行政院所屬各機關因公出國人員出國報告書

出國報告（出國類別：開會）

2019 年國際噪音年會

出國報告

服務機關：行政院環境保護署

姓名職稱：丁培修 技正

派赴國家：西班牙

出國期間：108 年 6 月 14 日至 6 月 21 日

報告日期：108 年 9 月 20 日

摘 要

2019年國際噪音年會（Inter-noise）於2019年6月16日至6月19日在西班牙馬德里市議會宮(The Municipal Palace of Congress of Madrid-IFEMA Palacio Municipal)召開，且由國際噪音控制工程協會（International Institute of Noise Control Engineering, I-INCE）與西班牙聲學學會（Spanish Acoustical Society, SEA）共同舉辦第48屆國際噪音控制工程大會暨展覽會。適逢西班牙聲學學會成立50週年，對該學會而言，本次年會能在西班牙舉行是件非常有歷史意義的事情。

本次噪音年會主題為「管制噪音以改善環境」(Control of Noise to Improve the Environment)，期望透過實施更好的技術來控制噪音，以提高生活環境品質，此次年會討論主題包括聲學材料、主動控制聲音與振動、航空噪音、建築與建築聲學、環境噪音、流動相關噪音與振動、工業噪音、噪音與健康、心理聲學、鐵路與公路車輛噪音、信號處理、聲音品質與產品噪音、音景、水下與海洋聲學、車輛噪音與振動、振動聲學及其他等合計17項主題。主辦單位並於年會安排共100場次技術會議，各國與會人員利用齊聚一堂的機會，針對各主題內容進行交流討論，呈現國際上噪音管制最新發展，並共享最新研究成果。

此次噪音年會共來自60多個國家及超過1,200位專家學者代表與會，約有近900篇學術論文於年會進行發表，並分別就各類噪音與振動管制及執行成果進行論文發表和討論，同時約有近60個參展廠商於會場展出各先進國家噪音量測儀器，也顯示出人們對噪音管理與控制相關的創新技術越來越感到興趣。

為提高台灣在國際上能見度與踴躍參與國際性會議，本署即於本次年會口頭發表專文「交通運輸系統噪音對台灣都會區居民暴露影響之探討」(Evaluation of transport related noise exposure to residents in Taiwan metropolitan area)。主要基於我國地狹人稠及住商混雜，噪音污染已為各環境陳情案件之首，近十年來都會區人口大幅增加與鐵路系統陸續完工，衍生鐵路噪音影響安寧問題已為民眾近來相當關心之議題，爰以我國一般鐵路與高速鐵路噪音現況及防制作法為報告主題。本署於口頭報告後，獲得在場聽眾熱烈迴響，包括西班牙、紐西蘭、英國及日本等國代表皆針對報告內容與本署作為進行意見交流。

此外，本署於本次年會針對交通噪音、建築噪音振動、寧靜建築設計、音景、噪音地圖、社區噪音，及環境噪音與健康影響等不同噪音相關議題，分別聆聽蒐集各國講者發表各領域研究成果，現場聽眾並與講者進行熱烈互動討論，本署所蒐集各噪音相關研究成果及改善技術策略，可供未來檢討修訂噪音管制法規及研提管制策略參考。

目　次

壹、目的

由於我國地狹人稠及住商混雜，再加上近十年來都會區人口呈現成長趨勢，噪音污染已居各類環境陳情案件之首，且鐵路系統建設已陸續完工，鐵路噪音影響生活安寧問題已為民眾近來相當關心之噪音議題，本署為有效改善鐵路系統噪音問題，除透過科技研究計畫持續研發改善技術與控制對策，並結合國際最新噪音管制技術作法，以有效落實於我國陸上運輸系統交通噪音之改善，提升環境生活品質。

國際噪音年會（Inter-noise）從1972年第1屆於美國華盛頓舉行以來，迄今已為第48屆，屬世界各國從事噪音或振動領域相關之產官學界在每一年度均會參與之重要代表性國際會議，且主辦單位於年會皆會安排不同分項主題之技術會議，各國與會人員並利用難得齊聚一堂的機會，針對噪音與振動相關主題內容進行意見交流與討論，共享國際上噪音管制最新研究技術與發展之成果。

2019年國際噪音年會（2019 Inter-noise）係2019年6月16日至6月19日假西班牙馬德里市議會宮(The Municipal Palace of Congress of Madrid-IFEMA Palacio Municipal)召開，並由國際噪音控制工程協會（International Institute of Noise Control Engineering, I-INCE）與西班牙聲學學會（Spanish Acoustical Society, SEA）共同舉辦第48屆國際噪音控制工程大會暨展覽會。也欣逢西班牙聲學學會成立50週年紀念，對該學會來說本次年會能在西班牙舉行是有歷史意義的事情。

本屆噪音年會主題為「管制噪音以改善環境」（Control of Noise to Improve the Environment），期望透過實施更好的技術來控制噪音，以提高生活環境品質，大會討論主題包括聲學材料、主動控制聲音與振

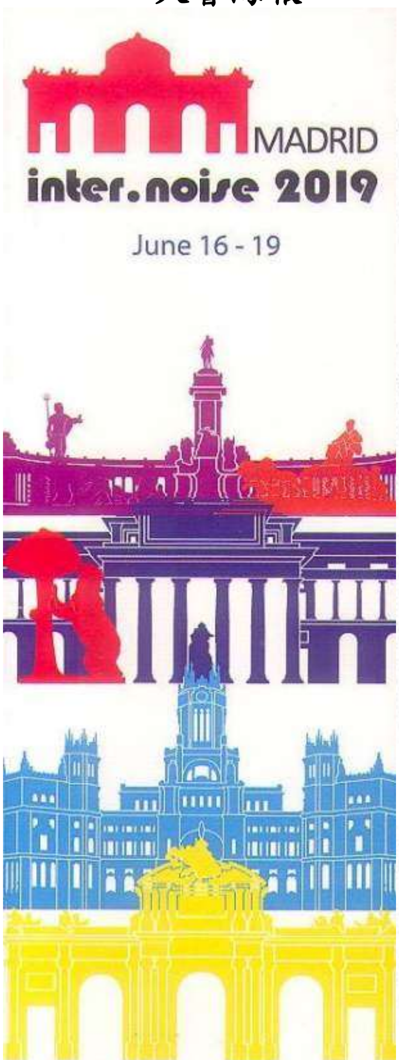
動、航空噪音、建築與建築聲學、環境噪音、流動相關噪音與振動、工業噪音、噪音與健康、心理聲學、鐵路與公路車輛噪音、信號處理、聲音品質與產品噪音、音景、水下與海洋聲學、車輛噪音與振動、振動聲學及其他等合計17項主題。主辦單位並安排100場次技術會議，針對各噪音主題進行意見交流與討論，共享最新噪音相關研究成果。

為讓世界看見台灣，我國也應踴躍出席世界級國際性會議，讓各國了解我國推動噪音管制工作成果，本署特參與本次國際噪音年會，並進行口頭發表專文「交通運輸系統噪音對台灣都會區居民暴露影響之探討」(Evaluation of transport related noise exposure to residents in Taiwan metropolitan area)。本署於此次年會針對交通噪音、建築噪音與振動、寧靜建築設計、音景、噪音地圖、社區噪音，及環境噪音與健康影響等不同噪音相關議題，聆聽蒐集各國講者發表各類噪音領域研究成果，所蒐集之各類噪音相關研究成果及改善技術策略，後續可供本署未來檢討噪音管制法規及研提管制策略參考，期以改善民眾生活安寧，並有效提升環境品質。

貳、行程

日　期	地　點	工　作　內　容
6 月 14 日至 6 月 15 日	台北→香港→英國→西班牙(馬德里)	去程（搭機及轉機）
6 月 16 日至 6 月 19 日	西班牙(馬德里)	參加國際噪音年會
6 月 20 日至 6 月 21 日	西班牙(馬德里)→英國→香港→台北	返程（搭機及轉機）

大會海報



年會主要議程

PROGRAMME AT A GLANCE

16th Sunday	**Congress Venue**
12:00 - 19:00	Registration Desk Opens
14:00 - 16:30	I-INCE General Assembly
16:30 - 16:50	Chairs Meeting
17:00 - 20:30	Opening Ceremony
	Plenary Lecture: *Ines López Arteaga*
	Musical Performance: Choir of the Polytechnic University of Madrid
	Welcome Tapas-Cocktail
17th Monday	**Congress Venue**
08:30 - 18:00	Registration Desk Open
09:00 - 18:00	Exhibition Open
09:00 - 12:00	Parallel Sessions S.01
12:10 - 13:10	Plenary Lecture: *Stephen A. Hambric*
13:10 - 14:30	Refreshment Break on Your Own
14:40 - 18:00	Parallel Sessions S.02
18th Tuesday	**Congress Venue**
08:30 - 18:00	Registration Desk Open
09:00 - 18:00	Exhibition Open
09:00 - 12:00	Parallel Sessions S.03
12:10 - 13:10	Plenary Lecture: *Jun Yang*
13:10 - 14:30	Refreshment Break on Your Own
14:40 - 18:00	Parallel Sessions S.04
18:00 - 20:30	50th Anniversary SEA
	Musical Performance: Spanish dance for Ballet *Esencia Ibérica*
	Cocktail liven up by the *Tuna* of the Polytechnic University of Madrid
19th Wednesday	**Congress Venue**
08:30 - 14:00	Registration Desk Open
09:00 - 14:00	Exhibition Open
09:00 - 13:00	Parallel Sessions S.05
13:00 - 14:00	Refreshment break on Your Own
13:00 - 14:00	FTCP Meeting
14:00 - 15:00	I-INCE Plenary Lecture: *André Fiebig*
15:00 - 17:30	Closing Ceremony
	Farewell Reception offered by INTER-NOISE 2020

參、過程

一、 本次國際噪音年會（2019 Inter-noise）係於 2019 年 6 月 16 日至 6 月 19 日於西班牙馬德里市議會宮(The Municipal Palace of Congress of Madrid-IFEMA Palacio Municipal)召開，同時由國際噪音控制工程協會與西班牙聲學學會共同舉辦第 48 屆國際噪音控制工程大會暨展覽會。

二、 此次噪音年會共有來自60多個國家及超過1,200位專家學者代表與會，約有將近900篇學術論文於該年會進行發表，並分別就各類噪音與振動管制與執行成果等類別進行論文發表及討論，同時亦有約60個參展廠商於會場展出各先進國家之噪音量測儀器，顯示人們對噪音管理與控制相關的創新技術越來越感興趣。

三、 本屆噪音年會主題為「管制噪音以改善環境」（Control of Noise to Improve the Environment），期望透過實施更好的技術來管制噪音，以提高生活環境品質，年會討論主題包括聲學材料、主動控制聲音與振動、航空噪音、建築與建築聲學、環境噪音、流動相關噪音與振動、工業噪音、噪音與健康、心理聲學、鐵路與公路車輛噪音、信號處理、聲音品質與產品噪音、音景、水下與海洋聲學、車輛噪音與振動、振動聲學及其他等共計17項主題。主辦單位並安排100場次技術會議，各國與會人員利用難得齊聚一堂機會，針對前述主題內容進行意見交流與討論，呈現國際上噪音管制最新發展與技術，共享最新研究成果。

四、 主辦單位特別在今年6月16日舉行之開幕儀式安排由荷蘭埃因霍溫科技大學（Eindhoven University of Technology, The Netherlands）機械工程系 Ines Lopez Arteaga 教授進行「公路與鐵路系統的滾動噪音」（Rolling noise in road and rail transportation system）專題演講。Ines 教授的演講聽來相當生動且有趣，她提到長期暴露於陸上交通運輸系統(包含公路與鐵路)噪音，是目前除了空氣污染外，最主要影響人口稠密地區的健康壓力因素，同時也會間接影響數百萬人生活品質與預期壽命。

五、 Ines 教授也提及道路上車輛時速到達 130 公里時，或行駛於鐵

路之車輛時速高達 300 公里時，此時最主要交通噪音來源為輪胎與道路（或是車輪與軌道）相互作用產生之滾動噪音。乍看之下，這兩種陸上運輸系統噪音之間似無關聯性，但更進一步探討這兩者關係卻發現，在既有滾動噪音之處理（包含模式建立、預測及噪音改善），都具有共同性且有價值性的見解。此外，教授也進一步說明噪音模式建立的策略與來源特徵方法，並強調表面的粗糙度對於接觸力產生的影響，以及公路和鐵路交通系統可採用相關噪音與振動改善措施。

六、 主辦單位將本次噪音年會的 17 項討論主題平均分配在 6 月 17 日至 6 月 19 日所召開的 100 場技術會議，並於會場兩側之視聽會議室舉行，與會人員可依每日會議議程所列主題前往聆聽，會場中央則是由 60 個參展商所展出各先進國家噪音量測儀器。另為提高我國能見度及踴躍參與國際性會議，也讓世界看見台灣推動陸上交通噪音改善成果，本署即於本次年會進行口頭發表專文「交通運輸系統噪音對台灣都會區居民暴露影響之探討」(Evaluation of transport related noise exposure to residents in Taiwan metropolitan area)。

七、 由於台灣地狹人稠及住商混雜，噪音污染已為各類環境陳情案件之首，且近年來都會區人口大幅增加與鐵路系統建設已陸續完工，鐵路噪音影響生活安寧問題已為我國民眾近年來相當關心之噪音議題，本署爰以我國一般鐵路與高速鐵路噪音現況及相關防制措施為本次噪音年會口頭報告專文之主題。本署代表於口頭報告後，獲得在場聽眾熱烈迴響，包括西班牙、紐西蘭、英國及日本等國代表皆在會場針對報告內容進行意見交流，並獲益良多。有關專文內容與口頭簡報內容，詳如附件。

八、 此外，本署並於本次噪音年會針對交通噪音、建築噪音與振動、寧靜建築設計、音景、噪音地圖、社區噪音，及環境噪音與健康影響等不同噪音相關議題，聆聽蒐集各國講者發表各類噪音領域研究成果，現場聽眾並與講者進行熱烈互動與討論，本署所蒐集各類噪音相關研究成果及改善技術策略，可供未來檢討修訂噪音管制法規及研提管制策略參考。

九、 另外在會場旁同時舉行的噪音控制工程展覽會，也參觀來自世界各國廠商參展的噪音偵測與控制相關儀器產品，蒐集現行世界上噪音偵測控制儀器最新資訊，以與國際現行噪音管制技術與作法進行接軌。透過本次國際噪音年會參與和學習，可瞭解目前各國最新之噪音防制技術、理論基礎研究及監測發展動向，並有助於未來規劃各項噪音防制措施參考及業務推行，期有效維護居家安寧，並改善生活環境品質。

本次噪音年會開幕專題演講：Ines Lopez Arteaga 教授進行「Rolling noise in road and rail transportation system」演講

