等。

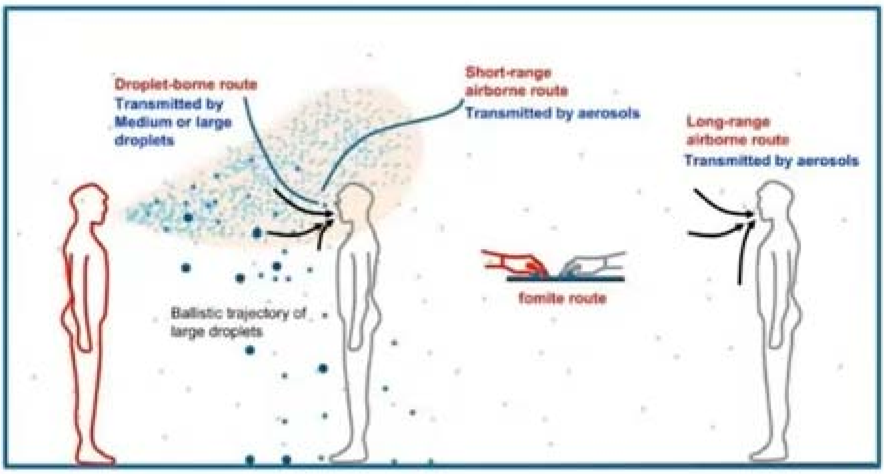


圖 8 SARS-CoV-2 主要傳播途徑為空氣傳播

室內通風不良會增加空氣傳播的感染風險，而疫情最容易爆發的使用空間，包括長照中心、幼兒園到國小之學校空間、餐廳、零售設施、辦公室等(圖 9)，而 COVID-19 在室內環境感染機率的部分，居家感染機率有 79.9%，交通運輸工具上之感染則有 34%。

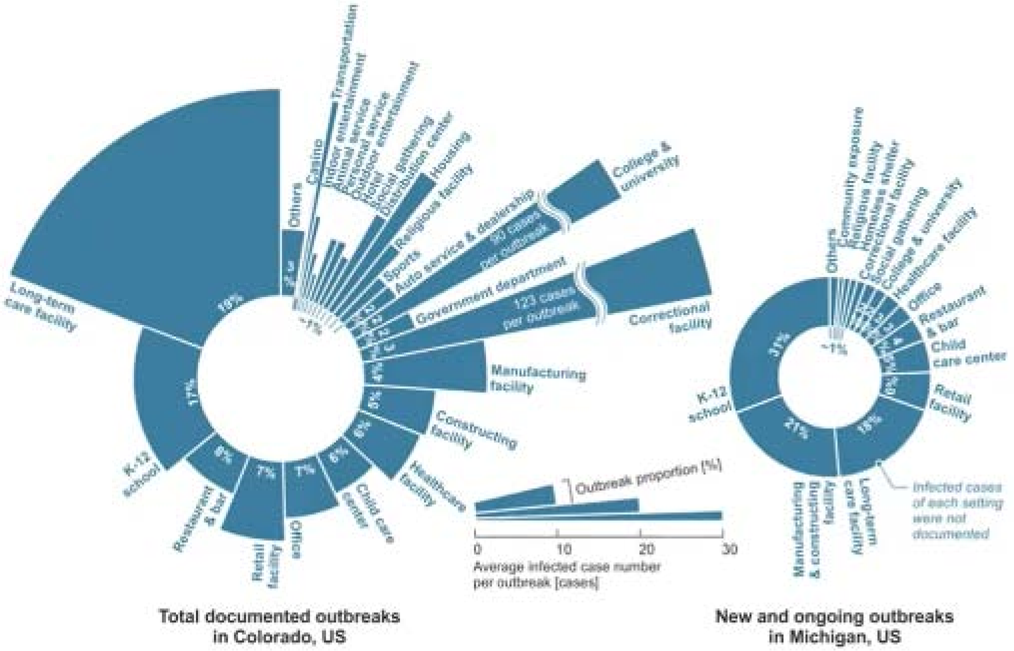


圖 9 疫情亦擴散之空間類別比例

因此，本研究建立了多尺度的空間模型，以模擬的方式評估多尺度室內空氣質量控制策略，在不同情況下減輕感染風險的有效性。多尺度由大至小分別從整棟建築到房間，再到立方體、個人周邊環境，與個人微呼吸區域 (圖 10)。

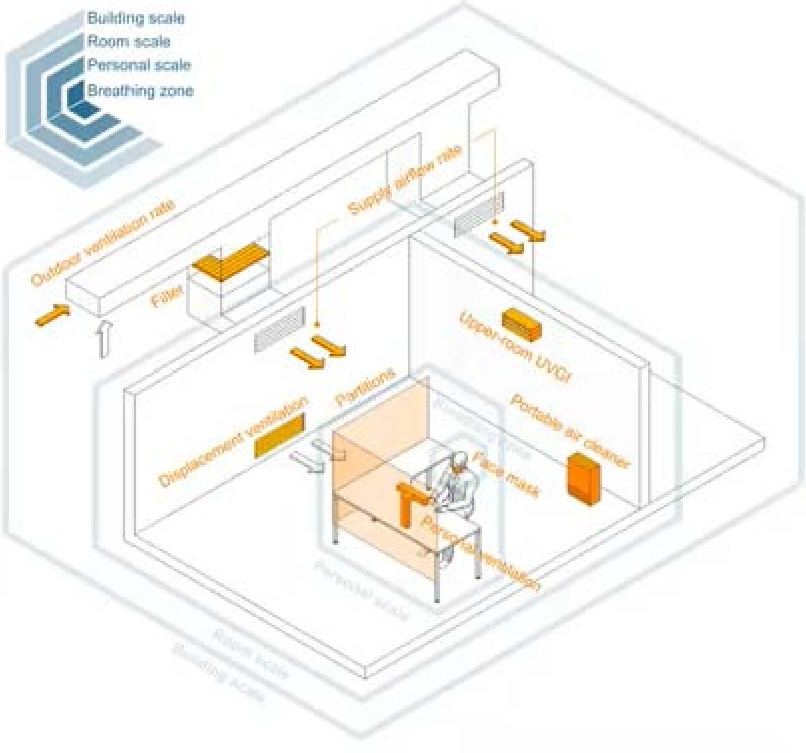
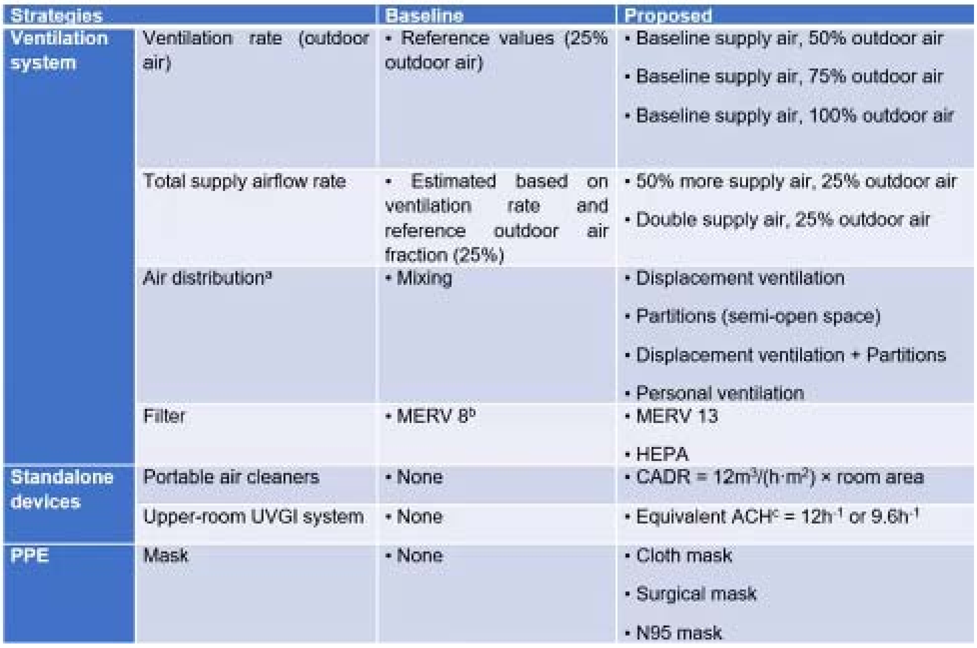


圖 10 多尺度室內空間模型

並依據現有標準(ASHREA 62.1)建立邊界環境條件，包括室內使用人數、送風量、外氣量、通風設備(置換通風)、設置隔板、高效過濾器(MERV、HEPA)、個人通風和配戴口罩種類等(圖 11)。



Strategies		**Baseline**	**Proposed**
Ventilation system	Ventilation rate (outdoor air)	• Reference values (25% outdoor air)	• Baseline supply air, 50% outdoor air • Baseline supply air, 75% outdoor air • Baseline supply air, 100% outdoor air
	Total supply airflow rate	• Estimated based on ventilation rate and reference outdoor air fraction (25%)	• 50% more supply air, 25% outdoor air • Double supply air, 25% outdoor air
	Air distribution[a]	• Mixing	• Displacement ventilation • Partitions (semi-open space) • Displacement ventilation + Partitions • Personal ventilation
	Filter	• MERV 8[b]	• MERV 13 • HEPA
Standalone devices	Portable air cleaners	• None	• CADR = $12m^3/(h{\cdot}m^2)$ × room area
	Upper-room UVGI system	• None	• Equivalent ACH[c] = $12h^{-1}$ or $9.6h^{-1}$
PPE	Mask	• None	• Cloth mask • Surgical mask • N95 mask

圖 11 多尺度模擬環境條件設定建議

另外，針對密度高、容易空氣傳播的特定室內空間，評估降低 COVID-19 感染風險策略的有效性，包括長期護理機構、學校和大學、肉類加工廠、零售店、醫院、辦公室、懲教機構、酒店、餐廳等室內空間，以及飛機、遊輪、地鐵、公共汽車和出租車等候空間等，根據每個室內空間的相對成本和實際工作量，歸納了幾種綜合緩解策略如下：

1. 先進的空氣分配可以顯著降低感染風險，但也需要專業的設計與執行，才能最大限度地發揮其防疫效果。
2. 於空調系統中使用 HEPA 過濾器，與使用引入 100%室外空氣的空調系統，二者具有相同的效果。
3. 獨立的空調和紫外線殺菌系統可以成為降低感染風險的有效解決方案。
4. 配戴口罩對降低感染風險非常有效。

模擬的成果可協助因應當前 COVID-19 疫情的挑戰，並為未來其他可能的空氣傳播傳染病提供更好的預防策略。

(三) ZEB 實驗室：適應未來氣候變化的零排放建築研究工具

根據國際能源總署（IEA）統計，建築物消耗全球能源占 40%以上，排放溫室氣體量則達 30%，遠比大眾所認為的交通運輸和工業製造所排放的溫室氣體量高出甚多，減緩氣候變遷成為刻不容緩的任務。近年歐盟在綠色新政中將建築物節能減碳列入氣候變遷減緩重點工作項目之一，因此挪威科技大學(NTNU)與 SINTEF 研究組織，在挪威特隆赫姆(Trondheim)挪威科技大學的校園中，建了 ZEB (Zero Emission Building) 實驗室(圖 12)。ZEB 實驗室為一 4 層樓高，建築面積 1,800 平方公尺全尺寸實驗性建築設施，由可隨時更換的建築外牆、構件和技術系統而組成，建築空間主要作為辦公、教學與實驗研究使用。

圖 12 挪威科技大學 ZEB 實驗室外觀

在環境目標方面，該建築應達到零排放建築（ZEB）水平，並對建築材料的建造、運營和生產 60 年以上的排放進行補償。這意味著該建築必須擁有當地的可再生能源生產能力，能夠補償 60 年來建築材料的建造、運營和生產過程中產生的溫室氣體排放，以達到 ZEB-COM 目標等級(等級如圖 13)。ZEB-O 是指與所有運營「O」相關之能源(Operational energy)排放應得到補償；ZEB-OM 是指與所有運營相關能源的排放，再加上來自材料「M」(Material)的可再生能源發電進行補償；ZEB-COM 是與 ZEB-OM 相同，再進一步考量與建設階段「C」(Construction)，材料與產品建築工地的排放應得到補償；而最高等級 ZEB-COME 則是與 ZEB-COM 相同，同時考量生命週期最終階段「E」(End of life)，包括解構/拆除、運輸、廢物處理和處置等。

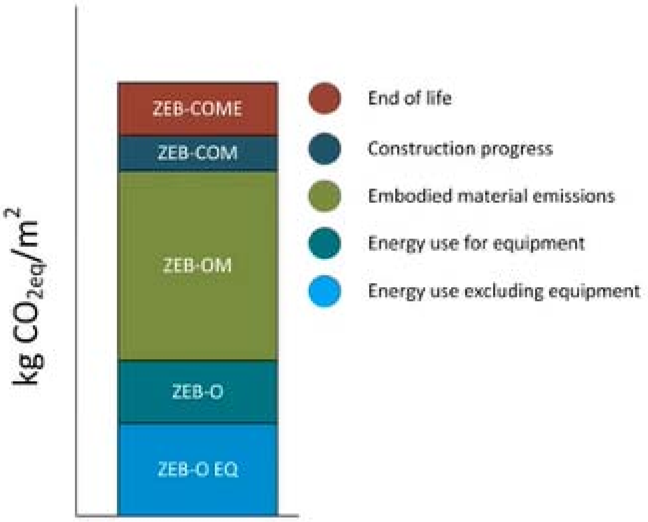


圖 13 ZEB 的 5 個目標等級

ZEB 實驗室為一木構造建築，整個建築物南向的屋頂，及部分建築物立面裝設有太陽能板。而南向一樓的南立面，包括一樓雙人房實驗單元(圖 14)，配備了專用 HVAC 系統、外牆材料及窗戶型式都可以更換，每個房間都代表一個 66 平方公尺的辦公空間，影響居住者舒適度的所有參數（溫度、相對濕度、二氧化碳、空氣變化率、照度等）都受到監控，可應用作為相關產品、構件和技術的性能實驗，將成果運用於優化整體建築性能，提升能源使用效率與用戶的舒適度。

圖 14　ZEB 實驗室一樓平面圖(一樓雙人實驗單元)

而建築物外殼建置的 BIPV(Building Integrated Photovoltaic，建築整合太陽光電)面板，和可以利用不同熱源（由室內及室外空氣中回收熱量）的熱泵，搭配相變材料 (Phase Change Material, PCM)蓄熱器，用於回收熱能和作為熱能緩衝器，以確保更有效地使用熱泵。同時將建築物所產生的可再生能源與當地電網連結，使能源的使用與製造能趨近於平衡。圖 15 為 ZEB 實驗室的能源供應系統說明圖。

