

CODE FOR

# Environmental Sustainability of Buildings

Edition 4.0



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CODE FOR  
**ENVIRONMENTAL  
SUSTAINABILITY**  
OF BUILDINGS

Edition 4.0

September 2021

# CODE FOR ENVIRONMENTAL SUSTAINABILITY OF BUILDINGS

## Table of Contents

Introduction .....	1
1 Scope .....	2
2 Definitions.....	2
3 Statutory Requirements .....	2
4 Compliance Methodology .....	4
5 Submission Procedures .....	23
Appendix A: Areas of Responsibility .....	25
Appendix B: Compliance Requirements & Documentation for Residential Buildings.....	28
Appendix C: Compliance Requirements & Documentation for Non-Residential Buildings.....	60
Appendix D: Energy Modelling Methodology and Requirements .....	117
Appendix E: Daylight Availability Tables and Methodology.....	147

# INTRODUCTION

The intent of this Code for Environmental Sustainability of Buildings (referred to as “this Code”) is to establish environmentally friendly practices on the planning, design and construction of buildings, which would help to mitigate the environmental impact of built structures.

This Code sets out the guidance and details in respect of the minimum environmental sustainability standard for buildings defined in the Building Control (Environmental Sustainability) Regulations 2008 and the administrative requirements.

This Code is not intended to abridge safety, health, environmental or related requirements contained in other applicable laws, codes or policies administered by relevant authorities. Where there is a conflict between a requirement of this Code and such other laws affecting the design and construction of the building, precedence shall be determined by the relevant authorities.

If you need clarification on any aspect of this Code, please contact the Building and Construction Authority, Singapore.

# 1 SCOPE

This Code sets out the minimum environmental sustainability standard for buildings and the administrative requirements in complying with the Building Control (Environmental Sustainability) Regulations 2008. It includes the compliance method for determining the level of environmental performance of building development.

The provisions of this Code shall apply to:

- a. building works which involve a gross floor area of 5,000 m<sup>2</sup> or more;
- b. building works which involve increasing the gross floor area of an existing building by 5,000 m<sup>2</sup> or more;
- c. building works relating to an existing building which involve a gross floor area of 5000 m<sup>2</sup> or more, and which involve the provision, extension or substantial alteration of the building envelope and building services in or in connection with an existing building.

The referenced codes, standards and other documents referred to in this Code shall be considered part of the requirements of this Code to the extent as prescribed.

# 2 DEFINITIONS

For the purpose of this Code, the following definitions shall apply:

Dwelling Unit	A unit within residential development that provides complete, independent living facilities for one or more persons.
Gross Floor Area (GFA)	The "gross floor area" has the same meaning as "floor area" in the Planning (Development Charges) Rules (Cap.232, R 5).
Major Retrofitting	The provision, extension or substantial alteration of the building envelope and building services in or in connection with an existing building.
Minimum Green Mark Score	The score that would meet the minimum level of environmental performance required for building works.
Total System Efficiency (TSE)	The combined system efficiency of the water-side component and air-side component of the building cooling system. It is a measure of how efficiently the building cooling system would operate to meet the operating condition and requirements in providing an acceptable indoor thermal environment.

In instances where terms are not expressly stated in this Code and are defined in other referenced documents, such terms shall have the meanings as determined in those documents.

# 3 STATUTORY REQUIREMENTS

## 3.1 Act and Regulations

The following Act and Regulations have relevance:

- a. The Building Control Act
- b. The Building Control Regulations
- c. The Building Control (Environmental Sustainability) Regulations

### 3.2 Reference Codes and Standards

The following codes and standards have relevance:

- a. Code on Envelope Thermal Performance for Buildings
- b. SS 212 : Specification for Aluminium Alloy Windows
- c. SS 654 : Code of Practice for Curtain Walls
- d. SS 530 : Code of Practice for Energy Efficiency Standard for Building Services and Equipment
- e. SS 531-1 : Code of Practice for Lighting of Work Places - Indoor
- f. SS 553 : Code of Practice for Air-Conditioning and Mechanical Ventilation in Buildings
- e. SS 591 : Code of Practice for Long Term Measurement of Central Chilled Water System Energy Efficiency
- f. AHRI Standard 550/590 - Performance Rating of Water Chilling and Heat Pump Water-Heating Packages using the Vapour Compression Cycle
- g. ANSI/ASHRAE/IES Standard 90.1 - Energy Standard for Buildings Except Low-Rise Residential Buildings

### 3.3 Responsibility

The developer or building owner shall engage appropriate practitioners that is the Qualified Person (QP), Professional Engineer (Mechanical) and Professional Engineer (Electrical) to ensure that the building works are designed with physical features or amenities, and may be carried out using methods and materials to ensure compliance with the minimum environmental sustainability standard stipulated in the Building Control (Environmental Sustainability) Regulations.

The QP who submits the building plan shall be overall responsible to ensure that the minimum environmental sustainability standard is met. The QP together with the other appropriate practitioners (i.e. PE (Mechanical) and PE (Electrical)) shall be responsible for the building works under their charge. The areas of responsibility are as prescribed in Appendix A of this Code.

### 3.4 Minimum Environmental Sustainability Standard

3.4.1 The minimum environmental sustainability standard of building works shall have a level of environmental performance that meets all relevant Base Requirements and incorporates the number of appropriate sustainability indicators under Carbon Reduction Measures as specified in Table 3.4, Section 4.1 and 4.2 in order to meet the minimum Green Mark score of 50 points.



Figure 3.4 – Overview of Compliance Framework

3.4.2 The level of environmental performance required based on the building categories are as stipulated in the following Table 3.4.

**Table 3.4 – Compliance Methodology and Required Level of Environmental Performance**

Residential Buildings		Non-Residential Buildings		
<ul style="list-style-type: none"> <li>▪ All Base Requirements as listed in Table 4.1(a), where applicable.</li> <li>▪ A selection of four (4) Carbon Reduction Measures in total as listed in Table 4.2(a) including a minimum of two (2) measures from Section 2 - Sustainable Construction.</li> </ul>		<ul style="list-style-type: none"> <li>▪ All Base Requirements as listed in Table 4.1(b), where applicable.</li> <li>▪ A selection of four (4) Carbon Reduction Measures in total as listed in Table 4.2(b) including a minimum of two (2) measures from Section 2 - Sustainable Construction.</li> </ul>		
Mixed-Use Building Developments				
<p>For mixed-use building developments consisting of residential and non-residential buildings/components, the minimum environmental sustainability standards for both residential and non-residential buildings/components are to be complied with. If the GFA of any building works relating to the residential building/component or to the non-residential building/component is less than 2000 m<sup>2</sup>, the minimum environmental sustainability standard shall apply to the larger part of the building works based on the requirements under the respective building categories and as summarised below.</p>				
Project Type	Total New GFA Residential (m <sup>2</sup> )	Total New GFA Non-Residential (m <sup>2</sup> )	Residential Applicable	Non-Residential Applicable
Mixed-Use Building Developments	≥ 2000	≥ 2000	Yes	Yes
	≥ 2000	< 2000	Yes	No
	< 2000	≥ 2000	No	Yes
Simple Structures and Buildings that are solely used for specific functions*				
<ul style="list-style-type: none"> <li>▪ All Base Requirements stipulated for Non-Residential Buildings, where applicable.</li> </ul>				
<p>*Applicable only to the following building works in relation to the erection of simple structures and buildings solely used for specific functions as listed below:</p>				
<ul style="list-style-type: none"> <li>• <i>Link-ways</i></li> <li>• <i>Underground passes</i></li> <li>• <i>Open sheds</i></li> <li>• <i>Standalone substation</i></li> <li>• <i>Lift upgrading</i></li> <li>• <i>Farm structures</i></li> <li>• <i>Temporary workers' dormitories</i></li> <li>• <i>Treatment Plants</i></li> <li>• <i>Transport facilities (i.e. bus interchanges, transit stations and the like)</i></li> </ul>				

## 4 COMPLIANCE METHODOLOGY

### 4.1 BASE REQUIREMENTS

The Base Requirements essentially are environmental sustainability attributes that have a direct impact on the building energy performance and are to be complied with, where applicable. The details are provided in the following Table 4.1(a) and Table 4.1(b) for the respective building categories.

**Table 4.1(a) – Base Requirements for Residential Buildings**

ENVIRONMENTAL SUSTAINABILITY ATTRIBUTES	APPLICABILITY & SCOPE												
<b>RB01 Envelope and Roof Thermal Transfer</b>													
A building shall be designed and constructed with good thermal performance to reduce solar heat gain through the building envelope and roof.	Thermal performance of building envelope and roof												
<b>RB01-1 Building Envelope</b>													
<p>Reduce heat gain through the building envelope to enhance thermal comfort and reduce the energy needed to condition the indoor environment, when required.</p> <p>(a) The building envelope is to be designed with Residential Envelope Transmittance Value (RETV) of not more than 22 W/m<sup>2</sup> based on the methodology stated in the Code on Envelope Thermal Performance for Buildings;</p> <p>OR</p> <p>(b) The building envelope design is deemed to have satisfied the performance requirements if it meets the following criteria.</p> <table border="1"> <thead> <tr> <th>Window to Wall Ratio (WWR)</th> <th>Shading Coefficients of Glass (SC<sub>glass</sub>)</th> </tr> </thead> <tbody> <tr> <td>&lt; 0.30</td> <td>≤ 0.67</td> </tr> <tr> <td>0.30 to &lt; 0.35</td> <td>≤ 0.59</td> </tr> <tr> <td>0.35 to &lt; 0.40</td> <td>≤ 0.52</td> </tr> <tr> <td>0.40 to &lt; 0.45</td> <td>≤ 0.48</td> </tr> <tr> <td>0.45 to ≤ 0.50</td> <td>≤ 0.43</td> </tr> </tbody> </table>	Window to Wall Ratio (WWR)	Shading Coefficients of Glass (SC <sub>glass</sub> )	< 0.30	≤ 0.67	0.30 to < 0.35	≤ 0.59	0.35 to < 0.40	≤ 0.52	0.40 to < 0.45	≤ 0.48	0.45 to ≤ 0.50	≤ 0.43	Building envelope design
Window to Wall Ratio (WWR)	Shading Coefficients of Glass (SC <sub>glass</sub> )												
< 0.30	≤ 0.67												
0.30 to < 0.35	≤ 0.59												
0.35 to < 0.40	≤ 0.52												
0.40 to < 0.45	≤ 0.48												
0.45 to ≤ 0.50	≤ 0.43												
<b>RB01-2 Roof</b>													
<p>The average thermal transmittance (U-Value) of roof shall not exceed the prescribed limits as stated below:</p> <table border="1"> <thead> <tr> <th>Roof Weight Group</th> <th>Weight Range (kg/m<sup>2</sup>)</th> <th>Maximum U- value (W/m<sup>2</sup>K)</th> </tr> </thead> <tbody> <tr> <td>Light</td> <td>&lt;50</td> <td>0.8</td> </tr> <tr> <td>Medium</td> <td>50 to 230</td> <td>1.1</td> </tr> <tr> <td>Heavy</td> <td>&gt;230</td> <td>1.5</td> </tr> </tbody> </table>	Roof Weight Group	Weight Range (kg/m <sup>2</sup> )	Maximum U- value (W/m <sup>2</sup> K)	Light	<50	0.8	Medium	50 to 230	1.1	Heavy	>230	1.5	Roof design
Roof Weight Group	Weight Range (kg/m <sup>2</sup> )	Maximum U- value (W/m <sup>2</sup> K)											
Light	<50	0.8											
Medium	50 to 230	1.1											
Heavy	>230	1.5											

Table 4.1(a) – Base Requirements for Residential Buildings							
ENVIRONMENTAL SUSTAINABILITY ATTRIBUTES	APPLICABILITY & SCOPE						
<b>RB02 Building Energy Performance</b>							
A building shall be designed and constructed with energy efficiency measures to reduce the energy consumption of building energy systems and meet the minimum energy efficiency improvements of 50% over the 2005 baseline.	Energy performance of building energy systems						
<b>RB02-1 Air-Conditioning System</b>							
Reduce energy required for space cooling by providing energy-efficient air-conditioning systems that could meet the following energy performance standard or equivalent.	Air-conditioning system for at least 80% of the total number of dwelling units and common facilities						
<table border="1"> <thead> <tr> <th colspan="2">Minimum Energy Performance Standard</th> </tr> </thead> <tbody> <tr> <td>Single/ Multi-Split System</td> <td>5-tick rated</td> </tr> <tr> <td>Variable Refrigerant Flow (VRF) system</td> <td>3-tick rated</td> </tr> </tbody> </table> <p>Note(1) – The single/multi-split air conditioners and VRF systems are to be rated and labelled with Energy Label as required under the Energy Conservation Act.</p> <p>Note (2) – Other systems such as centralised cooling systems (CCS) provided are to be designed to meet the minimum energy performance standard of 0.67 kW/RT.</p>	Minimum Energy Performance Standard		Single/ Multi-Split System	5-tick rated	Variable Refrigerant Flow (VRF) system	3-tick rated	
Minimum Energy Performance Standard							
Single/ Multi-Split System	5-tick rated						
Variable Refrigerant Flow (VRF) system	3-tick rated						
<b>RB02-2 Lighting System for Common Facilities and Areas</b>							
Reduce energy required to illuminate spaces in common facilities and areas with proper lighting levels. The lighting provision shall be at least 40% more energy efficient than the prescribed lighting power budget stated in SS 530 – Code of Practice for Energy Efficiency Standard for Building Services and Equipment. Lighting control for artificial lighting shall also be provided in accordance with SS 530, where applicable.	Lighting system for common facilities and areas						
<b>RB02-3 Mechanical Ventilation System for Car Parks</b>							
Reduce energy required by regulating the demand for mechanical ventilation in car parks by way of Carbon Monoxide (CO) detection sensor controls with Variable Speed Drives (VSDs).	Mechanical ventilation system for car parks						
<b>RB02-4 Vertical Transportation System</b>							
Reduce energy consumption by providing energy-efficient vertical transportation systems that are equipped with variable voltage variable frequency (VVVF) drives and sleep mode features.	Lift systems that serve four (4) floors or more						

**Table 4.1(b) – Base Requirements for Non-Residential Buildings**

ENVIRONMENTAL SUSTAINABILITY ATTRIBUTES	APPLICABILITY & SCOPE														
<b>NRB01 Envelope and Roof Thermal Transfer</b>															
A building shall be designed and constructed with good thermal performance to reduce solar heat gain through the building envelope and roof.	Thermal performance of building envelope and roof														
<b>NRB01-1 Building Envelope</b>															
<p>Reduce heat gain through the building envelope to enhance thermal comfort and reduce the energy needed to condition the indoor environment.</p> <p>(a) The building envelope is to be designed with Envelope Thermal Transfer Value (ETTV) of not more than 45 W/m<sup>2</sup> based on the methodology stated in the Code on Envelope Thermal Performance for Buildings;</p> <p>OR</p> <p>(b) The building envelope design is deemed to have satisfied the performance requirements if it meets the following criteria.</p> <table border="1"> <thead> <tr> <th>Window to Wall Ratio (WWR)</th> <th>Shading Coefficients of Glass (SC<sub>glass</sub>)</th> </tr> </thead> <tbody> <tr> <td>&lt; 0.20</td> <td>≤ 0.51</td> </tr> <tr> <td>0.20 to &lt; 0.25</td> <td>≤ 0.41</td> </tr> <tr> <td>0.25 to &lt; 0.30</td> <td>≤ 0.35</td> </tr> <tr> <td>0.30 to &lt; 0.35</td> <td>≤ 0.30</td> </tr> <tr> <td>0.35 to &lt; 0.40</td> <td>≤ 0.27</td> </tr> <tr> <td>0.40 to ≤ 0.50</td> <td>≤ 0.22</td> </tr> </tbody> </table>	Window to Wall Ratio (WWR)	Shading Coefficients of Glass (SC <sub>glass</sub> )	< 0.20	≤ 0.51	0.20 to < 0.25	≤ 0.41	0.25 to < 0.30	≤ 0.35	0.30 to < 0.35	≤ 0.30	0.35 to < 0.40	≤ 0.27	0.40 to ≤ 0.50	≤ 0.22	<p>Building envelope design</p> <p>Buildings with an aggregate air-conditioning area of more than 500 m<sup>2</sup></p>
Window to Wall Ratio (WWR)	Shading Coefficients of Glass (SC <sub>glass</sub> )														
< 0.20	≤ 0.51														
0.20 to < 0.25	≤ 0.41														
0.25 to < 0.30	≤ 0.35														
0.30 to < 0.35	≤ 0.30														
0.35 to < 0.40	≤ 0.27														
0.40 to ≤ 0.50	≤ 0.22														
<b>NRB01-2 Roof</b>															
<p>Reduce heat gain through the roof to reduce the energy needed to condition the indoor environment.</p> <p>(a) The roof with skylights is to be designed with Roof Thermal Transfer Value (RTTV) of not more than 50 W/m<sup>2</sup> based on the methodology stated in the Code on Envelope Thermal Performance for Buildings.</p> <p>(b) For roof without skylights, the average thermal transmittance (U-Value) of roof shall not exceed the prescribed limits as stated below:</p> <table border="1"> <thead> <tr> <th>Roof Weight Group</th> <th>Weight Range (kg/m<sup>2</sup>)</th> <th>Maximum U- value (W/m<sup>2</sup>K)</th> </tr> </thead> <tbody> <tr> <td>Light</td> <td>&lt;50</td> <td>0.5</td> </tr> <tr> <td>Medium</td> <td>50 to 230</td> <td>0.8</td> </tr> <tr> <td>Heavy</td> <td>&gt;230</td> <td>1.2</td> </tr> </tbody> </table>	Roof Weight Group	Weight Range (kg/m <sup>2</sup> )	Maximum U- value (W/m <sup>2</sup> K)	Light	<50	0.5	Medium	50 to 230	0.8	Heavy	>230	1.2	<p>Roof design with and without skylights</p>		
Roof Weight Group	Weight Range (kg/m <sup>2</sup> )	Maximum U- value (W/m <sup>2</sup> K)													
Light	<50	0.5													
Medium	50 to 230	0.8													
Heavy	>230	1.2													

**Table 4.1(b) – Base Requirements for Non-Residential Buildings**

ENVIRONMENTAL SUSTAINABILITY ATTRIBUTES	APPLICABILITY & SCOPE
<b>NRB02 Air-Tightness and Leakage</b>	
<p>A building shall be designed and constructed with energy conservation measures to reduce air leakage through doors, windows and other openings on the building envelope.</p>	<p>Measures to minimise air infiltration or exfiltration</p>
<b>NRB02-1 Windows and Curtain Walls</b>	
<p>Minimise air leakage through building envelope by way of effective means of weather-stripping of windows and curtain walls.</p> <p>All windows and curtain walls shall be designed to ensure that the air leakage rates do not exceed the limits specified in the following standards.</p> <ul style="list-style-type: none"> <li>(a) SS 212 : Specification for Aluminum Alloy Windows</li> <li>(b) SS 654 : Code of Practice for Curtain Walls</li> </ul>	<p>Windows and curtain walls – Component testing</p>
<b>NRB02-2 Openings between Conditioned and Non-Conditioned Spaces</b>	
<p>Conditioned air is to be well confined to minimise heat gain to the building due to air leakage with appropriate mitigation measures.</p> <p>Building entrances and door openings to building exterior or non-air-conditioned spaces and the like, shall</p> <ul style="list-style-type: none"> <li>(a) be provided with doors that are equipped with automated technology or self-closing devices. Where door opening of any commercial units are located along the perimeter of the building envelope, that unit shall be equipped with the addition of pressure independent control valve and energy meter to measure the consumption of fan coiled units (FCUs) within the unit; and</li> <li>(b) be equipped with enclosed vestibules or other appropriate measures for the doorway with high pedestrian traffic flow*. In the case of vestibules, the interior door and exterior door must have a minimum distance of not less than 2.5 m apart and should be interlocked to avoid being opened at the same time.</li> </ul> <p><i>* Doorway with high pedestrian traffic flow refers to main entrances and those leading to transport nodes or other commercial buildings.</i></p>	<p>Building entrances and door openings to building exterior or non-air-conditioned spaces</p>
<b>NRB03 Building Energy Performance</b>	
<p>A building shall be designed and constructed with energy performance that meets the minimum energy efficiency improvements of 50% over the 2005 baseline. For building works which involve major additions and alterations or retrofitting to an existing building, the minimum energy efficiency improvement is set at 40% over the 2005 baseline to account for inherent site limitation and technical constraints.</p> <p>The compliance with this requirement shall be demonstrated either by way of energy modelling methodology or by meeting the respective energy performance standards for the key energy systems as detailed in the following sections NRB03-1 and NRB03-2.</p>	<p>Energy performance of building energy systems</p>

**Table 4.1(b) – Base Requirements for Non-Residential Buildings**

ENVIRONMENTAL SUSTAINABILITY ATTRIBUTES	APPLICABILITY & SCOPE																													
<b>NRB03-1 Whole Building Approach via Energy Modelling</b>																														
<p>Facilitate integrated design process and energy use reduction by way of energy modelling to meet the minimum energy efficiency improvements required.</p> <p>The demonstration of the energy savings requirements of 30% over prevailing standards shall be carried out in accordance with the Energy Modelling Methodology and Requirements set out in Appendix D of this Code. The limits set for the Total System Efficiency (TSE) of respective building cooling systems stipulated under NRB03-2(a) shall apply.</p>	<p>Building energy systems that are stated in the energy modelling methodology and requirements</p>																													
<b>NRB03-2 System Level Approach via Enhanced Energy Performance Standards</b>																														
<p>Facilitate energy use reduction in meeting the minimum energy efficiency improvements required with the provision of energy-efficient building systems that could meet the enhanced energy performance standard set out in the following sub-sections.</p>	<p>Key building systems stated in the sub-sections</p>																													
<b>NRB03-2(a) Air-Conditioning System</b>																														
<p>Reduce energy required to provide and distribute conditioned air within the space through the use of energy-efficient air-conditioning system.</p> <p>(i) Water-Cooled Building Cooling System comprises the following systems and components, where relevant.</p> <ul style="list-style-type: none"> <li>• Water-Cooled Chiller</li> <li>• Water-Cooled Direct-Expansion (DX) System</li> <li>• Chilled Water Pump</li> <li>• Condenser Water Pump</li> <li>• Cooling Tower</li> <li>• Air Distribution System</li> </ul> <table border="1"> <thead> <tr> <th colspan="2"><i>Total System Efficiency (TSE) for Water-Cooled Building Cooling System</i></th> </tr> <tr> <th>New Buildings</th> <th>Existing Buildings undergoing Major Retrofitting/Additions &amp; Alterations</th> </tr> </thead> <tbody> <tr> <td>0.85 kW/RT</td> <td>0.9 kW/RT</td> </tr> </tbody> </table>	<i>Total System Efficiency (TSE) for Water-Cooled Building Cooling System</i>		New Buildings	Existing Buildings undergoing Major Retrofitting/Additions & Alterations	0.85 kW/RT	0.9 kW/RT	<p>Building cooling system that serves an aggregate air-conditioning area of more than 500 m<sup>2</sup></p> <p>District Cooling system and existing air-conditioning system that serve new buildings or floor areas</p>																							
<i>Total System Efficiency (TSE) for Water-Cooled Building Cooling System</i>																														
New Buildings	Existing Buildings undergoing Major Retrofitting/Additions & Alterations																													
0.85 kW/RT	0.9 kW/RT																													
<p>where TSE refers to the combined system efficiency of the chiller plant and air distribution systems.</p>																														
<p>For new commercial buildings, the limit set on the water-side component system efficiency is 0.63 kW/RT. As for other building developments, the minimum requirement on water-side component efficiency will be based on the chilled water supply temperature and as follows:</p>																														
<table border="1"> <thead> <tr> <th colspan="8"><i>Minimum Water-Cooled Chilled Water Plant Efficiency <math>\eta_c</math></i></th> </tr> <tr> <th>New Commercial Buildings</th> <th colspan="6">Other Building Developments</th> <th rowspan="2">For chilled water supply temp above 10°C, the threshold will be adjusted from 0.64 kW/RT by 0.01 kW/RT for every 1°C increase in chilled water supply temperature</th> </tr> <tr> <th>Chilled Water Supply Temp (°C)</th> <th>6</th> <th>7</th> <th>8</th> <th>9</th> <th>10</th> </tr> </thead> <tbody> <tr> <td>0.63 kW/RT</td> <td>Water-Cooled Chiller System Efficiency (kW/RT)</td> <td>0.68</td> <td>0.67</td> <td>0.66</td> <td>0.65</td> <td>0.64</td> </tr> </tbody> </table>		<i>Minimum Water-Cooled Chilled Water Plant Efficiency <math>\eta_c</math></i>								New Commercial Buildings	Other Building Developments						For chilled water supply temp above 10°C, the threshold will be adjusted from 0.64 kW/RT by 0.01 kW/RT for every 1°C increase in chilled water supply temperature	Chilled Water Supply Temp (°C)	6	7	8	9	10	0.63 kW/RT	Water-Cooled Chiller System Efficiency (kW/RT)	0.68	0.67	0.66	0.65	0.64
<i>Minimum Water-Cooled Chilled Water Plant Efficiency <math>\eta_c</math></i>																														
New Commercial Buildings	Other Building Developments						For chilled water supply temp above 10°C, the threshold will be adjusted from 0.64 kW/RT by 0.01 kW/RT for every 1°C increase in chilled water supply temperature																							
Chilled Water Supply Temp (°C)	6	7	8	9	10																									
0.63 kW/RT	Water-Cooled Chiller System Efficiency (kW/RT)	0.68	0.67	0.66	0.65	0.64																								

**Table 4.1(b) – Base Requirements for Non-Residential Buildings**

ENVIRONMENTAL SUSTAINABILITY ATTRIBUTES	APPLICABILITY & SCOPE								
<b>NRB03-2(a) Air-Conditioning System – Cont’d</b>									
<p><i>Exception: For buildings with cooling provisions from the District Cooling System (DCS) that are regulated to meet the Minimum Energy Efficiency Standards (MEES) under the Energy Conservation Act, the TSE requirement does not apply but the air-side component system efficiency standard shall not be more than 0.25 kW/RT.</i></p> <p>(ii) Air-Cooled Building Cooling System comprises the following systems and components, where relevant.</p> <ul style="list-style-type: none"> <li>• Unitary Air-Conditioners (Single or combination of systems)               <ul style="list-style-type: none"> <li>○ Variable Refrigerant Flow (VRF) system</li> <li>○ Single-Split Units</li> <li>○ Multi-Split Units</li> <li>○ Air Distribution System</li> </ul> </li> <li>• Air-Cooled Chilled-Water System can only be adopted for existing building developments with inherent constraints and with peak building cooling load of not more than 500 RT               <ul style="list-style-type: none"> <li>○ Air-Cooled Chiller</li> <li>○ Chilled Water Pump</li> <li>○ Air Distribution System</li> </ul> </li> </ul> <div style="border: 1px solid black; padding: 5px; margin: 10px auto; width: fit-content;"> <p style="text-align: center;"><b>Total System Efficiency (TSE) for Air-Cooled Building Cooling System</b></p> <p style="text-align: center;">All Buildings including Existing Buildings undergoing Major Retrofitting / Major Additions and Alterations</p> <p style="text-align: center;">1.0 kW/RT</p> </div>	<p>Building cooling system that serves an aggregate air-conditioning area of more than 500 m<sup>2</sup></p> <p>District Cooling system and existing air-conditioning system that serve new buildings or floor areas</p>								
<p>where TSE refers to the combined system efficiency of the condenser units/ air-cooled chilled water plant and air distribution systems.</p>									
<p>The minimum water-side component efficiencies for different systems are as stated in the following table.</p>									
<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th colspan="2"><b>Minimum Air-Conditioning Component Efficiency <math>\eta_c</math></b></th> </tr> <tr> <th><b>Unitary System (Outdoor Condenser Units)</b></th> <th><b>Air-Cooled Chilled Water Plant for Peak Cooling Load &lt; 500 RT</b></th> </tr> </thead> <tbody> <tr> <td style="text-align: center;">All Buildings</td> <td style="text-align: center;">Applicable only for Existing Buildings undergoing Major Retrofitting /Major Additions and Alterations</td> </tr> <tr> <td style="text-align: center;">0.78 kW/RT (inclusive of site derating factor)</td> <td style="text-align: center;">0.85 kW/RT</td> </tr> </tbody> </table>		<b>Minimum Air-Conditioning Component Efficiency <math>\eta_c</math></b>		<b>Unitary System (Outdoor Condenser Units)</b>	<b>Air-Cooled Chilled Water Plant for Peak Cooling Load &lt; 500 RT</b>	All Buildings	Applicable only for Existing Buildings undergoing Major Retrofitting /Major Additions and Alterations	0.78 kW/RT (inclusive of site derating factor)	0.85 kW/RT
<b>Minimum Air-Conditioning Component Efficiency <math>\eta_c</math></b>									
<b>Unitary System (Outdoor Condenser Units)</b>	<b>Air-Cooled Chilled Water Plant for Peak Cooling Load &lt; 500 RT</b>								
All Buildings	Applicable only for Existing Buildings undergoing Major Retrofitting /Major Additions and Alterations								
0.78 kW/RT (inclusive of site derating factor)	0.85 kW/RT								
<p>Note(1) – The air-side component efficiency of the fan systems can be adjusted to allow for pressure drop adjustments where there is a need for more allowance due to functionality and activities as per recommended in SS 553 : Code of Practice for Air-Conditioning and Mechanical Ventilation in Buildings – Table 2b.</p>									
<p>Note(2) – Where there is a combination of water-cooled and air-cooled building cooling systems adopted, the respective TSEs are to be complied with, except for the building cooling system that serves an aggregate air-conditioned floor area of not more than 500 m<sup>2</sup>.</p>									

Table 4.1(b) – Base Requirements for Non-Residential Buildings	
ENVIRONMENTAL SUSTAINABILITY ATTRIBUTES	APPLICABILITY & SCOPE
<b>NRB03-2(b) Lighting System</b>	
Reduce energy required to illuminate interior spaces with proper lighting levels. The lighting provision shall be at least 40% more energy efficient than the prescribed lighting power budget stated in SS 530 – Code of Practice for Energy Efficiency Standard for Building Services and Equipment. Lighting control for artificial lighting shall also be provided in accordance with SS 530, where applicable.	Lighting systems for interior spaces
<b>NRB03-2(c) Mechanical Ventilation System</b>	
Reduce energy required to supply and distribute fresh air within the space through the use of energy-efficient mechanical ventilation systems and controls. <ul style="list-style-type: none"> <li>(i) Mechanical ventilation systems for normally occupied spaces shall be designed to be at least 10% more energy efficient than the prescribed standard stated in SS 553; and</li> <li>(ii) Provision of Carbon Monoxide (CO) detection sensor control with Variable Speed Drives (VSDs) to regulate demand for mechanical ventilation in car parks.</li> </ul>	Mechanical ventilation systems for normally occupied spaces and car parks
<b>NRB03-2(d) Vertical Transportation System</b>	
Reduce energy consumption needed for vertical transportation with the provision of lifts and escalators that are equipped with variable voltage variable frequency (VVVF) drives and sleep mode features. In the case of escalators, the provision of occupancy sensors, standby speed and/or standby stop features will be required, where relevant.	Lifts and escalators
<b>NRB04 Measurement and Verification (M &amp; V) Instrumentation</b>	
A building shall be designed and equipped with means to facilitate monitoring and improvement in the efficiency of building cooling systems	Building cooling system efficiency
<b>NRB04-1 Instrumentation for Central Chilled Water System</b>	
Provision of permanent measuring instruments to monitor the energy performance of the water-cooled and air-cooled central chilled water plants and air distribution systems. <p>The installed instrumentation must have the capability to calculate the resultant system efficiency within 5% of its true value in accordance with SS 591 – Code of Practice for Long Term Measurement of Central Chilled Water System Energy Efficiency. Each measurement system shall include sensors, any signal conditioning, the data acquisition system and the wiring connecting these components.</p> <p>The permanent measuring instruments and devices are to be accessible (<i>See Note (1) below</i>) and must not be located directly above the chillers, to facilitate verification and maintenance. They must be installed according to manufacturers' recommendations and SS 591.</p> <p>The measurement systems provided shall also comply with the following requirements:</p> <ul style="list-style-type: none"> <li>(a) All data logging devices are to be equipped with the capability to trend at a 1-minute sampling time interval, and recorded to the 3rd decimal digit;</li> </ul>	Instrumentation for water-cooled and air-cooled chilled water plants and air distribution systems

**Table 4.1(b) – Base Requirements for Non-Residential Buildings**

ENVIRONMENTAL SUSTAINABILITY ATTRIBUTES	APPLICABILITY & SCOPE
<b>NRB04-1 Instrumentation for Central Chilled Water System – Cont’d</b>	
<p>(b) Building management system (BMS), standalone energy management system (EMS) or local sequential controller (LSC) shall have the capability to compute and display the total system energy efficiency and its component (water-side and air-side efficiency) as well as the calculated heat balance of the chilled water system;</p> <p>(c) Magnetic in-line flow meter, with 1% uncertainty and capable of electronic in-situ verification to within <math>\pm 2\%</math> of its original factory calibration. If the installation of magnetic in-line meters is not possible, ultrasonic flow meters or other flow meters that can meet the indicated performance may be used;</p> <p>(d) Temperature sensors are to be provided for chilled water and condenser water loop and shall have a measurement uncertainty within <math>\pm 0.05^\circ\text{C}</math> over the entire measurement range. Each temperature measurement location shall have test plugs or additional thermowells located before and after each temperature sensor along the chilled water and condenser water lines for verification of measurement accuracy. All thermowells shall be installed in a manner that would allow the sensors to be in direct contact with the fluid flow; and</p> <p>(e) Dedicated power meters (of IEC Class 1 or better) and metering current transformers (of Class 1 or better) are to be provided for each of the following groups of equipment, where applicable: chillers, chilled water pumps, condenser water pumps, cooling towers, air distribution sub-system (i.e. AHUs, PAHUs). The same should be provided for FCUs, where possible.</p> <p>Note(1) – The temperature sensors are best placed in an accessible location with a mounting height of not more than 3 m, where possible. Otherwise, there should be evidence of provision for access by way of mobile access platforms or other suitable forms.</p> <p><i>Exception: For buildings with cooling provisions from the District Cooling System (DCS) that are regulated to meet the Minimum Energy Efficiency Standards (MEES) under the Energy Conservation Act, only the relevant instrumentation in relation to the proposed building is applicable.</i></p>	<p>Instrumentation for water-cooled and air-cooled chilled water plants and air distribution systems</p>
<b>NRB04-2 Instrumentation for Variable Refrigerant Flow (VRF) System</b>	
<p>Provision of permanent measuring instruments to monitor the energy performance of the Variable Refrigerant Flow (VRF) condensing units and air distribution systems.</p> <p>The installed instrumentation must have the capability to calculate the resultant system efficiency within 10% uncertainty. Each measurement system shall include sensors, any signal conditioning, the data acquisition system and the wiring connecting these components.</p> <p>The measurement systems provided shall also comply with the following requirement:</p> <p>(a) All data logging devices with the capability to trend at a 5-minute sampling time interval, and preferably recorded to the 3rd decimal digit;</p>	<p>Instrumentation for VRF systems and air distribution systems that serve an aggregate conditioned floor area of 2000 m<sup>2</sup> or more.</p>

