Carbon Saving Effects of Building Retrofits Considering Life Cycle

Seongwon Seo and Greg Foliente

Cities Program, CSIRO Land & Water
5-6 November, 2014, avniR Conference
Contents

- Motivation & Objective
- Method
- Case study
- Results
- Summary
We can’t satisfy carbon reduction target with new construction. We need to think about existing building stock.

► How to use embodied carbon for existing building stock

• Number stakeholders agreed to reduce energy & carbon emission for existing building stock. And they can consider different technologies for that but not knowledgeable.

► What kind of information provide via embodied study

• What amount each of the technology can reduce impacts considering life cycle (prioritise technologies),
• What about the payback for
  ➢ environmental (e.g., carbon, energy etc)
  ➢ financial ($) (=>$ can help Govt rebates or incentives)
Motivation & Objective

- Analyse the life cycle energy/carbon of retrofit options for commercial office building;

- Examine financial and carbon payback time of potential retrofit options considering its capital energy and carbon emissions;

- Provide valuable information to decision makers
Boundary of retrofit options

Cradle-to-Grave Retrofit Package

50 years life span

Material

Manufacture

Retrofit package

Installation

Construction

Operation

Maintenance

End-of-Life

Final Treatment

GHG from Operation

GHG from Final Treatment

GHG from Installation

GHG from Retrofit package

Transportation

System Boundary

Retrofit options
Methodology

Life cycle carbon (retrofit $j$) = $Carbon_{Initial} + Carbon_{install} + Carbon_{Operation} + Carbon_{Maint} + Carbon_{Disposal}$

$Carbon_{Initial} = \sum (\text{material} \times \text{carbon intensity})$

$Carbon_{Install} = \sum (\text{energy use} \times \text{carbon intensity})_j$ (retrofit package $j$)

$Carbon_{Operation} = \sum (\text{energy use} \times \text{carbon intensity})_k$ (k: building equip)

$Carbon_{Maint} = \sum (\text{Recurring carbon} + \text{Installation} + \text{Disposal})$

$Carbon_{Disposal} = \sum (\text{energy} \times \text{carbon intensity}) + \sum (\text{material} \times \text{transportation} \times \text{carbon intensity})$
### Building type (Office)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of storey</td>
<td>3 storey</td>
</tr>
<tr>
<td>Dimension (m)</td>
<td>35 x 35</td>
</tr>
<tr>
<td>Floor to ceiling (m)</td>
<td>2.7</td>
</tr>
<tr>
<td>Total floor area (m²)</td>
<td>7240 (70% office area, 30% for others)</td>
</tr>
<tr>
<td>Wall</td>
<td>150mm LW concrete</td>
</tr>
<tr>
<td>Floor</td>
<td>150mm concrete</td>
</tr>
<tr>
<td>Glazing</td>
<td>Single colour tinted single glazing</td>
</tr>
<tr>
<td>Operation schedule</td>
<td>9:00am - 6:00 pm</td>
</tr>
<tr>
<td>HVAC system</td>
<td>VAV with reheat (DX split system air conditioning)</td>
</tr>
<tr>
<td>Temperature setting for cooling (°C)</td>
<td>24</td>
</tr>
<tr>
<td>Temperature setting for heating (°C)</td>
<td>21</td>
</tr>
<tr>
<td>Lifts</td>
<td>N/A</td>
</tr>
<tr>
<td>Occupancy* (m²/person)</td>
<td>15</td>
</tr>
<tr>
<td>Equipment load*(W/m²)</td>
<td>16</td>
</tr>
<tr>
<td>Lighting load*(W/m²)</td>
<td>13</td>
</tr>
</tbody>
</table>

* NABERS (National Australian Built Environment Rating System) Energy guideline for existing commercial building
HVAC system - Dominant contributor (eg., Brisbane and Darwin more than 45% of total carbon emissions. Perth and Sydney are also highly influenced by HVAC system with 40% and 38% respectively.
## Energy & Carbon Intensities