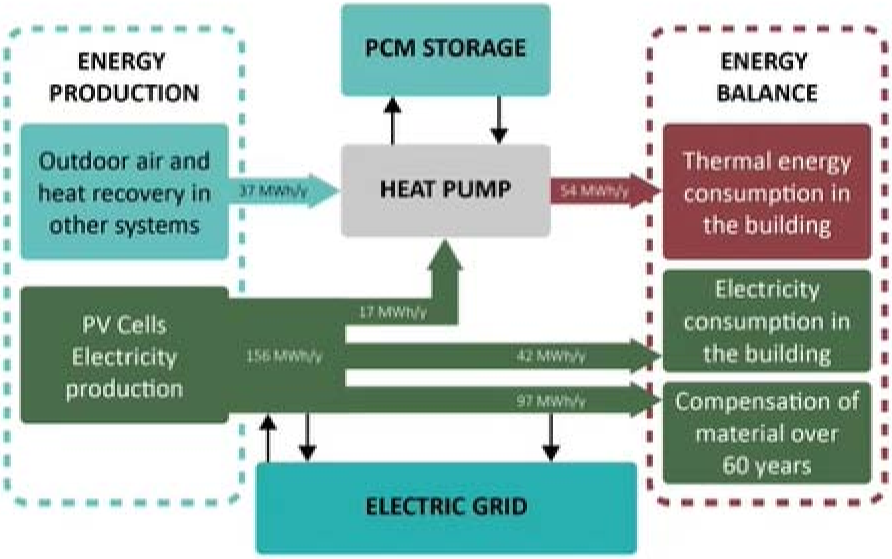


圖 15 ZEB 實驗室建築能源供應系統

另一方面，ZEB 實驗室同時為零排放示範性的建築物，因此建築物的使用運作與實驗量測等功能必須相互獨立，即在不干擾建築物使用運作的情況下可以獲得精確的研究數據，而 ZEB 實驗室在能源和暖通空調系統的使用、室內空間的使用、建築外牆的材料等，都能依研究內容與實驗項目進行調整，亦能因應各種氣候變化來進行調適，可進行之研究項目如下：

1. 建築物外殼型式解決方案。
2. 室內空氣品質(IAQ)。
3. 使用者對不同通風策略(自然和機械、自然和混合模式)的感知與滿意度。
4. 照明系統對使用者健康和福祉的影響。

5. 進行使用者與建築能源管理系統的主動交互的建築營運調查。
6. 能源管理系統。

ZEB 實驗室是由 NTNU、SINTEF、承包商、建築師和顧問共同合作的成果，並為遵循 ZEB-COM 目標所建造的零排放建築示範案例，對於學術與實務界具有很大的參考意義，可作為研擬相關政策之參考基礎策略。

肆、心得與建議

本次奉派參加「2021 國際建築物理環境研討會 (8th International Building Physics Conference Copenhagen Denmark, IBPC2021)」國際研討會，因國際間受到 COVID-19 疫情影響，改以視訊會議方式參加，獲致心得與建議如下：

一、心得

從本次會議發表之論文中可看出，全球綠建築永續發展之趨勢，目前著重在聯合國用續發展目標 SDGs、聯合國變遷大會對於淨零排放的目標、循環經濟，以及肆虐全球的 COVID-19 疫情的衝擊，各國皆針對這些議題進行相關策略之研究，以落實在政策中來改善整體後疫情時代的生活環境。

而我國為因應氣候、社會環境變遷與國際間的永續發展趨勢，本所長期推動「生態」、「節能」、「減廢」、「健康」之綠建築，同時依據總統政見(五+二)循環經濟創造節能、減廢與減排之循環經濟體系，促進環境資源永續利用，提升生活環境品質；並與內政部「建構永續宜居環境」之施政目標整合，以「建築節能與室內環境科技」、「循環建築工法與材料技術研發」、「永續城市環境科技」、「綠建築宣導推廣」為研發主軸，辦理「創新循環綠建築環境科技計畫(108-111)」，發展符合臺灣亞熱帶及熱帶高溫高濕氣候條件與生態環境之綠建築科技與技術。

因此，本次參與「2021 國際建築物理環境研討會, IBPC2021)」，得以蒐集到來自歐洲各國在防疫、循環建築、淨零排放等相關策略之文獻，經綜整

與本所創新循環綠建築研究業務較為密切相關的研究，包括：低碳排、低環境衝擊、循環利用、能源、水資源及室內環境健康等，皆能進一步幫助本所了解國外發展現況與趨勢，可做為我國健康永續綠建築發展之參考，以提升我國創新科技研發能力，提供民眾安居生活環境的同時，也能帶動健康永續綠建築與國際接軌。

二、建議

本所辦理「創新循環綠建築環境科技計畫(108-111)」即將屆滿，藉由本次會議資料蒐集發現，目前國際間用續綠建築發展趨勢著重於永續發展策略、循環經濟及 COVID-19 防疫，因此針對本所後續推動下一期科技計畫，提出下列建議：

建議一

參考 IBPC2021 研究成果，並持續追蹤國際間永續綠建築發展趨勢與我國政策需求，滾動檢討科技計畫研究成果，研提未來科技計畫草案。

執行時程：立即可行之建議

主辦機關：內政部建築研究所

為使未來科技計畫之規劃符合國際發展趨勢與我國政策需求，除參考本次 IBPC2021 研究成果外，亦應持續廣泛蒐集最新文獻資訊，以供下期科技計畫參考。

建議二

持續參與永續綠建築相關國際活動與會議，掌握國際永續發展主流趨勢。

執行時程：中長期性建議

主辦機關：內政部建築研究所

持續關注全球各國最新永續綠建築節能減碳政策、健康防疫等建築案例及研究議題，掌握最新國際永續綠建築技術發展趨勢，以利做為下一期科技計畫研究課題之參考。

伍、附錄

附錄一(IBPC 2021 會議議程)

Date: Wednesday, 25/Aug/2021

8:30am - 8:40am	**Welcome: Welcome Address**				
8:40am - 10:00am	**Plenary session I: Circular economy and reuse of materials** Location: **Auditorium - Room 082, Building: 116** Chair: **Dr. Pernille Berg**, BLOXHUB Professor (WSR) Morten Birkved, University of Southern Denmark Co-Founder, Architect Kasper Guldager, Home.Earth Moderator: Science Manager Pernille Berg, Bloxhub				
10:00am - 10:30am	**Coffee break I**				
10:30am - 11:15am	**Session 01: CLT & moisture** Chair: **Prof. Targo Kalamees**, Tallinn University of Technology	**Session 02: Health, performance and environment** Chair: **Dr. Marc Abadie**, La Rochelle Université	**Session 20: Building envelope** Chair: **Prof. Staf Roels**, KU Leuven	**Session 04: PCMs used in buildings** Chair: **Prof. Umberto Berardi**, Ryerson University	**Session 05: Artificial neural network (ANN)** Chair: **Prof. Ryozo Ooka**, The University Of Tokyo
11:15am - 11:40am	**Poster introductions 01: Moisture in building structures** Chair: **Prof. Targo Kalamees**, Tallinn University of Technology	**Poster introductions 02: IEQ & pollutants** Chair: **Dr. Marc Abadie**, La Rochelle Université	**Poster introductions 15: Building envelope** Chair: **Prof. Staf Roels**, KU Leuven	**Poster introductions 04: Innovative building materials** Chair: **Prof. Umberto Berardi**, Ryerson University	**Poster introductions 16: CFD simulations, machine learning** Chair: **Prof. Ryozo Ooka**, The University Of Tokyo
11:40am - 12:00pm	**Poster introductions 05: Heat and moisture transfer - numerical** Chair: **Prof. Targo Kalamees**, Tallinn University of Technology	**Poster introductions 10: COVID-19 & infection risk** Chair: **Dr. Marc Abadie**, La Rochelle Université	**Poster introductions 20: Building envelope** Chair: **Prof. Staf Roels**, KU Leuven	**Poster introductions 09: LCA, sustainable development** Chair: **Prof. Umberto Berardi**, Ryerson University	**Poster introductions 08: Acoustics** Chair: **Prof. Ryozo Ooka**, The University Of Tokyo
12:00pm - 1:00pm	**Lunch break I**				
1:00pm - 1:30pm	**Poster exhibition and Q&A 01: Moisture in building structures**	**Poster exhibition and Q&A 02: IEQ & pollutants**	**Poster exhibition and Q&A15: Building envelope**	**Poster exhibition and Q&A 04: Innovative building materials**	**Poster exhibition and Q&A 16: CFD simulations, machine learning**
1:30pm - 2:00pm	**Poster exhibition and Q&A 05: Heat and**	**Poster exhibition and Q&A 10: COVID-19 &**	**Poster exhibition and Q&A 20: Building**	**Poster exhibition and Q&A 09: LCA, sustainable**	**Poster exhibition and Q&A 08: Acoustics**

	moisture transfer - numerical	**infection risk**	**envelope**	**development**	
2:00pm - 3:30pm	**Session 06: Moisture transfer in wooden structures** Chair: **Dr. Berit Time**, SINTEF	**Session 11: Covid-19 & indoor environment** Chair: **Prof. Jarek Kurnitski**, Tallinn University of Technology	**Session 10: Building envelope optimization** Chair: **Prof. Juha Olavi Vinha**, Tampere University	**Session 08: Thermal performance & Insulation** Chair: **Prof. Miimu Airaksinen**, RIL Finnish Association of Civil Engineers	**Session 09: Ventilation, heat transfer and CFD** Chair: **Dr. Parham A Mirzaei**, The University of nottingham
3:30pm - 4:00pm	**Coffee break II**				
4:00pm - 5:30pm	**Session 13: Hygrothermal assessment building components** Chair: **Fitsum Tariku**, British Colubia University of Technology	**Session 12: Wind driven rain, ice and frost** Chair: **Prof. Jan Carmeliet**, ETH Zurich	**Session 07: Impact of climate & Adaptation** Chair: **Dr. Michael Lacasse**, National Research Council Canada	**Session 15: RES (Renewable energy systems)** Chair: **Prof. Dariusz Gawin**, Lodz University of Technology	**Session 14: Building acoustics and noise control** Chair: **Birgit Rasmussen**, Aalborg University Copenhagen, BUILD
7:00pm - 9:00pm	**Voluntary dinner: Meyers Spisehus, Handelstorvet 10, 2800 Kongens Lyngby** See location on map.				

Date: Thursday, 26/Aug/2021

8:30am - 10:00am	**Plenary session II: How the COVID-19 pandemic will reshape the built environment** Location: **Auditorium - Room 082, Building: 116** Chair: **Dr. Pawel Wargocki**, Technical University of Denmark Keynote speaker: Professor, Associate Dean Xudong Yang, Tsinghua University, China Keynote speaker: Dr. Andrew K. Persily, Chief of the Energy and Environment Division, U.S. National Institute of Standards and Technology (NIST), USA Moderator: Associate Professor Pawel Wargocki, Technical University of Denmark				
10:00am - 10:30am	**Coffee break III**				
10:30am - 11:15am	**Session 17: Hygroscopic materials** Chair: **Prof. Hans Janssen**, KU Leuven	**Session 03: Thermal comfort & physiological models** Chair: **Dr. Jiyun Song**, University of Hong Kong	**Session 18: Daylight & Visual comfort** Chair: **Gregers Reimann**, IEN Consultants Sdn Bhd	**Session 16: Cold & Arctic climate** Chair: **Prof. Eva B Møller**, Technical University of Denmark	**Session 19: Energy flexibility & Demand side management** Chair: **Dr. Rongling Li**, DTU Byg
11:15am - 11:35am	**Poster introductions 12: Heat and moisture transfer - experimental** Chair: **Prof. Hans Janssen**, KU Leuven	**Poster introductions 03: Thermal comfort** Chair: **Dr. Jiyun Song**, University of Hong Kong	**Poster introductions 13: Daylight, windows, glazing and shading** Chair: **Gregers Reimann**, IEN	**Poster introductions 11: Extreme climate & climate adaptation** Chair: **Prof. Eva B Møller**, Technical	**Poster introductions 14: Energy consumption & optimization** Chair: **Dr. Rongling Li**, DTU Byg

			Consultants Sdn Bhd	University of Denmark	
11:35am - 12:00pm	**Poster introductions 17: Heat and moisture transfer - experimental** Chair: **Prof. Hans Janssen**, KU Leuven	**Poster introductions 07: IAQ, health, sleep quality** Chair: **Dr. Jiyun Song**, University of Hong Kong	**Poster introductions 18: Solar radiation and energy** Chair: **Gregers Reimann**, IEN Consultants Sdn Bhd	**Poster introductions 06: Urban environment, outdoor environment** Chair: **Prof. Eva B Møller**, Technical University of Denmark	**Poster introductions 19: Energy consumption & optimization** Chair: **Dr. Rongling Li**, DTU Byg
12:00pm - 1:00pm	**Lunch break II**				
1:00pm - 1:30pm	**Poster exhibition and Q&A 17: Heat and moisture transfer - experimental**	**Poster exhibition and Q&A 03: Thermal comfort**	**Poster exhibition and Q&A 13: Daylight, windows, glazing and shading**	**Poster exhibition and Q&A 11: Extreme climate & climate adaptation**	**Poster exhibition and Q&A 14: Energy consumption & optimization**
1:30pm - 2:00pm	**Poster exhibition and Q&A12: Heat and moisture transfer - experimental**	**Poster exhibition and Q&A 07: IAQ, health, sleep quality**	**Poster exhibition and Q&A 18: Solar radiation and energy**	**Poster exhibition and Q&A 06: Urban environment, outdoor environment**	**Poster exhibition and Q&A 19: Energy consumption & optimization**
2:00pm - 3:30pm	**Session 22: Mould growth and related issues** Chair: **Dr. Petter Wallentén**, Lund University	**Session 23: ZEB (zero energy buildings)** Chair: **Prof. Arild Gustavsen**, NTNU	**Session 21: Glazing & shading technologies** Chair: **Ulrike Passe**, Iowa State University	**Session 24: Building simulations** Chair: **William Stuart Dols**, NIST	**Workshop II: Healthy, Durable and Sustainable Buildings – Augmented by Building Physics** Chair: **Dr. Freja Nygaard Rasmussen**, Aalborg University
3:30pm - 4:00pm	**Coffee break IV**				
4:00pm - 5:30pm	**Session 26: Moisture in buildings and its risks** Chair: **Prof. Thomas Bednar**, TU Wien	**Session 27: Thermal comfort studies** **Toftum**, Technical University of Denmark	**Session 25: Energy performance & consumption** Chair: **Prof. John Grunewald**, TU Dresden	**Session 29: Humidity control** Chair: **Prof. Wahid Maref**, ETS - University of Quebec	
6:30pm - 7:00pm	**Walk to restaurant. Drinks** See walking path on map.				
7:00pm - 9:00pm	**Conference dinner: Brede Spisehus, I. C. Modewegs Vej 40, 2800 Kongens Lyngby**				

Date: Friday, 27/Aug/2021

8:30am - 10:00am	**Plenary session III: Bio-based solutions - benefits and challenges** Location: **Auditorium - Room 082, Building: 116** Chair: **Dr. Ruut Hannele Peuhkuri** Keynote speaker: Professor Dominique Derome, Université de Sherbrooke, Canada Keynote speaker: Associate Professor Emil Engelund Thybring, University of Copenhagen, Denmark Moderator: Ruut H. Peuhkuri, Research Director, Aalborg University, Denmark				
10:00am - 10:30am	**Coffee break V**				
10:30am - 12:00pm	**Session 30: Refurbishment & energy retrofit** Chair: **Prof. Arnold Louis Janssens**, Ghent University UGent	**Session 34: IAQ, ventilation & pollutants** Chair: **Prof. Xudong Yang**, Tsinghua University	**Session 32: Urban environment, outdoor environment** Chair: **Prof. Holger Koss**	**Session 33: Historical buildings & heritage conservation** Chair: **Dr. Ernst Jan de Place Hansen**, Aalborg University	**Session 31: Innovative cooling systems** Chair: **Dr. Daisuke Ogura**, Kyoto University
12:00pm - 1:00pm	**Lunch break III**				
1:00pm - 2:30pm	**Session 35: Energy demand modelling and prediction** Chair: **Prof. Angela Sasic Kalagasidis**, Chalmers University of Technology	**Session 37: Health and environment** Chair: **Dr. Jianshun Zhang**, Syracuse University	**Session 36: Benchmarking & environmental impact** Chair: **Dr. Hua Ge**, Concordia University	**Session 28: Moisture, HAM** Chair: **Prof. Menghao Qin**, DTU	
2:30pm - 2:45pm	**Coffee break VI**				
2:45pm - 3:15pm	**Closing session: Closing session** Location: **Auditorium - Room 082, Building: 116** Chair: **Prof. Carsten Rode**, Technical University of Denmark				
3:15pm - 4:00pm	**Meeting II: IABP General Assembly** Chair: **Dr. Jianshun Zhang**, Syracuse University				

附錄二、IBPC 2021 會議發表文獻概要(與本所業務相關部分)

一、 A monitoring system for evaluation of COVID-19infection risk

Jevgenis Telicko, Dagis Daniels Vidulejs, Andris Jakovičs

Abstract

Monitoring systems allow operators to accomplish the greatest comfort indoors, but, as a rule, the available parameters are not enough to analyse the epidemiological threat in buildings. Due to the pandemic and increasing incidence of the disease, there is a need for monitoring systems that can provide the necessary information to analyse the risk of infection. With timely notification of people about the risks, such a system could not only increase safety in buildings, but also save crucial resources such as the work of medical personnel. This research presents an example of real-world implementation of a cheap and scalable system to indicate risks and inform people inside. To achieve this, an appropriate set of sensors and communication protocols was

selected, and processing of indirect measurements with artificial intelligence (AI) algorithms was carried out on an embedded Jetson Nano computer. Based on the experiments and a review of the literature, the necessary parameters for measurements were selected. Detailed analysis of measured data for risk evaluation is provided in ‘Numerical model for prediction of indoor covid19 infection risk based on sensor data’ paper.