**Table 4.1(b) – Base Requirements for Non-Residential Buildings**

ENVIRONMENTAL SUSTAINABILITY ATTRIBUTES	APPLICABILITY & SCOPE														
<b>NRB04-2 Instrumentation for Variable Refrigerant Flow (VRF) System – Cont'd</b>															
<p>(b) Building management system (BMS), standalone energy management system (EMS) or other suitable systems shall have the capability to compute and display the total system energy efficiency and its component (condensing unit and air distribution system efficiency) and to facilitate data extraction for verification purpose; and</p> <p>(c) Dedicated power meters (of IEC Class 1 or better) and metering current transformers (of Class 1 or better) are to be provided for all condensing units of the VRF system and air distribution sub-systems (i.e. AHUs, PAHUs), where applicable. The same should be provided for FCUs, where possible.</p>	<p>Instrumentation for VRF systems and air distribution systems that serve an aggregate conditioned floor area of 2000 m<sup>2</sup> or more.</p>														
<b>NRB05 Electrical Submetering</b>															
<p>A building shall be designed and equipped with means to facilitate measurement and monitoring of major energy end uses for energy management and audit. Separate sub-meters shall be provided and linked to a monitoring system that can measure and trend energy consumption data of the following systems:</p>	<p>Submetering for monitoring of major energy end uses and energy audit</p>														
<table border="1"> <thead> <tr> <th colspan="2">Sub-System for Metering</th> </tr> </thead> <tbody> <tr> <td>Lifts and escalators</td> <td>More than 5 numbers or sets or with a sum of all feeders &gt; 50 kVA.</td> </tr> <tr> <td>Mechanical ventilation systems</td> <td>                     Total subsystem's load &gt; 15 kW                      Sub-metering applicable to individual fan system motors that are more than 1.5 kW in the following areas                     <ul style="list-style-type: none"> <li>• Normally Occupied Spaces</li> <li>• Mechanical and Electrical Plant Rooms</li> <li>• Car Parks</li> </ul> </td> </tr> <tr> <td>Centralised hot water supply system</td> <td>&gt; 50 kW thermal heating capacity</td> </tr> <tr> <td>General power supply and lighting systems for tenancy areas and owners' premises*</td> <td>Sub-metering for tenancy areas and owners' premises are to be separated. The sub-circuits serving these areas can be provided based on a sub-system basis and /or per floor level.</td> </tr> <tr> <td colspan="2">                     Note(1): Sub-metering provision for chilled water plant, variable refrigerant flow (VRF) systems and air distribution systems are covered under NRB04.                 </td> </tr> <tr> <td colspan="2">                     Note (2): If there is a need to cater to high plug loads or process loads exceeding 50 kVA, please provide separate sub-metering for these specific loads or areas to better manage the energy consumption.                 </td> </tr> </tbody> </table>		Sub-System for Metering		Lifts and escalators	More than 5 numbers or sets or with a sum of all feeders > 50 kVA.	Mechanical ventilation systems	Total subsystem's load > 15 kW Sub-metering applicable to individual fan system motors that are more than 1.5 kW in the following areas <ul style="list-style-type: none"> <li>• Normally Occupied Spaces</li> <li>• Mechanical and Electrical Plant Rooms</li> <li>• Car Parks</li> </ul>	Centralised hot water supply system	> 50 kW thermal heating capacity	General power supply and lighting systems for tenancy areas and owners' premises*	Sub-metering for tenancy areas and owners' premises are to be separated. The sub-circuits serving these areas can be provided based on a sub-system basis and /or per floor level.	Note(1): Sub-metering provision for chilled water plant, variable refrigerant flow (VRF) systems and air distribution systems are covered under NRB04.		Note (2): If there is a need to cater to high plug loads or process loads exceeding 50 kVA, please provide separate sub-metering for these specific loads or areas to better manage the energy consumption.	
Sub-System for Metering															
Lifts and escalators	More than 5 numbers or sets or with a sum of all feeders > 50 kVA.														
Mechanical ventilation systems	Total subsystem's load > 15 kW Sub-metering applicable to individual fan system motors that are more than 1.5 kW in the following areas <ul style="list-style-type: none"> <li>• Normally Occupied Spaces</li> <li>• Mechanical and Electrical Plant Rooms</li> <li>• Car Parks</li> </ul>														
Centralised hot water supply system	> 50 kW thermal heating capacity														
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Note (2): If there is a need to cater to high plug loads or process loads exceeding 50 kVA, please provide separate sub-metering for these specific loads or areas to better manage the energy consumption.															
<b>NRB06 Maintenance of Building Cooling System Performance</b>															
<p>A building shall be designed and constructed with access space provisions to ensure the building cooling system performance can be maintained during operation as designed.</p> <p>The access space provisions for the following equipment shall comply with either the service clearances as per manufacturers' specification or the specifications set out in NRB06-1 to NRB06-4, whichever governs.</p>	<p>New building developments with water-cooled and air-cooled chilled water systems, and air distribution systems</p>														

**Table 4.1(b) – Base Requirements for Non-Residential Buildings**

ENVIRONMENTAL SUSTAINABILITY ATTRIBUTES	APPLICABILITY & SCOPE
<b>NRB06-1 Chillers</b>	
<p>Access space provisions shall be as follows:</p> <ul style="list-style-type: none"> <li>(a) Clearance of 2.0 m or more at the front of chiller unit piping section for tube maintenance and cleaning, repair and replacement of bigger components;</li> <li>(b) Clearance of 1.2 m or more between the chillers measured from plinth to plinth for regular maintenance; and</li> <li>(c) Clearance of 1.5 m or more above the chiller to facilitate maintenance, overhaul or replacement.</li> </ul>	Chillers
<b>NRB06-2 Pump Systems</b>	
<p>Access space provisions shall be as follows:</p> <ul style="list-style-type: none"> <li>(a) Except for the areas where the pipes are connected, clearance of 0.6 m or more is to be provided around the pump for regular maintenance; and</li> <li>(b) Clear headroom of 1.0 m or more above the pump and motor to facilitate maintenance, overhaul or replacement.</li> </ul>	Chilled water pumps (CHWP) and condensers water pumps (CWP)
<b>NRB06-3 Cooling Towers</b>	
<p>Maintenance provisions shall be as follows:</p> <ul style="list-style-type: none"> <li>(a) Provision of maintenance platform, stairs and catwalks of 600 mm width or more with handrails around the cooling towers and access to the level for periodic maintenance and inspection of the water basin and fill media; and</li> <li>(b) Clear distance of 2.0 m or more from the top of cooling towers to the location of the trellis, where applicable.</li> </ul>	Cooling towers
<b>NRB06-4 Air Distribution Systems</b>	
<p>Maintenance provisions shall be as follows:</p> <ul style="list-style-type: none"> <li>(a) Air handling units (AHUs) of cooling capacity greater than 35 kW shall be floor mounted as stipulated in SS 553; and</li> <li>(b) For AHUs that are floor mounted, the access space provisions are as follows: <ul style="list-style-type: none"> <li>(i) AHU access – Provide minimum 1.0 m clearance from the AHU room door entrance to the AHU for general maintenance;</li> <li>(ii) Cooling coil pipe and filter access – Provide minimum 800 mm clearance after pipe connection to facilitate cooling coil cleaning and filter access;</li> <li>(iii) Fan access – Provide minimum 800 mm clearance for fan/motor access and maintenance (if the access is not from the cooling coil connection side); and</li> <li>(iv) AHU side and back clearance – Provide minimum 600 mm clear width for general access and maintenance.</li> </ul> </li> </ul>	Floor mounted air handling units

## 4.2 CARBON REDUCTION MEASURES

4.2.1 A suite of environmental sustainability indicators in relation to energy and carbon emission reduction measures is provided and classified in the following three (3) sections.



### **Sustainable Design Strategies**

optimise the use of passive design strategies in response to local climate and site conditions to improve indoor environmental quality while minimising energy use.



### **Sustainable Construction**

promote the adoption of sustainable practices, material procurement and design which inculcate responsible use and conservation of resources during construction and building operation.



### **Sustainable Technologies**

encourage the provision of green building technologies that are oriented towards establishing low energy building consumption and smart control systems that could adapt to the users' needs and enhance building energy performance.

4.2.2 A selection of four (4) carbon reduction measures appropriate for the building development from the suite of environmental sustainability indicators provided in Table 4.2(a) and Table 4.2(b) will be required. In addition, there must be two (2) measures from Section 2 - Sustainable Construction as part of the requirements to meet the minimum environmental sustainability standard.

4.2.3 Alternative solutions which could meet the sustainability objectives under these sections can be considered on a case-to-case basis.

Table 4.2(a) – Carbon Reduction Measures for Residential Buildings	
SUSTAINABILITY INDICATORS	APPLICABILITY & SCOPE
<b>SECTION 1 - SUSTAINABLE DESIGN STRATEGIES</b>	
<b>RBE01-1 Enhanced Building Envelope Performance</b>	
<p>Enhance building envelope performance to minimise heat gain to internal spaces for better indoor thermal comfort with any of the following provisions:</p> <p>(a) Façade design with Residential Envelope Transmittance Value (RETV) of not more than 20 W/m<sup>2</sup>.</p> <p>(b) Application of cool materials that are certified by an approved local product certification body for 80% of all external wall areas of residential blocks or applicable roof areas.</p> <p>(c) Provision of innovative façade technology or solutions such as the use of electrochromic glass, integration of photovoltaic modules, parametric façade and so on for at least 20% of the fenestration areas.</p>	Building envelope and roof
<b>RBE01-2 Naturally Ventilated Building Design</b>	
<p>Enhance indoor thermal comfort through the provision of building and unit layout design which facilitates good natural ventilation.</p> <p>(a) Building layout design comprises 30% of all units with window openings facing prevailing wind directions.</p> <p>(b) Dwelling unit design comprises 25% of living rooms and bedrooms designed with effective inlet and outlet openings to facilitate good cross ventilation.</p> <p>(c) Passive design considerations for dwelling unit indoor comfort and design for natural ventilation with minimum coverage of 80% in at least two(2) of the following areas:</p> <ul style="list-style-type: none"> <li>• Toilets/bathrooms of dwelling units</li> <li>• Lift lobbies and corridors</li> <li>• Staircases</li> <li>• Car parks</li> <li>• Common facilities</li> </ul>	Dwelling units and common facilities and areas
<b>RBE01-3 Effective Daylighting</b>	
<p>Encourage design that optimises the use of effective natural lighting for better visual comfort.</p> <p>(a) Habitable Spaces - Daylighting provision for 25% of the total number of dwelling units that meet the desired lighting level of DA<sub>200lx,50%</sub> in 60% of applicable areas (namely living rooms and bedrooms) based on daylight availability table provided in Appendix E of this Code.</p> <p>(b) Non-Habitable Spaces - Provision of daylighting with minimum coverage of 80% in at least two (2) of the following areas:</p> <ul style="list-style-type: none"> <li>• Toilets/bathrooms of dwelling units</li> <li>• Lift lobbies and corridors</li> <li>• Staircases</li> <li>• Car parks</li> <li>• Common facilities</li> </ul>	Dwelling units and common facilities and areas

Table 4.2(a) – Carbon Reduction Measures for Residential Buildings											
SUSTAINABILITY INDICATORS	APPLICABILITY & SCOPE										
<b>SECTION 2 - SUSTAINABLE CONSTRUCTION</b>											
<b>RBE02-1 Resource Efficiency Measures</b>											
<p>Encourage building design and practices that facilitate efficient use of resources in building construction.</p> <p>(a) Existing building structures with more than 50% of the floor and/or wall areas are conserved for adaptive reuse.</p> <p>(b) Design with Concrete Usage Index (CUI) of not more than 0.50.</p> <p>(c) Embodied carbon reporting to account for the upfront carbon emissions of three (3) key construction materials namely, concrete, steel, and glass used in building developments.</p>	Building design and construction										
<b>RBE02-2 Low Carbon Concrete</b>											
<p>Enhance carbon reduction with the use of sustainable materials in building construction.</p> <p>(a) Use of concrete with eco-friendly cementitious materials that are classified under CEM II to V types for at least 80% of the super-structural works by volume.</p> <p>(b) Use of recycled concrete aggregate (RCA), washed copper slag (WCS) and/or granite fines from approved sources and meet the minimum usage requirement as stipulated in the following table.</p> <table border="1"> <thead> <tr> <th colspan="2"><i>Minimum Usage Requirements</i></th> </tr> </thead> <tbody> <tr> <td>Recycled Concrete Aggregate (RCA)</td> <td>1.50% X GFA</td> </tr> <tr> <td>Granite fines</td> <td>1.50% x GFA</td> </tr> <tr> <td>Washed Copper Slag (WCS)</td> <td>0.75% x GFA</td> </tr> <tr> <td colspan="2">Note: GFA refers to Approved Gross Floor Areas of the building</td> </tr> </tbody> </table> <p>(c) Alternative construction materials that can be used as a replacement for standard building materials for non-structural application.</p>	<i>Minimum Usage Requirements</i>		Recycled Concrete Aggregate (RCA)	1.50% X GFA	Granite fines	1.50% x GFA	Washed Copper Slag (WCS)	0.75% x GFA	Note: GFA refers to Approved Gross Floor Areas of the building		Concrete building elements and construction materials
<i>Minimum Usage Requirements</i>											
Recycled Concrete Aggregate (RCA)	1.50% X GFA										
Granite fines	1.50% x GFA										
Washed Copper Slag (WCS)	0.75% x GFA										
Note: GFA refers to Approved Gross Floor Areas of the building											
<b>RBE02-3 Sustainable Products</b>											
<p>Encourage the specification and use of environmentally friendly products that are certified with Environmental Product Declaration (EPD) requirements or two-tick rated by an approved local certification body.</p> <p>The provision shall include at least three (3) products for 80% of applicable areas or building components in relation to dwelling units.</p>	Building products/ M & E products that are applicable to dwelling units										

Table 4.2(a) – Carbon Reduction Measures for Residential Buildings	
SUSTAINABILITY INDICATORS	APPLICABILITY & SCOPE
<b>SECTION 3 - SUSTAINABLE TECHNOLOGIES</b>	
<b>RBE03-1 Renewable Energy System</b>	
Encourage the use of on-site renewable energy system with a minimum capacity installation that would take up 15% of the roof areas of residential blocks within the development. The provision must come with suitable means to record and monitor the energy generated from the system.	Solar photovoltaic (PV) system
<b>RBE03-2 Smart Technology Solutions</b>	
Encourage the adoption of smart solutions and technologies which help facilitate resource usage monitoring and reduce overall energy consumption. Examples of solutions or technologies that can be considered are as follows: <ul style="list-style-type: none"> <li>• Energy dashboard, web-based or mobile application or equivalent to provide useful and timely information on utility consumption and breakdown for homeowners and/or facility manager</li> <li>• Energy recovery system</li> <li>• Lifts with regenerative function</li> <li>• Occupancy sensors/controls for lighting in private lift lobbies, staircases or common facilities</li> <li>• Others (to be evaluated on a case-to-case basis)</li> </ul>	Building/sensor-related technologies and energy usage monitoring apps/system

Table 4.2(b) – Carbon Reduction Measures for Non-Residential Buildings	
SUSTAINABILITY INDICATORS	APPLICABILITY & SCOPE
<b>SECTION 1 - SUSTAINABLE DESIGN STRATEGIES</b>	
<b>NRBE01-1 Enhanced Building Envelope Performance</b>	
<p>Enhance building envelope performance to minimise heat gain to internal spaces for better indoor thermal comfort with any of the following provisions:</p> <p>(a) Façade design with Envelope Thermal Transfer Value (ETTV) of not more than 40 W/m<sup>2</sup> or enhanced with the provision of good thermal break/insulating profile framing.</p> <p>(b) Application of cool materials that are certified by an approved local product certification body for 80% of all external walls of the building development or applicable roof areas.</p> <p>(c) Provision of innovative façade technology or solutions such as the use of electrochromic glass, integration of photovoltaic modules, parametric façade and so on for at least 20% of the fenestration areas.</p>	Building envelope and roof
<b>NRBE01-2 Naturally Ventilated Building Design</b>	
<p>Enhance indoor thermal comfort through the provision of building layout design which facilitates good natural ventilation.</p> <p>(a) Building layout design comprises 20% of all normally occupied spaces with openings facing prevailing wind directions.</p> <p>(b) Design for natural ventilation with minimum coverage of 80% in at least two (2) of the following areas:</p> <ul style="list-style-type: none"> <li>• Lift lobbies</li> <li>• Corridors</li> <li>• Staircases</li> <li>• Car parks</li> <li>• Atriums</li> <li>• Toilets</li> </ul>	Normally occupied spaces and common areas
<b>NRBE01-3 Effective Daylighting</b>	
<p>Encourage the provision of natural lighting to improve visual comfort and reduce energy use associated with artificial lighting.</p> <p>(a) Normally occupied spaces: Daylighting provision with the integration of daylighting controls or other suitable means for minimum coverage of 15% of the total normally occupied spaces. The extent of daylight provision shall be determined based on the Daylight Availability Tables and Methodology provided in Appendix E of this Code and shall meet the desired lighting level and specific Daylight Autonomy (DA) requirements as listed below:</p>	Normally occupied spaces and common areas

**Table 4.2(b) – Carbon Reduction Measures for Non-Residential Buildings**

SUSTAINABILITY INDICATORS		APPLICABILITY & SCOPE
<b>SECTION 1 - SUSTAINABLE DESIGN STRATEGIES</b>		
<b>NRBE01-3 Effective Daylighting - <i>Cont'd</i></b>		
S/N	Minimum Lighting Level Based on Space Occupancy Type	Daylight Autonomy requirement per unit area of space
1	Office, Institutional spaces where lux requirement is 500 lux	DA <sub>500lx,50%</sub>
2	Industrial, sports facilities, retail areas where lux requirement is 300 lux	DA <sub>300lx,50%</sub>
3	Hotel, resort-like and service apartment where lux requirement is 200 lux	DA <sub>200lx,50%</sub>
<p>(b) Common areas: Daylighting provision with the integration of daylight controls for minimum coverage of 80% in at least two (2) of the following areas:</p> <ul style="list-style-type: none"> <li>• Lift lobbies</li> <li>• Corridors</li> <li>• Staircases</li> <li>• Car parks</li> <li>• Atriums</li> <li>• Toilets</li> </ul> <p>(c) Provision of daylight redirecting technologies such as light shelves or tubular daylight/sun pipes to enhance lighting level.</p>		Normally occupied spaces and common areas

Table 4.2(b) – Carbon Reduction Measures for Non-Residential Buildings											
SUSTAINABILITY INDICATORS	APPLICABILITY & SCOPE										
<b>SECTION 2 - SUSTAINABLE CONSTRUCTION</b>											
<b>NRBE02-1 Resource Efficiency Measures</b>											
<p>Encourage building design and practices that facilitate efficient use of resources in building construction.</p> <ul style="list-style-type: none"> <li>(a) Existing building structures with more than 50% of the floor and/or wall areas are conserved for adaptive reuse.</li> <li>(b) Design with Concrete Usage Index (CUI) of not more than 0.50.</li> <li>(c) Embodied carbon reporting to account for the upfront carbon emissions of three (3) key construction materials namely, concrete, steel, and glass used in building developments.</li> </ul>	Building design and construction										
<b>NRBE02-2 Low Carbon Concrete</b>											
<p>Enhance carbon reduction with the use of sustainable materials in building construction.</p> <ul style="list-style-type: none"> <li>(a) Use of concrete with eco-friendly cementitious materials that are classified under CEM II to V types for at least 80% of the super-structural works by volume.</li> <li>(b) Use of recycled concrete aggregate (RCA), washed copper slag (WCS) and/or granite fines from approved sources and meet the minimum usage requirement as stipulated in the following table.</li> </ul> <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th colspan="2"><i>Minimum Usage Requirements</i></th> </tr> </thead> <tbody> <tr> <td>Recycled Concrete Aggregate (RCA)</td> <td>1.50% X GFA</td> </tr> <tr> <td>Granite fines</td> <td>1.50% x GFA</td> </tr> <tr> <td>Washed Copper Slag (WCS)</td> <td>0.75% x GFA</td> </tr> <tr> <td colspan="2">Note: GFA refers to Approved Gross Floor Areas of the building</td> </tr> </tbody> </table> <ul style="list-style-type: none"> <li>(c) Alternative construction materials that can be used as a replacement for standard building materials for non-structural application.</li> </ul>	<i>Minimum Usage Requirements</i>		Recycled Concrete Aggregate (RCA)	1.50% X GFA	Granite fines	1.50% x GFA	Washed Copper Slag (WCS)	0.75% x GFA	Note: GFA refers to Approved Gross Floor Areas of the building		Concrete building elements and construction materials
<i>Minimum Usage Requirements</i>											
Recycled Concrete Aggregate (RCA)	1.50% X GFA										
Granite fines	1.50% x GFA										
Washed Copper Slag (WCS)	0.75% x GFA										
Note: GFA refers to Approved Gross Floor Areas of the building											
<b>NRBE02-3 Sustainable Products</b>											
<p>Encourage the specification and use of environmentally friendly products that are certified with Environmental Product Declaration (EPD) requirements or two-tick rated by an approved local certification body.</p> <p>The provision shall include at least three (3) products for 80% of applicable areas or building components in relation to functional spaces.</p>	Building products/ M & E products that are applicable for functional spaces										

Table 4.2(b) – Carbon Reduction Measures for Non-Residential Buildings	
SUSTAINABILITY INDICATORS	APPLICABILITY & SCOPE
<b>SECTION 3 - SUSTAINABLE TECHNOLOGIES</b>	
<b>NRBE03-1 Renewable Energy System</b>	
Encourage the use of on-site renewable energy sources to reduce the use of electricity by at least 1% of the expected total building electricity consumption.	Solar photovoltaic (PV) system
<b>NRBE03-2 Smart Building Solutions</b>	
<p>Encourage the provision of a minimum of two (2) smart building solutions to facilitate automation and controls over building systems for better energy management and thermal comfort. Examples of building solutions that can be considered are listed below:</p> <ul style="list-style-type: none"> <li>• Use of BACnet, Modbus or any other open protocol as the network backbone of the building management system where data points can be used to facilitate communication and integration with other building systems.</li> <li>• Energy portal and dashboard that helps building owners and/or tenants to better manage their energy consumption in an intuitive manner.</li> <li>• Real-time remote monitoring of chiller plant system operation such as BCA Chiller Efficiency Smart Portal.</li> <li>• Demand controlled ventilation systems such as carbon dioxide sensors or devices to regulate the fresh air intake and ventilation based on occupants' need.</li> <li>• Timer sensors/controls for lighting and/or ventilation systems in common areas and facilities.</li> <li>• Smart building sensors that are equipped with sensing capability, microprocessors and communication technology that can help facilitate some form of monitoring or automation.</li> <li>• Differential pressure switches for Air Handling Units (AHUs) that are linked to a building management system (BMS) or suitable means that can monitor the air filter condition.</li> <li>• Others (to be evaluated on a case-to-case basis).</li> </ul>	Building solutions that facilitate energy management and controls
<b>NRBE03-3 Green Building Technologies</b>	
<p>Encourage the adoption of low-carbon solutions and technologies which help reduce energy consumption. Examples of the systems that can be considered are as follows:</p> <ul style="list-style-type: none"> <li>• Energy recovery system</li> <li>• Lifts with regenerative function</li> <li>• Passive displacement ventilation system</li> <li>• Hybrid cooling system</li> <li>• Smart sensor and control technologies</li> <li>• Dedicated outdoor air system</li> <li>• Others (to be evaluated on a case-to-case basis)</li> </ul>	Building/sensor-related technologies

## 5 SUBMISSION PROCEDURES

### 5.1 General

The compliance with the Building Control (Environmental Sustainability) Regulations 2008 forms part of the requirements for Building Plan (BP) approval and Temporary Occupation Permit (TOP) or Certificate of Statutory Completion (CSC) clearance. The prescribed forms and supporting documentation are to be submitted by the QPs at the following stages:

- Application for Building Plan Approval (referred to as BP stage)
- Before the application for Temporary Occupation Permit (TOP)/Certificate of Statutory Completion (CSC) (referred to as TOP/CSC stage)

### 5.2 Submission at BP Stage

QP(BP) shall submit the prescribed forms and documentation relating to environmental sustainability requirements along with the Form BPD\_BP03 (Application for Approval of Building Plans) for Building Plan approval. The following documents are to be included and e-signed by the appropriate practitioners for submission:

- Form BPD\_GM01 and Appendix 1 and/or Appendix 2 to be e-signed by the QP, PE(Mechanical) and PE(Electrical) on proposed building works which include the joint declaration and a summary of the applicable Base Requirements and selected sustainability indicators as part of the Carbon Reduction Measures;
- Design parameters for building envelope and roof design in prescribed forms and format; and
- Design parameters for air-conditioning system design in prescribed forms and format.

### 5.3 Submission before TOP/CSC stage

Upon project completion, the QP shall submit the prescribed as-built forms and documentation relating to environmental sustainability requirements before making his application for TOP clearance or CSC clearance (for projects where no TOP is earlier applied for). The following documents are to be included and e-signed by the appropriate practitioners for submission.

- Form BPD\_GM02 and Appendix 1 and/or Appendix 2 to be e-signed by the QP, PE(Mechanical) and PE(Electrical) on as-built building works which include the joint declaration and a summary of the applicable Base Requirement and selected sustainability indicators implemented;
- Final design parameters for building envelope and roof design in prescribed forms and format if there are changes;
- Final design parameters for air-conditioning system design in prescribed forms and format if there are changes; and
- Documentation in support of the implementation of the Base Requirements and selected sustainability indicators under Carbon Reduction Measures to demonstrate compliance with the minimum environmental sustainability standard as stipulated in Appendix B and C.

## 5.4 Documentation Requirements

5.4.1 The QP and the other appropriate practitioners shall ensure that the documentation requirements stated in Appendix B and C are available as evidence to demonstrate compliance with the environmental sustainability standard set under Base Requirements and selected Carbon Reduction Measures. In general, the documentation can come in the following forms:

- Extracts of the tender specifications and other forms of documentary proof showing the pertinent details of the proposed green practices or features adopted;
- Relevant plan layouts, elevations and sectional drawings showing the applicable areas, locations or types of green features adopted;
- Summary sheets listing the detailed breakdown and the extent of implementation; and
- Calculations, worksheets or other data in the prescribed format as shown in Appendix B and Appendix C.

5.4.2 Submittal of the other documents may be required and shall be made in such manner and be in such form as the Commissioner of Building Control requires upon request.

## Appendix A

# Areas of Responsibility



**Table A-1 – Areas of Responsibility in relation to Residential Building Developments**

Residential Building Criteria	Responsibility
<b>BASE REQUIREMENTS</b>	
RB01 Envelope and Roof Thermal Transfer	
RB01-1 Building Envelope	QP (BP) <sup>1</sup>
RB01-2 Roof	QP (BP)
RB02 Building Energy Performance	
RB02-1 Air-Conditioning System	PE (Mechanical) <sup>2</sup>
RB02-2 Lighting System for Common Facilities and Areas	PE (Electrical) <sup>2</sup>
RB02-3 Mechanical Ventilation System for Car Parks	PE (Mechanical)
RB02-4 Vertical Transportation System	PE (Electrical)
<b>CARBON REDUCTION MEASURES</b>	
Section 1 – Sustainable Design Strategies	
RBE01-1 Enhanced Building Envelope Performance	QP (BP)
RBE01-2 Naturally Ventilated Building Design	QP (BP)
RBE01-3 Effective Daylighting	QP (BP)
Section 2 – Sustainable Construction	
RBE02-1 Resource Efficiency Measures	QP (BP)
RBE02-2 Low Carbon Concrete	QP (BP)
RBE02-3 Sustainable Products	QP (BP)
Section 3 – Sustainable Technologies	
RBE03-1 Renewable Energy System	PE (Electrical)
RBE03-2 Smart Technology Solutions	Appropriate Practitioners <sup>3</sup>

<sup>1</sup> QP (BP) refers to Qualified Person who submits Building Plan

<sup>2</sup> PE (Mechanical) or PE(Electrical) refers to a professional engineer registered under the Professional Engineers Act (Cap 253) in the branch of mechanical engineering or electrical engineering

<sup>3</sup> Appropriate practitioners refer to QP (BP), PE(Mechanical) and/or PE(Electrical)

**Table A-2 – Areas of Responsibility in relation to Non-Residential Building Developments**

Non-Residential Building Criteria	Responsibility
<b>BASE REQUIREMENTS</b>	
<b>NRB01 Envelope and Roof Thermal Transfer</b>	
NRB01-1 Building Envelope	QP (BP) <sup>1</sup>
NRB01-2 Roof	QP (BP)
<b>NRB02 Air-Tightness and Leakage</b>	
NRB02-1 Windows and Curtain Walls	QP (BP)
NRB02-2 Openings between Conditioned and Non-Conditioned Spaces	QP (BP)
<b>NRB03 Building Energy Performance</b>	
NRB03-1 Whole Building Approach via Energy Modelling	Appropriate Practitioners
NRB03-2 Energy Performance Standards for Key Systems	Appropriate Practitioners
<b>NRB04 Measurement and Verification (M &amp; V) Instrumentation</b>	
NRB04-1 Instrumentation for Central Chilled Water System	PE (Mechanical) <sup>1</sup>
NRB04-2 Instrumentation for Variable Refrigerant Flow (VRF) System	PE (Mechanical)
<b>NRB05 Electrical Submetering</b>	PE (Electrical)
<b>NRB06 Maintenance of Building Cooling System Performance</b>	
NRB06-1 Chillers	QP (BP) & PE (Mechanical)
NRB06-2 Pump Systems	QP (BP) & PE (Mechanical)
NRB06-3 Cooling Towers	QP (BP) & PE (Mechanical)
NRB06-4 Air-Distribution Systems	QP (BP) & PE (Mechanical)
<b>CARBON REDUCTION MEASURES</b>	
<b>Section 1 – Sustainable Design Strategies</b>	
NRBE01-1 Enhanced Building Envelope Performance	QP (BP)
NRBE01-2 Naturally Ventilated Building Design	QP (BP)
NRBE01-3 Effective Daylighting	QP (BP)
<b>Section 2 – Sustainable Construction</b>	
NRBE02-1 Resource Efficiency Measures	QP (BP)
NRBE02-2 Low Carbon Concrete	QP (BP)
NRBE02-3 Sustainable Products	QP (BP)
<b>Section 3 – Sustainable Technologies</b>	
NRBE03-1 Renewable Energy System	PE (Electrical)
NRBE03-2 Smart Building Solutions	Appropriate Practitioners
NRBE03-3 Green Building Technologies	Appropriate Practitioners

<sup>1</sup> QP (BP) refers to Qualified Person who submits Building Plan

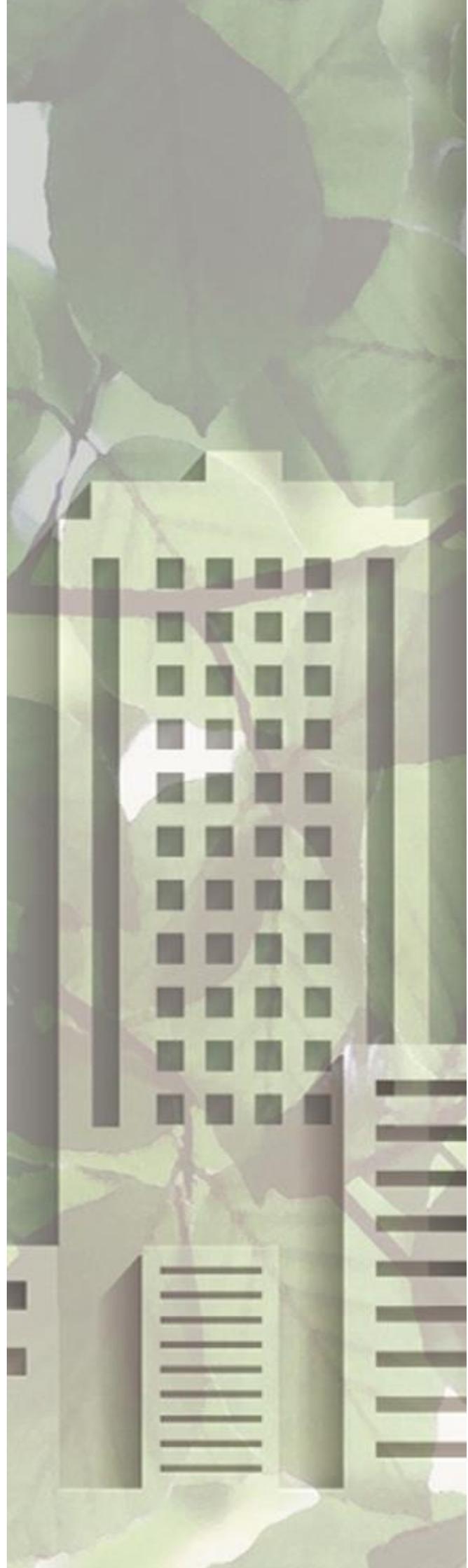
<sup>2</sup> PE (Mechanical) or PE(Electrical) refers to a professional engineer registered under the Professional Engineers Act (Cap 253) in the branch of mechanical engineering or electrical engineering

<sup>3</sup> Appropriate practitioners refer to QP (BP), PE(Mechanical) and/or PE(Electrical)

## Appendix B

# Compliance Requirements & Documentation

Residential Buildings



# BASE REQUIREMENTS

## For Residential Buildings

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Passive and active design strategies that have a direct influence on building performance and operating carbon and are to be complied with, where applicable.

**RB01 Envelope and Roof Thermal Transfer**

**RB02 Building Energy Performance**

# RB01 Envelope and Roof Thermal Transfer

## Intent

Enhance the overall thermal performance of the building envelope for better thermal comfort which would help reduce the demand to condition the indoor environment.

## Applicability & Scope

Generally applicable to all residential buildings.

## Base Requirement

A building shall be designed and constructed with good thermal performance to reduce solar heat gain through the building envelope and roof.

### RB01-1 Building Envelope

The Residential Envelope Transmittance Value (RETV) of the residential building shall not exceed 22 W/m<sup>2</sup>, as determined either by the formula and methodology set out in the prescribed Code stated in RB01-1(a) or by way of the Simplified Approach as detailed in RB01-1(b).

#### RB01-1(a) Design based on RETV formula

The RETV considers the three basic components of heat gain through the external walls and fenestrations of a building. These are (i) heat conduction through opaque walls (ii) heat conduction through fenestrations and (iii) solar radiation through fenestrations.

These three components of heat input are averaged over the whole envelope area of the building to give a RETV that represents the thermal performance of the whole envelope. For energy conservation, the maximum permissible RETV is set at 22 W/m<sup>2</sup>.

The computation of the Residential Envelope Transmittance Value (RETV) shall be based on the formula and methodology specified in the Code on Envelope Thermal Performance for Buildings issued by the Building and Construction Authority (BCA).

For developments consisting of more than one residential block, the weighted average of the RETVs based on the facade areas of these buildings shall not exceed 22 W/m<sup>2</sup>. There must also be due design consideration for the RETV of each block to be of reasonable range (i.e. less than 25 W/m<sup>2</sup>) to ensure good thermal comfort.

That is

$$RETV_{\text{Weighted average}} = \sum (RETV_{\text{bldg}} \times A_{\text{bldg}}) / A_{\text{devt}}$$

where

$RETV_{\text{bldg}}$  = RETV for a building (W/m<sup>2</sup>)

$A_{\text{bldg}}$  = Summation of all facade areas that enclose all the living rooms, dining rooms, study rooms and bedrooms of a residential building (m<sup>2</sup>)

$A_{\text{devt}}$  = Summation of total applicable facade areas of all residential buildings within the development (m<sup>2</sup>) (i.e.  $\sum A_{\text{bldg}}$ )

## RB01-1(b) Simplified Approach based on Design Parameters

The base requirement shall deem to be satisfied if the building envelope design and glazing specifications meet the criteria stipulated in the following Table B1.

Window to Wall Ratio (WWR)	Shading Coefficients of Glass ( $SC_{\text{glass}}$ )
<0.30	$\leq 0.67$
0.30 to <0.35	$\leq 0.59$
0.35 to <0.40	$\leq 0.52$
0.40 to <0.45	$\leq 0.48$
0.45 to $\leq 0.50$	$\leq 0.43$

*Note: Window to Wall Ratio (WWR) refers to fenestration areas/gross area of the exterior wall.*

### Guidance Notes

The RETV of the whole building envelope is obtained by taking the weighted average of the RETVs of individual external wall/fenestration. Detailed guidelines on the methodology and formula to derive the RETV can be found in the Code on Envelope Thermal Performance for Buildings. If the building development has more than one residential block, the weighted average of RETV can be derived by way of proration based on the respective wall/fenestration areas of the different residential blocks and shall not exceed the maximum permissible RETV of 22 W/m<sup>2</sup>.

### Worked Example RB01-1(a)

A proposed building development comprises three residential building blocks. The individual RETV of each building computed are as follows:

$$\begin{array}{l}
 \text{RETV}_{\text{bldg1}} = 20 \text{ W/m}^2 \quad A_{\text{bldg}} = 4000 \text{ m}^2 \\
 \text{RETV}_{\text{bldg2}} = 22 \text{ W/m}^2 \quad A_{\text{bldg}} = 3600 \text{ m}^2 \\
 \text{RETV}_{\text{bldg3}} = 19 \text{ W/m}^2 \quad A_{\text{bldg}} = 5000 \text{ m}^2
 \end{array}
 \left. \vphantom{\begin{array}{l} \\ \\ \end{array}} \right\}
 \begin{array}{l}
 A_{\text{devt}} = 4000 + 3600 + 5000 \\
 = 12600 \text{ m}^2
 \end{array}$$

Therefore

$$\begin{aligned}
 \text{RETV}_{\text{Weighted average}} &= \sum (\text{RETV}_{\text{bldg}} \times A_{\text{bldg}}) / A_{\text{devt}} \\
 &= \frac{(\text{RETV}_{\text{bldg1}} \times A_{\text{bldg1}}) + (\text{RETV}_{\text{bldg2}} \times A_{\text{bldg2}}) + (\text{RETV}_{\text{bldg3}} \times A_{\text{bldg3}})}{(A_{\text{devt}})} \\
 &= \frac{(20 \times 4000) + (22 \times 3600) + (19 \times 5000)}{12600} \\
 &= 20.2 \text{ W/m}^2 < 22 \text{ W/m}^2 \text{ ok}
 \end{aligned}$$

## Worked Example RB01-1(b)

Proposed erection of two (2) residential building blocks with the following design parameters.