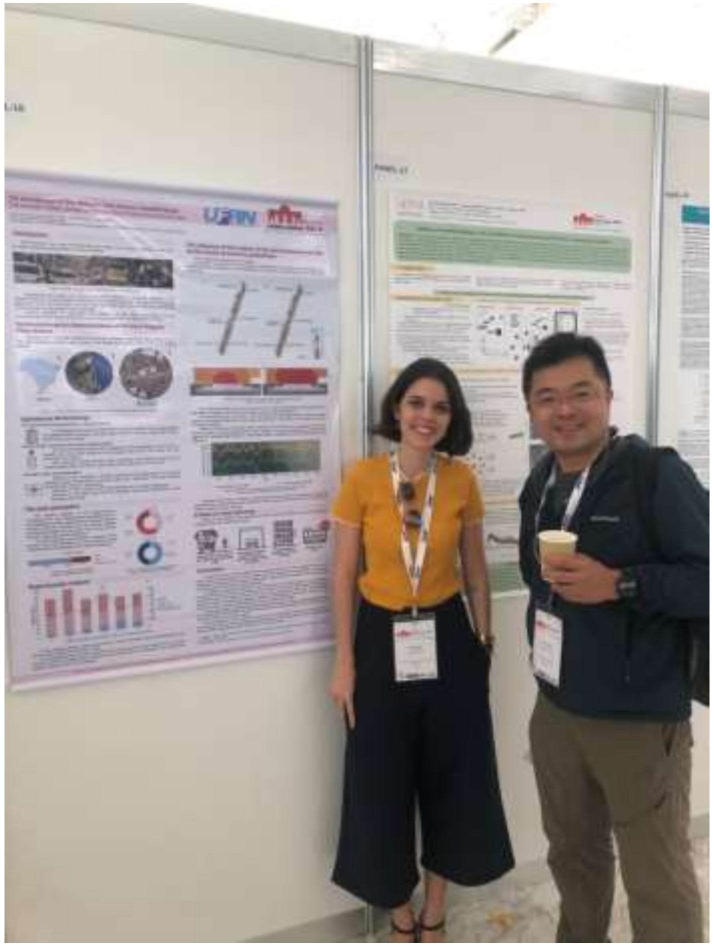
本年 6 月 16 日在本次國際噪音年會開幕式會場

本署丁培修技正於分組技術會議進行專題口頭報告

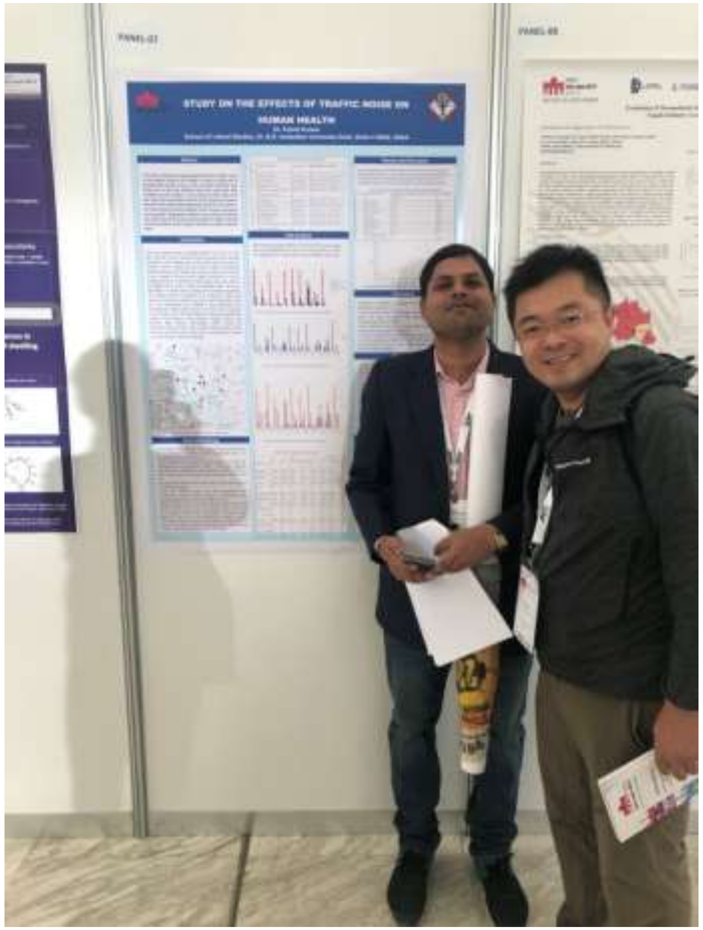
與日本 Shimane University 的 Thulan 教授合影

與西班牙鐵路建設局 Marta Ruiz 博士合影

與法國 EGIS 鐵路系統公司 Robin Walther 博士合影



與巴西 Rio Grande do Norte 大學 Bruna 博士合影



與印度 Ambedkar 大學 Kumar 博士討論及合影

與賽維亞 Belgrade 大學 Katarina 博士討論及合影

於分組討論技術會議現場聆聽各國講者發表噪音研究成果

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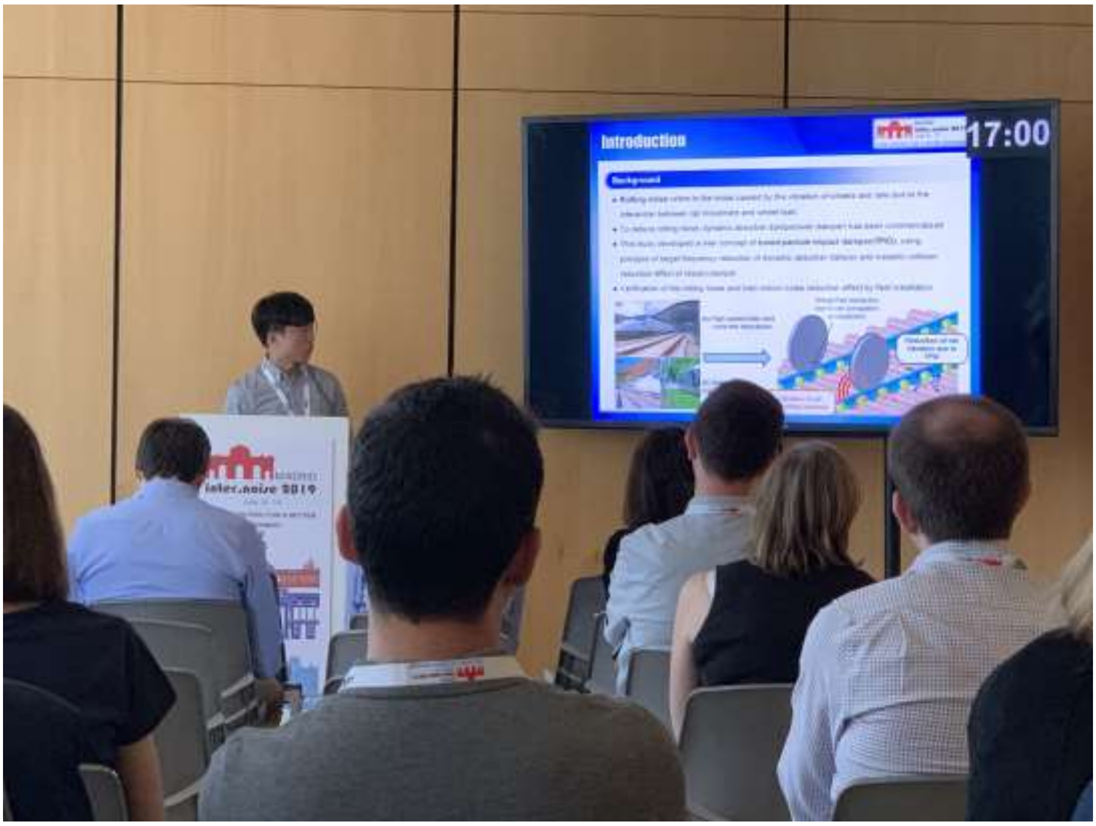


於分組討論技術會議現場聆聽各國講者發表噪音研究成果

在馬德里市議會宮前之本次噪音年會會場前留影

參展之國際上最新噪音管制規劃、模擬設備及測量儀器

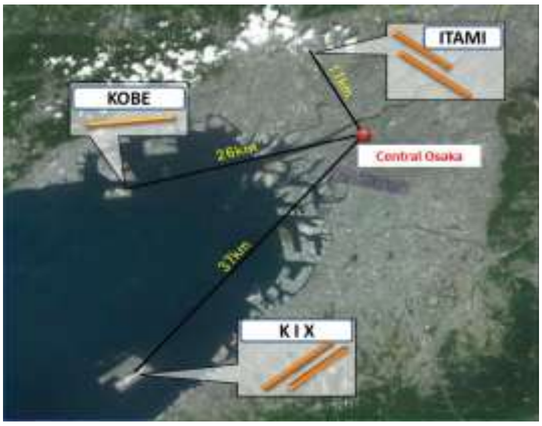
摘錄 INTER-NOISE 2019 國際噪音年會與本署相關之研究議題

項次	論文領域	論文編號	論文主題	論文題目
1	GA07. Transportation Noise B:	1274	TS.03.04. AIRPORT COMMUNITY NOISE	Noise Control Measure at ITAMI
2	GA05. Building Noise and Vibration, Design for Quiet Buildings, HVAC Noise, etc.	1269	TS.04.12. VENTILATION (NATURAL) -ENABLING NOISE REDUCTION DEVICES	Acoustically Treated Dual Vented Window System
3		1372		Land Traffic Noise Management at Recipient's End in Singapore
4		1456		The Current Status of Natural Ventilation - Enabling Noise Reduction Devices in Urban Green Buildings
5		1693		Sound Insulation of Ventilation Partitions with Different Configurations
6		1899		Effects of sound incidence angle on the effectiveness of noise reduction measures applied to acoustic windows
7		2086		Noise control through open windows - A solution model
8	GA11. Health Effects	1487	TS.08.01. NOISE AND HEALTH: GENERAL	Health impact of noise in Greater Paris Metropolis: assessment of healthy life years lost
9		1536	TS.08.02. HEALTH EFFECTS OF NOISE; TRANSPORTATION, SLEEP DISTURBANCE; SOUND QUALITY	Noise sensitivity and dwelling characteristics affect the quality of sleep among schoolchildren
10		1791		Assessment of health effects of aircraft noise on residents living around Noi Bai International Airport
11		2022		Study on the effects of traffic noise on human health
12	GA07. Transportation Noise B	2156	TS.10.01. RAILROAD NOISE: GENERAL	Rail shielding technology - Field test on German railway track

13		1589	TS.10.05. LIGHT RAIL NOISE AND VIBRATION	Railway Induced Groundborrne Noise And Vibration From Lines In Tunnel, Paris Rer E “Eole” Project
14	GA09. Environmental Noise, Community Noise, Noise Mapping, Soundscapes	1964	TS.13.05. SOUNDSCAPE IN ARCHITECTURE, URBAN PLANNING AND LANDSCAPE	The Soundscape Of Sen. Salgado Filho Avenue, Natal/RN-Brazil: The Acoustic Impact Caused By The Insertion Of Semi-exclusive Bus Lane
15	GA06. Transportation Noise A	1247	TS.15.05. NEW SOUNDS OF E-VEHICLE	Consistent Active Sound Generation Concept for Hybrid vehicles

1. **Noise Control Measure at ITAMI（日本大阪國際機場噪音控制措施）**

論文發表國家：日本



日本大阪國際機場(ITAMI)實施了各種噪音對策以改善機場周邊社區居民生活品質。ITAMI 機場係屬大阪市區附近的城市規模機場，常有航空噪音陳情問題。當地居民在過去常常要求該機場禁止夜間飛行之行為，後來機場透過實施各種噪音對策後，致使陳情案件減少，現已與當地社區大眾和諧相處。

但對機場而言仍然存在各種嚴格與航空噪音相關之操作限制，該機場現採取之各種噪音防制對策如下：

(1)機場降噪措施：包括限制飛機起降次數和運行時間，以及鼓勵航空公司使用更安靜的飛機，建立減少噪音影響之飛行時段及相關程序，同時該機場持續不斷監測飛機噪音。機場透過獨特的降落費收費方式，促使航空公司引入低噪音飛機，並針對高噪音飛機收取較高之附加費。另為減少跑道附近區域的夜間飛機噪音，在不危及飛航安全的情況下，針對該機場某一跑道之飛機在晚上 7 點至 9 點時段著陸時，限制使用反向推力。此外，為減少機場周圍區域飛機噪音的影響範圍，並設置優先飛行路徑，要求航空公司在不危及安全的範圍內使用該機場之 32 號跑道。機場並針對機場周邊遭受飛機噪音影響嚴重的地區(第 2 級和第 3 級地區)，透過搬遷補償方式，將獲得的土地改以建造公園和綠地，以減輕噪音影響。另透過限制飛行路徑的作法，有效抑制航空噪音影響範圍的擴大，並對較敏感之環境區域實施了營建工程之隔音施工等必要防制措施。

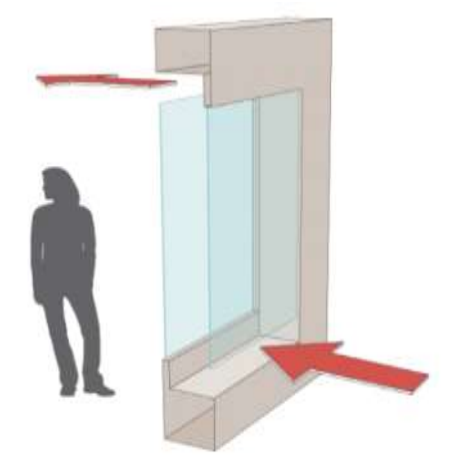
(2)機場噪音共享:在 ITAMI 機場共有兩條跑道,A 跑道為 1,828 公尺，B 跑道為 3,000 公尺。為有效減少機場周邊地區噪音影響，機場倡導航空公司多予增加 B 跑道的起飛比例。然而，這卻導致噪音影響集中在某一地區，卻引起當地居民的強烈反對。機場之後便透過採用飛機類型和跑道不同設置飛行路徑來實現噪音共享。同時隨著導航精度的提高和新操作方法的引入，機場正在與航空公司合作規劃在約 1 英里寬的優先飛

行路徑範圍內，針對不同機型和跑道設置航線。對於機場推動噪音共享的作法，當地居民沒有強烈反對，因此機場對於這種方法認為是有效的，未來仍要持續與社區民眾建立良好的關係，以有效改善環境品質。

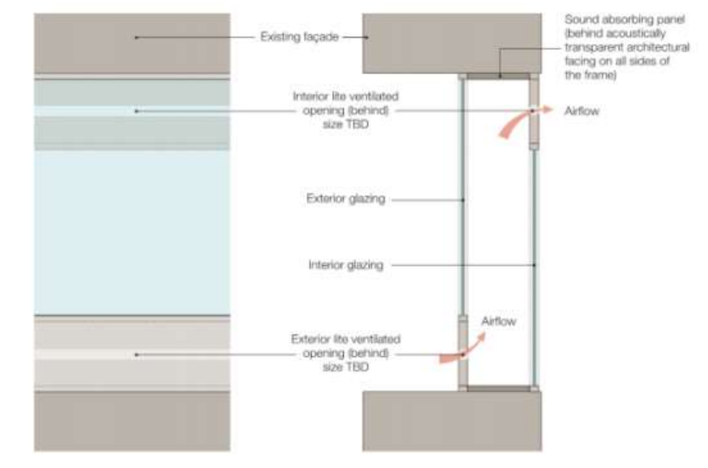
2. **Acoustically Treated Dual Vented Window System（因應聲學處理的雙道通風窗系統），論文發表國家：澳洲**

自然通風（natural ventilation）被廣泛接受為建築物的永續設計策略，在建築物中的主要功能可包括(1)有效降低室內空氣污染來改善室內空氣品質；(2)改善室內環境熱舒適條件；(3)降低空調建築的能耗。一般而言，在建築物內使用自然通風作法，通常與通過立面（façade）進入的外部噪音控制作法互相衝突。聲學領域專家顧問在考慮自然通風外牆的聲學性能時遇到的問題是不易去量化隔音性能。本研究之目的即為可開啟之雙通風窗系統的各種組合與配置，提供噪音量測數據以釐清其聲學性能與效率。

本研究所提雙道通風窗系統之設計原理如下圖，該窗戶系統設計主要是基於簡單、易操作及平衡的無框式窗戶代替一個標準的雙懸窗。該窗戶係由兩塊玻璃片組成，且允許通風開口大小由住戶來控制。



透視圖



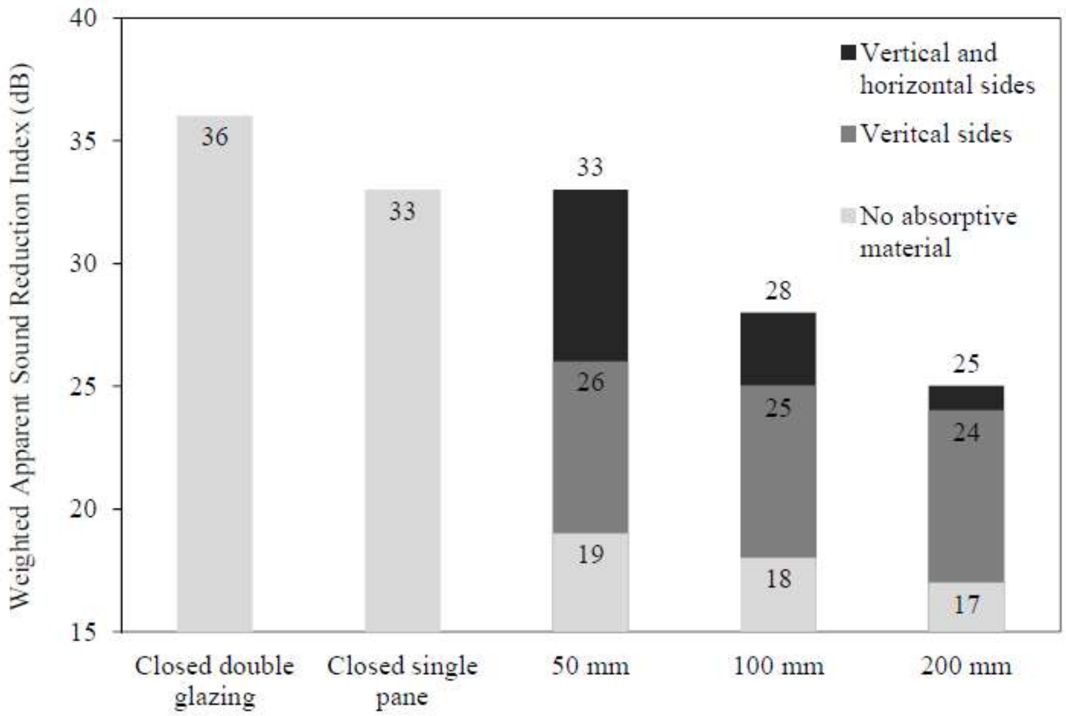
剖面圖和立面圖

雙通風窗系統的設計原理示意圖

該研究結果之各種通風開口尺寸和吸音材料配置的加權隔音指標（R’w）結果分布如下圖。該研究發現：(1)對於無吸音材料系統，當通風口尺寸從 50mm 增加到 200mm 時，R’w 將從 19 dB 減小到 17 dB。(2)在窗框之所有內表面均採用吸音材料時，具有 50mm 開口的雙通風窗，其 R’w

性能結果與完全密封的 6.38mm 夾層玻璃窗相同。(3)在窗框的所有內表面均採用吸音材料，且通風口尺寸從 50mm 增加到 200mm 時，R'w 將從 33 dB 減少到 25 dB。(4)僅在窗框之垂直內表面上應用吸音材料，且通風口尺寸從 50mm 增加到 200mm，R'w 將從 26 dB 減小到 24 dB。

研究人員指出當通風口尺寸最小時，雙通風窗系統的隔音性能表現最佳，且與通風開口區域相比，聲學襯裡（吸音材料）的相對面積對於窗戶系統的隔音性能是至關重要的。當考慮到壓降和氣流測量結果時，也需要考量通風要求來權衡這種系統的聲學性能要求,驗證此種雙通風窗系統應用在住宅中是可行，並能有效改善生活品質。