1. Set of sensors

It is known that some parameters such as relative humidity, temperature and amount of CO2 can affect infection risk. However, as a rule, standard building management system (BMS) measurement parameters are not enough to analyze the epidemiological threat in buildings, as the risk of infection depends on the concentration of the virus particles in the air, the number of people and their activity. In addition to the standard monitoring parameters, the system included dust sensors as well as sensors that process audio and video information using special data pre-processing and algorithms based on recurrent and convolutional neural networks.

2. Hardware

Not all buildings have built-in monitoring systems and integrating sensors into an existing one be difficult. Thus, there was a need for a portable independent monitoring solution that could provide all the necessary information. Each room is equipped with an AI sensor to record video and sound, a direct measurement board and infection risk indicator tower. To ensure the protection of private data over video and audio channels and reduce the cost of system, an embedded computer Jetson Nano was used and only the derived metrics of interest were via internet.

Figure 1 Infection Risk indicator

3. **People counting**

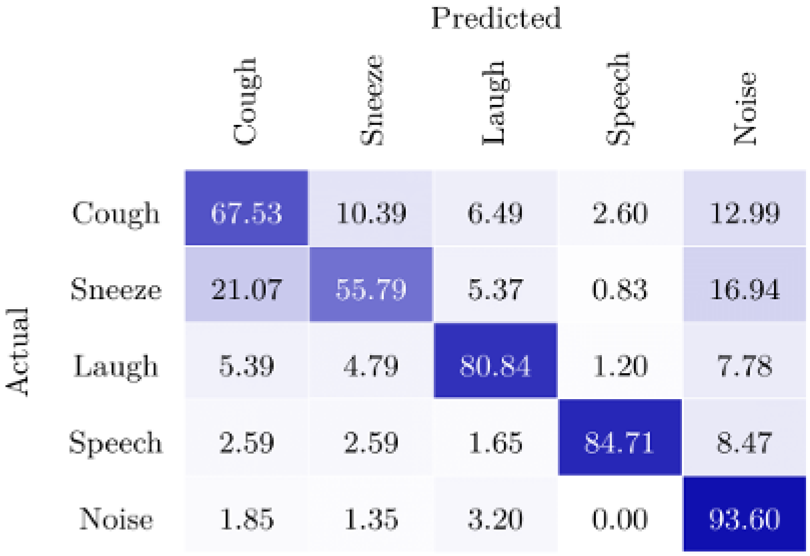
A camera and a neural network (NN) were used to count people. Fisheye cameras provide a better coverage of the room, but distort the image. Therefore, existing pretrained NN models such as YOLO v3, CSRNet and MaskR-CNN generate poor results. To solve this problem, OpenCV packages were used as well as post-processing methods such as the median filter with a buffer to make the result more stable.

Figure 2 Camera result with no correction

4. Sound classification

A neural network produces probability of events such as cough, sneeze, speech and laugh. The probabilities are used as a measurement of Covid-19 airborne transmission risk in a room. The audio engineering methods such as spectrograms come from the established field of automatic speech recognition. The spectrogram is denoised prior to input into the neural network. Denoising may provide better prediction accuracy in variable acoustic conditions such as large or noisy rooms. Likewise the neural network is a type of sequence processing network, which is susceptible to noisy data. To reduce false alarms, the network is biased towards classifying events as noise. To train the neural network cough sounds were collected and selected from volunteers using a smartphone app by the University of Cambridge. In practice it was found that capacative microphones work better than dynamic ones, due to being more sensitive at longer distances from the sound source.

Since the neural network shows difficulties discerning cough from sneeze, these can be considered a single event, yielding a better combined recall of 77%, accuracy of 89% and precision of 81% and for cough and sneeze events.



	Cough	Sneeze	Laugh	Speech	Noise
Cough	67.53	10.39	6.49	2.60	12.99
Sneeze	21.07	55.79	5.37	0.83	16.94
Laugh	5.39	4.79	80.84	1.20	7.78
Speech	2.59	2.59	1.65	84.71	8.47
Noise	1.85	1.35	3.20	0.00	93.60

Figure 3 Confusion matrix of neural net

Conclusion

Thanks to the use of embedded computers, it was possible to create a low-cost monitoring system that complies with data protection policies. For mass installations, the price can be further reduced by using a single powerful computer in combination with cheaper nodes such as ESP32. The developed system allows counting the number of people, analyzing sound information and measuring the necessary environmental parameters to provide data for evaluating the risk of infection according to the model provided in ‘Numerical model for prediction of indoor covid19 infection risk based on sensor data’ paper. Person detection can be significantly improved by using additional pre-processing and supplementing the NN with training data from the actual measurement location. The sound classification model distinguishes human voice from respiratory sounds well, although it is currently harder to differentiate between sneezing and coughing sounds. With increasing demand for COVID-19 risk warning systems, institutions are collecting auditory samples, allowing AI sound monitoring systems to improve greatly.

二、The impacts of COVID-19 pandemic on the hygrothermal environment of our homes

Arianna Brambilla, Alberto Sangiorgio

Abstract

In 2020 the residential sector witnessed a complete transformation of the way people live and occupy the spaces. Indeed, different Countries introduced total lockdowns as a measure to contain and prevent the spread of COVID-19, forcing people to stay at home. These measures impact the indoor hygrothermal environment: higher internal thermal loads and moisture generation rate may create the perfect situation to support mould growth. This project aims to understand the impacts of increased work-from-home practices on the hygrothermal performance of residential buildings.

The assessment uses a two-step methodology: firstly, whole building transient simulations (software trnsys) are used to generate the indoor temperature and humidity profiles, secondly hygrothermal transient simulations (software WUFI) are used to quantify the risk of mould growth. This research reveals the inadequacy of current design and construction practices to support flexible occupation patterns.

Background

The global pandemic of 2020 exposed the residential sector to new challenges, lifting the institutional barriers to remote work. It is estimated that 63% of NSW workers had the potential to WFH pre-pandemic, but only 25% took this advantage for 1 or 2 days per week. After 2020, between 67% and 76% expects to regularly WFH, with the majority aiming for 3 or more days in remote. With increasing time spent indoors, the ability of the buildings to provide healthy indoors become critical. However, Australian houses are known for their poor thermal performance, as well as hygrothermal behavior. Almost one on three Australia homes suffer from excessive damp and mould proliferation, with significant economic and health impacts. Higher occupancy rates resulting from WFH arrangements, as well as moisture-intense activities that rigid lockdowns forced to be performed at home, lead to increased levels of indoor humidity. This, in turn, may support faster mould growth and lead to unhealthy and hazardous indoor environments. This paper investigates the effects of WFH arrangements and cyclical lockdowns on the indoor environment, specifically looking at mould occurrence in Sydney, Australia homes.

Methods and Approach

The transient hygrothermal calculations are performed in WUFI Pro and assessed following the VTT mould growth model, based on the mould index (MI).

Wall Assemblies:

This study targets typical construction technologies to identify how standard buildings can cope with different occupancy scenarios. Hence, the selected wall assemblies reflect the most diffused construction typologies across Australia:

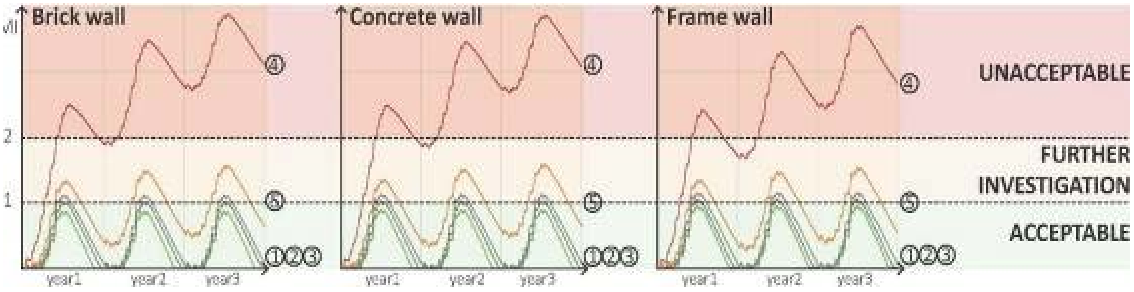
1. Steel/timber frame: plasterboard (26mm), steel or timber frame with glass wool 11kg/m3 (50mm) between the vertical studs, plasterboard (26mm), rainscreen
2. Concrete: plasterboard (13mm), concrete (75mm), glass wool 11kg/m3 (75mm), rainscreen
3. Masonry: interior plasterboard (13mm), clay bricks (110 mm), air gap (20mm), mineral wool 11/m3 (50mm), rainscreen.

Indoor climate:

The indoor climate has been generated through transient thermal simulations (trnsys). The selected architectural model is a two-bedroom apartment, designed according to the NSW Apartment Design Guide

Occupancy patterns: Starting from the internal gains standardized by the Energy Rating Scheme (NatHERS) guidelines, the occupancy density and moisture generation rate has been modified based on emerging WFH trends. The following scenarios have been considered:

1. Scenario 1: standard occupancy as per NatHERS;
2. Scenario 2 and Scenario 3: future WFH trends, 1 day/week WFH, 2 day/week WFH;
3. Scenario 4: lockdown scenario, full occupancy;
4. Scenario 5: cyclical lockdown, mixed WFH and full occupancy.



Results

When occupants work remotely 1 or 2 days per week, the associated risk of mould growth is higher, but still within the acceptable risk thresholds. On the contrary, full lock-down scenarios result in an unacceptable risk of mould growth, highlighting how the wall assemblies are very likely to be affected by mould growth due to the increasing hygrothermal loads. This scenario may be representative of increasing voluntary WFH situations.

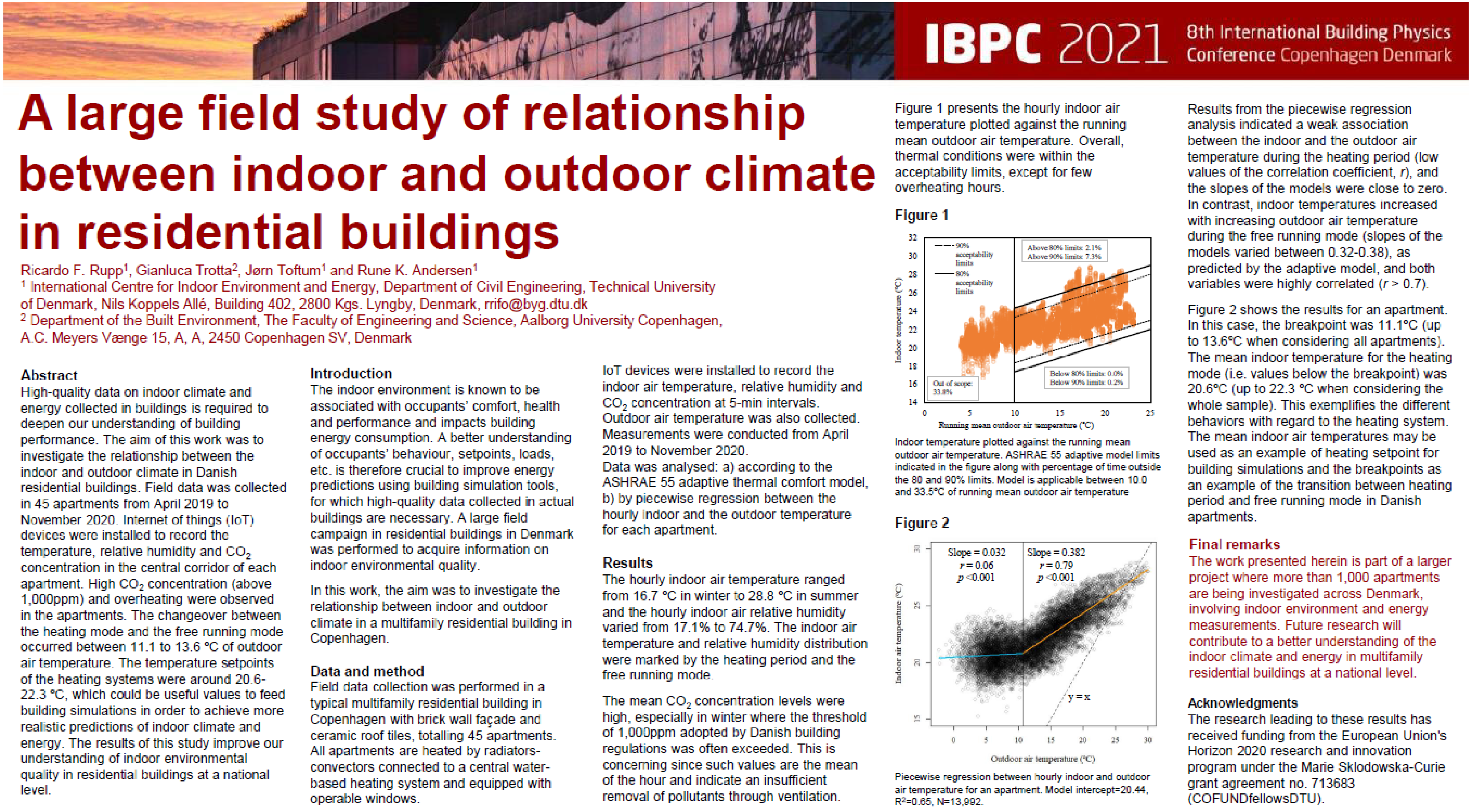
As suggested by scenario 5, also mixed WFH arrangements or cyclical lockdowns throughout the year are likely to result in mould occurrences. Indeed, the MI increases over time with a rate that would lead to unacceptable mould growth risk in less than 6 years.

Conclusion

This paper investigates the effects of novel work-from-home arrangements and it demonstrates that typical Australian homes are not equipped to cope with increasing indoor hygrothermal loads. Current construction practices already perform poorly under standard conditions [4][5][6], and this analysis reveals that future trends may aggravate this issue even further. The findings reveal the need for an update of the current design and construction practices, including a re-assessment of the occupancy schedules currently prescribed by the relevant certification standards, to ensure that present and future buildings will be capable to adapt to changing occupancy patterns and offer healthy indoor environments.