Façade Facing	Fenestration Areas	Gross Areas of Exterior Wall/Façade	Window to Wall Ratio WWR	Prescribed $SC_{\text{glass}}$	Proposed $SC_{\text{glass}}$	Remarks
<b>Residential Block 1</b>						
NE	410	970	0.42	0.48	0.42	ok
NW	480	1000	0.48	0.43	0.42	ok
SE	450	1010	0.45	0.43	0.42	ok
SW	600	1200	0.50	0.43	0.42	ok
<b>Residential Block 2</b>						
N	450	970	0.46	0.43	0.42	ok
S	500	1000	0.50	0.43	0.42	ok
E	500	1010	0.50	0.43	0.42	ok
W	400	1200	0.33	0.59	0.42	ok

In this case, the selection of the Shading Coefficients of Glass ( $SC_{\text{glass}}$ ) for all façades is better than the prescribed value stated in Table B1 and therefore, it is deemed to have met the RETV of 22 W/m<sup>2</sup>.

## Documentation Requirements

### At BP Submission Stage

- RETV computation and tabulation of design parameters in the prescribed forms and format;
- Architectural elevation drawings showing the composition of the different façade or wall systems that are relevant for the computation of the RETV; and
- Architectural plan layouts and elevations showing the mode of ventilation and location for various spaces including air-conditioning areas.

### Before TOP Application

The following documents are to be made available on-site or upon request.

- Material schedules showing salient data of material properties used for the façade and external wall systems; and
- As-built RETV computation or tabulation of design parameters if there are material changes to the design and RETV.

## RB01-2 Roof

In respect to the roofs, the average thermal transmittance (U-value) for the gross area of the roof shall not exceed the limit prescribed in Table B2 for the corresponding weight group.

Weight Group	Weight range (kg/m <sup>2</sup> )	Maximum Thermal Transmittance (W/m <sup>2</sup> K)
Light	Under 50	0.8
Medium	50 to 230	1.1
Heavy	Over 230	1.5

The computation of the thermal transmittance of roof (U-Value) shall be in accordance with the methodology and formula set out in the Code for Envelope Thermal Performance for Buildings.

## Documentation Requirements

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### At BP Submission Stage

- Architectural plan layout and sectional details of different roof types as well as the roof composition and respective U-values; and
- Technical material or product information and relevant calculation of U-value of the roof.

### Before TOP Application

The following documents are to be made available on-site or upon request.

- Technical material or product information and relevant U-value calculation if there are material changes that will affect the design and U value.

## References

Code on Envelope Thermal Performance for Buildings issued by the Building and Construction Authority (BCA)

## Related Information

**Better Thermal Performance:** Building envelope that is designed with better thermal performance and meets the RETV of not more than 20 W/m<sup>2</sup> can be considered separately under RBE01-1 – Enhanced Building Envelope Performance as one of the carbon reduction measures.

**Daylight Reflectance:** Under the Approved Document – Section P Daylight Reflectance, the external surface (including a roof) of a building must be designed and constructed in a manner such that any reflection of sunlight off the external surface of the building does not result in loss of amenity to occupants of other buildings in the vicinity of that building.

## RB02 Building Energy Performance

### Intent

Reduce energy use with the provision of building systems that are of enhanced energy efficiency standards.

### Applicability & Scope

Generally applicable to buildings with mechanical and/or electrical equipment and systems. This section specifies the minimum energy efficiency requirements for the following systems.

- (a) Air-conditioning systems
- (b) Lighting systems for common facilities and areas such as gymnasium, management office, function halls, lift lobbies, corridors, staircase areas and car parks
- (c) Mechanical ventilation systems for car parks
- (d) Lift systems that serve four floors or more

### Base Requirement

A building shall be designed and constructed with energy efficiency measures to reduce the energy consumption of building energy systems and meet the minimum energy efficiency improvements of 50% over the 2005 baseline.

### RB02-1 Air-Conditioning System

To reduce the energy required to provide and distribute conditioned air within the space by having energy-efficient air-conditioning system that could meet the following energy performance standard or equivalent. The provision shall cover at least 80% of the total number of dwelling units and common facilities.

Unitary Air-Conditioning System Type	Tick rating under MELS	Cooling Efficiency of System
Single/Multi-Split System	5-tick rated	Weighted COP $\geq$ 5.50 COP <sub>100%</sub> $\geq$ 4.86
Variable Refrigerant Flow (VRF) System	3-tick rated	$5.25 \leq$ IEER $<$ 5.70

where

- (i) Coefficient of Performance (COP) is the ratio of cooling capacity to effective power input. COP<sub>100%</sub> is defined as the ratio of total cooling capacity to effective power input at full load cooling capacity.
- (ii) Weighted COP is derived from  $0.4 \times \text{COP}_{100\%} + 0.6 \times \text{COP}_{50\%}$
- (iii) Energy efficiency ratio (EER) is defined as the ratio of cooling capacity to effective power consumption at a given set of rating conditions.
- (iv) Integrated Energy Efficiency Ratio (IEER) is derived based on the EER at different part-load conditions and as follows :  $(0.020 \times \text{EER}@100\%) + (0.617 \times \text{EER}@75\%) + (0.238 \times \text{EER}@50\%) + (0.125 \times \text{EER}@25\%)$

### Guidance Notes

- (1) The single/multi-split air conditioners and VRF system provided are to be rated and labelled with Energy Label as required under the Energy Conservation Act - Mandatory Energy Labelling Scheme.
- (2) Other systems such as centralised cooling systems, the water-side component efficiency (i.e. chilled water plants) provided shall meet the minimum energy performance standard of 0.67 kW/RT and in accordance with the methodology stated in NRB03-2(a) in Appendix C.

## Worked Example RB02-1

Proposed condominium housing development comprising 1 Block of 38-Storey and 1 Block of 39-Storey Residential Flat (Total: 695 Units) with one basement car park and other ancillary facilities.

### Air-Conditioning System Provision for the different unit types

Unit Types	No. of Dwelling units	Tick rating used	Meet the Prescribed Tick Rating
Type A – 1 bedroom	50	5-tick rated	Ok
Type B – 2 bedrooms	220	5-tick rated	Ok
Type C – 3 bedrooms	280	5-tick rated	Ok
Type D – Penthouse units	10	Combination of 4-tick and 5-tick rated	Not Ok

List of common facilities	Air-Conditioned Yes/No)	Air-Conditioning Type	Tick rating used
Function Hall	Yes	Multi-Split System	5-tick rated
Club House	Yes	Multi-Split System	4-tick rated
Gymnasium	Yes	Multi-Split System	5-tick rated
Reading Room	Yes	Single-Split System	5-tick rated
Management Office	Yes	Single-Split System	5-tick rated

Total no. of dwelling units: 695		
Total no. of common facilities that are air-conditioned: 5		
Type of Unitary Air-conditioning System used	No of Dwelling Units	No. of Common facilities
Single /Multi-Split system with 5-tick rated	560	4
VRF system with minimum 3-tick rated	0	0
Total number of units and common facilities with air-conditioners that meet the prescribed tick rating	560	4
Percentage (%) of air-conditioners that meet the requirements	80.5% ok	80% ok

## Documentation Requirements

### At BP Submission Stage

Generally, no supporting document submission at this stage.

### Before TOP Application

The following documents are to be made available on-site or upon request.

- Extracts of tender specification or delivery order showing the provision of the types of air-conditioners for dwelling units and common facilities of the development;
- Schedule of air-conditioners showing the numbers, types and the approved rating from Mandatory Energy Labelling Scheme; and
- For other air-conditioning system such as centralised cooling system, the salient information of the design efficiency and details required under NRB03-2(a) – Air-Conditioning System is to be provided.

## RB02-2 Lighting System for Common Facilities and Areas

To reduce energy required to illuminate interior spaces of common facilities and areas with proper lighting levels. The lighting provision shall be at least 40% more energy efficient than the maximum lighting power budget stated in SS 530 – Code of Practice for Energy Efficiency Standard for Building Services and Equipment.

### Guidance Notes

In the selection of light fittings, due consideration should be given to account for future phase-out of inefficient lighting and ballasts in Singapore. Reference can be made to the Minimum Energy Performance Standard (MEPS) on lamp efficacies and ballast energy performance for lighting design under the Energy Conservation Act. The lighting provision for building façade and landscape areas should adhere to the prescribed lighting power budget stated in SS 530 to minimise overall energy consumption.

Other than the provision of energy-efficient lighting, it is important to ensure that proper lighting levels are provided. Where relevant, the recommended lux levels stipulated in Singapore Standard SS 531 – Code of practice for lighting of workplaces should be adopted.

### Worked Example RB02-2

The proposed and maximum lighting power budget for artificial lighting can be computed by determining the total power consumption and efficiency level based on the lighting layout design for common facilities and areas and the light fitting types used as illustrated in this example.

Location	Areas (m <sup>2</sup> )	Light Fitting Type	Power Consumption Per Fitting (W)	Ballast Loss	No. of Fittings	Total Power Consumption based on Fitting Type
	(A)	(B)	(C)	(D)	(E)	[(C+D) x E]
<b>Common Facilities</b>						
Management Office	100	LED	12	0	50	600
Gymnasium	300	LED	12	0	150	1,800
Club House	300	LED	24	0	85	2,040
Reading Room	50	LED	12	0	30	360
<b>Common Areas</b>						
Lift Lobbies & Corridors	4000	LED	12	0	1246	14,952
Staircase Areas	1000	LED	12	0	240	2,900
Car Parks	8000	T5	28	3	550	17,050
<b>Total:</b>						<b>39,702</b>

Location	Area (m <sup>2</sup> )  (A)	Design Data		SS 530 Requirements	
		Total Power Consumption (by area)  (W)  (F)	Design Lighting Power Density (W/m <sup>2</sup> )  (F/A)	Reference Lighting Power Density (W/m <sup>2</sup> )  (H)	Reference Total Power Consumption (by area) (W)  (H x A)
<b>Common Facilities</b>					
Management Office	100	600	6.0	12	1,200
Gymnasium	300	1,800	6.0	11	3,300
Club House	300	2,040	6.8	12	3,600
Reading Room	50	360	7.2	12	600
<b>Common Areas</b>					
Lift Lobbies & Corridors	4000	14,952	3.74	7	28,000
Staircase Areas	1000	2,900	2.88	6	6,000
Car Parks	8000	17,050	2.13	3	24,000
<b>Total</b>	<b>13,750</b>	<b>39,702</b>	<b>2.89</b>	<b>4.85</b>	<b>66,700</b>

<b>% Improvement over reference standard</b>	$= [\sum (HxA) - \sum (F)] / \sum (HxA) \times 100$ $= (66,700 - 39,702) / 66,700 \times 100$ $= 40.5\% > 40\% \text{ ok}$
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## Documentation Requirements

### At BP Submission Stage

Generally, no supporting document submission at this stage.

### Before TOP Application

The following documents are to be made available on-site or upon request.

- As-built lighting layout plan and schedules showing the numbers, location and types of luminaries used;
- Calculation of lighting power budget based on actual installation and the percentage improvement over prescribed lighting power budget; and
- Delivery orders and technical product information of the lighting luminaries used

## RB02-3 Mechanical Ventilation System

To reduce energy required by regulating the demand for mechanical ventilation in car parks with the provision of Carbon Monoxide (CO) detection sensor controls with Variable Speed Drives (VSDs).

### Documentation Requirements

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#### At BP Submission Stage

Generally, no supporting document submission at this stage.

#### Before TOP Application

Plan layout showing the location of the CO detection sensors with VSDs and photographic evidence.

## RB02-4 Vertical Transportation System

To reduce energy consumption with the provision of energy-efficient lift systems that are equipped with Variable Voltage Variable Frequency (VVVF) and sleep mode features.

### Guidance Notes

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Other than the provision of vertical transportation systems that come with VVVF and sleep mode features, other energy-efficient technologies such as regenerative drive can be considered under RBE03-2.

### Documentation Requirements

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#### At BP Submission Stage

Generally, no supporting document submission at this stage.

#### Before TOP Application

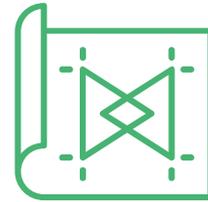
Extracts of specifications and technical information on the types of lifts and related features.

## References

- (1) Mandatory Minimum Energy Performance Standards (MEPS) and Mandatory Energy Labelling Scheme Air-Conditioners under the Energy Conservation Act can be found on the website of the National Environmental Agency (NEA)
- (2) SS 530 - Code of Practice for Energy Efficiency Standard for Building Services and Equipment
- (3) SS 553 – Code of Practice for Air-Conditioning and Mechanical Ventilation in Buildings
- (4) Mandatory Minimum Energy Performance Standards (MEPS) for Lamps and Ballasts can be found on the website of the National Environmental Agency (NEA)
- (5) SS 531 – Code of Practice for Lighting of Work Places – Indoor – Part 1

# CARBON REDUCTION MEASURES For Residential Buildings

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## SECTION 1 – SUSTAINABLE DESIGN STRATEGIES

Optimise the use of passive design strategies in response to local climate and site conditions to improve on indoor environmental quality thus reducing energy use.

RBE01-1 Enhanced Building Envelope Performance

RBE01-2 Naturally Ventilated Building Design

RBE01-3 Effective Daylighting

## RBE01-1 Enhanced Building Envelope Performance

Enhance building envelope performance to minimise heat gain to internal spaces for better indoor thermal comfort with any of the following provisions:

- (a) Façade design with Envelope Thermal Transmittance Value (RETV) of not more than 20 W/m<sup>2</sup>.
- (b) Application of cool materials that are certified by an approved local product certification body for 80% of all external walls of the residential building blocks or applicable roof areas.
- (c) Provision of innovative façade technology or solutions such as the use of electrochromic glass, integration of photovoltaic modules, parametric façade for at least 20% of the fenestration areas.

### Guidance Notes

RBE01-1(a): The Residential Envelope Transmittance Value (RETV) is to be determined using the methodology set out in the Code on Envelope Thermal Performance for Buildings and shall not exceed 20 W/m<sup>2</sup>.

RBE01-1(b): Cool materials in this context refer to surface coating, paints, tiles that come with high solar reflectance and infrared emissivity properties and are certified by an approved local product certification body. The extent of the application must cover at least 80% of all external wall areas of residential building blocks or all applicable roof areas.

### Worked Example RBE01-1(b)

Proposed condominium housing development comprising 1 block of 13-storey and 1 block of 15-storey residential flat with clubhouse facilities and car parks.

Example of a proposed residential building with an application of cool materials on external wall areas

Block Description	Total Applicable External Wall Areas (m <sup>2</sup> )	Areas with Cool materials (m <sup>2</sup> )	Extent of coverage = $8200/9800 * 100 = 83\%$ ok  Note: The green wall areas can be excluded in the computation
Blk 1	4800	4000	
Blk 2	5000	4200	
Total:	9800	8200	

Alternatively, the application of cool materials can be on the roof areas

Block Description	Total Roof areas (m <sup>2</sup> )	Non-Applicable Areas (m <sup>2</sup> )	Total Applicable Roof Areas (m <sup>2</sup> )	Roof Areas with Cool Materials (m <sup>2</sup> )
Blk 1	1000	100	900	400
Blk 2	1200	80	1120	1120
Car parks	400	0	400	400
Common facilities and others etc.	500	0	500	500
Total:	3100	180	2920	2420

Extent of coverage =  $2420/2920 * 100 = 83\%$  ok

Note(1): Non-applicable areas can include green roofs and areas beneath large equipment such as water tanks or photovoltaic (PV) panels where the application of cool materials may not be relevant.

Note(2): The selected cool materials or paint system must meet the allowable limits set for daylight reflectance as required under the Approved Document.

RBE01-1(c): Innovative façade technology or solutions such as the use of electrochromic glass, integration of photovoltaic modules, parametric façade for at least 20% of the fenestration areas.

### Worked Example RBE01-1(c)

Example of a proposed single building with a combination of electrochromic glass and BIPV incorporated as part of its envelope design.

Innovative Solutions	Areas of Application (m <sup>2</sup> )	Total Fenestration Areas = 20500 Extent of coverage = 5000/20500 = 24% ok
Electrochromic glass	2000	
BIPV	3000	
Total areas of application	5000	

## Documentation Requirements

### At BP Submission Stage

#### RBE01-1(a)

- RETV computation in prescribed forms and format;
- Architectural elevation drawings showing the composition of the different façade or wall systems that are relevant for the computation of the RETV; and
- Architectural plan layouts and elevations showing the mode of ventilation and location for various spaces including air-conditioning areas.

#### RBE01-1(b)

- Extracts from tender specifications showing the requirement to incorporate cool materials for the external wall areas or roof areas.

#### RBE01-1(c)

- Extract from tender specifications showing the requirements on the specific façade technology or solutions.

### Before TOP Application

The following documents are to be made available on-site or upon request.

#### RBE01-1(a)

- Material schedules showing salient data of material properties used for the façade and external wall systems; and
- As-built RETV computation if there are material changes that will affect the design and RETV.

#### RBE01-1(b)

- Certification details of the cool materials used, technical product information, delivery orders, confirmation on the extent of application and coverage.

#### RBE01-1(c)

- Elevation drawings and details showing the areas where the façade technology or solutions are used and confirmation on the extent of application and coverage.

## Related information

**Daylight Reflectance:** Under the Approved Document – Section P Daylight Reflectance, the external surface (including a roof) of a building must be designed and constructed in a manner such that any reflection of sunlight off the external surface of the building does not result in loss of amenity to occupants of other buildings in the vicinity of that building. Hence, there is a need to ensure that the selected cool materials meet the allowable daylight reflectance as required under the Approved Document issued by the Building and Construction Authority.

## RBE01-2 Naturally Ventilated Building Design

Enhance indoor thermal comfort through the provision of building and unit layout designs that facilitate good natural ventilation.

- (a) Building layout design with window openings that are oriented to take advantage of the prevailing wind conditions with minimum coverage of 30% of all dwelling units within the building development.
- (b) Dwelling unit design that provides effective inlet and outlet openings to facilitate good cross ventilation with minimum coverage of 25% of all dwelling units' living rooms and bedrooms within the building development.
- (c) Passive design considerations for dwelling units' indoor comfort and design for natural ventilation with minimum coverage of 80% in at least two(2) of the following areas:
  - Toilets/bathrooms of dwelling units
  - Lift lobbies and corridors
  - Staircases
  - Car parks
  - Common facilities

### Guidance Notes

RBE01-2(a): Naturally ventilated buildings with window openings facing prevailing wind conditions would enhance indoor thermal comfort thus reducing the need for air-conditioning. Locally, the two predominant wind directions are North to North-East during Northeast monsoon seasons and South to South-East during the South-West monsoon seasons. Meteorological data on the precise wind directions and velocity at site location should be used as the basis for design to optimise ventilation and thermal comfort, where available.

In considering the building layout design and coverage, it is not necessary for window openings to be located perpendicularly to the prevailing wind directions. However, there must be openings facing the prevailing wind directions as shown in the following illustrations.

### Illustrations on building layout designs that facilitate good natural ventilation

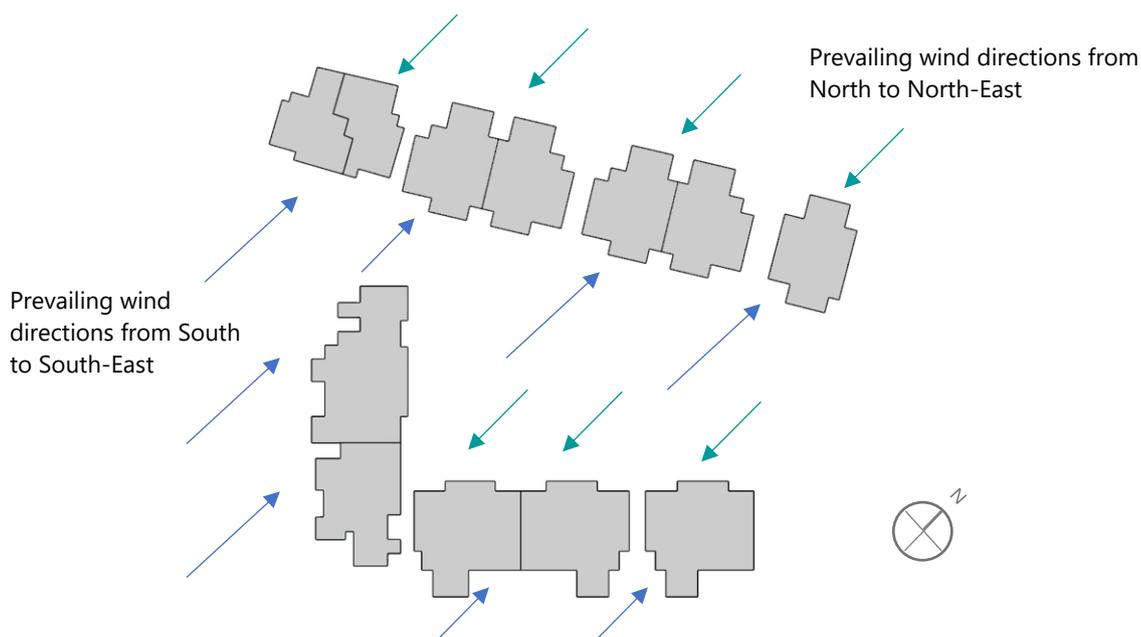
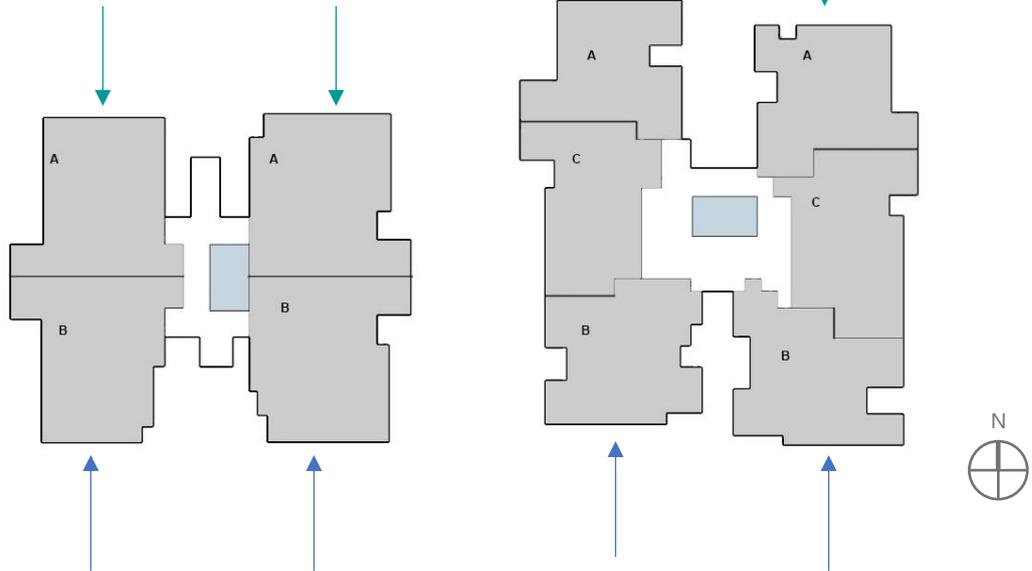


Illustration 1 – Building layout showing all dwelling units with window openings facing the north and south direction. In this instance, all units can be considered meeting the requirement.

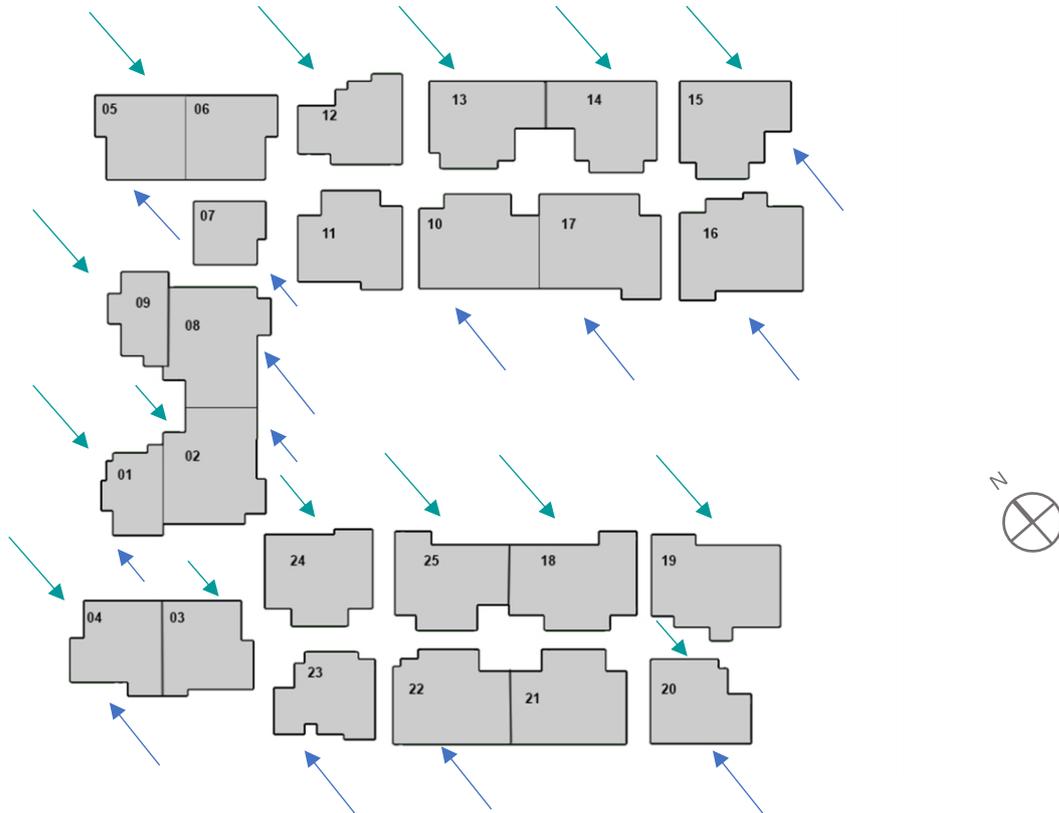
Prevailing wind directions from North to North-East



Prevailing wind directions from South to South-East

Illustration 2 – Building layout showing all dwelling units with only window openings facing either the North OR South direction. The dwelling unit Type C has no window opening facing both the North and South directions. In this instance, no unit can be considered meeting the requirement.

Prevailing wind directions from North to North-East



Prevailing wind directions from South to South-East

Illustration 3 – Building layout showing all dwelling units with window openings facing the North and South direction except for Dwelling Unit 01,02,09,08 which have window openings facing only North or South direction. In this project, there will be 21 out of 25 units which is 84% meeting the requirement.

RBE01-2(b): Dwelling unit design is considered to have good cross ventilation when there are unobstructed air flow paths through the windows or vents on either opposite or adjacent walls. For this requirement, all the windows/internal doors are assumed to be open.

### Illustrations on dwelling unit designs that facilitate good cross ventilation

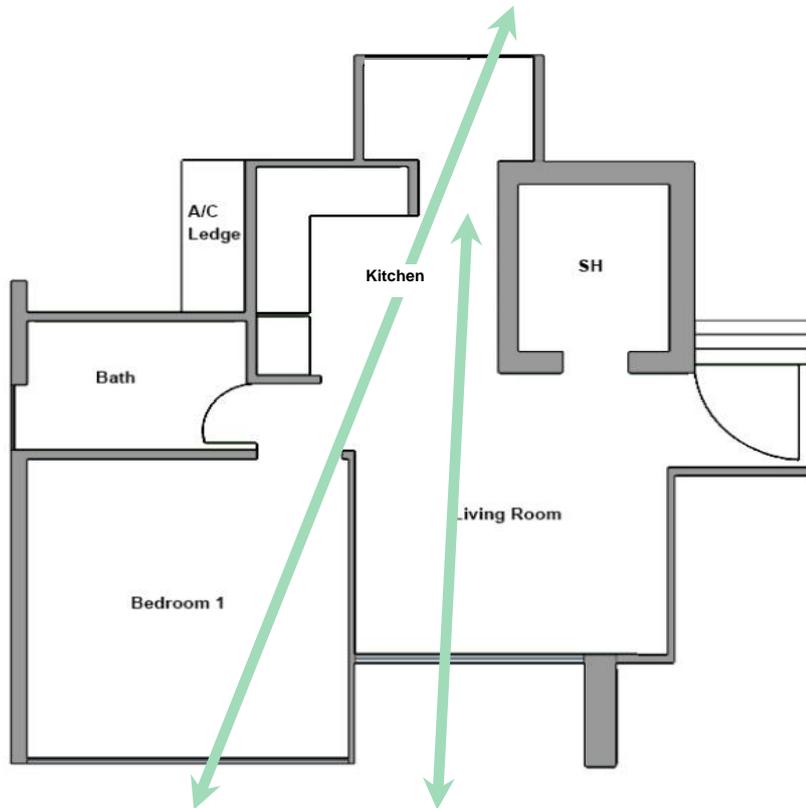


Illustration 4 – Dwelling unit layout with living room and bedroom 1 with good cross ventilation and meet the requirement.

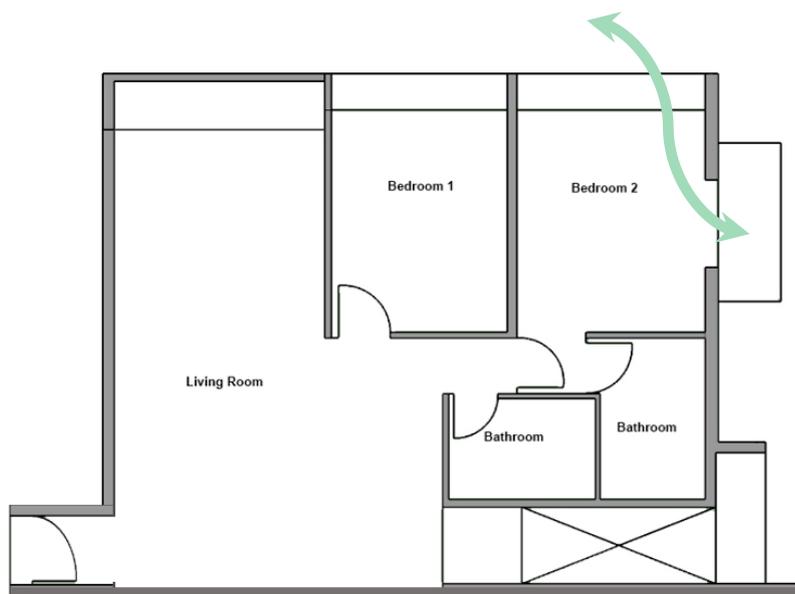
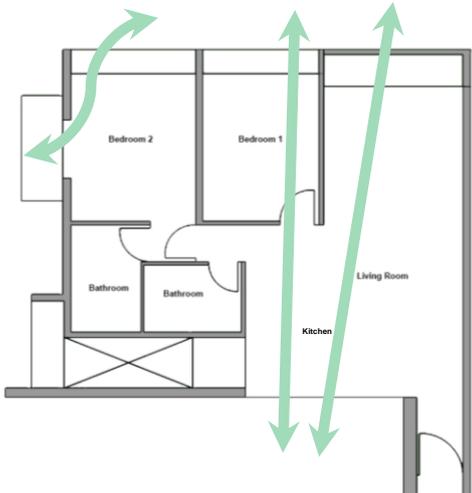
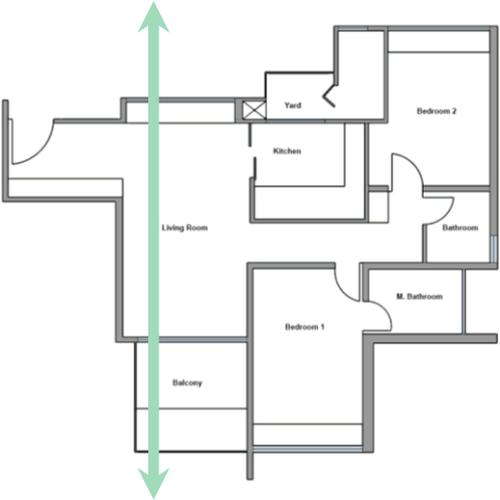


Illustration 5 – Dwelling unit layout showing Bedroom 2 with good cross ventilation and meet the requirement.

## Worked Example RBE01-2(b)

Proposed residential building development with one block of 10 storey apartment comprises 40 dwelling units. Each dwelling unit comes with a living room and two bedrooms. There are two typical unit types for this development as shown below.

Two-Bed Room Type A	Two-Bed Room Type B
	
Living room, Bedroom 1 and Bedroom 2 are considered having good cross ventilation	Only the living room is considered having good cross ventilation. Bedroom 1 and 2 do not meet the requirement

Percentage of dwelling unit design that meet the requirement are as tabulated below

Dwelling Unit Type	No of Units	For each unit		Total living rooms and bedrooms with cross ventilation (b + c) x (a)	Total number of living rooms and bedrooms = 3 x 40 units = 120  <i>Note: Each unit has 1 living and 2 bedrooms.</i>
	(a)	Living Room with cross ventilation (b)	Bedrooms with cross ventilation (c)		
2-bedroom Type A	20	1	2	60	<b>Percentage of dwelling units that meet the requirement is about 67% ok</b>
2- bedroom Type B	20	1	0	20	
Total:				80	

RBE01-2(c) Evidence of passive design considerations for dwelling unit indoor comfort is required along with the design provision of at least two (2) naturally ventilated spaces (i.e. common areas or facilities) with minimum coverage of 80% of the respective spaces. Examples of passive design considerations that are acceptable are as follows:

- Assessment of the building layout design or dwelling unit design as stipulated in RBE01-2(a) or (b).
- Macro design strategies considering building massing which can come in the form of multiple block configuration, staggered heights or void openings to facilitate wind flow within the development.

The minimum coverage of 80% can be determined based on the number or the areas of respective naturally ventilated spaces provided. For example, design with 80% (in areas) of the lift lobbies and corridors are naturally ventilated can be considered meeting the requirement.

## Documentation Requirements

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### At BP Submission Stage

Generally, no supporting document submission at this stage.

### Before TOP Application

The following documents are to be made available on-site or upon request.

#### RBE01-2(a) & (b)

- As-built architectural plan layouts showing the units/rooms of all blocks with highlights of those with window openings facing the prevailing wind directions and/or with good cross ventilation; and
- Tabulation showing the total number/applicable areas and percentage of units or rooms with window openings facing the prevailing wind directions and/or with good cross-ventilation.

#### RBE01-2(c)

- *Consideration for building layout design or dwelling units:* Documents are as stated above.
- *Mass design strategies:* Summary of design consideration and relevant drawing showing the block layout or void provision to facilitate wind flow.
- As-built architectural plan layouts showing the applicable common areas with highlights of those that are designed to be naturally ventilated.
- Tabulation showing the total number/areas and percentage of applicable common areas that are naturally ventilated.

## Related Information

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**Natural Ventilation:** Under the Approved Document – Section G – Ventilation regulated under the Building Control Regulations, there are specific requirements in relation to natural ventilation, to protect people from loss of amenity due to lack of fresh air. There are requirements on the minimum size of openable windows or other openings as well as their location to ensure adequate ventilation is provided in a building.

## RBE01-3 Effective Daylighting

Encourage design that optimises the use of natural lighting to improve visual comfort and reduce the need for artificial lighting during daylight hours.

- (a) Habitable Spaces – Daylighting provision with minimum coverage of 25% of the total number of dwelling units. The extent of daylight provision shall meet the desired lighting level of  $DA_{200lx,50\%}$  in 60% of habitable spaces (mainly living rooms and bedrooms) within the units as determined based on the Daylight Availability Tables and Methodology provided in Appendix E of this Code.
- (b) Non-habitable Spaces – Daylighting Provision with minimum coverage of 80% in at least two(2) of the following spaces:
  - Toilets/bathrooms of dwelling units
  - Lift lobbies and corridors
  - Staircases
  - Car parks
  - Common facilities

### Guidance Notes

RBE01-3(a): The effective daylighting of habitable spaces can be quantified using the Daylight Availability Tables provided in Appendix E if the building design layouts are relatively standardised and have the following characteristics and urban parameters stated below.

#### ***Building Characteristics and Urban Parameters suitable for use of Daylight Availability Tables***

- Spaces that are side lit and located adjacent to the vertical fenestration.
- Spaces with typical room floor-to-ceiling heights within the range of 2.5 m to 3.1 m
- Simple horizontal overhang/shading devices or no shading devices adopted for the vertical fenestration
- Relatively unobstructed by surrounding buildings and with average urban obstruction angles (AUOA)  $\leq 57.25^\circ$

*Note: Average Urban Obstruction Angle describes the portion of the sky blocked by surrounding obstructions such as neighbouring buildings. Refer to Appendix E for more details.*

The simplified methodology in determining the availability of daylighting is as follows:

- Determine the quality of daylight provision, daylit and overlit areas of habitable spaces through the use of Daylight Availability Tables based on the following design parameters:
  - Orientation and Obstruction and Lux requirement for the space
  - Space design (applicable areas), Façade (WWR) and Glazing type (visible light transmittance)
- Determine the percentage of habitable spaces (mainly living rooms and bedrooms) that have effective daylighting. Refer to the worked example in Appendix E.

