Arizona State University Green Apple Project

#### **Healthy Housing for Seniors**



# **Healthy Housing for Seniors**

- Indoor Environmental Quality
- Housing & Community Design for Active Aging
- □ Assistive Technologies in the Home



### **Components of Healthy Housing**





### **Aging & Generational Attributes**

#### Physiological Changes

Joints, Bones, Muscles

**Respiratory Systems** 

Sensory

#### **Cognitive Changes**

Attention, Reactions

Memory

#### **Emotional Challenges**

Depression

Hormonal

**Cultural Stereotypes** 

"The Greenest Generation"



#### **INDOOR ENVIRONMENTAL QUALITY**

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#### **Overview**

#### 1. Indoor Thermal Conditions

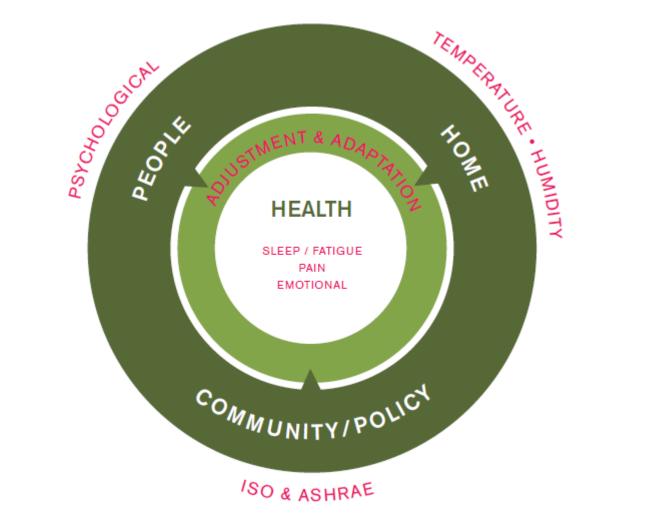
- a) Air Temperature
- b) Relative Humidity

#### 2. Indoor Air Quality

- a) Particle Matter
- b) Aldehydes
- c) Acetones
- d) Acetyls



### **Components of Thermal Conditions**



#### **STANDARDS**

#### 1. ASHRAE 55-2010

- a) Sets parameters to provide adequate and productive thermal conditions
- b) ASHRAE 62
- 2. ISO/TS 14415, addresses conditions of the working ill and disable
  - a) Describes the wide range of responses of people with special needs.





#### **Temperature & Comfort**

"Thermal comfort, or the lack of it, is well understood to be one of the most significant restrictors to the health and general wellbeing of the older people" (Novieto & Zhang, 2010)

- a) Activity levels are affected
- b) Behavior
- c) Sleeping patterns
- d) Emotional responses





### **Temperature & Health**

#### 1. Novieto and Zhang

- a) More prone to thermal related comfort
- Relationships between aging and thermal conditions, aging and gradual changes, thermoregulation

#### 2. Van Hoof and Hensen

a) Older adults require higher ambient temperatures, about 2°C

#### 3. Parsons

- a) Standards do not consider older adults' requirements
- b) Fitness state decreases, mortality increases on adults 40 and older.





# **Relationship - Housing & Health**

- Housing/home conditions directly affect health and the ability for independent living for elderly populations
- 2. Casual links between housing and health include: respiratory conditions, heart disease, cerebrovascular disease, injuries, mental health and some cancers
- 3. Mortality increases with high temperatures
- 4. Higher healthcare cost

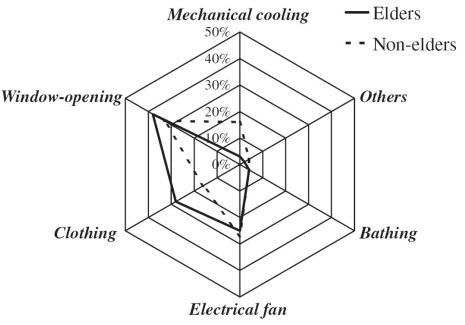


Image credit: bocahomecareservices.com



### **Temperature & Adaptive Behavior**

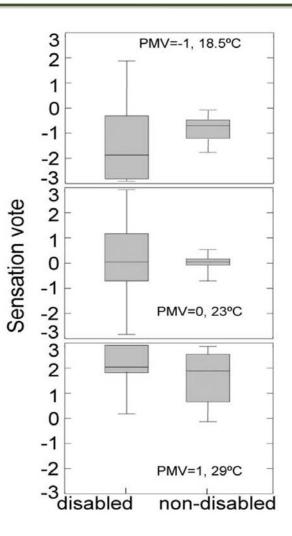
- Age groups often choose different adaptive strategies for comfort
- Window opening (summer) and clothing adjustment (winter)
- 3. Comfort temperature range of 80% of the elderly sample was found to be narrower than the younger population. (23.2-27.1° C (73.7-80.78° F), vs 23.0–28.6° C (73.4-83.5° F)





### **Thermal Differences due to Age**

- PMV index over estimates the comfort vote for elderly populations by 0.5 scale units
- 2. All things being equal (uniform clo and activity levels) elderly prefer higher ambient temperatures
- Under constant temperature experiments older adults preferred warmer temperatures than younger adults
- Moderate temperature drifts are not seen as unacceptable thermal conditions.





### **IAQ Overview**

#### 1. Thresholds

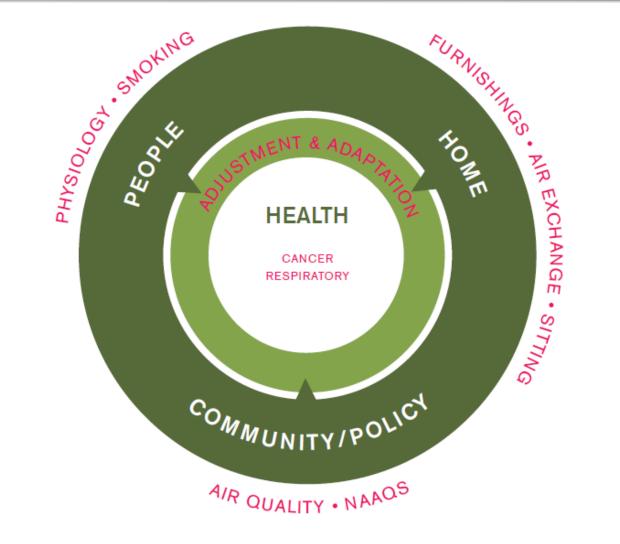
- a) Formaldehyde
- b) Particle Matter

#### 2. IAQ and Health

- a) PM and health Impacts
- b) Indoor formaldehyde



#### **Indoor Air Quality Components**





## **PM exposure guidelines**

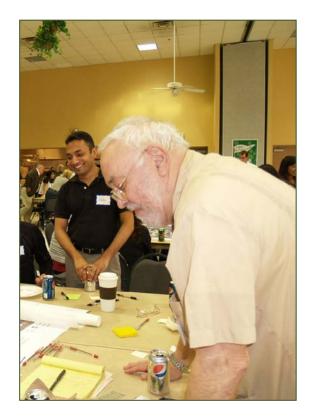
- While WHO and other guidelines govern numerous pollutants, do not specifically quantify PM Exposure Guidelines.
- 2. Standards for ambient (outdoor) air quality cover a range of sizes and time periods.
- 3. Ambient Air Quality Standards range from:
  - a) 35 mg/m<sup>3</sup> for PM2.5 over 24-hrs (US NAAQS)
  - b) 50 mg/m<sup>3</sup> for PM10 annual average (US NAAQS)
  - c) 50 mg/m<sup>3</sup> for PM10 over 24-hr (EU)





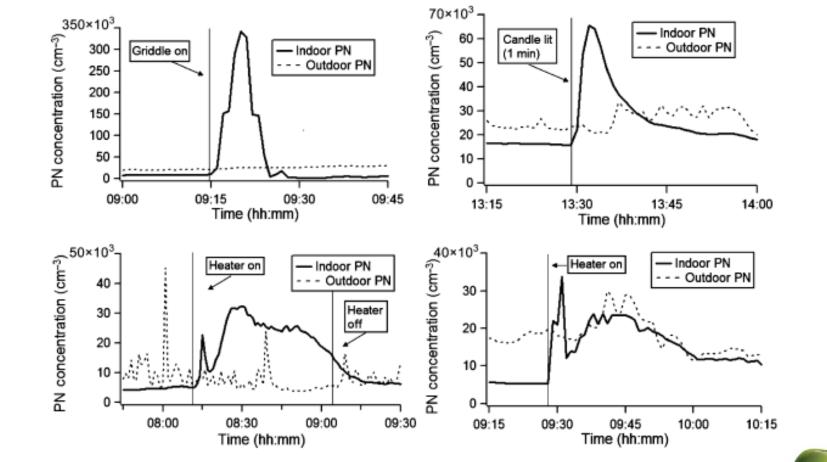
### **PM & Health Impacts**

- Numerous studies have quantified the increase risk of health impacts from a 10 mg m<sup>-3</sup> increase in PM levels.
- For PM10, an increase in ambient PM10 of 10 mg m<sup>-3</sup> will lead to:
  - a) An increase daily mortality of 0.5-0.6% (Samet et al. 2000)
  - b) Increased hospitalization for asthma of 1.0-1.5% (Zanobetti et al. 2000)
  - c) Increased hospitalization for chronic obstructive pulmonary disease or cardiovascular disease of 0.5-1.1% (Atkinson et al. 2001)