### Retrofit packages

<table>
<thead>
<tr>
<th>Package</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Replacing T5 lighting in office area (28W T5 fluorescent tube)</td>
</tr>
<tr>
<td>2</td>
<td>Chiller replacement (COP 4.2)</td>
</tr>
<tr>
<td>3</td>
<td>Replacing single glazing with high performance double glazing (6mm low-E)</td>
</tr>
</tbody>
</table>

\[
N \text{ (Number of lamp fitting)} = \frac{E \times A}{F \times \mu F \times LLF}
\]

- **E**: Lux level required on working plan (desk, normally 320 lx from AS [37])
- **A**: Area of room (L X W) Office area assumes 70% of total building floor area.
- **F**: total flux (lumens) from all the lamps in one fitting
- **μF**: Utilization factor from the table for the fitting to be used (0.5 for ceiling reflectance)
- **LLF**: Lighting Loss Factor, depreciation over time of lamp output and dirt accumulation on the fitting (typical LLF for air conditioned office = 0.8 [38])

\[
\frac{320 \text{ lx} \times 1690.9 \text{ m}^2 / \text{floor}}{3320 \text{ lm} \times 0.5 \times 0.8} = 407 \text{ of lamps per floor, thus, total lamps are 1,222 (=407 ×3 floor) of lamps.}
\]
Life cycle carbon of options

Initial embodied carbon
Embodied carbon/lamp X total lamp
T5 linear fluorescent lamp (35W):
24.78 kg CO$_2$eq/lamp (8,000 hrs) X 1122 lamps
30,294 kg CO$_2$eq/total

Installation
Assumed 8.25% of initial emb. Carbon (Buchanan & Honey, 1994)
2,499 kg CO$_2$eq/building

Maintenance
14 times replacement during the life span (50 years)
470,992 kg CO$_2$eq/building’s life span

Final treatment
Assumed no recycle (all go to landfill site)
848 kg CO$_2$eq (114g for avg T5 lamp, 20km distance of local landfill site)
Life cycle carbon of options

Initial embodied carbon

Air cooled screw chiller (300kW):
10,661 kg CO$_2$eq (Chen et al., 2011)

Installation

Assumed 8.25% of initial emb. Carbon (Buchanan & Honey, 1994)
879.5 kg CO$_2$eq/building

Maintenance

1 time replacement (25 years life span) during the life span (50 years)
11,559 kg CO$_2$eq/building’s life span

Final treatment

Assumed all recycled (mostly iron & copper)
18.3 kg CO$_2$eq (30km distance of local recycling centre)
Life cycle carbon of options

Initial embodied carbon
718,728 kg CO₂eq
971 m² of total window area (density 2.55 ton/m³)
691 kg CO₂eq/m² of aluminium frame
  (U=1.6W/m²K, 30% recycled)
49 kg CO₂eq/m² of double glazing (6mm)

Installation
Assumed 8.25% of initial emb. Carbon (Buchanan & Honey, 1994)
59,295 kg CO₂eq/building

Maintenance
Assumed no required maintenance during the life cycle of building

Final treatment
Assumed all recycled
220 kg CO₂eq (30km distance of local recycling centre)
Life cycle carbon emission of retrofit options

- Life cycle carbon (kg CO₂eq):
  - T5: 504,635 (65%)
  - Chiller: 23,218 (3%)
  - DG 6mm: 778,244 (100%)

- Emission factors:
  - 69.6 kg CO₂eq/m²
  - 3.2 kg CO₂eq/m²
  - 92%

- Operational benefit:
  - 107.4 kg CO₂eq/m²

- Percentage contributions:
  - 93%
GHG Reduction due to Retrofit

**Adelaide**

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>T5 lamp</th>
<th>Chiller replacement</th>
<th>Double glazing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>kg CO₂/eq/mt (Adelaide)</strong></td>
<td>138</td>
<td>120</td>
<td>6% (24%)</td>
<td>108</td>
</tr>
</tbody>
</table>