RBE01-3(b): In general, the provision of windows and openings is not the only determining factor that would translate to good daylighting provision. There will be a need to consider other factors such as the building overhangs, opening configurations and placement among other things. For simplicity, if daylight can be infiltrated over the spaces such as common corridors with a depth of about two (2) times the height of the openings, it is deemed to have been designed with daylighting. These spaces must be well-lit without the need for artificial lighting provision during the daytime to meet the requirement.

Depending on the locality and design of the common areas, there may be a need to integrate with daylight sensor lighting control system to turn the lights up to provide proper lighting level, when required.

## Documentation Requirements

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### At BP Submission Stage

Generally, no supporting document submission at this stage.

### Before TOP Application

The following documents are to be made available on-site or upon request.

#### RBE01-3(a)

- As-built architectural plan layouts showing the units/rooms of all blocks with highlights of those with daylight provision; and
- Tabulation showing the percentage of habitable spaces that are designed with effective daylighting. Refer to the worked example for residential buildings on the detailed computation in Appendix E.

#### RBE01-3(b)

- As-built architectural plan layouts showing the applicable common areas with highlights of those that are designed with daylight.
- Tabulation showing the total number/areas and percentage of applicable common areas that are come with daylighting.

## References

Daylight Availability Tables developed under the BCA-SUTD Joint Research Collaboration: Daylighting in Singapore - Establishing Lighting Preferences, Design Guidelines and Predictive Methods

# CARBON REDUCTION MEASURES

For Residential Buildings

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## SECTION 2 – SUSTAINABLE CONSTRUCTION

Promote the adoption of sustainable practices, materials procurement and design which inculcate responsible use and conservation of resources during construction and building operation.

RBE02-1 Resource Efficiency Measures

RBE02-2 Sustainable Construction

RBE02-3 Sustainable Products

## RBE02-1 Resource Efficiency Measures

Encourage building design and practices that facilitate efficient use of resources in building construction.

- (a) Existing building structures with more than 50% of the floor and/or wall areas are conserved for adaptive reuse.
- (b) Design with Concrete Usage Index (CUI) of not more than 0.50.
- (c) Embodied carbon reporting to account for the upfront carbon emissions of three (3) key construction materials namely, concrete, steel, and glass used in building developments.

### Guidance Notes

RBE02-1(a): Existing buildings, whether they are of historic significance or not, can be conserved for adaptive reuse. This can form an important part of sustainability strategies to reduce the overall resource use and building waste. To meet this requirement, there must be more than 50% of the existing building floor and/or wall areas conserved for reuse.

RBE02-1(b): It is critical and more effective to optimise concrete usage at the early design stage where a range of design solutions that could improve concrete use efficiency for e.g. post-tensioned concrete or void formers can be considered. In this requirement, the benchmark set is based on the Concrete Usage Index (CUI) which is an indicator of the amount of concrete used to construct the superstructure that includes both the structural and non-structural elements. It is defined as the volume of concrete in cubic metres needed to cast a square metre of constructed floor area and expressed as follows:

$$\text{Concrete Usage Index (CUI)} = \frac{\text{Concrete Volume in m}^3}{\text{Constructed Floor Area in m}^2}$$

The benchmark set for this requirement is CUI of 0.50.

### Worked Example RBE02-1(b)

A proposed development comprises a 15-storey residential block with two (2) basement car parks. The quantity of concrete used for the different structural systems is summarised as below :

Concrete usage for the superstructure	Constructed floor areas
1st storey = 587 m <sup>3</sup> From 2nd to 15th storey = 5,400 m <sup>3</sup> (including roof level)	1st storey = 1,000 m <sup>2</sup> From 2nd to 15th storey = 14,000 m <sup>2</sup> (including roof level)
Total concrete usage = 5,987 m <sup>3</sup>	Total constructed floor areas = 15,000 m <sup>2</sup>

$$\begin{aligned} \text{Concrete Usage Index (CUI)} &= \frac{\text{Concrete Volume in m}^3}{\text{Constructed Floor Area in m}^2} \\ &= \frac{5987}{15000} = 0.4 \text{ m}^3/\text{m}^2 < 0.50 \text{ ok} \end{aligned}$$

*Note: The concrete usage for external works and sub-structural works for foundation and basement structures are excluded in CUI computation.*

Refer to the following tabulation on the details and computation required for the various structural systems.

COMPUTATION OF CONCRETE USAGE INDEX			RESIDENTIAL BUILDING
Project Reference No.: <u>AXXXX-00001-20XX</u>		Total no. of storey for the project: <u>15</u>	
Block No : <u>A</u>			
Structural System	Thickness (mm) or size (mm x mm)	Volume of concrete (m <sup>3</sup> )	Remark *
<b>1 1<sup>st</sup> storey</b>			
1.1 Columns	200x400, 200x200	72	Precast
1.2 Beams	200x400, 200x500	145	Precast
1.3 Slabs	150,200	265	Precast
1.4 Staircases	150	30	Precast
1.5 Suspended structures like planter boxes, bay windows, ledges etc.	150	10	Precast
1.6 Parapets	150	5	RC
1.7 External walls - loadbearing	Nil	0	-
1.8 External walls – non-loadbearing	125	15	RC
1.9 Internal walls – loadbearing	200	40	RC
1.10 Internal walls – non-loadbearing	Nil	0	Light weight concrete
1.11 Others (kerbs, ramps, services risers, etc.)	Not required	5	RC
Total volume of concrete for this storey (m <sup>3</sup> )		587	
Total constructed floor area for this storey (m <sup>2</sup> )		1000	
<b>2 Typical floor layout (2<sup>nd</sup> to 15<sup>th</sup> storey)</b>			
2.1 Columns	200x400, 200x200	25	Precast
2.2 Beams	200x400, 200x500	20	Precast
2.3 Slabs	150,200	80	Precast
2.4 Prefabricated prefinished Volumetric Construction (PPVC)	-	135	Precast by modules
2.4 Staircases	150	30	Precast
2.5 Suspended structures like planter boxes, bay windows, ledges etc.	150	10	Precast
2.6 Parapets	150	5	RC
2.7 External walls - loadbearing	Nil	0	-
2.8 External walls – non-loadbearing	125	15	RC
2.9 Internal walls – loadbearing	200	40	RC
2.10 Internal walls – non-loadbearing	Nil	0	-
2.11 Others (kerbs, ramps, services risers etc.)	Nil	0	-
Volume of concrete for one storey (m <sup>3</sup> )		360	
Constructed floor area for one storey (m <sup>2</sup> )		933.3	
Total volume of concrete for 2 <sup>nd</sup> to 15 <sup>th</sup> storey (m <sup>3</sup> ) (including roof level)		360 X 15 = 5400	
Total constructed floor area for 2 <sup>nd</sup> to 15 <sup>th</sup> storey (m <sup>2</sup> ) (including roof level)		933.3 x 15 = 14000	
Total volume of concrete for this project (m <sup>3</sup> )		5987	
Total constructed floor area for this project (m <sup>2</sup> )		15000	
Concrete Usage Index (CUI in m <sup>3</sup> /m <sup>2</sup> )		0.4	

*\*To indicate if the structural elements are of precast concrete, post-tensioned concrete, high strength concrete (>Grade 60) or reinforced concrete (RC) under the 'Remarks' column.*

**Compliance Notes:** The quantities of the concrete for all the structural and non-structural elements for each floor level are to be computed. All the elements listed in the table such as columns, beams, slabs, suspended structures (like planter boxes, bay windows and ledges, etc.), parapets, walls and others (service risers, kerbs, ramps, etc.) are to be included. The concrete used for foundation and basement works are to be excluded in CUI computation. However, in the case of raft foundation that forms part of the floor slab, half of its concrete volume will have to be accounted for in deriving the CUI.

RBE02-1(c): Embodied carbon reporting would cover the assessment of the carbon footprint of a building or infrastructure before it becomes operational. The requirement would require the account for the upfront carbon emissions of three (3) key construction materials namely concrete, steel and glass used in building developments. The emission factors used can be based on established carbon datasets such as the Inventory of Carbon and Energy (ICE) database, the RICS Building Carbon Database.

## Documentation Requirements

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### At BP Submission Stage

Generally, no supporting document submission at this stage.

### Before TOP application

The following documents are to be made available on-site or upon request.

#### RBE02-1(a)

- Architectural and structural plan layout, elevation and sectional plans showing the existing floor and/ or wall areas that are conserved for adaptive reuse.
- Details on the extent of conservation in percentage over the total existing floor and/or wall areas.

#### RBE02-1(b)

- BIM model (if applicable), architectural and structural plan layout, elevation and sectional plans showing the type of building elements/ systems used, the dimensions and sizes of all the building and structural elements ;
- Summary showing the quantity of concrete for each floor level in the prescribed tabulated format shown in the Worked Example RBE02-1(b). Calculation showing the quantity of concrete for each floor level which should include all the concrete building elements, such as non-load bearing and architectural concrete components;

#### RBE02-1(c)

- Embodied carbon footprint report which includes the computation with detailed breakdown on the grade and type of concrete, steel and glass provided and the basis of the respective emission factors used.

## References

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Sustainable Construction - Guide on Concrete Usage Index published by the Building and Construction Authority (BCA)

## RBE02-2 Low Carbon Concrete

Enhance carbon reduction potential with the use of sustainable materials for construction.

- (a) Use of concrete with eco-friendly cementitious materials that are classified under CEM II to V types for at least 80% of the super-structural works by volume.
- (b) Use of recycled concrete aggregate (RCA), washed copper slag (WCS) and/or granite fines from approved sources and meet the minimum usage requirement as stated in the following Table B4.

Recycled Concrete Aggregate (RCA)	1.50% X GFA
Granite fines (GF)	1.50% x GFA
Washed Copper Slag (WCS)	0.75% x GFA
<i>Note: GFA refers to Approved Gross Floor Areas of the building development.</i>	

- (c) Alternative construction materials that can be used as a replacement for standard building materials for non-structural application.

### Guidance Notes

RBE02-2(a): The use of concrete with considerable proportion of clinker replaced with eco-friendly cementitious materials would help reduce the overall embodied carbon in buildings. Essentially, these materials comprise Portland Cement in combination with approved industrial by-products such as Ground Granulated Blast Furnace Slag (GGBS), silica fume, fly ash and could serve as alternative binder in concrete production. These cementitious materials are classified under CEM II/III/IV/V in Table 1 of SS EN 197-1. Concrete products certified by an approved local product certification body can be considered if eco-friendly cementitious materials are required as part of the certification criteria.

### Worked Example RBE02-2(a)

#### Clinker content

The proposed residential development uses two (2) types of Grade 40 concrete with the following provision.

Concrete Grade 40	Extent of Coverage (Super-structural work only)	Provision	Remarks
Type 1 Concrete	40% by volume	20% of GGBS which is classified under CEM II in Table 1 of SS EN 197	Ok
Type 2 Concrete	60% by volume	Certified concrete products under an approved local product certification body.	Ok, concrete products produced with eco-friendly cementitious materials classified under SS EN 197 and as certified.

In this instance, the use of concrete with eco-friendly cementitious materials took up 100% of the super-structural works (by volume) which would fulfill the overall requirement of minimum 80%.

RBE02-2(b): Recycled concrete aggregates (RCA) is derived mainly from the crushed concrete from demolition works which can be adopted to replace natural coarse aggregates for a range of structural and non-structural application. Washed Copper Slag (WCS) on the other hand is derived by reprocessing (cleaning, washing and drying) copper slag used in the first place as an abrasive in grit blasting at the shipyard. For structural grade concrete, the use of RCA and WCS shall be limited to a maximum of 20% and 10% replacement by mass of coarse/fine aggregates respectively or as approved by the relevant authorities. Locally, granite fines of which the quality and grading are in accordance with SS EN 12620 can be used as a direct substitute for fine aggregates (that is replacement of natural sand in concrete).

The RCA/WCS/Granite fines quantity (in tonnes) required for the concrete production of main building elements can be estimated based on the concrete volume and replacement rate comprising these sustainable materials and as follows :

Type of Sustainable Materials	Estimation of Quantity Requirement
Recycled Concrete Aggregate (RCA)	$1.0 \text{ (tonnes/m}^3\text{)} \times (\text{Concrete vol in m}^3\text{)} \times (\text{RCA Replacement Rate}) \%$
Granite fines (GF)	$0.7 \text{ (tonnes/m}^3\text{)} \times (\text{Concrete vol in m}^3\text{)} \times (\text{GF Replacement Rate}) \%$
Washed Copper Slag (WCS)	$0.7 \text{ (tonnes/m}^3\text{)} \times (\text{Concrete vol in m}^3\text{)} \times (\text{WCS Replacement Rate}) \%$

### Worked Example RBE02-2(b)

#### Replacement of coarse and fine aggregates

The project uses 10% replacement of coarse aggregate with RCA and 5% replacement of fine aggregate with granite fines (GF) for all slabs, and 30% replacement of coarse aggregate with RCA for all external non-load bearing walls of the superstructure. The Gross Floor Areas (GFA) is 13,500 m<sup>2</sup>. Refer to Worked Example RBE02-1(b) on the concrete volume used for the respective building elements.

#### Replacement of Coarse Aggregate with Recycled Concrete Aggregates (RCA)

Minimum usage requirement for RCA =  $0.015 \times \text{GFA} = 0.015 \times 13,500 = 202.2 \text{ tonnes}$

Total concrete volume of all slabs =  $265 \text{ m}^3 + 80 \text{ m}^3 \times 15 = 1,465 \text{ m}^3$

Total concrete volume of all external non-load bearing walls =  $15 \text{ m}^3 + (15 \text{ m}^3 \times 15) = 240 \text{ m}^3$   
*[Approximate coarse aggregate content in concrete = 1 tonne/m<sup>3</sup>]*

Total tonnage of RCA used for superstructure  
 =  $[(10\% \times 1 \text{ tonne/m}^3) \times 1465\text{m}^3] + [(30\% \times 1 \text{ tonne/m}^3) \times 240\text{m}^3] = 218.5 \text{ tonnes} > 202.2 \text{ tonnes, ok}$

#### Replacement of Fine Aggregate with Granite Fines (GF)

Minimum usage requirement for GF =  $0.015 \times \text{GFA} = 0.015 \times 13,500 = 202.2 \text{ tonnes}$   
*[Approximate fine aggregate content in concrete = 0.7 tonne/m<sup>3</sup>]*

Total tonnage of GF used for superstructure  
 =  $[(5\% \times 0.7 \text{ tonne/m}^3) \times 1,465\text{m}^3] = 51.28 \text{ tonnes} < 202.1 \text{ tonnes. Not ok}$

Therefore, the provision does not meet the minimum requirement.

In this example, based on the replacement of coarse aggregate with RCA, it can be considered meeting one carbon reduction measure under Sustainable Construction.

RBE02-2(c): Other than the use of eco-friendly cementitious materials, RCA, WCS and granite fines stated in RBE02-2(a) and (b), other alternative construction materials can be considered as a replacement for standard building materials for non-structural application. However, there is a need to ensure that the alternative materials adopted could meet the physical, chemical and engineering characteristics for the intended application and requirements from relevant authorities, where applicable.

An example of alternative materials is NEWSand derived from municipal solid waste (MSW) which can be used to replace sand and similar aggregates for non-structural applications such as footpaths, road building materials, concrete products like benches. It can be considered with no specific minimum replacement rate. However, note that it is currently a new material with limited supply source administered by the National Environment Agency (NEA).

## Documentation Requirements

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### At BP Submission Stage

Generally, no supporting document submission at this stage.

### Before TOP application

The following documents are to be made available on-site or upon request.

#### RBE02-2(a) and (b)

- Extract of tender specification or concrete mix design showing the cement type used and/or the detailed usage of recycled/ engineered aggregates (e.g. RCA/WCS/granite fines);
- Calculation showing the quantity of recycled/ engineered aggregates (e.g. RCA/WCS/granite fines) used for the project;
- Certificates from an approved local product certification body for concrete products/mixes that are certified and evidence of the use of eco-friendly cementitious materials in concrete production; and
- Delivery orders and details of the actual concrete mix used in the project showing the usage of clinkers/ engineered aggregates (e.g. RCA/ WCS/granite fines).

#### RBE02-2(c)

- Extract of tender specification or confirmation showing the use of alternative construction materials and the areas of its application.

## References

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SS EN 197-1 – Cement - Part 1 : Composition, specifications and conformity criteria for common cement

SS EN 12620 – Specification for Aggregates for Concrete

Sustainable Construction : Guide on the use of Recycled Materials published by the Building and Construction Authority (BCA)

## RBE02-3 Sustainable Products

Encourage the specification and use of environmentally friendly products that are certified with Environmental Product Declaration (EPD) requirements and/or with a two-tick rating by an approved local product certification body.

The provision shall include at least three (3) building and/or Mechanical and Electrical ( M&E) products for 80% of applicable areas and/or building components/systems in relation to dwelling units.

### Guidance Notes

An Environmental Product Declaration (EPD) is a transparent, objective report that communicates the environmental performance and impact of a product over its life cycle. EPDs support carbon emission reduction by making it possible to compare the environmental impacts of different products and facilitate the selection of more sustainable options. For this requirement, products with EPDs that are third-party certified and in conformance with ISO 14025 and EN 15804 and/or products certified with a two-tick rating by an approved local product certification body can be considered. The extent of coverage must be at least 80% of the applicable areas/building components/systems intended for the dwelling units.

### Worked Example RBE02-3

Example of a proposed residential development with provision of the following products and coverage that meet the requirements.

Products	Extent of Coverage	Provision	Remarks
Waterproofing system for wet areas	100% All dwelling units	Two-tick rated based on the extent of environmental friendliness by an approved local product certification body	√
Drywall partitions	80% of dwelling units	With EPD that is third-party certified and in conformance with ISO 14025 and EN 15804	√
Air-Conditioners	90% of dwelling units	Two-tick rated based on the extent of environmental friendliness by an approved local product certification body	√

### Documentation Requirements

#### At BP Submission Stage

Generally, no supporting document submission at this stage.

#### Before TOP application

The following documents are to be made available on-site or upon request.

- Extract of tender specification and drawings showing the requirements to incorporate specific products with EPDs and/or with a two-tick rating by an approved local certification body;
- Certification of EPDs or details from an approved local certification body such as the material certification standards, rating and product reference; and
- Technical product information and delivery records.

### References

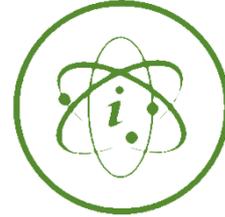
SS ISO 14205 : Environmental Labels and Declarations – Type III environmental declarations – Principles and procedures

EN 15804 : Sustainability of Construction Works – Environmental Product Declarations – Core Rules for the Product Category of Construction Products

# CARBON REDUCTION MEASURES

For Residential Buildings

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## SECTION 3 – SUSTAINABLE TECHNOLOGIES

Encourage the provision of green building technologies that are oriented towards establishing low energy building consumption and smart control systems that could adapt to the users' needs and enhance building energy performance.

- RBE03-1 Renewable Energy Sources
- RBE03-2 Smart Technology Solutions

## RBE03-1 Renewable Energy System

Encourage the use of an on-site renewable energy system with a minimum capacity installation that would take up 15% of the roof areas of residential blocks within the development. The provision must come with suitable means to record and monitor the energy generated from the system.

### Guidance Notes

In the context of Singapore's tropical climate, solar photovoltaic (PV) system remains the most viable option for wider deployment when it comes to electricity generation. In the case of residential buildings, maximising the limited roof space for solar PV deployment could be made possible with better space utilisation design such as co-location with greenery and optimisation in area efficiency of the PV systems used.

For this requirement, the solar PV system capacity installation must minimally take up 15% of the roof areas of residential blocks within the development. The placement of these systems need not be restricted to the rooftop areas of each residential block and can be placed at any suitable location or selected residential blocks where the solar energy harvesting can be optimised. Based on the supplier's specification and areas efficiency and space utilisation, the proposed Solar PV capacity can be worked out with due consideration for the spaces between panels and gangways around the perimeter.

### Worked Example RBE03-1

A proposed residential building development with five (5) residential blocks, each block with a rooftop space of about 500 m<sup>2</sup>

Total Roof areas for all 5 residential blocks = 5 x 500 = 2,500 m<sup>2</sup>

Minimum roof coverage with PV system = 15% x 2,500 = 375 m<sup>2</sup>

Based on the supplier's specifications and area efficiency design of 0.17 kWp/m<sup>2</sup>, the estimated solar PV capacity can be worked out to be as follows :

Proposed Location of PV system Installation – Rooftop areas	Proposed Areas for PV Array (m <sup>2</sup> )	Estimated PV capacity (kWp)
Residential Block 1	150	25.5
Residential Block 2	150	25.5
Residential Block 3	80	13.6
Total:	380 > 375 (min) ok	64.6 kWp

### Documentation Requirements

#### At BP Submission Stage

Generally, no supporting document submission at this stage.

#### Before TOP application

The following documents are to be made available on-site or upon request.

- As-built drawings and on-site photographs of the renewable energy systems installed;
- Technical specifications and integration reports of the installed system(s) including total capacity installed; and
- Total roof areas of residential blocks, location and capacity of the systems installed.

## RBE03-2 Smart Technology Solutions

Encourage the adoption of smart solutions and technologies which help facilitate resource usage monitoring and reduce overall building energy consumption. Examples of solutions or technologies that can be considered are as follows:

- Energy dashboard, web-based or mobile application or equivalent to provide useful and timely information on utility consumption and breakdown for homeowners and/or facility manager
- Energy recovery system
- Lifts with regenerative function
- Occupancy sensors/controls for lighting in private lift lobbies, staircases or common facilities
- Others (to be evaluated on a case-to-case basis)

### Guidance Notes

Smart Building Technologies	General Information
Energy dashboard, web-based or mobile application	The provision of smart utility submeters / smart energy management applications for key energy-consuming systems/appliances.
Energy recovery system	Energy recovery system can be integrated as part of the solutions to minimise overall building energy demand. For example, heat recovery system that captures waste heat discharged from the air-conditioning system and transfers for water heating purpose, which otherwise is exhausted or wasted.
Lifts with regenerative function	Lift with regenerative function can help conserve and minimise energy use. Depending on lift usage, operating speed, height of building and floors, it would typically be a viable option for larger and taller buildings.
Occupancy sensors/ controls for lighting in private lift lobbies, common areas like corridors, lift lobbies, staircases or common toilets	Occupancy sensors for lighting controls can help save energy use. They can be designed to switch lights off automatically with no occupancy or with multi-level switching or dimming to reduce lighting power when required.

### Documentation Requirements

#### At BP Submission Stage

Generally, no supporting document submission at this stage.

#### Before TOP application

The following documents are to be made available on-site or upon request.

- Design intent and details of the smart building solutions or technologies implemented; and
- Tender specification, as-built drawings and photographic evidence showing the provision and location of smart building solutions and technologies implemented.

## Appendix C

# Compliance Requirements & Documentation

Non-Residential Buildings



# BASE REQUIREMENTS

## For Non-Residential Buildings

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Passive and active design strategies and measures that have direct influence on building performance and operating carbon and are to be complied with, where applicable.

**NRB01 Envelope and Roof Thermal Transfer**

**NRB02 Air-Tightness and Leakage**

**NRB03 Building Energy Performance**

**NRB04 Measurement and Verification (M&V) Instrumentation**

**NRB05 Electrical Submetering**

**NRB06 Maintenance of Building Cooling System Performance**

# NRB01 Envelope and Roof Thermal Transfer

## Intent

Enhance the overall thermal performance of the building envelope for better thermal comfort and would help reduce the overall cooling load requirement.

## Applicability & Scope

Generally applicable to buildings with an aggregate air-conditioning area of more than 500 m<sup>2</sup> except for underground building structures or facilities.

## Base Requirement

A building shall be designed and constructed with good thermal performance to reduce solar heat gain through the building envelope and roof.

### NRB01-1 Building Envelope

The Envelope Thermal Transfer Value (ETTV) of the non-residential building shall not exceed 45 W/m<sup>2</sup>, as determined either by the methodology and formula set out in the prescribed Code stated in NRB01-1(a) or by way of the Simplified Approach as detailed in NRB01-1(b).

#### NRB01-1 (a) Design based on ETTV formula

The ETTV considers the three basic components of heat gain through the external walls and fenestrations of a building. These are (i) heat conduction through opaque walls (ii) heat conduction through fenestrations and (iii) solar radiation through fenestrations.

These three components of heat input are averaged over the whole envelope area of the building to give an ETTV that represents the thermal performance of the whole envelope. For energy conservation, the maximum permissible ETTV is set at 45 W/m<sup>2</sup>.

The computation of the Envelope Thermal Transfer Value (ETTV) shall be based on the formula and methodology specified in the Code on Envelope Thermal Performance for Buildings issued by the Building and Construction Authority (BCA).

For developments consisting of more than one building, the weighted average of the ETTVs based on the facade areas of these buildings shall not exceed 45 W/m<sup>2</sup>. There must also be due design consideration for the ETTV of each block to be of reasonable range (i.e. less than 50 W/m<sup>2</sup>) to ensure good thermal comfort.

That is

$$ETTV_{\text{Weighted average}} = \sum (ETTV_{\text{bldg}} \times A_{\text{bldg}}) / A_{\text{devt}}$$

where

$ETTV_{\text{bldg}}$  = ETTV for a building (W/m<sup>2</sup>)

$A_{\text{bldg}}$  = Summation of all facade areas that enclose all the air-conditioning areas (m<sup>2</sup>) in a building

$A_{\text{devt}}$  = Summation of total applicable facade areas of all buildings within the development (m<sup>2</sup>)  
(i.e.  $\sum A_{\text{bldg}}$ )

## NRB01-1(b) Simplified Approach based on Design Parameters

The base requirement shall deem to be satisfied if the building envelope design and glazing specifications meets the criteria stipulated in the following Table C1.

Window to Wall Ratio (WWR)	Shading Coefficients of Glass (SC <sub>glass</sub> )
<0.20	≤0.51
0.20 to <0.25	≤0.41
0.25 to <0.30	≤0.35
0.30 to <0.35	≤0.30
0.35 to ≤0.40	≤0.27
0.40 to ≤0.50	≤0.22

*Note: Window to Wall Ratio (WWR) refers to fenestration areas/gross area of the exterior wall.*

### Guidance Notes

The ETTV of the whole building envelope is obtained by taking the weighted average of the ETTVs of individual external wall/fenestration. Detailed guidelines on the methodology and formula to derive the ETTV can be found in the Code on Envelope Thermal Performance for Buildings. If the building development has more than one building block, the weighted average of ETTV can be derived by way of proration based on the respective wall/fenestration areas of the different building blocks and shall not exceed the maximum permissible ETTV of 45 W/m<sup>2</sup>.

### Worked Example NRB01-1(a)

A proposed building development comprises three building blocks. The individual ETTV of each building computed are as follows :

$$\begin{array}{l}
 \text{ETTV}_{\text{bldg1}} = 35 \text{ W/m}^2 \quad A_{\text{bldg}} = 5000 \text{ m}^2 \\
 \text{ETTV}_{\text{bldg2}} = 45 \text{ W/m}^2 \quad A_{\text{bldg}} = 6800 \text{ m}^2 \\
 \text{ETTV}_{\text{bldg3}} = 40 \text{ W/m}^2 \quad A_{\text{bldg}} = 7500 \text{ m}^2
 \end{array}
 \left. \vphantom{\begin{array}{l} \text{ETTV}_{\text{bldg1}} \\ \text{ETTV}_{\text{bldg2}} \\ \text{ETTV}_{\text{bldg3}} \end{array}} \right\}
 \begin{array}{l}
 A_{\text{devt}} = 5000+6800+7500 \\
 = 19300 \text{ m}^2
 \end{array}$$

Therefore

$$\begin{aligned}
 \text{ETTV}_{\text{Weighted average}} &= \frac{\sum (\text{ETTV}_{\text{bldg}} \times A_{\text{bldg}})}{A_{\text{devt}}} \\
 &= \frac{(\text{ETTV}_{\text{bldg1}} \times A_{\text{bldg1}}) + (\text{ETTV}_{\text{bldg2}} \times A_{\text{bldg2}}) + (\text{ETTV}_{\text{bldg3}} \times A_{\text{bldg3}})}{(A_{\text{devt}})} \\
 &= \frac{(35 \times 5000) + (45 \times 6800) + (40 \times 7500)}{19300} \\
 &= 42.4 \text{ W/m}^2 < 45 \text{ W/m}^2 \text{ ok}
 \end{aligned}$$

## Worked Example NRB01-1(b)

Proposed erection of an industrial warehouse building and office block with the following design parameters.

Façade Facing	Fenestration Areas	Gross Areas of Exterior Wall/Façade	Window to Wall Ratio WWR	Prescribed $SC_{glass}$	Proposed $SC_{glass}$	Remarks
<b>Office block</b>						
NE	410	970	0.42	0.22	0.22	ok
NW	480	1000	0.48	0.22	0.22	ok
SE	370	1010	0.37	0.30	0.27	ok
SW	160	500	0.32	0.27	0.27	Ok
<b>Warehouse</b>						
N	440	1000	0.44	0.22	0.22	Ok
S	330	1000	0.33	0.30	0.30	Ok
E	450	1010	0.37	0.22	0.22	Ok
W	240	1000	0.24	0.41	0.40	Ok

In this case, the selection of the proposed Shading Coefficients of Glass ( $SC_{glass}$ ) is better than the prescribed value stated in Table C1 and therefore, it is deemed to have met the ETTV of 45 W/m<sup>2</sup>.

## Documentation Requirements

### At BP Submission Stage

- ETTV computation and tabulation of design parameters in the prescribed forms and formats;
- Architectural elevation drawings showing the composition of the different façade or wall systems that are relevant for the computation of the ETTV; and
- Architectural plan layouts and elevations showing the mode of ventilation and location for various spaces including air-conditioning areas.

### Before TOP Application

The following documents are to be made available on-site or upon request.

- Material schedules showing salient data of material properties used for the façade and external wall systems; and
- As-built ETTV computation or tabulation of design parameters if there are material changes that will affect the design and ETTV.

## NRB01-2 Roof

The roof designed and constructed shall meet the thermal performance as detailed in the following sections NRB01-2(a) and NRB01-2(b).

### NRB01-2(a) Roofs with Skylight

In respect to the roofs with skylights, the Roof Thermal Transfer Value (RTTV) as determined in accordance with the formula and methodology set out in the Code on Envelope Thermal Performance for Buildings, shall not exceed 50 W/m<sup>2</sup>.

## NRB01-2(b) Roofs without Skylight

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In respect to the roofs without skylights, the average thermal transmittance (U-value) for the gross area of the roof shall not exceed the limit prescribed in Table C2 for the corresponding weight group.

Weight Group	Weight range (kg/m <sup>2</sup> )	Maximum Thermal Transmittance (W/m <sup>2</sup> K)
Light	Under 50	0.5
Medium	50 to 230	0.8
Heavy	Over 230	1.2

The computation of the thermal transmittance of roof (U-Value) shall be in accordance with the formula set out in the prescribed Code for Envelope Thermal Performance for Buildings.

## Documentation Requirements

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### At BP Submission Stage

- RTTV computation for roofs with skylight in prescribed forms and formats, where relevant;
- Architectural plan layout and sectional details of different roof types as well as the roof composition and respective U-values; and
- Technical material or product information and relevant calculation of U-value of the roof.

### Before TOP Application

The following documents are to be made available on-site or upon request.

- Technical material or product information and relevant U-value calculation or RTTV computation if there are material changes that will affect the design and U value.

## References

Code on Envelope Thermal Performance for Buildings issued by the Building and Construction Authority (BCA)

## Related Information

**Better Thermal Performance** : Building envelope that is designed with better thermal performance and meets the ETTV of not more than 40 W/m<sup>2</sup> can be considered separately under NRBE 1-1 – Enhanced Building Envelope Performance as one of the carbon reduction measures.

**Daylight Reflectance** : Under the Approved Document – Section P Daylight Reflectance, the external surface (including a roof) of a building must be designed and constructed in a manner such that any reflection of sunlight off the external surface of the building does not result in loss of amenity to occupants of other buildings in the vicinity of that building.

## NRB02 Air-Tightness and Leakage

### Intent

Minimise air leakage in buildings as part of energy conservation measures.

### Applicability & Scope

Generally applicable to buildings with an aggregate air-conditioning area of more than 500 m<sup>2</sup>.

### Base Requirement

A building shall be designed and constructed with energy conservation measures to reduce air leakage through doors, windows and other openings on the building envelope.

#### NRB02-1 Windows and Curtain Walls

All windows and curtain walls shall be designed to ensure that air leakage rates do not exceed the limits specified in the following standards.

- (i) SS 212 – Specification for Aluminium Alloy Windows
- (ii) SS 654 – Code of Practice for Curtain Walls

#### NRB02-2 Openings between Conditioned and Non-Conditioned Spaces

Building entrances and door openings to building exterior or non-air-conditioned spaces and the like shall

- (i) be provided with doors that are equipped with automated technology or self-closing devices. Where door opening of any commercial units are located along the perimeter of the building envelope, that unit shall be equipped with the addition of pressure independent control valve and energy meter to measure the consumption of fan coiled units (FCUs) within the unit; and
- (ii) be equipped with vestibules or other appropriate measures for the doorway with high pedestrian traffic flow. In the case of vestibules, the interior and exterior door must have a minimum distance of not less than 2.5 m apart and should be interlocked to avoid being opened at the same time.

Note: Doorway with high pedestrian traffic flow refers to building main entrances and those leading to transport nodes or other commercial buildings.

### Guidance Notes

NRB02-1 : While there is no requirement for air leakage testing for the whole building, it is important to ensure that the building envelope is designed and constructed with a continuous air barrier system. Having proper workmanship through good construction practices and attention to details such as sealing joints around fenestration, openings for services, building assemblies will be imperative to be effective in mitigating air leakage between conditioned space and the exterior.

For this requirement, the sampling for the air permeability tests would require the representative units/components of the building envelope to be tested. There should have one test for each typical window and curtain wall component type. The Qualified Person (QP) can evaluate and determine the appropriate number of tests for the development.

NRB02-2 : Other than the provision of vestibule as a means to reduce energy losses from air infiltration/exfiltration, appropriate measures could be considered in instances where doors are required to stay open for operational purposes. For example, the use of a highly efficient air-curtain system with its performance

tested in accordance with ANSI/AMCA Standard 220 to ensure a minimum of 2.0 m/s airstream velocity at the floor. Other design approaches such as using temperature stratification concept with justification by way of Computer Fluid Dynamics (CFD) simulation along with appropriate placement of diffusers are possible alternatives to minimise air leakage.

As this requirement is intended for normal building operation, there could be a need to consider the provision of sufficient ventilation openings and effective air extraction/exhaust to cater for specific operational requirements, when needed.

## **Documentation Requirements**

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### **At BP Submission Stage**

- Extracts of the tender specification showing the requirement for air permeability tests for windows and curtain walls; and
- Plan layout showing the vestibules and details of the automated technology or self-closing devices provided for the doors and other appropriate measures, where relevant.

### **Before TOP Application**

The following documents are to be made available on-site or upon request.

- Air permeability test results and report for windows and curtain wall system (mock-up) from an accredited laboratory; and
- Photographs showing the provision of vestibules or other appropriate measures implemented.

## **References**

SS 212 – Specification for Aluminum Alloy Windows

SS 654 – Code of Practice for Curtain Walls

ANSI/AMCA Standard 220-5 – Laboratory Methods of Testing Air Curtain Units for Aerodynamic Performance Rating

# NRB03 Building Energy Performance

## Intent

Reduce energy demand associated with key building services and equipment during operation.

## Applicability & Scope

Generally applicable to buildings with mechanical and/or electrical equipment and systems. This section specifies the minimum energy efficiency requirements for the following systems.

- (a) Building cooling systems that serve an aggregate air-conditioned area > 500 m<sup>2</sup>
- (b) Lighting systems for interior spaces
- (c) Mechanical ventilation systems for normally occupied spaces and car parks
- (d) Vertical transportation systems

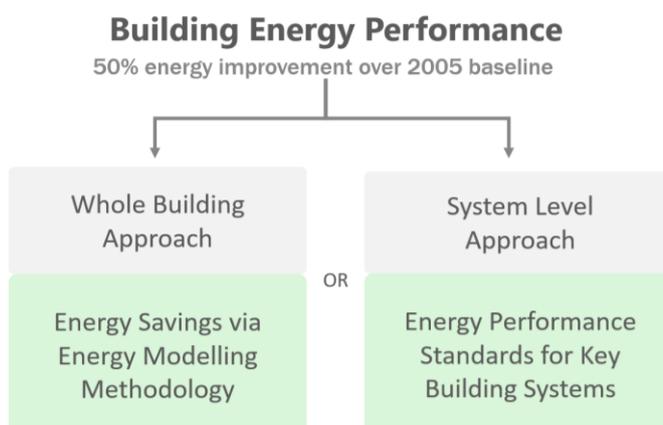
## Base Requirement

A building shall be designed and constructed with enhanced energy performance that meets the minimum energy efficiency improvements of 50% over the 2005 baseline. For building works that involve major additions and alterations or retrofitting to an existing building, the minimum efficiency improvement is set at 40% over the 2005 baseline to account for inherent site limitation and technical constraints.