三、 A large field study of relationship between indoor and outdoor climate in residential buildings

Ricardo F. Rupp1, Gianluca Trotta2, Jørn Toftum1and Rune K. Andersen1



IBPC 2021 8th International Building Physics Conference Copenhagen Denmark

A large field study of relationship between indoor and outdoor climate in residential buildings

Ricardo F. Rupp[1], Gianluca Trotta[2], Jørn Toftum[1] and Rune K. Andersen[1]
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Abstract

High-quality data on indoor climate and energy collected in buildings is required to deepen our understanding of building performance. The aim of this work was to investigate the relationship between the indoor and outdoor climate in Danish residential buildings. Field data was collected in 45 apartments from April 2019 to November 2020. Internet of things (IoT) devices were installed to record the temperature, relative humidity and CO_2 concentration in the central corridor of each apartment. High CO_2 concentration (above 1,000ppm) and overheating were observed in the apartments. The changeover between the heating mode and the free running mode occurred between 11.1 to 13.6 °C of outdoor air temperature. The temperature setpoints of the heating systems were around 20.6-22.3 °C, which could be useful values to feed building simulations in order to achieve more realistic predictions of indoor climate and energy. The results of this study improve our understanding of indoor environmental quality in residential buildings at a national level.

Introduction

The indoor environment is known to be associated with occupants' comfort, health and performance and impacts building energy consumption. A better understanding of occupants' behaviour, setpoints, loads, etc. is therefore crucial to improve energy predictions using building simulation tools, for which high-quality data collected in actual buildings are necessary. A large field campaign in residential buildings in Denmark was performed to acquire information on indoor environmental quality.

In this work, the aim was to investigate the relationship between indoor and outdoor climate in a multifamily residential building in Copenhagen.

Data and method

Field data collection was performed in a typical multifamily residential building in Copenhagen with brick wall façade and ceramic roof tiles, totalling 45 apartments. All apartments are heated by radiators-convectors connected to a central water-based heating system and equipped with operable windows. IoT devices were installed to record the indoor air temperature, relative humidity and CO_2 concentration at 5-min intervals. Outdoor air temperature was also collected. Measurements were conducted from April 2019 to November 2020.

Data was analysed: a) according to the ASHRAE 55 adaptive thermal comfort model, b) by piecewise regression between the hourly indoor and the outdoor temperature for each apartment.

Results

The hourly indoor air temperature ranged from 16.7 °C in winter to 28.8 °C in summer and the hourly indoor air relative humidity varied from 17.1% to 74.7%. The indoor air temperature and relative humidity distribution were marked by the heating period and the free running mode.

The mean CO_2 concentration levels were high, especially in winter where the threshold of 1,000ppm adopted by Danish building regulations was often exceeded. This is concerning since such values are the mean of the hour and indicate an insufficient removal of pollutants through ventilation.

Figure 1 presents the hourly indoor air temperature plotted against the running mean outdoor air temperature. Overall, thermal conditions were within the acceptability limits, except for few overheating hours.

Figure 1

Indoor temperature plotted against the running mean outdoor air temperature. ASHRAE 55 adaptive model limits indicated in the figure along with percentage of time outside the 80 and 90% limits. Model is applicable between 10.0 and 33.5°C of running mean outdoor air temperature

Figure 2

Piecewise regression between hourly indoor and outdoor air temperature for an apartment. Model intercept=20.44, $R^2=0.65$, N=13,992.

Results from the piecewise regression analysis indicated a weak association between the indoor and the outdoor air temperature during the heating period (low values of the correlation coefficient, r), and the slopes of the models were close to zero. In contrast, indoor temperatures increased with increasing outdoor air temperature during the free running mode (slopes of the models varied between 0.32-0.38), as predicted by the adaptive model, and both variables were highly correlated ($r > 0.7$).

Figure 2 shows the results for an apartment. In this case, the breakpoint was 11.1°C (up to 13.6°C when considering all apartments). The mean indoor temperature for the heating mode (i.e. values below the breakpoint) was 20.6°C (up to 22.3 °C when considering the whole sample). This exemplifies the different behaviors with regard to the heating system. The mean indoor air temperatures may be used as an example of heating setpoint for building simulations and the breakpoints as an example of the transition between heating period and free running mode in Danish apartments.

Final remarks

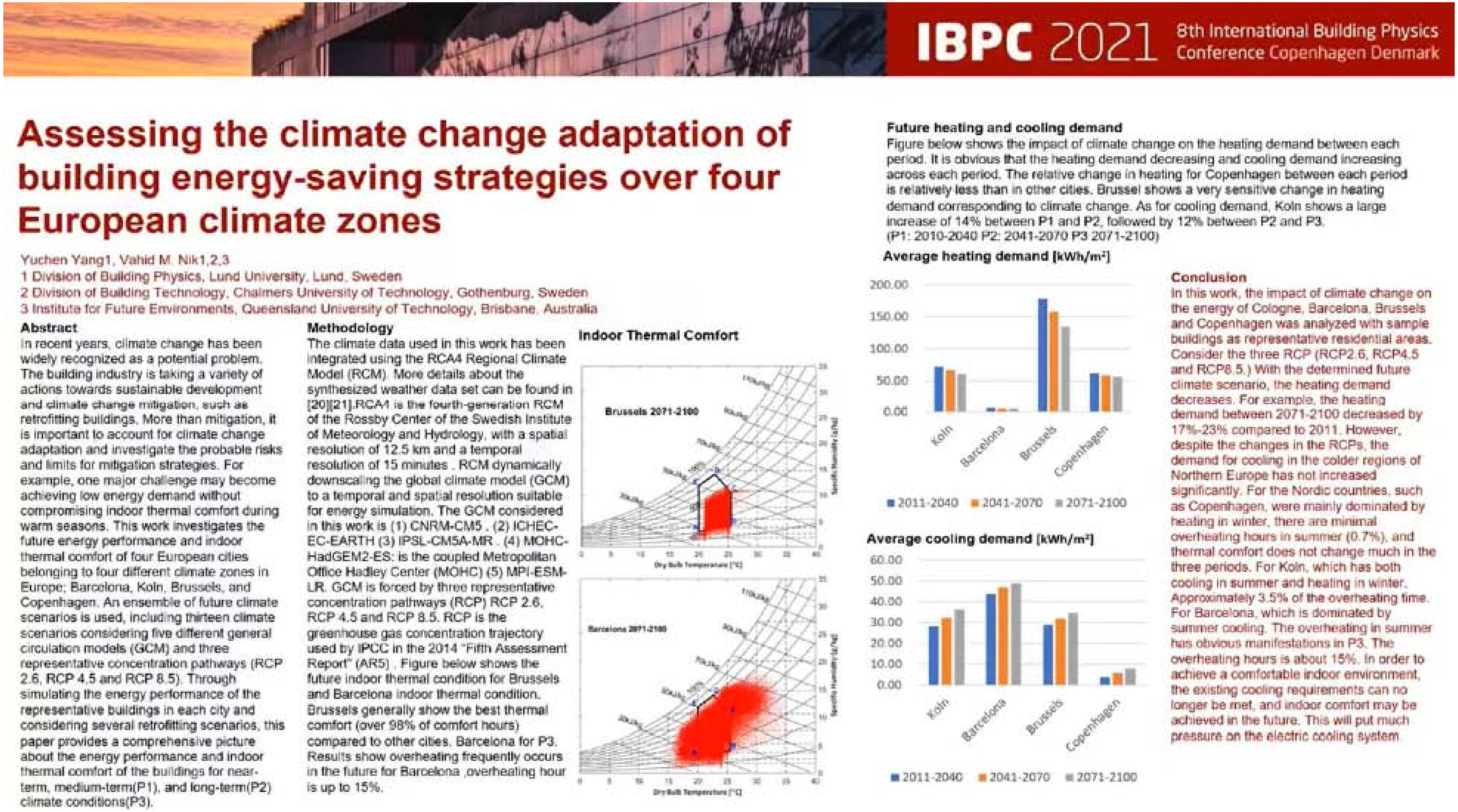
The work presented herein is part of a larger project where more than 1,000 apartments are being investigated across Denmark, involving indoor environment and energy measurements. Future research will contribute to a better understanding of the indoor climate and energy in multifamily residential buildings at a national level.

Acknowledgments

The research leading to these results has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Sklodowska-Curie grant agreement no. 713683 (COFUNDfellowsDTU).

四、 Assessing the climate change adaptation of building energy saving strategies over four European citiesclimate zones

Yuchen Yang1, Vahid M, Nik1,2,3



Assessing the climate change adaptation of building energy-saving strategies over four European climate zones

Yuchen Yang1, Vahid M. Nik1,2,3
1 Division of Building Physics, Lund University, Lund, Sweden
2 Division of Building Technology, Chalmers University of Technology, Gothenburg, Sweden
3 Institute for Future Environments, Queensland University of Technology, Brisbane, Australia

Abstract

In recent years, climate change has been widely recognized as a potential problem. The building industry is taking a variety of actions towards sustainable development and climate change mitigation, such as retrofitting buildings. More than mitigation, it is important to account for climate change adaptation and investigate the probable risks and limits for mitigation strategies. For example, one major challenge may become achieving low energy demand without compromising indoor thermal comfort during warm seasons. This work investigates the future energy performance and indoor thermal comfort of four European cities belonging to four different climate zones in Europe; Barcelona, Koln, Brussels, and Copenhagen. An ensemble of future climate scenarios is used, including thirteen climate scenarios considering five different general circulation models (GCM) and three representative concentration pathways (RCP 2.6, RCP 4.5 and RCP 8.5). Through simulating the energy performance of the representative buildings in each city and considering several retrofitting scenarios, this paper provides a comprehensive picture about the energy performance and indoor thermal comfort of the buildings for near-term, medium-term(P1), and long-term(P2) climate conditions(P3).

Methodology

The climate data used in this work has been integrated using the RCA4 Regional Climate Model (RCM). More details about the synthesized weather data set can be found in [20][21].RCA4 is the fourth-generation RCM of the Rossby Center of the Swedish Institute of Meteorology and Hydrology, with a spatial resolution of 12.5 km and a temporal resolution of 15 minutes . RCM dynamically downscaling the global climate model (GCM) to a temporal and spatial resolution suitable for energy simulation. The GCM considered in this work is (1) CNRM-CM5 , (2) ICHEC-EC-EARTH (3) IPSL-CM5A-MR . (4) MOHC-HadGEM2-ES: is the coupled Metropolitan Office Hadley Center (MOHC) (5) MPI-ESM-LR. GCM is forced by three representative concentration pathways (RCP) RCP 2.6, RCP 4.5 and RCP 8.5. RCP is the greenhouse gas concentration trajectory used by IPCC in the 2014 "Fifth Assessment Report" (AR5) . Figure below shows the future indoor thermal condition for Brussels and Barcelona indoor thermal condition. Brussels generally show the best thermal comfort (over 98% of comfort hours) compared to other cities. Barcelona for P3. Results show overheating frequently occurs in the future for Barcelona ,overheating hour is up to 15%.

Indoor Thermal Comfort

Future heating and cooling demand

Figure below shows the impact of climate change on the heating demand between each period. It is obvious that the heating demand decreasing and cooling demand increasing across each period. The relative change in heating for Copenhagen between each period is relatively less than in other cities. Brussel shows a very sensitive change in heating demand corresponding to climate change. As for cooling demand, Koln shows a large increase of 14% between P1 and P2, followed by 12% between P2 and P3.
(P1: 2010-2040 P2: 2041-2070 P3 2071-2100)

Average heating demand [kWh/m²]

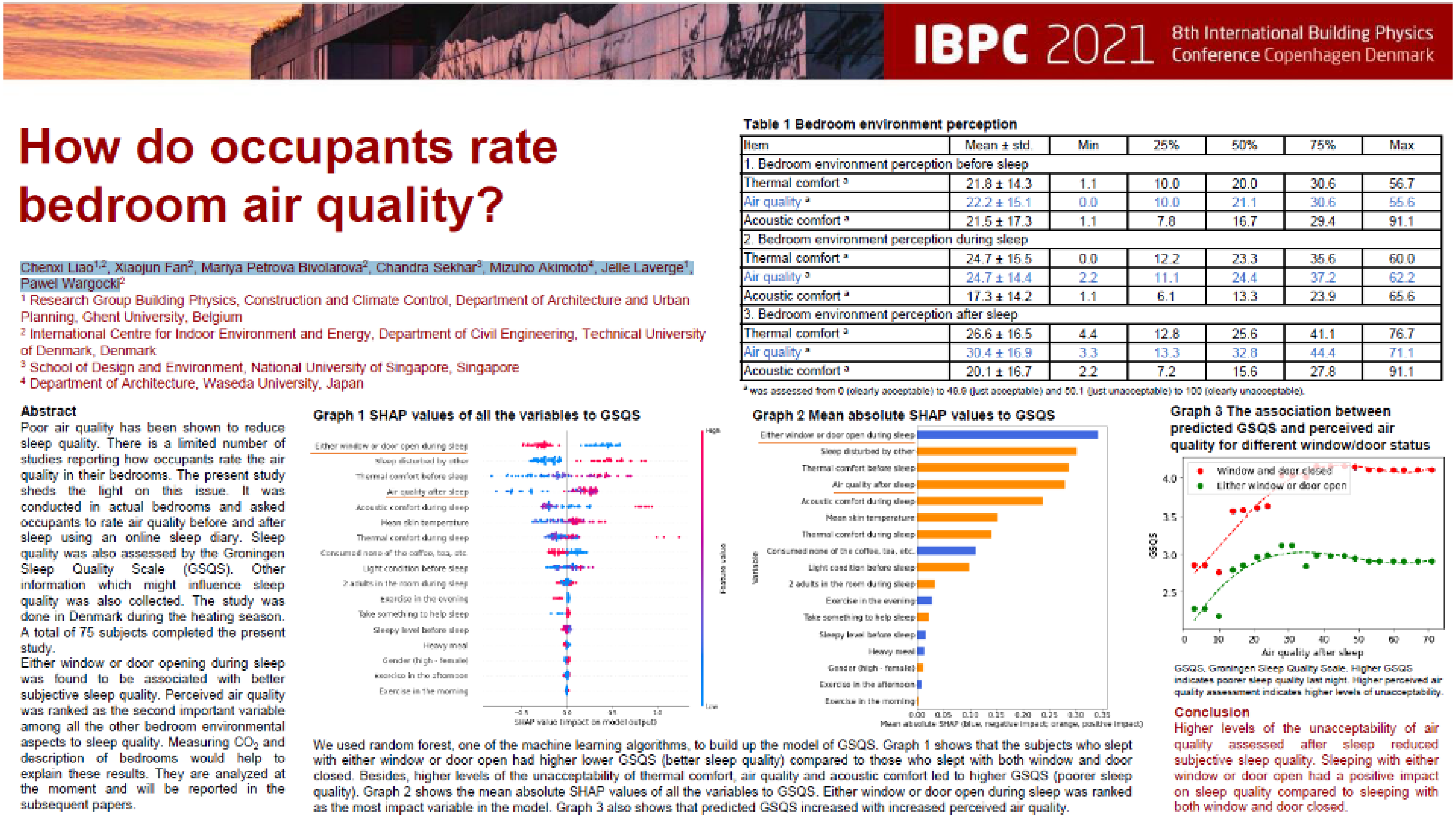
Average cooling demand [kWh/m²]

Conclusion

In this work, the impact of climate change on the energy of Cologne, Barcelona, Brussels and Copenhagen was analyzed with sample buildings as representative residential areas. Consider the three RCP (RCP2.6, RCP4.5 and RCP8.5.) With the determined future climate scenario, the heating demand decreases. For example, the heating demand between 2071-2100 decreased by 17%-23% compared to 2011. However, despite the changes in the RCPs, the demand for cooling in the colder regions of Northern Europe has not increased significantly. For the Nordic countries, such as Copenhagen, were mainly dominated by heating in winter, there are minimal overheating hours in summer (0.7%), and thermal comfort does not change much in the three periods. For Koln, which has both cooling in summer and heating in winter. Approximately 3.5% of the overheating time. For Barcelona, which is dominated by summer cooling. The overheating in summer has obvious manifestations in P3. The overheating hours is about 15%. In order to achieve a comfortable indoor environment, the existing cooling requirements can no longer be met, and indoor comfort may be achieved in the future. This will put much pressure on the electric cooling system

五、 How do occupants rate bedroom air quality?

