



室內空氣品質的發展： 過去、現在和未來

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SMOG



Great Smog of London December 5 to 9, 1952

It killed 4,000 people as per
official estimates but 12,000 as
per later research.

<https://factslegend.org/26-interesting-great-smog-facts-know/>



San Gabriel Valley Tribune, 30 Aug., 2017

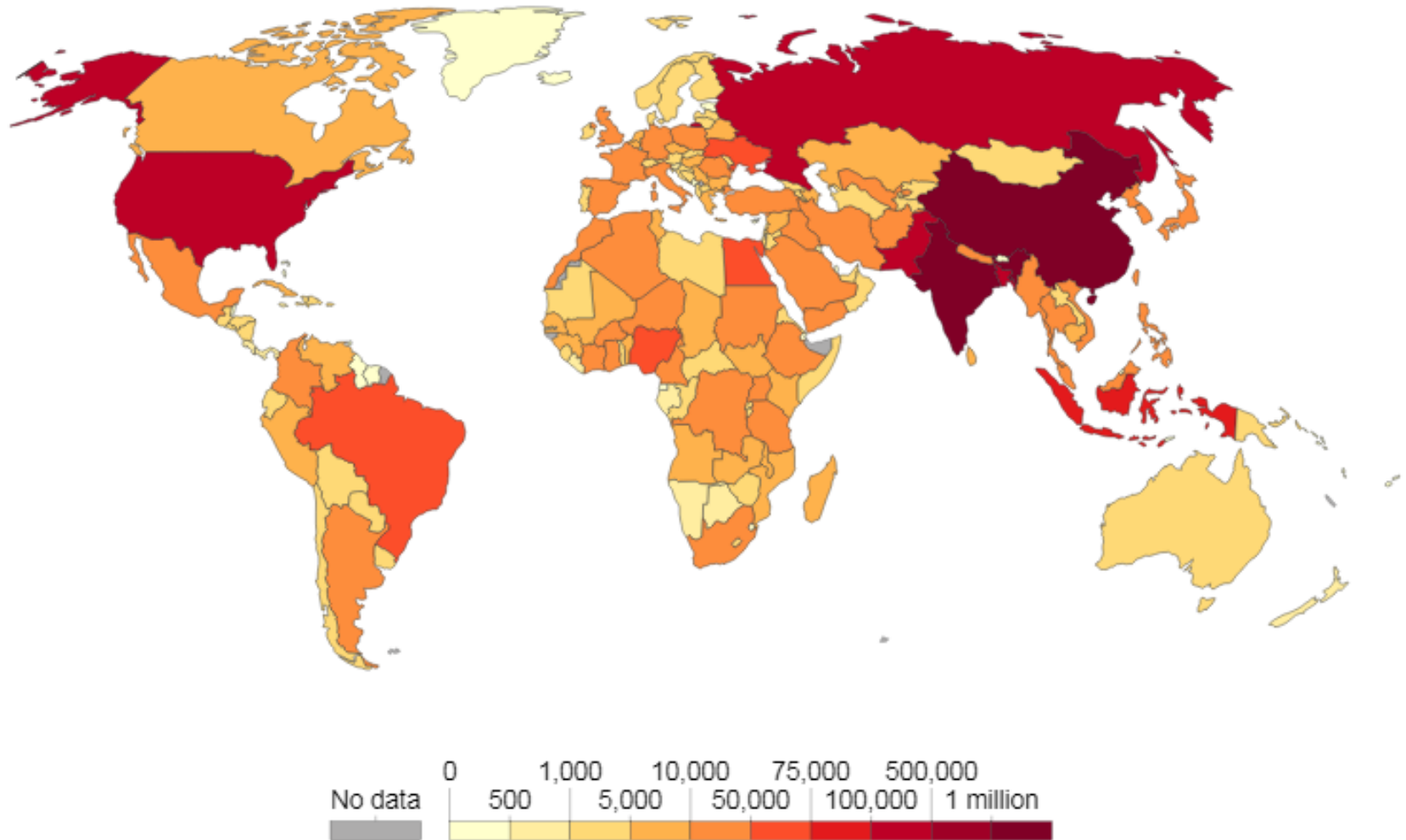
SMOG



MAIL ONLINE, 2 Dec., 2015

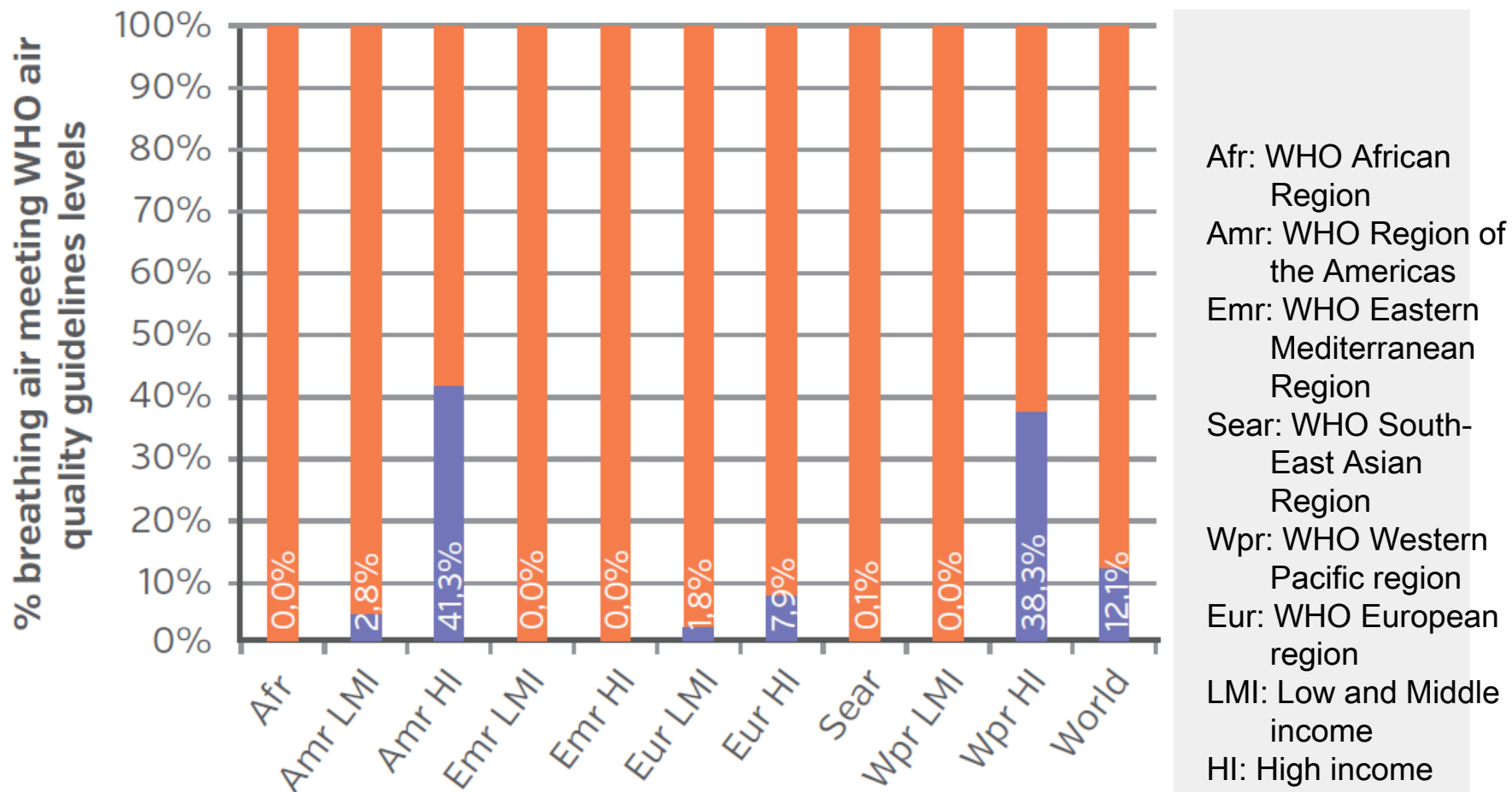
Absolute number of deaths from outdoor air pollution, 2016

Absolute number of deaths by country attributed to ambient (outdoor) air pollution of particulate matter (PM) and ozone (O₃).



Source: Institute of Health Metrics and Evaluation (IHME)

OurWorldInData.org/air-pollution/ • CC BY-SA



ONLY APPROXIMATELY 12% OF POPULATION BREATHES AIR THAT MEETS THE WHO STANDARD

WHO 2015

TOTAL EXPOSURE

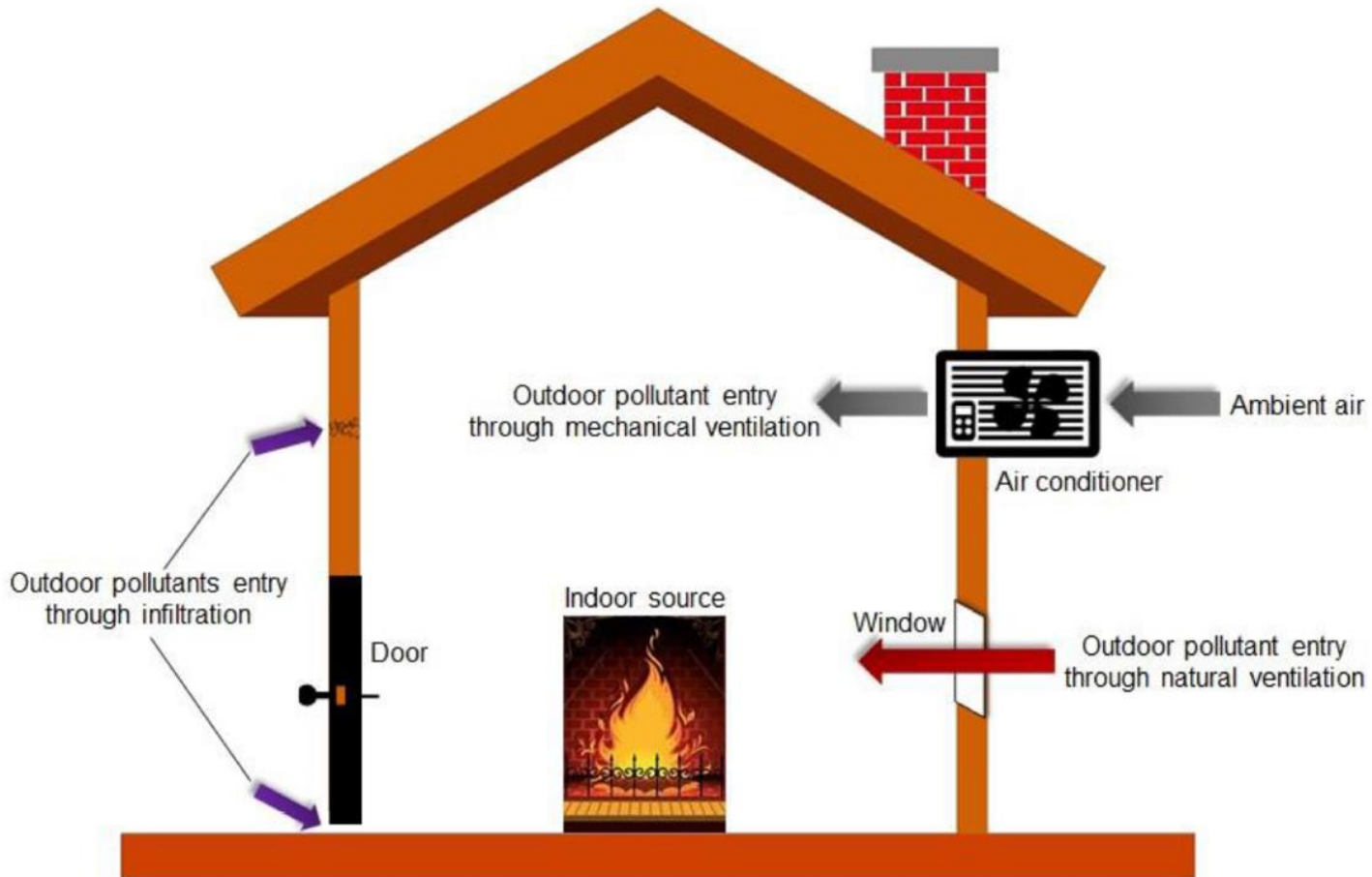
80~90% in
indoor

10~20% in
outdoor



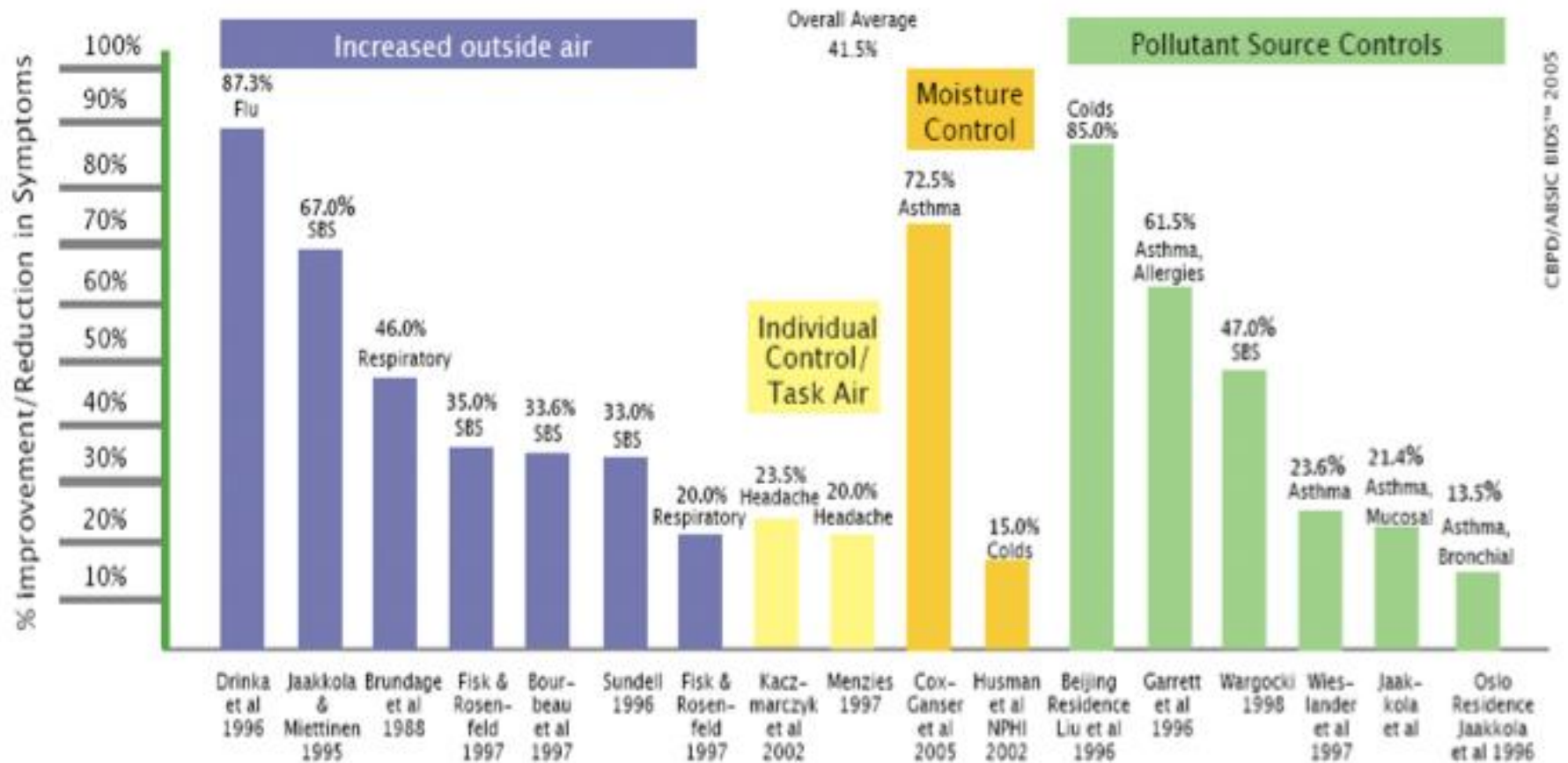
(Klepeis et al., 2001; Leech et al., 2002)