The compliance with the requirement shall be demonstrated either by way of energy modelling based on the methodology detailed in NRB03-1 and Appendix D or by meeting the enhanced energy performance standards set for the key building systems as detailed in NRB03-2.

### Compliance Level

### Compliance Options



## NRB03-1 Whole Building Approach via Energy Modelling

The Whole Building Approach via energy modelling could provide a holistic approach considering the potential integration and optimisation of major building attributes and systems to facilitate greater energy use reduction. It would provide more flexibility in the design of key building attributes and energy systems in a more integrated manner.

Using this approach, the demonstration of energy saving requirements of 30% over the prevailing Singapore Standards and baseline will be required. It shall be conducted in accordance with the Energy Modelling Methodology and Requirements set out in Appendix D of this Code. In addition, the limits set for the Total System Efficiency (TSE) of respective building cooling systems stipulated in Table C3 and C5 under NRB03-2(a) shall also apply.

For buildings with cooling provision from the District Cooling System (DCS) that are required to meet the Minimum Energy Efficiency Standards (MEES) under the Energy Conservation Act, the energy contribution from

the DCS can be excluded in the energy modelling simulation. However, the system efficiency standard for the air distribution systems provided for these buildings shall not exceed 0.25 kW/RT.

**Exception :** Air-Cooled Chilled-Water System can only be adopted if the peak building cooling load of not more than 500 RT and the building works involves major retrofitting or additions and alterations to an existing building.

## Documentation Requirements

### At BP Submission Stage

- Salient design information and proposed energy efficiency standard to be tabulated and provided in the prescribed forms and formats; and
- Energy modelling report with details as stated in Appendix D, if ready.

### Before TOP Application

- Updated energy modelling report with details stated in Appendix D if there are changes; and
- Salient as-built design information and proposed energy efficiency standard to be tabulated and provided in the prescribed forms and formats.

## NRB03-2 System Level Approach via Enhanced Energy Performance Standards

Alternatively, the System Level Approach shall be adopted where all enhanced energy performance standards set for the key building systems are to be complied with, to meet the minimum energy efficiency improvements.

### NRB03-2(a) Air-Conditioning System

To reduce energy required to provide and distribute conditioned air within the space through the use of energy-efficient air-conditioning system.

The Total System Efficiency (TSE) which is the combined system efficiency of the chilled water plant or condenser unit (that is the water-side component) and air distribution systems (that is the air-side component) shall not exceed the limits set in respective Table C3 and C5 during the building operating hours as defined below.

Building Type	Operational Hours
Office Buildings	9 a.m. to 6 p.m. (Monday to Friday)
Retail Malls	10 a.m. to 10 p.m.
Hotels	24 hours
Other Building Types	To be determined based on operating hours

The minimum threshold set on the component system efficiency of chilled water plant or condenser units stipulated in Table C4 and C6 are required to be complied with.

(i) Water-Cooled Building Cooling system comprises a combination of the following components :

- Water-Cooled Chiller
- Water-Cooled Direct-Expansion (DX) System
- Chilled Water Pump
- Condenser Water Pump
- Cooling Tower
- Air Distribution System

The limits set for Total System Efficiency set for water-cooled building cooling system is as shown in the following Table C3.

<b>Table C3 – Total System Efficiency (TSE) for Water-Cooled Building Cooling System</b>	
<b>New Buildings</b>	<b>Existing Buildings undergoing Major Retrofitting/Alterations and Additions</b>
0.85 kW/RT	0.9 kW/RT

where the minimum water-side component efficiency of a new commercial building development shall not be more than 0.63 kW/RT. As for other building developments, the minimum water-side component efficiency will be based on the chilled water supply temperature and as summarised in Table C4.

<b>Table C4 – Minimum Water-Cooled Chilled Water Plant Efficiency <math>\eta_c</math></b>							
<b>New Commercial Buildings</b>	<b>Other Building Developments</b>						
	Chilled Water Supply Temp (°C)	6	7	8	9	10	For chilled water supply temp above 10°C, the threshold will be adjusted from 0.64 kW/RT by 0.01 kW/RT for every 1 °C increase in chilled water supply temperature
0.63 kW/RT	Water-Cooled Chiller System Efficiency (kW/RT)	0.68	0.67	0.66	0.65	0.64	

**Exception** : For buildings with cooling provisions from the District Cooling System (DCS) that are regulated to meet the Minimum Energy Efficiency Standards (MEES) under the Energy Conservation Act, the TSE requirement does not apply. However, the system efficiency standard for the air distribution systems provided for these buildings shall not exceed 0.25 kW/RT.

(ii) Air-Cooled Building Cooling System comprises the following systems and components :

- Unitary Air-Conditioners (Single or combination of systems)
  - Variable Refrigerant Flow (VRF) system
  - Single-Split Units
  - Multi-Split Units
  - Air Distribution System
- Air-Cooled Chilled-Water System can only be adopted for existing building development with inherent constraints and with peak building cooling load of not more than 500 RT
  - Air-Cooled Chiller
  - Chilled Water Pump
  - Air Distribution System

The limits set for Total System Efficiency set for air-cooled building cooling system is as shown in the following Table C5.

<b>Table C5 – Total System Efficiency (TSE) for Air-Cooled Building Cooling System</b>
<b>All Buildings including Existing Buildings undergoing Major Retrofitting / Major Additions and Alterations</b>
1.0 kW/RT

where the minimum water-side component efficiencies for different systems are as stated in Table C6.

<b>Table C6 – Minimum Air-Conditioning Component Efficiency <math>\eta_c</math></b>	
<b>Unitary System (Outdoor Condenser Units)</b>	<b>Air-Cooled Chilled Water Plant Peak Load &lt; 500 RT</b>
<b>All Buildings</b>	<b>Applicable only for Existing Buildings undergoing Major Retrofitting/Major Additions and Alterations</b>
0.78 kW/RT (inclusive of site derating factor)	0.85 kW/RT

### Compliance Notes:

- (1) Where there is a combination of water-cooled and air-cooled building cooling systems adopted, the respective TSEs shall be complied with, except for the building cooling system that serves an aggregate air-conditioned floor area of not more than 500 m<sup>2</sup>.
- (2) For buildings that tap on the existing chilled water plant for cooling provision, the compliance will be based on the TSE which is the combined system efficiency of the existing plant and air distribution systems.
- (3) In any hotel building, a control device shall be installed in every guestroom for the purpose of automatically reducing the air-conditioning when a guestroom is not occupied.
- (4) Air-conditioning system shall be equipped with manual switches, timers or automatic controllers for shutting off part of the air-conditioning system during periods of non-use or reduced heat load.
- (5) The air-conditioning systems designed should be rightly sized with good configuration to cater to a wider range of operating cooling load conditions so that the systems could operate at optimal energy efficiency level and comfort most of the time. There should also be considerations to cater for night load conditions for better building energy effectiveness and performance.

## Guidance Notes

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### (1) Building Cooling System with Chilled Water Plant

The total system efficiency of the building cooling system is to be derived considering the building operation at part load conditions. It is computed based on the annual energy consumption (kWh) of the system over the annual cooling consumption in RTh. The units used in kW/RT. The simplified methodology in determining the TSE can be adopted and as follows :

- Determine the expected daily average cooling load profile based on heat load simulation of one whole year over the building operating hours defined for a day in RTh.

Building Type	Operational Hours
<i>Office Buildings</i>	9 a.m. to 6 p.m. (Monday to Friday)
<i>Retail Malls</i>	10 a.m. to 10 p.m.
<i>Hotels</i>	24 hours
<i>Other Building Types</i>	To be determined based on operating hours

- Propose air-conditioning plant configuration and derive the respective power inputs of various plant equipment selected over the operating range of cooling load conditions. The minimum frequency set point for the Variable Speed Drives (VSDs) used for regulating the speed of chilled-water pumps, condenser water pumps or cooling tower fans are to be considered to ensure that chilled-water flow can be effectively distributed.
- Propose air distribution system and derive the respective power inputs over the operating range of cooling load conditions with due consideration for the minimum airflow rate requirement.
- The air-side component efficiency of the fan systems can be adjusted to allow for pressure drop adjustments where there is a need for more allowance due to functionality and activities as recommended in SS 553: Code of Practice for Air-Conditioning and Mechanical Ventilation in Buildings – Table 2b.
- Derive the Total System Efficiency (TSE) of the proposed building cooling system (in kW/RT) based on total power input of the air-conditioning plant (kWh) and air distribution system required over the total average cooling load requirement in RTh during building operating hours.

## Worked Example NRB03-2(a)(i)

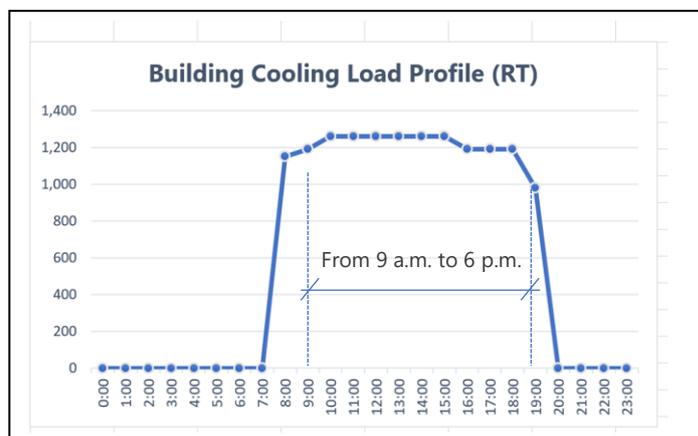
### Computation of the Total System Efficiency (TSE) of a Water-Cooled Chilled-Water Plant with Primary Chilled-Water System

An office building has an air-conditioned floor area of 67,500 m<sup>2</sup> with cooling provision served by a chilled water plant. Variable speed drive (VSD) systems will be used in connection with the pump and fan applications to vary the speed of chilled-water pumps, condenser water pumps and cooling tower fans according to demand. The building operating hours specified for the office building is Monday to Friday from 9 a.m. to 6 p.m.

#### Step 1 – Determine the building cooling load profile

Simulation of annual building cooling load profile shall be carried out to determine the daily average cooling load profile and as follows :

Time	Average Cooling Load (RT)
8:00	1,150
9:00	1,190
10:00	1,260
11:00	1,260
12:00	1,260
13:00	1,260
14:00	1,260
15:00	1,260
16:00	1,190
17:00	1,190
18:00	1,190
19:00	980



**Important note:** It is essential to design and consider for other load conditions that are not within the building operating hours specified so as to minimise overall energy usage for cooling, although this is not required for TSE calculation purposes

#### Step 2 – Propose air-conditioning plant configuration and derive the respective power input of various system components

The proposed water-cooled chilled water plant configuration for the building operating hours specified are as follows:

- Chillers: 3 nos. x 700 RT (2 duty and 1 stand by)
- Chilled Water Pumps (CHWP): 3 nos. x 45 kW (2 duty and 1 stand by)
- Condenser Water Pumps (CWP): 3 nos. x 37 kW (2 duty and 1 stand by)
- Cooling Towers (CT): 3 nos. x 900 RT (2 duty and 1 stand by)
- Each cooling tower has 3 no. of 7.5 kW fans

#### Step 2(a) Centrifugal water-cooled chiller (700 RT)

Based on the performance data of the selected chillers from the manufacturer:

% Load	Capacity (RT)	Chiller Input Power (kW)	Chiller Efficiency kW/RT	Evaporator		Condenser	
				CHWST (°C)	CHWRT (°C)	CWST (°C)	CWRT (°C)
100	700	363	0.519	6.67	12.31	29.68	34.80
90	630	329	0.522	6.67	12.31	29.68	34.29
80	560	291	0.520	6.67	12.31	29.68	33.78
70	490	260	0.533	6.67	12.31	29.68	33.28

Installed capacity of the chillers (excluding standby) = 1,400 RT

Chillers configuration: 2 x 700 RT centrifugal chillers (operating)  
1 x 700 RT centrifugal chiller (standby)

Based on the simulated total building load profile, the proposed chiller plant configuration is as follows:

Time	Cooling Load (RT)	No. of Chillers in Operation	Chiller Efficiency	Chiller Input Power (kW)
From 900 to 1000 and 1500 to 1800	1,190 RT	2 x 700RT @ 85%	0.521	620
From 1000 to 1500	1,260 RT	2 x 700RT @ 90%	0.522	658

Step 2(b) Chilled-water pumps (primary only):

- 2 nos. x 45 kW primary chilled-water pump to be installed with Variable Speed Drives (VSDs)
- Water flow rate per pump at full load (Q) = 106 L/s
- Operating static head (h) = 28 m
- Pump efficiency ( $\eta_p$ ) = 86.8 %
- Motor efficiency ( $\eta_m$ ) = 94.2 %

$$\text{Power requirement of chilled-water pump at full load (kW)} = \frac{(Q)(\rho)(g)(h)}{(10^6)(\eta_p)(\eta_m)}$$

where

- Q: Water flow rate in L/s
- $\rho$ : Density of water in kg/m<sup>3</sup>
- g: Gravitational acceleration in m/s<sup>2</sup>
- h: Static pressure head m
- $\eta_p$ : Pump efficiency
- $\eta_m$ : Motor efficiency

$$\text{Power requirement of chilled-water pump (kW)} = \frac{(106)(1000)(9.81)(28)}{(10^6)(0.868)(0.942)} = 35.61 \text{ kW}$$

$$\text{Power of 2 pumps @ full load} = 35.61 \text{ kW} \times 2 = 71.22 \text{ kW}$$

The following equation for pump part load power curve, referenced from Appendix 5.7 of the *Non-Residential Alternative Calculation Method Reference Manual 2013* by the California Energy Commission (CEC) takes into account for the losses during actual operating conditions and is to be used to estimate the pump power at the part load conditions.

$$\text{Pump power ratio} = 0.0205x + 0.4101x^2 + 0.5753x^3$$

where x is the part-load ratio.

$$\left. \begin{array}{l} \text{Total Pump Power} \\ \text{@ 85\% part-load (kW)} \end{array} \right\} \begin{array}{l} \text{Total Pump power @ full load} \times \text{Pump power ratio} \\ = 71.22 \times 0.66703 = 47.50 \text{ kW (when } x = 0.85, \text{ the corresponding power ratio is } 0.66703) \end{array}$$

$$\left. \begin{array}{l} \text{Total Pump Power} \\ \text{@ 90\% part-load (kW)} \end{array} \right\} \begin{array}{l} \text{Total Pump power @ full load} \times \text{Pump power ratio when } x = 0.90 \\ = 71.22 \times 0.77002 = 54.84 \text{ kW (when } x = 0.90, \text{ the corresponding power ratio is } 0.77002) \end{array}$$

Cooling Load (RT)	No. of Chilled-Water Pumps in Operation	Total Operating Pump Power (kW)
1,190 RT	2 x 45 kW @ 85%	47.50
1,260 RT	2 x 45 kW @ 90%	54.84

Step 2(c) Condenser water pumps:

- 2 nos. x 55 kW condenser water pumps to be installed with VSDs
- Water flow rate for the condenser water pump (Q) = 132.5 L/s
- Operating static head (h) = 20 m
- Pump efficiency ( $\eta_p$ ) = 88.5%
- Motor efficiency ( $\eta_m$ ) = 94.7%

$$\text{Power requirement of condenser water pump at full load (kW)} = \frac{(132.5)(1000)(9.81)(20)}{(10^6)(0.885)(0.947)} = 31.02 \text{ kW}$$

$$\begin{aligned} \text{Power of 2 pumps @ full load} &= 31.02 \text{ kW} \times 2 \\ &= 62.04 \text{ kW} \end{aligned}$$

Although VSDs are installed, the flow is fixed at 45Hz (90%). Hence, power consumption should be based on 90% part load condition.

Using the pump part load power curve equation,

$$\left. \begin{array}{l} \text{Total Pump Power} \\ \text{@90\% part-load (kW)} \end{array} \right\} = \text{Total Pump power @ full load} \times \text{Pump power ratio} \\ = 62.04 \times 0.77002 = 47.77 \text{ kW (when } x = 0.90, \text{ the corresponding power ratio is } 0.77002)$$

Cooling Load (RT)	No. of Condenser Water Pumps in Operation	Total Operating Pump Power (kW)
1,190 RT	2 x 37 kW @ 90%	47.77
1,260 RT	2 x 37 kW @ 90%	47.77

Step 2(d) Cooling towers:

- 2 nos. of cooling towers to be installed with VSDs
- Heat rejection capacity per cooling tower = 900 RT
- Total heat rejection for 2 x cooling towers = 1,800 RT
- Each cooling tower with 3 fan cells with fan motor = 7.5 kW
- Fan motor efficiency = 92%

$$\text{Input power per cooling tower} = (7.5 \text{ kW} \times 3 \text{ fans}) / 92\% = 24.46 \text{ kW}$$

$$\text{Total input power for 2 nos. of cooling towers} = 24.46 \text{ kW} \times 2 = 48.92 \text{ kW}$$

In general, total heat rejection of chiller plant (kW) = Total Cooling load (kW) + Total electrical power input of chiller compressor (kW)

The following equation for cooling tower power adjustment curve, referenced from Appendix 5.7 of the Non-Residential Alternative Calculation Method Reference Manual 2013 by the California Energy Commission (CEC) is to be used to estimate the power input requirement at the part-load conditions to take into account losses during actual operating conditions:

$$\text{Cooling tower fan power ratio} = 0.331629 - 0.885676x + 0.605565x^2 + 0.948482x^3$$

where x is the part-load ratio.

$$\left. \begin{array}{l} \text{Fan power} \\ \text{@76\% part-load (kW)} \end{array} \right\} \begin{array}{l} \text{Fan power @ full load} \times \text{Cooling tower fan power ratio} \\ = 48.92 \times 0.42465 \\ = 20.77 \text{ kW (when } x = 0.76, \text{ the corresponding power ratio is } 0.42465) \end{array}$$

$$\left. \begin{array}{l} \text{Fan power} \\ \text{@80\% part-load (kW)} \end{array} \right\} \begin{array}{l} \text{Fan power @ full load} \times \text{Cooling tower fan power ratio when } x = 0.80 \\ = 48.92 \times 0.4963 \\ = 24.28 \text{ kW (when } x = 0.80, \text{ the corresponding power ratio is } 0.4963) \end{array}$$

Cooling Load	Chiller Input Power	Required Heat Rejection	Total Heat Rejection capacity for 2 no. of Cooling Towers	Percentage Loading for Required and Available Heat Rejection	Total Fan Motor Power at Required Part Load Condition
A	B	C = A + (B/3.517)	D	C / D x 100%	
1,190 RT	620	1,366.28	1,800	76%	20.78 kW
1,260 RT	658	1,447.08	1,800	80%	24.28 kW

Step 3 – Derive the Chilled Water Plant Efficiency during defined building operating hours.

Hours	Daily Average Cooling Load (RT)	Chillers Power Input (kW)	CHWP Power (kW)	CWP Power (kW)	CT Power (kW)	Total Power Input (kW)
9:00:00 AM	1,190	620	47.50	47.77	20.78	736.05
10:00:00 AM	1,260	658	54.84	47.77	24.28	784.89
11:00:00 AM	1,260	658	54.84	47.77	24.28	784.89
12:00:00 PM	1,260	658	54.84	47.77	24.28	784.89
1:00:00 PM	1,260	658	54.84	47.77	24.28	784.89
2:00:00 PM	1,260	658	54.84	47.77	24.28	784.89
3:00:00 PM	1,260	658	54.84	47.77	24.28	784.89
4:00:00 PM	1,190	620	47.50	47.77	20.78	736.05
5:00:00 PM	1,190	620	47.50	47.77	20.78	736.05
6:00:00 PM	1,190	620	47.50	47.77	20.78	736.05
<b>Daily Consumption (9:00AM to 6:00 PM)</b>	12,320 RTh	6,428 kWh	519.04 kWh	477.70 kWh	226.80 kWh	7,653.54 kWh
<b>Chilled Water Plant Efficiency kW/RT</b>		0.522	0.042	0.038	0.019	0.62

Proposed chiller water plant efficiency = Total Power Input /Total Cooling Load  
= 7,665.44/12,320  
= 0.62 kW/RT better than the minimum threshold of 0.63 kW/RT ok

Step 4 –Derive the Air Distribution System Efficiency and Total System Efficiency (TSE) during defined building operating hours

Hours	Daily Average Cooling Load (RT)	Total Power Input from Chilled Water Plant (kW)	Air Distribution System		Total System	
			Type	Air-Side (CF/VF) (kW)	Total Water + Air	
					kW	KW/RT
9:00:00 AM	1,190	736.05	AHU-VAV	262.84	998.89	0.839
10:00:00 AM	1,260	784.89	AHU-VAV	253.91	1038.80	0.824
11:00:00 AM	1,260	784.89	AHU-VAV	298.58	1083.47	0.860
12:00:00 PM	1,260	784.89	AHU-VAV	302.31	1087.20	0.863

Cont'd

Hours	Daily Average Cooling Load (RT)	Total Power Input from Chilled Water Plant (kW)	Air Distribution System		Total System	
			Type	Air-Side (CF/VF) (kW)	Total Water + Air	
					kW	KW/RT
1:00:00 PM	1,260	784.89	AHU-VAV	295.60	1080.49	0.858
2:00:00 PM	1,260	784.89	AHU-VAV	297.84	1082.73	0.859
3:00:00 PM	1,260	784.89	AHU-VAV	294.86	1079.75	0.857
4:00:00 PM	1,190	736.05	AHU-VAV	289.65	1025.70	0.862
5:00:00 PM	1,190	736.05	AHU-VAV	271.78	1007.83	0.847
6:00:00 PM	1,190	736.05	AHU-VAV	224.87	960.92	0.807
Daily Consumption (9:00AM to 6:00 PM)	12,320 RTh	7,653.54 kWh	-	2792.23 kWh	10445.77 kWh	0.848
<b>Water-Side Component System Efficiency, kW/RT</b>					0.62	
<b>Air-Side Component System Efficiency, kW/RT</b>					0.23	
<b>Total System Efficiency (TSE), kW/RT</b>					0.85	
					meets the limit of 0.85 kW/RT ok	

The above methodology will also apply to air-cooled chilled water plant systems.

## (2) Unitary Air-Conditioning System

The total system efficiency (TSE) of the unitary air-conditioning system can be determined based on the concept of Integrated Energy Efficiency Ratio (IEER) which would take into consideration the different load capacities with due consideration for part load conditions. The IEER is defined as

$$(0.020 \times A) + (0.617 \times B) + (0.238 \times C) + (0.125 \times D)$$

where

- A = EER or COP at full load
- B = EER or COP at 75% load
- C = EER or COP at 50% load
- D = EER or COP at 25% load

The Energy Efficiency Ratio (EER) describes the system's level of efficiency and can be defined as the ratio of cooling capacity to effective electrical power input required to provide the cooling. The higher EER, the more energy efficient is the equipment/system.

In the case of single and multiple split unitary conditioners, the efficiency can be computed based on the weighted Coefficient of Performance (COP) measured and registered in accordance with the applicable test standards under the Mandatory Energy Labelling Scheme (MELS) under the Energy Conservation Act.

$$COP_{\text{weighted}} = 0.4 \times COP_{100\%} + 0.6 \times COP_{50\%}$$

*COP<sub>100%</sub> is defined as the ratio of the cooling capacity to effective power input at full load cooling capacity*

*COP<sub>50%</sub> is defined as the ratio of the cooling capacity to effective power input at 50% cooling capacity*

The methodology in determining the TSE is as follows :

- Determine the cooling capacity requirement by conducting heat load calculations, cooling load profile and system sizing analysis for the various zones.
- Propose the required system configuration in terms of the number of indoor units and the outdoor condensing unit capacity by considering the total capacity and operational requirements.
- Where there is a combination of unitary air-conditioning systems serving different zones, the weighted system efficiency will be determined by pro-ration according to the respective cooling capacity served and expressed as follows :

$$TSE_{\text{Weighted average}} \text{ (in kW/RT)} = \frac{3.517 / \sum (\text{Cooling capacity} \times IEER)_i}{\text{Total Cooling Capacity}_{\text{overall}}}$$

- As there could be a need to account for possible efficiency losses due to site inherent constraints and considerations, the site derating factor should be included to account for the system efficiency of the condenser units to better reflect its expected operating performance when measured.

### Worked Example NRB03-2(a)(ii)

#### Computation of the Total System Efficiency (TSE) of Variable Refrigerant Flow (VRF) Systems

An office building has an air-conditioned floor area of 4,250 m<sup>2</sup> with cooling provisions served by two VRF systems. The building operating hours is Monday to Friday from 9 a.m. to 6 p.m. Based on the cooling capacity requirement, the system and equipment schedule, the TSE can be determined to be as follows :

*Step 1 – Determine the individual IEER of the condensing units based on the load conditions of 100%, 75%, 50% and 25% can be based on published technical specifications or verification testing results.*

Outdoor Condenser Units / System	Zone	Location Served	Specification of VRF Outdoor Condensing Unit					IEER <sub>i</sub> (0.020 x A) + (0.617 x B) + (0.238 x C) + (0.125 x D)	
			Full Installed Capacity (KW)	Designed Cooling Capacity (kW)	100% EER (A)	75% EER (B)	50% EER (C)		25% EER (D)
VRF System 1	1	FCC Room	22.4	14.18	4.1	5.5	7.3	7.6	6.16
		Lift lobby Corridor							
		Reception							
VRF System 2	2	Office 1	44.8	28.36	3.90	5.20	7.10	7.90	5.96
	3	Office 2	44.8	28.36	3.90	5.20	7.10	7.90	5.96
	4	Office 3	44.8	28.36	3.90	5.20	7.10	7.90	5.96
Total cooling capacity :			156.8	99.26	–	–	–	–	–

*Step 2 – Determine the overall weighted system efficiency of condensing units by proration.*

$$\begin{aligned} \text{Weighted Design System, } \eta_{C(\text{overall})} \text{ (in kW/RT)} &= 3.517 / \left[ \frac{\sum (\text{Cooling capacity} \times IEER)_i}{\text{Total Cooling Capacity}_{\text{Overall}}} \right] \\ \text{Efficiency of outdoor condenser units} &= 3.517 / \left[ \frac{(14.18 \times 6.16) + (28.36 \times 5.96) \times 3}{99.26} \right] \\ &= 0.608 \text{ kW/RT} \end{aligned}$$

If site deration factor is about 10%, corrected  $\eta_{C(\text{overall})} = 0.608 \times 1.1 = 0.668 \text{ kW/RT} < 0.78 \text{ kW/RT}$  ok

Note that the site derating factor would depend on design, site constraints and installation considerations such as losses due to piping, which would vary from project to project.

*Step 3 – Determine the individual air distribution system efficiencies. For simplicity, the air distribution system efficiency can be derived based on rated cooling capacity and nameplate power from the technical specification in particular for fans coil units (FCUs) with speed determined by the constant frequency of the power supply. The derivation of overall air distribution system efficiency is as follows :*

Indoor Unit / System	Zone	Location Served	Specification of Air Distribution Units				Air Distribution System efficiency based on design cooling capacity $\eta_a$ in kW/RT
			Unit Type	Installed Capacity (kW)	Design cooling Capacity (kW)	Nameplate Motor Power (kW)	
VRF System 1	1	FCC Room	Ceiling Cassette (FCUs)	4.2	2.67	0.043	0.0569
		Lift lobby Corridor	Ceiling Cassette (FCUs)	9.0	5.70	0.092	0.0568
		Reception	Ceiling Cassette (FCUs)	9.0	5.70	0.092	0.0568
VRF System 2	2	Office 1	Ducted FCUs	44.0	27.85	1.8	0.2273
	3	Office 2	Ducted FCUs	44.0	27.85	1.8	0.2273
	4	Office 3	VAV AHUs	44.8	28.36	5.2	0.6449
			Total :	155	98.13	9.027	–

*Step 4 – Determine the overall weighted system efficiency of air distribution system by proration.*

Weighted System Efficiency of air distribution system  $\eta_{a(overall)}$  (in kW/RT) will be as follows :

$$\begin{aligned}
 &= \left[ \frac{\sum (\text{Cooling capacity} \times \eta_a)_i}{\text{Total Cooling Capacity}_{Overall}} \right] \\
 &= \left[ \frac{(2.67 \times 0.0569) + 2 \times (5.70 \times 0.0568) + 2 \times (27.85 \times 0.2273) + (28.36 \times 0.6449)}{98.13} \right] \\
 &= 0.324 \text{ kW/RT}
 \end{aligned}$$

*Step 5 – Derive the Total System Efficiency (TSE) of the proposed VRF system*

Total system efficiency, TSE (in kW/RT) =  $\eta_c(overall) + \eta_a(overall)$

$$= 0.668 + 0.324 = 0.992 \text{ kW/RT} < 1.0 \text{ kW/RT ok}$$

*Note that the system efficiency of the VAV-AHUs derived was based on full load condition similar to that for FCUs. The consideration for the part load conditions can be found in the next section.*

#### **Consideration for Part Load Performance of VAV AHUs**

In the case of Variable Air Volume (VAV) AHUs with VSDs, the part load fan power calculator from ASHRAE 90.1, Table G3.1.3.15, Part Load Performance for VAV Fan Systems, Method 2 – Part-Load Fan Power Equation can be used to account for the part load performance.

Fraction of full-load fan power =  $0.0013 + 0.1470x + 0.9506x^2 - 0.0998x^3$   
 where x is the part-load ratio (Ratio of current L/s against design L/s)

In this instance, the power input can be derived based on the part-load fan ratio at 100%, 75%, 50% and 25%.

The fan ratios computed based on the equation are as follows:

x	1 (100%)	0.75 (75%)	0.50 (50%)	0.25 (25%)
Fan ratio	0.9991	0.60415938	0.299975	0.299975

To derive the air distribution system efficiency of the VAV-AHUs based on the same concept of IEER

$$IEER = (0.020 \times A) + (0.617 \times B) + (0.238 \times C) + (0.125 \times D)$$

where

- A = EER or COP at full load
- B = EER or COP at 75% load
- C = EER or COP at 50% load
- D = EER or COP at 25% load

In this instance,

$$\begin{aligned} EER_{100\%} &= \text{Installed capacity at 100\%/Fan part-load power ratio} \times \text{power input} \\ &= 44.8 \times 1.0 / (0.9991 \times 5.2) = 8.623 \end{aligned}$$

$$\begin{aligned} EER_{75\%} &= \text{Installed capacity at 75\%/Fan part-load power ratio} \times \text{power input} \\ &= 44.8 \times 0.75 / (0.60415938 \times 5.2) = 10.695 \end{aligned}$$

$$\begin{aligned} EER_{50\%} &= \text{Installed capacity at 50\%/Fan part-load power ratio} \times \text{power input} \\ &= 44.8 \times 0.50 / (0.299975 \times 5.2) = 14.360 \end{aligned}$$

$$\begin{aligned} EER_{25\%} &= \text{Installed capacity at 25\%/Fan part-load power ratio} \times \text{power input} \\ &= 44.8 \times 0.25 / (0.299975 \times 5.2) = 7.180 \end{aligned}$$

Note that the minimum volume setpoint shall be 50% of the maximum design airflow rate. In this instance, the Fan part-load power ratio at 25% is to be the same as that at 50%.

System efficiency of VAV-AHU (in kW/RT) is as follows:

$$\begin{aligned} &= 3.517 / (0.020 \times 8.623) + (0.617 \times 10.695) + (0.238 \times 14.360) + (0.125 \times 7.180) \\ &= 0.317 \text{ kW/RT} \end{aligned}$$

**Determine the overall weighted system efficiency of air distribution system by proration**

Weighted System Efficiency  $\eta_{a(\text{overall})}$  (in kW/RT) of air distribution system = 
$$\left[ \frac{\sum (\text{Cooling capacity} \times \eta_a)_i}{\text{Total Cooling Capacity}_{\text{Overall}}} \right]$$

That is 
$$\left[ \frac{(2.67 \times 0.0569) + 2 \times (5.70 \times 0.0568) + 2 \times (27.85 \times 0.227) + (28.36 \times 0.317)}{98.13} \right]$$

= 0.229 kW/RT instead of 0.324 kW/RT in Step 3

**(3) Use of Existing Chilled-Water Plant and/or Air Distribution System**

Existing chilled-water plants with actual operating system efficiency (OSE) that could meet the relevant system efficiency standard stipulated in Table C3 and Table C4 can be used to provide for the space cooling of new building areas. In this instance, an energy audit is to be conducted in accordance with the Code on Periodic Energy Audit of Building Cooling System to ascertain the actual OSE of these plants. If the new cooling load is considerably substantial and takes up more than 30% of the existing cooling load, there must be design consideration to account for these additional building cooling loads and with reference to the actual power

consumption obtained from the energy audit. The same will apply to the use of an existing air distribution system where there should be a trend log or VSD readings to ascertain the air-side efficiency for a period of two (2) weeks. Where needed, optimisation of existing chilled water plant and/or air distribution systems would have to be carried and completed, to meet the minimum energy efficiency standard required.

## **Documentation Requirements**

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### **At BP Submission Stage**

Supporting documents listed in the following section, if ready.

### **Prior to Design Finalisation and Installation**

The following documents are to be submitted before finalisation.

- Drawings showing the schematic and layout of proposed building cooling system;
- Plan layouts showing the mode of ventilation of spaces within the buildings as well as the location of plant room and cooling towers;
- Air-conditioning system information with details on the chiller configuration and type, pumps and cooling towers, air distribution system, unitary air-conditioners in the prescribed forms and formats;
- Air-conditioning design and pump head calculation and technical specification and performance data sheet of various components of the cooling system designed in the prescribed forms and formats;
- Detailed calculation of the Total System Efficiency (TSE) of the cooling system using the methodology provided in the guidance notes for the respective air-conditioning systems; and
- Operating system efficiency (OSE) report showing the measured system efficiency of the existing chilled water plant during normal operating hours and trend log or VSD reading of air-side efficiency for a period of two (2) weeks if the building is designed to tap on the existing chiller plant system for cooling provision.

### **Before TOP Application**

Update of the air-conditioning system information with the supporting calculation listed above will be required if there are changes to the installation which would materially affect the TSE of the building cooling system. The as-built operating system efficiency (OSE) report will be required for buildings that are designed to tap on the existing chilled water plant for cooling provision.

## **NRB03-2(b) Lighting System**

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To reduce energy required to illuminate interior spaces with proper lighting levels. The lighting provision shall be at least 40% more energy efficient than the prescribed lighting power budget stated in SS 530 – Code of Practice for Energy Efficiency Standard for Building Services and Equipment. Lighting control for artificial lighting shall also be provided in accordance with SS 530, where applicable. In any hotel building, a control device shall be installed in every guest room to automatically switch off the lighting when the room is not occupied.

## **Guidance Notes**

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In the selection of light fittings, due consideration should be given to account for future phase-out of inefficient lighting and ballasts in Singapore. Reference can be made to the Minimum Energy Performance Standard (MEPS) on lamp efficacies and ballast energy performance for lighting design under the Energy Conservation Act.

Other than the provision of energy-efficient lighting, it is important to ensure that proper lighting levels are provided. Where relevant, the recommended lux levels stipulated in the Singapore Standard SS 531 - Code of Practice for Lighting of Work Places – Indoor – Part 1 should be adopted.

## Worked Example NRB03-2(b)

The proposed and maximum lighting power budget for artificial lighting can be computed by determining the total power consumption and efficiency level based on the lighting layout design for each area and light fitting types used as illustrated in the following example.

Description	Areas (m <sup>2</sup> )	Design Data		SS 530 Requirements	
		Total Power Consumption (by area) (W)	Design Lighting Power Density (W/m <sup>2</sup> )	Reference Lighting Power Density (W/m <sup>2</sup> )	Reference Total Power Consumption (by area) (W)
<b>Office, Work and Study</b>					
Open Office 1	1,500	9,630	6.42	12	18,000
Open Office 2	3000	19,260	6.42	12	36,000
Meeting Rooms	100	720	7.20	12	1,200
<b>Transport and Goods</b>					
Corridors	500	2,900	5.80	7	3,500
Stairs, Escalators, Travellators areas	300	1,599	5.33	6	1,800
Lift Lobbies	500	2,500	5	7	3,500
Car Parks	2000	6,000	3	3	6,000
<b>Rest, Clean, Exercise and Play</b>					
Toilets	150	900	6	10	1,500
<b>Manufacturing &amp; Maintenance</b>					
Mechanical & Electrical Rooms	150	900	6	10	1,500
<b>Others</b>					
Collaborative Spaces	1,500	9,000	6	12	18,000
<b>Total</b>	<b>9,700</b>	<b>53,409</b>	<b>5.506</b>	<b>9.381</b>	<b>91,000</b>

<b>% Improvement over reference standard</b>	<i>41.3 % &gt; 40% which meet the minimum energy efficiency standard set for lighting provision</i>
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## Documentation Requirements

### At BP Submission Stage

Generally, no supporting document requirement at this stage.

### Before TOP Application

The following documents are to be made available on-site or upon request.

- As-built lighting layout plan and schedules showing the numbers, location and types of luminaries used;
- Calculation of lighting power budget based on actual installation and the percentage improvement over the prescribed lighting power budget; and
- Delivery orders and technical product information of the lighting luminaries used.