各種通風開口尺寸與吸音材料的 R'w 結果分布圖

3. Land Traffic Noise Management at Recipient's End in Singapore（新加坡住戶端的陸上交通運輸噪音管理），論文發表國家：新加坡

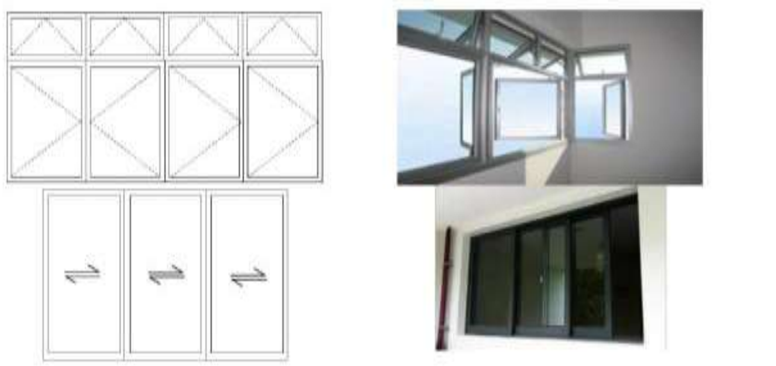
隨著城市人口密度增加及經濟和交通活動的土地使用競合，新加坡居民現正面臨更多的環境噪音問題，而公眾對生活環境品質的要求也越來越高。新加坡國家環境局（National Environment Agency, NEA）正透過陸上交通運輸系統噪音影響進行評估，且將噪音影響納入土地利用規劃與各項擬議開發項目的設計中。新加坡並已在 2016 年 7 月針對公路和鐵路基礎設施附近的住宅和噪音敏感開發項目，納入陸上運輸系統交

通噪音影響評估技術指引，針對住宅和噪音敏感地區的開發應設計成符合該技術指引之噪音限制要求。如果前揭開發項目無法達到噪音限制，則必須採取有效之緩解措施。

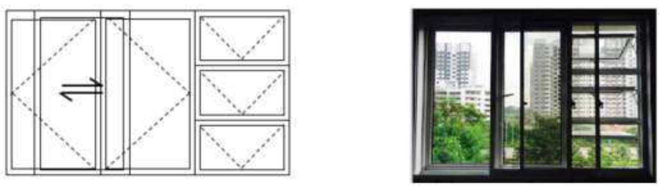
本研究針對新加坡現行在自然通風條件下，於噪音源、傳播途徑和受體端緩解措施及管理公眾對交通噪音滋擾的期望所採取的方法進行說明，以實現有利的生活環境。茲將受體端的窗戶配置及相關限制等措施，說明如下：

1. 窗戶配置：大部分交通噪音係透過窗戶進入住宅內部，窗戶是減輕受體端受到交通噪音影響的重要因素（如下圖），該研究並介紹不同類型窗戶配置的「插入損失（insertion loss）」性能（如雙層窗、雙層夾層玻璃、雙層帶底掛窗、帶散熱片雙層窗…等）。研究發現以具有底部懸掛窗戶配置的雙層窗是最有效的，將可達到 1 dB 至 3 dB 的減音量。

2. 限制裝置：新設住宅之開發還安裝了限制裝置以限制住宅之窗戶開啟及推拉門之開口，並採用最大限度地減少從外部到內部空間的噪音干擾（如下圖）。同時限制開口也必須符合新加坡建設局（Building and Construction Authority, BCA）規定的自然通風要求，這種作法一般將產生 1 dB 至 3 dB 的減音效果。



平開窗和一排頂部懸掛窗（上）；滑動窗（下）



由窗扇、滑動和頂部懸掛組成的雙層窗戶

限制裝置

新加坡新設住宅之不同類型窗戶配置與限制裝置

4.The Current Status of Natural Ventilation - Enabling Noise Reduction Devices in Urban Green Buildings（自然通風的現況－在城市綠色建築中採用降噪裝置），論文發表國家：中國

在城市化過程中，為降低能耗及改善室內環境品質，自然通風系統均被廣泛應用於許多綠色建築中。但反而因為噪音污染的干擾，很難在通風和降噪之間取得一種均衡的關係。本文彙整城市之綠色建築自然通風降噪裝置的現況，並介紹了窗戶、陽台和通風管道的隔音性能，其與交通管理、綠化帶和隔音牆設置之作法相比，這些設備反倒更易於實施，且具有更高之成本效益。

該研究提到在城市峽谷效應（urban canyon effect）下，噪音會加劇對市民的干擾，特別是在高密度之高樓層建築的城市。雖然高樓層建築可緩解城市人口迅速增加與土地短缺之間的矛盾，但卻也加劇控制城市噪音污染的難度。如何為住家環境提供令人滿意的室內聲學環境，一直是政策制定者和公眾日益關注的問題。道路交通噪音多被認為是城市噪音的主要來源，依據中國環境噪音防制之年度報告，市和省會城市的平均日間道路交通噪音為 68.9 dB(A)，遠遠高於世界衛生組織所訂之 53 dB。隨著中國城市化蓬勃發展，城市車輛越來越飽和，也難以及時調整交通管理政策（如改變車速及交通強度），並且與白天相對穩定的城市噪音相比較，夜間時段之間歇性噪音對住家的危害更大。

使用大量土地去設置道路隔音牆和綠化帶被認為是不符合成本效益的作法，噪音很容易透過繞射或兩側高層建築立面的多次反射而擴散。因此對於住家來說，減少噪音的最直接方法是關閉窗戶，但卻付出犧牲自然通風和室內空氣品質的代價。雖然採取機械通風系統可提供室內通風，但並不符合綠色建築和零能耗建築的永續發展概念。如何滿足自然通風的要求，同時減弱外部噪音是自然通風降噪裝置的設計理念。

該研究指出通風窗是現有住宅建築隔音改造的關鍵內容和降噪的主要手段。通常壓力通風窗被定義為具有進氣口（室外）和出氣口（室內）的窗戶，其在通風室中形成 S 形通風流線；在腔室中設置橫向或垂直穿孔板以分隔腔體，或者使用包含吸音材料的消音通道來阻擋腔體。在完全關閉的情況下，住家建築外窗的隔音能力可達 20 dB 至 40 dB。通風窗結構的研究主要集中在開口的大小、開口的位置、兩層開口的相對位移。為了有系統的分析具交錯開放結構的自然通風降噪裝置的不同結構

參數，研究指出 Egzon Bajraktari 等人在 2015 年從事研究多個開口的組合，以便可以透過經驗累積和實際計算來評估不同系統參數的影響。

為提高通風窗的降噪性能，研究人員經常在窗戶的內壁添加吸音材料或裝置。近年來，儘管吸音裝置或材料的發展緩慢，且測試成本非常高，但仍是從事噪音研究人員相當關注之焦點。除了通風窗外，陽台還具有良好的降噪性能，並作為隔熱和隔音的緩衝空間，也為居民提供舒適的噪音控制環境。但是在兩棟相鄰的高樓層建築之間，在不平坦的牆壁上經過多次反射後，噪音很容易從外露的半封閉式陽台進入建築內部，並透過陽台內牆的多次反射形成局部混響場，也降低的陽台的降噪性能。研究指出全封閉的陽台與半封閉陽台相比，降噪能力並沒有太大的提升，未來綠色建築在以自然通風和降噪為目標努力的前提之下，不僅要設置通風窗或隔音陽台，也應發展成整個建築的通風系統。

透過自然通風研究和噪音現況問題的分析，可看出自然通風是建築設計的一個重要不可或缺的概念，但因涉及許多專業領域知識，且大部分噪音相關研究工作成果分散，尚未形成有效整合的技術可予以應用。如何將自然通風應用在城市和郊區各種建築，還需要大量的研究工作，也要考慮到建築外殼（building envelope）結構材料、自然通風方式和使用壽命，未來對於特殊城市氣候下之建築物綜合自然通風技術的發展仍需進一步持續的探索與努力。

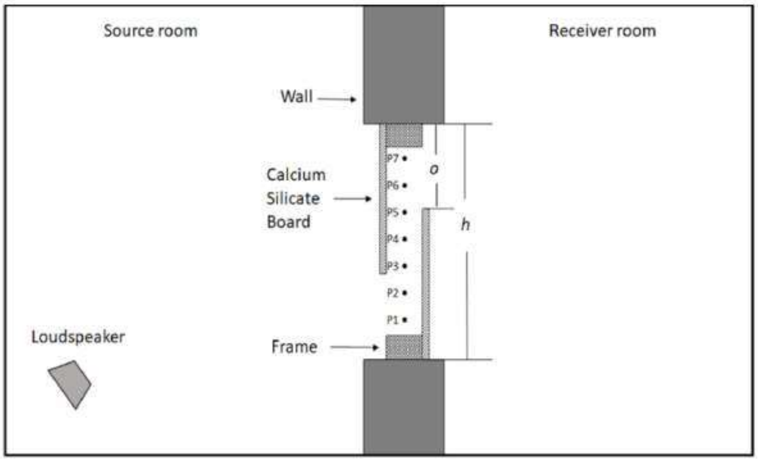
5.Sound Insulation of Ventilation Partitions with Different Configurations（不同結構的通風隔音性能），論文發表國家：新加坡

依據新加坡住房和發展委員會（Housing and Development Board, HDB）的調查，高噪音問題是在 23 個最不喜歡的居住環境問題方面排名第 1。具體而言，交通噪音是新加坡和香港等高密度城市的最主要噪音源。對鄰近交通道路或鐵路附近之住宅，隔離外部交通噪音的簡單方法即是關閉面向公路和鐵路的門窗，但卻阻礙了自然通風，如何在保持自然通風的同時兼顧有效隔離噪音的影響，在近十年來已提出了多種解決方案。

採用主動噪音控制（Active Noise Control, ANC）技術來減輕透過傳統開窗會發生的噪音傳播，可將次級噪音源安裝在窗框中以產生反相聲音來對抗入射聲音，從而減少透過窗口的噪音傳播。然而 ANC 技術僅限

於低頻噪音之降低，為了控制寬頻率範圍內的聲音傳播，Ford 及 Kerry 等人在 1973 年提出由兩個交錯的玻璃窗格組成的壓力通風窗（plenum window）的觀念。Tong 等人基於這樣的設計，在 2015 年即對壓力通風窗的聲音插入損失進行了全尺寸的現場測量，並將壓力通風窗和傳統的側掛式平開窗分別安裝在兩個相同的模擬試驗室中，這些試驗室採並排建造且面向繁忙的道路，通風窗的聲學效益主要介於 7.1 dB(A)至 9.5 dB(A)。同時為提高壓力通風窗的降噪性能，許多研究人員已進行研究被動噪音控制（passive noise control, PNC）技術，Kang 和 Brocklesby 等人在 2005 年即採取在壓力通風窗的兩個玻璃板之間，安裝了透明的微穿孔吸音器，且不會影響窗戶的透明度。然而，由於透明材料的低吸音性能，降噪的改善並不顯著。

　　該研究即採用由兩個交錯面板組成的通風隔板，在不考慮光穿透的情況下，通風隔板可以與許多聲學處理相結合，因此可實現更好的降噪性能，該研究並以實測的聲音穿透損失（transmission loss, TL）性能來評估隔板的降噪性能。也進行量測採用沒有聲學處理，以及經過聲學處理的通風隔板之聲音穿透損失，5 種不同配置的通風隔板之隔音等級（Sound Transmission Class, STC），詳如下表所示。沒有聲學處理的通風隔板由兩個隔板（矽酸鈣板）組成，具有交錯的開口。就具有聲學處理的三個通風隔板而言，玻璃纖維以各種樣式放置在兩個面板之間，以增強降噪性能。在實驗室條件下測試通風隔板的聲音穿透損失，測量結果顯示，附加玻璃纖維的通風隔板可以達到隔音等級（STC）22 dB 至 31d B，比沒有任何聲學處理的通風隔板高出 11 dB 以上。



測量設置

從接收室檢測通風隔板的前視圖

通風隔板聲音穿透損失之測量設置

5 種不同配置的通風隔板之隔音等級（STC）

案例	描述	隔音等級
B0	無任何聲學處理的通風隔板	11 dB
B1	封閉的單層隔板	31 dB
C1	沿隔板框架放置厚度為 25mm 的玻璃纖維	22 dB
C2	沿隔板框架放置厚度為 25mm 的玻璃纖維，並在一個隔板上放置一層	31 dB
C3	覆蓋空腔頂部和底部的厚度為 25mm 的玻璃纖維；沿空腔左側和右側放置 10 個邊長為 200mm、厚度為 82mm 的三角形塊	26 dB

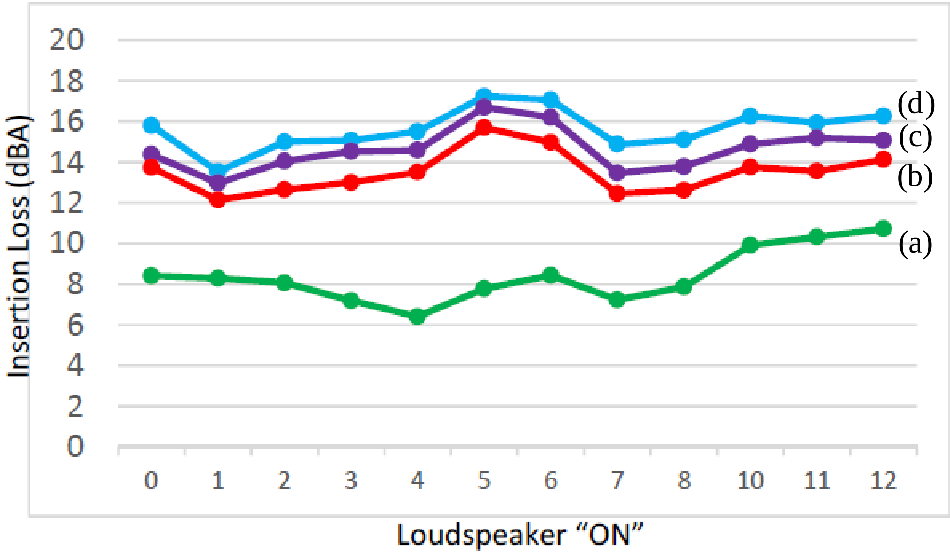
(a) C1, STC 22dB　(b) C2, STC 31dB　(c) C3, STC 26dB

6.Effects of sound incidence angle on the effectiveness of noise reduction measures applied to acoustic windows（聲音入射角對隔音窗降噪措施效果之影響），論文發表地區：香港

香港是住宅區發展有限的最擁擠的城市之一，因此許多新的高樓層住宅建築靠近交通量大的繁忙道路，造成嚴重的交通噪音污染。根據香港環境保護署的資料，香港約有超過 100 萬人受到重度交通噪音的影響。香港採取的噪音緩解措施通常集中在噪音源、傳播途徑和受體端，大多數建築物只能採用受體端的解決方案，包括建築退縮、隔音陽台和裝設隔音窗等，該研究即針對提高面向交通噪音的窗戶之降噪能力進行探討，並指出微孔板（micro-perforated panel, MPP）以及 pomute 等不同吸音材料應用在隔音窗改善的性能方面呈現出出很高的改善潛力，而不會大幅降低自然通風效率，且也易於維護。

在這項研究中，作者透過構建所提議窗口設置的實際模型來進行實驗，並設計了 13 種面向窗戶及不同的角度之揚聲器，所有揚聲器具有相同的方向，以模擬道路交通噪音。該研究也以全尺寸的模型試驗探討不同吸音材料性能對各種角度噪音的有效性，並比較如何改善窗戶的聲學性能。發現透過將吸音材料安裝到具有窄間隙寬度的窗戶中，可呈現 1.1

dB(A)至 3.0 dB(A)的隔音效果。

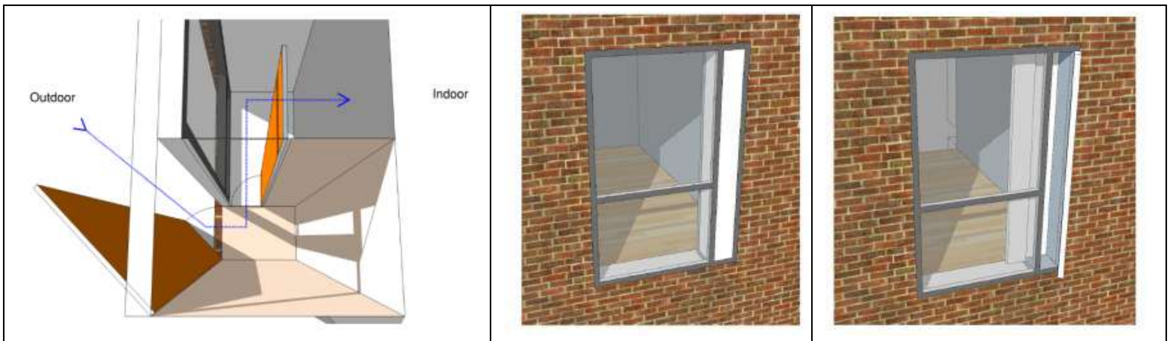


不同測試例之所有揚聲器位置的吸音性能比較

7.Noise control through open windows - A solution model（透過開窗方式進行噪音控制－解決方案模型），論文發表國家：丹麥

不斷增加的道路交通噪音與住戶對於自然通風的要求，已成為丹麥近來都會區住宅所面臨之重要難題。該國環境保護局自 2007 年以來，一直敦促有關部門必須採用解決方案，來減少開窗所引發交通噪音影響。

該研究採用自然通風消音設計的初步概念，包括：(1)垂直框，內置於窗框一側。(2)在開放式配置中，外部噪音通過垂直彎曲的傳輸路徑加以抑制，並有不同的吸收厚度（如下圖）。



衰減傳輸路徑	關閉配置	打開配置

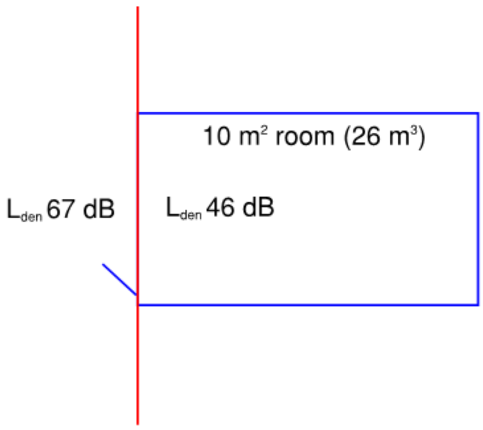
噪音衰減傳輸路徑及配置

該研究採用 ISO 16283-3「建築物和建築構件中的隔音現場測量 – 外牆隔音」中的兩種現場測試方法，在電腦模擬軟體中建立模型，並進行現場實地量測，量測結果如下表。