INDOOR AIR AND OUTDOOR AIR



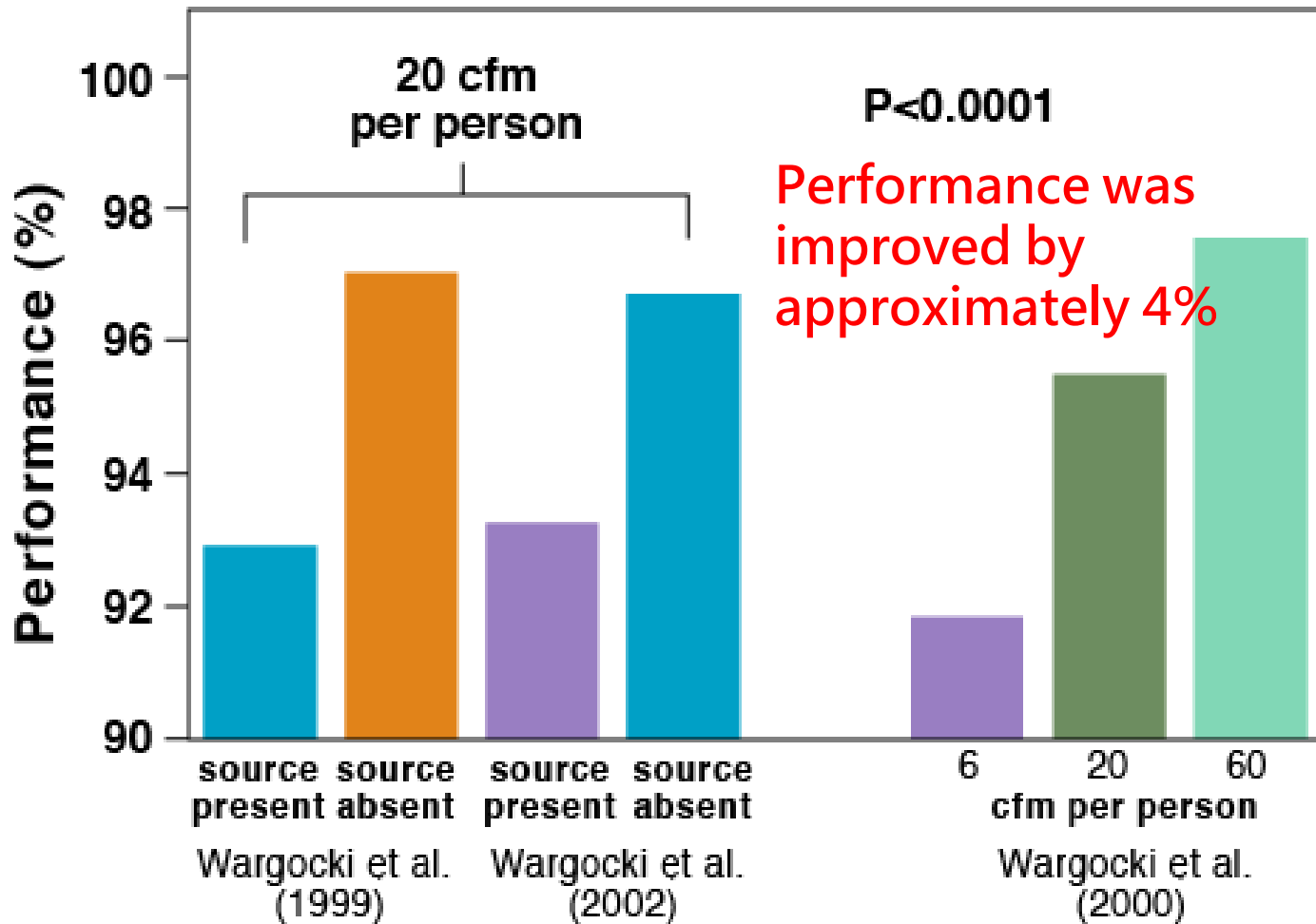
(Leung, 2015)

HEALTH GAINS FROM IMPROVED INDOOR AIR QUALITY (IAQ)



<http://thinkprogress.org/climate/2011/06/16/247259/fox-news-labels-green-buildings-bad-for-your-health-in-fact-the-reverse-is-true/>

IMPROVED PERFORMANCE BY REMOVING INDOOR POLLUTANT SOURCES



ESTIMATED POTENTIAL PRODUCTIVITY GAINS FROM IMPROVED IEQ

Source of Productivity Gain	Potential Annual Health Benefits	Potential U.S. Annual Savings or Productivity Gain (1996 U.S. \$)
Reduced Respiratory Illness	16 Million to 37 Million Avoided Cases of Common Cold or Influenza	\$6 Billion to \$14 Billion
Reduced Allergies And Asthma	8% to 25% Decrease in Symptoms within 53 Million Allergy Sufferers and 16 Million Asthmatics	\$1 Billion to \$4 Billion
Reduced Sick Building Syndrome Symptoms	20% to 50% Reduction in SBS Health Symptoms Experienced Frequently at Work by ~15 Million Workers	\$10 Billion to \$30 Billion
Improved Worker Performance from Changes in Thermal Environment and Lighting	Not Applicable	\$20 Billion to \$160 Billion

(Fisk WJ, 2002)

Past & Present

INDOOR AIR QUALITY HISTORY

1950s

- Rapid growth in “aerosol” air fresheners propelled by chlorofluorocarbons (CFCs)
- Over one million window air conditioners sold in the U.S...

1960s

- 90% of U.S. homes have TV sets
- Air clean act...

1970s

- U.S. EPA created
- Water-based (latex) paint displaces solvent-based (oil) paint for indoor
- Andersen, Lundqvist & Molhave publish article on **formaldehyde** in Danish homes
- Almost 25% of U.S. households have central air conditioning...

1980s

- National Research Council (NRC) issues **report** on “Indoor Pollutants”
- **ASHRAE ventilation guidelines** distinguish between smoking and nonsmoking spaces
- U.S. EPA restricts indoor use of pentachlorophenol (PCP)
- U.S. EPA “TEAM Study” finds **high exposures** to indoor air pollutants...

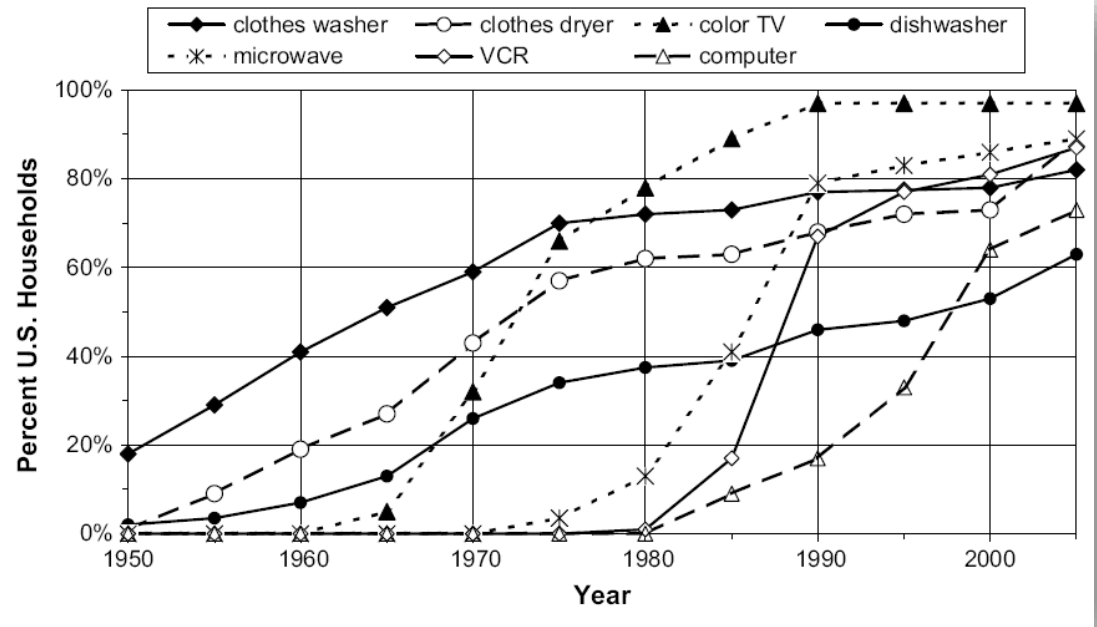
1990s

- U.S. EPA bans mercury in all interior paints
- Almost 50% of U.S. households have **central air conditioning**
- EPA issues rule limiting **VOC emissions** from consumer products and architectural coatings...

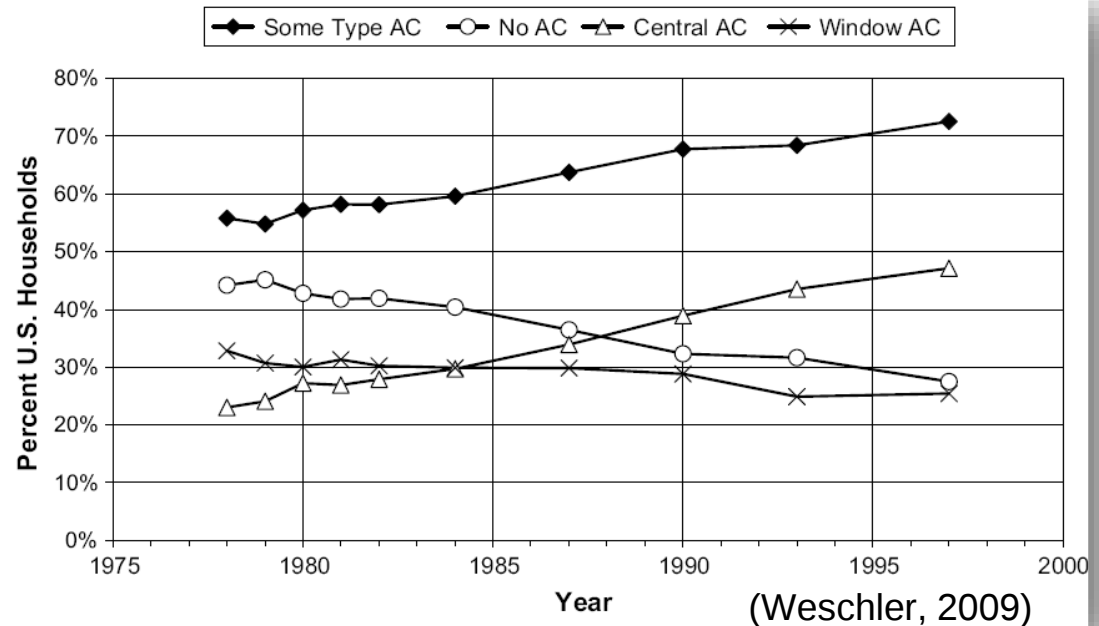
2000s

- More than 50% of U.S. homes have personal computers
- CDC publishes first National Report on **Human Exposure to Environmental Chemicals...**

HOUSEHOLD ELECTRONICS USAGE (1950-2005)

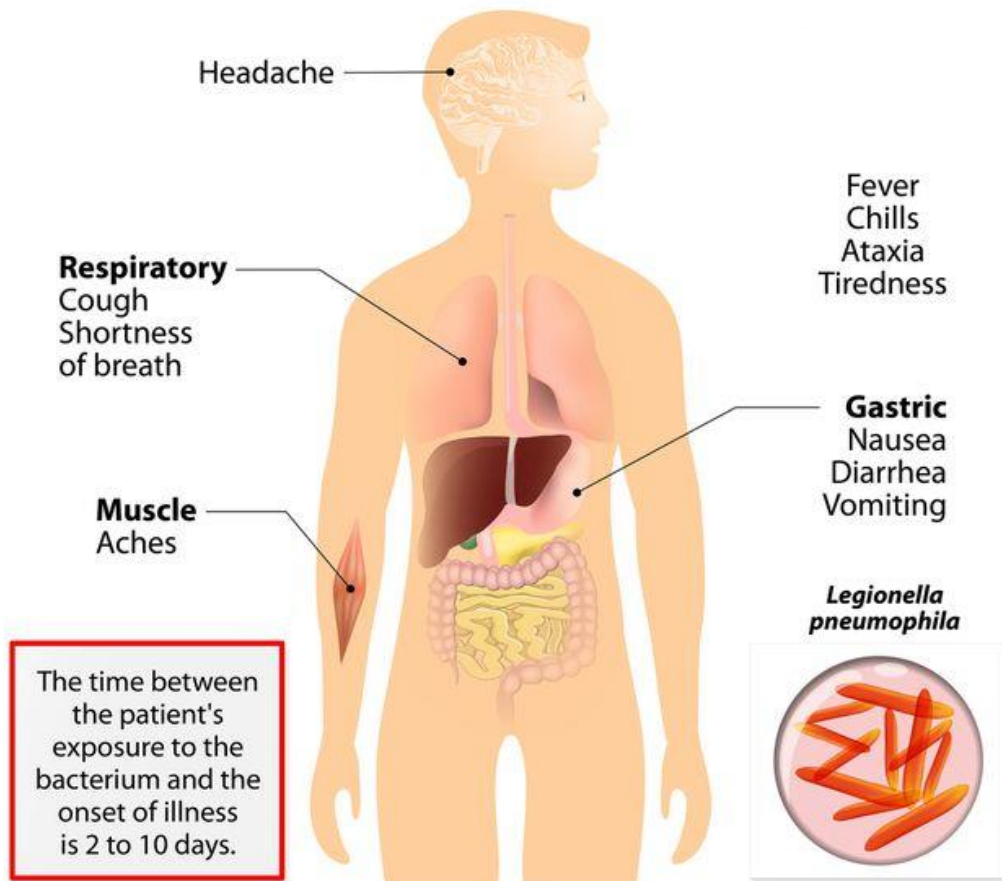


HOUSEHOLD AIR CONDITIONER USAGE



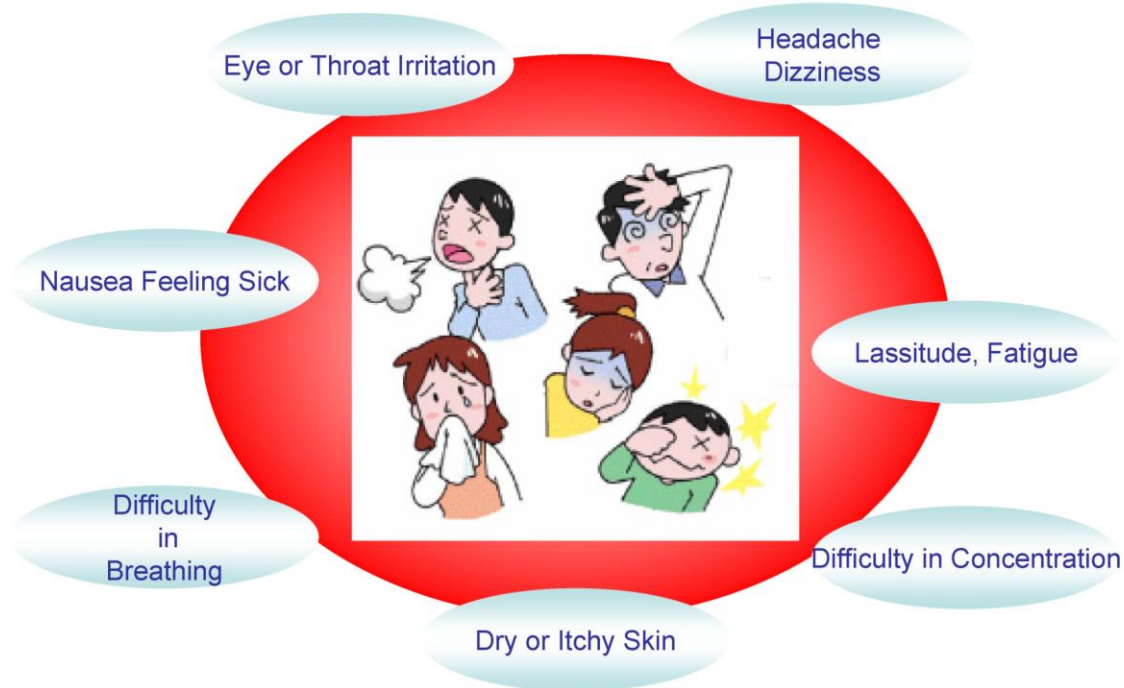
Legionnaires' disease (退伍軍人症)

1976~



SICK BUILDING SYNDROME (病態大樓症候群)