## NRB03-2(c) Mechanical Ventilation System

To reduce energy required to supply and distribute fresh air within the space through the use of energy-efficient mechanical ventilation systems and controls.

- (i) Mechanical ventilation systems for normally occupied spaces shall be designed to be at least 10% more energy efficient than the prescribed standard stated in SS 553; and
- (ii) Provision of Carbon Monoxide (CO) detection sensor controls with Variable Speed Drives (VSDs) to regulate demand for mechanical ventilation in car parks.

### Guidance Notes

The energy efficiency improvement can be considered based on Option (1) Fan System Motor Nameplate Power or Option (2) Fan System Input in accordance with SS 553 and as stated in Table C7 below.

<b>Table C7 – Baseline Standard for Mechanical Ventilation System for Normally Occupied Spaces</b>
<b>Fan Power Limitation for Constant Volume and Variable Volume</b>
Option 1: Fan system motor nameplate → Allowable nameplate motor: 0.35 W/CMH
Option 2: Fan System Input → Allowable Fan System Input Power: $\leq 0.3 + A^*$ W/CMH
<i>*A is the sum of the pressure drop adjustments (in Pa) that can be considered according to the recommendation provided in Table 2b of SS 553 and are subject to BCA's evaluation.</i>

### Worked Example NRB03-2(c)

The small industrial factory development comprises a 4-storey block with 6 workshop spaces that are mechanically ventilated with the following schedule and information.

#### Option 1 – Fan Motor Nameplate Power

MV Fan Schedule									
Work shop	Fan Ref	Fan Type	Floor Areas (m <sup>2</sup> )	Space Height (m)	ACH	Air Flow Rate (CMH)	External static (Pa)	Motor Nameplate Power (kW)	Fan Efficiency (W/CMH)
1	FAF 1-1	Axial	650	10	6	39000	650	11	0.28
2	FAF 1-2	Axial	650	10	6	39000	650	11	0.28
3	FAF 1-3	Axial	650	10	6	39000	650	11	0.28
4	FAF 1-4	Axial	500	8	6	24000	500	5.5	0.23
5	FAF 1-5	Axial	500	8	6	24000	500	5.5	0.23
6	FAF 1-6	Axial	500	8	6	24000	500	5.5	0.23
1	EAF 1-1	Axial	650	10	6	39000	650	11	0.28
2	EAF 1-2	Axial	650	10	6	39000	650	11	0.28
3	EAF 1-3	Axial	650	10	6	39000	650	11	0.28
4	EAF 1-4	Axial	500	8	6	24000	500	5.5	0.23
5	EAF 1-5	Axial	500	8	6	24000	500	5.5	0.23
6	EAF 1-6	Axial	500	8	6	24000	500	5.5	0.23

Total Air-Flow Rate	378000 CMH
Total Fan Power (Design)	99 kW
Total Fan Power (Baseline)	378000 CMH x 0.35 W/CMH = 132.3 kW
% Improvement over Baseline	25 % over baseline > 10% ok

## Option 2 – Fan Motor Input Power

MV Fan Schedule									
Work shop	Fan Ref	Fan Type	Floor Areas (m <sup>2</sup> )	Space Height (m)	ACH	Air Flow Rate (CMH)	External static (Pa)	Fan System Input Power (kW)	Fan Efficiency (W/CMH)
1	FAF 1-1	Axial	650	10	6	39000	650	8.28	0.21
2	FAF 1-2	Axial	650	10	6	39000	650	8.28	0.21
3	FAF 1-3	Axial	650	10	6	39000	650	8.28	0.21
4	FAF 1-4	Axial	500	8	6	24000	500	3.92	0.16
5	FAF 1-5	Axial	500	8	6	24000	500	3.92	0.16
6	FAF 1-6	Axial	500	8	6	24000	500	3.92	0.16
1	EAF 1-1	Axial	650	10	6	39000	650	8.28	0.21
2	EAF 1-2	Axial	650	10	6	39000	650	8.28	0.21
3	EAF 1-3	Axial	650	10	6	39000	650	8.28	0.21
4	EAF 1-4	Axial	500	8	6	24000	500	3.92	0.16
5	EAF 1-5	Axial	500	8	6	24000	500	3.92	0.16
6	EAF 1-6	Axial	500	8	6	24000	500	3.92	0.16

Total Air-Flow Rate	378000 CMH
Total Fan Power (Design)	73.20 kW
Total Fan Power (Baseline)	378000 CMH x 0.30 W/CMH = 113.4 kW
% Improvement over Baseline	35% over baseline > 10% ok

## Documentation Requirements

### At BP Submission Stage

- Architectural plan layouts showing the mode of ventilation for various spaces;
- Mechanical ventilation design plan layouts;
- Computation of the fan static calculations, design air flow rate and energy efficiency improvement; and
- MV fan equipment schedule and technical product information of these MV fans and fan curves.

### Before TOP Application

- As-built details similar to design submission if there are major changes.

## NRB03-2(d) Vertical Transportation System

To reduce energy consumption from vertical transportation such as lifts and escalators by adopting energy-efficient technologies and control. The lift and escalator systems provided for the building developments are required to be equipped with Variable Voltage Variable Frequency (VVVF) and sleep mode features. In the case of escalators, the provision of occupancy sensors, standby speed and/or standby stop features will be required, where relevant.

## Guidance Notes

Other than the provision of vertical transportation systems that come with VVVF and sleep mode features, there are other energy-efficient technologies such as regenerative drive or deployment of advanced dispatching software that could reduce occupant wait time while reducing energy use by up to 50% compared to traditional systems. These technologies if adopted can be considered under NRBE03-3.

## Documentary Requirements

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### At BP Submission Stage

Generally, no supporting document submission at this stage.

### Before TOP Application

Extracts of specifications that indicate the types of lifts, escalators and related features.

## References

- (1) Mandatory Energy Labelling Scheme (MELS), Minimum Energy Performance Standards (MEPS) for Air-Conditioners and Minimum Energy Efficiency Standards (MEES) for Water-Cooled Chilled Water Systems in Industrial Facilities under the Energy Conservation Act can be found on the website of the National Environmental Agency (NEA)
- (2) SS 530 – Code of Practice for Energy Efficiency Standard for Building Services and Equipment
- (3) SS 553 – Code of Practice for Air-Conditioning and Mechanical Ventilation in Buildings
- (4) Code on Periodic Energy Audit of Building Cooling System issued by the Building and Construction Authority (BCA)
- (5) Mandatory Minimum Energy Performance Standards (MEPS) for Lamps and Ballasts can be found on the website of the National Environmental Agency (NEA)
- (6) SS 531 – Code of Practice for Lighting of Work Places – Indoor – Part 1

## Related Information

- (1) It is recommended to adopt chillers that use climate-friendly refrigerants with Global Warming Potential (GWP) of 15 or less, which will help reduce Singapore's greenhouse gas (GHG) emissions arising from the use of hydrofluorocarbons (HFCs). Note that the supply of water-cooled chillers that use refrigerants with GWP above 15 will be banned from Q4 2022 under the Energy Protection Management Act. Please refer to NEA's website for more details.
- (2) To ensure that the cooling systems designed continue to operate efficiently, building owners may be issued a notice to conduct periodic energy audits at any time after building occupation. The detailed requirements can be found in the Code on Periodic Energy Audit of Building Cooling System issued by the Building and Construction Authority (BCA). Please refer to BCA's website for more details.
- (3) Water-cooled chilled water systems for defined groups of new and existing industrial facilities are required to meet the Minimum Energy Efficiency Standards (MEES) under the Energy Conservation Act. For new industrial facilities that requires Planning Permission or equivalent on or after 1 December 2020, a report showing the chilled water system operating performance would need to be submitted to the National Environment Agency (NEA) at stipulated timeframe after the Temporary Occupation Permit (TOP) is issued. Please refer to NEA's website for more details.
- (4) Under the Approved Document – Section G – Ventilation regulated under the Building Control Regulations, there are specific ventilation rate requirements which referenced to SS 553 – Code of Practice for Air-Conditioning and Mechanical Ventilation in Buildings that need to be complied with. Please refer to the BCA's website on Approved Document for more details.

# NRB04 Measurement and Verification (M&V) Instrumentation

## Intent

Facilitate energy management and monitoring of the building cooling system efficiency.

## Applicability & Scope

Applicable to buildings with central chilled water plant and/or Variable Refrigerant Flow (VRF) systems that serve an aggregate conditioned floor area of 2000 m<sup>2</sup> or more.

## Base Requirement

A building shall be designed and equipped with means to facilitate monitoring and improvement in the efficiency of the building cooling systems.

### NRB04-1 Instrumentation for Central Chilled Water System

There shall be a provision of permanent measuring instruments to monitor the energy performance of the water-cooled and air-cooled central chilled water plants and air distribution systems.

The installed instrumentation must have the capability to calculate the resultant system efficiency within 5% of its true value in accordance with SS 591. Each measurement system shall include sensors, any signal conditioning, the data acquisition system and the wiring connecting these components.

The permanent measuring instruments and devices are to be accessible <sup>see Note (1)</sup> and must not be located directly above the chillers, to facilitate verification and maintenance. They must be installed according to the manufacturers' recommendations and SS 591. The measurement systems provided shall also comply with the following requirements:

- (a) All data logging devices are to be equipped with the capability to trend at a 1-minute sampling time interval, and recorded to the 3rd decimal digit;
- (b) Building management system (BMS), standalone energy management system (EMS) or local sequential controller (LSC) shall have the capability to compute and display the total system energy efficiency and its component (water-side and air-side system efficiency) as well as the calculated heat balance of the chilled water system;
- (c) Magnetic in-line flow meter, with 1% uncertainty and capable of electronic in-situ verification to within  $\pm 2\%$  of its original factory calibration. If the installation of magnetic in-line meters is not possible, ultrasonic flow meters or other flow meters that can meet the indicated performance may be used;
- (d) Temperature sensors are to be provided for chilled water and condenser water loop and shall have a measurement uncertainty within  $\pm 0.05^\circ\text{C}$  over the entire measurement range. Each temperature measurement location shall have test plugs or additional thermowells located before and after each temperature sensor along the chilled water and condenser water lines for verification of measurement accuracy. All thermo-wells shall be installed in a manner that would allow the sensors to be in direct contact with the fluid flow; and
- (e) Dedicated power meters (of IEC Class 1 or better) and metering current transformers (of Class 1 or better) are to be provided for each of the following groups of equipment, where applicable: chillers, chilled water pumps, condenser water pumps, cooling towers, air distribution sub-system (i.e. AHUs, PAHUs). The same should be provided for FCUs, where possible.

**Exception:** For buildings with cooling provisions from the District Cooling System (DCS) that are regulated to meet the Minimum Energy Efficiency Standards (MEES) under the Energy Conservation Act, only the relevant instrumentation in relation to the proposed building is applicable.

Note(1): The temperature sensors are best placed in an accessible location with a mounting height of not more than 3 m, where possible. Otherwise, there should be provision for access by way of mobile access platforms or other suitable forms.

Note (2): Under NRB02-2(i), it is a requirement to provide dedicated power meters for FCUs serving the commercial units with door openings that are located along the perimeter of the building envelope.

## Guidance Notes

As instrumentation measurement uncertainties stated in calibration certificates and technical specifications are based on controlled conditions in a laboratory, it is necessary to allow for on-site deviations and measurements. The overall measurement system comprising the temperature, flow and power measurement shall be capable of calculating resultant chiller-water plant efficiency with the uncertainty within  $\pm 5\%$  for on-site measurement. Each measurement shall include the sensor, any signal conditioning (if available), the data acquisition system and the wiring connecting them.

The methodology for determining the total uncertainty of measurement shall be computed using the root-sum square formula as follows:

$$\text{Error}_{\text{rms}} = \sqrt{\sum(U_N)^2} \quad \text{where}$$

$U_N$  = Individual uncertainty of variable N (%)  
 $N$  = Mass flow rate, electrical power input or delta T

In deriving the measurement uncertainty contributed by flow meters, an additional 1% is to be included in the computation.

### Worked Example NRB04-1

Computation of uncertainty of the overall measurement system

Item	Measurement System	Measurement Uncertainty (% of reading)
1	Temperature <small>see Note(1)</small>	$\frac{\sqrt{0.05^2 + 0.05^2}}{5.5} = 1.3$
2	Flow <small>see Note(2)</small>	1% + 1% (i.e. 2%)
3	Power <small>see Note(3)</small>	$\sqrt{1^2 + 1^2} = 1.4\%$

Note(1): The temperature measurement system shall have a measurement uncertainty not exceeding  $\pm 0.05^\circ\text{C}$  over the entire measurement range. The combined uncertainty for  $\Delta T$  is computed based on the root-sum square formula with  $\Delta T$  assumed to be  $5.5^\circ\text{C}$  as illustrated above.

Note(2): An additional 1% to be included in the computation of measurement uncertainty for flow meter.

Note (3): Uncertainty of power measurement system shall include that of the current transformer where applicable. It is recommended that 3<sup>rd</sup> party verified power meter be specified to ensure accuracy.

The overall uncertainty of the measurement system shall be the combination of the individual uncertainty of each measurement system. Based on the above information, the overall uncertainty of measurement is as shown in the following:

$$\begin{aligned} \text{Error}_{\text{rms}} &= \sqrt{\sum(U_N)^2} && \text{where } U_N = \text{individual uncertainty of} \\ &= \sqrt{(1.3^2 + 2^2 + 1.4^2)} && \text{variable } N (\%) \\ &= 2.8\% && N = \text{mass flow rate, electrical} \\ & && \text{power input or delta T} \end{aligned}$$

Therefore, the total uncertainty for the calculated chilled-water plant efficiency (kW/RT) is 2.8 %, which falls within 5% of the true value.

It is important to ensure correct placement of the temperature sensors for proper measurement. A heat balance-substantiating test can be carried out to ascertain the overall accuracy of the permanent instrumentation provided for the central chilled water system. To meet the accuracy requirement, more than 80% of the heat balance (%) derived over the entire normal operating hours is to be within  $\pm 5\%$  for a period of one (1) week. Detailed guidelines on the placement of temperature sensors and heat balance-substantiating test can be found in SS 591 – Code of Practice for Long Term Measurement of Central Chilled Water System Energy Efficiency.

## **Documentation Requirements**

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### **At BP Submission Stage**

Supporting documents listed in the following section, if ready.

### **Prior to Finalisation and Installation**

The following supporting documents are to be submitted before finalisation.

- Computation showing that overall uncertainty of measurement of the resultant chiller plant efficiency in kW/RT is within  $\pm 5\%$  of the true value based on the specifications of the selected measuring instruments and devices based on the methodology illustrated in the guidance notes;
- Technical product information and calibration certificates of measuring instruments and devices from accredited laboratory or equivalent; and
- Design schematics and single-line drawings showing the locations of the temperature sensors, flow meters, power meters and BMS system.

### **Before TOP Application**

The following documents are to be made available on-site or upon request.

- As-built schematics and single-line drawings including the photos of chilled water plant system showing the locations of temperature sensors, flow meters, power meters and Building Management System (BMS) or energy monitoring devices/system;
- Summary list of measuring instruments and devices showing the ID, description, sensor type, measurement & calibration range, measurement uncertainty, calibration certificate number and last calibration date;
- Technical product information and calibration certificates of measuring instruments and devices and delivery orders;
- Screenshots from BMS showing the relevant calibration inputs for temperature measurement and the display of the key indicators including total system energy efficiency and its component (water-side and air-side efficiency) as well as the calculated heat balance of the chilled water system; and
- Temperature measurement verification report with evidence that the temperature sensors installed for chilled water and condenser water loop have a measurement uncertainty within  $\pm 0.05^\circ\text{C}$ .

## **NRB04-2 Instrumentation for Variable Refrigerant Flow (VRF) System**

There shall be a provision of permanent measuring instruments to monitor the energy performance of the Variable Refrigerant Flow (VRF) systems and air distribution systems that serve an aggregate conditioned floor area of 2000 m<sup>2</sup> or more.

The installed instrumentation must have the capability to calculate the resultant system efficiency within 10% uncertainty. Each measurement system shall include sensors, any signal conditioning, the data acquisition system and the wiring connecting these components.

The measurement systems shall also comply with the following requirement:

- (a) All data logging devices with the capability to trend at a 5-minute sampling time interval, and preferably recorded to the 3rd decimal digit;
- (b) Building management system (BMS), standalone energy monitoring system (EMS) or other suitable systems shall have the capability to compute and display the total system energy efficiency and its component (condensing unit and air distribution system efficiency) and to facilitate data extraction for verification purposes; and
- (c) Dedicated power meters (of IEC Class 1 or better) and metering current transformers (of Class 1 or better) are to be provided for all condensing units of the VRF system and air distribution sub-systems (i.e. AHUs, PAHUs), where applicable. The same should be provided for FCUs, where possible.

## Documentation Requirements

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### At BP Submission Stage

Supporting documents listed in the following section, if ready.

### Prior to Finalisation and Installation

The following supporting documents are to be submitted before finalising the design and installation.

- Detailed catalogue and evidence showing that overall uncertainty of measurement of the resultant system efficiency in kW/RT is within  $\pm 10\%$ ;
- Technical specifications and/or sample data sheets/product information for instruments and meters for data logging; and
- Design schematics and single-line drawings showing the locations of the power meters and BMS system.

### Before TOP Application

The following documents are to be made available on-site or upon request.

- Extract of data from logging system or other suitable platforms for verification of performance;
- As-built schematics and single-line drawings including the photos of the power meters and BMS system; where relevant;
- As-built technical product information and calibration certificates of instruments and devices for data logging, where relevant; and
- Screenshots from BMS or monitoring platform made available to building owners showing the display of key indicators including the total system efficiency and its component system efficiencies (that is the condensing units and air-distribution system).

## References

SS 591 – Code of Practice for Long Term Measurement of Central Chilled Water System Energy Efficiency

## Related Information

Building owners may be issued a notice to conduct periodic energy audits at any time after the temporary occupation permit (TOP) or certificate of statutory completion (CSC) is granted and at an interval of not less than 3 years after the date of last notice served. Hence, it is important to ensure that the M & V instrumentation installed is in order by conducting the heat balance substantiating test before handover so that the operating system efficiency of the cooling systems can be effectively monitored and audited. Please refer to the Code on Periodic Energy Audit of Building Cooling System which can be found on the BCA's website for more details.

# NRB05 Electrical Submetering

## Intent

Facilitate measurement and monitoring of major energy end uses for energy management and audit.

## Applicability & Scope

Generally applicable to buildings with mechanical and/or electrical equipment and systems.

## Base Requirement

A building shall be designed and equipped with suitable means to monitor energy consumption of key systems. The provision shall come in the form of separate electrical sub-meters for the sub-systems as listed below. The sub-metering for these systems is to be equipped with data logging capability to communicate energy consumption and metered data to a monitoring system that can store, measure and trend energy use data and comply with the specifications set out in the following tabulation.

Sub-Systems for Metering	
<b>Lifts and escalators</b>	More than 5 numbers or sets or with a sum of all feeders > 50 kVA.
<b>Mechanical ventilation systems</b>	Total subsystem's load > 15 kW Sub-metering applicable to individual fan system motors that are more than 1.5 kW in the following areas: <ul style="list-style-type: none"><li>• Normally Occupied Spaces</li><li>• Mechanical and Electrical (M &amp; E) Plant Rooms</li><li>• Car Parks</li></ul>
<b>Centralised hot water supply system</b>	> 50 kW thermal heating capacity
<b>General power supply and lighting systems</b>	Sub-metering for tenancy areas and owners' premises are to be separated. The sub-circuits serving these areas can be provided on a sub-system level basis and/or per floor level.

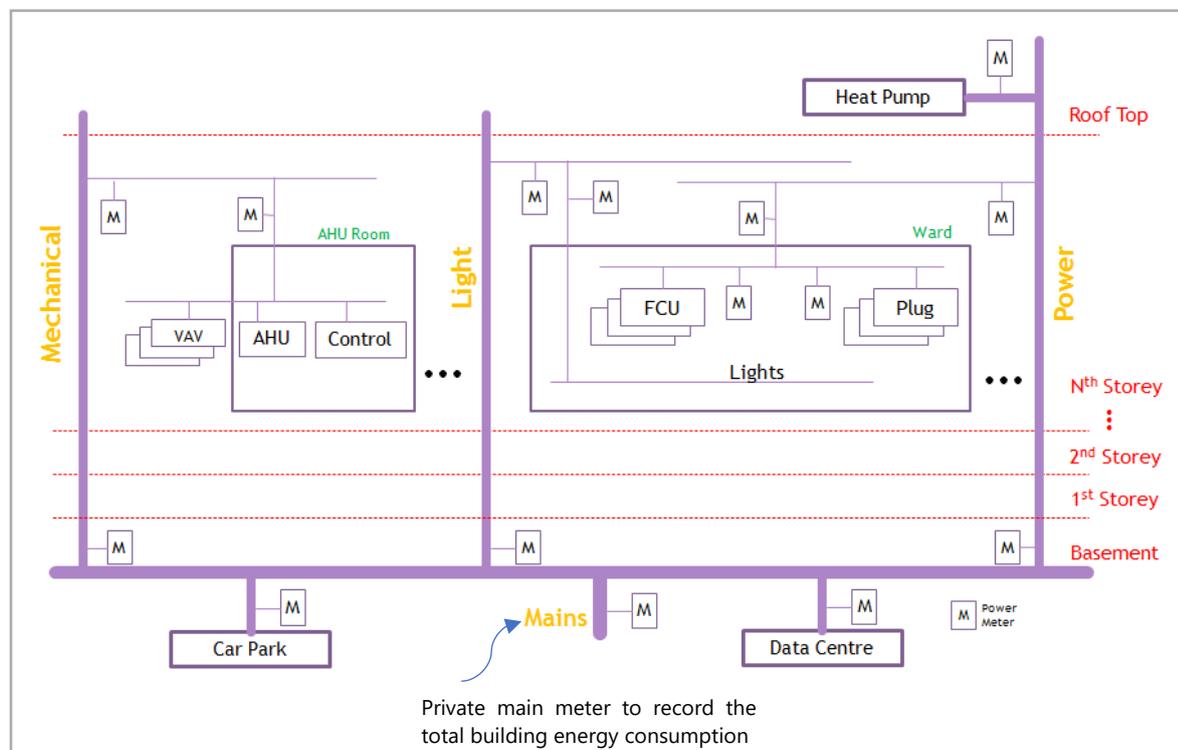
Note(1): Sub-metering provision for chilled water plant, variable refrigerant flow (VRF) systems and air distribution systems are covered under NRB04.

Note(2): If there is a need to cater to high plug loads or process loads exceeding 50 kVA, please provide separate sub-metering for these specific loads or areas to better manage and audit the building energy consumption.

## Guidance Notes

An example of a sub-metering arrangement for a hospital is as follows:

- Each major energy load areas: data centre, car parks, heat pump
- Each major energy use: light, plug load (power)
- Air distribution sub-system (VAV, AHU, FCU)
- Each floor and ward



## Documentation Requirements

### At BP Submission Stage

Generally, no supporting document requirement at this stage.

### Before TOP application

The following documents are to be made available on-site or upon request.

- Sub-system equipment, power meter and current transducer specifications;
- As-built electrical single-line diagrams showing the location of the power meters;
- As-built design of main switchboards (MSBs) and power distribution boxes (DBs); and
- Evidence of the remote capability and link to a BMS/EMS system.

# NRB06 Maintenance of Building Cooling System Performance

## Intent

Ensure adequate access space provision for building cooling system maintenance and upgrade so as to upkeep the system energy performance during operation.

## Applicability & Scope

Applicable to new building developments with centralised chilled water plant system and air distribution systems. In the case of existing buildings with major additions and alterations /retrofits, the compliance with any of the requirements under NRB06-1 to NRB06-4 can be considered as alternative solutions under the Carbon Reduction Measures – Section 2 Sustainable Design Strategies.

## Base Requirement

A building shall be designed and constructed with access space provisions to facilitate maintenance of building cooling system performance. The access space provisions for the following equipment shall comply with either the service clearances as per manufacturers' specification or the specifications set out in NRB06-1 to NRB06-4, whichever governs.

## NRB06-1 Chillers

Access space provisions shall be as follows:

- Clearance of 2.0 m or more at the front of chiller unit piping section for tube maintenance and cleaning, repair and replacement of bigger components;
- Clearance of 1.2 m or more between the chillers measured from plinth to plinth for regular maintenance; and
- Clearance of 1.5 m or more above the chiller for maintenance, overhaul or replacement.

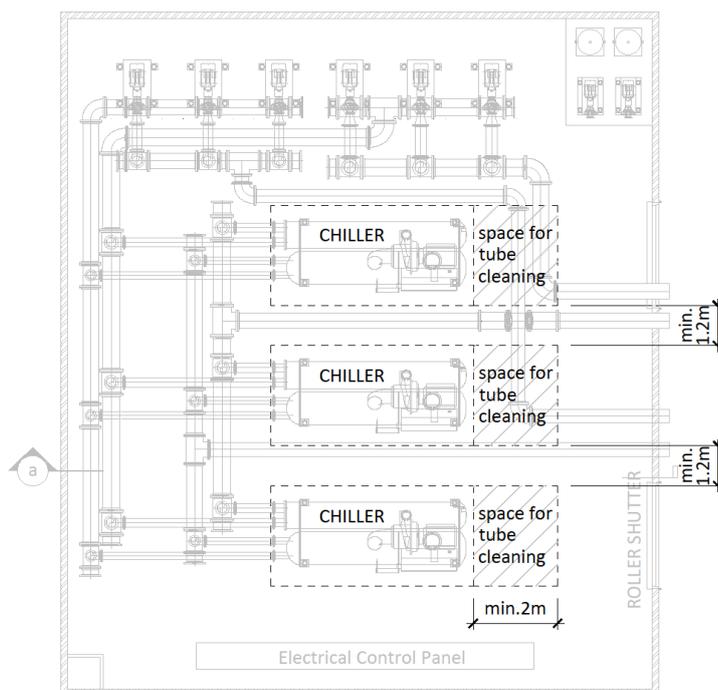


Figure 06-1 – Access space for the chillers

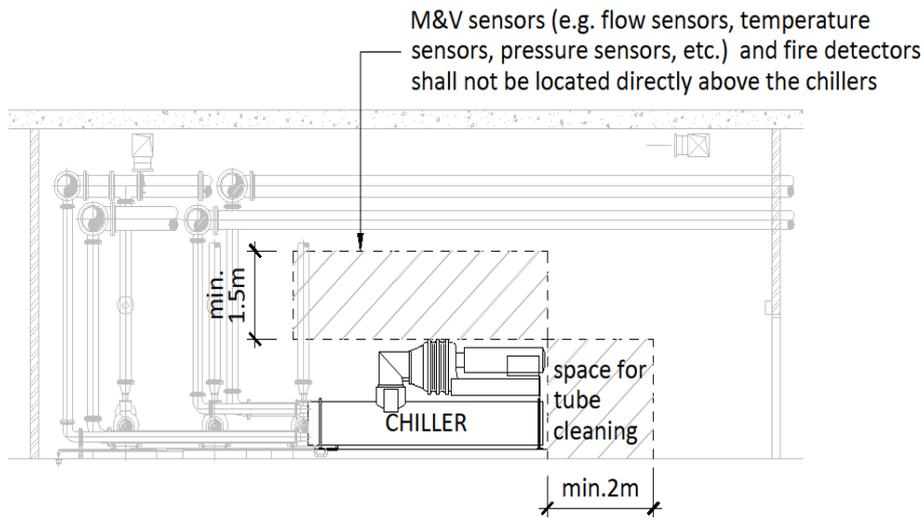


Figure 06-2 – Head room requirements for the chillers

## Documentation Requirements

### At BP Submission Stage

- Architectural/mechanical plan drawings indicating the chiller plant location; and
- ACMV chiller plant layout drawing showing the access space provisions or tender specifications indicating the access space provisions.

### Before TOP application

The following documents are to be made available on-site or upon request.

- Shop drawing/as-built chiller plant layout and sectional drawing indicating the access space provisions based on actual equipment selection; and
- Photographs showing the clear access space provisions for chiller plant equipment including M&V sensors.

## NRB06-2 Pump Systems

Access space provisions shall be as follows:

- Except for the areas where the pipes are connected, clearance of 0.6 m or more is to be provided around the pump for regular maintenance; and
- Clear headroom of 1.0 m or more above the pump and motor to facilitate maintenance, overhaul or replacement.

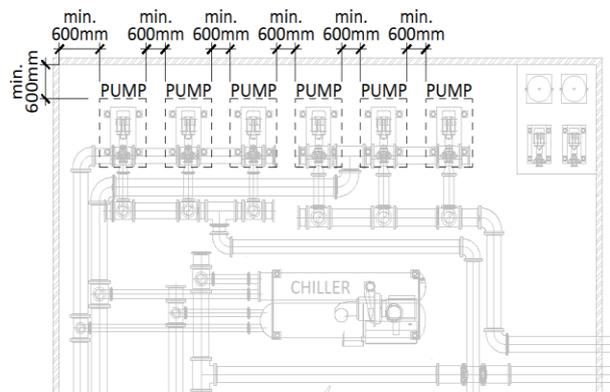


Figure 06-3 – Access space for the pump systems

## Documentation Requirements

### At BP Submission Stage

- Chiller plant layout drawing showing the access space provisions and headroom requirement; and
- Tender specification indicating the access/space provisions for chilled water pumps and condenser water pumps.

### Before TOP application

The following documents are to be made available on-site or upon request.

- Shop drawings/as-built drawings highlighting the space and headroom provision for pumps with dimensions as per the actual equipment selection; and
- Photographs showing the provision of access space and headroom.

## NRB06-3 Cooling Towers

Maintenance provisions shall be as follows:

- (a) Provision of maintenance platform, stairs and catwalks of 600 mm width or more with handrails around the cooling towers and access to the level for periodic maintenance and the inspection of water basin and fill media; and
- (b) Clear distance of 2.0 m or more from the top of cooling towers to the location of the trellis, where applicable.

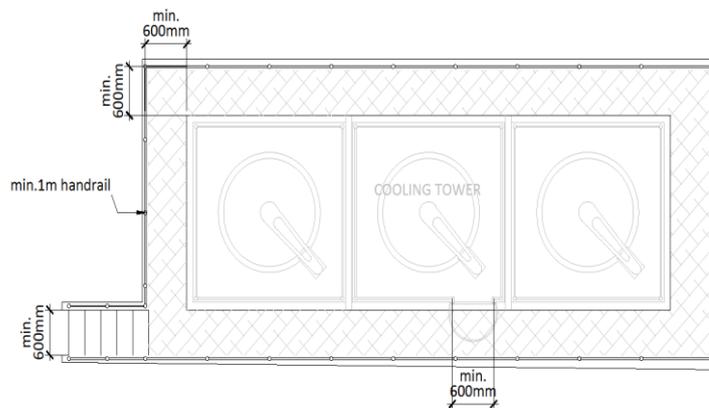


Figure 06-4 – Maintenance provisions for the cooling towers

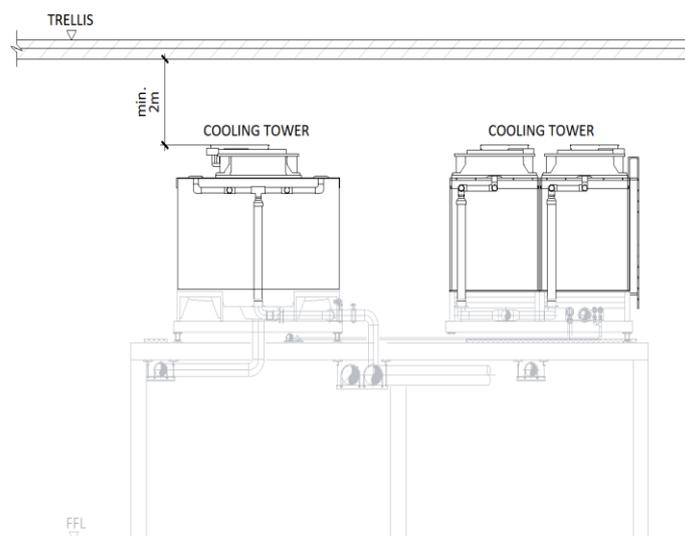


Figure 06-5 – Clearance from top of cooling towers to the location of the trellis

Note(1): In the event that the clearance from the top of cooling towers to the location of trellis could not be met due to height restrictions, the trellis must be designed to be easily removable for access and maintenance.

Note(2): Proper clearances on all sides of the cooling tower should be provided in accordance with the manufacturer's technical recommendation to ensure the heat rejection performance of cooling towers is not affected or should not be less than the lateral width of the cooling tower, whichever governs

## Documentation Requirements

### At BP Submission Stage

- ACMV plan drawing showing the requirement on the maintenance platform; and
- Tender specifications indicating the maintenance platform requirements.

### Before TOP application

The following documents are to be made available on-site or upon request.

- ACMV shop drawing/as-built drawings indicating the permanent stairs and catwalk around the cooling tower; and
- Photographs showing the catwalk and maintenance platform installed.

## NRB06-4 Air Distribution Systems

Maintenance provisions shall be as follows:

- (a) Air handling units (AHUs) of **cooling capacity greater than 35 kW shall be floor mounted** as stipulated in SS 553; and
- (b) For AHUs that are floor mounted, the access space provisions are as follows:
  - (i) AHU access – Provide minimum 1.0 m clearance from the AHU room door entrance to the AHU for general maintenance;
  - (ii) Cooling coil pipe and filter access – Provide minimum 800 mm clearance after pipe connection to facilitate cooling coil cleaning and filter access;
  - (iii) Fan access – Provide minimum 800 mm clearance for fan/motor access and maintenance (if the access is not from the cooling coil connection side); and
  - (iv) AHU side and back clearance – Provide minimum 600 mm clear width for general access and maintenance.

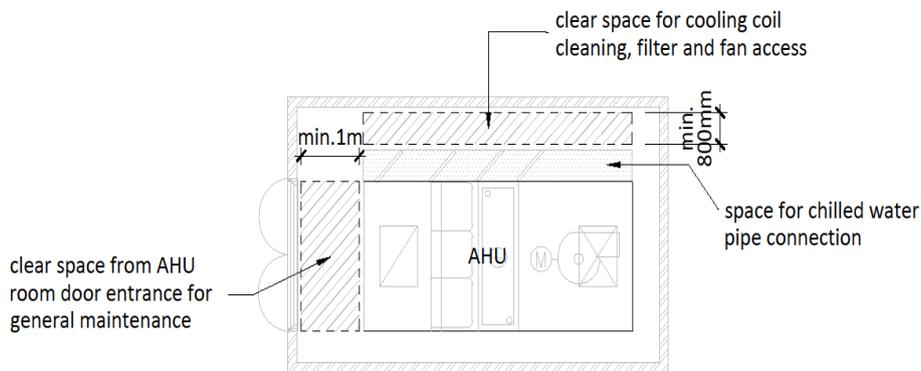


Figure 06-6 – Space provisions for Air Handling Units

Note: All AHUs of cooling capacity greater than 35 kW shall be floor mounted

## Documentation Requirements

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### At BP Submission Stage

- Tender specifications indicating the access/space provisions for air handling units (AHUs).

### Before TOP application

The following documents are to be made available on-site or upon request.

- As-built drawings/shop drawings (including plan drawing/section) highlighting the AHU room access space provision; and
- Photographs showing the access space provisions.

## References

Design for Maintainability Guide on Non-Residential Buildings published by the Building and Construction Authority (BCA)

Maintainability Section under the Green Mark 2021 Framework

## Related Information

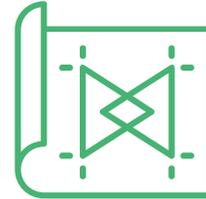
There are considerations under the Workplace Safety and Health (Design for Safety) Regulations 2015 which can potentially affect the provision of access and space for mechanical and electrical services for safety purposes. Please ensure that the access provisions meet the WSH guidelines published by the Ministry of Manpower (MOM) - Workplace Safety and Health Guidelines on Design for Safety (DfS), where relevant.

# CARBON

## REDUCTION MEASURES

For Non-Residential Buildings

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### SECTION 1 – SUSTAINABLE DESIGN STRATEGIES

Optimise the use of passive design strategies in response to local climate and site conditions to improve on indoor environmental quality thus reducing energy use.

- NRBE01-1 Enhanced Building Envelope Performance
- NRBE01-2 Naturally Ventilated Building Design
- NRBE01-3 Effective Daylighting

## NRBE01-1 Enhanced Building Envelope Performance

Enhance building envelope performance to minimise heat gain to internal spaces for better indoor thermal comfort with any of the following provisions:

- Façade design with Envelope Thermal Transmittance Value (ETTV) of not more than 40 W/m<sup>2</sup> or enhanced with the provision of good thermal break/insulating profile framing.
- Application of cool materials that are certified by an approved local product certification body for 80% of all external walls of the building development or applicable roof areas.
- Provision of innovative façade technology or solutions such as the use of electrochromic glass, integration of photovoltaic modules, parametric façade for at least 20% of the fenestration areas.