#### **PM sources**





### **Formaldehyde Thresholds**

| e 5. International Gui | deline Values and Reco | ommendations for For                                 | maldehyde in Indoor Aii | r                                 |  |
|------------------------|------------------------|--|-------------------------|-----------------------------------|--|
| country                | year issued            | value  |                         | comments                          |  |
| Australia              | 1982226                | 0.1 ppm  | 120 µg m <sup>-3</sup>  | short-duration                    |  |
|                        | 2006227                | 0.08 ppm   | $100 \ \mu g \ m^{-3}$  |                                   |  |
| Canada                 | 1987 <sup>220</sup>    | 0.1 ppm $120 \ \mu g \ m^{-3}$ action level          |                         | action level                      |  |
|                        | 1987                   | 0.05 ppm $60 \ \mu g \ m^{-3}$ target level          |                         | target level                      |  |
|                        | 200522                 | 0.1 ppm  | $123 \ \mu g m^{-3}$    | 1 h                               |  |
|                        | 2005                   | 0.04 ppm   | $50 \ \mu g \ m^{-3}$   | 8 h                               |  |
| China                  | 2003225                | 0.08 ppm   | $100 \ \mu g \ m^{-3}$  | 1 h average                       |  |
| Denmark                | 1990 <sup>207</sup>    | 11   | 0.15 mg m <sup>-3</sup> | c                                 |  |
| Finland                | 2001209                |  | $30 \ \mu g \ m^{-3}$   | S1                                |  |
|                        |                        |  | 50 $\mu g m^{-3}$       | S2                                |  |
|                        |                        |  | $100 \ \mu g \ m^{-3}$  | \$3                               |  |
| France                 | 2008 <sup>213</sup>    |  | 50 $\mu g m^{-3}$       | 2 h (proposed)                    |  |
|                        |                        |  | $10 \ \mu g \ m^{-3}$   | long-term exposure (proposed)     |  |
| Germany                | 1977 <sup>216</sup>    | 0.1 ppm  |                         |                                   |  |
| Singapore              | 1996 <sup>224</sup>    | 0.1 ppm  | $120 \ \mu g \ m^{-3}$  | 8 h                               |  |
| Hong Kong              | 1999                   | 0.025 ppm  | $30 \ \mu g \ m^{-3}$   | level 1 (8 h)                     |  |
| 0 0                    |                        | 0.081 ppm  | $100 \ \mu g \ m^{-3}$  | level 2 (8 h)                     |  |
|                        |                        | 0.3 ppm  | $370 \ \mu g \ m^{-3}$  | level 3 (8 h)                     |  |
|                        | 2003221                | 0.025 ppm  | $30 \ \mu g \ m^{-3}$   | excellent                         |  |
|                        |                        | 0.081 ppm  | $100 \ \mu g \ m^{-3}$  | good                              |  |
| Japan                  | 1997 <sup>223</sup>    | 0.08 ppm   | $100 \ \mu g \ m^{-3}$  | 0.5 h                             |  |
| Korea                  | 2004222                | 0.1 ppm  | $120 \ \mu g \ m^{-3}$  | 8 h                               |  |
| Norway                 | 1990 <sup>210</sup>    | 0.05 ppm   | $60 \ \mu g \ m^{-3}$   | 24 h average                      |  |
|                        | 1999 <sup>211</sup>    | 0.05 ppm   | $100 \ \mu g \ m^{-3}$  | 30 min average                    |  |
| Sweden                 | 2000                   | 0.08 ppm   | $100 \ \mu g \ m^{-3}$  | adopted from WHO                  |  |
| Poland                 | 1996 <sup>215</sup>    | 0.04 ppm 50 $\mu$ g m <sup>-3</sup> category A: 24 h |                         | category A: 24 h                  |  |
|                        |                        | 0.08 ppm   | $100 \ \mu g \ m^{-3}$  | category B: 8-10 h                |  |
| U.K.                   | $2004^{208}$           |  | $100 \ \mu g \ m^{-3}$  | 0.5 h                             |  |
| USA (California)       | 1991 <sup>217</sup>    | 0.1 ppm  | $120 \ \mu g \ m^{-3}$  | action level                      |  |
|                        |                        | 0.05 ppm   | $60 \ \mu g \ m^{-3}$   | target level (ALARA) <sup>a</sup> |  |
|                        | 1999 <sup>203</sup>    | 0.076 ppm  | 94 μg m <sup>-3</sup>   | 1 h (acute REL) <sup>b</sup>      |  |
|                        | 2004 <sup>219</sup>    | 0.027 ppm  | $33 \ \mu g \ m^{-3}$   | 8 h (interim REL)                 |  |
|                        | 2005218                | 0.002 ppm  | $3 \mu g  m^{-3}$       | annual average (chronic REL)      |  |
| WHO                    | 1987 <sup>228</sup>    | 0.08 ppm   | $100 \ \mu g \ m^{-3}$  | 0.5 h average                     |  |

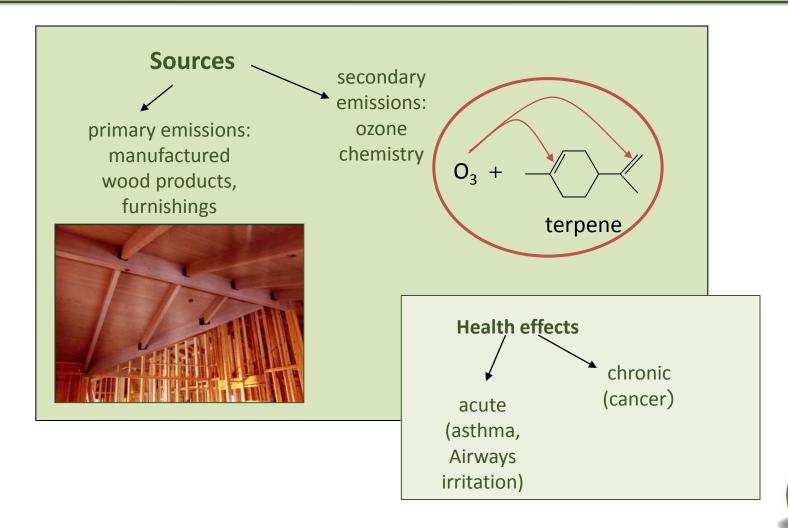
<sup>*a*</sup> ALARA = as low as reasonably achievable. <sup>*b*</sup> REL = reference exposure limit.