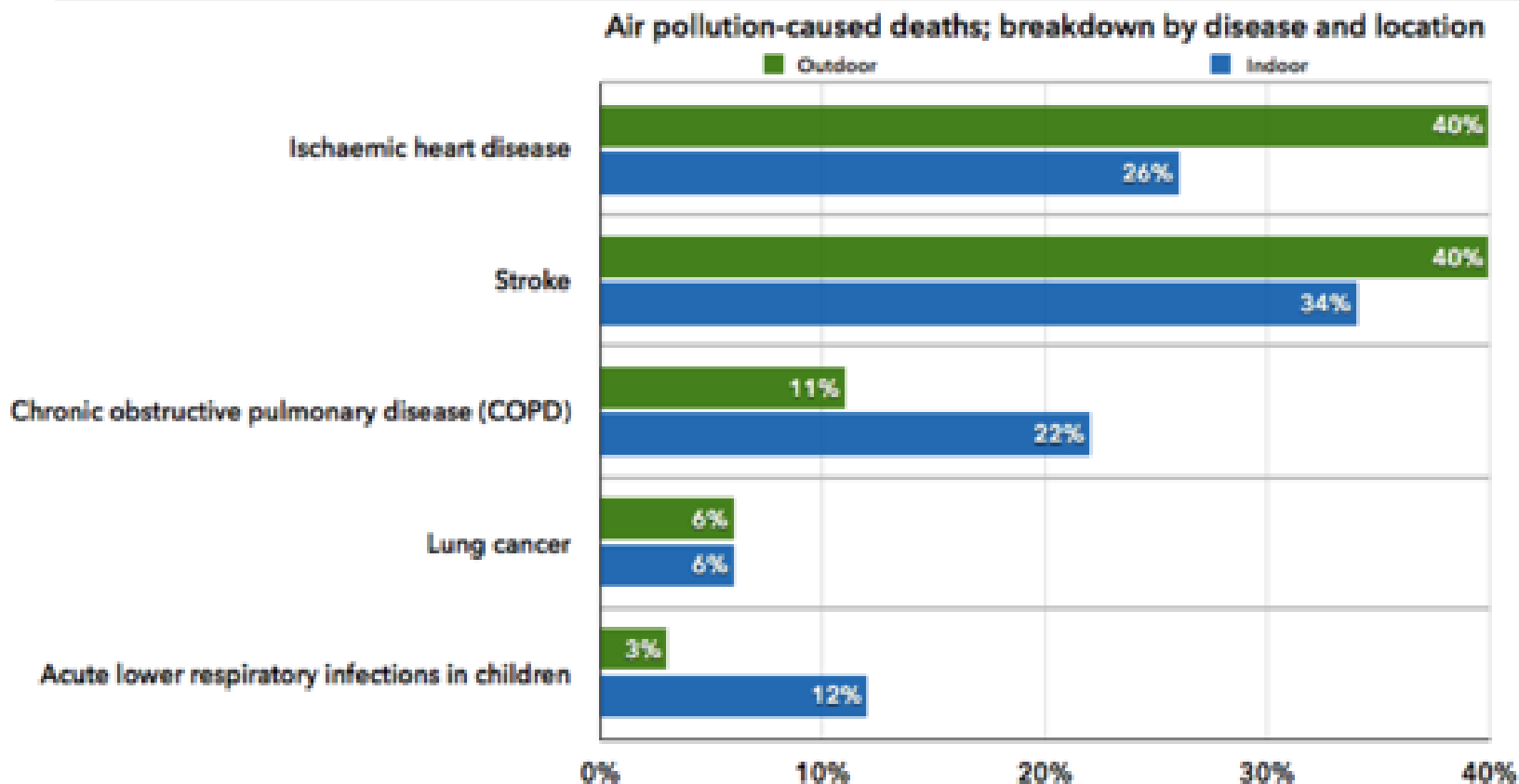
1984~



<https://www.pinterest.ie/pin/192388215306897255/>

Health effect of indoor air pollutants exposure

不佳的室內空氣品質會增加室內人員的病態大樓症候群症狀風險，並造成每年約**10億美元**的損失 (Fisk et al., 2011; Fisk and Rosenfeld, 1997)。



WHO, 2014

1981-1990

1991-2000

2001-2010

after 2011

KOREA**1986** Indoor Air Hygiene Standards**1992** Ventilation Standard for Buildings
1996 Air Quality Guideline in Underground Public Places**2003** Indoor Air Quality Control in Public Use Facilities Act**2014** Public Transportation Indoor Air Quality Control Guideline**HONG KONG****1995** Office and Public Place IAQ Research
1998 Found Indoor Air Quality Management Team
1999 Implement IAQ plan
2000 Promote Indoor Air Quality**2001** Found Indoor Air Quality Information center
2003 Establish Indoor Air Quality Management Guideline
2006 Review the IAQ Management Guideline**2011** Updated the IAQ Management Guideline
2012 Supplementary Notes for Renewal Cases**TAIWAN****1998~** Indoor Air Quality Survey**2005** Indoor Air Quality Guideline in Public Places**2011** Indoor Air Quality Management Act
2012 Establish IAQ Act Enforcement Rules, IAQ Standard, IAQ manager in Public Places and IAQ Measurement Rules
2014 Announcement of the First Public Places List**IAQ POLICY
PROGRESS**

SOCIETY

Taiwan readies for indoor air quality law

Publication Date: November 2, 2012 Source: Taiwan Today



**Indoor Air Quality
Management Act
室內空氣品質管理法
November 23, 2012**



The EPA will help public facilities such as high-speed rail stations meet the standards of the Indoor Air Quality Management Act. (CNA)

Taiwan's Indoor Air Quality Management Act is set to take effect Nov. 23, only the second such law in the world after South Korea's, according to the ROC Environmental Protection Administration.

"We have finalized quality standards and measurement procedures for suspended particulates, carbon dioxide, carbon monoxide, ozone, volatile organic compounds, formaldehyde, fungal flora and bacteria," EPA Minister Stephen Shu-hung Shen said Nov. 1.

Certification of qualified inspectors is ongoing, to upgrade the monitoring of indoor air quality, he added.

In the first stage of the law's implementation, the EPA will provide assistance in meeting the standards to large-scale kindergartens; hospitals; train, high-speed rail and mass rapid transit stations;

hypermarkets; and department stores, the agency said.

In earlier public hearings on the regulations, owners and managers called for an extended grace period, Shen noted. They said extra ventilation and electricity would be needed to maintain indoor air quality, running counter to efforts to reduce carbon emissions, while the medical sector explained that it would be a challenge to meet the standards because CO2 and bacteria are brought into hospitals by the public. In addition, monitoring institutions were not yet up to the job, the operators claimed.

The initial stage is scheduled to last six months to one year, according to the EPA. "This gradual approach to applying the law, with guidance from our agency, is expected to help reduce the burden on public and private venues," Shen said. (THN)

RELATED POLICY AROUND THE WORLD

Country	Responsible authority			IAQ Related Practices					Books or Publications					
	Single Unit	Cooperation	Special Team	Standard	Guideline	Ventilation or Fugitive Guideline	New Building or Vehicle	Else	Household	School	Office	Public Places	Chemical material or Bioaerosols	Else
WHO	☐		☐		☐				☐				☐	☐
US		☐	☐		☐	☐				☐	☐			☐
Canada		☐			☐	☐			☐		☐			
EU	☐		☐											
Germany		☐	☐		☐	☐		☐	☐	☐			☐	☐
Finland		☐			☐	☐		☐	☐					
Australia		☐	☐			☐			☐					
Korea		☐		☐		☐	☐	☐						
Japan		☐	☐		☐	☐		☐	☐	☐				
China		☐			☐	☐	☐	☐						
Hong Kong		☐	☐		☐		☐	☐	☐		☐	☐	☐	☐
Macao		☐			☐					☐	☐	☐		
Singapore	☐		☐		☐	☐					☐			
Taiwan	☐			☐		☐		☐						☐

NOTE: "Else" are indoor environment of noise, lighting, drainage and special labels or certification, etc.

IAQ MANAGEMENT ACT IN TAIWAN

1. 室內空氣品質管理法 (101.11.23.訂定)
2. 室內空氣品質管理法施行細則 (101.11.23.訂定)
3. 室內空氣品質標準 (101.11.23.訂定)
4. 室內空氣品質維護管理專責人員設置管理辦法 (105.08.11.訂定)
5. 室內空氣品質檢驗測定管理辦法 (101.11.23.訂定)
6. 違反室內空氣品質管理法罰鍰額度裁罰準則 (101.11.23.訂定)
7. 應符合室內空氣品質管理法之第一批公告場所 (103.01.23.訂定)
8. 應符合室內空氣品質管理法之第二批公告場所 (106.01.11.訂定)

IAQ MANAGEMENT ACT IN TAIWAN

📍 法規內容

法規名稱：應符合室內空氣品質管理法之第一批公告場所 ← 115家

公發布日：民國 103 年 01 月 23 日

修正日期：民國 103 年 01 月 23 日

發文字號：環署空字第1030006258號

法規體系：室內空氣管理

立法理由：[立法理由.pdf](#)

📍 法規內容

法規名稱：應符合室內空氣品質管理法之第二批公告場所 ← 940家

公發布日：民國 106 年 01 月 11 日

修正日期：民國 106 年 01 月 11 日

發文字號：環署空字第1060001644號 公告

法規體系：室內空氣管理

圖表附件：[行政院公報電子檔.pdf](#)
[公告-附表.doc](#)
[公告-附表.odt](#)

IAQ MANAGEMENT ACT IN TAIWAN

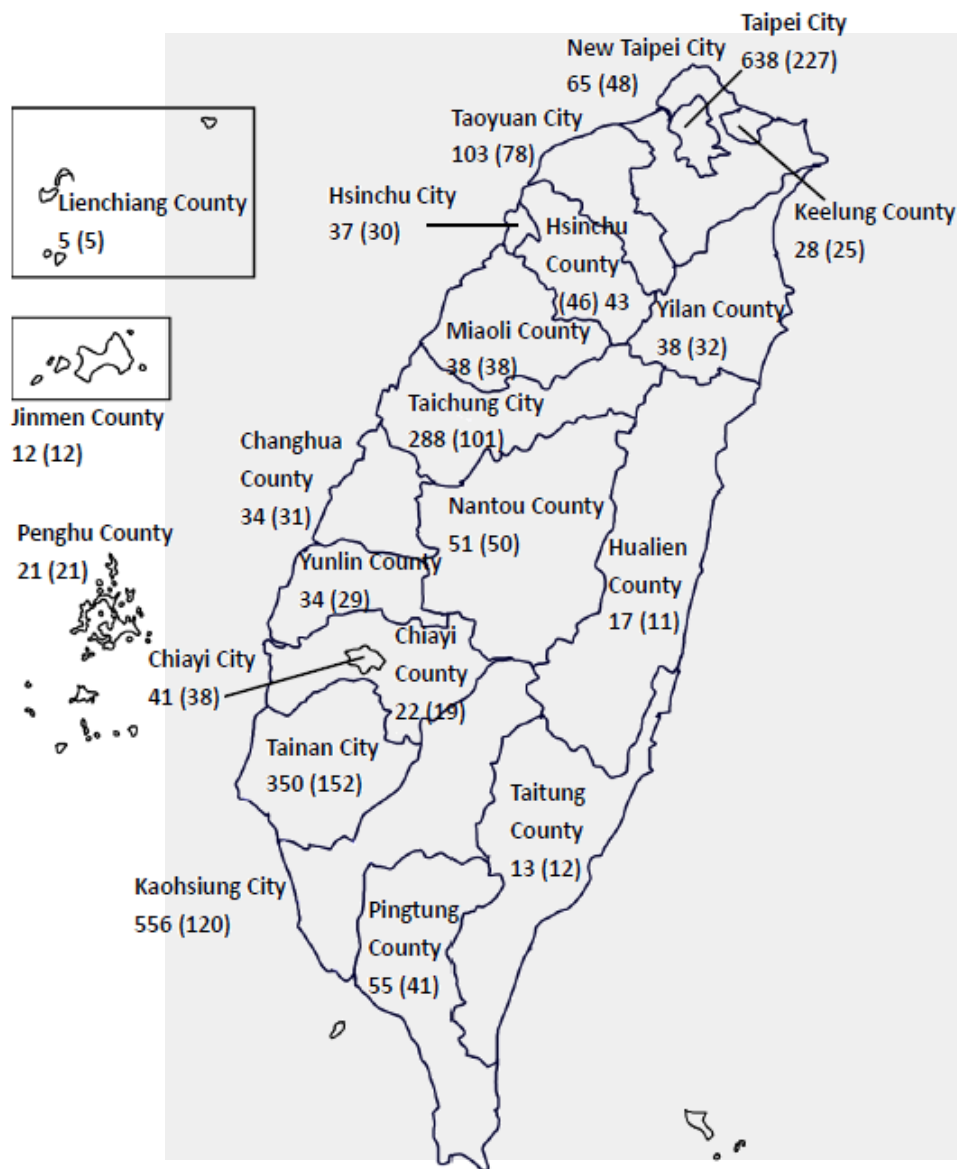
Index	Period	Level
CO (ppm)	8-h average	9
CO ₂ (ppm)	8-h average	1000
O ₃ (ppm)	8-h average	0.06
TVOC (ppm)	1-h average	0.58
HCHO (ppm)	1-h average	0.08
PM ₁₀ (μg/m ³)	24-h average	75
PM _{2.5} (μg/m ³)	24-h average	35
Fungi (CFU/m ³)	Peak value	1000 or I/O ratio less 1.30
Bacteria (CFU/m ³)	Peak value	1500

I/O ratio: Indoor and Outdoor ratio. TVOC (total volatile organic compound).

AIR POLLUTANTS AND SOURCES IN INDOOR

Category	Pollutant	Source
Gas	CO	Secondary hand smoke, cooking, incense, outdoor air
	CO ₂	
	HCHO	Secondary hand smoke, building material, cooking, incense, detergent, paint, photocopier, insecticide
	TVOC	
	O ₃	Photocopier, outdoor air
Particle	PM _{2.5} , PM ₁₀	Secondary hand smoke, cooking, incense, photocopier, outdoor air
	Bacteria, Fungi	Carpet, building material, humidifier, pet

Sampling Sites (Buildings)



- From 1998 to 2015
- 2,512 sampling sites in public buildings
 - Schools
 - social education places
 - office space
 - health facilities
 - public consumption places
 - transit station
 - Exhibition
 - public leisure venues
 - sports or fitness centers

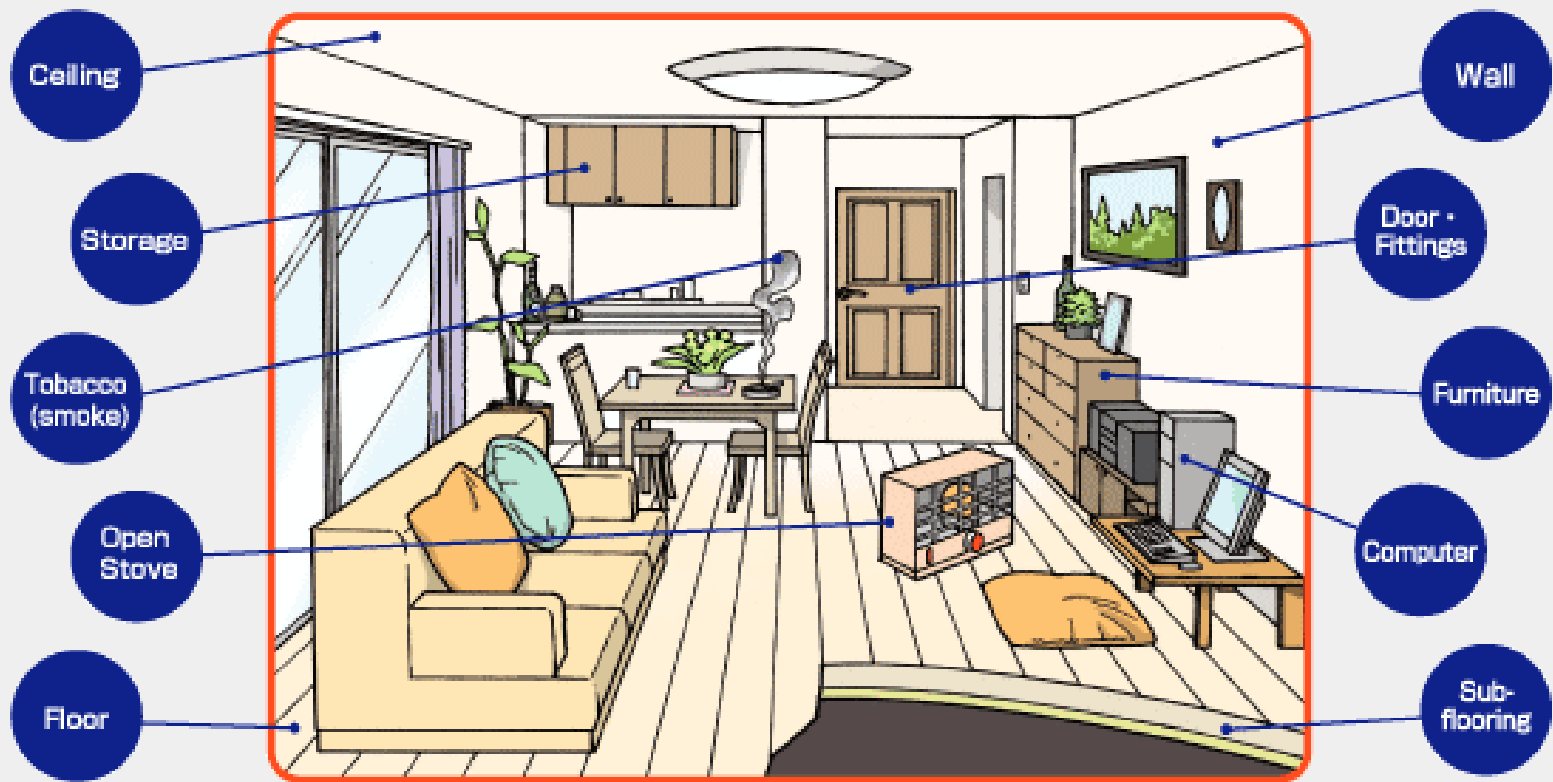
TAIWAN IAQ INVESTIGATION

ATTAINMENT RATE OF INDOOR AIR POLLUTANTS

項目(合格率)	CO ₂	CO	O ₃	TVOC	HCHO	PM _{2.5}	PM ₁₀	Bacteria	Fungi
2012/11/23以前	89%	99%	92%	-	100%	78%	89%	66%	49%
2012/11/23以後	89%	100%	99%	98%	89%	94%	97%	94%	89%
立法前後之 合格率變化	-	1%	7%	-	-11%	16%	8%	28%	40%