Chenxi Liao1,2, Xiaojun Fan2, Mariya Petrova Bivolarova2, Chandra Sekhar3, Mizuho Akimoto4, Jelle Laverge1, Pawel Wargocki



How do occupants rate bedroom air quality?

Chenxi Liao[1,2], Xiaojun Fan[2], Mariya Petrova Bivolarova[2], Chandra Sekhar[3], Mizuho Akimoto[4], Jelle Laverge[1], Pawel Wargocki[2]

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[2] International Centre for Indoor Environment and Energy, Department of Civil Engineering, Technical University of Denmark, Denmark

[3] School of Design and Environment, National University of Singapore, Singapore

[4] Department of Architecture, Waseda University, Japan

Abstract

Poor air quality has been shown to reduce sleep quality. There is a limited number of studies reporting how occupants rate the air quality in their bedrooms. The present study sheds the light on this issue. It was conducted in actual bedrooms and asked occupants to rate air quality before and after sleep using an online sleep diary. Sleep quality was also assessed by the Groningen Sleep Quality Scale (GSQS). Other information which might influence sleep quality was also collected. The study was done in Denmark during the heating season. A total of 75 subjects completed the present study.

Either window or door opening during sleep was found to be associated with better subjective sleep quality. Perceived air quality was ranked as the second important variable among all the other bedroom environmental aspects to sleep quality. Measuring CO_2 and description of bedrooms would help to explain these results. They are analyzed at the moment and will be reported in the subsequent papers.

Table 1 Bedroom environment perception

Item	Mean ± std.	Min	25%	50%	75%	Max
1. Bedroom environment perception before sleep						
Thermal comfort [a]	21.8 ± 14.3	1.1	10.0	20.0	30.6	56.7
Air quality [a]	22.2 ± 15.1	0.0	10.0	21.1	30.6	55.6
Acoustic comfort [a]	21.5 ± 17.3	1.1	7.8	16.7	29.4	91.1
2. Bedroom environment perception during sleep						
Thermal comfort [a]	24.7 ± 15.5	0.0	12.2	23.3	35.6	60.0
Air quality [a]	24.7 ± 14.4	2.2	11.1	24.4	37.2	62.2
Acoustic comfort [a]	17.3 ± 14.2	1.1	6.1	13.3	23.9	65.6
3. Bedroom environment perception after sleep						
Thermal comfort [a]	26.6 ± 16.5	4.4	12.8	25.6	41.1	76.7
Air quality [a]	30.4 ± 16.9	3.3	13.3	32.8	44.4	71.1
Acoustic comfort [a]	20.1 ± 16.7	2.2	7.2	15.6	27.8	91.1

[a] was assessed from 0 (clearly acceptable) to 49.9 (just acceptable) and 50.1 (just unacceptable) to 100 (clearly unacceptable).

Graph 1 SHAP values of all the variables to GSQS

Graph 2 Mean absolute SHAP values to GSQS

Graph 3 The association between predicted GSQS and perceived air quality for different window/door status

GSQS, Groningen Sleep Quality Scale. Higher GSQS indicates poorer sleep quality last night. Higher perceived air quality assessment indicates higher levels of unacceptability.

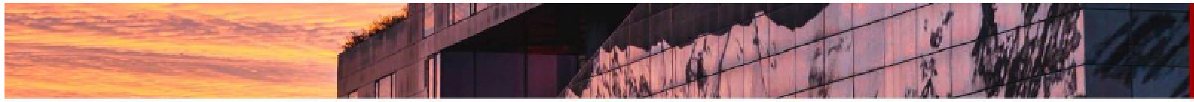
We used random forest, one of the machine learning algorithms, to build up the model of GSQS. Graph 1 shows that the subjects who slept with either window or door open had higher lower GSQS (better sleep quality) compared to those who slept with both window and door closed. Besides, higher levels of the unacceptability of thermal comfort, air quality and acoustic comfort led to higher GSQS (poorer sleep quality). Graph 2 shows the mean absolute SHAP values of all the variables to GSQS. Either window or door open during sleep was ranked as the most impact variable in the model. Graph 3 also shows that predicted GSQS increased with increased perceived air quality.

Conclusion

Higher levels of the unacceptability of air quality assessed after sleep reduced subjective sleep quality. Sleeping with either window or door open had a positive impact on sleep quality compared to sleeping with both window and door closed.

六、 Improving thermal comfort conditions in K-12 educational buildings in hot and humid climate: a case study in Cucuta, Colombia

Guerrero Diana, Ge Hua, Lee Bruno



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Improving thermal comfort conditions in K-12 educational buildings in hot and humid climate: a case study in Cucuta, Colombia

Guerrero Diana, Ge Hua, Lee Bruno.
Concordia University, Montreal, Canada.

Abstract

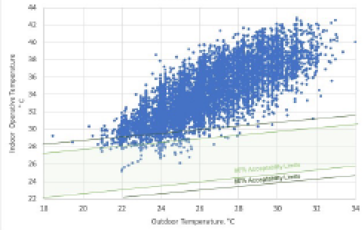
The school buildings in Colombia are built based on geographical locations and regional construction systems. However, external weather conditions and building design can have a significant impact on the students thermal comfort , which affects the academic performance and productivity.

This study investigates the thermal comfort performance for an educational building in Cucuta, Colombia. This school is a concrete structure without mechanical cooling and built under national guidelines. However, field observation discovered that:

82% Thermal Discomfort. Perception

78% Request decrease Indoor Temperature

To investigate causes and provide mitigation strategies, a whole building energy simulation is conducted. Design Builder is used to evaluate the indoor thermal conditions compared to outdoor data collected. ASHRAE 55 adaptative model is used for the evaluation. It is found that 79% of the time the thermal conditions are outside the acceptable range during the year



It is found that occupancy and natural ventilation rate have a significant impact on the indoor temperature and relative humidity, and thus the thermal comfort. Passive design strategies are proposed in optimizing the school building design to meet ASHARE-55 requirements.

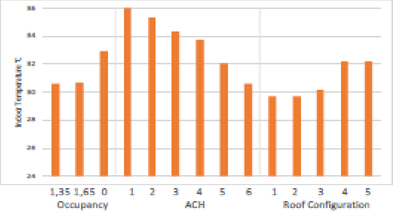
Building Conditions

the indoor thermal condition for the classroom standard type complies with the ASHRAE 55-2017 thermal comfort ranges criteria (80% acceptability limits) 21.2% of the time over the one-year period. The monthly analysis shows that November is the period with the highest number of overheating hours. 11.2% of the time, the indoor operative temperature is above 34,2°C, and 8.5% of the time the temperature is over 36°C which establishes a thermal stress period.

Occupancy Results

The simulation results identified the building performance for four levels of occupancy: 1.35 m2/person according to the national standard NTC 4595, 2.85 m2/person based in ASHRAE, 1.65 m2/person, identified in the building performance, and an empty classroom. The standards reduced to 2.5°C the indoor conditions Comparing the current two regulations a the reduction only 0.06 °C of temperature operating and decreasing by 36% the level of occupancy per classroom. Also the simulation shows that the increase of occupancy, the operative temperature increases; The increase of occupancy also increases indoor humidity ratio.

November Results



Natural Ventilation Results

the relationship between thermal comfort and natural ventilation was evidenced through the simulation varying the rate from 1-6 ACH , indicating the operative temperature decreased when the airflow increases. it shows that the ranges established by ASHRAE 55 for school buildings (five ac/h to six ac/h) can reduce the operative temperature to 2,6°C and comply with the accepted range of thermal comfort for hot and humid areas.

Roof Configuration Results

The building has a sloping roof in tiles and a metal frame. five roof configurations were selected to study their ability to improve thermal conditions: Open cell spray foam, fiberglass, polystyrene, and EPS foam. The insulation layer with a thickness of 25 cm R-22 open cell spray foam and R-12 Batt insulation fiberglass configurations showed 1°C lower operative temperature during 8:00 to 16:00, a crucial period in school activities. The insulation material in the roof improves the thermal comfort for classrooms located on the second floor of the building, reducing the indoor temperature by 3.5 °C and controlling the indoor operative temperature, but also delaying the occurrence of discomfort temperatures

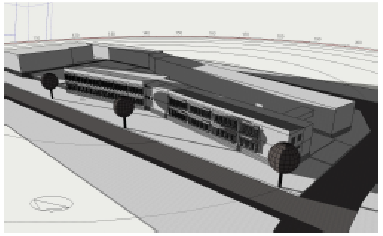
Conclusion

Overheating is the primary concern for a hot semi-humid climate where natural ventilation and adding an insulation layer in the roof configuration significantly influence the thermal conditions.

Three strategies were proposed as the most effective:

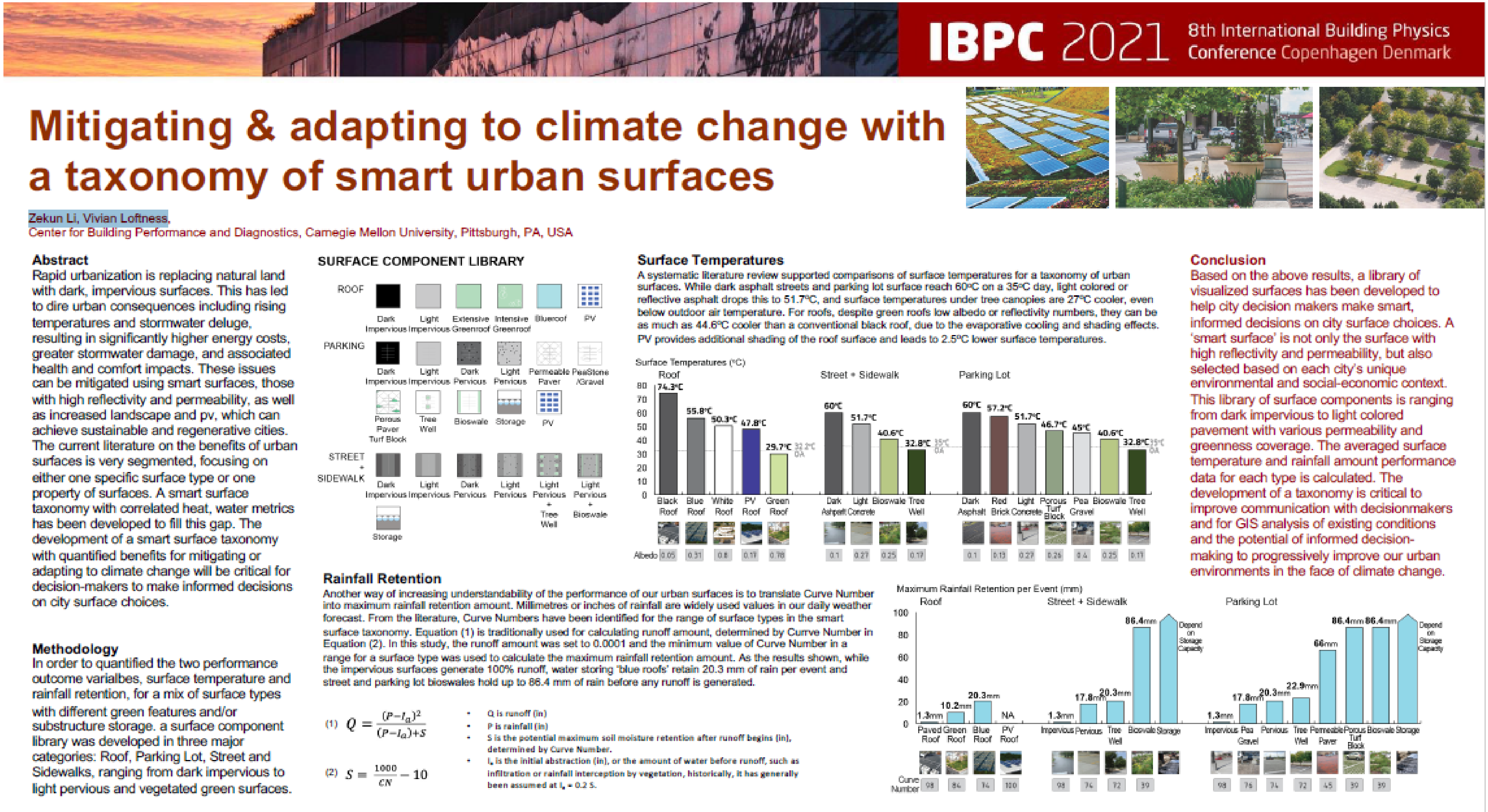
- Improving air renewal by cross-ventilation through openings to the north and southeast and manually operable windows to ensure dehumidification.
- Maintaining the occupancy percentage following current regulations.
- Including insulation layer in the roof configuration.

Evaluate the proposed passive strategies' impacts, besides validating the current elements identified in the building as shading elements, arrangement of external native vegetation, or ventilated double-leaf construction with reflective surfaces. Additionally, more research in a thermal comfort classification according to age and a "clothes adjustment zone" is suggested.



七、 Mitigating & adapting to climate change with a taxonomy of smart urban surfaces Influence of climate change on the energy performance assessment of NZEB houses

Zekun Li, Vivian Loftness



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Mitigating & adapting to climate change with a taxonomy of smart urban surfaces

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Abstract

Rapid urbanization is replacing natural land with dark, impervious surfaces. This has led to dire urban consequences including rising temperatures and stormwater deluge, resulting in significantly higher energy costs, greater stormwater damage, and associated health and comfort impacts. These issues can be mitigated using smart surfaces, those with high reflectivity and permeability, as well as increased landscape and pv, which can achieve sustainable and regenerative cities. The current literature on the benefits of urban surfaces is very segmented, focusing on either one specific surface type or one property of surfaces. A smart surface taxonomy with correlated heat, water metrics has been developed to fill this gap. The development of a smart surface taxonomy with quantified benefits for mitigating or adapting to climate change will be critical for decision-makers to make informed decisions on city surface choices.

Methodology

In order to quantified the two performance outcome varialbes, surface temperature and rainfall retention, for a mix of surface types with different green features and/or substructure storage. a surface component library was developed in three major categories: Roof, Parking Lot, Street and Sidewalks, ranging from dark impervious to light pervious and vegetated green surfaces.

SURFACE COMPONENT LIBRARY

Surface Temperatures

A systematic literature review supported comparisons of surface temperatures for a taxonomy of urban surfaces. While dark asphalt streets and parking lot surface reach 60°C on a 35°C day, light colored or reflective asphalt drops this to 51.7°C, and surface temperatures under tree canopies are 27°C cooler, even below outdoor air temperature. For roofs, despite green roofs low albedo or reflectivity numbers, they can be as much as 44.6°C cooler than a conventional black roof, due to the evaporative cooling and shading effects. PV provides additional shading of the roof surface and leads to 2.5°C lower surface temperatures.