**Perth**

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>T5 lamp</th>
<th>Chiller replacement</th>
<th>Double glazing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>kg CO₂/eq/mt (Perth)</strong></td>
<td>200</td>
<td>180</td>
<td>7% (19%)</td>
<td>160</td>
</tr>
</tbody>
</table>

**Melbourne**

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>T5 lamp</th>
<th>Chiller replacement</th>
<th>Double glazing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>kg CO₂/eq/mt (Melbourne)</strong></td>
<td>150</td>
<td>138</td>
<td>12% (26%)</td>
<td>118</td>
</tr>
</tbody>
</table>

**Brisbane**

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>T5 lamp</th>
<th>Chiller replacement</th>
<th>Double glazing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>kg CO₂/eq/mt (Brisbane)</strong></td>
<td>250</td>
<td>230</td>
<td>9% (18%)</td>
<td>210</td>
</tr>
</tbody>
</table>

**Sydney**

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>T5 lamp</th>
<th>Chiller replacement</th>
<th>Double glazing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>kg CO₂/eq/mt (Sydney)</strong></td>
<td>100</td>
<td>88</td>
<td>7% (19%)</td>
<td>70</td>
</tr>
</tbody>
</table>

**Darwin**

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>T5 lamp</th>
<th>Chiller replacement</th>
<th>Double glazing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>kg CO₂/eq/mt (Darwin)</strong></td>
<td>180</td>
<td>160</td>
<td>6% (24%)</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td>Unit</td>
<td>MEL</td>
<td>SYD</td>
<td>ADE</td>
</tr>
<tr>
<td>----------</td>
<td>---------------------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>T5</td>
<td>LCCO$_2$eq</td>
<td>70</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>Reduction</td>
<td>16</td>
<td>13</td>
<td>8.8</td>
</tr>
<tr>
<td>Chiller</td>
<td>LCCO$_2$eq</td>
<td>3.2</td>
<td>3.2</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>Reduction</td>
<td>9</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Double</td>
<td>LCCO$_2$eq</td>
<td>107.4</td>
<td>107.4</td>
<td>107.4</td>
</tr>
<tr>
<td>Glazing</td>
<td>Reduction</td>
<td>22</td>
<td>21</td>
<td>17</td>
</tr>
</tbody>
</table>
Carbon & Financial Payback Time

<table>
<thead>
<tr>
<th>Location</th>
<th>Carbon Payback Time</th>
<th>Financial Payback Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T5</td>
<td>Chiller</td>
</tr>
<tr>
<td>ADE</td>
<td>7.7</td>
<td>0.4</td>
</tr>
<tr>
<td>MEL</td>
<td>4.3</td>
<td>0.3</td>
</tr>
<tr>
<td>SYD</td>
<td>5.3</td>
<td>0.3</td>
</tr>
<tr>
<td>BRI</td>
<td>5.4</td>
<td>0.2</td>
</tr>
<tr>
<td>PER</td>
<td>5.9</td>
<td>0.2</td>
</tr>
<tr>
<td>DAR</td>
<td>6.4</td>
<td>0.2</td>
</tr>
</tbody>
</table>

T5: T5 replacement, Chiller: Chiller replacement, D-G: Double Glazing
Conclusion

This study presented a systematic life cycle evaluation for retrofit options and demonstrated life cycle impact of several retrofits based on Australian cities having different climate zones.

*Chiller replacement* has the *least* carbon emission while replacement *double glazing window* was identified having *largest* carbon emission during the life cycle of building (50 years).

Efficient *lighting (T5) replacement* has *small amount of initial embodied carbon* (6% of total) but it requires lot of carbon emissions in the *maintenance stage* having more than *93% of total carbon*.

Payback time can provide decision makers to distinguish short payback time for their retrofit selection. While carbon has relatively short payback, financial payback generally requires longer period.

*Chiller replacements* are more *effective* for the carbon reduction in the *tropical/subtropical area* due to shorter payback than other regions. But there exists trade off relationship between carbon emissions versus economic (investment).