透過打開窗戶的聲學衰減

Noise reduction through the open ventilation box（透過打開的通風箱降低噪音）	Modelled results（模擬結果）	Measured results（測量結果）
ISO 16283-3 ”Element loudspeaker” $R'_{45\ degree} + C_{tr}$	15 dB	13 dB
ISO 16283-3 ”Element road traffic” $R'_{tr,s} + C_{tr}$	14 dB	11 dB

該研究發現：(1)測量結果的開口參考面積為 0.35 平方公尺，顯示聲衰減 R’trs + Ctr = 11 dB。(2)在 10 平方公尺面積（體積 26 立方公尺）的房間內透過自然通風方式，可得相當於內部噪音 L_{den} 為 46 Db 及外部噪音 L_{den} 為 67 dB 之初步結果。



10 平方公尺的房間內透過自然通風的聲音衰減

8.Health impact of noise in Greater Paris Metropolis: assessment of healthy life years lost（巴黎大都會區噪音對健康的影響：健康壽命損失的評估），論文發表國家：法國

噪音污染是在目前都會區民眾面臨之環境風險因素中排名第 2 高，其嚴重程度僅次於大氣污染。根據歐盟公路、鐵路和飛機交通相關策略噪音地圖（2002/49/EC），Bruitparif 在該研究已經採用了一

種方法來評估每網格單位（500×500 平方公尺）和市區民眾健康影響。這種方法類似 2011 年由 Bruitparif 和法蘭西島（Île-de-France）地區衛生主管部門用於評估巴黎大都會區（Greater Paris Metropolis, GPM）居民健康影響與危害，並以每年損失的健康生命年 DALY（disability-adjusted life-years，殘疾調整生命年）作為評估指標。

GPM 的居民由於暴露在交通噪音中，平均失去 8 個月的健康生活。對於一些城市，DALY 值可達到 18 個月。Bruitparif 已經為該區域開發了一種噪音診斷程式，以便對存在關鍵噪音問題的小地區進行優先排序及採取改善作法。該研究結果將有助於協助釐清交通運輸噪音污染嚴重性並提出改善作法，以便政府部門制定 GPM 全面性有效之噪音行動計畫（指令 2002/49/EC）。

該研究併發現在人口稠密的法蘭西島地區，每年約有近 10.8 萬年的殘疾調整壽命損失（如下表），每年經濟損失為 54 億歐元，此與世界衛生組織在歐洲流行病學調查結果趨勢呈現一致性。該研究重新評估了該人口稠密地區噪音對健康和經濟的影響，也為政府公共政策制定者提供了重要的參考資訊。

巴黎大都會區的DALY統計結果

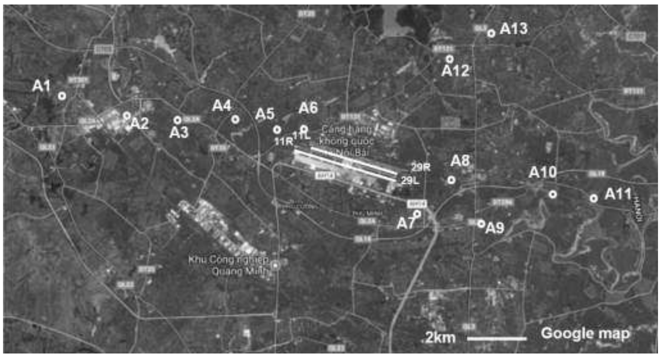
DALY	Road	Rail	Air	Total
Sleep disturbance	33,613	15,088	12,227	60,929 (57%)
Annoyance	31,994	8,352	6,491	46,837 (43%)
Total	65,607 (61%)	23,440 (22%)	18,718 (17%)	107,766

9.Noise sensitivity and dwelling characteristics affect the quality of sleep among schoolchildren（噪音敏感度和居家特性影響學齡兒童睡眠品質之研究），論文發表國家：塞爾維亞

該研究目的是為評估塞爾維亞的貝爾格萊德市中心（Central Belgrade municipality）學齡兒童的睡眠品質與夜間道路交通噪音暴露、噪音敏感度和居家生活特性的關係。兒童的噪音敏感度與入睡所需時間、早晨感到疲勞、睡眠品質差和夜間被噪音吵醒等因素發現具有顯著高度統計相關。研究指出睡在面向街道的臥室裡的孩子睡眠品質較差，醒來後感到疲勞。此與居住在擁擠公寓裡的孩子們面對安靜一側的臥室相比，被噪

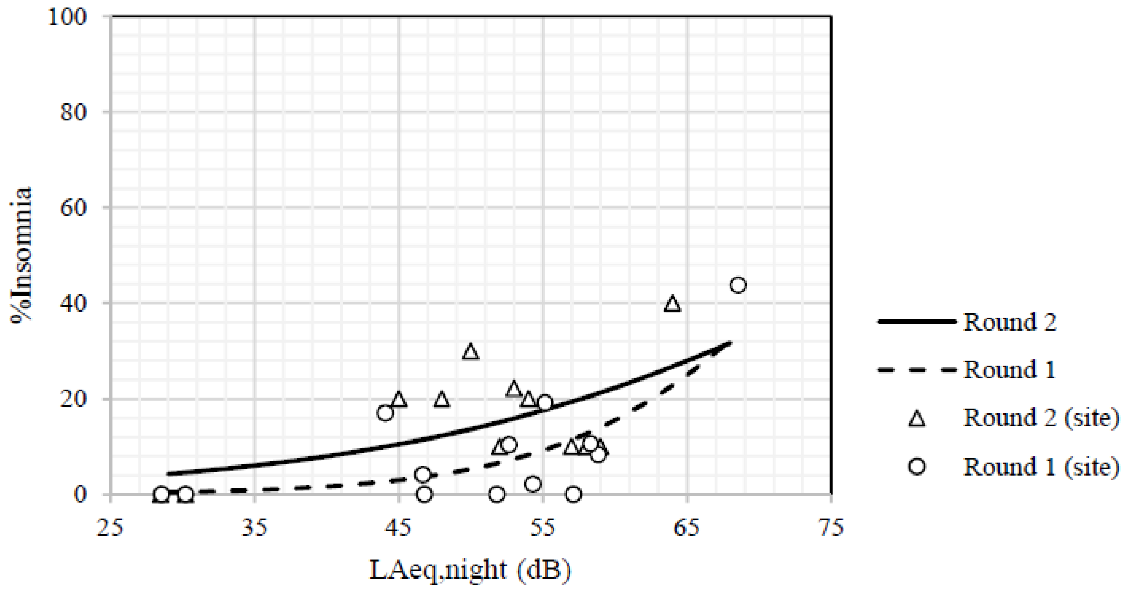
音吵醒的孩子和從不開著窗戶睡覺的孩子睡的時間更少，而被噪音吵醒的孩子比住在更寬敞公寓的孩子更多。研究發現居住特性和噪音敏感度可能會影響兒童的睡眠品質，但發現年齡和性別卻是不具統計相關。前述居住特性，如:公寓大小、樓層和臥室的座向等，均有可能影響兒童的睡眠；但從睡眠時間、噪音喚醒和早晨的疲勞程度來看，與年齡，性別和噪音無關。建議貝爾格萊德市應落實的改善措施包括有效減少夜間交通噪音和其他環境噪音，此外還應透過經濟有效的方式來呼籲改善民眾居住特性，並應向公眾週知減少交通噪音暴露的有效方法。

10.Assessment of health effects of aircraft noise on residents living around Noi Bai International Airport（航空噪音對河內內排國際機場周邊居民的健康影響評估），論文發表國家：日本



對於發展中國家的國際機場周圍居民而言，關於航空噪音對健康影響的研究相當有限。該研究分別於 2017 年 11 月和 2018 年 8 月，在越南河內國際機場（HNBIA）周圍的 13 個地點進行航空噪音對民眾健康影響的調查，調查內容包括航空噪音暴露量、噪音煩惱度、睡眠干擾和身體質量指數（BMI）及血壓等健康指標，研究方法包括透過現場測量和噪音地圖推估獲得噪音暴露量，並透過當面訪談民眾調查等方式，進行比較不同噪音暴露量範圍內高血壓和失眠比率的受訪者。

研究發現高血壓和噪音暴露量（L_{den}）之間沒有顯著的統計相關，但夜間噪音暴露量卻和失眠之間存在顯著的劑量效應關係(如下圖)。該研究結果顯示居住在機場周圍之居民的高血壓率很高，但與噪音量卻沒有顯著統計關係，此外在夜間起飛頻繁的調查期間，發現居民的失眠率較高。為進一步研究噪音對越南機場周邊居民總體健康的影響，後續仍需要採用可靠的健康資料蒐集方法再持續進行調查。該研究是首次針對越南主要機場航空噪音對健康影響進行評估，建議機場主管機關應考慮對夜間飛航限制和具體明定航空噪音限值，以保護機場周圍居民之健康，並促進越南航空運輸永續和環境平衡發展。



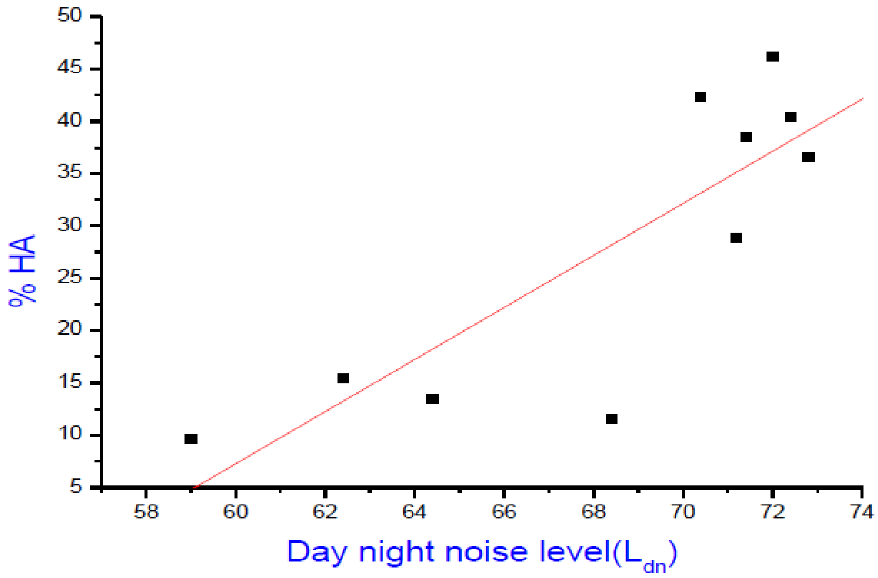
失眠百分比與$L_{Aeq,night}$之間的關係

11. Study on the effects of traffic noise on human health（交通噪音對人體健康影響之研究），論文發表國家：印度

該研究針對交通噪音對印度德里市（Delhi city）主要道路附近居民的生理影響進行探討。研究單位在該市選取 10 個地點並進行問卷調查，同時在每個位置也記錄了環境噪音量。經調查發現所有選定位置的噪音量均高於法規所規定之限值。研究結果顯示，道路車輛交通是噪音污染的主要來源，並對人們造成了干擾。該研究並對日夜音量（L_{dn}）與高度煩惱人群百分比（%HA, highly annoyed）進行統計迴歸分析，結果發現二者之間有很強的相關性，如下圖所示。

該研究採用問卷方法進行調查交通噪音對暴露人群的不良影響，指出主要問題是騷亂、頭痛和煩躁。研究發現約 70%的人認為，道路車輛交通是造成個人煩惱的主要噪音源。透過統計分析結果，也發現了日夜音量（Ldn）與噪音煩擾度（%HA）的線性關係，二者之間存在很強的

相關性，可見隨著交通噪音量增加，對民眾造成的煩擾程度也會增加。



高度煩惱人口百分比與L_{dn}的關係

12. Rail shielding technology- Field test on German railway track（鐵路遮罩技術-德國鐵路軌道現場試驗），論文發表國家：奧地利及西班牙

德國 Calmmoon 軌道於 2010 年被政府相關部門核可需使用鐵路網遮罩（Rail web shielding, RWS）技術。截至 2014 年底，已有超過 80 公里的德國鐵路軌道安裝 RWS(如下圖)。作為德國經濟刺激計畫 II 的一部分，測量結果顯示對於 Calmmoon 軌道，平均降噪效果為 3 dB(A)，如下表所示。Calmmoon 板材以 1.3mm 厚的消音板的型式黏在鋼板（蓋板）上，其應用之概念主要來自汽車工業的吸音泡沫。

在歐洲，自 2008 年起 Calmmoon 鐵路網遮罩系統便已開始使用，在經濟刺激計畫的過程中，德國基礎設施部和鐵路長途區域服務營運商於 2012 年即指出 Calmmoon 軌道是減少鐵路噪音最有效、最經濟和用戶友好的技術。依據在德國和瑞士所進行的現場試驗顯示，鐵路基礎設施的總噪音水準可降低 4.4 dB，另據 Star Damp 在自由振盪軌道上進行的實驗室測試顯示改善結果可達 19 dB。當軌道衰減率（track decay rate, TDR）較高的情況下，Calmmoon 軌道比軌道阻尼器（Rail web dampers, RWD）更有效，如 TDR 為 15.2 dB/m 時，Calmmoon 軌道將可比 TDR 為 2 dB/m

時的軌道阻尼器（RWD）提供更大的降噪效果。此與鐵路隔音牆的效果類似，但 Calmmoon 軌道僅通過遮罩來降低輻射噪音。對於鐵路營運商的幾乎所有現有軌道系統而言，Calmmoon 軌道應能有效降低鐵路基礎設施噪音，也值得其他歐洲國家陸續予以應用。

Calmmoon軌道, RWS橫截面及RWS蓋板

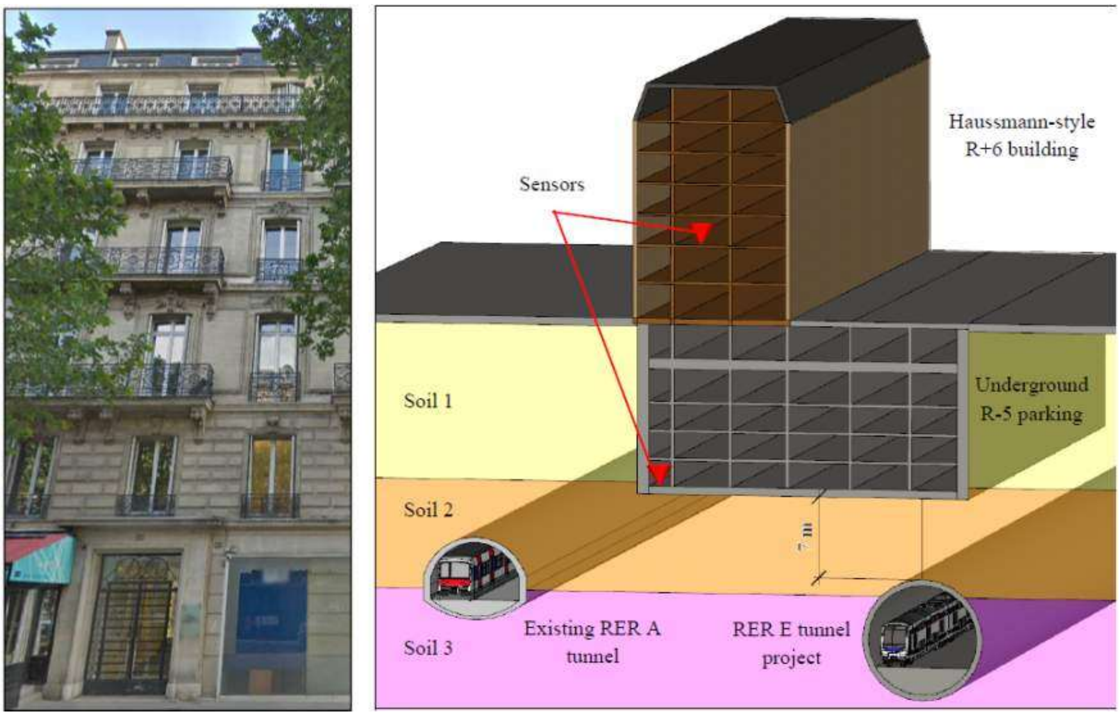
德國經濟刺激計畫II（KP II）之RWD和RWS的試驗結果

Technology	Effect [dB] acc. to calc. method Schall 03 [2012]	Rating
Rail web damper (RWD)	2 dB (RWD)	4 Manufacturers
Rail web shielding (RWS)	**3 dB (RWS)**	**1 Manufacturer**

13. Railway Induced Groundborne Noise And Vibration From Lines In Tunnel, Paris Rer E “Eole” Project（鐵路所致地面噪音和隧道線路振動-Paris Rer E “Eole”計畫），論文發表國家：法國

位於法國巴黎的 St-Lazare 車站和巴黎西部之間的 RER E“EOLE”隧道線已於 2018 年開工建設，在開工期間的營運列車產生之地面噪音和振

動都已被營運單位納入考量，以妥善降低鄰近建築之居民遭受到鐵路噪音影響。該研究係介紹隧道列車運行時，所進行之地面噪音預測模型與量測做法。隧道係處 1870 年代的建築下方，並位於巴黎奥斯曼(Boulevard Haussmann）大道的位置(如下圖所示)。營運單位選用預測鐵路營運之地面噪音和振動模型，包括 Finite Element Method, FEM/ Boundary Element Method, BEM。