標準濃度：CO：9 ppm；CO₂：1000 ppm；O₃：0.60 ppm；TVOC：0.56 ppm；HCHO：0.08 ppm；PM_{2.5}：35 µg/m₃；PM₁₀：75 µg/m₃；細菌：1500 CFU/m³；真菌：1000 CFU/m³。

FORMALDEHYDE (甲醛)



<http://www.home-air-purifier-expert.com/formaldehyde.html>

GREEN BUILDING MATERIALS

(綠建材)

- 生態綠建材：主要是著重在原料取得和製造階段。
- 低逸散健康建材：擁有低逸散、低汙染、低生理危害等特性的建材。
- 高性能綠建材：耐久性佳的建材。
- 再生綠建材：能循環再利用，使廢棄物減量之建材。
- $\text{HCHO} < 0.05 \text{ mg/hr} \cdot \text{m}^2$
- $\text{TVOC} < 0.19 \text{ mg/hr} \cdot \text{m}^2$



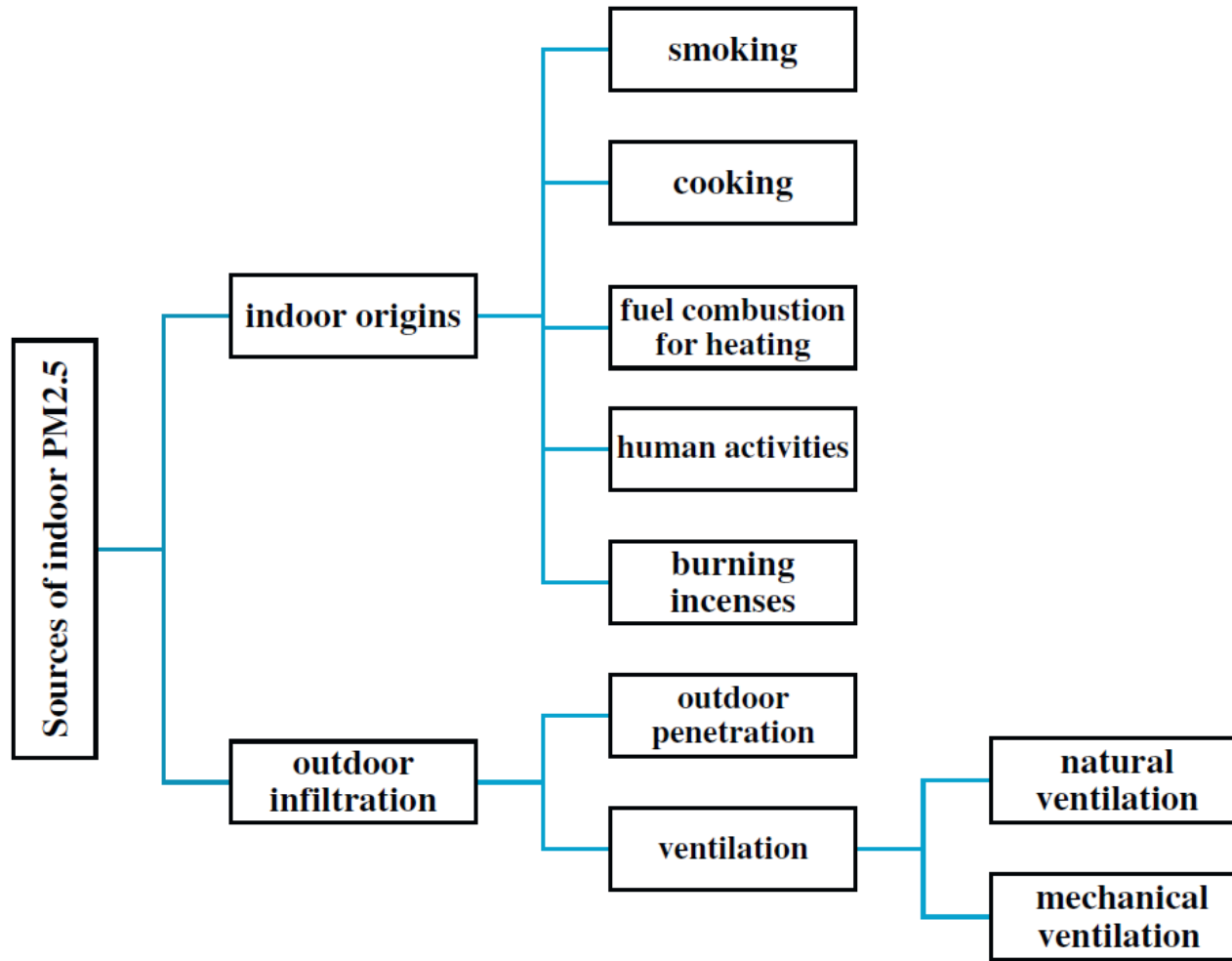
GREEN BUILDING MATERIALS

(綠建材)

國際綠建材標章認證比較（*針對建材認證標章）

	德國		芬蘭	北歐	歐盟	
標章	藍天使標章	GuT 標章*	建材逸散分級標章*	天鵝標章	EU-flower 標章	
	美國		加拿大	日本		中國
標章	GREEN SEAL 標章	綠色防護標章*	EcoLogo 標章	Eco-Mark 標章	住宅性能評價標章	中國環境標誌

PM_{2.5}



Li et al., 2017

PM_{2.5}



PM_{2.5}

□成人在室內的呼吸量平均為0.36 m³/hr * 24 hr/day * 365 day/yr * 室內懸浮微粒PM_{2.5}濃度標準 35 μg/m³ * 10⁻⁶ g/μg ÷ 懸浮微粒密度 (以空氣密度計) 0.001205 g/cm³ = 65 cc 的灰塵

□意思是：在剛好符合標準的室內環境中，您等於得把**一瓶雞精容積 (65 cc)** 的灰塵從**鼻子**吸進去!



AIR CLEANER

□**UV+光催化**：光觸媒是利用光線能量作為空氣淨化機制的原動力。光線照射激發二氧化鈦（ TiO_2 ）表層的電子（ e^- ）脫離，留下電洞（positive holes h^+ ），電洞吸引水中的氫氧離子，變成極不穩定的氫氧根（Hydroxyl Radicals）。為轉變成穩定狀況，氫氧根會與有機化合物反應變成無害之 CO_2 、 H_2O 釋放至空氣中。

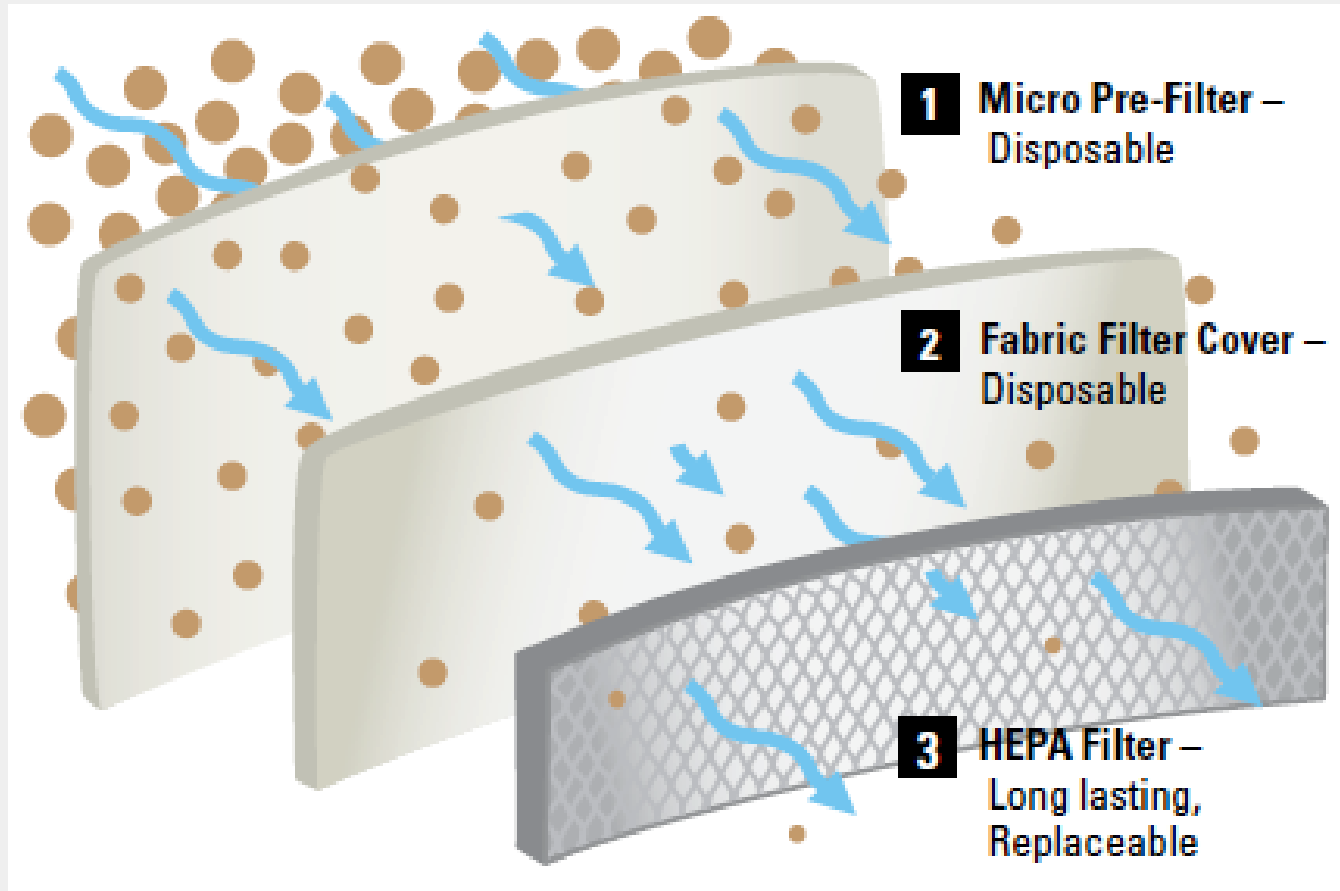
□**臭氧產生機**：臭氧有極強的氧化性，當遇到細菌、臭味或有機物時能產生氧化反應，達到清淨空氣之效果。

□**奈米銀**：將奈米銀粒子鍍於空調系統濾網材質表面，當奈米銀與細菌體接觸時，奈米銀粒子可造成細菌無法代謝而衰竭死亡。

AIR CLEANER

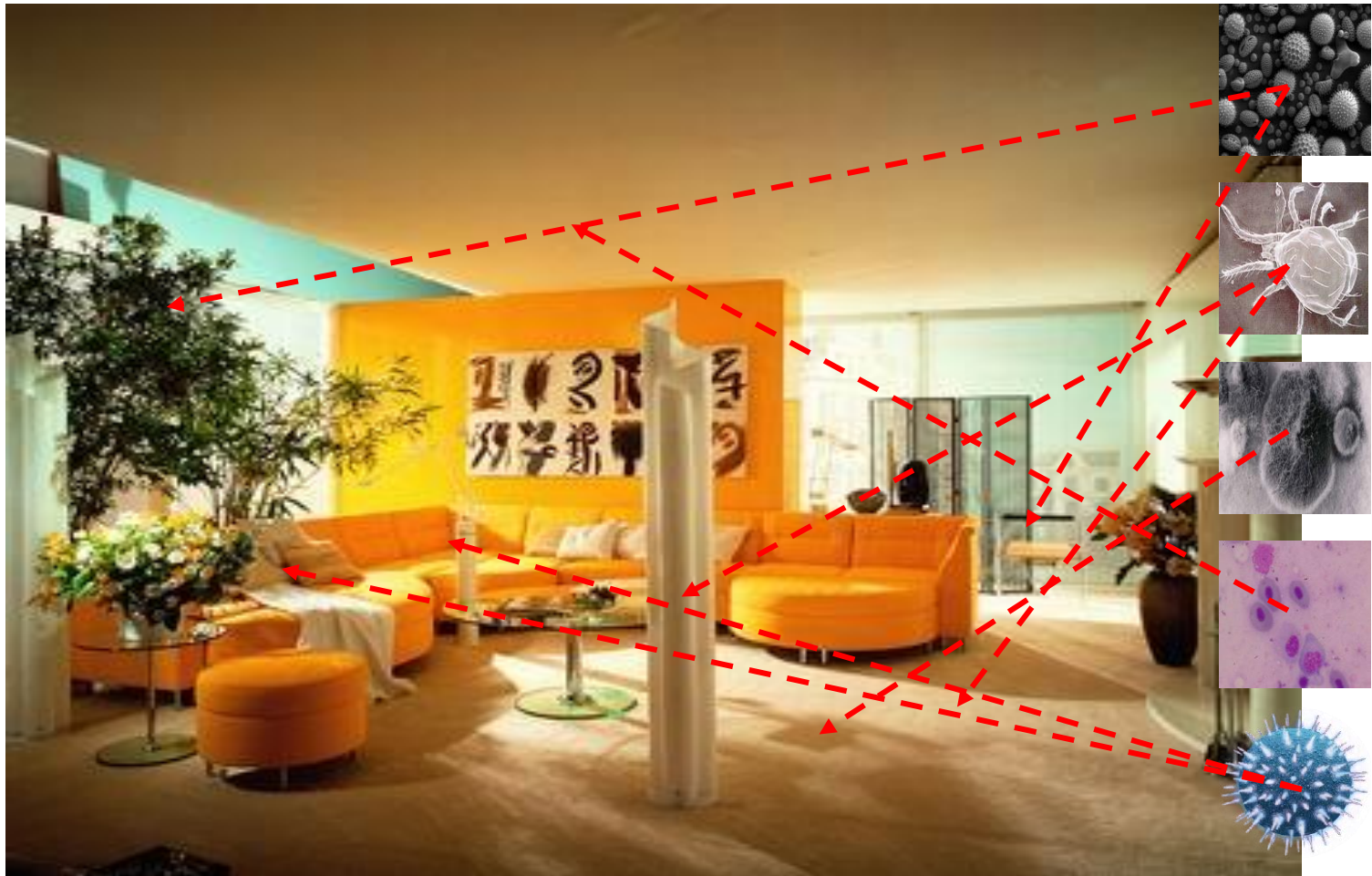
- **機械式過濾集塵**：利用各種濾材以達過濾微粒的目的。
- **靜電集塵**：如靜電集塵器及靜電式濾網捕集帶電的微粒
- **離子產生器**：釋放離子於環境中，當其與微粒結合後，該帶電的微粒隨即會被一些表面如地板、牆壁、窗簾等所吸附。
- **吸附**：利用各種吸附濾材以達吸附揮發性有機物(VOCs)之目的。目前活性碳纖維（Activated Carbon Fibers, ACF）由於體積小且置換容易，因此常被使用做空氣清淨機吸附濾材。

HIGH-EFFICIENCY PARTICULATE AIR (HEPA)



<http://drywallzone.com/hepa-certified.html>

SOURCE OF FUNGI



SOURCE OF FUNGI

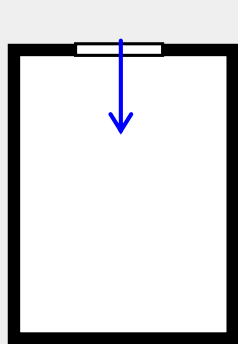




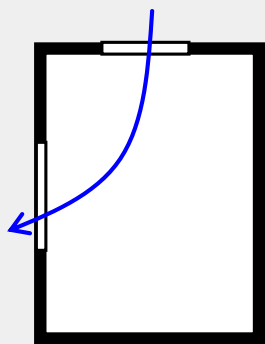
請保持通風乾燥...