### **Formaldehyde Indoors**

#### Table 7. Comparison of Formaldehyde Levels in Indoor Air as Determined in Different International Studies

| $ \begin{array}{c} \mbox{rminy} (191) & 327 \mbox{residences} & 55 \mbox{g} \mbox{m}^{-3} & USA (1989) & 470 \mbox{mohs} \mbox{homes} & 70 \mbox{pol} \\ \mbox{rminy} (2003) & 14 \mbox{office buildings, 1366 measurements} \\ \mbox{soft are many} (2003) & 14 \mbox{office buildings, 1366 measurements} \\ \mbox{soft are many} (2003) & 14 \mbox{office buildings, 1366 measurements} \\ \mbox{soft are many} (2005) & 257 \mbox{residences} & 12 \mbox{-}69 \mbox{mohs} \mbox{residences} & 62 \mbox{soft are many} (2005) & 95 \mbox{obs} \mbox{obs} \mbox{soft are many} (2005) & 95 \mb$   | continent/country  | location                               | $C_{indoor}$                  | continent/country    | location                        | $C_{\text{indoor}}$          |
|--|--------------------|--|-------------------------------|----------------------|---------------------------------|------------------------------|
| $\begin{array}{c} 106\ \mu \text{g}^{-3} \\ 105\ \mu$  | Europe             |  |                               |                      |                                 |                              |
| smmary (2008)S6 residences $\frac{53 \times gc}{31 \times gc}$ USA (2008)360 travel trailers81 ppb81 ppbsmmary (2003)14 office buildings, 1386 measurements1380 Berlin residences90 park models44 ppbsmmary (1995)22 residences15 pmg m <sup>-3</sup> Canada (2003)59 residences25 gt gc m <sup>-3</sup> smmary (1995)22 residences16 pmg m <sup>-3</sup> Canada (2005)59 residences25 gt gc m <sup>-3</sup> suffa (2002)160 homes88-115 gg m <sup>-3</sup> Latin America7-5 gg msuffa (2002)private residences46 gg m <sup>-3</sup> Asiasmmark (1997)2 new twin apartments63-384 gg m <sup>-3</sup> Asiasmmark (1997)2 hew twin apartments63-384 gg m <sup>-3</sup> Asiasmmark (1997)2 hew twin apartments19, 21, 26 gg m <sup>-1</sup> Asianemark (1997)2 hew twin apartments19, 21, 26 gg m <sup>-1</sup> Korea (2008)5 partments111 dug (2006)8 buildings19, 21, 26 gg m <sup>-1</sup> Korea (2008)6 apartments112 dug (2006)22 office buildings19, 21, 26 gg m <sup>-1</sup> Japan/Korea (2006)22 chew homes113 dug (2006)8 buildings19, 21, 26 gg m <sup>-1</sup> Japan/Korea (2006)29 new homes134 fg m <sup>-3</sup> seeden (2001)181 classrooms23 gg m <sup>-3</sup> Japan/Korea (2006)29 new homes134 fg m <sup>-3</sup> ance (2006)Strasbourg libraries3-72 gg m <sup>-3</sup> Japan (2002)6 residences71.5 gg m <sup>-3</sup> ance (2006)Strasbourg libraries3-72 gg m <sup>-3</sup> Japan (2002)6 residences71.   | Germany (1991)     | 327 residences                         |                               | USA (1989)           | 470 mobile homes                | 70 ppb                       |
| $\begin{array}{c} 47.7g\text{m}^{-1} \\ 48.7g\text{m}^{-1} \\ 48.7g$   |                    |  |                               |                      |                                 | <30 to >300 pp               |
| $\begin{array}{c c c c c c c c c c c c c c c c c c c $   | Germany (2008)     | 586 residences                         | $23.5 \mu g \mathrm{m}^{-3}$  | USA (2008)           | 360 travel trailers             | 81 ppb                       |
| prmary (2003)<br>prmary (2004)<br>promary (2004)14 office buildings, 1386 measurements<br>$180 Berlin residences60 measurements98 \mu g m-398 \mu g m-398 \mu g m-32 anada (2005)60 meas (2005)90 Quebe homes57 man29 Agg g m-129 Agg g m-129 Agg m-140 \mu g m-240 \mu g m-140 \mu g m-240 \mu g m-241$   |                    |  | $47.7 \ \mu g \ m^{-3}$       |                      | 90 park models                  | 44 ppb                       |
| armang (2001)180 Berlin residences $38 \ gg m^2$<br>$gg \ gg m^2$<br>$236 \ gg m^2$<br>$296 \ gg m^2$<br>$36 \ gg m^2$<br>$46 \ gg m^2$ <  | Germany (2003)     | 14 office buildings, 1386 measurements | $6.0 \ \mu g \ m^{-3}$        |                      | 69 mobile homes                 |                              |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$   | Germany (2001)     |  |                               | Canada (2003)        |                                 | 29.8 $\mu$ g m <sup>-3</sup> |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$   | (2001)             |  |                               |                      |                                 |                              |
| armary (1993)<br>istra (2002)190 residences<br>160 homes $62 \text{ pp}^{-1}$<br>$\frac{32 \text{ kg m}^{-2}}{16 \text{ kg m}^{-2}}$ Latin America<br>Brazil (2006)academic institute $< (-82 \text{ kg m}^{-2})$<br>$\frac{3}{2} \text{ Jg m}^{-2}$ straid (1992)<br>istration (1992)private residences $46 \text{ kg m}^{-2}$<br>$46 \text{ kg m}^{-3}$ Mexico (2003)different locations $(-82 \text{ kg m}^{-2})$<br>$\frac{3}{2} \text{ Jg m}^{-2}$ annark (1997)14 Danish town halls $0 \text{ Jg m}^{-3}$<br>$0 -80 \text{ Jg m}^{-3}$ Mexico (2003)different locations $(-82 \text{ Jg m}^{-1})$<br>$4 - 122 \text{ Jg m}^{-1}$ annark (1992)36 apartments $0 \text{ Jg m}^{-3}$<br>$14 - 276 \text{ Jg m}^{-3}$ Mexico (2003)52 classrooms summer<br>$48$ classrooms summer70 ppb<br>$48$ classrooms summerannark (1992)36 apartments $11/2 \text{ Jg Jg m}^{-3}$<br>$12 \text{ Jg m}^{-3}$ Korea (2008)52 classrooms summer<br>$48$ classrooms summer70 ppb<br>$48$ classrooms summeranace (2006)223 office buildings19 2 / 1 / 2 / 2   | Germany (1995)     | 252 residences                         | $12-649 \ \mu g \ m^{-3}$     |                      |                                 |                              |
| ustria (2002)160 homes $8.8^{-115}_{-15}$ f/g m <sup>-3</sup> Lattin America<br>Brazil (2006)academic institute $<1-82$ // g mannark (1987)14 Danish town halls40 //g m <sup>-3</sup> Mexico (2003)different locations $4-122$ //g mannark (1987)14 Danish town halls40 //g m <sup>-3</sup> Asia $4-122$ //g m $4-122$ //g mannark (1987)14 Danish town halls63-384 //g m <sup>-3</sup> Korea (2008)52 classroons summer70 ppbannark (1992)36 apartments $3-384$ //g m <sup>-3</sup> Korea (2008)52 classroons summer70 ppbannark (1992)36 apartments $3-324$ //g m <sup>-3</sup> Korea (2008)63 partments $209-437$ //g manda (2006)8 buildings11 //g m <sup>-3</sup> Korea (2009)50 school buildings150 ppbanda (2005)64 bedrooms23 //g m <sup>-3</sup> Japan/Korea (2006)52 school buildings100 ppbveden (2001)181 classrooms $3-74$ //g m <sup>-3</sup> Japan (2006)25 Shimizu residences71.5 //g m <sup>-3</sup> ance (2006)Strasbourg libraries $3-74$ //g mJapan (2004)37 Nagoya residences71.5 //g m <sup>-3</sup> ance (2006)Strasbourg locations $5.3-7.74$ //g mHong Kong (2000)6 residential homes $11-24$ //g mance (2006)Strasbourg locations $5.3-7.74$ //g mHong Kong (2006)42 coffices $32.7$ //g m <sup>-3</sup> ance (2006)Strasbourg locations $5.3-7.74$ //g mHong Kong (2007)9 N kitchens, inpact on children $3-94$ //g mance (2006)15 Ankara dwellings $2.3-36.62$ /   |                    |  |                               |                      | yo Quebee nomes                 | 210 20 µB III                |
| Strend (192)<br>(interchance)private residences $\frac{1}{46} \mu g m^{-1}$<br>$\frac{46}{46} \mu g m^{-1$   |                    |  |                               | Latin America        |                                 |                              |
| vitzerland (1992) private residences $46 \mu g m^{-3}$<br>enmark (1987) 14 Danish town halls $40 \mu g m^{-3}$ Mexico (2003) different locations $4-122 \mu g m^{-3}$<br>enmark (1991) 2 new twin apartments $63-384 \mu g m^{-3}$ Asia<br>enmark (1992) 36 apartments $63-384 \mu g m^{-3}$ Korea (2008) 52 classrooms summer 70 ppb<br>46 classrooms atumn 40 ppb<br>47 ups and 48 classrooms atumn 40 ppb<br>48 classrooms atumn 40 ppb<br>49 classrooms atumn 40 ppb<br>40 classrooms winter 60 pph<br>11 $\mu g m^{-3}$ Korea (2008) 6 apartments 209-457 $\mu g m^{-3}$<br>12 $\mu g m^{-3}$ Japan (Xorea (2006) 6 ave homes 134 $\mu g m^{-3}$<br>eveden (2001) 181 classrooms $3.3 \mu g m^{-3}$ Japan (2006) 22 new homes 134 $\mu g m^{-3}$ Japan (2006) 25 Shimizu residences 71.5 $\mu g m^{-3}$<br>ance (2006) Strasbourg lotraries $3.7 + 38 \mu g m^{-3}$ Hong Kong (2002) 6 residential homes 117-6 $\mu g m^{-3}$<br>ance (2008) for homes $3.3 + 27 + 38 \mu g m^{-3}$ Hong Kong (2000) 100 homes $85.7 / \mu g m^{-3}$<br>ance (2009) 157-187 babies' homes $17.7 - 19.4 \mu g m^{-3}$ Hong Kong (2000) 128 hotel balloroms $12.9 - 9.2 \mu g m^{-3}$<br>ance (2009) 157-187 babies' homes $17.7 - 19.4 \mu g m^{-3}$<br>thong Kong (2007) 24 homes $12.9 - 9.2 \mu g m^{-3}$<br>ance (2008) 25 Ankara dwellings $3.4 \mu g m^{-3}$ Hong Kong (2007) public vehicles $96.6 \mu g m^{-3}$<br>$34 (\mu g m^{-3}$ Hong Kong (2007) 294 Cairo residences $96.6 \mu g m^{-3}$<br>$34 (\mu g m^{-3}$ Hong Kong (2007) 194 kitchens, inpact on children $3.6 - \mu g m^{-3}$<br>$3.6 / \mu g m^{-3}$ Hong Kong (2007) 194 kitchens, inpact on children $3.6 / \mu g m^{-3}$<br>$3.6 / \mu g m^{-3}$<br>$3.6 / \mu g m^{-3}$ Hong Kong (2007) 194 kitchens in Perth $1 - 166 \text{ ppb}$<br>$3.7 / \mu g m^{-3}$<br>$3.6 / \mu g m^{-3}$<br>3.   | astria (2002)      | 100 homes                              |                               | Brazil (2006)        | academic institute              | $<1-82 \ \mu g \ m^{-3}$     |
| Hordman (1927)Just an restoratesTop g in markennark (1987)14 Danish town halls46 $kg$ m <sup>-3</sup> Asiaennark (1991)2 new twin apartments63-384 $\mu_{\rm g}$ m <sup>-3</sup> Asiaennark (1992)36 apartments63-384 $\mu_{\rm g}$ m <sup>-3</sup> Asiainald (2006)8 buildings19-27, 26 $\mu_{\rm g}$ m <sup>-3</sup> Asiaennark (1992)36 apartments19-27, 26 $\mu_{\rm g}$ m <sup>-3</sup> Asiainald (2006)8 buildings19-27, 26 $\mu_{\rm g}$ m <sup>-3</sup> Korea (2008)6 apartmentsinald (2007)23 office buildings11 $\mu_{\rm g}$ m <sup>-3</sup> Korea (2008)6 apartmentsinald (2006)25 office buildings11 $\mu_{\rm g}$ m <sup>-3</sup> Japan/Korea (2006)50 school buildingsveden (2001)181 classrooms23 $\mu_{\rm g}$ m <sup>-3</sup> Japan/Korea (2006)22 new homes134 $\mu_{\rm g}$ m <sup>-3</sup> acce (2006)Strasbourg locations53-73.8 $\mu_{\rm g}$ m <sup>-3</sup> Japan (2004)37 Nagoya residences17.5 $\mu_{\rm g}$ m <sup>-3</sup> ace (2008)G trasbourg locations53-73.8 $\mu_{\rm g}$ m <sup>-3</sup> Japan (2004)37 Nagoya residences17.6 $\mu_{\rm g}$ m <sup>-3</sup> ace (2008)Strasbourg homes24-72.3 $\mu_{\rm g}$ m <sup>-3</sup> Hong Kong (2000)42 offices25.9 $\mu_{\rm g}$ m <sup>-3</sup> ace (2008)G farasbourg homes17.7 -19.4 $\mu_{\rm g}$ m <sup>-3</sup> Hong Kong (2006)42 coffices37.8 $\mu_{\rm g}$ m <sup>-3</sup> ace (2009)10 homes2.7 -2 $\mu_{\rm g}$ m <sup>-3</sup> China (2004)28 hotel ballrooms12-26 $\mu_{\rm g}$ m <sup>-3</sup> ace (2006)25 Ankara dwellings2.4 -23 $\mu_{\rm g}$ m <sup>-3</sup> China (2004)   | witzerland (1002)  | neivata sasidancas                     |                               |                      |                                 | $7-8 \ \mu g \ m^{-3}$       |