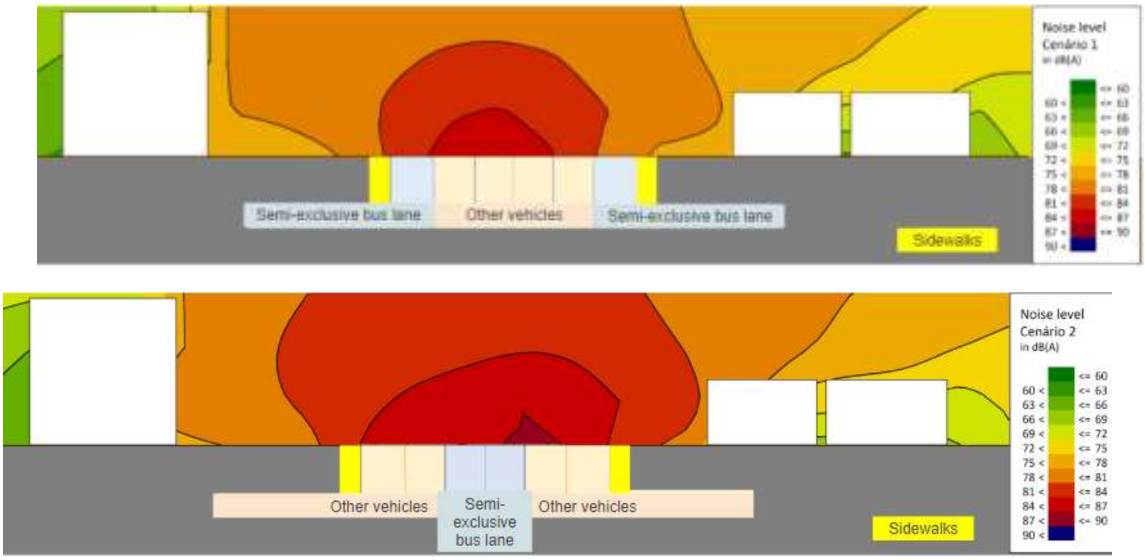
奥斯曼式建築與隧道之立面和橫截面輪廓圖

該研究並依建築物內測量結果，提出鄰近隧道奥斯曼式建築物之地基到樓層聲音傳遞函數，應整合在地面噪音預測模型內，此種數值與經驗相結合的方法可用以提高預測模型的精準度。但預測模型之建立仍需將列車動態納入考量來提高預測之有效性，未來此類模型與量測之運用可在歐洲各地類似之建築物推廣加以應用並進行比較，供鐵路營運機關防制噪音時之參考。

14.The Soundscape of Sen. Salgado Filho Avenue, Natal/RN-Brazil: The Acoustic Impact Caused By The Insertion Of Semi-exclusive Bus Lane（都會區使用半專用公車道造成的聲學影響），論文發表國家：巴西

在巴西 Natal/RN 都會區的公路主管機關已規劃將緊鄰人行道旁的 Senador Salgado Filho Avenue 的車道設計成半專用公車道，卻也引發人們對公車站和人行道上的噪音影響的質疑。該研究目的是為瞭解道路配置對環境噪音品質的影響，並提出交通規劃的考量與建議。該研究除進行測量公共汽車站的噪音分布情形，同時以問卷方式去了解行人對半專用車道所致噪音的影響。研究發現結果緊鄰人行道的噪音量測結果超出世界衛生組織的建議值，顯見人們受到公共汽車噪音干擾的嚴重性，另外透過 Sound PLAN 軟體之模型進行模擬，發現半專用車道位置的噪音小於單一中央車道的噪音(模擬結果如下圖)，也顯示在進行都市計畫時應納入道路交通噪音相關研究，以確保行人在人行道上的舒適度。

該研究指出車輛噪音是城市環境中噪音污染的主要來源，其與人們面臨的噪音干擾具有明顯直接相關。因為較高音量的交通噪音加上每個人不同的生理因素，產生顯著的負面影響。特別是在城市規劃未考慮聲學與舒適度的國家，此類問題更加嚴重。透過該研究結果可發現，人們在緊鄰大型公共汽車通過的人行道，易受到交通噪音顯著影響，且未來交通工程之施作與公共交通之規劃應考量當地交通噪音現況與緊鄰公車站的行人觀點，以有效維護都會區的環境品質。

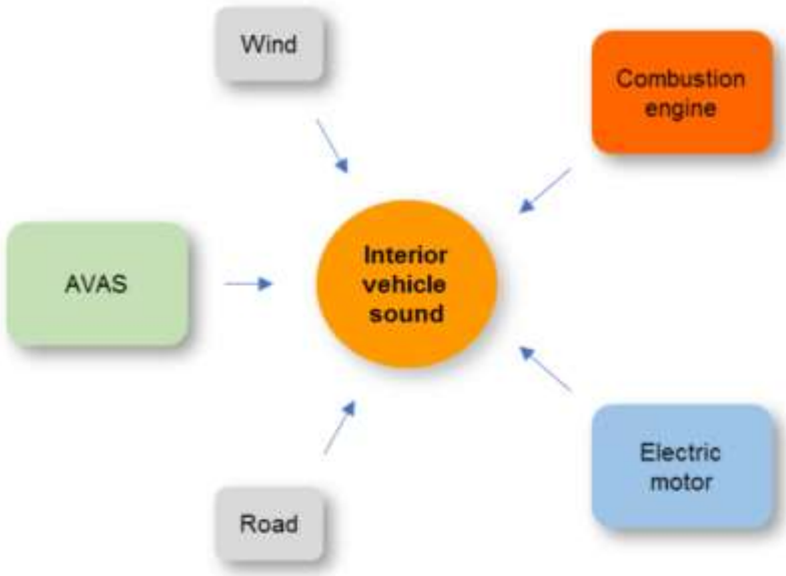


SoundPLAN軟體模擬之半專用車道位置產生的噪音比較

15.Consistent Active Sound Generation Concept for Hybrid vehicles(混合動力汽車的持續性主動發聲概念)，論文發表國家：德國

混合動力汽車內部的聲音來源眾多且複雜（如下圖），但與內燃機車輛內部聲音相比較，混合動力車內的噪音往往是容易被忽視的。在德國的交通相關法規已要求混合動力電動車輛(Hybrid Electric Vehicle，HEV）、插電式混合動力電動車輛（Plug-in Hybrid Electric Vehicle，PHEV）應配備行人警告系統（Acoustic Vehicle Alerting System 或 Approaching Vehicle Audible Systems, AVAS），所產生之電動車輛低速警示音，將使得這種車輛內的既有噪音情況更加複雜。

對於車廠來說，有其必要針對混合動力車內的噪音、振動及舒適度的性能加以嚴格的要求，其目的是為將所有不同來源的聲音貢獻降至最低，但卻會導致成本的增加與車重的提升。該研究指出採用主動音源發聲方法（Active Sound Generation）可視為採用比較柔性和降低成本的解決方案以解決這個問題。但與燃燒式或電動車輛相比，混合動力車輛在聲學方面的挑戰卻更為複雜。因內燃機和電動發動機必須要在各種不同的模式下運作，可考慮使用主動聲音設計（Active Sound Design）方法來產生對應不同操作模式的聲音，並使不同的聲音協調成一致性。未來車廠可針對量產的車輛，採用專用硬體、數位訊號處理與放大器結合進行不同主動發聲模式之演算來加以實現。



混合動力汽車內部聲音的組成

伍、 心得與建議

一、 透過這次國際噪音年會的參與,可實際了解到世界上不同國家目前所關心與推動的諸多噪音研究議題和成果,各國推動噪音防制工作重點與方向有相當大的差異性,並非單純僅以環境保護為唯一考量因素，例如:荷蘭、塞爾維亞與西班牙等歐洲國家,除以環境為管制考量外,更延伸到弱勢族群(如:孩童)的健康保護目的，這些國家並在本次年會中進行多篇研究發表,說明探討交通噪音對孩童在學校之認知行為與多動障礙之影響,並對於居家環境健康與生活品質影響等議題有更進一步的探討。

二、 在這次噪音年會特別觀察到歐美先進國家對於噪音議題,已從傳統的噪音防制作法,進一步提升到從都市規劃及寧靜建築設計等面向,這些先進國家也期盼能從源頭採用多樣化噪音調適措施,而非僅從末端管制來改善民眾所面臨之噪音困擾，兼顧環境永續與循環經濟之共存性及友善性，實際落實於居民生活品質之改善，此種先進之概念與務實的作法，可作為我國政府未來學習與借鏡之重要參考。

三、 此次國際噪音年會與不同領域噪音專家學者進行交流,發現不同國家會因地理特性與國情文化差異,採取多樣性噪音管制與環境管理措施。因噪音多屬區域性環保議題，易對民眾直接產生干擾，甚至造成身心健康之影響，除參考他國之推動經驗與管制作法，但仍需因地制宜，從源頭改善與管末處理分進合擊採取適合有效之解決方式,方能有效改善噪音對民眾的影響，確實提升環境品質。

四、 值得一提的是在本次年會之開幕酒會及各場次技術會議休息時間，把握機會與各國與會人員進行交流時，有部分國際友人居然表示沒聽過台灣，或是雖有聽過台灣但不知道詳細地理位置，只好透過電子行動裝置向國際友人說明台灣地理位置與現況，深深感覺到推動環保工作，也是另外一種外交的觸媒，透過參與國際性會議獲取科學新知，除可推動國際環保交流，亦能兼顧推動國民外交，有效提升台灣在國際上的能見度。

五、 有幸能代表本署飛越半個地球前來西班牙馬德里參與2019年國際噪音年會，個人深感獲益匪淺。透過實地參與一年一度的世界級國際性會議盛事，不論是聆聽來自各國產官學界的噪音管制經驗分享，或是代表本署口頭發表我國推動噪音管制成果，並與各國友人進行意見交流與經驗分享，深感有幸可站在巨人的肩膀上汲取他國寶貴豐富的經驗，以內化為未來研提我國噪音管制政策與改善環境品質之助力，讓世界看見台灣身為地球村一員的努力。

六、 值此同時，我國正面臨日益艱難的外交困境，為能讓世界看見台灣，本署未來仍應持續派員出席世界性的國際會議，以提升台灣在國際上的能見度，署內同仁除從事環保業務工作外，更應走出台灣，透過世界性會議的參與，有效提升個人國際視野及自我本職學能，蒐集最新環境污染管制作法並結合先進國家推動經驗，有助於未來檢討我國環保法規及研提管制策略與措施，有效提升國內環境品質，確保民眾健康。

附件一

附件一

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NOISE CONTROL FOR A BETTER ENVIRONMENT

Evaluation of transport related noise exposure to residents in Taiwan metropolitan area

Pei-Hsiou Ding[1], Sheng-Zhong Wu[2], Jen-Shou Hsieh[3]

[1,2,3]**Department of Air Quality Protection and Noise Control**
Environmental Protection Administration, Executive Yuan
14F No.83 Sec.1 Chunghwa Rd., Taipei, Republic of China (Taiwan)

ABSTRACT

With increasing density of urban population and completion of railway construction, noise pollution has become an important issue in Taiwan in last decade. This study aimed to evaluate the relationship between railway noise, speed rate and noise effect in metropolitan areas in Taiwan. Both general and high-speed railway noise were measured in Taipei and Taichung metropolitan areas from 2017 to 2018. Analyses indicated that relationship between railway noise level and speed rate logarithm of the general railway train is 35 log(v), while that with high-speed railway is 30 log(v). And sound insulation between indoor and outdoor under closed door/window condition is 20 dB(A), while with open door/window condition is 10 dB(A) in residential area close to the railway. Taiwan Environmental Protection Administration (EPA) plans to launch technical approaches including improved solar panel noise barriers along railway and active control type soundproof windows to achieve environmental sustainability goals for noise reduction, carbon reduction and pollution reduction.

Keywords： railway noise, metropolitan area, active control type soundproof window, solar panel noise barrier
I-INCE Classification of Subject Number: 13

1. INTRODUCTION

Due to increasing density of urban population, various living lifestyles and intensive use of land in Taiwan, newly constructed residential buildings may be close to main traffic roads in metropolitan areas. Railroad related noise has become an important issue in Taiwan in last decade. In order to reduce impact of noise pollution on residents along railroad, it is necessary to understand the characteristics of noise sources, sound insulation between indoor and outdoor under closed door/window condition residential area. This research aimed to evaluate the relationship between railway noise, speed rate and noise effect in metropolitan areas in Taiwan.

According to High-Speed Ground Transportation Noise and Vibration Impact Assessment by Federal Railroad Administration (FRA) of US Department of Transportation, the effective height of radiation rolling noise between wheels and rails

[1] phding@epa.gov.tw
[2] shengjong.wu@epa.gov.tw
[3] jshsieh@sun.epa.gov.tw

is about 0.6m above the orbital plane. With increasing speed of train, the increment of rolling noise is much bigger than that of propulsion noise. The regression coefficient of speed and railway noise was 30. When the speed reached to 290 km/h, pneumatic noise becomes more apparent by the high-speed airflow flows across the train. And the typical relationship is 60 to 70 times of rate logarithm by train [1].

In Japan, Nagakura Kiyoshi and Zenda Yasuo identified four noise sources of high-speed railway (Shinkansen N700 series) , which included wheel-rail noise, locomotive noise, pneumatic noise, and power collection system noise. And proposed a calculation formula for noise source SWL[2]. A French study found that the rolling noise is the main noise source of high-speed trains (TGV) with increasing speed [3]. And the correlation coefficient of speed and railway noise was 0.93, and the regression coefficient was 30.4[4, 5, 6]. The causes of noise level difference between indoor and outdoor environment are related to many factors including building characteristics, outer wall types, room capacity, outdoor noise sources and window types. According to our comprehensive analysis of literatures, sound insulation between indoor and outdoor under open and slightly open window condition were 10 dB(A) and 15 dB(A). However, sound insulation between indoor and outdoor was about 25 to 30 dB(A) with tilt-in windows(Table 1).

Table 1 Comparison of results of indoor/outdoor L_{eq} noise level difference found in foreign related researches [7、8]

Researcher	Noise source	Window Position dB(A)		
		open	tilted	closed
DLR	Freight Trains	11.3 (4)	18.6 (10)	30.1 (13)
	Trains Passenger	11.9 (4)	18.0 (10)	29.7 (13)
	Road	11.6 (4)	17.7 (10)	30.1 (13)
DLR	Road	13.4 (4)	13.7 (32)	27.0 (15)
	Aircraft	10.0 (4)	15.3 (32)	25.6 (15)
EEA		5~10	10~15	
Barbara Locher	Road	10.0 (115) 1.7~17.3	15.8 (116) 8.7~21.7	27.8 (76) 16.2~38.0
Researcher	Noise source Type	Window Position dB(A)		
		open	tilted	closed
Scamoni	Reference Road			31.2 (334)
Ryan	Road	10.7 (11) 5.4(vacant)~14.7		
Maschke	Aircraft		12	
FOEN	Aircraft		15	25
Jansen	Aircraft		15	
Pabst	Aircraft			24~35

Note: Figures in parentheses refer to number of positions analyzed. DLR stands for German Aerospace Center. FOEN stands for Federal Office for the Environment (Switzerland). EEA stands for European Environment Agency.

2. Research method

2.1 Characteristics of train noise sources

(1) In-situ measurement

This study measures the noise level of various types of trains with general railways and high-speed railways (THSR 700T series) under different speeds with the following conditions: (a) measuring instrument: RION NL32 noise meter, (b) measuring time and indicator: A-weighted slow feature event equivalent sound level (L_{Aeq}), (c) measuring sites: wayside embankment sections without parapet walls or soundproof walls and horizontal alignment is straight line without switches (speed: general railway ＜200 km/h, THSR 700T ≧200 km/h), (d) measuring location: for general railway, the noise meter is about 3.8m horizontally from the center line of rail, and 0.5m vertically from the track surface (as shown in Figure 1). For high-speed railways, the noise meter is about 25m horizontally from the the center line of rail,and 1.5m vertically from the track surface (as shown in Figure 2), (e) measured types of trains (as shown in Table 2): for general railway, 14 trains included local trains, Tze-Chiang Limited Express, Chu-Kuang Express, and Puyuma Express. For high-speed railway, 21 THSR trains included northbound 700T and southbound 700T, (f) speeds of trains: 48.0 to 115.2 km/h for general railway, 157.6 to 281.3 km/h for THSR.

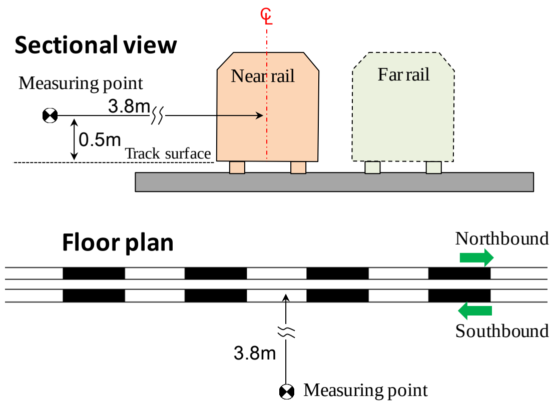

Figure 1 Diagram of in-situ measurement position for general railways

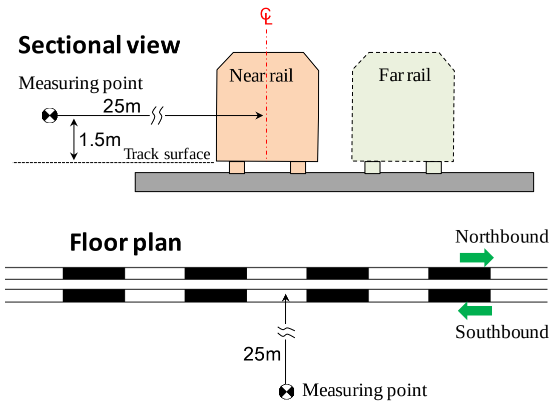

Figure 2 Diagram of in-situ measurement position for THSR

Table 2 Number of measurements of train noise sources

Direction	1. General Railway				2. THSR
	(1) Local trains	(2) Tze-Chiang Express	(3) Chu-Kuang Express	(3) Puyuma Express	(1) 700T
Southbound	9	3	1	1	11
Northbound	—	—	—	—	10

(2) Theoretical formula

This study aimed to explore the logarithmic relationship between the increment of train event equivalent sound level (L_{Aeq}) with increasing speed (general equation is shown in Equation 1). We performed a linear regression analysis on measured results to obtain the regression coefficient, namely the relationship between noise level and train speed.

$$L_{Aeq}(v) - L_{Aeq}(v_0) = k \times \log(v/v_0) \quad \text{Eq. 1}$$

where v refers to train speed (km/h); v0 refers to reference train speed (v0=1); k refers to regression coefficient.