Rainfall Retention

Another way of increasing understandability of the performance of our urban surfaces is to translate Curve Number into maximum rainfall retention amount. Millimetres or inches of rainfall are widely used values in our daily weather forecast. From the literature, Curve Numbers have been identified for the range of surface types in the smart surface taxonomy. Equation (1) is traditionally used for calculating runoff amount, determined by Curve Number in Equation (2). In this study, the runoff amount was set to 0.0001 and the minimum value of Curve Number in a range for a surface type was used to calculate the maximum rainfall retention amount. As the results shown, while the impervious surfaces generate 100% runoff, water storing 'blue roofs' retain 20.3 mm of rain per event and street and parking lot bioswales hold up to 86.4 mm of rain before any runoff is generated.

$$Q = \frac{(P-I_a)^2}{(P-I_a)+S} \quad (1)$$

$$S = \frac{1000}{CN} - 10 \quad (2)$$

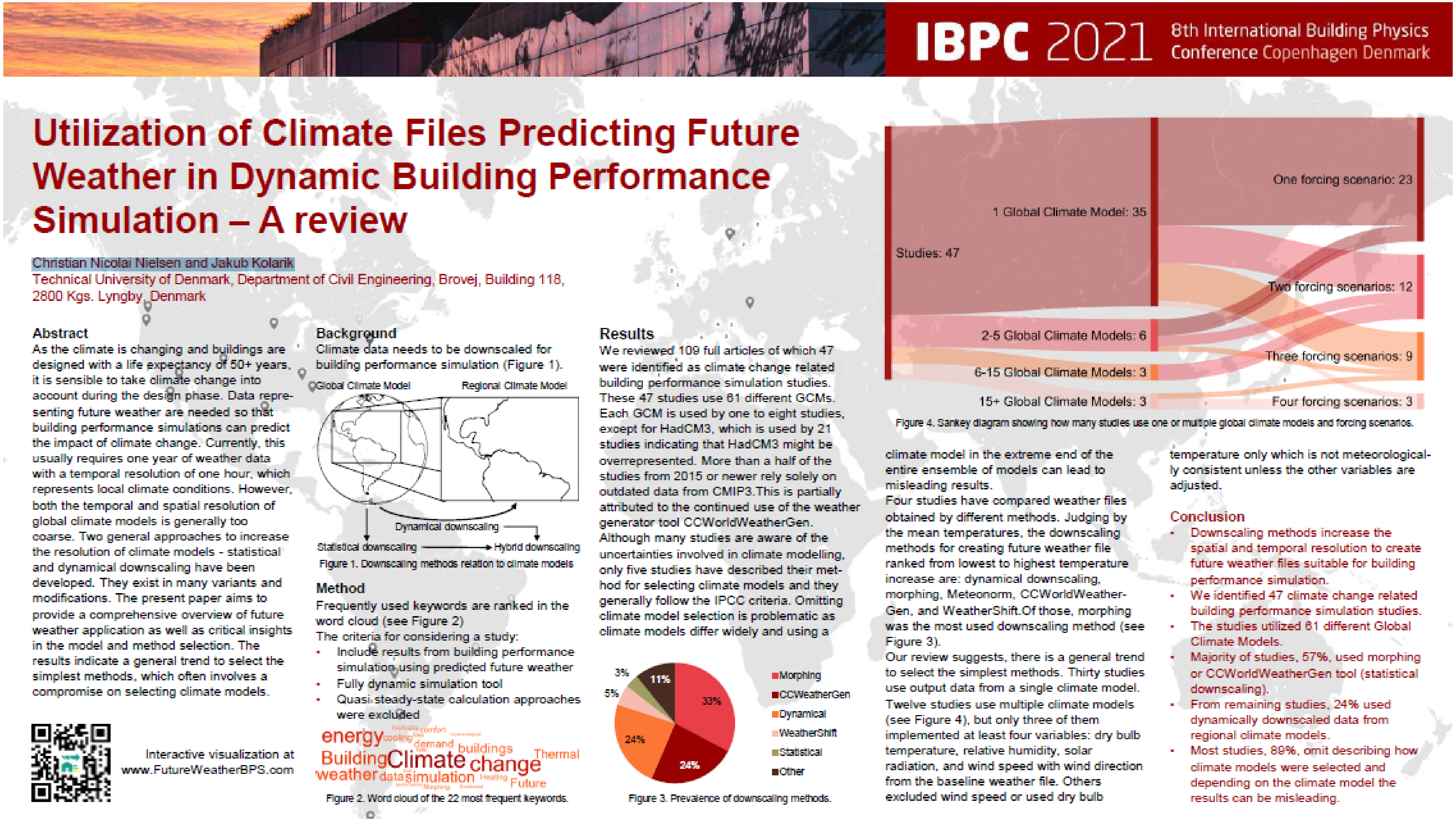
- Q is runoff (in)
- P is rainfall (in)
- S is the potential maximum soil moisture retention after runoff begins (in), determined by Curve Number.
- I_a is the initial abstraction (in), or the amount of water before runoff, such as infiltration or rainfall interception by vegetation, historically, it has generally been assumed at I_a = 0.2 S.

Conclusion

Based on the above results, a library of visualized surfaces has been developed to help city decision makers make smart, informed decisions on city surface choices. A 'smart surface' is not only the surface with high reflectivity and permeability, but also selected based on each city's unique environmental and social-economic context. This library of surface components is ranging from dark impervious to light colored pavement with various permeability and greenness coverage. The averaged surface temperature and rainfall amount performance data for each type is calculated. The development of a taxonomy is critical to improve communication with decisionmakers and for GIS analysis of existing conditions and the potential of informed decision-making to progressively improve our urban environments in the face of climate change.

八、 Utilization of Climate Files Predicting Future Weather in Dynamic Building Performance Simulation – A review

Christian Nicolai Nielsen and Jakub Kolarik



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Utilization of Climate Files Predicting Future Weather in Dynamic Building Performance Simulation – A review

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Abstract

As the climate is changing and buildings are designed with a life expectancy of 50+ years, it is sensible to take climate change into account during the design phase. Data representing future weather are needed so that building performance simulations can predict the impact of climate change. Currently, this usually requires one year of weather data with a temporal resolution of one hour, which represents local climate conditions. However, both the temporal and spatial resolution of global climate models is generally too coarse. Two general approaches to increase the resolution of climate models - statistical and dynamical downscaling have been developed. They exist in many variants and modifications. The present paper aims to provide a comprehensive overview of future weather application as well as critical insights in the model and method selection. The results indicate a general trend to select the simplest methods, which often involves a compromise on selecting climate models.

Interactive visualization at www.FutureWeatherBPS.com

Background

Climate data needs to be downscaled for building performance simulation (Figure 1).

Figure 1. Downscaling methods relation to climate models

Method

Frequently used keywords are ranked in the word cloud (see Figure 2)
The criteria for considering a study:

- Include results from building performance simulation using predicted future weather
- Fully dynamic simulation tool
- Quasi steady-state calculation approaches were excluded

Figure 2. Word cloud of the 22 most frequent keywords.

Results

We reviewed 109 full articles of which 47 were identified as climate change related building performance simulation studies. These 47 studies use 61 different GCMs. Each GCM is used by one to eight studies, except for HadCM3, which is used by 21 studies indicating that HadCM3 might be overrepresented. More than a half of the studies from 2015 or newer rely solely on outdated data from CMIP3.This is partially attributed to the continued use of the weather generator tool CCWorldWeatherGen. Although many studies are aware of the uncertainties involved in climate modelling, only five studies have described their method for selecting climate models and they generally follow the IPCC criteria. Omitting climate model selection is problematic as climate models differ widely and using a climate model in the extreme end of the entire ensemble of models can lead to misleading results.

Figure 3. Prevalence of downscaling methods.

Four studies have compared weather files obtained by different methods. Judging by the mean temperatures, the downscaling methods for creating future weather file ranked from lowest to highest temperature increase are: dynamical downscaling, morphing, Meteonorm, CCWorldWeatherGen, and WeatherShift.Of those, morphing was the most used downscaling method (see Figure 3).

Our review suggests, there is a general trend to select the simplest methods. Thirty studies use output data from a single climate model. Twelve studies use multiple climate models (see Figure 4), but only three of them implemented at least four variables: dry bulb temperature, relative humidity, solar radiation, and wind speed with wind direction from the baseline weather file. Others excluded wind speed or used dry bulb temperature only which is not meteorologically consistent unless the other variables are adjusted.

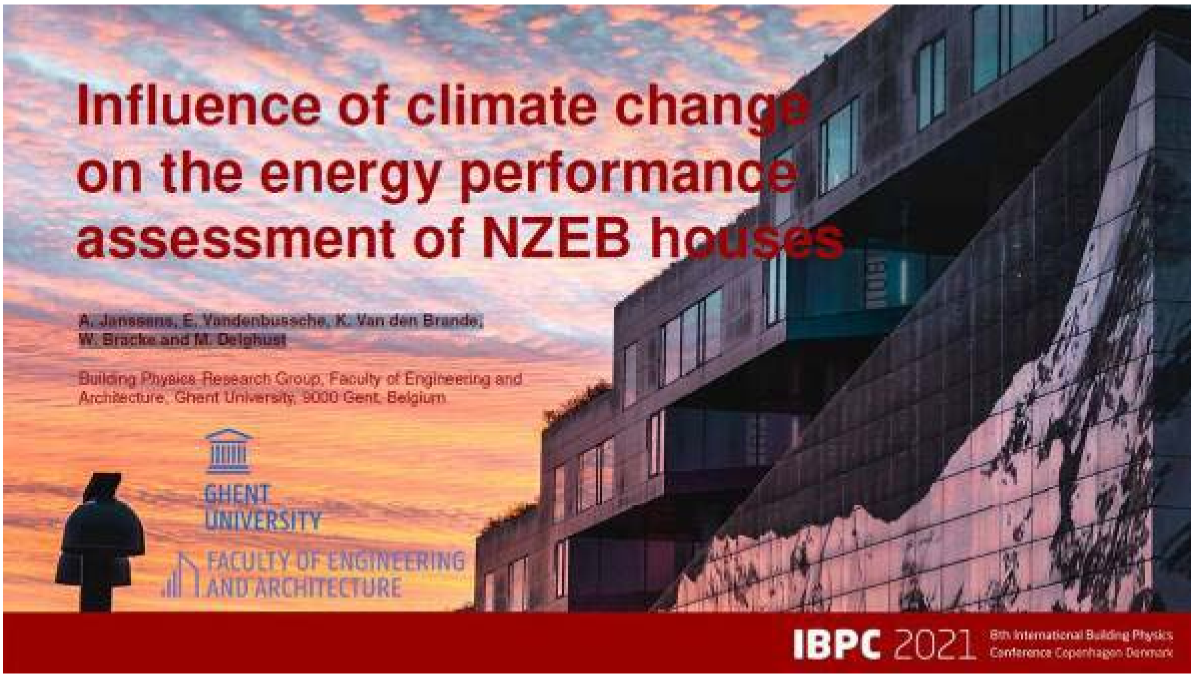
Figure 4. Sankey diagram showing how many studies use one or multiple global climate models and forcing scenarios.

Conclusion

- Downscaling methods increase the spatial and temporal resolution to create future weather files suitable for building performance simulation.
- We identified 47 climate change related building performance simulation studies.
- The studies utilized 61 different Global Climate Models.
- Majority of studies, 57%, used morphing or CCWorldWeatherGen tool (statistical downscaling).
- From remaining studies, 24% used dynamically downscaled data from regional climate models.
- Most studies, 89%, omit describing how climate models were selected and depending on the climate model the results can be misleading.

九、 Influence of climate change on the energy performance assessment of NZEB houses

A. Janssens, E. Vandenbussche, K. Van den Brande, W. Bracke and M. Delghust



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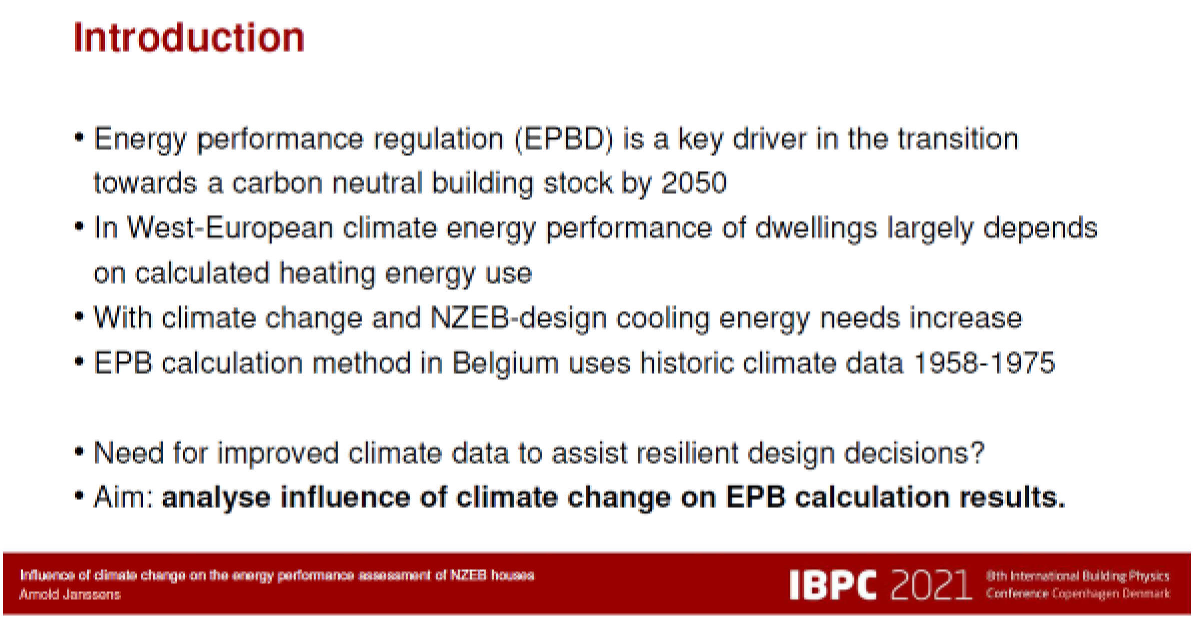

Introduction

- Energy performance regulation (EPBD) is a key driver in the transition towards a carbon neutral building stock by 2050
- In West-European climate energy performance of dwellings largely depends on calculated heating energy use
- With climate change and NZEB-design cooling energy needs increase
- EPB calculation method in Belgium uses historic climate data 1958-1975

- Need for improved climate data to assist resilient design decisions?
- Aim: **analyse influence of climate change on EPB calculation results.**

Influence of climate change on the energy performance assessment of NZEB houses
Arnold Janssens

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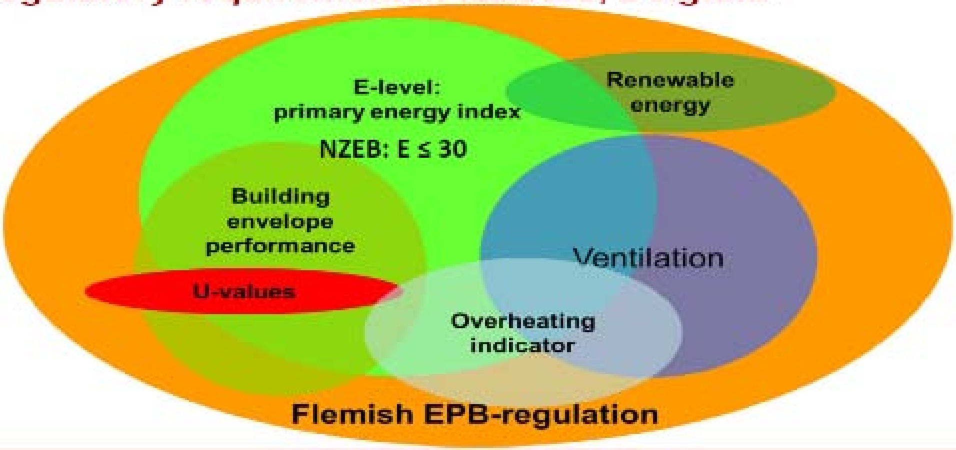
Energy and indoor climate (EPB): Regulatory requirements Flanders, Belgium