| enmark (1987)14 Danish town halls $140 \text{ kg m}^{-3}$ Mexico (2003)different locations $4-122 \mu \text{g m}^{-3}$ enmark (1991)2 new twin apartments $0^{-580} \mu \text{g m}^{-3}$ Asia70 ppbenmark (1992)36 apartments $14-276 \mu \text{g m}^{-3}$ Korea (2008)52 classrooms summer70 ppbenmark (1992)36 apartments $14-276 \mu \text{g m}^{-3}$ Korea (2008)62 classrooms winter60 ppbnand (2006)23 office bouldings19, 21, 26 \mu \text{g m}^{-3}Korea (2008)63 partments209-437 \mu \text{g m}^{-3}nand (2004)23 U (phe docoms $23 \mu \text{g m}^{-3}$ Korea (2009)50 school buildings100 ppbveden (2001)181 classrooms $23 \mu \text{g m}^{-3}$ Japan/Korea (2006)25 shinizi residences71.5 $\mu \text{g m}^{-3}$ ance (2006)Strasbourg libraries $20-457 \mu \text{g m}^{-3}$ Japan (2004)37 Nagoya residences17.6 $\mu \text{g m}^{-3}$ ance (2006)Strasbourg locations $53-724 \mu \text{g m}^{-3}$ Hong Kong (2002)6 residential homes $12-24 \mu \text{g m}^{-3}$ ance (2006)Strasbourg locations $53-724 \mu \text{g m}^{-3}$ Hong Kong (2004)37 Nagoya residences $17.6 \mu \text{g}^{-3}$ ance (2006)Strasbourg locations $53-724 \mu \text{g m}^{-3}$ Hong Kong (2004)22 offices $32 \mu \text{g}^{-3}$ ance (2007)Strasbourg homes $17.7-194 \mu \text{g m}^{-3}$ Hong Kong (2004)28 hotel ballrooms $23.2 \mu \text{g}^{-3}$ ance (2006)25 Ankara dwellings $2.3-4062, \mu \text{g m}^{-3}$ Africa $29-94 \mu \text{g}^{-3}$ Africa  | witzerialiu (1992) | private residences                     | $40 \ \mu g \ m^{-3}$         |                      |                                 | $5-9 \mu g m^{-3}$           |
| $\begin{array}{c} \text{mark (1987)} & \text{if P Dalish (own hans)} & \text{if O p b} \\ \text{emark (1991)} & 2 \ \text{new twin apartments} & 63 - 384 \ pg  \text{m}^{-3} & \text{Asia} \\ \text{emark (1992)} & 36 \ \text{apartments} & 63 - 384 \ pg  \text{m}^{-3} & \text{Korea (2008)} & 52 \ \text{classrooms summer} & 40 \ \text{pp b} \\ \text{if A - 276 \ pg \ m}^{-3} & \text{Korea (2008)} & 52 \ \text{classrooms summer} & 40 \ \text{pp b} \\ \text{if A - 276 \ pg \ m}^{-3} & \text{Korea (2008)} & 52 \ \text{classrooms summer} & 40 \ \text{pp b} \\ \text{if A - 276 \ pg \ m}^{-3} & \text{Korea (2008)} & 52 \ \text{classrooms summer} & 40 \ \text{pp b} \\ \text{if A - 276 \ pg \ m}^{-3} & \text{Korea (2008)} & 52 \ \text{classrooms summer} & 40 \ \text{pp b} \\ \text{if A - 276 \ pg \ m}^{-3} & \text{Korea (2008)} & 50 \ \text{school buildings} & 100 \ \text{pb} \\ \text{so apartments} & 20 - 457 \ \text{ng m} \\ \text{if A pg m}^{-3} & \text{Japan/Korea (2006)} & 25 \ \text{Shimizu residences} & 71.5 \ \text{ng m}^{-3} \\ \text{ace (2006)} & \text{Strasbourg libraries} & 20 \ \text{rg m}^{-3} & \text{Japan (2004)} & 37 \ \text{Nagoya residences} \\ \text{if A pg m}^{-3} & \text{Japan (2004)} & 25 \ \text{Shimizu residences} & 71.5 \ \text{ng m}^{-3} \\ \text{ance (2008)} & \text{Strasbourg lormes} & 52 \ \text{-77.3 \ ng m}^{-3} & \text{Hong Kong (2006)} & 425 \ \text{Shimizu residences} & 71.5 \ \text{ng m}^{-3} \\ \text{ance (2008)} & \text{Strasbourg lormes} & 52 \ \text{-77.3 \ ng m}^{-3} & \text{Hong Kong (2006)} & 422 \ \text{offices} & 32 \ \text{ng m}^{-3} \\ \text{ance (2008)} & \text{Strasbourg homes} & 77.7 \ \text{-93 \ ng m}^{-3} & \text{Hong Kong (2006)} & 422 \ \text{offices} & 32 \ \text{-17.7 \ 19 \ ng m}^{-3} \\ \text{ance (2008)} & \text{S office buildings} & 23 \ \text{-37.3 \ ng m}^{-3} \\ \text{ance (2009)} & 20 \ \text{homes} & 32 \ \text{-17.7 \ 19 \ ng m}^{-3} \\ \text{Japan (2004)} & 28 \ \text{hole balrooms} & 32 \ \text{-17.7 \ 19 \ ng m}^{-3} \\ \text{Japa (2004)} & 28 \ \text{hole balrooms} & 32 \ \text{-17.7 \ 19 \ ng m}^{-3} \\ \text{Japa (2006)} & 5 \ \text{offices buildings} & 23 \ \text{-37.3 \ ng m}^{-3} \\ \text{Japa (2005)} & 5 \ \text{office buildings} & 23 \ \text{-37.3 \ ng m}^{-3} \\ \text{Japa (2005)} & 5 \ \text{office buildings} & 23 \ \text{-37.3 \ ng m}^{-3} \\ \text{Japa (2005)} & 5 \ \text{office buildings} & 23 \ \text{-37.3 \ ng m}^{-3} \\ \text$  | 2                  | 14 Desish terms halls                  | $408 \mu g \mathrm{m}^{-3}$   | Mexico (2003)        | different locations             |                              |
| nmark (1991)2 new twin apartments $63-38^4 \ pg \ m^{-3}$<br>$14-276 \ pg \ m^{-3}$ Korea (2008)52 classrooms summer70 ppband (2006)8 buildings19, 21, 26 \ pg \ m^{-3}<br>$11 \ pg \ m^{-3}$ Korea (2008)52 classrooms autumn40 ppband (2006)8 buildings19, 21, 26 \ pg \ m^{-3}<br>$23 \ office buildings19, 21, 26 \ pg \ m^{-3}$<br>$23 \ pg \ m^{-3}$ Korea (2008)52 classrooms autumn40 ppband (2006)23 office buildings19, 21, 26 \ pg \ m^{-3}<br>$23 \ pg \ m^{-3}$<br>$23 \ pg \ m^{-3}$ Japan/Korea (2006)50 school buildings100 ppbweden (2001)181 classrooms29 \ pg \ m^{-3}<br>$3 \ pg \ m^{-3}$<br>$3 \ pg \ m^{-3}$ Japan (2006)22 l Shimizu residences71.5 \ pg \ m^{-3}<br>$10 \ ppb$ ance (2006)Strasbourg libraries $23 \ pg \ m^{-3}$<br>$23 \ pg \ m^{-3}$ Japan (2006)6 residential homes11 - 24 \ pg \ m^{-3}<br>Hong Kong (2002)6 residential homes25.5 \ pg \ m^{-3}<br>$11 - 24 \ pg \ m^{-3}$<br>Hong Kong (2006)22 offices25.7 \ pg \ m^{-3}<br>$11 - 24 \ pg \ m^{-3}$<br>Hong Kong (2006)242 offices25.7 \ pg \ m^{-3}<br>$12 - 9 \ 3 \ pg \ m^{-3}$<br>Hong Kong (2007)294 Cairo residences72.5 \ pg \ m^{-3}<br>$12 - 9 \ 3 \ pg \ m^{-3}$<br>Hong Kong (2007)294 Cairo residences25.7 \ pg \ m^{-3}<br>$12 - 9 \ 3 \ pg \ m^{-3}$<br>Hong Kong (2007)294 Cairo residences25.7 \ pg \ m^{-3}<br>$12 - 9 \ 3 \ pg \ m^{-3}$<br>Hong Kong (2007)294 Cairo residences96.6 \ pg \ m^{-3}<br>$26.7 \ ue \ m^{-3}$ ance (2006)25 Ankara dwellings $2.3 - 8662 \ pg \ m^{-3}$<br>$2.3 - 9662 \ pg \ m$   | Jennark (1987)     | 14 Danish town nails                   | $40 \ \mu g \ m^{-2}$         |                      |                                 |                              |
| $\begin{array}{c} 14-276\ gm^{-3} \\ 161\ gm^{-3} \\ 192\ gm^{-3} \\ 192\ gm^{-3} \\ 192\ gm^{-3} \\ 192\ gm^{-3} \\ 20\ gm^{-3} \\ 21\ Shimizu\ residences \\ 71.5\ gm^{-3} \\ 25\ gm^{-3} \\ 25\ gm^{-3} \\ 21\ Shimizu\ residences \\ 71.5\ gm^{-3} \\ 25\ gm^{-3} \\ 25\ gm^{-3} \\ 20\ gm^{-3} \\ 25\ Shimizu\ residences \\ 71.5\ gm^{-3} \\ 20\ gm^{-3} \\ 21\ Shimizu\ residences \\ 71.5\ gm^{-3} \\ 25\ gm^{-3} \\ 25\ gm^{-3} \\ 25\ gm^{-3} \\ 20\ gm^{-3} \\ 21\ Shimizu\ residences \\ 71.5\ gm^{-3} \\ 25\ gm^{-3} \\ 25\ gm^{-3} \\ 21\ 25\ gm^{-3} \\ 20\ gm^{-3} \\ 21\ 25\ gm^{-3} \\ 20\ gm^{-3} \\ 225\ gm^{-3} \\ 20\ gm^{-3} \\ 225\ gm^{-3} \\ 20\ gm^{-3} \\ 22\ 20\ fice \\ 20\ fice \\ 22\ 20\ fice \\ $   |                    |  |                               |                      |                                 |                              |
| anmark (1992)36 apartments $17 \mu \mu_{B} m^{-1}$ 46 classrooms winter60 ppbnland (2006)8 buildings19, 21, 26 $\mu$ g m <sup>-3</sup> Korea (2009)60 school buildings150 ppbnland (2006)23 office buildings11 $\mu$ g m <sup>-3</sup> Korea (2009)50 school buildings100 ppb06 new homes23 $\mu$ g m <sup>-3</sup> 1 apan/Korea (2006)292 new homes134 $\mu$ g m <sup>-3</sup> 06 new homes86 $\mu$ g m <sup>-3</sup> 1 apan/Korea (2006)292 new homes86 $\mu$ g m <sup>-3</sup> 07 opt181 classrooms $3 \mu$ g m <sup>-3</sup> 1 apan (2004)37 Nagoya residences17.6 $\mu$ g m <sup>-3</sup> ance (2006)Strasbourg libraries $20 \mu$ g m <sup>-3</sup> Hong Kong (2002)6 residential homes $25.9 \mu$ g m <sup>-3</sup> ance (2008)Strasbourg locations $5.3 - 73.8 \mu$ g m <sup>-3</sup> Hong Kong (2002)6 residential homes $32 \mu$ g m <sup>-3</sup> ance (2008)Strasbourg homes $26.7 \mu$ g m <sup>-3</sup> Hong Kong (2002)6 residential homes $32.4 \mu$ g m <sup>-3</sup> ance (2003)61 Paris dwellings $34.4 \mu$ g m <sup>-3</sup> China (2004)28 hotel ballrooms $29.7 \mu$ g m <sup>-3</sup> ance (2003)50 office buildings $17.7 - 19.4 \mu$ g m <sup>-3</sup> China (2004)28 hotel ballrooms $29.7 \mu$ g m <sup>-3</sup> ance (2006)25 Ankara dwellings $2.6 - 9.3 \mu$ g m <sup>-3</sup> Bangladesh (2007)9 likitchens, impact on children $26.2 \mu$ g m <sup>-3</sup> ance (2009)100 momes $2.7 + 20 \mu$ g m <sup>-3</sup> China (2007)9 likitchens, impact on children $26.2 \mu$ g m <sup>-3</sup> ance (2006)25 Ankara dwellings $2.3 - 23.8 \mu$ g m <sup>-3</sup> China (2007) <t< td=""><td>Jenmark (1991)</td><td>2 new twin apartments</td><td><math>63-384 \ \mu g \ m^{-3}</math></td><td>Korea (2008)</td><td></td><td>70 ppb</td></t<>   | Jenmark (1991)     | 2 new twin apartments                  | $63-384 \ \mu g \ m^{-3}$     | Korea (2008)         |                                 | 70 ppb                       |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$   | 1 (1000)           |  | $14-276 \ \mu g \ m^{-3}$     |                      |                                 |                              |
| nland (2009) 23 office buildings 11 $\mu g$ m <sup>-3</sup> Korea (2009) 50 school buildings 150 pp $^{10}$ 45 school buildings 150 pp $^{10}$ 45 school buildings 100 pp $^{10}$ 131 ( $\mu g$ m <sup>-3</sup> 29 $\mu g$ m <sup>-3</sup> 20 ( $\mu g$ m <sup>-3</sup> 10 ( |                    |  |                               |                      |                                 |                              |
| veden (2004)<br>veden (2005)27 Uppsala dwellings<br>64 bedrooms8.3 $\mu$ g m^{-3}<br>23 $\mu$ g m^{-3}<br>3 $\mu$ g m^{-3}Japan/Korea (2006)<br>292 new homes45 school buildings<br>292 new homes100 ppb<br>134 $\mu$ g m^{-3}<br>3 $\mu$ g m^{-3}veden (2001)181 classrooms29 $\mu$ g m^{-3}<br>3 $\mu$ g m^{-3}Japan/Korea (2006)<br>292 new homes292 new homes<br>60 new homes86 $\mu$ g m^{-3}<br>134 $\mu$ g m^{-3}ance (2006)Strasbourg libraries $\frac{20  \mu$ g m^{-3}}{20  \mug m^{-3}}<br>$\frac{200  \mu$ g m^{-3}}{100  g \muJapan (2004)27 Nagoya residences<br>$17.6  \mu$ g m^{-3}<br>11 - 24 $\mu$ g m<br>$3  ance (2003)$ 18 binizu residences<br>$11 - 24  \mu$ g m<br>$3  ance (2003)$ 17.6 $\mu$ g m^{-3}<br>$11 - 24  \mu$ g m<br>$3  ance (2003)$ 19 binizu residences<br>$11 - 24  \mu$ g m<br>$3  ance (2003)$ 19 binizu residences<br>$12.9 - 9.3  \mu$ g m^{-3}<br>$11 - 24  \mu$ g m<br>$12.9 - 9.3  \mu$ g m^{-3}<br>$12.9 - 9.3  \mu$ g m^{-3}<br>  |                    |  |                               |                      | 6 apartments                    |                              |
| veden (2005)64 bedrooms23 $\mu g$ m <sup>-3</sup><br>3 $\mu g$ m <sup>-3</sup> Japan/Korea (2006)292 new homes134 $\mu g$ m <sup>-3</sup><br>60 new homes134 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup> 134 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup> 134 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup> 134 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup> 134 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup> 134 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup> 134 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup> 134 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup> 134 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup> 134 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup> 134 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup> 134 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup> 134 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup> 134 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup> 134 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup> 134 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup> 134 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup> 134 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup> 134 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup> 134 $\mu g$ m <sup>-3</sup><br>71.5 $\mu g$ m <sup>-3</sup> <b< td=""><td></td><td></td><td></td><td>Korea (2009)</td><td></td><td></td></b<>  |                    |  |                               | Korea (2009)         |                                 |                              |