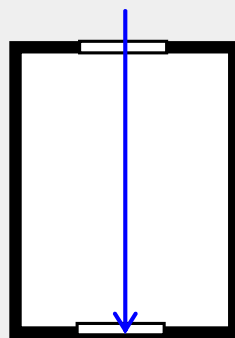
VENTILATION



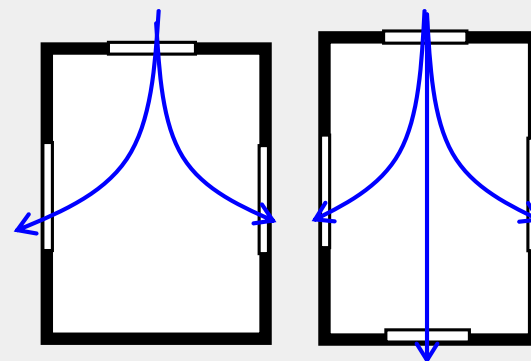
(a) 單側通風



(b) 相鄰側通風



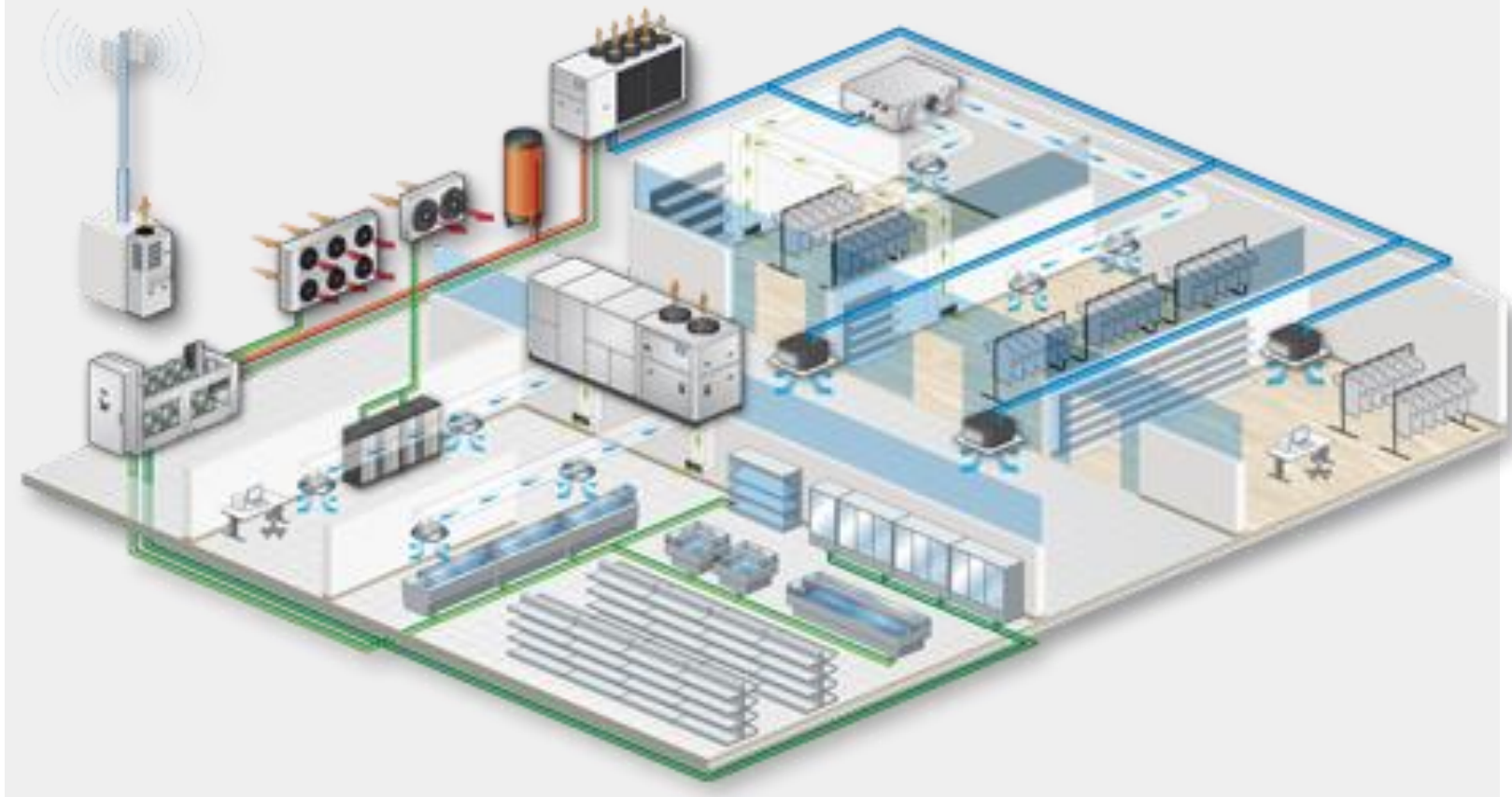
(c) 相對側通風



(d) 多側通風路

不同類型之通風路徑 (內政部建築研究所.2007)

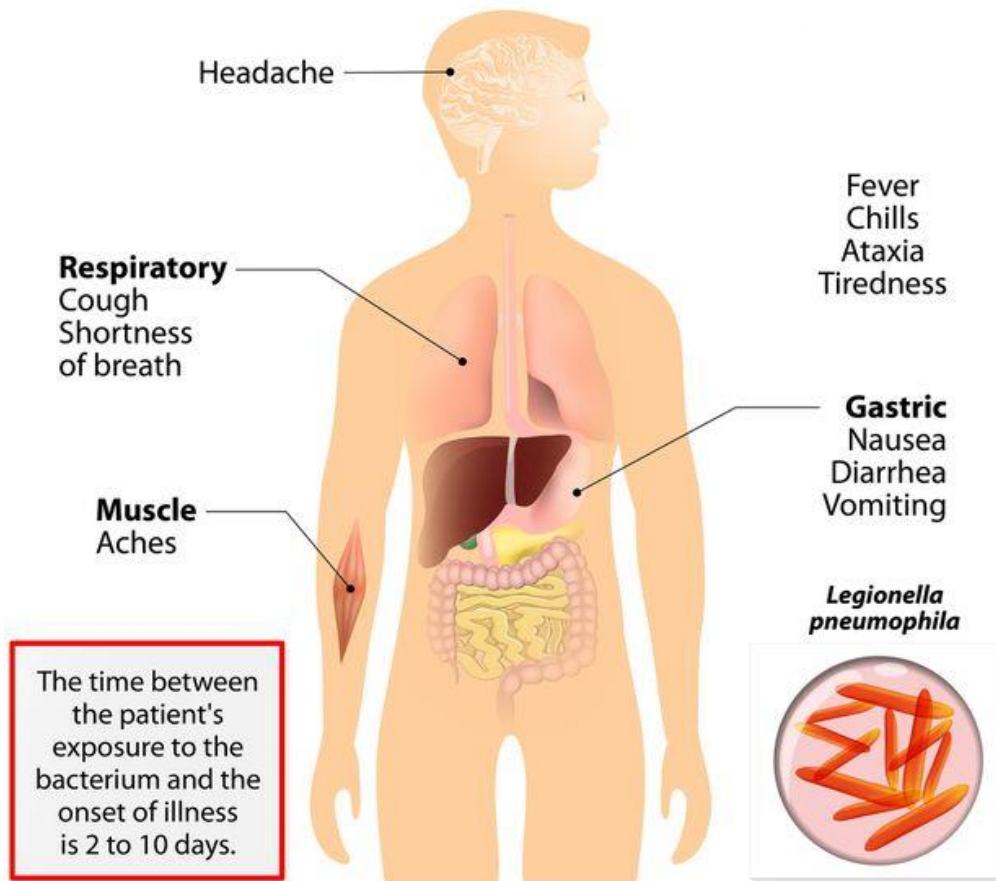
VENTILATION



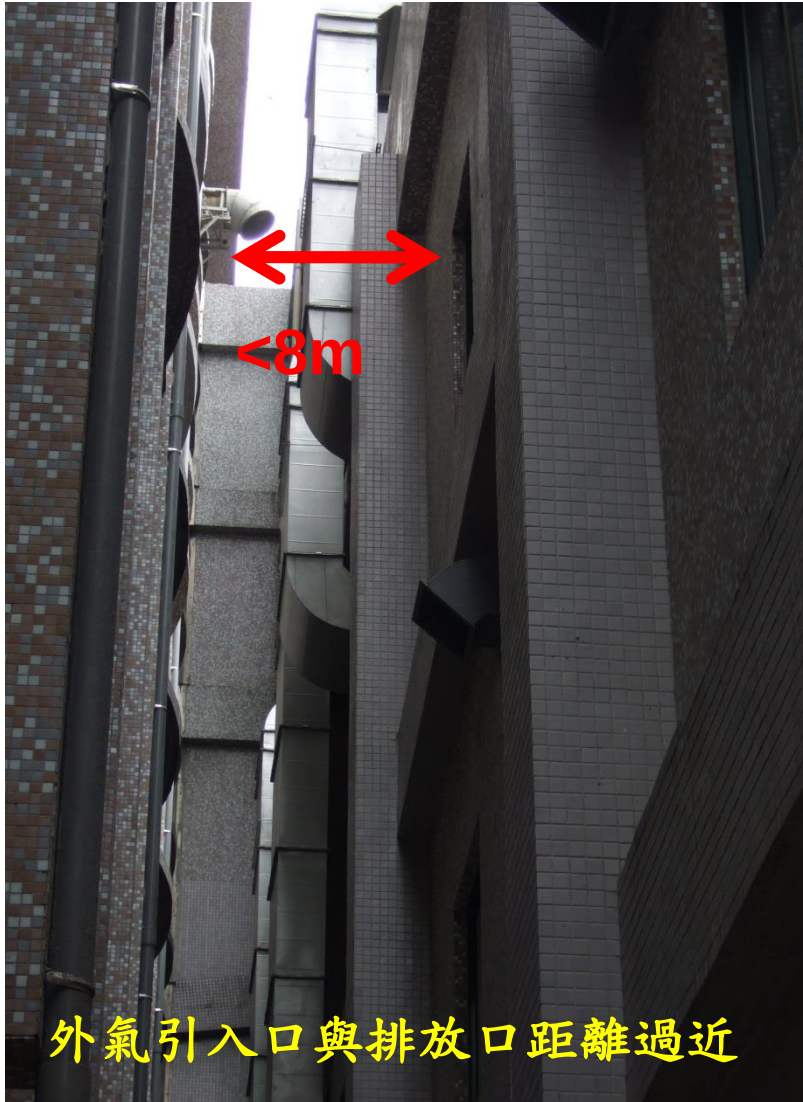
<http://gallettigroup.com/en/solutions-and-systems/service-sector/shopping-malls>

Legionnaires' disease (退伍軍人症)

1976~



VENTILATION



VENTILATION



交通廢氣



加油站



廟宇



建築工地

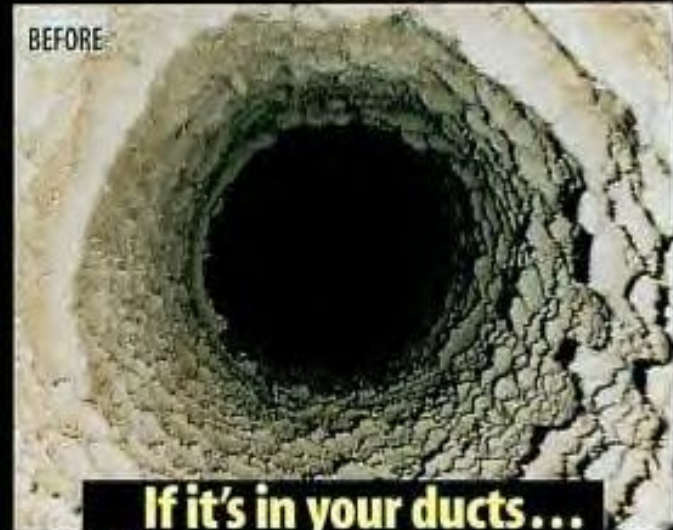
VENTILATION



clogged air ducts can be a health hazard...



a clean air duct will keep your family healthy...



**If it's in your ducts...
It's in your lungs!**

AFTER



Have your air ducts ever been cleaned?

VENTILATION

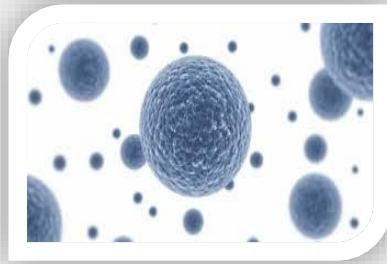
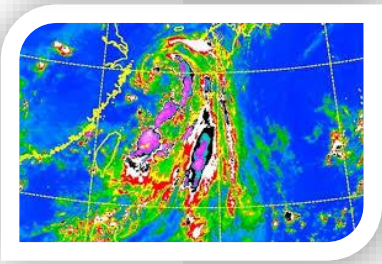
Table 5. Predictive model for the contribution levels of indoor- and outdoor-generated PM_{2.5} and PM_{2.5-10} to indoor air.

Fixed effect*	Parameter estimate (β)	Standard error (σ)	Proportion of explained (%)	Fixed effect*	Parameter estimate (β)	Standard error (σ)	Proportion of explained (%)
Indoor-PM_{2.5}				Indoor-PM_{2.5-10}			
Intercept	1.40	0.26	42	Intercept	2.30	0.30	11
Obstacle in air outlet	2.82	0.55		Lack of a return air pathway	2.64	1.15	
Lack of a return air pathway	2.15	0.89					
Outdoor-PM_{2.5}				Outdoor-PM_{2.5-10}			
Intercept	10.57	1.28	17	Intercept	6.85	2.22	17
Close to the restaurant emission	4.92	1.65		Outdoor CO level (ppm)	1.42	0.67	
				Lack of a return air pathway	5.46	2.16	

* The effect was selected into the final model when the $p < 0.05$ by a step-wise regression model.

(Jung et al., 2018)

FUTURE CHALLENGES



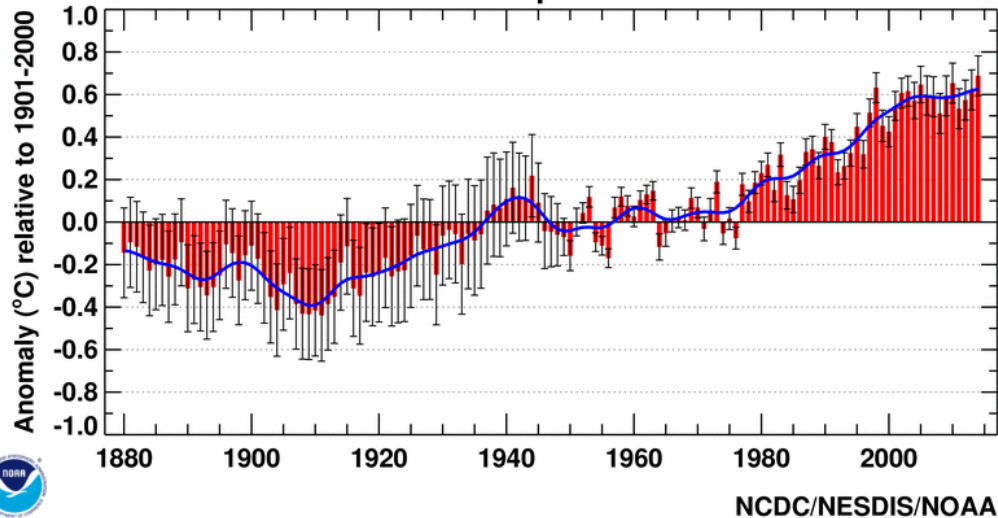
- CLIMATE CHANGE
- CHEMICAL CONTAMINATION
- BIOAEROSOL
- CIRCULAR ECONOMY

TEMPERATURE CHANGING

Temperature changing over the past century

Global

Jan-Dec Global Mean Temperature over Land & Ocean

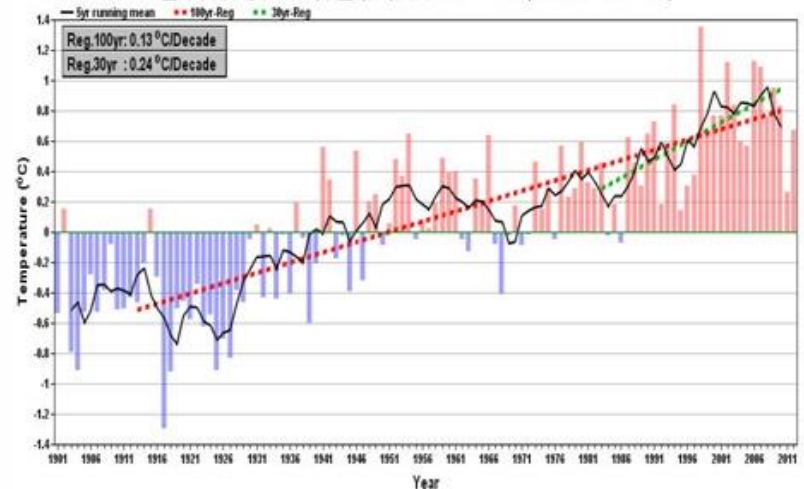


+0.7°C

Relative to 1901-2000

Taiwan

臺灣13個平地站 年平均氣溫時間序列圖 1901 - 2012 (Refer to 1901-2000)