E-level:
primary energy index
NZEB: E ≤ 30

Renewable energy

Building envelope performance

U-values

Ventilation

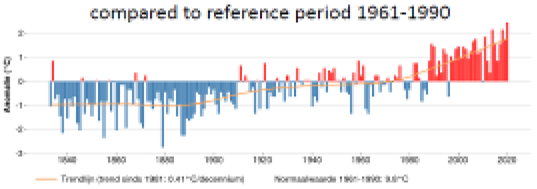
Overheating indicator

Flemish EPB-regulation

Global warming data

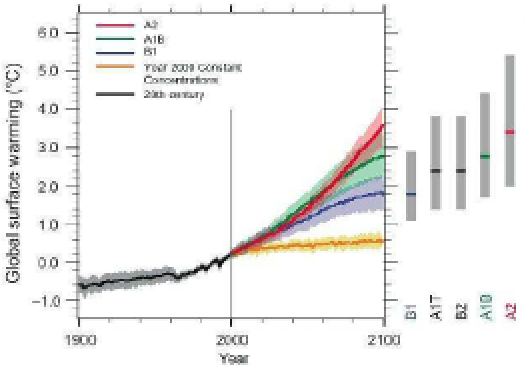
- Historical increase of ambient temperature
- Various IPCC future emission scenarios
- Scenario SRES-A2 selected for 2050

Deviation of yearly mean temperature in Brussels compared to reference period 1961-1990



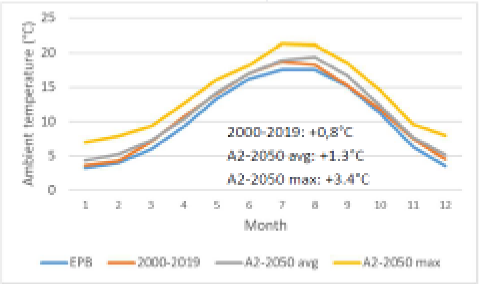
IPCC Special Report Emissions Scenarios (SRES)

Multi-model Averages and Assessed Ranges for Surface Warming

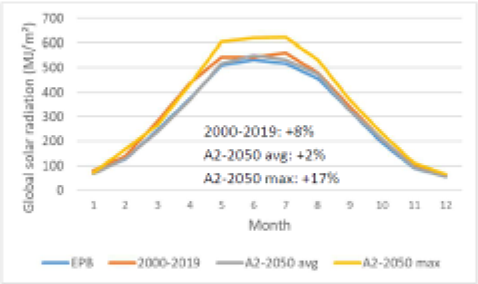


Comparison climate data Brussels

Outside temperature

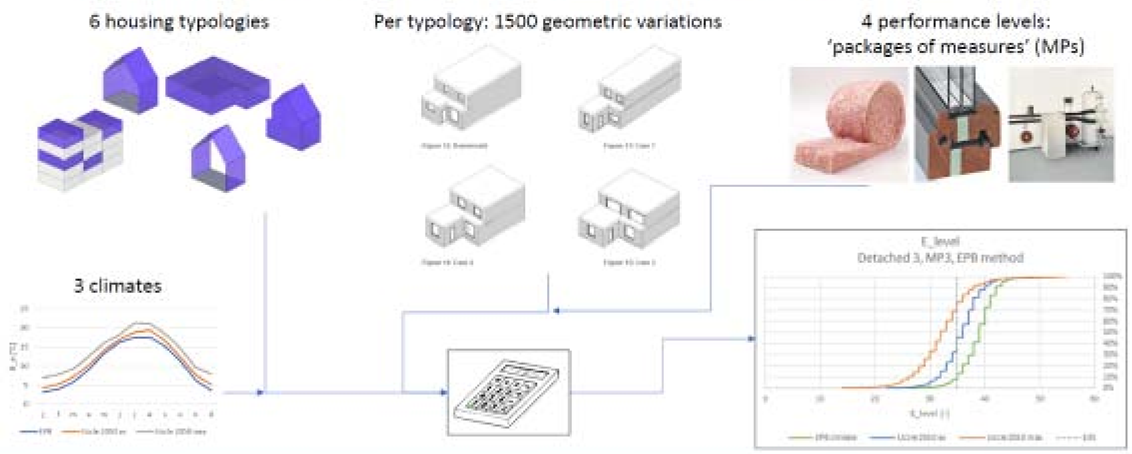


Global solar radiation, horizontal



- EPB: data in regulatory calculations
- 2000-2019: historic data
- A2-2050 avg: future SRES data, developed in Meteonorm, 10-year average
- A2-2050 max: future SRES data, developed in Meteonorm, 10-year maximum

Energy performance calculation approach

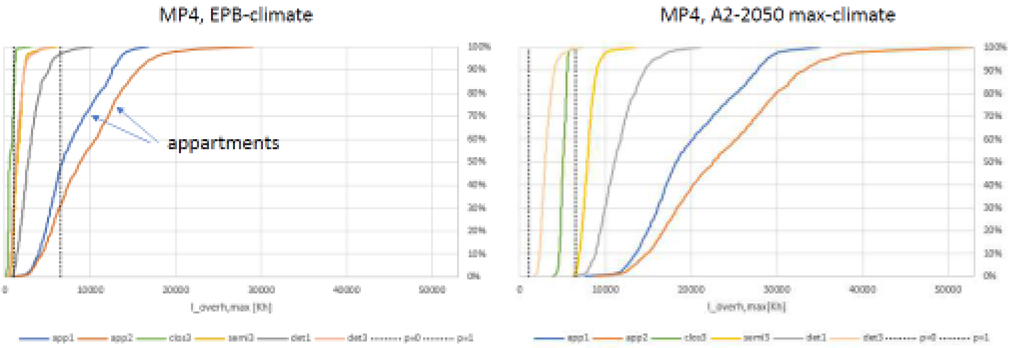


Packages of measures (MPs)

	$U_{roof+wall}$ W/(m²K)	U_{window} W/(m²K)	$g_{glazing}$ -	shading	v_{50} m³/(hm²)	Ventilation system	Heating system
MP3	0,20	1,4	0,38	-	3	MEV	AWHP
MP4	0,20	1,4	0,38	-	3	MVHR	CGB
MP5	0,15	0,8	0,50	exterior	1	MEV	GWHP
MP6	0,15	0,8	0,50	exterior	1	MVHR	CGB

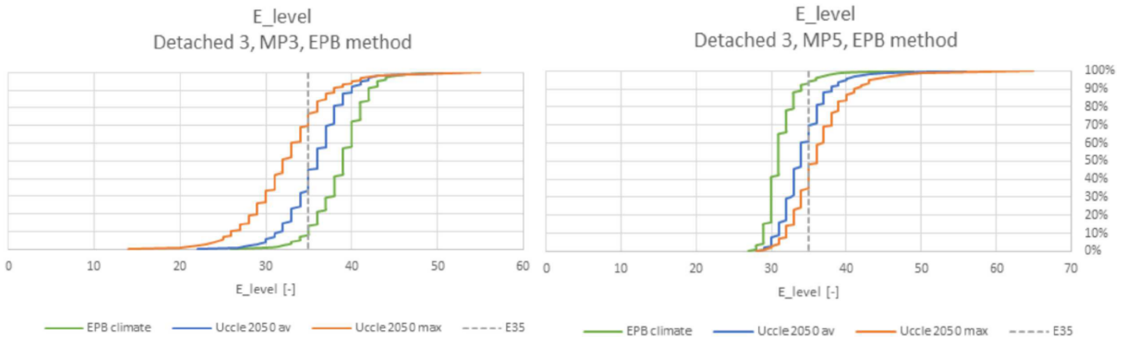
- Variations in envelope performance, ventilation system, heating system
- 6 housing typologies: 1 and 2 room appartements, 3 room terraced house, 3 room semi-detached house, 1 and 3 room detached house

Results: Overheating indicator



- Overheating increases depending on typology
- Cooling energy use taken into account in calculation when calculated overheating indicator is above threshold

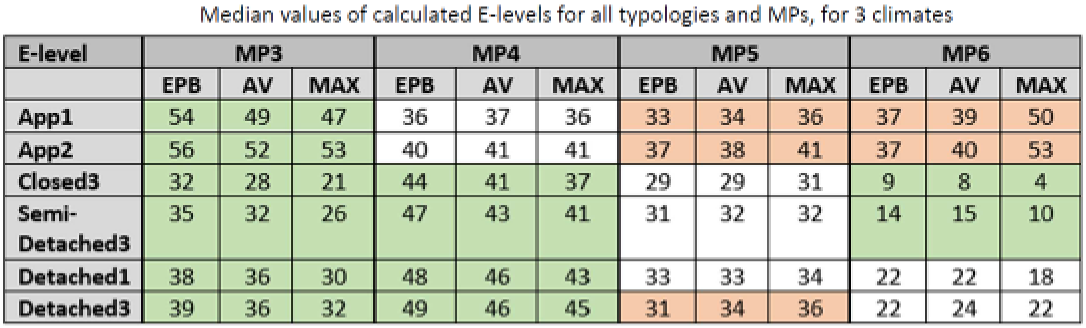
Results: Primary energy index ‘E-level’



MP3: less performing building envelope:
- Heating energy use dominates
- E-level reduces as a result of climate change

MP5: high performing building envelope:
- Increased cooling energy outweighs decreased heating energy use
- E-level increases as a result of climate change

Results: Primary energy index ‘E-level’



Median values of calculated E-levels for all typologies and MPs, for 3 climates

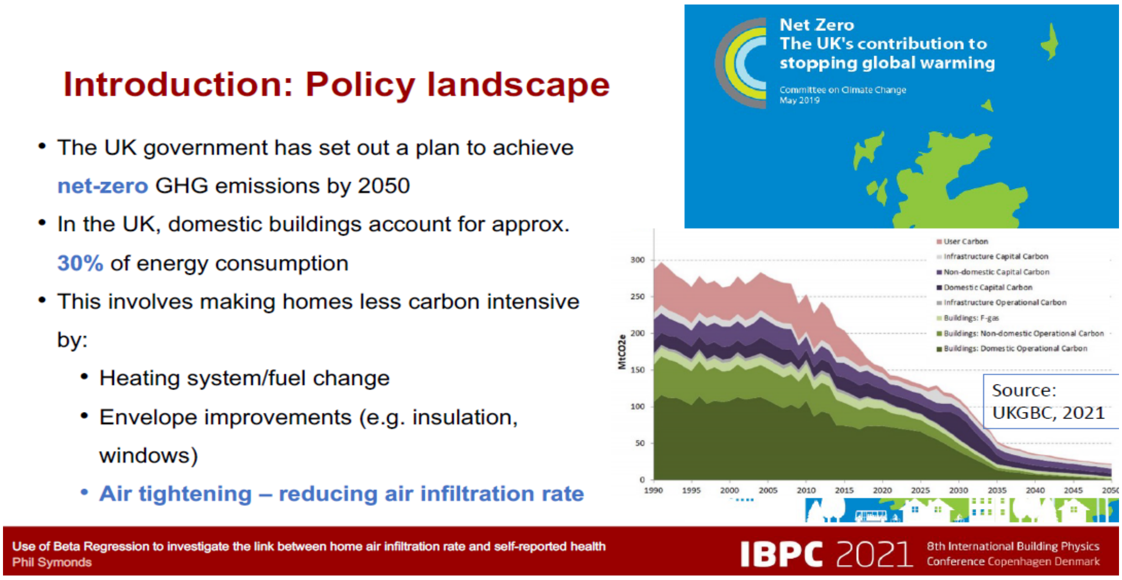
E-level	MP3			MP4			MP5			MP6		
	EPB	AV	MAX	EPB	AV	MAX	EPB	AV	MAX	EPB	AV	MAX
App1	54	49	47	36	37	36	33	34	36	37	39	50
App2	56	52	53	40	41	41	37	38	41	37	40	53
Closed3	32	28	21	44	41	37	29	29	31	9	8	4
Semi-Detached3	35	32	26	47	43	41	31	32	32	14	15	10
Detached1	38	36	30	48	46	43	33	33	34	22	22	18
Detached3	39	36	32	49	46	45	31	34	36	22	24	22

Conclusions

- Analysis of global warming based on IPCC-scenario SRES-A2
  - 10-year average and extreme year with monthly mean values for temperature and solar radiation in 2050
- Impact of climate change:
  - Increasing overheating and cooling energy use
    - Apartments more sensitive
    - Depending of potential for intensive ventilation (window opening)
  - Decreasing heating energy use
  - Total primary energy use decreases in most cases
  - Total primary energy use increases in some cases, depending on typology and measures applied
- Recommendation: add ‘resilience check’ to EPBD based on future climate

十、 Use of Beta Regression to investigate the link between home air infiltration rate and self-reported health

Lu S.1, Symonds P1., Verschoor N2, Chalabi Z.1, Taylor J.3, Davies M.1



Introduction: Policy landscape

- The UK government has set out a plan to achieve **net-zero** GHG emissions by 2050
- In the UK, domestic buildings account for approx. **30%** of energy consumption
- This involves making homes less carbon intensive by:
  - Heating system/fuel change
  - Envelope improvements (e.g. insulation, windows)
  - **Air tightening – reducing air infiltration rate**

Source: UKGBC, 2021

Use of Beta Regression to investigate the link between home air infiltration rate and self-reported health
Phil Symonds

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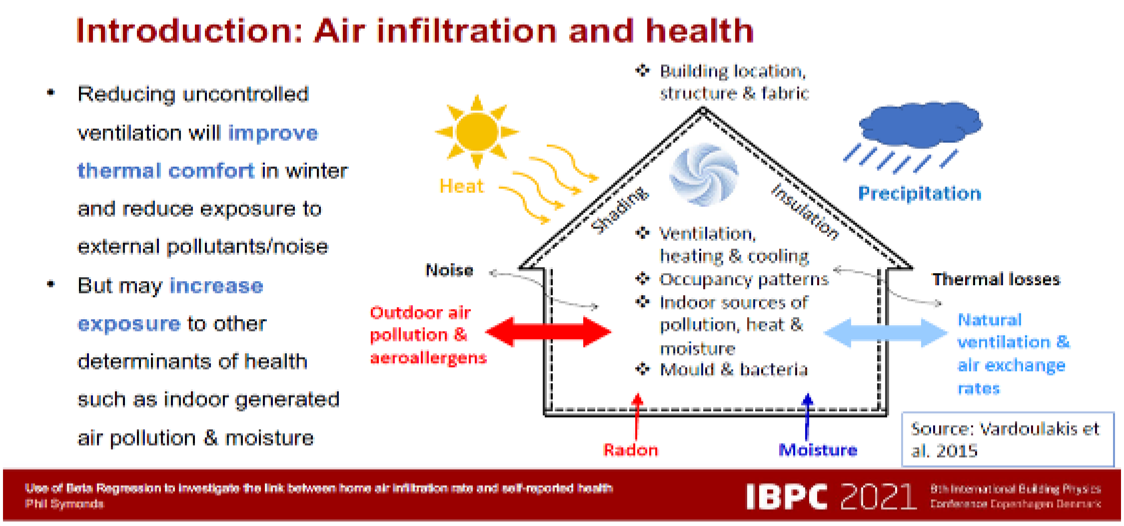

Introduction: Air infiltration and health

- Reducing uncontrolled ventilation will **improve thermal comfort** in winter and reduce exposure to external pollutants/noise
- But may **increase exposure** to other determinants of health such as indoor generated air pollution & moisture