| $29 \ \mu g \ m^{-3}$ Japan (2006) $25 \ Shimizu residences$ $86 \ h g \ m^{-3}$ ance (2006)Strasbourg libraries $20 \ \mu g \ m^{-3}$ Japan (2006) $25 \ Shimizu residences$ $71.5 \ \mu g \ m^{-3}$ ance (2006)Strasbourg locations $5.3 - 72.8 \ \mu g \ m^{-3}$ Japan (2004) $37 \ Nagoya residences$ $11 - 24 \ \mu g \ m^{-3}$ ance (2008)Strasbourg homes $5.3 - 72.8 \ \mu g \ m^{-3}$ Hong Kong (2006) $422 \ offices$ $22 \ \mu g \ m^{-3}$ ance (2009)157 - 187 babies' homes $77.7 - 194 \ \mu g \ m^{-3}$ Hong Kong (2006) $422 \ offices$ $29 \ \mu m^{-3}$ ance (2009)157 - 187 babies' homes $17.7 - 194 \ \mu g \ m^{-3}$ China (2007)public vehicles $13 - 94 \ \mu g \ m^{-3}$ ance (2005)5 office buildings $2.3 - 866.2 \ \mu g \ m^{-3}$ China (2007)91 kitchens, impact on children $26.2 \ \mu c \ m^{-3}$ arkey (2006)25 Ankara dwellings $2.3 - 866.2 \ \mu g \ m^{-3}$ Africa $294 \ Cairo residences$ $96.6 \ \mu g \ m^{-3}$ SCanada $53 - 71.4 \ \mu g \ m^{-3}$ $53.4 \ \mu g \ m^{-3}$ Africa $294 \ Cairo residences$ $20.4 - 23.8 \ p^{-3}$ SA (2006)41 residences $21 - 47 \ p pb$ Australia (2000)192 caravans $29 \ nbme^{-3}$ SA (2006)41 residences $21 - 47 \ p pb$ Australia (2006)4 schools $3 - 38 \ \mu g \ m^{-3}$ SA (2006)41 residences $21 - 47 \ p pb$ Australia (2006)4 schools $3 - 38 \ \mu g \ m^{-3}$ SA (2007)234 homes $21 - 47 \ p pb$ Australia (2006  | weden (2004)       |  | 8.3 $\mu g m^{-3}$            |                      | 45 school buildings             | 100 ppb                      |
| veden (2001)181 classrooms $3 \mu g m^{-3}$<br>$< 4 = 72 \mu g m^{-3}$ Japan (2006)25 Shimizu residences $71.5 \mu g m^{-3}$<br>$17.6 \mu g m^{-3}$ ance (2006)Strasbourg libraries $20 \mu g m^{-2}$<br>$95 \mu g m^{-3}$ Japan (2004)37 Nagoya residences $25.9 \mu g m^{-3}$<br>$17.6 \mu g m^{-3}$ ance (2008)Strasbourg homes $2.67 \mu g m^{-3}$<br>$3.4 7 \mu g m^{-3}$ Hong Kong (2002)6 residential homes $11 - 24 \mu g m$<br>$32 \mu g m^{-3}$ ance (2009)61 Paris dwellings $34.4 \mu g m^{-3}$<br>$34.4 \mu g m^{-3}$ Hong Kong (2009)100 homes $85.7 \mu g m^{-3}$<br>$29.7 \mu g m^{-3}$ ance (2009)157 - 187 babies' homes $17.7 - 19.4 \mu g m^{-3}$<br>$2.3 - 32.3 \mu g m^{-3}$ China (2007)28 hotel ballrooms $29.7 \mu g m^{-3}$<br>$2.3 - 32.3 \mu g m^{-3}$ ance (2006)25 Ankara dwellings $2.3 - 866.2 \mu g m^{-3}$<br>$2.3 - 866.2 \mu g m^{-3}$ Africa<br>Egypt (2000)294 Cairo residences $96.6 \mu g m^{-3}$<br>$36.9 \mu g m^{-3}$ S/Canada $54 (2007)$ 14 residences $11.1 ppb$<br>$21 - 47 ppb$ Australia (2000)192 caravans $29.7 \mu g m^{-3}$<br>$32.5 \mu g m^{-3}$ SA (2006)4 manufactured houses<br>$7 \pm 34 \mu g m^{-3}$<br>$2.1 - 47 ppb$ Australia (2000)192 caravans $29.9 nch$<br>$-3 - 38 \mu g m^{-3}$<br>$100 ppb$ SA (2007)234 homes $14 - 58 pnb$<br>$14.3 \mu g m^{-3}$<br>$2.5 \mu g m^{-3}$ Other<br>aircraft (simulated)<br>submarine (2006)submarine (2006) $8 - 10 ppb$<br>$<10 \mu g m^{-3}$ SA (2007)234 homes $14 - 58 pnb$<br>$14.3 \mu g m^{-3}$<br>$2.5 \mu m^{-3}$ $0 ther$<br>aircraft (simulated)<br>subm   | weden (2005)       | 64 bedrooms                            | $23 \ \mu g \ m^{-3}$         | Japan/Korea (2006)   | 292 new homes                   | $134 \mu g  m^{-3}$          |
| veden (2001)181 classrooms $3 \mu g m^{-3}$ Japan (2006)25 Shimizu residences $71.5 \mu g m^{-3}$ ance (2006)Strasbourg libraries $20 \mu g m^{-3}$ $95 \mu g m^{-3}$ Japan (2004)37 Nagoya residences $25.9 \mu g m^{-3}$ ance (2006)Strasbourg locations $5.3 - 73.8 \mu g m^{-3}$ Hong Kong (2002)6 residential homes $11 - 24 \mu g m$ ance (2003)61 Paris dwellings $34.4 \mu g m^{-3}$ Hong Kong (2006) $422$ offices $32. \mu g m^{-3}$ ance (2009)157 - 187 babies' homes $17.7 - 19.4 \mu g m^{-3}$ China (2004)28 hotel ballrooms $29.7 \mu g m^{-3}$ ance (2006)5 office buildings $2.3 - 32.3 \mu g m^{-3}$ China (2007)91 kitchens, impact on children $26.2 \mu g m^{-3}$ ance (2009)20 homes $2.3 - 866.2 \mu g m^{-3}$ Bangladesh (2007)91 kitchens, impact on children $26.2 \mu g m^{-3}$ arkey (2006)25 Ankara dwellings $2.3 - 866.2 \mu g m^{-3}$ Egypt (2000)294 Cairo residences $96.6 \mu g m^{-3}$ S/ (2007)21 + residences $11.1 pph$ Australia (2002)185 homes in Perth $1-166 pph$ SA (2006)4 manufactured houses $21 - 47 pph$ Australia (2000)192 caravans $29 ngh$ SA (2007)234 homes $14 - 58 pnh$ $14 - 58 pnh$ $14 - 58 pnh$ $14 - 58 pnh$ SA (2007)234 homes $32.4 \mu m^{-3}$ $20.6 \mu m^{-3}$ $20.9 mnh$ SA (2007)234 homes $34 \mu g m^{-3}$ $20.5 \mu m^{-3}$ $20.9 mnh$ SA (2007)234 homes $34 \mu m^{-3}$ </td <td></td> <td></td> <td><math>29 \ \mu g \ m^{-3}</math></td> <td>1</td> <td>60 new homes</td> <td></td>  |                    |  | $29 \ \mu g \ m^{-3}$         | 1                    | 60 new homes                    |                              |
| ance (2006) Strasbourg libraries $20 \text{ µg m}^2$ Japan (2004) 37 Nagoya residences $17.6 \text{ µg m}^3$<br>ance (2008) Strasbourg locations $5.3-73.8 \text{ µg m}^3$ Hong Kong (2002) 6 residential homes $11-24 \text{ µg m}^3$<br>ance (2008) 61 Paris dwellings $26.7 \text{ µg m}^3$ Hong Kong (2009) 100 homes $85.7 \text{ µg m}^3$<br>ance (2009) $157-187$ babies' homes $17.7-194 \text{ µg m}^3$ China (2007) public vehicles $29.7 \text{ µg m}^3$ China (2007) $91$ kitchens, in Ankara $79.9 \text{ µg m}^3$ $2-3-32.3 \text{ µg m}^3$ Hong Kong (2000) 20 homes $2.3-32.3 \text{ µg m}^3$ $-3.36.9 \text{ µg m}^3$ $-2.3-32.3 \text{ µg m}^3$ $-2.3-32.3 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-2.3-32.3 \text{ µg m}^3$ $-2.3-32.3 \text{ µg m}^3$ $-2.3-32.3 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-2.3-32.6 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-2.3-32.6 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-2.3-32.3 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-2.3-32.6 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-2.3-32.6 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-2.3-32.6 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-2.3-36.6.2 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-2.3-36.6.2 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-2.3-866.2 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-2.3-866.2 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-2.3-866.2 \text{ µg m}^3$ $-3.69 \text{ µg m}^3$ $-2.3-866.2 \text{ µg m}^3$ $-3.69  µg$  | weden (2001)       | 181 classrooms                         | $3 \mu g m^{-3}$              | Japan (2006)         |                                 |                              |
| ance (2006)Strasbourg libraries $20 \ \mu g \text{ m}^{-3}$<br>95 $\mu g \text{ m}^{-3}$ Japan (2004) $37 \ \text{Nagoya residences}$<br>17.6 $\mu g \text{ m}^{-3}$<br>11.24 $\mu g \text{ m}^{-3}$ $25.9 \ \mu g \text{ m}^{-3}$<br>11.24 $\mu g \text{ m}^{-3}$<br>11.24 $\mu g \text{ m}^{-3}$ ance (2006)Strasbourg locations $5.3 - 73.8 \ \mu g \text{ m}^{-3}$<br>$3 (2003)$ Hong Kong (2002)6 residential homes<br>6 residential homes $11 - 24 \ \mu g \text{ m}^{-3}$<br>$32 \ \mu g \text{ m}^{-3}$ ance (2003)61 Paris dwellings $34.4 \ \mu g \text{ m}^{-3}$<br>$34.4 \ \mu g \text{ m}^{-3}$ Hong Kong (2004)<br>  | ()                 |  | $<3-12 \ \mu g \ m^{-3}$      | 54pan (2000)         |                                 |                              |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$   | France (2006)      | Strasbourg libraries                   |                               |                      |                                 |                              |
| ance (2006) Strasbourg locations $5.3 = 73.8 \ \mu g \text{ m}^{-3}$ Hong Kong (2002) 6 residential homes $11 = 24 \ \mu g \text{ m}$<br>ance (2008) Strasbourg homes $26.7 \ \mu g \text{ m}^{-3}$ Hong Kong (2009) 422 offices $32.4 \ \mu g \text{ m}^{-3}$ ance (2009) 157 = 187 babies' homes $17.7 = 19.4 \ \mu g \text{ m}^{-3}$ China (2004) 28 hotel ballrooms $29.7 \ \mu g \text{ m}^{-3}$ China (2004) 28 hotel ballrooms $29.7 \ \mu g \text{ m}^{-3}$ China (2007) public vehicles $13 = 94.4 \ \mu g \text{ m}^{-3}$ China (2007) public vehicles $13 = 94.4 \ \mu g \text{ m}^{-3}$ China (2007) public vehicles $13 = 94.4 \ \mu g \text{ m}^{-3}$ China (2007) $91 \ kitchens, impact on children 26.2 \ \mu g \text{ m}^{-3} 2.3 = 32.3 \ \mu g \text{ m}^{-3} Africa 79.9 \ \mu g \text{ m}^{-3} 2.3 = 866.2 \ \mu g \text{ m}^{-3} Africa 36.9 \ \mu g \text{ m}^{-3} Canada 53.7 \ \mu g \text{ m}^{-3} China (2000) 294 Cairo residences 96.6 \ \mu g \text{ m}^{-3} 36.4 \ \mu g \text{ m}^{-3} Australia (2002) 185 homes in Perth 1 = 166 \text{ ppb} Australia (2002) 192 caravans 100 \text{ ppb} 20.4 = 23.8 \ \mu g \text{ m}^{-3} 100 \text{ ppb} 32.5 \ \mu g \text{ m}^{-3} 32.4 \ \mu g \text{ m}^{-3} 32.5 \ \mu g \text{ m}^{-3} 32.5 \ \mu g \text{ m}^{-3} 32.5 \ \mu g \text{ m}^{-3} 33.4 \ \mu g \text{ m}^{-3} 33.4$   | ()                 | 0                                      |                               |                      |                                 | 17.6 μg m <sup>-3</sup>      |
| ance (2008)<br>ance (2003)Strasbourg homes<br>61 Paris dwellings $267 \mu u m^{-3}$<br>$344 \mu g m^{-3}$ Hong Kong (2006)<br>   | rance (2006)       | Strasbourg locations                   |                               | Hong Kong (2002)     | 6 residential homes             | 11-24 μg m                   |
| ance (2003)61 Paris dveilings $34.4  \mu g  m^{-3}$<br>$\approx 78  \mu g  m^{-3}$ Hong Kong (2009)<br>China (2004)100 homes $85.7  \mu g  m^{-3}$ ance (2009)157–187 babies' homes<br>uly (2009)17.7–19.4 $\mu g  m^{-3}$ Hong Kong (2009)<br>China (2007)100 homes $85.7  \mu g  m^{-3}$ ance (2009)20 homes<br>12.9–9.3 $\mu g  m^{-3}$ 17.7–19.4 $\mu g  m^{-3}$ China (2007)<br>Bangladesh (2007)public vehicles $13-94  \mu g  m^{-3}$ ance (2003)5 office buildings<br>rkey (2003)5 office buildings $2.3-323  \mu g  m^{-3}$ Africa<br>Egypt (2000)294 Cairo residences $96.6  \mu g  m^{-3}$ arkey (2006)25 Ankara dwellings $2.3-866.2  \mu g  m^{-3}$ Egypt (2000)294 Cairo residences $96.6  \mu g  m^{-3}$ S/Canada<br>SA (2000)4 manufactured houses<br>7 site-built houses11.1 ppb<br>16.1 ppbAustralia (2002)185 homes in Perth1-166 ppb<br>20.4–23.8 pp<br>100 ppbSA (2006)different locations19.6 $\mu g  m^{-3}$<br>32.5 $\mu g  m^{-3}$ Other<br>aicraft (simulated)<br>submarine (2006)occupied cabin<br>submarine (2006) $8-10  ppb$<br><100 ppb   |                    |  |                               | Hong Kong (2006)     | 422 offices                     | $32 \ \mu g \ m^{-3}$        |