### Guidance Notes

NRBE01-1(a): The Envelope Thermal Transfer Value (ETTV) is to be determined using the methodology set out in the Code on Envelope Thermal Performance for Buildings and shall not exceed 40 W/m<sup>2</sup>. Alternatively, it can be considered acceptable if the building envelope design is enhanced with the provision of a thermally broken framing system. The thermal transmittance value of the frame design  $U_{fr}$  should be less than 2.5 W/m<sup>2</sup>K for each frame for  $\geq 80\%$  of the applicable facades.

In view of the complex construction of fenestration frames, it is recommended to use simulation tools to derive the thermal properties of fenestration  $U_{fr}$  for the different profile sections used in the project. The calculation procedures should exclude the thermal transmittance of the glazing and comply with ANSI/NRFC standard or ISO 10077 using the environmental conditions of Singapore context and as specified in the following Table C8.

Temperature Inside, $T_i$	25 °C
Temperature Outside, $T_o$	35 °C
Solar Radiation	400 W/m <sup>2</sup>
Surface Heat Transfer Coefficient (inside), $h_i$	8 W/m <sup>2</sup> K
Surface Heat Transfer Coefficient (outside), $h_o$	19 W/m <sup>2</sup> K

NRBE01-1(b): Cool materials in this context refer to surface coating, paints, tiles that come with high solar reflectance and infrared emissivity properties and are certified by an approved local product certification body. The extent of the application shall cover at least 80% of all external wall areas of building blocks or all applicable roof areas.

Example of a proposed building development with application of cool paints on external wall areas

Block Description	Total Applicable External Wall Areas (m <sup>2</sup> )	Areas with cool materials (m <sup>2</sup> )	Extent of coverage = 16500/22500 *100 = 80.5% ok  Note: The green wall areas can be excluded in the computation.
Blk 1	4500	3500	
Blk 2	6000	5000	
Blk 3	10000	8000	
Total:	20500	16500	

Example of a proposed building development with application of cool paints on roof areas

Block Description	Total roof areas (m <sup>2</sup> )	Non-Applicable Areas (m <sup>2</sup> )	Total Applicable Roof Areas (m <sup>2</sup> )	Roof Areas with Cool Materials (m <sup>2</sup> )
Blk 1	5000	400	4600	3100
Blk 2	4000	400	3600	3500
Blk 3	5000	500	4500	4000
	14000	1300	12,700	10600
<b>Extent of coverage = <math>10600/12700 \times 100 = 83.5\%</math> ok</b>				
Note(1): Non-applicable areas can include green roofs and areas beneath large equipment such as cooling towers, water tanks or photovoltaic (PV) panels where the application of cool materials may not be relevant.				
Note(2): The selected cool materials or paint system must meet the allowable limits set for daylight reflectance as required under the Approved Document.				

NRBE01-1(c): Innovative façade technology or solutions such as the use of electrochromic glass, integration of photovoltaic modules, parametric façade for at least 20% of the fenestration areas.

Example of a proposed single building with a combination of electrochromic glass and Building Integrated Photovoltaic (BIPV) system incorporated as part of its envelope design.

Innovative Solutions	Areas of Application (m <sup>2</sup> )	Total Fenestration Areas = 20500 Extent of coverage = $5000/20500 = 24\%$ ok
Electrochromic glass	2000	
BIPV system	3000	
Total areas of application	5000	

## Documentation Requirements

### At BP Submission Stage

#### NRBE01-1(a)

- ETTV computation in the prescribed forms and formats;
- Architectural elevation drawings showing the composition of the different façade or wall systems that are relevant for the computation of the ETTV;
- Architectural plan layouts and elevations showing the mode of ventilation and location for various spaces including air-conditioning areas; and
- Where relevant, extracts from tender specifications showing the requirement to have a thermally broken framing system incorporating thermal break/insulating profile and the requirement of  $U_{fr}$  value  $< 2.5 \text{ W/m}^2\text{K}$  for each frame for  $\geq 80\%$  of the applicable facades.

#### NRBE01-1(b)

- Extracts from tender specifications showing the requirement to incorporate cool materials for the specific wall or roof areas; and
- Relevant certificate from an approved local product certification body.

#### NRBE01-1(c)

- Extract from tender specifications showing the requirements on the specific façade technology or solutions.

## Before TOP Application

The following documents are to be made available on-site or upon request.

### NRBE01-1(a)

- Material schedules showing salient data of material properties used for the façade and external wall systems; and
- As-built ETTV computation if there are material changes that will affect the design and ETTV.
- Frame with thermal break/ insulating profile clearly labelled in the as-built drawings; and
- Thermal simulation report from fenestration supplier or facade consultant showing that Ufr of the relevant facades used in the project meets the requirements

### NRBE01-1(b)

- Certification details of the cool materials used, technical product information, delivery orders, confirmation on the extent of the application and coverage.

### NRBE01-1(c)

- Elevation drawings and details showing the areas where the façade technology or solutions are used and confirmation on the extent of application and coverage.

## References

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ISO 15099 : 2003 - Thermal Performance of Windows, Doors and Shading Devices

BS EN ISO 10077-1 : 2017 -Thermal Performance of Windows, Doors and Shutters : Calculation of Thermal Transmittance – Part 1 - General.

ANSI/NFRC 100-2020 Procedure for determining fenestration product U-factors

ANSI/NFRC 200-2020 Procedure for determining fenestration product solar heat gain coefficient and visible transmittance at normal incidence

NFRC simulation manual (July 2017)

## Related Information

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**Daylight Reflectance:** Under the Approved Document – Section P Daylight Reflectance, the external surface (including a roof) of a building must be designed and constructed in a manner such that any reflection of sunlight off the external surface of the building does not result in loss of amenity to occupants of other buildings in the vicinity of that building. Hence, there is a need to ensure that the selected cool materials meet the allowable daylight reflectance as required under the Approved Document issued by the Building and Construction Authority (BCA).

## NRBE01-2 Naturally Ventilated Building Design

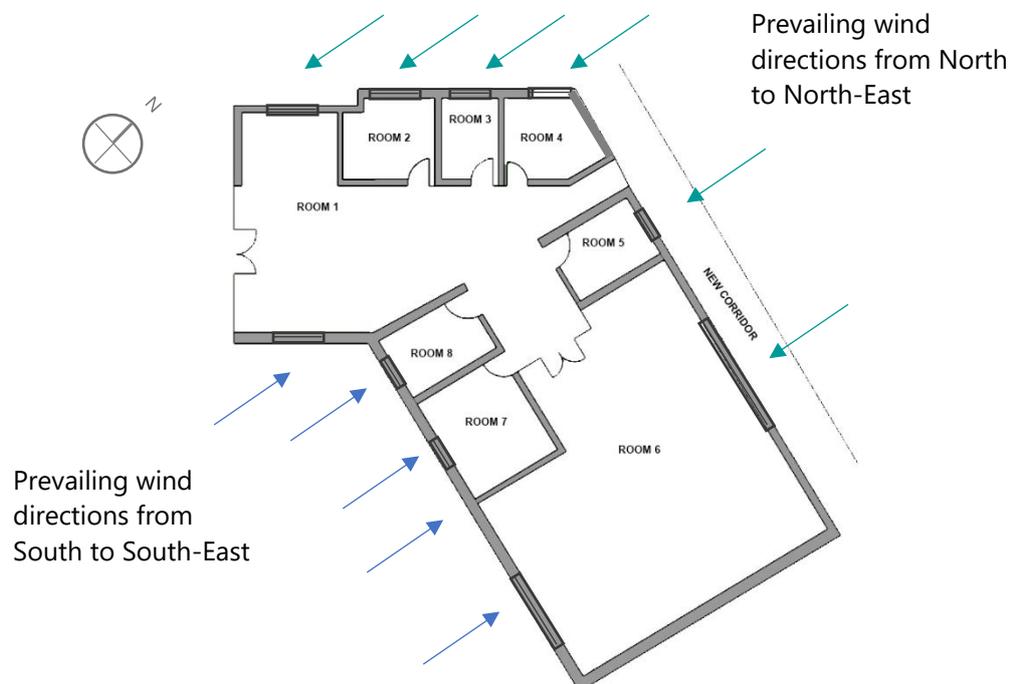
Enhance building and space layout design to facilitate good natural ventilation and better thermal comfort with any of the following provisions.

- (a) Building layout design with openings that are oriented to take advantage of the prevailing wind conditions for minimum coverage of 20% of all normally occupied spaces of the building development.
- (b) Design for natural ventilation with minimum coverage of 80% in at least two (2) of the following areas:
  - Lift lobbies
  - Corridors
  - Staircases
  - Car parks
  - Atriums
  - Toilets

### Guidance Notes

NRBE01-2(a): Naturally ventilated buildings with window openings facing prevailing wind conditions would enhance indoor thermal comfort thus reducing the need for air-conditioning. Locally, the two predominant wind directions are North to North-East during Northeast monsoon seasons and South to South-East during the South-West monsoon seasons. Meteorological data on the precise wind directions and velocity at site location should be used as the basis for design to optimise ventilation and thermal comfort, where available.

In considering the building layout design and coverage, it is not necessary for window openings to be located perpendicularly to the prevailing wind directions. However, there must be openings facing the prevailing wind directions as shown in the following illustrations.



Note: Building layout shows that not all rooms with window openings facing the North and South directions. Room 2 to 5 and Room 7 & 8 would only have prevailing wind directions in one direction. Only Room 1 and 6 can be considered. In this case, there are two (2) out of eight (8) rooms which is 25% which is greater than the minimum requirement of 20%.

NRBE01-2(b): As these spaces are generally typical in terms of areas, the extent of coverage can be determined based on the number or areas of the applicable spaces that are naturally ventilated.

For example, a proposed development with 6 levels of car parks and only one level is mechanically ventilated, the extent of coverage will be 83%. In addition, it comprises an atrium that is naturally ventilated. In this case, it meets the requirement of having two areas that are naturally ventilated with minimum coverage of 80%.

## **Documentation Requirements**

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### **At BP Submission Stage**

#### NRBE01-2(a) Building Design Layout

- Architectural plan layouts showing the units/rooms of all blocks with highlights of those with window openings facing the prevailing wind directions; and
- Tabulation showing the total number/applicable areas and percentage of units or rooms with window openings facing the prevailing wind directions.

#### NRBE01-2(b) Common Areas

- Architectural plan layouts showing the applicable common areas with highlights of those that are designed to be naturally ventilated; and
- Tabulation showing the total number/areas and percentage of applicable common areas that are naturally ventilated.

### **Before TOP Application**

As-built submission of the above if there are changes.

## **Related Information**

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**Natural Ventilation:** Under the Approved Document – Section G – Ventilation regulated under the Building Control Regulations, there are specific requirements in relation to natural ventilation, to protect people from loss of amenity due to lack of fresh air. There are requirements on the minimum size of openable windows or other openings as well as their location to ensure adequate ventilation is provided in a building.

## NRBE01-3 Effective Daylighting

Encourage design that optimises the use of natural lighting to improve visual comfort and reduce energy use associated with artificial lighting.

- (a) Normally occupied spaces – Daylighting provision with the integration of daylighting controls or other suitable means for minimum coverage of 15% of the total normally occupied spaces. The extent of daylight provision shall be determined based on the Daylight Availability Tables and Methodology provided in Appendix E of this Code and shall meet the desired lighting level and specific Daylight Autonomy (DA) requirements as listed below:

S/N	Minimum Lighting Level Based on Space Occupancy Type	Daylight Autonomy requirement per unit area of space
1	Office, Institutional spaces where lux requirement is 500 lux	DA <sub>500lx,50%</sub>
2	Industrial, sports facilities, retail areas where lux requirement is 300 lux	DA <sub>300lx,50%</sub>
3	Hotel, resort-like and service apartment where lux requirement is 200 lux	DA <sub>200lx,50%</sub>

- (b) Common areas – Daylighting provision with the integration of daylighting controls for minimum coverage of 80% in at least two (2) of the following areas.

- Lift lobbies
- Corridors
- Staircases
- Car parks
- Atriums
- Toilets

- (c) Provision of daylight redirecting technologies such as light shelves or tubular daylight/sun pipes to enhance lighting level.

### Guidance Notes

NRBE01-3(a): The effective daylighting of normally occupied spaces can be quantified using the Daylight Availability Tables provided in Appendix E if the building design layouts are relatively standardised and have the following characteristics and urban parameters stated below.

#### *Building Characteristics and Urban Parameters suitable for use of Daylight Availability Tables*

- Spaces that are side lit and located adjacent to the vertical fenestration.
- Spaces with typical room floor-to-ceiling heights within the range of 2.5 m to 3.1 m
- Simple horizontal overhang/shading devices or no shading devices adopted for the vertical fenestration
- Relatively unobstructed by surrounding buildings and with average urban obstruction angles (AUOA)  $\leq 57.25^\circ$

*Note: Average Urban Obstruction Angle describes the portion of the sky blocked by surrounding obstructions such as neighbouring buildings. Refer to Appendix E for more details.*

The simplified methodology in determining the availability of daylighting is as follows:

- Determine the quality of daylight provision, daylit and overlit areas of normally occupied spaces through the use of Daylight Availability Tables based on the following design parameters :
  - Orientation and Obstruction and Lux requirement for the space
  - Space design (applicable areas), Façade (WWR) and Glazing type (visible light transmittance)

- Determine the percentage of normally occupied spaces that have effective daylighting. There must be provision and integration with a light sensor lighting control system that can turn the lights up to provide proper lighting levels when required.

NRBE01-3(b): In general, the provision of windows and openings is not the only determining factor that would translate to the actual daylighting provision. There will be a need to consider other factors such as the building overhangs, opening configurations and placement among other things.

For simplicity, if daylight can be infiltrated over spaces such as common corridors with a depth of about two (2) times the height of the openings it is deemed to have been designed with daylighting. These spaces must be well-lit without the need for artificial lighting provision during the daytime to meet the requirement.

Depending on the locality and design of the common areas, there may be a need to integrate with daylight sensor lighting control system to turn the lights up to provide proper lighting level, when required.

NRBE01-3(c): Daylight redirecting technologies would help reduce the need for artificial lighting by bringing natural light to the interior space. These technologies can come in the form of light shelves, tubular daylight/sun pipes, light redirecting blinds, daylight redirecting films etc.

## **Documentation Requirements**

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### **At BP Submission Stage**

#### NRBE01-3(a) Normally Occupied Areas

- Extract of drawings showing the spaces with effective daylight provision;
- Tabulation showing the total number of spaces with effective daylight provision and the percentage of daylit areas over total areas. Refer to the worked example for non-residential buildings on the detailed computation in Appendix E; and
- Details of the daylighting control system or other proposed means.

#### NRBE01-3(b) Common Areas

- Extracts of drawings showing the use of daylighting and opening provision for staircase areas, corridors & lift lobbies and car parks, where applicable;
- Tabulation showing the total number of applicable common areas with effective daylight provision and the percentage of daylit areas (in number) over the total number of applicable areas; and
- Details of the daylighting control system or other proposed means.

#### NRBE01-3(c) Daylight redirecting technologies

- Extract of drawings showing the spaces with the application of daylight redirecting technologies; and
- Technical information of the technologies used.

### **Before TOP Application**

The following documents are to be made available on-site or upon request.

- Spot measurements of the effective daylighting through lux measurements and photographs of the applicable functional/normally occupied spaces; and
- Photographs of the daylight redirecting technologies implemented.

## **References**

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Daylight Availability Tables developed under the BCA-SUTD Joint Research Collaboration: Daylighting in Singapore - Establishing Lighting Preferences, Design Guidelines and Predictive Methods

# CARBON REDUCTION MEASURES

For Non-Residential Buildings

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## SECTION 2 – SUSTAINABLE CONSTRUCTION

Promote the adoption of sustainable practices, materials procurement and design which inculcate responsible use and conservation of resources during construction and building operation.

NRBE02-1 Resource Efficiency Measures

NRBE02-2 Sustainable Construction

NRBE02-3 Sustainable Products

## NRBE02-1 Resource Efficiency Measures

Encourage design that optimises resource efficiency and minimises waste generation in building construction.

- (a) Existing building structures with more than 50% of the floor and/or wall areas are conserved for adaptive reuse.
- (b) Design with Concrete Usage Index (CUI) of not more than 0.50.
- (c) Embodied carbon reporting to account for the upfront carbon emissions of three (3) key construction materials namely, concrete, steel, and glass used in building developments.

### Guidance Notes

NRBE02-1(a): Existing buildings, whether they are of historic significance or not, can be conserved for adaptive reuse. This can form an important part of sustainability strategies to reduce the overall resource use and building waste. To meet this requirement, there must be more than 50% of the existing building floor and/or wall areas conserved for reuse.

NRBE02-1(b): It is critical and more effective to optimise concrete usage at the early design stage where a range of design solutions that could improve concrete efficiency for e.g. post-tensioned concrete or void formers can be considered. In this requirement, the benchmark set is based on the Concrete Usage Index (CUI) which is an indicator of the amount of concrete used to construct the superstructure that includes both the structural and non-structural elements. It is defined as the volume of concrete in cubic meters needed to cast a square metre of constructed floor area and expressed as follows :

$$\text{Concrete Usage Index (CUI)} = \frac{\text{Concrete Volume in m}^3}{\text{Constructed Floor Area in m}^2}$$

The benchmark set for this requirement is CUI of 0.50.

### Worked Example NRBE02-1(b)

Proposed development comprises a 30-storey block with a basement car park. The quantity of concrete used for different structural systems is tabulated below:

Concrete usage for the superstructure	Constructed floor areas
1st storey = 1,035.5 m <sup>3</sup> From 2nd to 30th storey = 27,360 m <sup>3</sup> (including roof level)	1st storey = 2,200 m <sup>2</sup> From 2nd to 30th storey = 57,798 m <sup>2</sup> (including roof level)
Total concrete usage = 28,395.5 m <sup>3</sup>	Total constructed floor areas = 59,998m <sup>2</sup>

$$\begin{aligned} \text{Concrete Usage Index (CUI)} &= \frac{\text{Concrete Volume in m}^3}{\text{Constructed Floor Area in m}^2} \\ &= \frac{28395.5}{59998} = 0.473 \text{ m}^3/\text{m}^2 < 0.50 \text{ ok} \end{aligned}$$

*Note: The concrete usage for external works and sub-structural works for foundation and basement structures are excluded in CUI computation.*

Refer to the following tabulation on the details and computation required for the various structural systems.

Computation of Concrete Usage Index				NON-RESIDENTIAL BUILDING
Project Reference No.: AXXXX-00001-20XX		Total no. of storey for the project: 30		
Block No: A				
	Structural System	Thickness (mm) or size (mm x mm)	Volume of concrete (m <sup>3</sup> )	Remark *
1	1st storey			
	1.1 Columns	300x300, 400x400	120	57 nos of C80 300x300 precast columns
	1.2 Beams	300x500, 200x500	320	Precast
	1.3 Slabs	200,225,250	400	Post-tensioned (Total floor area = 1,600 m <sup>2</sup> )
	1.4 Staircases	175	93.5	Precast
	1.5 Suspended structures like planter boxes, bay windows, ledges, etc.	-	0	-
	1.6 Parapets	-	0	-
	1.7 External walls - loadbearing walls	-	0	-
	1.8 External walls – non-loadbearing walls	125	22	Precast green wall (wall area = 176 m <sup>2</sup> )
	1.9 Internal walls – loadbearing walls	200	55	RC (wall area = 275 m <sup>2</sup> )
	1.10 Internal walls –nonloadbearing walls	100	10	Light weight concrete (wall area = 100 m <sup>2</sup> )
	1.11 Others (kerbs, ramps, services risers, etc.)	-	15	RC
	Total volume of concrete for this storey (m <sup>3</sup> )			1,035.5
	Total constructed floor area for this storey (m <sup>2</sup> )			2,200
2	Typical storey (2nd to roof)			
	1.1 Columns	300x300, 400x400	115	Precast
	1.2 Beams	300x500, 200x500	301.5	Precast
	1.3 Slabs	200,225,250	320	Post-tensioned (Total floor area = 1,280 m <sup>2</sup> per floor)
	1.4 Staircases	175	93.5	Precast
	1.5 Suspended structures like planter boxes, bay windows, ledges, etc.	-	0	-
	1.6 Parapets	-	0	-
	1.7 External walls - loadbearing walls	-	0	-
	1.8 External walls –non-loadbearing walls	125	22	Precast green wall (wall area = 176 m <sup>2</sup> )
	1.9 Internal walls – loadbearing walls	200	50	RC (wall area = 250m <sup>2</sup> )
	1.10 Internal walls – nonloadbearing walls	100	10	Light weight concrete (wall area = 100 m <sup>2</sup> )
	1.11 Others (kerbs, ramps, services risers, etc.)	-	0	RC
	Total volume of concrete for one storey (m <sup>3</sup> )			912
	Total constructed floor area for one storey (m <sup>2</sup> )			1,926.6
Total volume of concrete for 2nd to 30th storey – includes roof level (m <sup>3</sup> )			27,360	
Total constructed floor area for 2nd to 30th storey – includes roof level (m <sup>2</sup> )			57,798	
Total volume of superstructure concrete for this project (m <sup>3</sup> )			28,095.5	
Total constructed floor area of superstructure for this project (m <sup>2</sup> )			59,998	
Concrete Usage Index (CUI in m <sup>3</sup> /m <sup>2</sup> )			0.473	

\*To indicate if the structural elements are of precast concrete, post-tensioned concrete, high strength concrete (>Grade 60) or reinforced concrete (RC) under the 'Remarks' column.

**Compliance Notes:** The quantities of the concrete for all the structural and non-structural elements for each floor level are to be computed. All the elements listed in the table such as columns, beams, slabs, suspended structures (like planter boxes, bay windows and ledges, etc.), parapets, walls and others (service risers, kerbs, ramps, etc.) are to be included. The concrete used for foundation and basement works are to be excluded in CUI computation. However, in the case of raft foundation that forms part of the floor slab, half of the concrete volume will have to be accounted for in deriving the CUI.

NRBE02-1(c): Embodied carbon reporting would cover the assessment of the carbon footprint of a building or infrastructure before it becomes operational. The requirement would require the account for the upfront carbon emissions of three (3) key construction materials namely concrete, steel and glass used in building developments. The emission factors used can be based on established carbon datasets such as the Inventory of Carbon and Energy (ICE) database, the RICS Building Carbon Database.

## **Documentation Requirements**

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### **At BP Submission Stage**

Generally, no supporting document requirement at this stage.

### **Before TOP application**

The following documents are to be made available on-site or upon request.

#### NRBE02-1(a)

- Architectural and structural plan layout, elevation and sectional plans showing the existing floor and/ or wall areas that are conserved for adaptive reuse; and
- Details on the extent of conservation in percentage over the total existing floor and/or wall areas.

#### NRBE02-1(b)

- BIM model (if applicable), architectural and structural plan layout, elevation and sectional plans showing the type of building elements/ systems used, the dimensions and sizes of all the building and structural elements; and
- Summary showing the quantity of concrete for each floor level in the prescribed tabulated format shown in the Worked Example NRBE02-1(b). Calculation showing the quantity of concrete for each floor level which should include all the concrete building elements, such as non-load bearing and architectural concrete components.

#### NRBE02-1(c)

- Embodied carbon footprint report which includes the computation with detailed breakdown on the grade and type of concrete, steel and glass provided and the basis of the respective emission factors used.

## **References**

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Sustainable Construction - Guide on Concrete Usage Index published by the Building and Construction Authority (BCA)

## NRBE02-2 Low Carbon Concrete

Enhance carbon reduction potential with the use of sustainable materials for construction.

- (a) Use of concrete with eco-friendly cementitious materials that are classified under CEM II to V types for at least 80% of the super-structural works by volume.
- (b) Use of recycled concrete aggregate (RCA), washed copper slag (WCS) and/or granite fines from approved sources and meet the minimum usage requirement as stated in the following Table C9.

Recycled Concrete Aggregate (RCA)	1.50% X GFA
Granite fines	1.50% x GFA
Washed Copper Slag (WCS)	0.75% x GFA
<i>Note: GFA refers to Approved Gross Floor Areas of the building development.</i>	

- (c) Alternative construction materials that can be used as a replacement for standard building materials for non-structural application.

### Guidance Notes

NRBE02-2(a): The use of concrete with considerable proportion of clinker replaced with eco-friendly cementitious materials would help reduce the overall embodied carbon in buildings. Essentially, these materials comprise Portland Cement in combination with approved industrial by-products such as Ground Granulated Blast Furnace Slag (GGBS), silica fume, fly ash and could serve as alternative binder in concrete production. These cementitious materials are classified under CEM II/III/IV/V in Table 1 of SS EN 197-1. Concrete products certified by an approved local product certification body can be considered if eco-friendly cementitious materials are required as part of the certification criteria.

### Worked Example NRBE02-2(a)

#### Clinker content

The proposed non-residential development uses three (3) types of Grade 40 concrete with the following provision.

Concrete Grade 40	Extent of Coverage (Super-Structural work only)	Provision	Remarks
Type 1 Concrete	30% by volume	20% of GGBS which is classified under CEM II in Table 1 of SS EN 197	Ok
Type 2 Concrete	40% by volume	Certified concrete products under an approved local product certification body.	Ok, concrete products produced with eco-friendly cementitious materials classified under SS EN 197 and as certified.
Type 3 Concrete	30% by volume	CEM I with no replacement of OPC	No eco-friendly cementitious materials used.

In this instance, the use of concrete with eco-friendly cementitious materials only took up 70% of the super-structural works (by volume) which would not fulfill the overall requirement of minimum 80%.

NRBE02-2(b): Recycled concrete aggregates (RCA) is derived mainly from the crushed concrete from demolition works which can be adopted to replace natural coarse aggregates for a range of structural and non-structural application. Washed Copper Slag (WCS) on the other hand is derived by reprocessing (cleaning, washing and drying) copper slag used in the first place as an abrasive in grit blasting at the shipyard. For structural grade concrete, the use of RCA and WCS shall be limited to a maximum 20% and 10% replacement by mass of coarse/fine aggregates respectively or as approved by the relevant authorities. Locally, granite fines

of which the quality and grading are in accordance with SS EN 12620 can be used as a direct substitute for fine aggregates (that is replacement of natural sand in concrete).

The RCA/WCS/Granite fines quantity (in tonnes) required for the concrete production of main building elements can be estimated based on the concrete volume and replacement rate comprising these sustainable materials and as follows :

Type of Sustainable Materials	Estimation of Quantity Requirement
Recycled Concrete Aggregate (RCA)	1.0 (tonnes/m <sup>3</sup> ) x (Concrete vol in m <sup>3</sup> ) x (RCA Replacement Rate) %
Granite fines (GF)	0.7 (tonnes/m <sup>3</sup> ) x (Concrete vol in m <sup>3</sup> ) x (GF Replacement Rate) %
Washed Copper Slag (WCS)	0.7 (tonnes/m <sup>3</sup> ) x (Concrete vol in m <sup>3</sup> ) x (WCS Replacement Rate) %

### Worked Example NRBE02-2(b)

#### Replacement of coarse and fine aggregates

The project uses 10% replacement of coarse aggregate with RCA, 10% replacement of fine aggregate with WCS for all slabs, and 30% replacement of coarse aggregate with RCA for all external non-load bearing walls of the superstructure. The Gross Floor Areas (GFA) is 58,000 m<sup>2</sup>. Refer to Worked Example NRBE02-1(b) on the concrete volume used for the respective building elements.

#### Replacement of Coarse Aggregate with Recycled Concrete Aggregates (RCA)

Minimum usage requirement for RCA = 0.015 x GFA = 0.015 x 58,000 = 870 tonnes

Total concrete volume of all slabs = 400 m<sup>3</sup> + 320 m<sup>3</sup> x 30 = 10,000m<sup>3</sup>

Total concrete volume of all external non-load bearing walls = 22 m<sup>3</sup> + (22 m<sup>3</sup> x 30) = 682 m<sup>3</sup>  
*[Approximate coarse aggregate content in concrete = 1 tonne/m<sup>3</sup>]*

Total tonnage of RCA used for superstructure  
 = [(10% x 1 tonne/m<sup>3</sup>) x 10,000m<sup>3</sup>] + [(30% x 1 tonne/m<sup>3</sup>) x 682m<sup>3</sup>] = 1,204.6 tonnes > 870 tonnes, ok

#### Replacement of Fine Aggregate with Washed Copper Slag (WCS)

Minimum usage requirement for WCS = 0.0075 x GFA = 0.0075 x 58,000 = 435 tonnes

Total concrete volume of all slabs = 400m<sup>3</sup> + 320m<sup>3</sup> x 30 = 10,000m<sup>3</sup>  
*[Approximate fine aggregate content in concrete = 0.7 tonne/m<sup>3</sup>]*

Total tonnage of WCS used for superstructure  
 = [(10% x 0.7 tonne/m<sup>3</sup>) x 10000m<sup>3</sup>] = 700 tonnes < 435 tonnes ok

In this example, based on the replacement of coarse aggregate with RCA and fine aggregate with WCS, it can be considered meeting one carbon reduction measure under Sustainable Construction.

NRBE02-2(c): Other than the use of eco-friendly cementitious materials, RCA, WCS and granite fines stated in NRBE02-2(a) and (b), other alternative construction materials can be considered as a replacement for standard building materials for non-structural application. However, there is a need to ensure that the alternative materials used would meet the physical, chemical and engineering characteristics for the intended application and requirements from relevant authorities, where applicable.

An example of alternative materials is NEWSand derived from municipal solid waste (MSW), which can be used to replace sand and similar aggregates for non-structural application such as footpaths, road building materials, concrete products like benches. It can be considered with no specific minimum replacement rate. However, note that it is currently a new material with limited supply source administered by the National Environment Agency (NEA).

## Documentation Requirements

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### At BP Submission Stage

Generally, no supporting document submission at this stage.

### Before TOP application

The following documents are to be made available on-site or upon request.

#### NRBE02-2(a) and (b)

- Extract of tender specification or concrete mix design showing the cement type used and/or the detailed usage of recycled/ engineered aggregates (e.g. RCA/WCS/granite fines);
- Calculation showing the quantity of recycled/ engineered aggregates (e.g. RCA/WCS/granite fines) used for the project;
- Certificates from an approved local product certification body for concrete products/mixes that are certified and evidence of the use of eco-friendly cementitious materials in concrete production; and
- Delivery orders and details of the actual concrete mix used in the project showing the usage of clinkers/ engineered aggregates (e.g. RCA/ WCS/granite fines).

#### NRBE02-2(c)

- Extract of tender specification or confirmation showing the use of processed waste and the areas of its application.

## References

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SS EN 197-1 – Cement - Part 1 : Composition, specifications and conformity criteria for common cement

SS EN 12620 – Specification for Aggregates for Concrete

Sustainable Construction : Guide on the use of Recycled Materials published by the Building and Construction Authority (BCA)

## NRBE02-3 Sustainable Products

Encourage the specification and use of environmentally friendly products that are certified with Environmental Product Declaration (EPD) requirements and/or with a two-tick rating by an approved local product certification body.

The provision shall include at least three (3) building and/or Mechanical and Electrical ( M&E) products for 80% of applicable areas and/or building components/systems in relation to functional spaces.

### Guidance Notes

An Environmental Product Declaration (EPD) is a transparent, objective report that communicates the environmental performance and impact of a product over its life cycle. EPDs support carbon emission reduction by making it possible to compare the environmental impacts of different products and facilitate the selection of more sustainable options. For this requirement, products with EPDs that are third-party certified and in conformance with ISO 14025 and EN 15804 and/or products certified with a two-tick rating by an approved local product certification body can be considered. The extent of coverage must be at least 80% of the applicable areas/building components/systems intended for the functional spaces.

### Worked Example NRBE02-3

Example of a proposed office building development with provision of the following products and coverage that meet the requirements.

Products	Extent of Coverage	Provision	Remarks
Chillers	100% Applicable to all office spaces	Two-tick rated based on the extent of environmental friendliness by an approved local product certification body	√
Timber Doors	80% of all conference rooms	With EPD that is third-party certified and in conformance with ISO 14025 and EN 15804	√
Drywall partitions	100% Applicable to all office spaces	Two-tick rated based on the extent of environmental friendliness by an approved local product certification body	√

### Documentation Requirements

#### At BP Submission Stage

Generally, no supporting document submission at this stage.

#### Before TOP application

The following documents are to be made available on-site or upon request.

- Extract of tender specification and drawings showing the requirements to incorporate specific products with EPDs and/or with two-tick rating by an approved local certification body;
- Certification of EPDs or details from an approved local certification body such as the material certification standards, rating and product reference; and
- Technical product information and delivery records.

### References

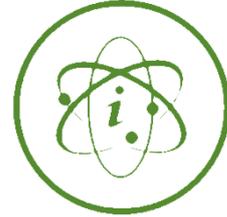
SS ISO 14205 : Environmental Labels and Declarations – Type III environmental declarations – Principles and procedures

EN 15804 : Sustainability of Construction Works – Environmental Product Declarations – Core Rules for the Product Category of Construction Products

# CARBON REDUCTION MEASURES

For Non-Residential Buildings

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## SECTION 3 – SUSTAINABLE TECHNOLOGIES

Encourage the provision of green building technologies that are oriented towards establishing low energy building consumption and smart control systems that could adapt to the users' needs and enhance building energy performance.

- NRBE03-1 Renewable Energy Sources
- NRBE03-2 Smart Building Solutions
- NRBE03-3 Green Building Technologies

## NRBE03-1 Renewable Energy System

Encourage the use of an on-site renewable energy system to reduce at least 1% of the expected annual total building electricity consumption. There must be suitable means for monitoring and records of the energy generated from the system used.

### Guidance Notes

The expected total building electricity consumption can be obtained either from the energy modelling results or based on the estimated electricity consumption, usage pattern, operational hours of all major energy-consuming systems and equipment. For the receptacle loads, the nominal values shown in Table C8 can be adopted.

Receptacle Loads	Standard	Nominal Values
Computer intensive offices	Source: ASHRAE 90.1.2013	22.0 W/m <sup>2</sup>
General office areas		16.0 W/m <sup>2</sup>
Large conference areas		11.0 W/m <sup>2</sup>
Schools (Tertiary/IHL)		8.0 W/m <sup>2</sup>
Schools (Primary/Secondary)		5.0 W/m <sup>2</sup>
Computer room (Information Technology Equipment)	Source: ASHARE 90.4 2016	215 W/m <sup>2</sup>

### Worked Example – NRBE03-1

A proposed development with GFA of 86,000 m<sup>2</sup>, operating hours per week is 55 hours at 100% occupancy rate. The expected total building electricity consumption per year is estimated to be as follows:

System/ Equipment	Total Annual Building Electricity Consumption (kWh)/year
Lighting – (Air-Conditioned Space)	3,094,380
Lighting- (Non-Air-Conditioned Space)	236,321
Exterior Lighting	405,800
Air-Conditioned Plant	7,924,425
Air System Fans	632,293
Mechanical Ventilation Fans	207,571
Lifts	792,966
Escalators	45,865
Receptacle Equipment (@16W/m <sup>2</sup> )	3,936,517
Domestic Water Pump Systems	226,088
Hot Water Systems	93,789
Others	-
<b>Total:</b>	<b>17,596,015</b>

Based on the supplier's specifications on the renewable system, compute the percentage (%) replacement.

Description	kWp Installed (kWp)	Annual Yield (kWh)
Upper Roof Block A	200	240,000
Roof Block B	200	240,000
Other blocks	0	0
Total	400	480,000

Total Building Consumption (kWh)	17,596,015
Annual Replacement Rate	2.73% > 1% ok

## Documentation Requirements

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### At BP Submission Stage

Generally, no supporting document submission at this stage.

### Before TOP application

The following documents are to be made available on-site or upon request.

- As-built drawings and on-site photographs of the renewable energy systems installed;
- Technical specifications and integration reports of the installed system(s) including total capacity installed; and
- Calculation of the percentage replacement of electricity and the total annual electricity consumption of the development.

## NRBE03-2 Smart Building Solutions

Encourage the provision of a minimum of two (2) smart building solutions to facilitate automation and controls over building systems for better energy management and thermal comfort. Examples of building solutions that can be considered are listed below:

- Use of BACnet, Modbus or any other open protocol as the network backbone of the building management system where data points can be used to facilitate communication and integration with other building systems.
- Energy portal and dashboard that helps building owners and/or tenants to better manage their energy consumption in an intuitive manner. It should comprise display metered data, trending of energy consumption (historical data) of the building and tenanted spaces on a monthly basis and other useful parameters.
- Real-time remote monitoring of chiller plant system operation such as BCA Chiller Efficiency Smart Portal.
- Demand controlled ventilation systems such as carbon dioxide sensors or devices to regulate the fresh air intake and ventilation based on occupants' needs.
- Timer sensors/controls for lighting and/or ventilation systems in common areas and facilities.
- Smart building sensors that are equipped with sensing capability, microprocessors and communication technology that can help facilitate some form of monitoring or automation.
- Differential pressure switches for Air Handling Units (AHUs) that are linked to a building management system (BMS) or suitable means that can monitor the air filter condition.
- Others (to be evaluated on a case-to-case basis).