Source: Vardoulakis et al. 2015

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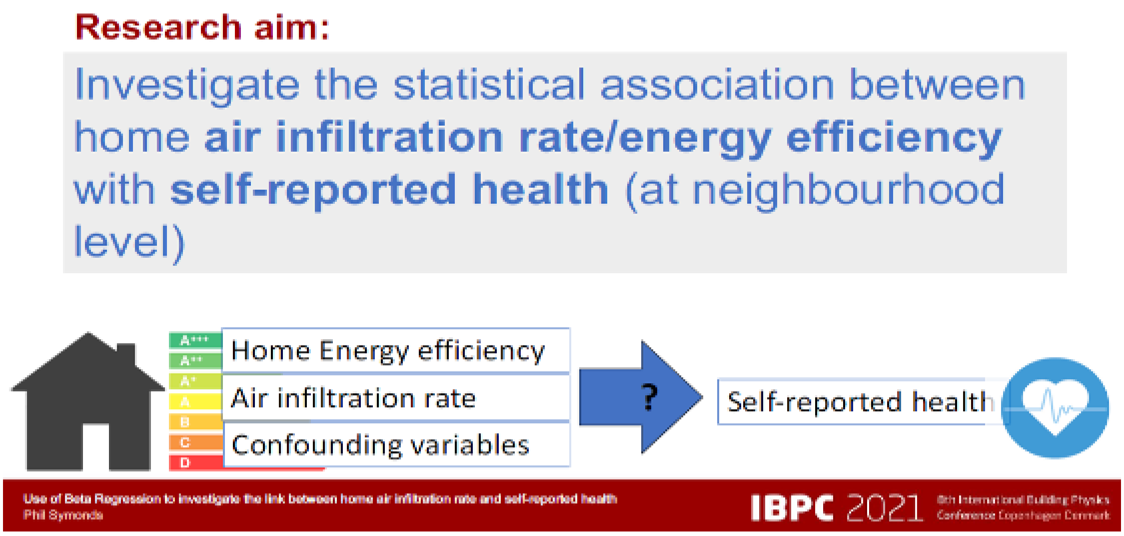

Research aim:

Investigate the statistical association between home **air infiltration rate/energy efficiency** with **self-reported health** (at neighbourhood level)

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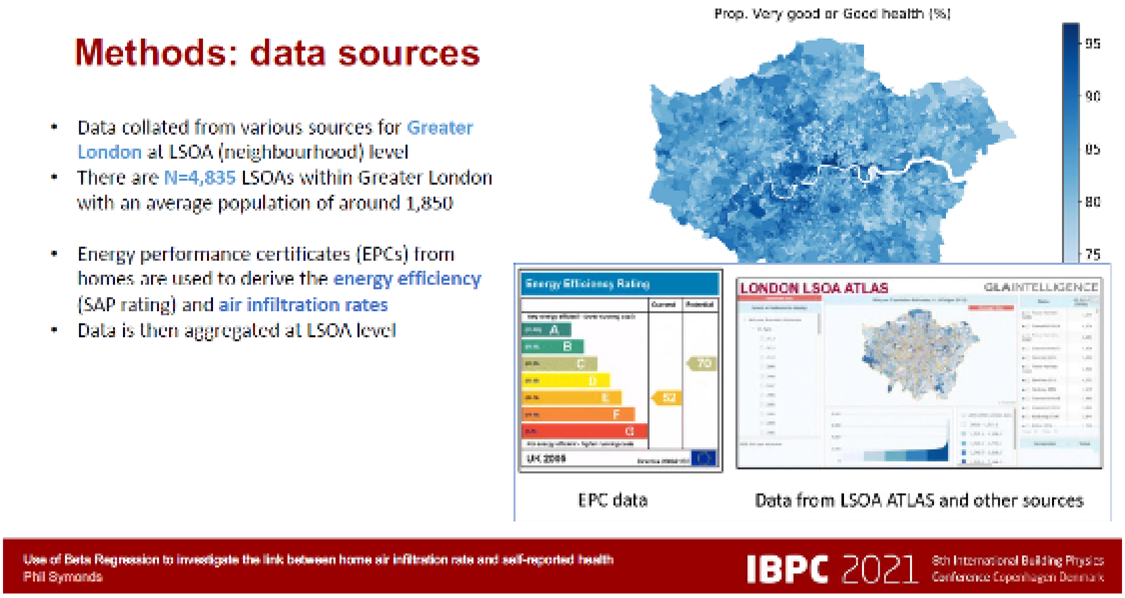


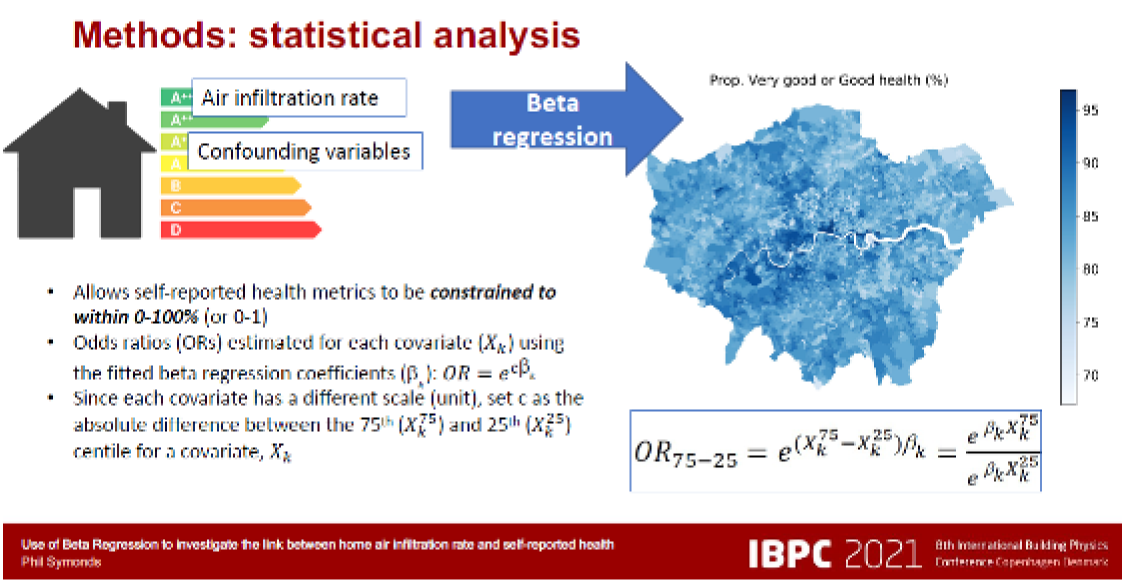
Methods: data sources

- Data collated from various sources for Greater London at LSOA (neighbourhood) level
- There are N=4,835 LSOAs within Greater London with an average population of around 1,850

- Energy performance certificates (EPCs) from homes are used to derive the energy efficiency (SAP rating) and air infiltration rates
- Data is then aggregated at LSOA level

EPC data

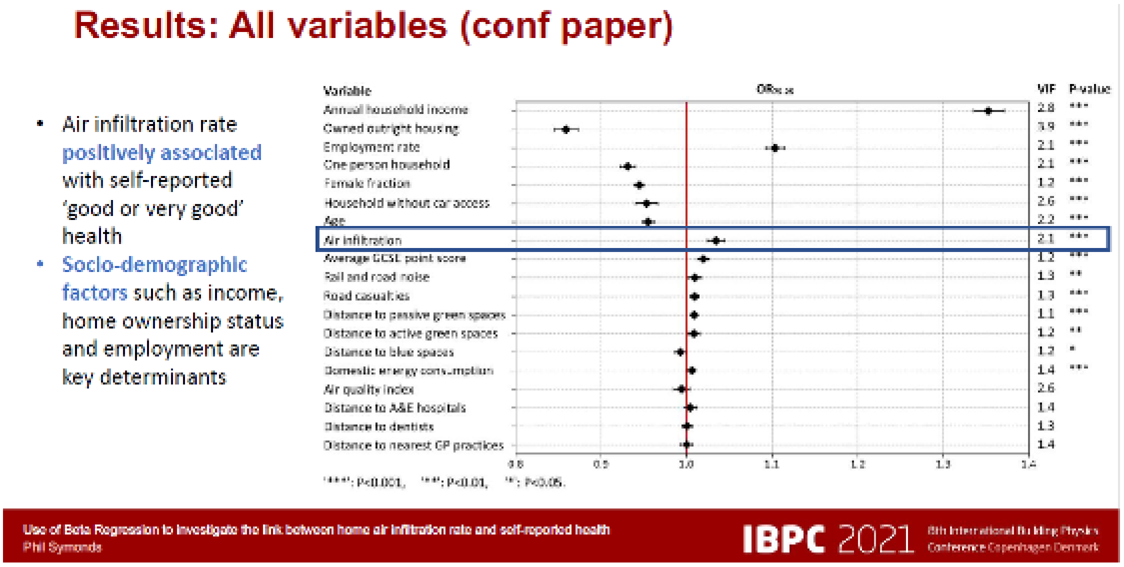
Data from LSOA ATLAS and other sources



Methods: statistical analysis

- Allows self-reported health metrics to be ***constrained to within 0-100%*** (or 0-1)
- Odds ratios (ORs) estimated for each covariate (X_k) using the fitted beta regression coefficients (β_k): $OR = e^{c\beta_k}$
- Since each covariate has a different scale (unit), set c as the absolute difference between the 75th (X_k^{75}) and 25th (X_k^{25}) centile for a covariate, X_k

$$OR_{75-25} = e^{(X_k^{75}-X_k^{25})\beta_k} = \frac{e^{\beta_k X_k^{75}}}{e^{\beta_k X_k^{25}}}$$

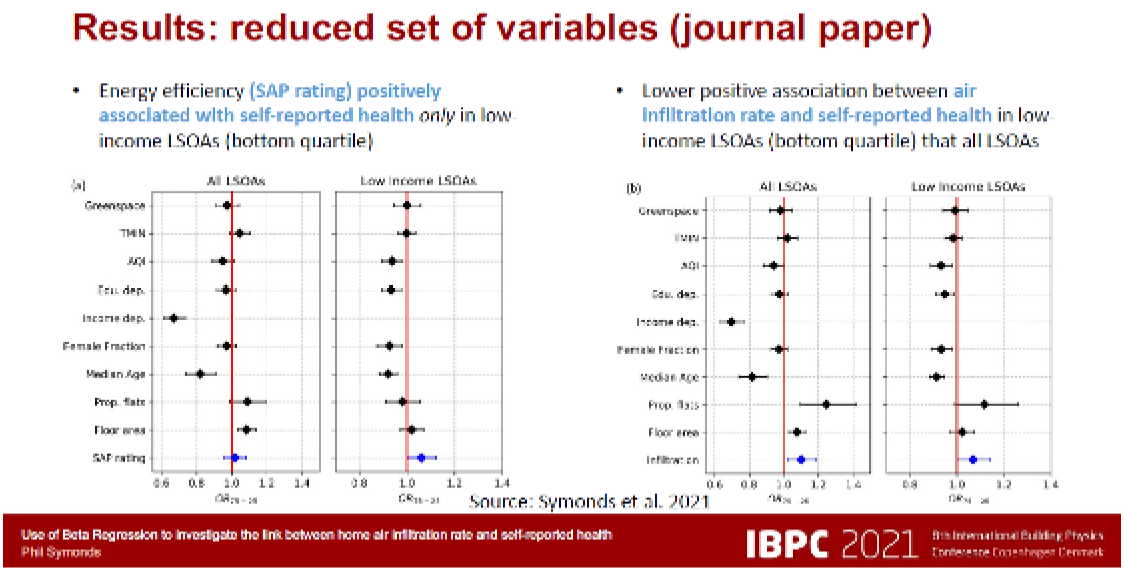


Results: All variables (conf paper)

- Air infiltration rate positively associated with self-reported 'good or very good' health
- Socio-demographic factors such as income, home ownership status and employment are key determinants

Variable	VIF	P-value
Annual household income	2.8	***
Owned outright housing	3.9	***
Employment rate	2.1	***
One person household	2.1	***
Female fraction	1.2	***
Household without car access	2.6	***
Age	2.2	***
Air infiltration	2.1	***
Average GCSE point score	1.2	***
Rail and road noise	1.3	**
Road casualties	1.3	***
Distance to passive green spaces	1.1	***
Distance to active green spaces	1.2	**
Distance to blue spaces	1.2	*
Domestic energy consumption	1.4	***
Air quality index	2.6	
Distance to A&E hospitals	1.4	
Distance to dentists	1.3	
Distance to nearest GP practices	1.4	

'***': P<0.001, '**': P<0.01, '*': P<0.05.



Results: reduced set of variables (journal paper)

- Energy efficiency **(SAP rating) positively associated with self-reported health** *only* in low income LSOAs (bottom quartile)
- Lower positive association between **air infiltration rate and self-reported health** in low income LSOAs (bottom quartile) that all LSOAs

Source: Symonds et al. 2021

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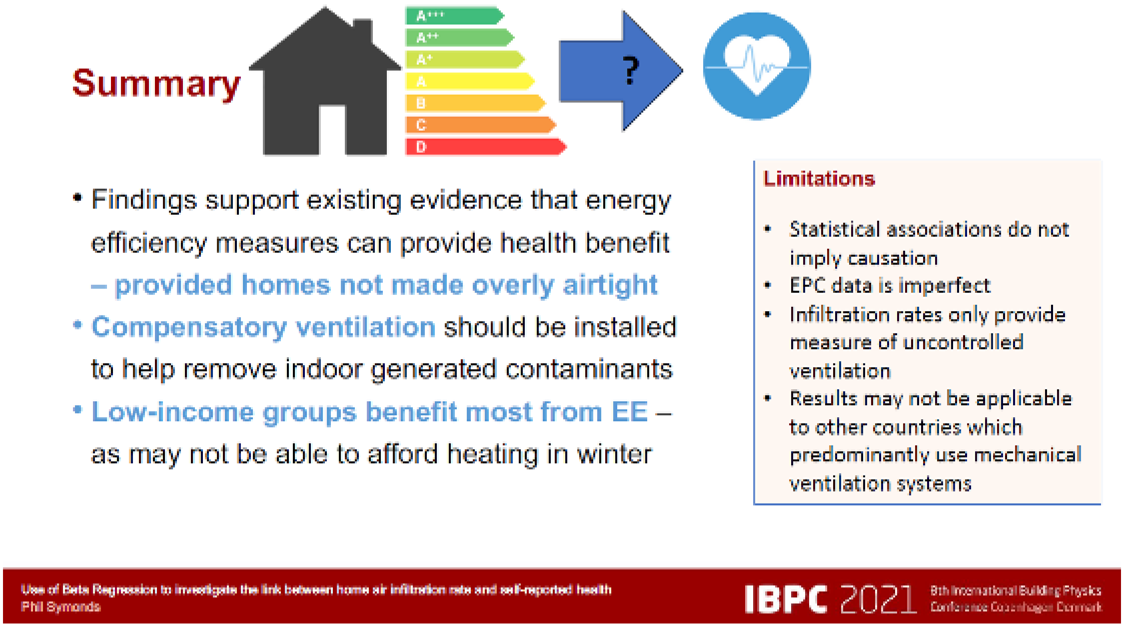

Summary

- Findings support existing evidence that energy efficiency measures can provide health benefit **– provided homes not made overly airtight**
- **Compensatory ventilation** should be installed to help remove indoor generated contaminants
- **Low-income groups benefit most from EE** – as may not be able to afford heating in winter

Limitations

- Statistical associations do not imply causation
- EPC data is imperfect
- Infiltration rates only provide measure of uncontrolled ventilation
- Results may not be applicable to other countries which predominantly use mechanical ventilation systems

Use of Beta Regression to investigate the link between home air infiltration rate and self-reported health
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陸、參考文獻

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