| $\approx 78 \ \mu g \ m^{-3} \qquad China (2004) \qquad 28 \ hotel ballrooms \qquad 29.7 \ \mu g \ m^{-2} \ China (2004) \qquad 28 \ hotel ballrooms \qquad 29.7 \ \mu g \ m^{-2} \ China (2007) \qquad public vehicles \qquad 13-94 \ \mu g \ m^{-3} \ China (2007) \qquad public vehicles \qquad 13-94 \ \mu g \ m^{-3} \ China (2007) \qquad public vehicles \qquad 3-32.3 \ \mu g \ m^{-3} \ China (2007) \qquad public vehicles \qquad 3-9.4 \ \mu g \ m^{-3} \ China (2007) \qquad public vehicles \qquad 3-9.4 \ \mu g \ m^{-3} \ China (2007) \qquad public vehicles \qquad 3-9.4 \ \mu g \ m^{-3} \ China (2007) \qquad public vehicles \qquad 3-9.4 \ \mu g \ m^{-3} \ China (2007) \qquad public vehicles \qquad 3-9.4 \ \mu g \ m^{-3} \ China (2007) \qquad public vehicles \qquad 3-9.4 \ \mu g \ m^{-3} \ China (2007) \qquad public vehicles \qquad 3-9.4 \ \mu g \ m^{-3} \ China (2007) \qquad public vehicles \qquad 3-9.4 \ \mu g \ m^{-3} \ China (2007) \qquad public vehicles \qquad 3-9.4 \ \mu g \ m^{-3} \ China (2007) \qquad public vehicles \qquad 3-9.4 \ \mu g \ m^{-3} \ China (2007) \qquad 294 \ Cairo residences \qquad 96.6 \ \mu g \ m^{-3} \ China (2002) \qquad 185 \ homes in Perth \qquad 1-166 \ ppb \ Coupled call and China (2002) \qquad 185 \ homes in Perth \qquad 1-166 \ ppb \ Coupled call and China (2000) \qquad 192 \ caravans \qquad 29 \ nob \ 29 \ 20 \ nob \ 29 \ nob \ 29 \ nob \ 29 \ nob \ 29 \ 20 \ nob \ 20 \ 100 \ ppb \ China (2002) \qquad 185 \ homes \ 100 \ ppb \ 20 \ nob \ 29 \ nob \ 29 \ nob \ 29 \ nob \ 29 \ 20 \ 20 \ 20 \ 20 \ 20 \ 20 \ 20$  |                    |  |                               |                      | 100 homes                       | $85.7 \ \mu g \ m^{-3}$      |
| ance $(2009)$ 157–187 babies' homes $17.7-19.4 \ \mu g m^{-3}$ $12.9-9.3 \ \mu g m^{-3}$ $12.9-9.3 \ \mu g m^{-3}$ $2.3-32.3 \ \mu g m^{-3}$ $2.3-866.2 \ \mu g m^{-3}$ $4frica$ $294$ Cairo residences $96.6 \ \mu g m^{-3}$ $36.9 \$   | Tance (2005)       | of fails dwellings                     |                               | China (2004)         |                                 |                              |
| dy (2009)20 homes $12.9-9.3 \ \mu g \text{ m}^{-3}$ Bangladesh (2007)91 kitchens, impact on children $26.2 \ \mu g \text{ m}^{-3}$ aland (2005)5 office buildings $2.3-32.3 \ \mu g \text{ m}^{-3}$ $3.2-32.3 \ \mu g \text{ m}^{-3}$ Africa $36.9 \ \mu g \text{ m}^{-3}$ irkey (2003)399 kitchens in Ankara $0-2086 \ \mu g \text{ m}^{-3}$ Africa $96.6 \ \mu g \text{ m}^{-3}$ irkey (2006)25 Ankara dwellings $2.3-866.2 \ \mu g \text{ m}^{-3}$ AfricaS/Canada $2.3-866.2 \ \mu g \text{ m}^{-3}$ Egypt (2000)294 Cairo residences $96.6 \ \mu g \text{ m}^{-3}$ S/Canada $67.1 \ \mu g \text{ m}^{-3}$ Australia (2002)185 homes in Perth $1-166 \text{ ppb}$ SA (2000)4 manufactured houses $21-47 \text{ ppb}$ Australia (2006)4 schools $3-38 \ \mu g \text{ m}^{-3}$ SA (2006)different locations $19.6 \ \mu g \text{ m}^{-3}$ Other $100 \text{ ppb}$ SA (2007)234 homes $20.1 \ \mu g \text{ m}^{-3}$ $34 \ \mu g \text{ m}^{-3}$ Other $34 \ \mu g \text{ m}^{-3}$  | Franca (2000)      | 157-187 babias' homas                  |                               |                      |                                 |                              |
| Jand (2005)5 office buildings $2.3 = 32.3 \mu m^{-3}$ Africaarkey (2003)399 kitchens in Ankara $0 - 2088 \mu g m^{-3}$ Africaarkey (2006)25 Ankara dwellings $2.3 = 86.2 \mu g m^{-3}$ Egypt (2000)294 Cairo residencess/Canada $67.1 \mu g m^{-3}$ Australia/New ZealandS/Canada $67.1 \mu g m^{-3}$ Australia (2002)185 homes in Perth $1 - 166 \text{ ppb}$ SA (1995)14 residences $11.1 \text{ ppb}$ Australia (2002)185 homes in Perth $1 - 166 \text{ ppb}$ SA (2000)4 manufactured houses $21 - 47 \text{ ppb}$ Australia (2000)192 caravans $29 \text{ ppb}$ SA (2006)different locations $19.6 \mu g m^{-3}$ Other $100 \text{ ppb}$ SA (2007)234 homes $234 \text{ homes}$ $25.4 \mu g m^{-3}$ $34 \mu g m^{-3}$   |                    |  | $12.0-0.3 \ \mu g \ m^{-3}$   |                      |                                 |                              |
| inkey (2003)399 kitchens in Ankara $0-2086 \ \mu g \ m^{-3}$<br>$79.9 \ \mu g \ m^{-3}$ Africa<br>Egypt (2000)294 Cairo residences $96.6 \ \mu g \ m^{-3}$ inkey (2006)25 Ankara dwellings $2.3-866.2 \ \mu g \ m^{-3}$ Egypt (2000)294 Cairo residences $96.6 \ \mu g \ m^{-3}$ S/Canada $57.1 \ \mu g \ m^{-3}$ Australia/New Zealand<br>Australia (2002)185 homes in Perth $1-166 \ ppb$ SA (1995)14 residences $21-47 \ ppb$ Australia (2006)4 schools $3-38 \ \mu g \ m^{-3}$ SA (2000)4 manufactured houses $21-47 \ ppb$ Australia (2000)192 caravans $29 \ npb$ SA (2006)different locations $19.6 \ \mu g \ m^{-3}$<br>$14.3 \ \mu g \ m^{-3}$ OtherSA (2007)234 homes $20.1 \ \mu g \ m^{-3}$<br>$354 \ \mu g \ m^{-3}$ Other $34 \ \mu g \ m^{-3}$ $34 \ \mu g \ m^{-3}$ $34 \ \mu g \ m^{-3}$  |                    |  |                               | Baligiadesii (2007)  | 91 kitchens, impact on children |                              |
| $79.9 \ \mu g \text{ m}^{-3}$ Affica $97.9 \ \mu g \text{ m}^{-3}$ $2.3 - 866.2 \ \mu g \text{ m}^{-3}$ $Egypt (2000)$ $294 \ Cairo \ residences$ $96.6 \ \mu g \text{ m}^{-3}$ $5/Canada$ $67.1 \ \mu g \text{ m}^{-3}$ Australia/New Zealand $4ustralia (2002)$ $185 \ homes \ in \ Perth$ $1-166 \ ppb$ $5/Canada$ $26 \ residences$ $11.1 \ ppb$ $20.4 - 23.8 \ pp$ $20.4 - 23.8 \ pp$ $26 \ residences$ $21 - 47 \ ppb$ Australia (2006) $4 \ schools$ $3-38 \ \mu g \ m^{-3}$ $5X \ (2000)$ $4 \ manufactured houses$ $21 - 47 \ ppb$ Australia (2000) $192 \ caravans$ $29 \ ppb$ $5X \ (2006)$ different locations $14 - 58 \ pnb$ $4ustralia \ (2000)$ $192 \ caravans$ $29 \ ppb$ $5X \ (2007)$ $234 \ homes$ $20.1 \ \mu g \ m^{-3}$ $34 \ \mu g \ m^{-3}$ Other $34 \ \mu g \ m^{-3}$  |                    |  |                               |                      |                                 | 30.9 µg m 3                  |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$   | urkey (2005)       | 599 kuchens III Alikara                | $-2080 \ \mu g \ m^{-3}$      | Africa               |                                 |                              |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$   | (200C)             | 25 Antern develling                    |                               |                      | 294 Cairo residences            | 96.6 µg m <sup>-3</sup>      |
| S/Canada<br>SA (1995)14 residences<br>26 residences11.1 ppb<br>16.1 ppbAustralia (2002)185 homes in Perth1-166 ppb<br>20.4-23.8 pp<br>3-38 $\mu g$ m <sup>-3</sup> SA (2000)4 manufactured houses21-47 ppbAustralia (2006)4 schools3-38 $\mu g$ m <sup>-3</sup> SA (2006)4 inferent locations14-58 ppbAustralia (2000)192 caravans29 ppbSA (2007)234 homes20.1 $\mu g$ m <sup>-3</sup><br>32.5 $\mu g$ m <sup>-3</sup> Other<br>submarine (2006)submerged operation8-10 ppbSA (2007)234 homes20.1 $\mu g$ m <sup>-3</sup><br>34 $\mu g$ m <sup>-3</sup> submarine (2006)submerged operation8-10 $\mu g$ m <sup>-3</sup>  | urkey (2006)       | 25 Ankara dwellings                    |                               | 071                  | 271 Carlo residences            | 70.0 µg III                  |
| SA (1997)<br>26 residences14 residences<br>16.1 ppb11.1 ppb<br>16.1 ppb20.4-23.8 pp<br>3-38 $\mu g m^{-3}$ SA (2000)4 manufactured houses21-47 ppbAustralia (2006)4 schools3-38 $\mu g m^{-3}$ SA (2006)different locations19.6 $\mu g m^{-3}$ Other<br>aircraft (simulated)100 ppbSA (2007)234 homes20.1 $\mu g m^{-3}$<br>32.5 $\mu g m^{-3}$ Other<br>submarine (2006)submerged operation8-10 ppb<br><10 $\mu g m^{-3}$   |                    |  | 67.1 μg m 3                   |                      |                                 |                              |
| SA (1995)14 residences<br>26 residences11.1 ppb<br>16.1 ppbAustralia (2006)4 schools $20.4-23.8 \text{ pp}$<br>$3-38 \mu g \text{ m}^3$ SA (2000)4 manufactured houses<br>7 site-built houses21-47 ppb<br>14-58 npbAustralia (2000)192 caravans $29. \text{ npb}$<br>100 ppbSA (2006)different locations19.6 $\mu g \text{ m}^{-3}$<br>14.3 $\mu g \text{ m}^{-3}$ Other<br>aircraft (simulated)0ccupied cabin<br>submerged operation $8-10 \text{ ppb}$<br><10 $\mu g \text{ m}^{-3}$   | JS/Canada          |  |                               | Australia (2002)     | 185 homes in Perth              | 1-166 ppb                    |
| $26$ residences $16.1$ ppbAustralia (2006)4 schools $3-38$ µg m^{-3}SA (2000)4 manufactured houses $21-47$ ppbAustralia (2000) $192$ caravans $29$ ppb7 site-built houses $14-58$ ppb $14-58$ ppb $100$ ppbSA (2006)different locations $19.6$ µg m^{-3} $10.1$ µg m^{-3}SA (2007)234 homes $20.1$ µg m^{-3} $20.1$ µg m^{-3} $20.5$ µg m^{-3} $20.5$ µg m^{-3} $34$ µg m^{-3}   | JSA (1995)         | 14 residences                          | 11.1 ppb                      |                      |                                 |                              |
| SA (2000)    4 manufactured houses    21-47 ppb    Australia (2000)    192 caravans    29 ppb      7 site-built houses    14-58 ppb    14-58 ppb    100 ppb      SA (2006)    different locations    19.6 µg m <sup>-3</sup> Other    100 ppb      SA (2007)    234 homes    20.1 µg m <sup>-3</sup> aircraft (simulated)    occupied cabin    8-10 ppb      SA (2007)    234 homes    20.5 µg m <sup>-3</sup> 34 µg m <sup>-3</sup> aircraft (simulated)    submarine (2006)    submerged operation    8-10 µg m <sup>-3</sup>  | ()                 |  |                               | Australia (2006)     | 4 schools                       | 3-38 µg m-3                  |
| 7 site-built houses<br>different locations14–58 ppb100 ppbSA (2006) $19.6 \ \mu g \ m^{-3}$<br>$14.3 \ \mu g \ m^{-3}$ Other<br>aircraft (simulated)100 ppbSA (2007)234 homes $20.1 \ \mu g \ m^{-3}$<br>$32.5 \ \mu g \ m^{-3}$ submarine (2006)submerged operation $8-10 \ ppb$ $34 \ \mu g \ m^{-3}$ $34 \ \mu g \ m^{-3}$ $34 \ \mu g \ m^{-3}$ submarine (2006) $8-10 \ \mu g \ m^{-3}$   | ISA (2000)         |  |                               |                      |                                 |                              |
| SA (2006) different locations<br>SA (2007) 234 homes<br>SA (2007) 234 homes<br>$19.6 \mu g  m^{-3}$<br>$14.3 \mu g  m^{-3}$<br>$20.1 \mu g  m^{-3}$<br>$32.5 \mu g  m^{-3}$<br>$20.5 \mu g  m^{-3}$<br>$34 \mu g  m^{-3}$<br>$34 \mu g  m^{-3}$<br>$34 \mu g  m^{-3}$  | 2000)              |  |                               | Australia (2000)     | 172 varavano                    |                              |
| SA (2007) 234 homes $14.3 \ \mu\text{g m}^{-3}$ $20.1 \ \mu\text{g m}^{-3}$ $12.5 \ \mu\text{g m}^{-3}$  | ISA (2006)         |  |                               |                      |                                 | 100 Pho                      |
| SA (2007) 234 homes $20.1 \ \mu g \ m^{-3}$ $32.5 \ \mu g \ m^{-3}$ $34 \ \mu g \ m^{-3}$  | 3A (2000)          | unrerent locations                     | $14.3 \ \mu g \ m^{-3}$       | Other                |                                 |                              |
| $\begin{array}{c} 32.5 \ \mu \text{g m}^{-3} \\ 20.5 \ \mu \text{g m}^{-3} \\ 34 \ \mu \text{g m}^{-3} \end{array} \qquad \text{submarine (2006)} \qquad \text{submerged operation} \qquad <10 \ \mu \text{g m}^{-3} \end{array}$  | ISA (2007)         | 224 homos                              | $17.5 \ \mu g \ m^{-3}$       | aircraft (simulated) | occupied cabin                  | 8-10 ppb                     |
| $20.5  \mu \text{g m}^{-3}$<br>34 $\mu \text{g m}^{-3}$  | JSA (2007)         | 254 nomes                              | $20.1 \ \mu g \ m^{-3}$       |                      |                                 | $< 10 \ \mu g \ m^{-3}$      |
| $34 \mu \mathrm{g} \mathrm{m}^{-3}$  |                    |  | $52.5 \ \mu g \text{ m}^{-3}$ | Submarne (2000)      | submerged operation             | 10 µg m                      |
| 34 µg m <sup>-3</sup>  |                    |  |                               |                      |                                 |                              |
|  |                    |  | $34 \ \mu g \ m^{-3}$         |                      |                                 |                              |