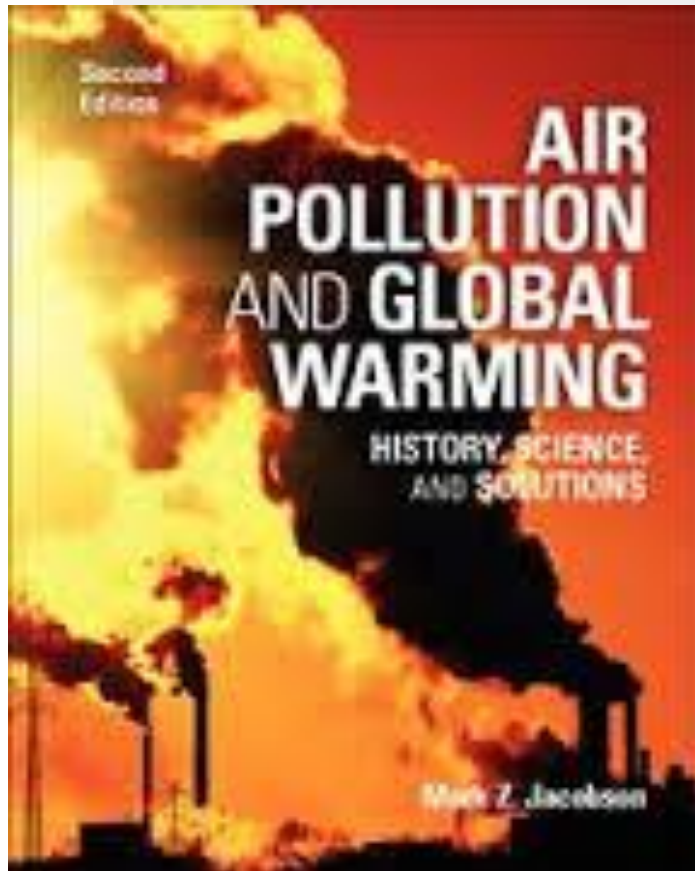


+0.8°C

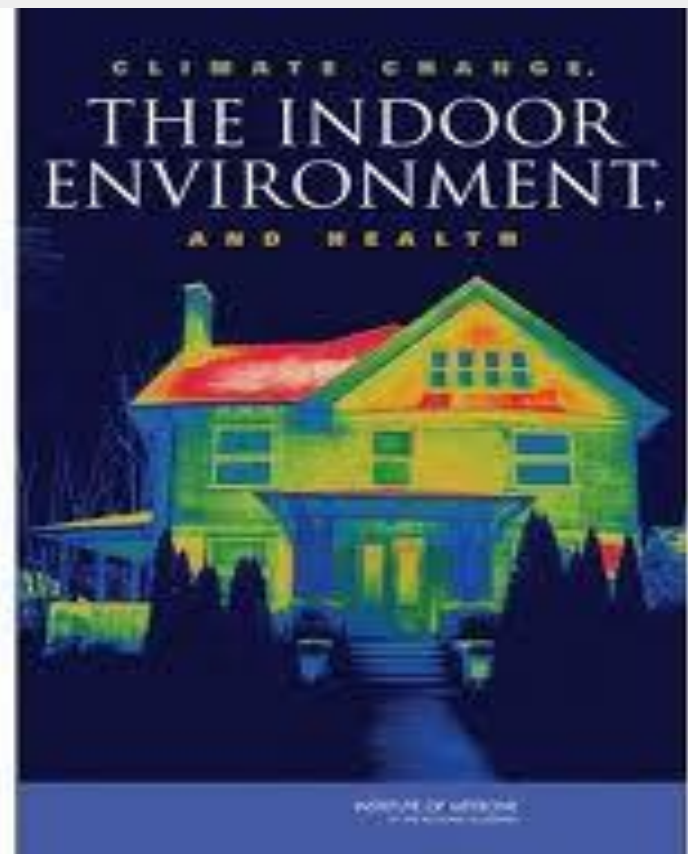
CLIMATE IMPACTS ON HUMAN HEALTH

USGCRP, 2016

	Climate Driver	Exposure	Health Outcome	Impact
 Extreme Heat	More frequent, severe, prolonged heat events	Elevated temperatures	Heat-related death and illness	Rising temperatures will lead to an increase in heat-related deaths and illnesses.
 Outdoor Air Quality	Increasing temperatures and changing precipitation patterns	Worsened air quality (ozone, particulate matter, and higher pollen counts)	Premature death, acute and chronic cardiovascular and respiratory illnesses	Rising temperatures and wildfires and decreasing precipitation will lead to increases in ozone and particulate matter, elevating the risks of cardiovascular and respiratory illnesses and death.
 Flooding	Rising sea level and more frequent or intense extreme precipitation, hurricanes, and storm surge events	Contaminated water, debris, and disruptions to essential infrastructure	Drowning, injuries, mental health consequences, gastrointestinal and other illness	Increased coastal and inland flooding exposes populations to a range of negative health impacts before, during, and after events.
 Vector-Borne Infection (Lyme Disease)	Changes in temperature extremes and seasonal weather patterns	Earlier and geographically expanded tick activity	Lyme disease	Ticks will show earlier seasonal activity and a generally northward range expansion, increasing risk of human exposure to Lyme disease-causing bacteria.
 Water-Related Infection (<i>Vibrio vulnificus</i>)	Rising sea surface temperature, changes in precipitation and runoff affecting coastal salinity	Recreational water or shellfish contaminated with <i>Vibrio vulnificus</i>	<i>Vibrio vulnificus</i> induced diarrhea & intestinal illness, wound and blood-stream infections, death	Increases in water temperatures will alter timing and location of <i>Vibrio vulnificus</i> growth, increasing exposure and risk of water-borne illness.
 Food-Related Infection (<i>Salmonella</i>)	Increases in temperature, humidity, and season length	Increased growth of pathogens, seasonal shifts in incidence of <i>Salmonella</i> exposure	<i>Salmonella</i> infection, gastrointestinal outbreaks	Rising temperatures increase <i>Salmonella</i> prevalence in food; longer seasons and warming winters increase risk of exposure and infection.
 Mental Health and Well-Being	Climate change impacts, especially extreme weather	Level of exposure to traumatic events, like disasters	Distress, grief, behavioral health disorders, social impacts, resilience	Changes in exposure to climate- or weather-related disasters cause or exacerbate stress and mental health consequences, with greater risk for certain populations.

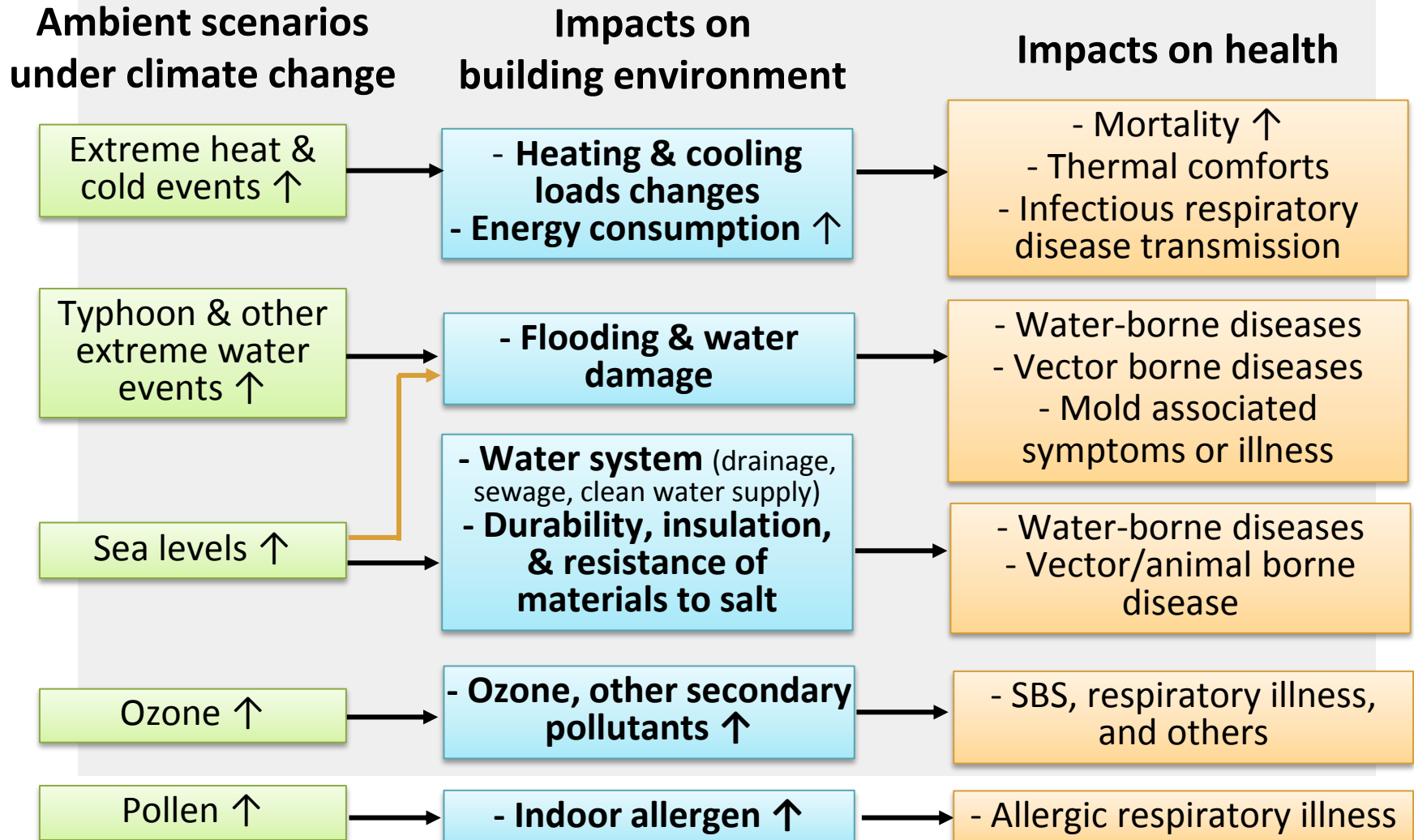


<http://www.stanford.edu/group/efmh/jacobson/POLbook2/>



<http://pegasia.blogspot.tw/2011/12/new-book-climate-change-indoor.html>

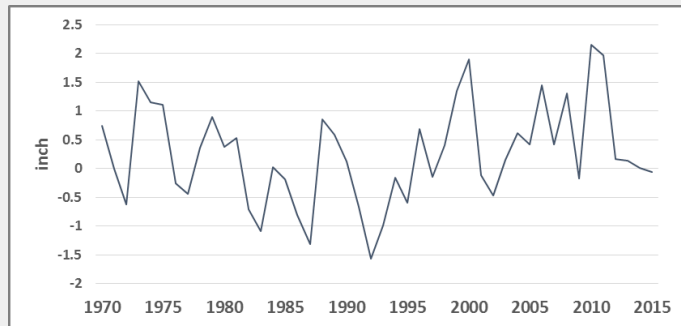
THE ROLE OF BUILDING & IAQ IN THE CAUSATION