2.2 Sound insulation between indoor and outdoor

The main purpose of measurement is to understand the sound insulation (transmission loss) and indoor/outdoor sound attenuation of the building under open or closed door/window condition (Figure 3). RION NL-32 noise meter (Japan) is used for measurement. For the road system, conditions such as 5-minute A-weighted equivalent sound level L_{Aeq} (20 to 20,000 Hz), maximum noise level L_{Amax}, and fast feature are adopted. As for the railway system, noise event A-weighted equivalent sound level L_{Aeq} (20 to 20,000 Hz), maximum noise level L_{Amax}(event), and slow feature are adopted. Measures of each train (about 3 trains) were averaged. And 26 measurements were made in total (Table 3). Indoor and outdoor measurements were made simultaneously in order to catch the same noise event. The outdoor noise meter was placed about 1.5m vertically from the extension line of the ground or floor and about 1.5m horizontally from the wall. The indoor noise meter was placed about 1.5m vertically from the ground or floor and about 1.5m horizontally from the door and window.

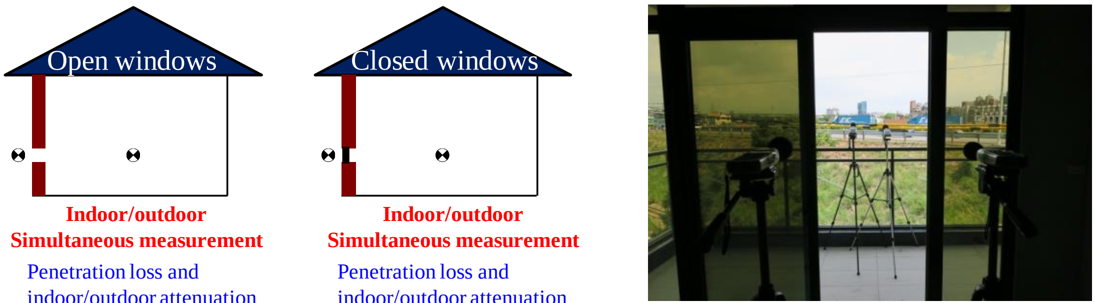

Figure 3 Diagram of conditions for indoor/outdoor noise measurement in residential areas

Note: ⊗ refers to the sound receiving point for indoor/outdoor simultaneous measurement.

Table 3 Number of measurements of indoor/outdoor noises in residential areas

Type of transport	1. General roads	2. Ground road transportation system		3. Ground rail transportation system		
	(1) Urban roads	(1) Freeway	(2) Expressway	(1) MRT	(2) General railway	(3) THSR
Measurements	1	7	2	4	10	2

3. Results

3.1 Regression analysis between noise level and train speed on general railways

The relationship between noise level and rate logarithm of the southbound near-rail train is shown as Figure 4. And the regression formula is shown as Equation 2. The regression coefficient (k) is 35.1 and correlation coefficient is 0.93. With increasing train speed, the increment of raild noise level has a highly positive trend.

$$y = 35.112x + 22.637 \quad \text{Eq. 2}$$

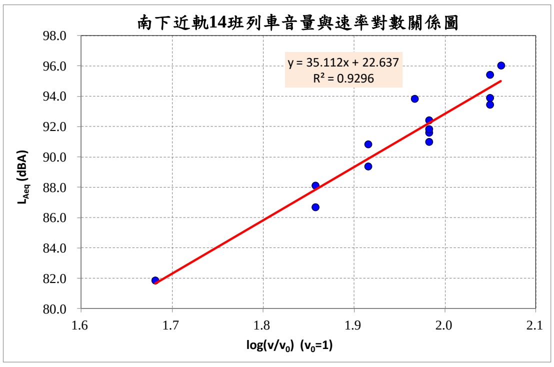

Figure 4 Relationship between noise level and rate logarithm of general railways southbound near-rail trains

3.2 Regression analysis between noise level and train speed on THSR

(1)Southbound near-rail train

The relationship between THSR noise level and rate logarithm is shown in Figure 5. The range of speed we measured was from 191.9 to 281.3 km/h. The regression formula is shown as Equation 3. The regression coefficient (k) is 29.73 and correlation coefficient is 0.89.

$$y = 29.734x + 16.433 \quad \text{Eq. 3}$$

(2)Northbound far-rail train

The relationship between noise level and rate logarithm is shown in Figure 6. The rang of speed is 157.6 to 262.9 km/h. The regression formula is shown as Equation 4. And the regression coefficient (k) is 30.87 and correlation coefficient is 0.83.

$$y = 30.869x + 12.542 \quad \text{Eq. 4}$$

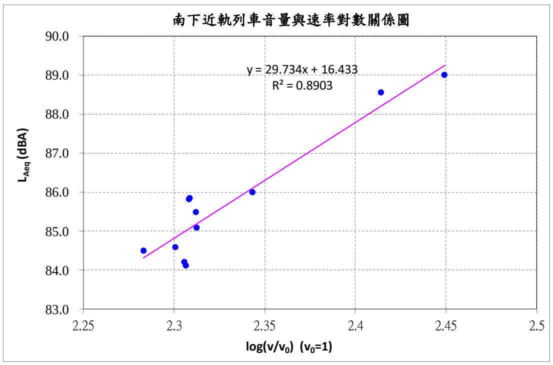

Figure 5 Relationship between noise level and rate logarithm of THSR southbound near-rail trains

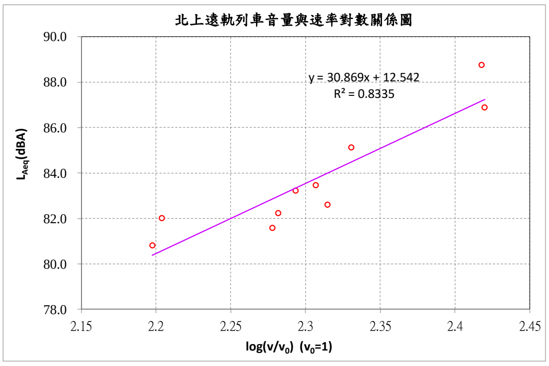

Figure 6 Relationship between noise level and rate logarithm of THSR northbound far-rail trains

3.3Indoor and outdoor noise level

(1)Sound insulation with closed doors/windows

We measured indoor and outdoor railway noise simultaneously (20 to 20,000 Hz) with closed doors/windows. Figure 7 and Figure 8 showed the correlation coefficient less than 0.5, which indicated low linear correlation between the two variables (indoor/outdoor noise levels). In other words, the noise was more affected by the path media (door/window frame and glass) passing through doors and windows. The indoor/outdoor noise level difference under closed doors/windows condition is mainly related to the door and window frame materials and glass types. And the average sound insulation with closed (doors) windows is 20 dB(A).

For air as sound transmission medium, adequate soundproof windows, and good construction quality, it should be sufficient to block the noise from enter into the building. However, low frequency noises (20 to 200 Hz) may be transmitted into or out of the building through other building structures than windows. Besides, since low frequency noises have longer wavelength, only structures with bigger surface density can effectively block the sound transmission. On account of the above possible influencing factors, the analyses on measured noise values under closed (doors) windows condition showed that sound insulation for full frequency noise is better than that for low frequency noises (Figure 11). It indicated that the soundproof effect for full frequency noise is better.

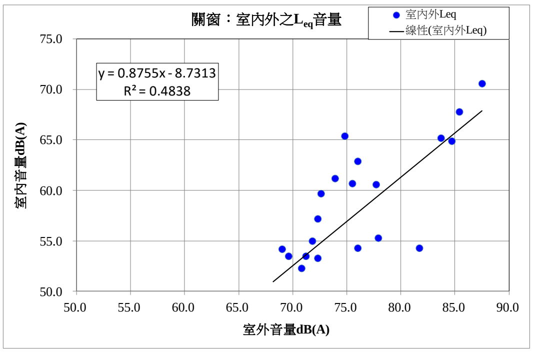

Figure 7 Linear regression of indoor/outdoor L_{eq} (20 Hz~20,000 Hz) with closed (doors) windows

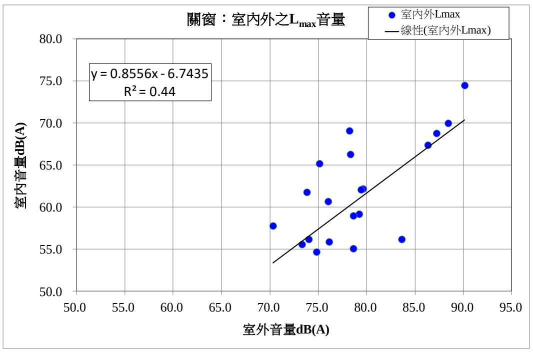

Figure 8 Linear regression of indoor/outdoor L_{max} with closed (doors) windows

(2)Sound insulation with open doors/windows

We also measured indoor and outdoor railway noise simultaneously (20 to 20,000 Hz) with open doors/windows. Figure 9 and Figure 10 showed the correlation coefficient is 0.87, which indicated high linear correlation between the two variables (indoor/outdoor noise levels). We found that the noise level was less affected by the path media (door/window frame and glass) passing through doors and windows. As shown by above preliminary results, the factors that affect the indoor/outdoor noise level difference with open (doors) windows are mainly related to the indoor space, sound absorbing ability, and the position of opened doors and windows. According to the preliminary measuring results, average sound insulation with closed (doors) windows is 10 dB(A).

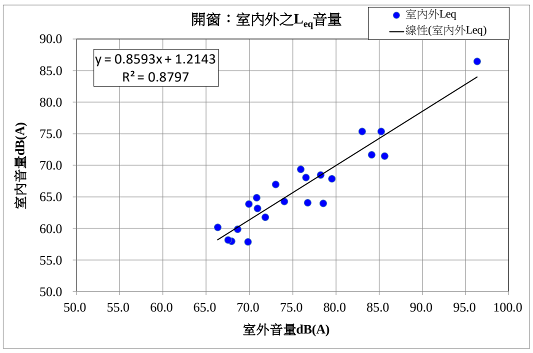

Figure 9 Linear regression of indoor/outdoor L_{eq} (20 Hz~20,000 Hz) with open (doors) windows

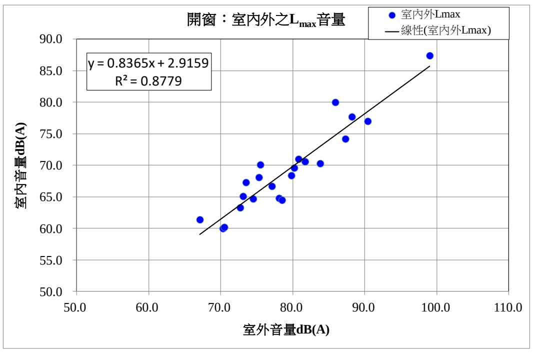

Figure 10 Linear regression of indoor/outdoor L_{max} with open (doors) windows

4. Discussion

4.1 General Railway

(1)Compare with related literature

The regression analysis on different train types of general railways measurements showed that the relationship between noise level and rate logarithm is about 35 times (35log(v)), which is slightly higher than the previous US, Japan, and France related study findings (30 times). The train type used in our study is Electric Multiple Unit (EMU), of which the traction power is separately deployed on each car. In other words, the power components or air compressors are evenly distributed under the train. Since the power of the train belongs to the dispersed type, the noise level may also be affected by power components.

(2)Estimation of train noise level under different speeds

The above-mentioned regression empirical formula (Equation 2) was used to estimate the train noise level under different speeds, such as 50 km/h, 60 km/h, and 110 km/h (as shown in Table 4). The estimation point was located about 3.8m horizontally from the near-rail centerline and about 0.5m vertically from the track surface, which was pretty close to the noise source end. It can be estimated that every increase of 20 km/h of the train speed may cause the noise level to increase about 3 to 5 dB(A).

Table 4 Estimation of general railway train noise level under different speeds

VU: dB(A)

Operating speed (km/h)	50	60	70	80	90	100	110
Southbound near-rail noise level	82.3	85.1	87.4	89.5	91.3	92.9	94.3

Note: The estimation point is about 3.8m horizontally from the near-rail centerline and 0.5m vertically from the track surface. No parapet walls or soundproof walls built beside the rail track.

4.2 High-speed Railway

(1)Compare with related literature

The regression analysis on measured results on THSR 700T shows that the relationship between noise level and rate logarithm is about 30 times (30log(v)), which is consistent with results found in previous research from the US, Japan, and France, indicating that this feature exists in wheel-rail rolling noise of all high-speed trains from different countries and does not apparently change with the locations or train types. The speed range we adopted in this study is 157.6 to 281.3 km/h. Due to the limitation of THSR 700T's operating speeds, the train noise level under higher speeds cannot be measured. However, the results show that even when the train speed reaches 280 km/h, wheel-rail rolling noise is still the main noise source.

(2)Estimation of train noise level under different speeds

The above-mentioned regression empirical formula (Equation 3 and 4) were used to estimate the train noise level under four THSR operating speeds (285 km/h, 230 km/h, 170 km/h, and 120 km/h), and results are shown in Table 5. We found the estimated noise level reducing with the decrease of train speed. Particularly, when the train speed decreases to 170 km/h, the noise level at the estimation point (about 25m horizontally from the near-rail centerline and about 1.5m vertically from the track surface) has reduced to be lower than the maximum mean noise level (85 dB(A)) stipulated by the EPA Noise Control Standards. The results may serve as reference for determining train operating speeds at noise-sensitive sections without affecting the operating practices and train dispatching when soundproof walls do not work very well or are not adopted.

Table 5 Estimation of THSR train noise level under different speeds

VU: dB(A)

Operating speed (km/h)	Southbound near-rail noise level	Northbound far-rail noise level
285	89.4	88.3
230	86.7	85.4
170	82.8	81.4
120	78.3	76.7

Note: The estimation point is about 25m horizontally from the near-rail centerline and 1.5m vertically from the track surface. No parapet walls or soundproof walls built beside the rail track.

4.3 Indoor/outdoor noise level difference

In the metropolitan area, the equipment we used that tends to produce low frequency noises (such as cooling tower, air conditioning system, exhaust fan, and pumping motor), which was often used and over development causing more residential communities to be located next to traffic arteries or overpasses. Therefore, the noise made by these mechanical power machines in operation and the acoustic resonance generated by transportation may be transmitted to people's residence through building structures, such as roof beams, columns, floors, and walls.

In addition, thin building structures, inadequate cement grouting, and cracks in the wall may also be possible factors that cause increase of low frequency noises or poor soundproofing performance. Due to the above possible influencing factors, analysis on measurements with condition of open windows (Figure 12) showed that the indoor/outdoor sound insulation of full frequency noises and low frequency noises didn't show a specific regularity. Therefore, doors and windows are important factors that influence soundproofing performance.

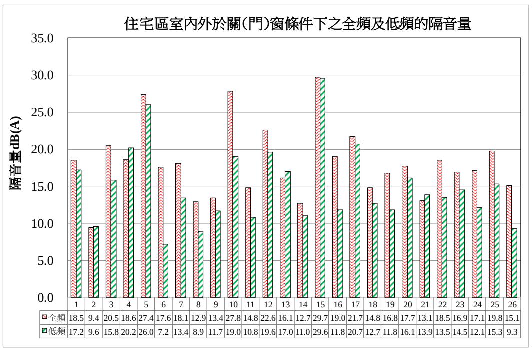

Figure 11 Noise level difference (sound insulation) of full frequency (20 Hz~20,000 Hz) and low frequency (20 Hz~200 Hz) indoor/outdoor L_{eq} with closed (doors) windows

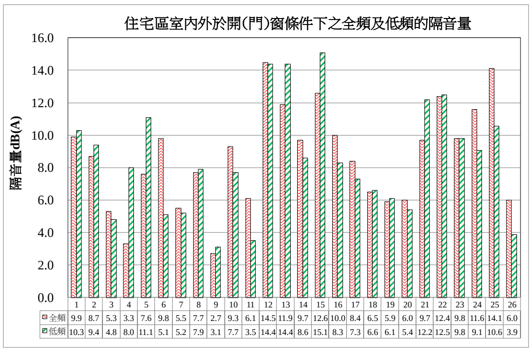

Figure 12 Noise level difference (sound insulation) of full frequency (20 Hz~20,000 Hz) and low frequency (20 Hz~200 Hz) indoor/outdoor L_{eq} with open (doors) windows

5. Conclusions and Recommendations

5.1 Conclusions

(1) Characteristics of train noise sources

The regression analysis on measured results on different train types of general railways shows that the relationship between noise level and rate logarithm is about 35 times (35log(v)), slightly higher than the 30 times (30log(v)) found in related research literature on high-speed rail wheel-rail noise from the US, Japan, and France. The relationship between noise level and rate logarithm of THSR trains is about 30 times (30log(v)), which is consistent with the results found in related research literature from foreign countries.

With preliminary empirical regression formula, it can be estimated that every increase of 20 km/h of the speed of general trains may cause the noise level to increase around 3 dB(A)~5 dB(A). When the speed of THSR trains decreases to 170 km/h, the maximum mean noise level of operating trains should be lower than the 85 dB(A) stipulated by the EPA Noise Control Standards. The results may serve as reference for determining the thinking direction of operation and management under the conditions of without spending huge noise countermeasures cost or affecting the train dispatching operation (for example, increasing train speed at sections with less population).