### Formaldehyde & Health Impacts



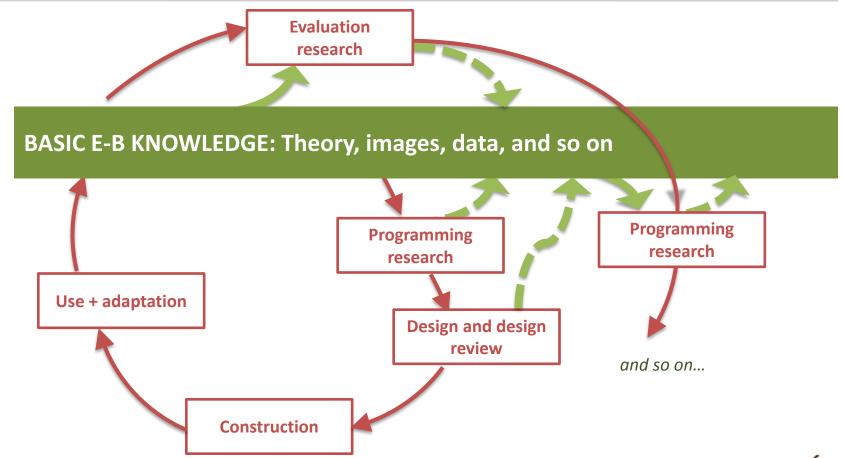
#### **DESIGN FOR ACTIVE AGING**

Sherry Ahrentzen, Elif Tural Stardust Center for Affordable Homes + the Family Arizona State University

Sherry.ahrentzen@asu.edu Elif.tural@asu.edu



#### **Scientific Research v Design Research**



Occasions for research/design cooperation in the design-process cycle.

From: Zeisel, J. (2006). *Inquiry by Design: Environment/Behavior/Neuroscience in Architecture, Interiors, Landscape, and Planning* (p. 36). New York: W. W. Norton & Co.