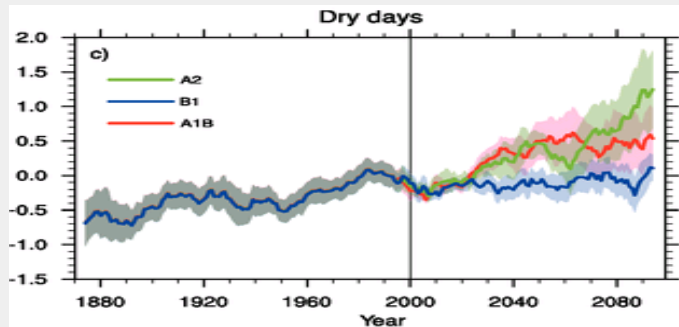
PRECIPITATION CHANGING

Global

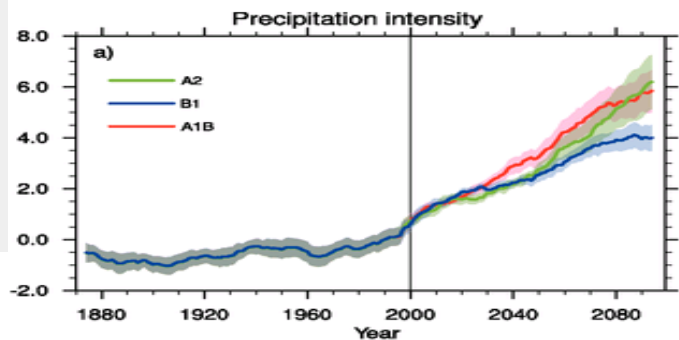
Precipitation



Dry days

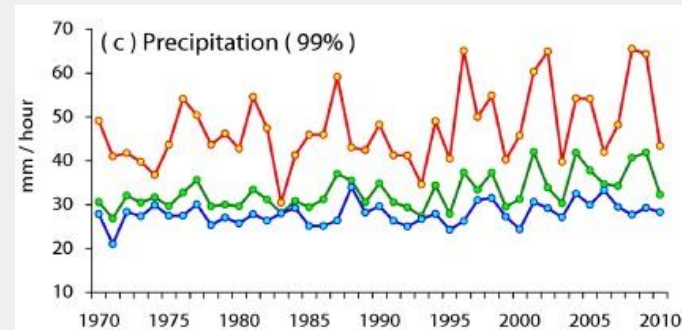


Intensity

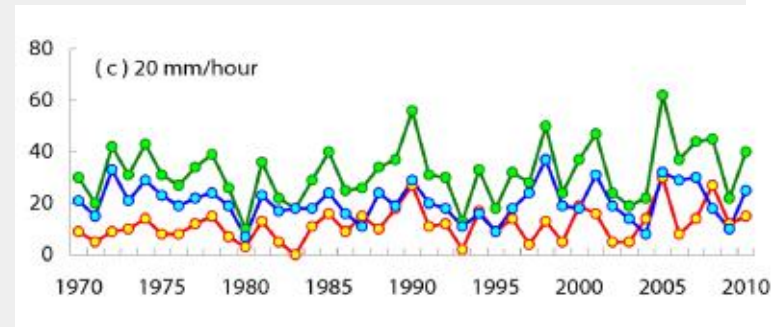


Taiwan

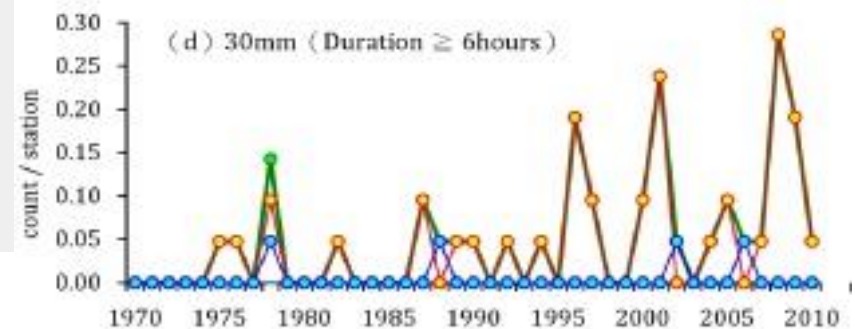
Precipitation



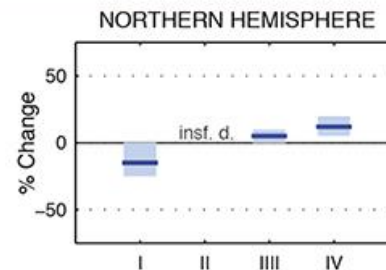
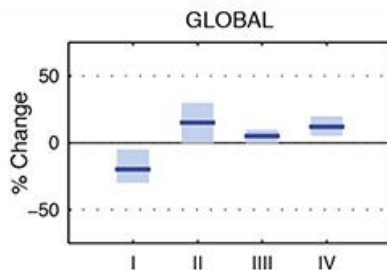
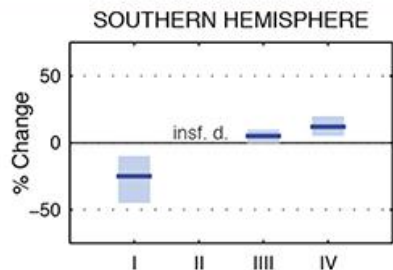
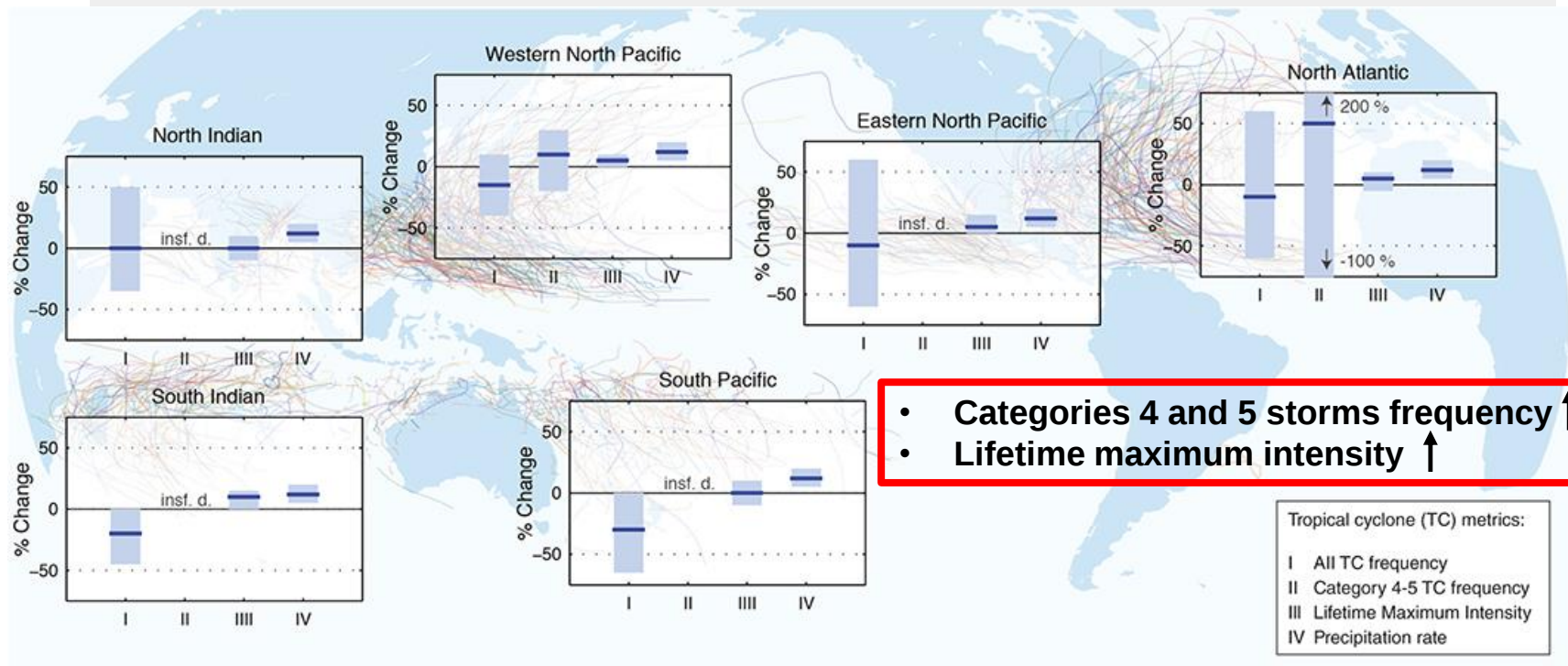
Rain hours



Intensity

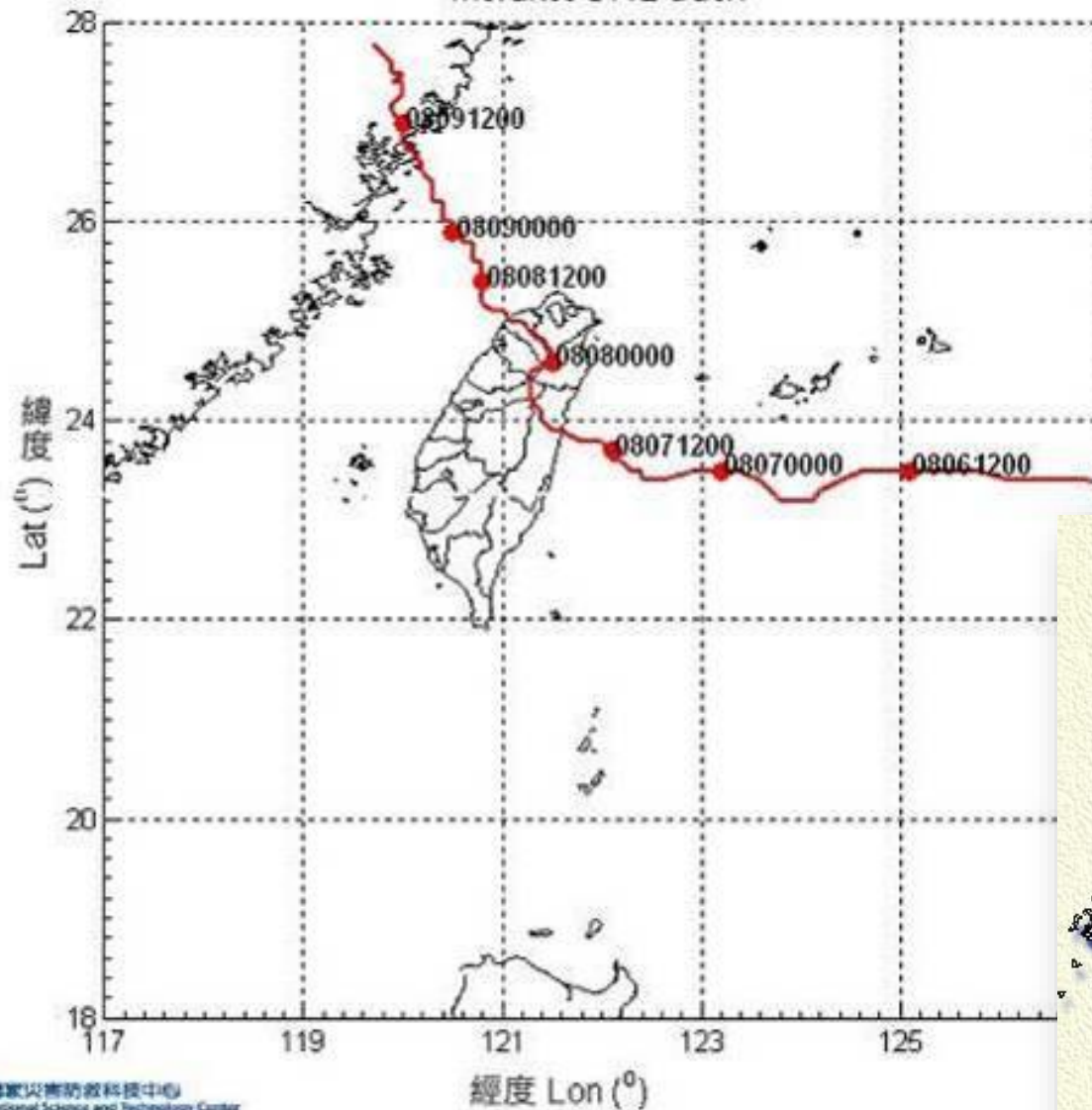


相較於2000-2019年，2081-2100年的颱風數量將明顯上升



莫拉克颱風路徑(中央氣象局)

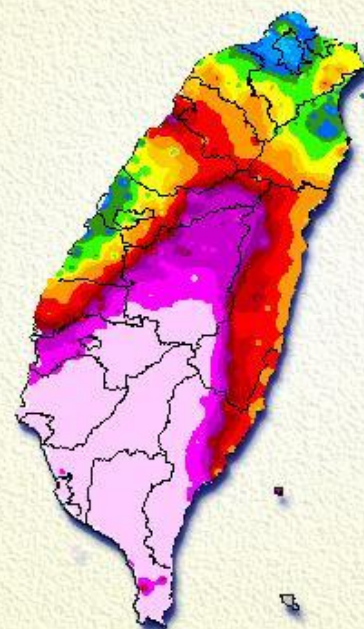
Morakot CWB track



MORAKOT TYPHOON 2009

8/08 00:00 ~ 8/08 21:30

累積雨量圖
毫米 (mm)



中央氣象局製

MORAKOT TYPHOON



<http://changaoho.blogspot.tw/2009/08/blog->



<http://yblog.org/archive/index.php/10523>

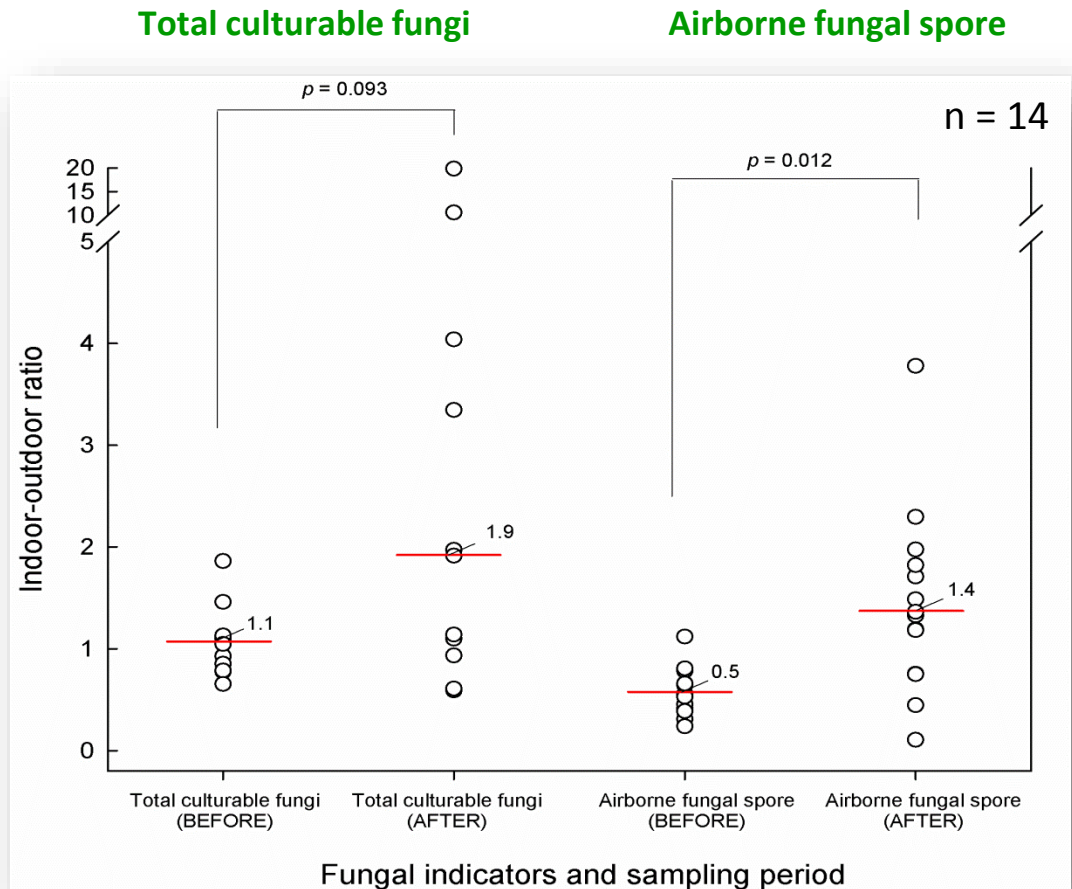


INCREASING THREAT OF FUNGAL EXPOSURE AFTER FLOODING

[Science of The Total Environment 2011; 409(9):1677-82]



About
100 cm
height



Changing profile of fungal I/O ratio before and 1 month after Typhoon Morakot



Thousands of houses were destroyed by the hurricane and are now covered with mold.

KATRINA HURRICANE

A resident walks through her damaged home where mold growing on all the walls and furniture in an attempt to salvage personal items, but she is not wearing a protective mask. (Photo by Patsy Lynch courtesy FEMA)



THERMAL STRESS

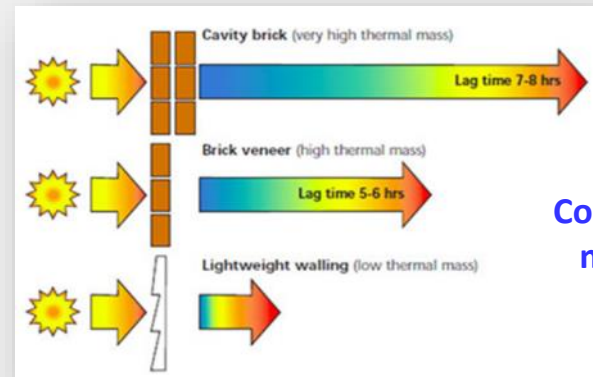


<http://weblogs.sun-sentinel.com/news/weather/hurricane/blog/heatwave.jpg>

Vulnerable populations

- Elders
- Young children
- Patients with chronic diseases
- Low-income family

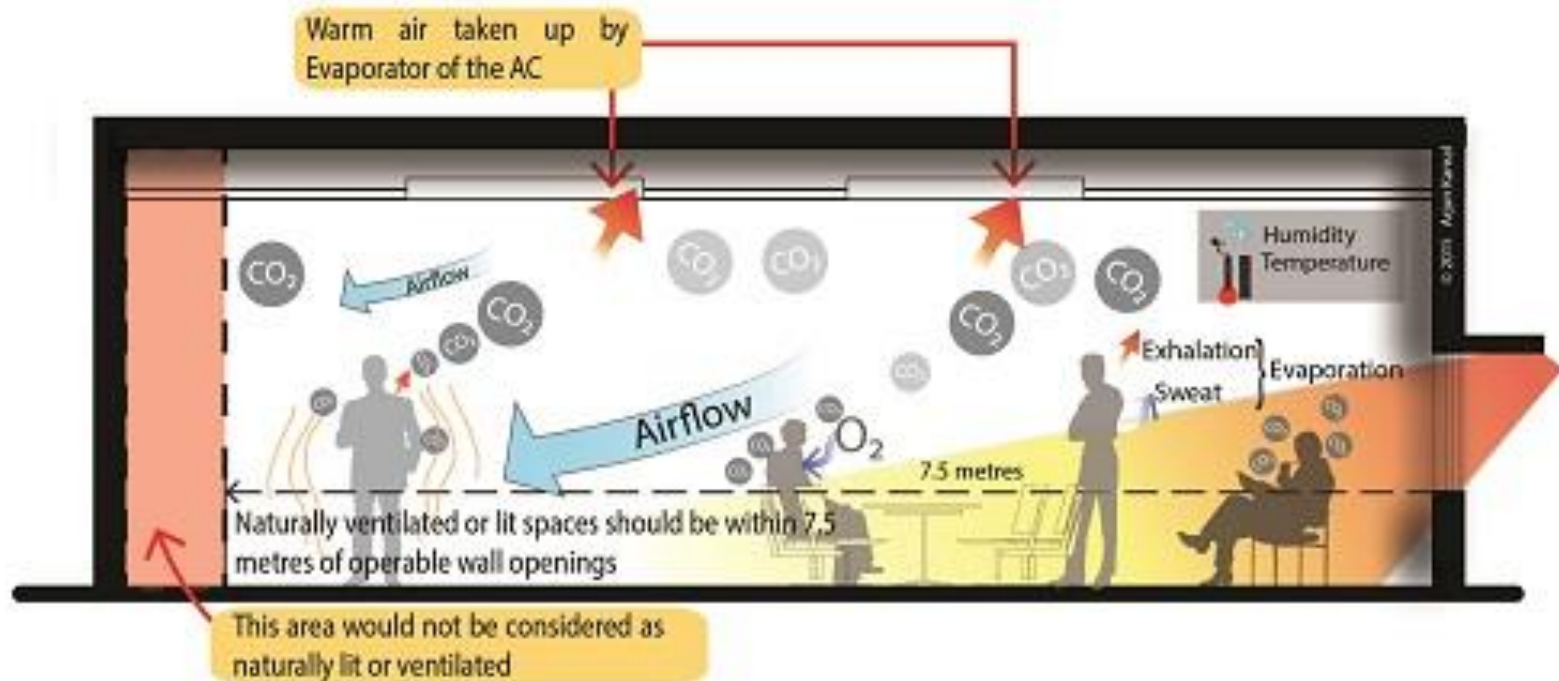
Adaptive strategy:
“open the air
conditioner”



Construction
materials

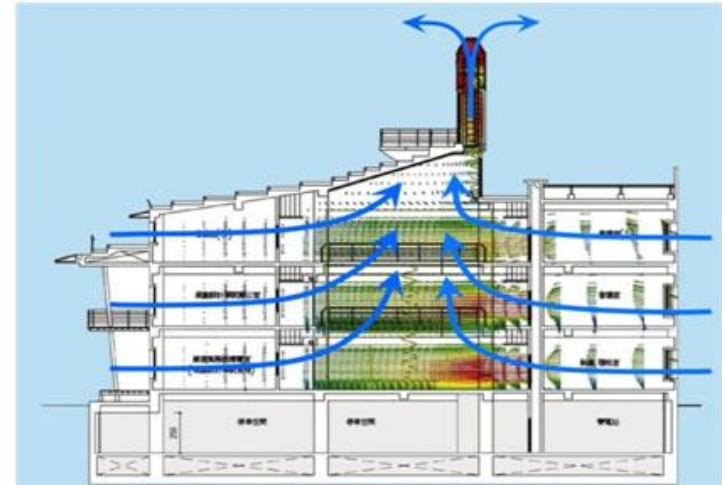
<http://www.azobuild.com/details.asp?ArticleID=8095>