The 30log(v) relationship between noise level and rate logarithm is still true at least when the train speed reaches 280 km/h, which confirms that wheel-rail rolling noise is the main noise source of THSR trains. Since the wheel-rail rolling noise falls into the frequency band that is sensitive to human ears, this noise source is in need of urgent improvement. Therefore, control measures should be formulated in accordance with the characteristics of this noise source.

(2) Indoor/outdoor noise level difference

In both actual measurement and regression analysis, the indoor/outdoor noise level difference with closed (doors) windows is about 20 dB(A), while that with open (doors) windows is about 10 dB(A). In other words, the noise level difference with open or closed (doors) windows is about 10 dB(A). With closed (doors) windows, the noise level difference is more affected by the path media (door/window frame and glass) passing through doors and windows. On the other hand, with open (doors) windows, the noise level difference is mainly related to the indoor space, sound absorbing ability, and the position of opened doors and windows.

The results of in-situ measurement show that the sound simulation of doors and windows is less than the Sound Transmission Class (STC) used in the lab. The soundproof effect of doors and windows is better for full frequency noises (20 Hz~20,000 Hz) and relatively poor for low frequency noises (20 Hz~200 Hz).

5.2 Recommendations

It is advisable to conduct repeated measurements and obtain empirical results of more train types and under more train speeds, so as to further verify the relationship between noise level and train speed. In the future, it is advisable to conduct measurements through microphone array in order to further analyze the noise characteristics and contribution of each noise source in trains of both general railway and high speed railway.

If the doors and windows of the residential building are usually closed, it is advisable to improve sound insulation by using strengthened frame materials for doors and windows and adopting glass types with higher STC. On the other hand, if the doors and windows of the residential building are usually open, it is advisable to improve sound insulation by adjusting the position of opened doors and windows and adopting mechanical ventilation.

Taiwan EPA planned some innovative and sustainable noise reduction practices to deal with environmental traffic noise effect to residents. As following:

(1) Solar panel noise barriers

A. First stage:

We Use green-energy materials (such as solar panels) to modify the existing soundproof walls or add green-energy material modules to the design of new soundproof walls. Evaluate the feasibility of applying green-energy materials to the ground transportation system for the purpose of reducing pollution, carbon emission, and noise.（Landscape simulation as Figure 13）

B. Second stage:

Use estimation models to analyze the effectiveness of pollution, carbon, and noise reduction when applying renewable energy to the ground transportation system. Use the measured results to evaluate the feasibility of renewable energy to other systems.

(2) Active control type soundproof walls

A. First stage:

Run a trial on active soundproof walls for the purpose of reducing noise levels (including low frequency noises) without having to close the windows. The goal of noise reduction is over 10 dB(A) in order to allow the residents to feel the same quietness as when windows are closed and enjoy a quiet and ventilated indoor space so as to reduce their use of air conditioning and electricity expenses.

B. Second stage:

Make every effort to reduce the size of active facilities, enhance their performance, and reduce their cost. Integrate noise reduction devices into windows to make the windows more pleasing to the eye. In the future, it is hoped that different noises can be identified to ensure that not all noises be eliminated, such as alarm sound. Besides, consider the possibility of integrating soundproof functions into personal mobile devices to allow residents to eliminate the annoying noises as they wish, such as road noise, railway noise, and construction noise.

6. REFERENCES

1.High-Speed Ground Transportation Noise and Vibration Impact Assessment(Final Report), Office of Railroad Policy and Development, Federal Railroad Administration, U.S. Department of Transportation, Washington, DC, Sep 2012.

2.Nagakura Kiyoshi and Zenda Yasuo's RTRI Report entitled, *"Prediction Model of Wayside Noise Level of Shinkansen"*, (Vol.14, No.9, 2000, Ps 5~10).

3.P.-E Gautier, F; Poisson, F; Letourneaux, *"High Speed Trains external noise : a review of measurements and source models for the TGV case up to 360km/h"* France, 2008.

4.German-French cooperation, Annex K, Final Report, December 1994.

5.German-French cooperation, Annex K2, Final Report, December 1999.

6.C. Mellet, F. Létourneaux, F. Poisson, C. Talotte, "*High Speed Train noise emission latest investigation for the aerodynamic / rolling noise contribution"*, Journal of Sound and Vibration , Vol 293 (2006), P. 535-546.

7.Mitchell Ryan, Michael Lanchester, Stephen Pugh, "*Noise Reduction through Facades with Open Windows"*, Paper Number 37, Proceedings of ACOUSTICS 2011, 2-4 November 2011, Gold Coast, Australia.

8.Barbara Locher et al., *"Differences between Outdoor and Indoor Sound Levels for Open, Tilted, and Closed Windows"*, Int. J. Environ. Res. Public Health 2018, 15, 149; doi:10.3390/ijerph15010149.

Figure 13. Landscape simulation

Pre-construction	After construction
	
	
	

附件二

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Evaluation of transport related noise exposure to residents in Taiwan metropolitan area

Dr. Pei-Hsiou Ding

Department of Air Quality Protection and Noise Control
Environmental Protection Administration, Executive Yuan, R.O.C. (Taiwan)

2019.6.19

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Environmental Protection Administration
Executive Yuan, R.O.C. (Taiwan)

Contents

- Background
- Research purpose
- Research methods
- Results and discussion
- Conclusions and recommendations

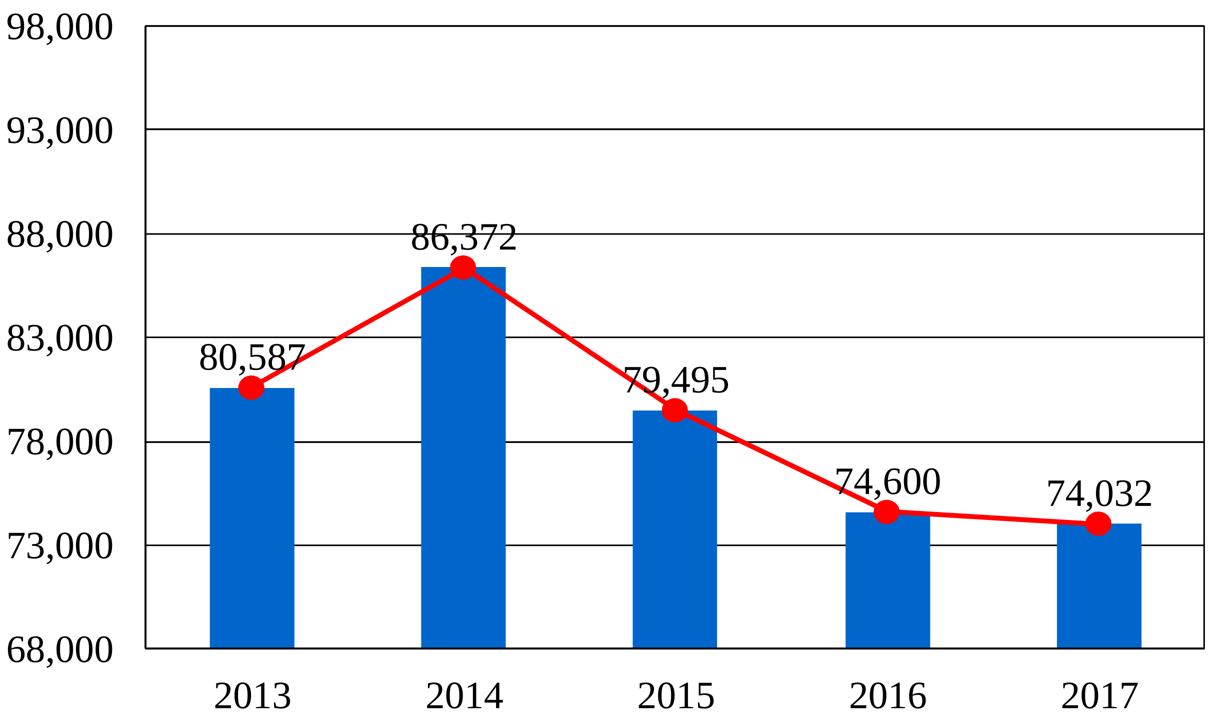
Background

Where is Taiwan?

- ***Area: 36,192 km²***
- ***Population: 23 million***
- ***Population density: 650 people/km² .***

- *Central authority: Environmental Protection Administration (EPA)*
- *Local government authority: 22 EPBs*

Noise complaint distribution in Taiwan



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交通部臺灣鐵路管理局
Taiwan Railways Administration

行政院環境保護署
Environmental Protection Administration
Executive Yuan, R.O.C. (Taiwan)

台灣高鐵
Taiwan High Speed Rail

Stations: 228

Operating Length: 1,065 km

Stations:12

Operating Length：350 km

Research purpose

- **To explore the correlation between train speed and railway noise**
- **Evaluation of railway noise exposure to residents in metropolitan area**
- **Innovative and sustainable noise reduction practices in Taiwan**

Research methods

Literature review

Relationship between train speed and noise level

Indoor/outdoor noise differences in residential area

Statistical Analysis

Results

Recommendations
(Innovative and sustainable practices)

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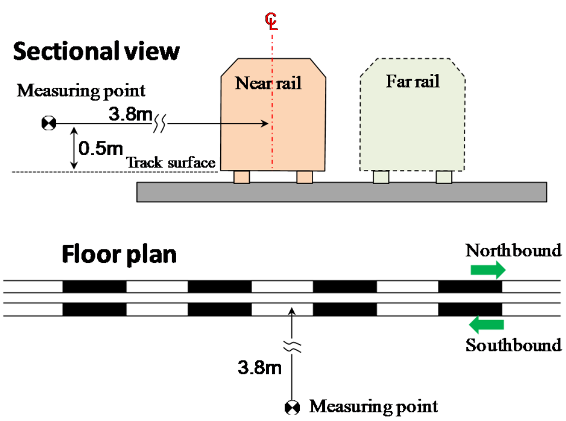

Fig.1 In-situ measurement position for general railways (14 trains)

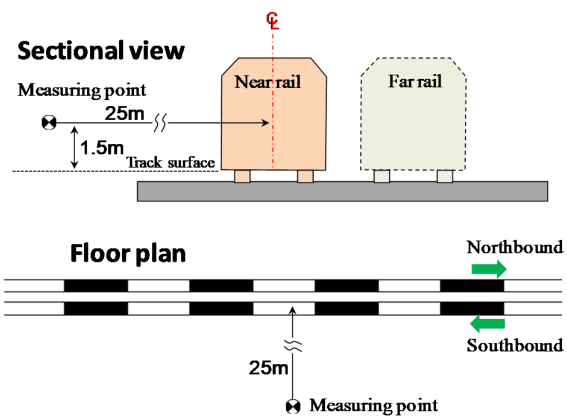

Fig.2 In-situ measurement position for THSR (21 trains)

*Theoretical formula**

The logarithmic relationship between the increase of event equivalent sound level (L_{Aeq}) and train speed

$$L_{Aeq}(v) - L_{Aeq}(v_0) = k \times \log(v/v_0)$$

where v refers to train speed (km/h); v_0 refers to reference train speed (v_0 =1); k refers to regression coefficient

* **References：**
High Speed Trains external noise : a review of measurements and source models for the TGV case up to 360km/h. P.-E Gautier(1), F; Poisson (1), F; Letourneaux (2)
(1)SNCF, Paris, France; (2)SNCF, Vitry, France

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Fig.3 Indoor and outdoor noise measurement in residential areas

Results and discussion

Relationship between general railway train speed and noise level

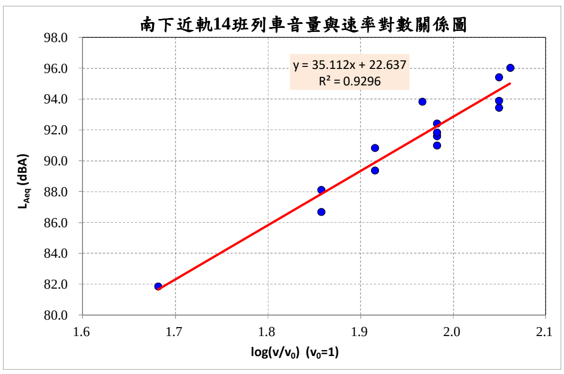

Fig.4 Distribution of noise level and rate logarithm of general railways southbound near-rail trains

Estimation of general railway train noise under different speed

Operating speed (km/h)	50	60	70	80	90	100	110
Southbound near-rail noise level , dB(A)	82.3	85.1	87.4	89.5	91.3	92.9	94.3

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Relationship between THSR train speed and noise level

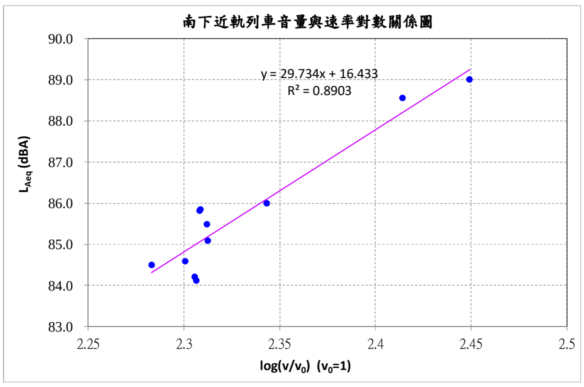

Fig. 5 Noise level and rate logarithm of THSR southbound near-rail trains

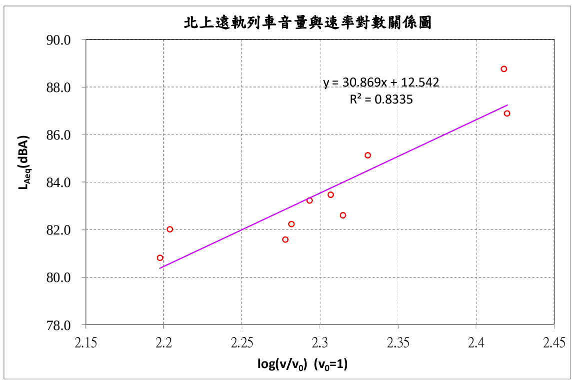

Fig.6 Noise level and rate logarithm of THSR northbound far-rail trains

Estimation of THSR train noise level under different speed

Operating speed (km/h)	Southbound near-rail noise level, dB(A)	Northbound far-rail noise level, dB(A)
285	89.4	88.3
230	86.7	85.4
170	82.8	81.4
120	78.3	76.7

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Indoor/outdoor noise difference with closed door/window condition

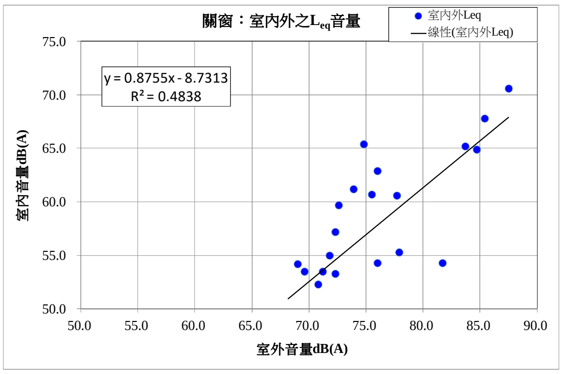

Fig.7 Distribution of indoor/outdoor noise level difference (L_{eq}, 20 Hz to 20,000 Hz) with closed doors/windows

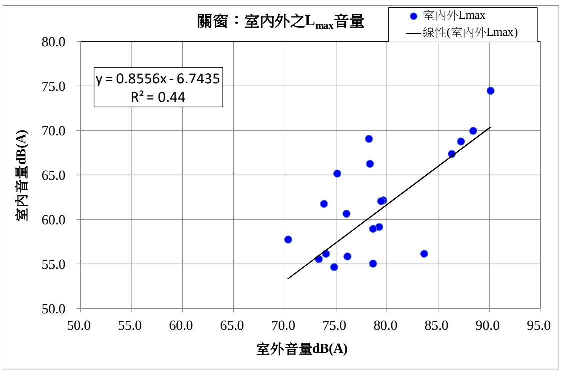

Fig.8 Distribution of indoor/outdoor noise level difference (L_{max}) with closed doors/windows

Indoor/outdoor noise difference with opened door/ window condition

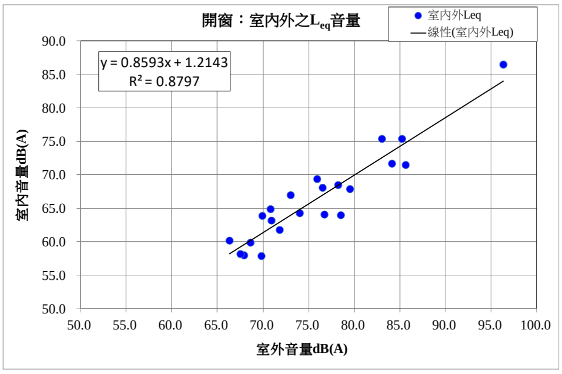

Fig.9 Distribution of indoor/outdoor noise level difference (L_{eq}, 20 to 20,000 Hz) with opened doors/ windows

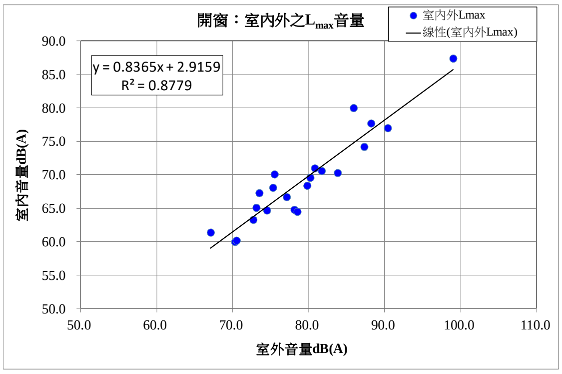

Fig.10 Distribution of indoor/outdoor noise level difference (L_{max}) with opened doors/ windows

Comparison of results of indoor/outdoor Leq noise level in previous researches

Countries	Noise source Type	Window PositiondB(A)	
		Open	closed
DLR, 2010	Freight Trains	11.3(4)	30.1 (13)
	Trains Passenger	11.9 (4)	29.7 (13)
	Road	11.6 (4)	30.1 (13)
DLR, 2006	Road	13.4 (4)	27.0 (15)
EEA		5-10	
Barbara Locher et al. 2018	Road	10.0 (115) 1.7-17.3	27.8 (76) 16.2~38.0
Scamoni 2014	Reference Road		31.2 (334)
Ryan 2011	Road	10.7 (11) 5.4(vacant)-14.7	
Taiwan EPA 2018	Road	**10.0**	**20.0**

DLR：Deutsches Zentrum für Luft- und Raumfahrt e.V. 。
EEA ：European Environment Agency。
FOEN：Federal Office for the Environment 。

Conclusions and recommendations

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Conclusions

1.Relationship between railway train speed and noise level

(1) General train:

- **Relationship between noise level and rate logarithm is about 35 times (35log(v)), slightly higher than in previous studies (30log(v)).**
- **With increasing general train speed (20 km/h), the noise level of train may increase about 3 dB(A) to 5 dB(A).**

(2) THSR train:

- Relationship between noise level and rate logarithm is about 30 times (30log(v)), which is consistent with previous studies.
- When the speed of THSR decreased to 170 km/h, the maximum noise level of operating trains would met noise control standards set by Taiwan EPA.
- The wheel-rail rolling noise may be the main noise source of THSR trains. It is necessary to propose relevant effective control measures for this noise source..