# **Active Aging**

The desire, ability and opportunity for older adults to integrate physical activity into both structured and unstructured daily routines

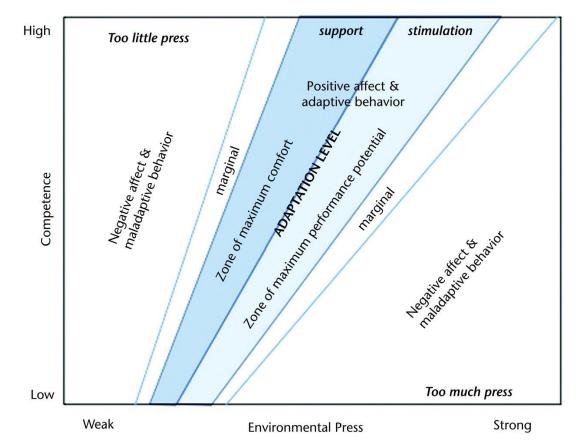


Includes physical engagement in economic or socially productive activities





#### **Environmental Press-Competence**



From: Lawton, M.P. & Nahemow, L. (1973). Ecology and the aging process. In C. Eisdorfer & M.P. Lawton (Eds.), *Psychology of adult development and aging* (pp. 657-668). Washington, DC: American Psychological Association.



#### **Secure Independence**





### **Secure Independence**

#### Safety from Falls & the Unfamiliar

- Secure only doors to high-risk areas
- Secure outdoor areas
- Smooth, well-maintained flooring and paths
- **Resilient materials**
- Lighting and glare
- Previewing

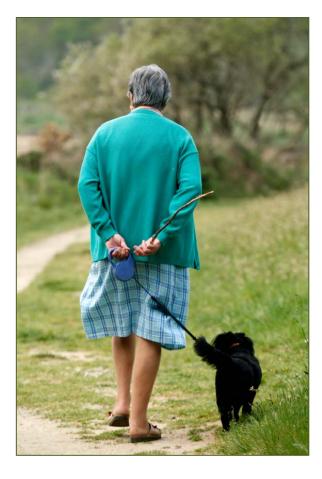
Previewing

#### Home Use & Activity

Small and familiar tasks Cultural and generational ties



#### **Secure Independence**





Small & familiar tasks



#### **Engagement in Place**





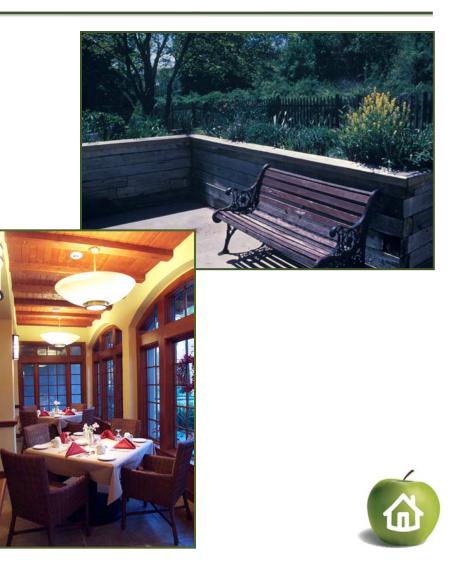
### **Engagement in Place**

Heighten interest & curiosity Environmental contrast

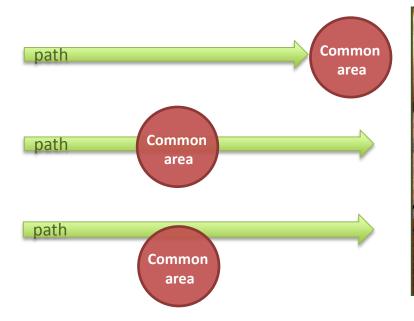
Minimize distraction, stress Auditory privacy Visual attention

Social gathering places **Places near the heart** Socially stimulating alcoves

Neighborhood Amenities Resting areas and furnishings Transit accessibility



### **Engagement in Place**





Places near the heart

Adapted from: "Common Areas at the Heart." Alexander, C. , *et al.* (1977). *A Pattern Language: Towns, Buildings, Construction*. New York: Oxford University Press.









#### Mobility

For wheelchairs & scooters For walkers and canes

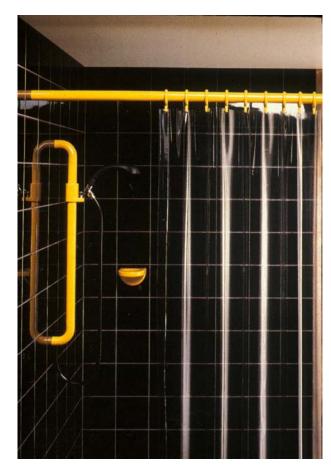
#### Sensory

Lighting & glare Auditory **Kinetic & touch** 

#### Cognitive

Multiple cues for orientation Clear floor plan Control of stimulation







Flooring material change as a visual cue

Color contrast for cueing





Enhance touch



Minimize squatting





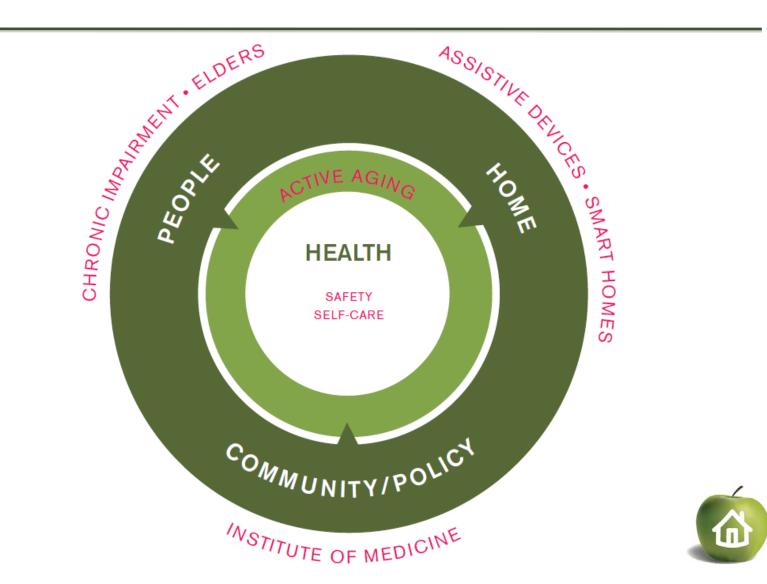
# ELDER HOME HEALTH TECHNOLOGY ASSISTANCE

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#### **Elder Home Health Technology Assistance**



## **Elders in Their Homes**

• 65-and-over population (U.S. Department of Health and Human Services' Administration on Aging, 2009)

- -55 million in 2020
- -72 million in 2030 (2x 2007)
  - •>19 percent of the population
- Chronic diseases with co-morbidity
  - -medication
    - •complicated
    - •compliance issues
  - -lifestyle guidance
  - -memory assistance
  - -physical care

Chronic physical or mental impairment– (Building Health Systems, RWJ, 2002)

- –99 million
- -\$470 billion annually



## **Institute of Medicine**

- Nonprofit, non-governmental organization founded in 1970, under the congressional charter of the United States National Academy of Sciences.
- Provides unbiased, evidence-based, and authoritative information and advice concerning health and science policy to policy-makers, professionals, leaders in every sector of society, and the public at large
- In 2001 issued aims and design rules for the new century

-6 aims

•Safe, effective, efficient, patient-centered, timely and provides equitable health care

-10 rules

•Patient as source of control, shared knowledge with free flow of information, evidence-based decision making, continuous healing relationships, customization based on patients needs, transparency, anticipation of needs, decrease in waste & cooperation among clinicians.



## **Assistive Devices**

•Environment Interventions

Ramps, lowered cabinets, secure flooring

Assistive Technology

•Canes, walkers, bath benches

•Ehealth, Telemedicine, Telehealth

Monitoring

•Self

•Feedback goes to user

•Wellness or disease management

•Heart rate monitors, blood pressure, glucose

Wearable sensors

Motivation for self-care

•Challenge to make meet needs of consumer

Persuasive technology

•Remote

•Feedback goes to family or professional

•Disease exacerbation, independent living, recuperation

•Fall sensors, movement monitors , risk evaluation

•Embedded in environment

•Detect change in status

•Just-in-time rescue

Reassurance



### **The Smart Home**

- The term "smart home" refers to a residence equipped with technology that facilitates monitoring of residents and/ or promotes independence and increases residents' quality of life. (Demiris & Hensel, 2008)
- Promoting Independence <u>http://www.tiresias.org/research/guidelines/smart\_home.htm</u>
  - Provide an environment that is constantly monitored to ensure the householder is safe (activity monitoring)
  - Automate specific tasks that a householder is unable to perform (turning lights on or off)
  - Provide a safe and secure environment (alerting the householder of potentially dangerous activities)
  - Alert helpers or caregivers should the householder be in difficulties (through linking to a local community alarm scheme)
  - Enable and empower the user
  - Facilitate in the rehabilitation of householders (by giving prompts that b auditory and/or visual)



## What Do Patients Need to Engage in Proactive Self-care? (Horowitz, 2008)

- Enable early diagnosis
  - Ability to collect data that detects a change, assess the meaning of the data, alert patient and make recommendation for making decisions for action
- Enable personal intervention
  - Empowered without calling a healthcare provider
- Improve the quality of communication
  - Better coordinate/communicate among caregiver, service provider, medical provider and peers



## **Most Common Assistive Devices**

- Purpose
  - gathering and transmitting information,
    reporting and informing (telemonitoring)
- Types
  - Medication Regulation
  - Wandering precautions
    - Managing wandering in the home (monitoring location)
    - Managing exit from the home (alarms)





#### **Smart Home Research**

- Systematic Review of research projects on Smart Homes (Demiris & Hensel, 2008)
  - Physiologic monitoring (47%)
  - Functional monitoring and emergency detection (71%)
  - Safety monitoring and assistance (67%)
  - Security monitoring and assistance (19%)
  - Social interaction monitoring and assistance (19%)
  - Cognitive and sensory assistance (43%)
- Need more research on effectiveness of smart homes



#### **Smart Home Complexity**





Photo from -http://www.homecontrolplus.net/solutions.html

## **Labs for Monitoring**



Photo from- http://www.topnews.in/your-smarthouse-future-will-take-care-you-old-age-2142820





# Smart Home Mixes Old with Green and High-tech



## **Ambient Kitchen**

- Lab-based replication of a real kitchen (Newcastle, UK)
- Preparing food and drink was to their sense of autonomy.
- Prompting people in the early stages of dementia through multistep tasks (Wherton & Monk, 2008)
- The environment integrates data projectors, cameras, RFID tags and readers, object mounted accelerometers, and under-floor pressure sensing using a combination of wired and wireless networks



Photo from: Oliver et al., 2009



## **Challenges to Home Design**

- Ubiquitous, ambient, non-invasive, & ergonomic
- Aesthetics, trends, style, fashion & compatibility with interior design
  - Cost vs. extension of a few months
  - Balancing health needs with home design
- Avoid image of sickness or disability
- Attractive things work better (Norman, D. Emotional Design)
- Aesthetics and usability correlate (Tractinsky et al 2000).
- Floor plan
  - Interaction between devices
  - openness so sensors are not blocked
  - Access to buttons on devices (ex. mirror)
- Connectivity
- Privacy



## Conclusion

- Great impetus to keep aging population in their homes
- Smart Home technology is evolving rapidly
- Elders want technology to empower them to make decisions and stay independent
- Research has not focused on effective use
- Many challenges to integration into home
- Opportunities for exploring influence of smart home technology on home design