THERMAL STRESS

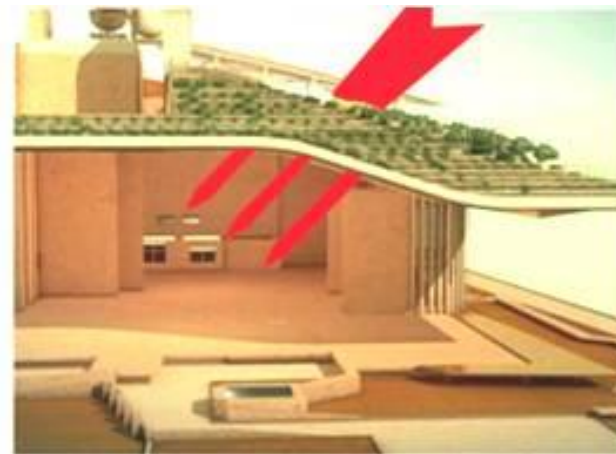


<http://www.coolingindia.in/blog/post/id/14670/improving-indoor-air-quality>

BUILDING DESIGN FOR WARMING

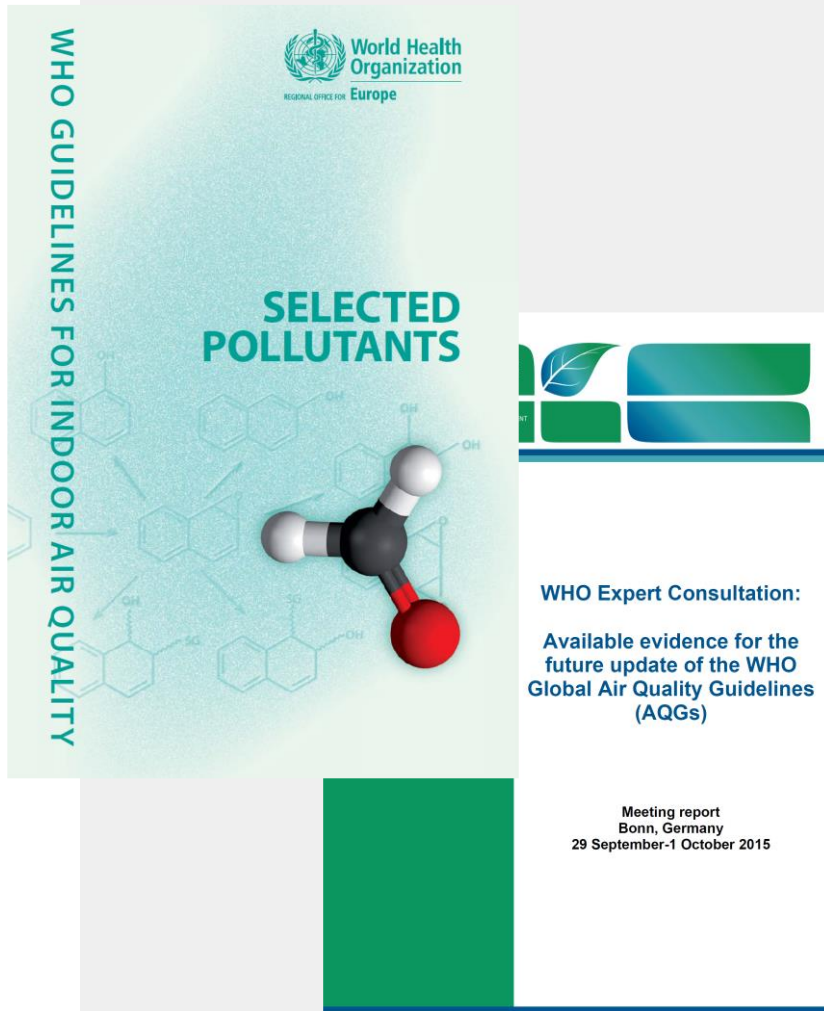


屋頂無植栽



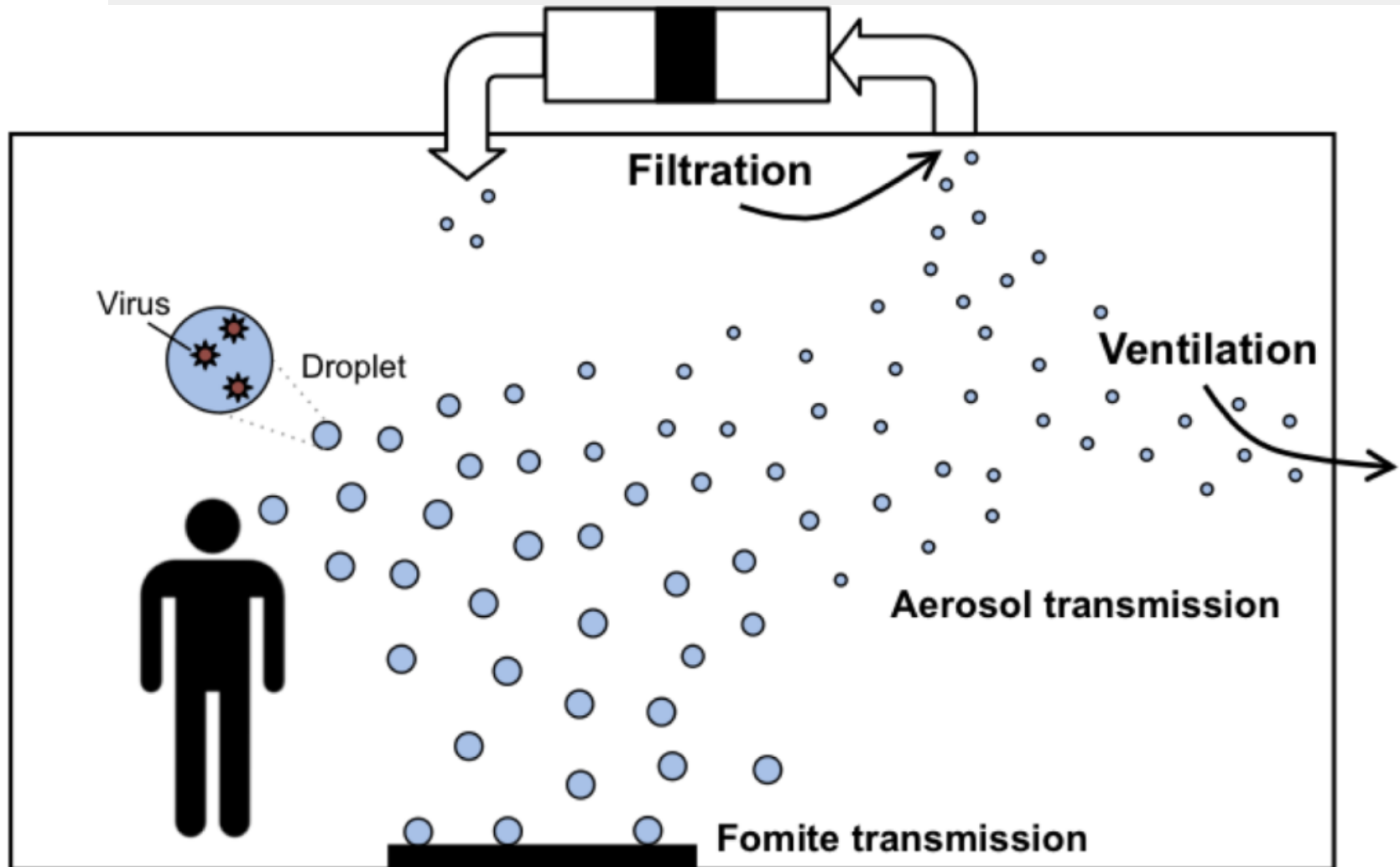
屋頂有植栽

CHEMICAL CONTAMINATION

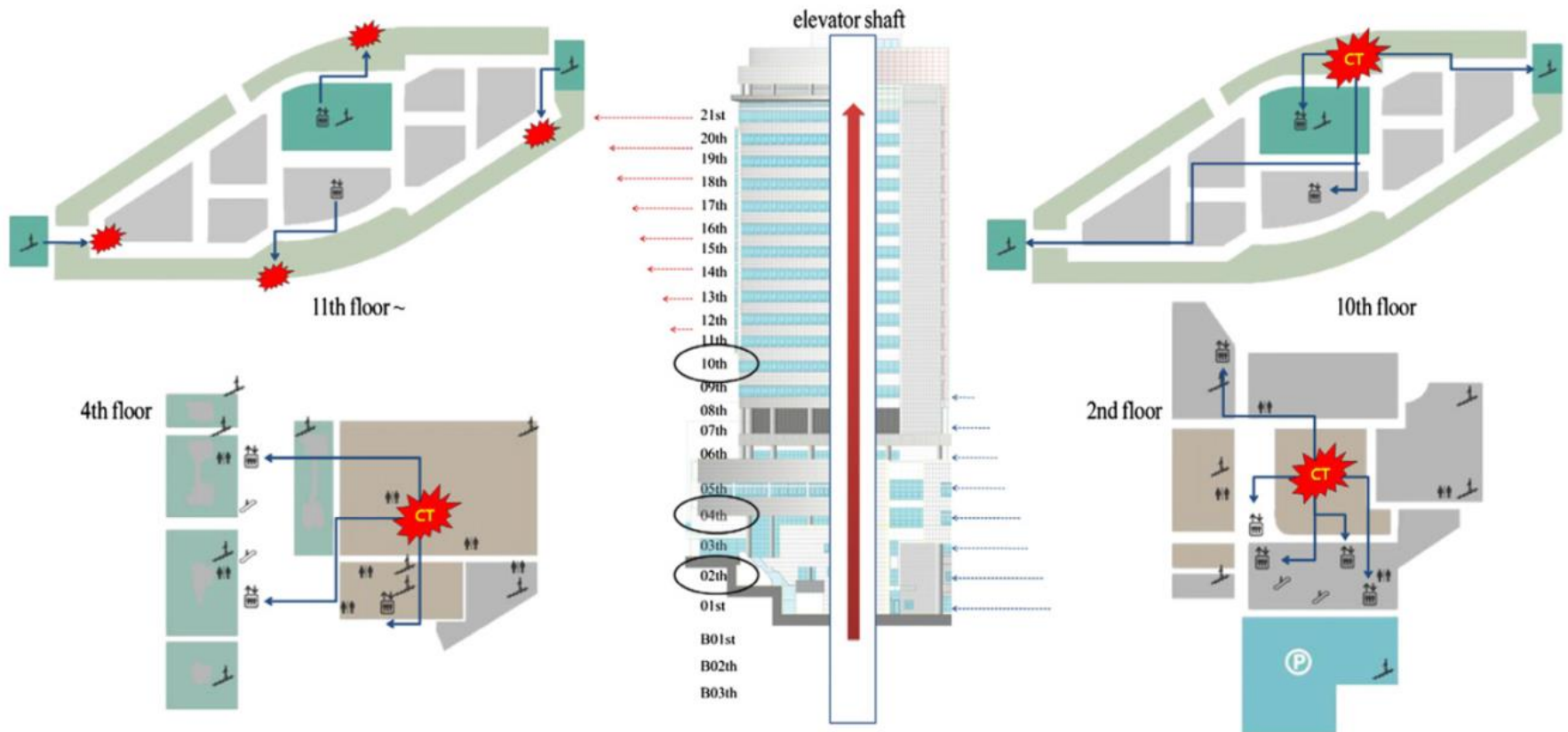


- **WHO 歐盟 (2010)**：苯、一氧化碳、甲醛、苯、二氧化氮、多環芳香烴化合物、氫氣、三氯乙烯和四氯乙烯。
- **WHO (2015)**：一氧化碳、二氧化氮、二氧化硫和甲醛。

TRANSMISSION & CONTROL OF VIRUSES VIA INFECTIOUS DROPLETS AND AEROSOLS

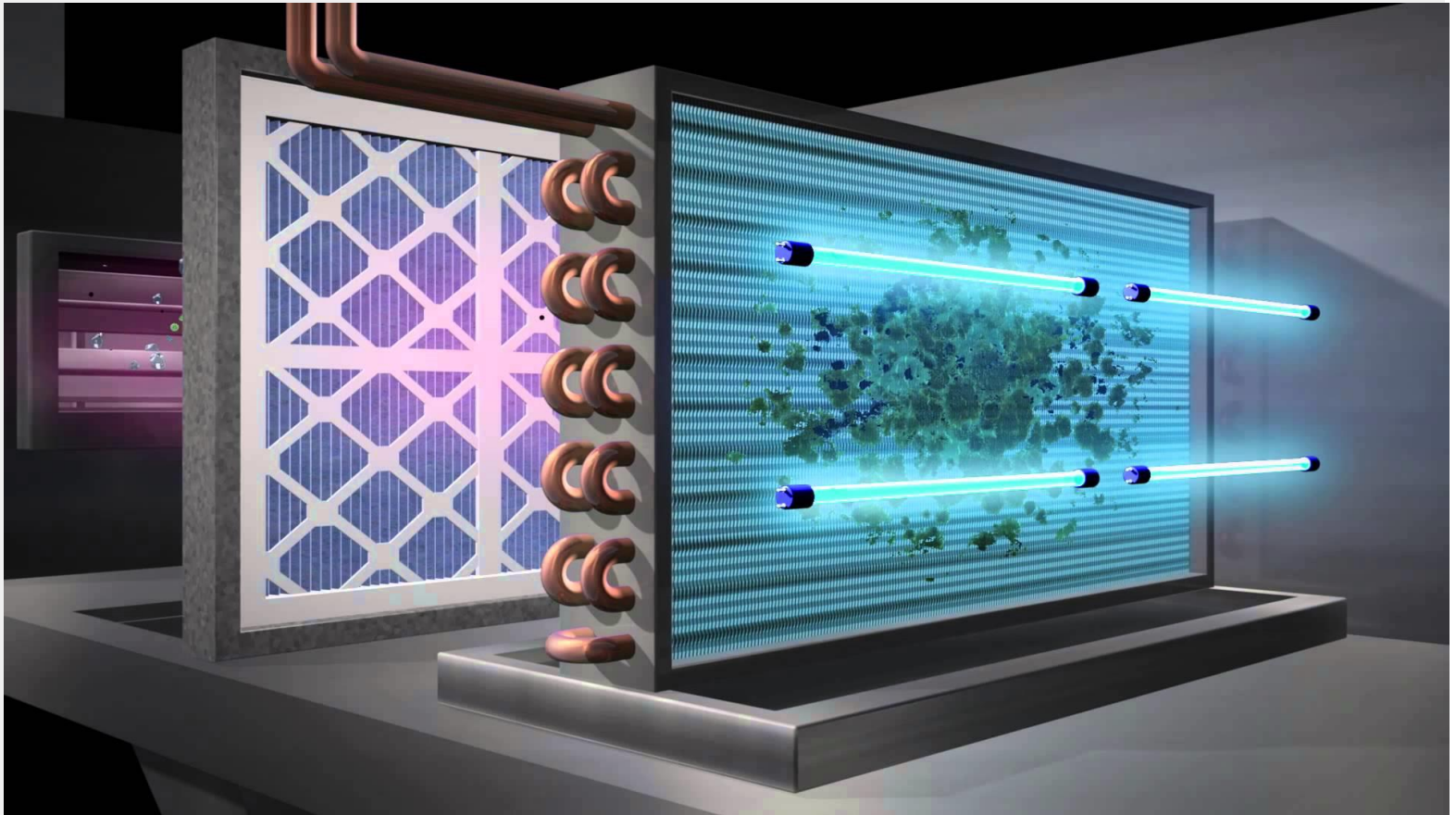


AIR TRANSMISSION OF PATHOGEN IN HVAC SYSTEM



(Lim et al., 2011)

UVGI IN AIR CONDITIONER



<https://www.airconditioningcayman.com/related-services/uv-lights/>

EXTENDING RADING

- 台灣環保署室內空氣品質資訊網:
<http://iaq.epa.gov.tw/indoorair/index.aspx>
- 台灣社團法人台灣室內環境品質學會:
<https://www.facebook.com/tsieq/>
- 美國環保署IAQ
<https://www.epa.gov/indoor-air-quality-iaq>
- 美國環保署IAQ for School:
<http://www.epa.gov/iaq/schools/>

**THANK YOU
FOR
LISTENING**