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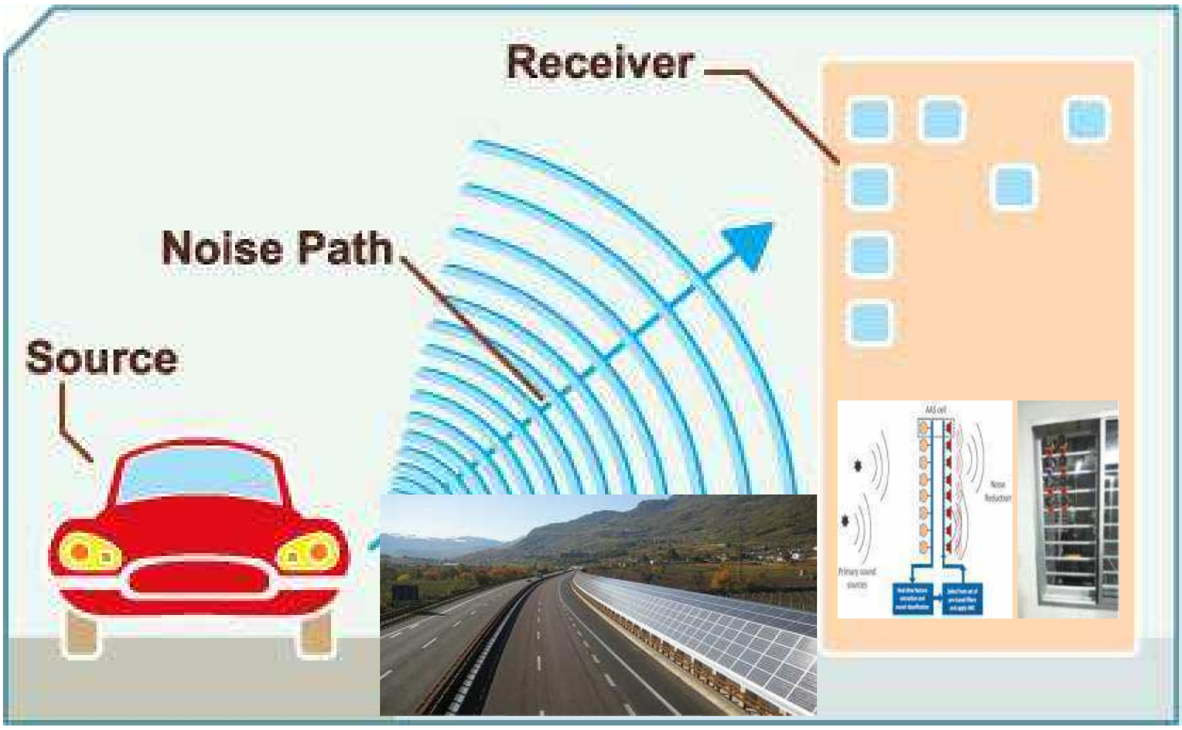
2.Indoor/outdoor noise level difference

- Indoor and outdoor noise level difference with closed door/window is 20 dB(A), while with opened condition is 10 dB(A). These findings were consistent with previous studies.
- The noise level difference with closed condition may affected by path media (frame and glass of window) . However, noise level difference with open condition maybe related to the size of indoor space, sound absorption capacity, and position of opened doors and windows.



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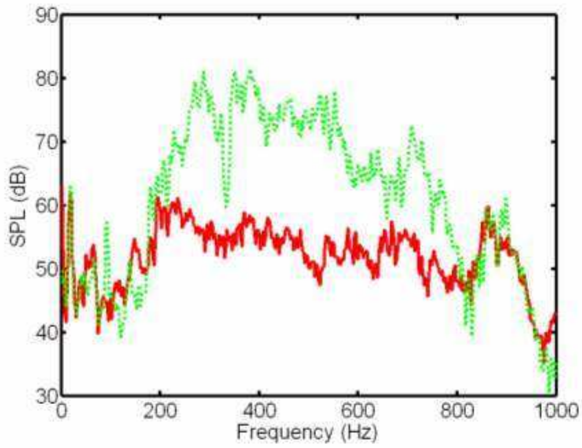
Recommendations

Innovative and sustainable reduction practices

1. Active soundproof window

2. Solar panel sound barriers

Active soundproof window



Natural ventilation ANC windows – plenum type

- Don't need to close windows at home
- Noise reduction is over 10 dB(A)

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Solar panel sound barriers

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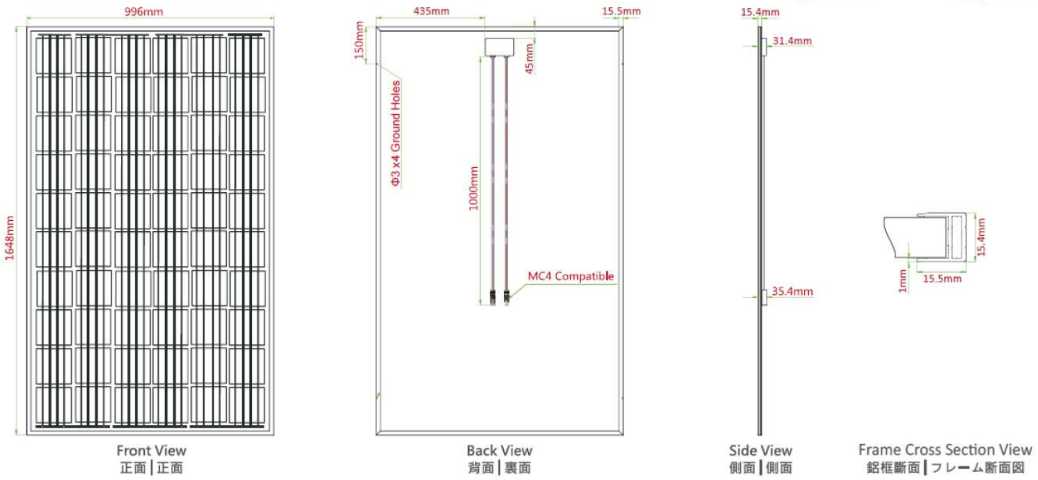
Waveguide Lightweight Solar Module
輕量化太陽能模組｜高耐久・軽量化太陽光パネル

Module Specification (模組規格｜部品と機器仕様)			
Weight (kg)	模組重量	重量	15.5
Back-sheet Color	背材顏色	バックシートの色	White (白)
Frame Color	外框顏色	フレームの色	Silver (銀)



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1 吸音：

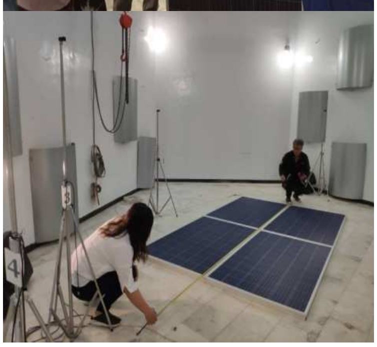
ASTM C423

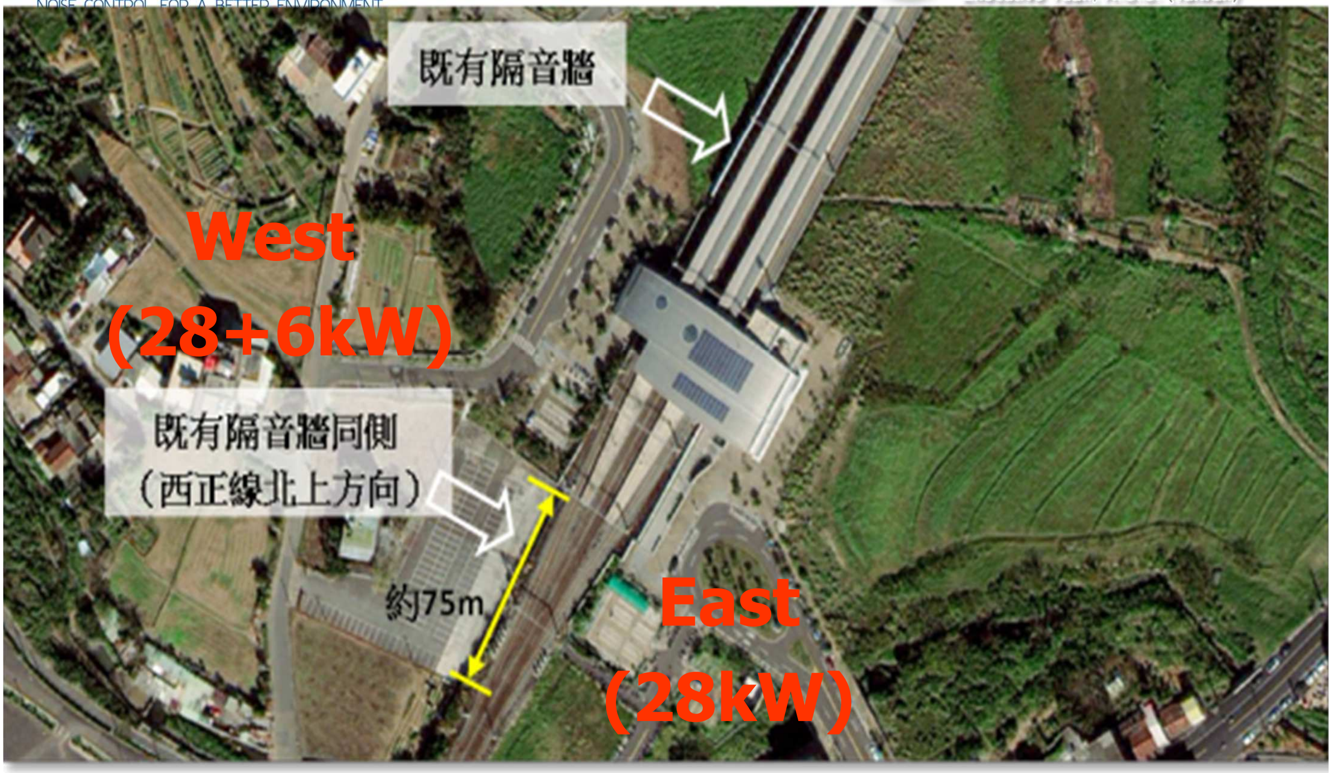
➤Noise Reduction Coefficient ；NRC0.05

2 隔音

ASTM E413

➤**Sound Transmission Class** ；STC 35dB





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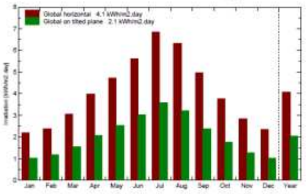
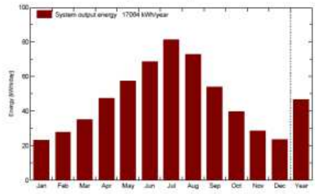
First solar panel sound barriers for general train in Taiwan

West 28kW | East 28kW

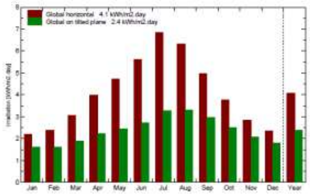
Meteo and incident energy



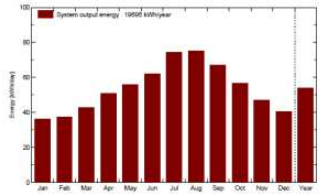
System output



Meteo and incident energy



System output



West 28kW:

	Gl. horiz.	Coll. Plane	System output	System output
	kWh/m2.day	kWh/m2.day	kWh/day	kWh
Jan.	2.20	1.02	23.10	716
Feb.	2.47	1.22	27.76	777
Mar.	3.06	1.54	35.09	1088
Apr.	3.97	2.08	47.34	1420
May	4.72	2.52	57.34	1778
June	5.60	3.01	68.44	2053
July	6.85	3.58	81.37	2522
Aug.	6.31	3.21	72.95	2261
Sep.	4.96	2.38	54.06	1622
Oct.	3.76	1.75	39.84	1235
Nov.	2.83	1.26	28.73	862
Dec.	2.34	1.04	23.53	[illegible]
Year	4.10	2.06	46.75	17064

East 28kW:

	Gl. horiz.	Coll. Plane	System output	System output
	kWh/m2.day	kWh/m2.day	kWh/day	kWh
Jan.	2.20	1.60	36.26	1124
Feb.	2.47	1.65	37.55	1051
Mar.	3.06	1.89	42.97	1332
Apr.	3.97	2.24	50.89	1527
May	4.72	2.46	55.84	1731
June	5.60	2.73	62.05	1861
July	6.85	3.28	74.40	2306
Aug.	6.31	3.31	75.11	2328
Sep.	4.96	2.95	67.06	2012
Oct.	3.76	2.49	56.62	1755
Nov.	2.83	2.07	47.03	1411
Dec.	2.34	1.78	40.51	[illegible]
Year	4.10	2.38	53.96	19695

- 17,064 kWh/year
- 19,695 kWh/year

Double-sided Total 36759 kWh/year

MADRID
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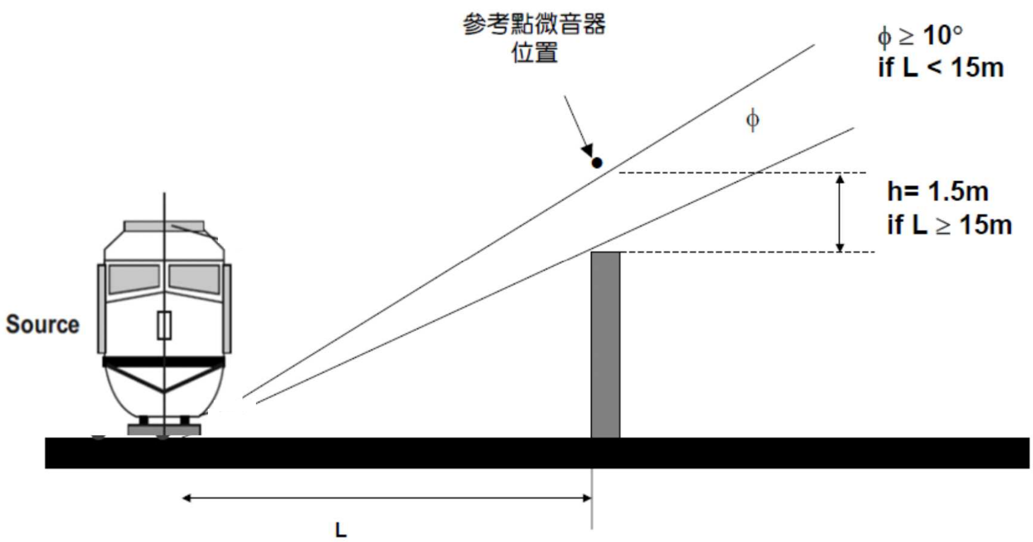
行政院環境保護署
Environmental Protection Administration
Executive Yuan, R.O.C. (Taiwan)

- **ISO 10847 -1997 "Acoustics—In situ determination of insertion loss of outdoor noise barriers of all types"**



Thanks for your attention!

- **Contact : Dr. Pei-Hsiou Ding**
- **E-mail : phding@epa.gov.tw**
- **Taiwan EPA:**
  https://www.epa.gov.tw
  https://ncs.epa.gov.tw/noise

附件三

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CERTIFICATE OF ATTENDANCE

This certificate recognizes that

Mr. PEI-HSIOU DING

has participated in the

48th International Congress and Exhibiton on Noise Control Engineering

Madrid June 16-19, 2019

Organized by the Spanish Acoustical Society –SEA

on behalf of the International Institute of Noise Control Engineering – I-INCE

Antonio Pérez-López
Congress President
SEA President

Antonio Calvo-Manzano
Congress General Secretary
SEA General Secretary

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附件四

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NOISE CONTROL FOR A BETTER ENVIRONMENT

CERTIFICATE OF PRESENTATION

MANUSCRIPT

With this we certify that the work entitled:

Evaluation of transport related noise exposure to residents in Taiwan metropolitan area

It has been presented by:

Dr. PEI-HSIOU DING

Mr. SHENG-ZHONG WU

Mr. JEN-SHOU HSIEH

In the 48th International Congress and Exhibiton on Noise Control Engineering
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Congress General Secretary
SEA General Secretary

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NOISE CONTROL FOR A BETTER ENVIRONMENT

CERTIFICATE OF PRESENTATION

ABSTRACT

With this we certify that the work entitled:

Evaluation of transport related noise exposure to residents in Taiwan metropolitan area

It has been presented by:

Dr. Pei-Hsiou Ding

Mr. Sheng-Zhong Wu

Mr. Jen-Shou Hsieh

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