### Documentation Requirements

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#### At BP Submission Stage

Generally, no supporting document submission at this stage.

#### Before TOP application

The following documents are to be made available on-site or upon request.

- Extract of tender specification or drawings showing the provision of the building solutions implemented for the project; and
- Technical specification on the systems or features used.

## NRBE03-3 Green Building Technologies

Encourage the adoption of low-carbon solutions and technologies which would help reduce building energy consumption. Examples of solutions that can be considered are as follows:

- Energy recovery systems for building applications
- Lifts with regenerative function
- Passive Displacement ventilation system
- Dedicated outdoor air system
- Others (to be evaluated on a case-to-case basis)

### Guidance Notes

Green Building Technologies	General Information
Energy recovery systems for building applications	Energy recovery system can be integrated to minimise overall building energy demand. For example, heat recovery system that captures waste heat discharged from the air-conditioning system and transfers for water heating purpose, which otherwise is exhausted or wasted.
Lifts with regenerative function	Lifts with regenerative function can help conserve and minimise energy use. Depending on lift usage, operating speed, height of building and floors, it would typically be a viable option for larger and taller buildings.
Passive displacement ventilation system	An innovative system that uses chilled water-cooling coils to create air circulation through the natural convection process to deliver conditioned air, without mechanical fans. It taps on the principle of natural buoyancy and temperature stratification to deliver cooled air to end-users using less to no energy.
Dedicated outdoor air system	Dedicated outdoor air system (DOAS) such as precool unit can be used to condition all outdoor air (OA) for more effective cooling and ventilation control. It can enhance the opportunity to reduce the energy use for ventilation, air conditioning and fan operations as the system does not need to condition as much outdoor air (OA) as is the case with a variable air volume (VAV) system.

### Documentation Requirements

#### At BP Submission Stage

Generally, no supporting document submission at this stage.

#### Before TOP application

The following documents are to be made available on-site or upon request.

- Brief on design intent and details of the proposed green building technologies;
- Extract of tender specification, as-built drawings and photographic evidence showing the provision and location of green building technologies implemented;
- Computation of expected energy savings over the estimated total building consumption; and
- Technical specification on the systems or features used.

## Appendix D

# Energy Modelling Methodology and Requirements

Non-Residential Buildings



# Energy Modelling Methodology and Requirements

## D1 General

The energy modelling for evaluating the energy performance of a building shall be carried out in a prescribed manner to quantify the potential savings from the energy efficiency measures and improvements over the Reference Model.

## D2 Simulation Software

The simulation software used for energy modelling shall meet the following criteria:

- (a) It must have the capability to model the thermal performance of buildings in a multi-zone format and calculate the building's total energy consumption over a continuous 12-months period.
- (b) It must be tested by a recognised institution in accordance to the Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs – ANSI/ASHRAE 140 or other equivalent standards.

## D3 Energy Modelling Methodology

D3.1 The simulation model of the proposed design (known as Proposed Model) shall be developed in accordance with the design parameters of the building. This includes:

- (i) Building design layout in terms of shape, size and orientation.
- (ii) Materials for walls, windows, roofs, floors, doors and permanent shading devices, internal partitions between conditioned and non-conditioned spaces.
- (iii) Internal loads such as levels and schedules for occupancy, lighting systems, equipment, appliances and machinery within the building
- (iv) ACMV equipment, controls and other associated components selected for use in the building.

D3.2 The Reference Model shall be developed using similar data as stated in paragraph D3.1 and in accordance with the requirements stated under Section D5 and D6 of this Appendix.

D3.3 The simulations for the Proposed Model and Reference Model shall be calculated using

- (i) the same software
- (ii) the same appropriate up-to-date weather data set shall be used for energy modelling such as ASHRAE's International Weather for Energy Calculation data for Singapore.
- (iii) the same operating schedules
- (iv) the same occupancy rates
- (v) the same building design in terms of shape, size and orientation
- (vi) the same receptacle loads
- (vii) the same indoor environmental conditions in terms of thermal comfort level. If there is a different condition such as higher space temperature is used in the Proposed Model, there must be evidence to demonstrate that the overall thermal comfort level is not lower than that of the Reference Model.
- (viii) the same internal illuminance levels (lux) for space lightings

D3.4 The overall energy consumptions of the Reference Model and Proposed Model are to be computed over a period of one (1) year using the building envelope and all energy-consuming equipment that are selected during the design stage. This includes energy consumed by chillers, air handling systems, plant equipment (for e.g. water pumps, cooling towers, tube cleaning devices, chillers, etc.), and non-ACMV systems such as lightings

lifts, escalators, ceiling fans and receptacle loads from equipment (for e.g. photocopiers, printers, fax machines, computer room information technology equipment (ITE), computers, laptops, fridges, projectors, audio-cum video systems, water heaters, dryers, washers, etc).

D3.5 The basis for deriving the overall energy consumption and potential energy savings must be spelled out and justified by way of the calculation for consideration. Notwithstanding this, the potential energy savings for the following systems/devices shall be capped as follows:

List of Systems/Devices	Applications and Descriptions	Cap on Energy Savings
Escalator	Application to escalator with sleep mode or 2 speed function.	30%
Lift with regenerative features	Application to lifts with regenerative features.	18% Project team shall provide simulation results of the energy saving from the regenerative features. Simulation shall be based on the travel distance and the expected occupancy corresponding to the building activities.
Auto-dimming systems with occupancy sensors	Applicable to lighting at office space, meeting rooms, staircase, toilets and corridors. Device integrated to the lighting system to lower the output of the lighting system when the office desk is unoccupied.	10%
Occupancy sensors / Motion sensors	Applicable to lighting at staircases, toilets and corridors	15%
	Applicable to lighting at car parks	30%
Photosensors	Applicable to transient spaces and corridors of office space. Device integrated to the lighting system to adjust the output of the lighting system based on the amount of light it senses. when the office desk is unoccupied.	No cap on energy savings. Project team shall provide daylight simulation to demonstrate the energy savings achievable from photosensor.
Carbon Monoxide Detectors (CO Sensors)	Applicable to mechanical ventilation fans only. Not applicable to jet fans that are required to be in full operating conditions, 24/7 to ensure good air circulation within the car parks. The energy savings consideration for the provision of CO sensors can be found in the worked example D1 under guidance notes.	30% No cap on energy savings. Project team shall provide CO simulation to demonstrate the energy savings from the use of CO sensors by way of Computational Fluid Dynamics (CFD) simulation.

D3.6 **Receptacle Load Cap:** For projects with receptacle loads that take up more than 25% of the total building consumption in the reference model, the receptacle load shall be capped at 25% and the same load/value shall be applied to the proposed model. However, additional energy savings from receptacle load reduction can be accorded. Details are provided in the following section D3.7.

D3.7 **Energy Saving Considerations for projects with receptacle load cap:** Energy savings from receptacle load reduction can be accorded if there are provisions to measure and monitor the receptacle load during operation. Energy monitoring devices such as dedicated energy meters to measure receptacle load must be in place so that the actual receptacle load density can be determined for verification purposes. Refer to the table below on specific considerations for different building typologies/functions. The methodology to accord the energy savings for receptacle load reduction is provided in worked example D2 under guidance notes.

Building Type/Function	Specific Considerations
Office	Energy savings can be considered if the proposed receptacle load density is lower than that of the reference model (16 W/m <sup>2</sup> ). There must be a commitment made to deliver lower receptacle density during operation along with green lease and tenant/User engagement programmes.
Data Centres	Energy consumption from the data centre operation is to be included for both reference and proposed model and based on the methodology under the guidance provided in BCA-IMDA Green Mark for New Data Centre GM NDC: 2019. Energy savings cannot be considered for the energy consumption from the data centre, server rooms and computer rooms (ITE).
Laboratories	Reference can be made to the receptacle load values stated in the ASHRAE Handbook – Fundamentals or other internationally recognised guides with diversity. Existing measured data shall be considered.
Industrial Buildings	Energy consumption from process load/equipment and services dedicated (e.g. air-conditioned system, supply and exhaust air fan system) for the manufacturing process shall be excluded. Energy consumption of receptacle loads such as lighting, ventilation system, air conditioning system and relevant system provided for these spaces shall be included in the Energy Modelling. The energy consumption of shared systems serving process load and the normally occupied spaces shall be accounted based on the weighted consumption with the provision of adequate meters or equipment to measure and determine the respective energy consumption for verification purposes.
Schools	Energy savings can be considered if the proposed receptacle load density is lower than that of the reference model. There must be a commitment made to deliver lower receptacle density during operation and student engagement programmes must be in place.
Transit Stations	Receptacle loads from train operation such as train traction load and transfer loss can be excluded

D3.8 The improved performance of the proposed building design can then be obtained by making a comparison of the overall energy consumption of the Reference Model against the Proposed Model.

D3.9 The normalised Energy Use Intensity (EUI) and Energy Efficiency Index (EEI) for both the Proposed and Reference Models shall also be computed. The details are as follows:

#### Calculation of EUI and EEI:

$$\text{EUI} = \text{TBEC}/\text{GFA}$$

$$\text{EEI} = [(\text{TBEC} - \text{DCEC}) / (\text{GFA}_{\text{excluding car parks}} - \text{DCA} - \text{GLV} \times \text{VCR})] \times (\text{NF}/\text{OH})$$

where

- (a) TBEC : Total building energy consumption (kWh/year)
- (b) DCEC : Data centre energy consumption (kWh/year)
- (c) GFA : Gross floor area (exclude car parks) (m<sup>2</sup>)
- (d) DCA : Data centre area (m<sup>2</sup>)
- (e) GLA : Gross lettable area (m<sup>2</sup>)
- (f) VCR : Weighted floor vacancy rate of gross lettable area (%)
- (g) NF : Normalising factor based on operating hours of a typical week that is 55 hrs/week
- (h) OH : Weighted weekly operating hours (hrs/week)

Reference: NUS Centre for Total Building Performance –

[http://www.bdg.nus.edu.sg/buildingenergy/e\\_energy/audit\\_results.html](http://www.bdg.nus.edu.sg/buildingenergy/e_energy/audit_results.html)

## Guidance Notes

### Worked Example D1

#### Calculation of Proposed Energy Consumption - Car parks of an office building

Proposed car park of an office building that is equipped with a combination of mechanical ventilation (MV) system and jet fans with Carbon Monoxide (CO) detection sensors. As it is an office building, the MV fan schedule is to be based on the default profile of Car Park Lighting and Mechanical Ventilation System provided under Section D6 – Table 10 of this Appendix. In the case of jet fans, they are required to be operating at 100%, 24/7 along with the CO detection sensors to ensure good air circulation within the car park. The input power of MV Fans and jet fans shall be based on the contractor or supplier's specification for the proposed building.

*Default MV Fan Schedule with CO sensors (Refer to Section D6 – Table 10)*

Day	ACMV Schedule	MV Fans Percentage of Input Power (%) controlled by CO Sensors	Jet Fans Percentage of Input Power (%)
Mon – Fri (peak)	7 AM to 10 PM - 3,900 hours (15 hours* 5 days/week * 52 weeks)	100	100
Mon – Fri (off-peak)	10 PM to 7 AM - 2,340 hours (9 hours * 5 days/week * 52 weeks)	50	100
Sat (off-peak)	1,248 hours (24 hours * 52 weeks)	50	100
Sun (off-peak)	1,248 hours (24 hours * 52 weeks)	50	100

CO sensors to operate during off-peak hours to reduce the MV input power. MV fans shall operate at 50% of the input power with the use of CO sensors.

#### Car park Fan - Calculation of Proposed Model Energy Consumption

System Configuration	No of Fans	Motor Input Power (W)	Total Motor Input Power (W)	Annual Energy Consumption (kWh)
Mechanical Ventilation Fans	2 Supply 2 Exhaust	11	44	171,600 (44kW * 100% * 3,900 hours) + 106,392 (44kW * 50% * 4,836 hours)
Jet Fans	10	0.15	1.5	13,104 (1.5*100% * 8736 hours)
Total				291,096

### Worked Example D2

#### Energy Savings Considerations for Receptacle Load Reduction

*(Applicable for projects where the receptacle load is capped at 25% of the total energy consumption in the Reference Model)*

Example of an office building that is designed with a reduction in the receptacle load density from 16 W/m<sup>2</sup> to 13 W/m<sup>2</sup> for 50% of the office spaces. Assume that these office spaces have the same operating hours. The percentage saving for the overall energy reduction can be computed and prorated based on areas.

Step 1: Determine the overall percentage energy savings by reducing the receptacle load density

Description	Areas (m <sup>2</sup> )	Percentage Distribution by Areas	Reference Model Receptacle Load Density (W/m <sup>2</sup> )	Proposed Model Receptacle Load Density (W/m <sup>2</sup> )	Energy Savings from Receptacle Load Reduction Effort
Office Space 1	1000	50%	16	10	37.5%
Office Space 2	1000	50%	16	16	0%
Average receptacle load density & Overall energy savings:			16	13	18.8%

Step 2: Check on the energy consumption distribution of the reference model and receptacle load cap of 25%

End Use	Reference Model Energy Consumption (MWh)	Proposed Model Energy Consumption (MWh)	Remarks
Receptacle Load (a)	2000 (16 W/m <sup>2</sup> )	1625 (13 W/m <sup>2</sup> )	Assume receptacle load from reference model to be 2000 MWh. Energy consumption of proposed model – receptacle load is derived from reference model with 18.8% reduction in Step 1. Reference model exclude passive design enhancement and renewable energy sources.
Other Energy Consuming System and Equipment (b)	3800	Assume 2350	Assume the proposed energy consumption for other energy-consuming systems to be 2350 MWh. These systems include chillers, condenser pumps, chilled water pumps, cooling towers, internal and external lights, lift and escalators, domestic water pumps, and so forth.
Total Energy Building Consumption (TBEC) [(a)+(b)]	5800	3975	Overall energy savings for building is 31.5 %
Percentage of receptacle load over TBEC [(a)/(c)]	34%	41%	Reference receptacle load is more than 25%
Apply 25% cap to the reference receptacle load	3800 => 75% Receptacle load with 25% cap will be 1267	1,625 > 1,267 (Apply same reference value)	Note that the proposed receptacle load is more than the reference receptacle load after applying a 25% cap. In other words, the receptacle load reduction effort is negated and there is a need to have the corresponding adjustment as detailed in Step 3.

Step 3: Adjustment to the receptacle load for the reference and proposed model

End Use	Reference Model Energy Consumption (MWh)	Proposed Model Energy Consumption (MWh)	Remarks
Adjusted Receptacle Load (d)	1,267 (Cap at 25%)	1029 $1267 \times (100\% - 18.8\%) = 1029$	The proposed receptacle load is adjusted by applying the percentage of energy savings accorded for receptacle load reduction to the cap receptacle load value.
Other Energy Consuming System and Equipment	3800	2350	Values remain unchanged
Total Building Energy Consumption (TBEC) [(b)+(d)]	5067	3379	Overall energy savings for the building is 33.3 %

## D4 Documentation Requirements

D4.1 The Qualified Person (QP) and the appropriate practitioners shall certify that the energy modelling for the building has been carried out in accordance with the requirements using the Energy Modelling methodology and shall ensure that the assumptions and inputs used for energy modelling are bona fide.

D4.2 The QP and the appropriate practitioners shall ensure the following documents and records are available as evidence to demonstrate compliance with the energy modelling framework and validation of the potential energy savings. They are:

- (a) Certification showing that the simulation software is tested and meet the criteria in accordance with the ASHRAE Standard 140
- (b) Detailed drawings and other necessary information of proposed design
- (c) Detailed system design calculation
- (d) Summary of Space and ETTV of the Building Envelope as in Table D4.2-1.
- (e) List of data such as
  - (i) Space input data for all zones comprising detailed information on construction materials and their properties designed for each individual zone. For example, room area, walls, windows, doors, floors, partitions, sensible and latent loads (lightings, occupancy rates, receptacle loads, Outdoor ventilation rates, misc. loads, etc.).
  - (ii) Schedules for each individual operating zone (e.g. lighting, occupants, mechanical fans, AHUs, other mechanical and electrical equipment, etc.)
  - (iii) Executable input data files used in the generation of the energy estimates for the Proposed and Reference Models
  - (iv) Output data on the monthly energy consumption by mechanical and electrical system components (e.g. Air-conditioned systems, Lighting Systems, Receptacle Equipment, Lifts, Escalators, etc.)
  - (v) One year simulated hourly cooling load data in the form of the Frequency vs Cooling Load (RT) plot, Cooling Load vs Time, A/C efficiency over Time
  - (vi) Detailed computation of the ETTV for both Reference and Proposed Models
  - (vii) Comparison of Reference Model versus Proposed Model as in Table D4.2-2
- (f) Summary of Energy of End Use including Efficiency Indicators for both Reference and Proposed Models as in Table D4.2-3.
- (g) Summary printouts of energy modelling software for the Reference Model including a summary of weather data results
- (h) Monthly energy consumption of mechanical and electrical system components such as air-conditioning system, lighting systems, receptacle equipment, lift and escalator, etc.
- (i) Executable excel file of the EM simulation for both the Proposed and Reference Models.

D4.3 Similar documentation requirements as above will also be required to reflect the as-built condition upon project completion for validation.

Table D4.2-1 Summary of Space and ETTV of the Building Envelope

(A) Space Summary			
Building Use	Air-Conditioned Area (m <sup>2</sup> )	Non-Air-Conditioned Area (m <sup>2</sup> )	Total Area (m <sup>2</sup> )
1. Office			
2. Toilets			
3. Storage			
4. Corridor			
5. Atrium			
6. Food Court			
7. Mechanical / Electrical			
8. Staircase			
9. Conference			
10. Retail Outlets			
11. Car parks			
12. Others			
<b>Total</b>			

Note: The building floor areas for both the Reference and Proposed Models must be the same.

(B) Building Envelope Summary – ETTV			
Orientation of Façade	Gross Area of External Walls (m <sup>2</sup> )	Reference Model ETTV (W/m <sup>2</sup> )	Proposed Model ETTV (W/m <sup>2</sup> )
North			
North-East			
East			
South-East			
South			
South-West			
West			
North-West			
Average ETTV of the Building Envelope (W/m <sup>2</sup> )		45 W/m <sup>2</sup>	

Table D4.2-2 Comparison of Reference Model versus Proposed Model

BUILDING ELEMENT	REFERENCE MODEL	PROPOSED MODEL
<b>BUILDING ENVELOPE</b>		
Wall Construction		
Opaque Doors		
Windows		
Floor		
Roof		
Window to Wall Ratio (WWR)		
Others		
<b>ELECTRICAL SYSTEMS</b>		
Lighting Power Density (W/m <sup>2</sup> )		
Lighting Occupant Sensor Controls		
Lighting Daylighting Controls		
Receptacle Power (W/m <sup>2</sup> )		
Lifts & Escalators		
Others		
<p>Note: The Receptacle Loads for both the Reference and Proposed Models must be the same.</p>		
<b>RENEWABLE ENERGY SYSTEMS</b>		
Photovoltaics		
<p>Note: To include a description of renewable energy systems used to reduce Proposed Model energy consumption.</p>		
<b>SCHEDULES</b>		
Occupancy, Lighting & Equipment		
HVAC		
<p>Note: The Occupancy Rates and Operating Schedules for both Reference and Proposed Models must be the same.</p>		
<b>MECHANICAL &amp; PLUMBING SYSTEMS</b>		
HVAC System Type		
AHU Fan Properties		
Boiler Efficiency		
Central Plant Efficiency		
<p>Note: Central plant efficiencies and capacities for chillers and cooling towers should be listed whenever the central plant is included as part of the energy model.</p>		
HVAC Circulation Loop Properties		
Domestic Water System		
Mechanical Ventilation Fans		
<b>OTHERS</b>		

**Table D4.2-3 – Summary of Energy by End Use including Efficiency Indicators**

End Use	Reference Model Energy Consumption (kWh)	Proposed Building Energy Consumption (kWh)	Energy Consumption Savings (%)
Lighting – (Air-Conditioned Space)			
Lighting- (Non Air-Conditioned Space)			
<sup>1</sup> Air-Conditioned Plant			
<sup>2</sup> Air System Fans			
Mechanical Ventilation Fans			
Lifts			
Escalators			
Receptacle Equipment			
Domestic Water Systems			
Others			
Total Building Energy Consumption			

**Renewable Energy Sources**

End Use	Energy Produced (kWh)	Reference Model Energy Consumption (kWh)	Proposed Building Energy Consumption (kWh)	Energy Consumption Savings (%)
Photovoltaics				
Others				
Total Building Energy Consumption including Renewable Energy Sources				

**Efficiency Indicators**

Efficiency Indicators	Reference Model	Actual Building Model
Energy Use Intensity, EUI (kWh/m <sup>2</sup> /yr)		
Energy Efficiency Index, EEI (kWh/m <sup>2</sup> /yr)		
System Efficiency of Air-Conditioned Plant (in i kW/kW and kW/RT)		
System Efficiency of the Air-Distribution System (in kW/RT)		
Total System Efficiency of the Air-Conditioning System (in kW/RT)		

<sup>1</sup> Chilled Water System (Chillers, Water Pumps and Cooling Towers)

<sup>2</sup> Chilled Water Air Handling and Fan Coil Units

## D5 Modelling Requirements for Reference Model

In general, the simulation model for calculating the baseline building performance (known as Reference Model) shall be developed in accordance with the requirements set out in the following sections (i) Baseline Standards and (ii) Default Chiller Efficiency Curve.

### (i) Baseline Standards

The baseline standards and minimum requirements set to establish the reference model are as listed below.

S/N	Component	Baseline Standard	Minimum Requirement															
<b>1.0 Building Description</b>																		
1.1	Building Envelope Design	<p><i>BCA Approved Document Code on Envelope Thermal Performance for buildings</i></p> <p><i>SS 212: 2007 – Specification for Aluminium Alloy Windows</i></p> <p><i>SS654 – Code of Practice for Curtain Walls</i></p>	<p>(a) ETTV shall not exceed 45W/m<sup>2</sup></p> <p>(b) For roof with skylight, RTTV shall not exceed 50 W/m<sup>2</sup></p> <p>(c) For roof without skylight, the average U value of the gross area of the roof shall not exceed the limits below:</p> <table border="1"> <thead> <tr> <th colspan="3">Maximum Thermal Transmittance for Roof (U-value)</th> </tr> <tr> <th>Weight Group</th> <th>Weight range (kg/m<sup>2</sup>)</th> <th>Max Thermal Transmittance (W/m<sup>2</sup>K)</th> </tr> </thead> <tbody> <tr> <td>Light</td> <td>Under 50</td> <td>0.5</td> </tr> <tr> <td>Medium</td> <td>50 to 230</td> <td>0.8</td> </tr> <tr> <td>Heavy</td> <td>Over 230</td> <td>1.2</td> </tr> </tbody> </table> <p>(d) All windows and curtain walls are designed to ensure air leakage rates do not exceed the limits specified in SS 212 – Specification for Aluminium Alloy Windows and SS654 – Code of Practice for Curtain Walls.</p> <p>(e) Building entrances and door openings to building exterior or non-air-conditioned spaces and the like shall</p> <ul style="list-style-type: none"> <li>(i) be provided with doors that are equipped with automated technology or self-closing devices. Where door opening of any commercial units located along the perimeter of the building envelope, that unit shall be equipped with the addition of pressure independent control valve and energy meters to measure the consumption of fan coiled units (FCUs) within the unit; and</li> <li>(ii) be equipped with vestibules or other appropriate measures for the doorway with high pedestrian traffic flow. In the case of vestibules, the interior and exterior door must have a minimum distance of not less than 2.5 m apart and should be interlocked to avoid being opened at the same time.</li> </ul> <p>Note: Doorway with high pedestrian traffic flow refers to building main entrances and those leading to transport nodes or other commercial buildings.</p>	Maximum Thermal Transmittance for Roof (U-value)			Weight Group	Weight range (kg/m <sup>2</sup> )	Max Thermal Transmittance (W/m <sup>2</sup> K)	Light	Under 50	0.5	Medium	50 to 230	0.8	Heavy	Over 230	1.2
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Light	Under 50	0.5																
Medium	50 to 230	0.8																
Heavy	Over 230	1.2																
1.2	Building Shape, Size and Configuration		Reference Model to be the same as Proposed Model															
1.3	Building Zoning & Thermal Block		<p>Reference Model to be the same as Proposed Model.</p> <p>Zoning of air-conditioned and non-air-conditioned areas shall be modelled based on the approved building plan except for floor areas that conform to the provisions for <i>Passive Design Features</i> under Para 3.9 to reduce air-conditioned spaces. Where ACMV zones are defined on the ACMV design drawings, each ACMV zone shall be modelled as a separate thermal block.</p>															

S/N	Component	Baseline Standard	Minimum Requirement
<b>2.0 System Description</b>			
2.1	Air-conditioning System Types	<p><i>SS 530 – Code of Practice for Energy efficiency Standard for Building Services and Equipment</i></p> <p><i>ASHRAE 90.1 – Energy Standard for Buildings Except Low-Rise Residential Buildings</i></p>	<p>(a) Based on the peak building cooling load, the reference system shall be as follows:</p> <p>(i) Peak building cooling load <math>\geq</math> 500RT: centrifugal chiller.</p> <ul style="list-style-type: none"> <li>- Peak cooling load <math>\leq</math> 800 RT: 1 number of centrifugal chiller</li> <li>- Peak cooling load <math>&gt;</math> 800 RT: N numbers of centrifugal chillers equally sized with each chiller <math>\leq</math> 800 RT</li> </ul> <p>(ii) Peak building cooling load <math>&lt;</math> 500RT and air-conditioned area <math>\geq</math> 5,000m<sup>2</sup>: Screw chiller</p> <ul style="list-style-type: none"> <li>- Peak cooling load <math>\leq</math> 300 RT: 1 number of screw chiller</li> <li>- Peak cooling load <math>&gt;</math> 300 RT: 2 numbers of screw chillers sized equally sized with each chiller <math>\leq</math> 300 RT</li> </ul> <p>(iii) Peak building cooling load <math>&lt;</math> 500RT and air-conditioned area <math>&lt;</math> 5,000m<sup>2</sup>: The reference system shall be of the same type as the proposed system.</p> <p>(iv) For VRF systems, the baseline of constant COP of 3.28, 3.22 and 2.93 shall be adopted, with reference to <i>SS 530 : 2014, Table 1B</i>.</p> <p>(b) Additional chiller or other air conditioning configuration may be considered if the reference chiller(s) operate at less than 50% of its capacity for more than 20% of the time.</p> <p>(c) The energy consumption contribution from the District Cooling System (DCS) shall be excluded from the energy modelling.</p>
2.2	Chiller Efficiency	<i>SS 530 – Code of Practice for Energy Efficiency Standard for Building Services and Equipment</i>	Minimum energy efficiency standard stated in <i>SS 530 – Code of Practice for Energy Efficiency Standard for Building Services and Equipment</i> . Please refer to the default chiller efficiency curve in the following section.
2.3	Air-Conditioning Hydronic Systems	<p><i>SS 553 - Code of Practice for Air-conditioning and Mechanical Ventilation in Buildings</i></p> <p><i>California Energy Commission Non-Residential Alternative Calculation Method Reference Manual 2013 Appendix 5.7</i></p>	<p>(a) Pumping system design criteria</p> <p>(b) For air-conditioning hydronic systems having a total pump system power exceeding 7.5 kW, the pump power limitation for chilled water systems shall be 349 kW/m<sup>3</sup>/s. The pump power limitation for condensing water systems is 301 kW/m<sup>3</sup>/s.</p> <p>(i) For motors <math>&gt;</math> 3.7 kW: The chilled water pump shall have VSD and the motor shall have controls and/ or devices (such as variable speed control) that will result in pump motor demand of no more than 30% of design wattage at 50% of design water flow.</p> <p>(ii) For motors <math>\leq</math> 3.7 kW: The chilled water pump shall be the equivalent of a constant speed pump if the motor is less than 3.7 kW.</p> <p>(iii) Condenser water pump shall be the equivalent of a constant speed pump.</p> <p>(iv) Buildings served by District Cooling System (DCS), code-compliance chilled water pump efficiency will be 0.0586 kW/RT.</p>

S/N	Component	Baseline Standard	Minimum Requirement																				
2.3	Air-Conditioning Hydronic Systems	<p>SS 553 - Code of Practice for Air-conditioning and Mechanical Ventilation in Buildings</p> <p>California Energy Commission Non-Residential Alternative Calculation Method Reference Manual 2013 Appendix 5.7</p>	<p>(c) Calculation for part load performance of chilled water pump with VSD and the minimum operating load shall be capped at 50% (25 Hz) of the equipment capacity.</p> <p>Pump power ratio  <math>= 0.0205x + 0.4101x^2 + 0.5753x^3</math>  <i>where x is the part load ratio</i></p> <p>Values in the table below are for reference only            (projects are advised to use actual value and formula for computation)</p> <table border="1"> <thead> <tr> <th>X</th> <th>0.2</th> <th>0.3</th> <th>0.4</th> <th>0.5</th> <th>0.6</th> <th>0.7</th> <th>0.8</th> <th>0.9</th> <th>1.0</th> </tr> </thead> <tbody> <tr> <td>Pump ratio</td> <td>0.025</td> <td>0.059</td> <td>0.111</td> <td>0.185</td> <td>0.284</td> <td>0.413</td> <td>0.573</td> <td>0.770</td> <td>1.000</td> </tr> </tbody> </table> <p><i>Other equivalent methodology can be considered but affinity law is not recommended as it does not account for the loss in actual operating conditions.</i></p>	X	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	Pump ratio	0.025	0.059	0.111	0.185	0.284	0.413	0.573	0.770	1.000
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Pump ratio	0.025	0.059	0.111	0.185	0.284	0.413	0.573	0.770	1.000														
2.4	Cooling Tower	<p>SS 530 – Code of Practice for Energy Efficiency Standard for Building Services and Equipment</p> <p>California Energy Commission Non-Residential Alternative Calculation Method Reference Manual 2013 Appendix 5.7</p>	<p>Performance requirement for heat rejection equipment:</p> <p>(a) Propeller or axial fan cooling towers: Cooling tower performance shall not be less than 3.23 L/s/kW.</p> <p>(b) Centrifugal fan cooling towers: Cooling tower performance shall not be less than 1.7 L/s/kW.</p> <p>(c) Calculation for part load performance of Cooling tower with VSD and the minimum operating load shall be capped at 50% (25 Hz) of the equipment capacity.</p> <p>Cooling tower fan power ratio = <math>0.331629 - 0.885676x + 0.605565x^2 + 0.948482x^3</math>  <i>where x is the part load ratio</i></p> <p>Values in the table below are for reference only            (projects are advised to use actual value and formula for computation)</p> <table border="1"> <thead> <tr> <th>x</th> <th>0.2</th> <th>0.3</th> <th>0.4</th> <th>0.5</th> <th>0.6</th> <th>0.7</th> <th>0.8</th> <th>0.9</th> <th>1</th> </tr> </thead> <tbody> <tr> <td>CT ratio</td> <td>0.186</td> <td>0.146</td> <td>0.135</td> <td>0.159</td> <td>0.223</td> <td>0.334</td> <td>0.496</td> <td>0.716</td> <td>1.000</td> </tr> </tbody> </table> <p><i>Other equivalent methodology can be considered but affinity law is not recommended as it does not account for the loss in actual operating conditions.</i></p>	x	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	CT ratio	0.186	0.146	0.135	0.159	0.223	0.334	0.496	0.716	1.000
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2.5	Air Conditioning Fan Systems	<p>SS 553 - Code of Practice for Air-conditioning and Mechanical Ventilation in Buildings</p> <p>ASHRAE 90.1- Energy Standard for Buildings</p>	<p>The ratio of fan system power to the supply fan air flow rate (main fan) of each air-conditioning system at design conditions shall not exceed the allowable fan system power.</p> <p><u>Airflow Rate for Reference Model</u></p> <p>(a) The airflow rate for the Reference Model shall be based on the auto-sizing function of the energy modelling software used.</p> <p>(b) The Reference Model for spaces served by fan coil units (FCUs) shall be of constant flow system, and the airflow rate shall be auto sized by the energy modelling software. In instances where, airflow rate simulated is less than that of the smallest FCU available in the market (e.g. FCUs in hotel guest rooms), the airflow rate of the proposed FCU can be adopted for the Reference Model.</p>																				

S/N	Component	Baseline Standard	Minimum Requirement
2.5	Air Conditioning Fan Systems	<p>SS 553 - Code of Practice for Air-conditioning and Mechanical Ventilation in Buildings</p> <p>ASHRAE 90.1- Energy Standard for Buildings Except Low-Rise Residential Buildings</p>	<p><u>Fan System Design Criteria</u></p> <p>(a) For fan systems with a motor nameplate power <math>\geq 4</math> kW, the fan power limitation of the air-conditioning systems shall be referenced to SS 553, Table 2a- Fan power limitation.</p> <p>(b) For fan system having a motor nameplate power <math>&lt; 4</math> kW, the allowable fan system input power shall be <math>\leq 0.6</math> kW/m<sup>3</sup>/s (0.17 W/CMH) of supply air. For cases where the proposed fan power exceeds the reference power limitation, the energy consumption of the reference model is to be the same as that of the proposed fan systems.</p> <p>(c) Constant volume shall not exceed 1.5 kW/m<sup>3</sup>/s (or 0.42 W/CMH + A) of supply air. Reference control strategy for CAV system shall be constant speed.</p> <p>(d) Variable volume shall not exceed 2.1 kW/m<sup>3</sup>/s (or 0.58 W/CMH + A) of supply air.</p> <p>(e) Fan power limitation pressure drop adjustment (A) can be considered and shall be based on SS 553, Table 2b - Fan power limitation pressure drop adjustment. Pressure drop adjustment is applicable to particulate filtration credit MERV 14, MERV 15 and filters with higher MERV ratings, but not applicable to particulate filtration credit MERV 9 to MERV 13.</p> <p>(f) Fan power limitation pressure drop adjustment can be considered for activities where higher fan power is expected to overcome the high static pressure of the specialized hardware such as kitchen exhaust, heap filter or high-pressure exhaust system used in clean room, laboratories and hospitals. There is no exception to the reference for cases when the proposed fan power exceeds the reference power limitation in Table 2b of SS 553.</p> <p>(g) For Transit Station and Underground Structures / Spaces - Pressure adjustment can be considered for horizontal long duct of 70m or more at 2Pa/m run.</p> <p><u>Part load fan power limitation</u></p> <p>(a) The reference control strategy for VAV system shall come with VSD without exemption, applicable to all fans including small fan motors <math>\leq 7.4</math> kW.</p> <p>(b) Individual VAV fans with motors of <math>\geq 7.4</math> kW shall meet one of the following requirements:</p> <ul style="list-style-type: none"> <li>• Be driven by an electrical variable speed drive.</li> <li>• Have other controls and devices for the fan that will result in fan motor demand of less than 30% of design wattage at 50% of design air volume when static pressure set point equals one-third of the total design static pressure based on manufacturer's certified fan data.</li> <li>• Calculation for part load performance of VAV fan with VSD and the minimum operating load shall be capped at 50% (25 Hz) of the equipment capacity. The part load fan power calculator may be referenced from ASHRAE 90.1, Table G3.1.3.15, Part-Load Performance for VAV Fan Systems, Method 2 – Part-Load Fan Power Equation for part load fan power calculation.</li> </ul> <p>Fraction of full-load fan power = <math>0.0013 + 0.1470x + 0.9506x^2 - 0.0998x^3</math>  where x is the part load ratio (Ratio of current L/s against design L/s). The values indicated in table below are for reference only. It is advisable to use formula and actual value for computation.</p>

S/N	Component	Baseline Standard	Minimum Requirement																																			
2.5	Air Conditioning Fan Systems	<p>SS 553 - Code of Practice for Air-conditioning and Mechanical Ventilation in Buildings</p> <p>ASHRAE 90.1- Energy Standard for Buildings Except Low-Rise Residential Buildings</p>	<table border="1"> <tr> <td>x</td> <td>0.2</td> <td>0.3</td> <td>0.4</td> <td>0.5</td> <td>0.6</td> <td>0.7</td> <td>0.8</td> <td>0.9</td> <td>1</td> </tr> <tr> <td>Fan ratio</td> <td>0.068</td> <td>0.128</td> <td>0.206</td> <td>0.300</td> <td>0.410</td> <td>0.536</td> <td>0.676</td> <td>0.831</td> <td>1.000</td> </tr> </table> <p>For laboratories, ACH baseline will reference to existing laboratory with similar function and there shall be setback ACH during non-occupancy. Where information is not readily available, the following baseline can be considered after discussion with assessors. Projects shall design for minimum flowrate to reduce energy consumption within safety limit.</p> <table border="1"> <thead> <tr> <th>Laboratories</th> <th>ACH* for unoccupied hours</th> <th>ACH* for occupied hours</th> </tr> </thead> <tbody> <tr> <td>BSL1</td> <td>3</td> <td>4</td> </tr> <tr> <td>BSL2 &amp; 3 (Sprinkled)</td> <td>4</td> <td>8</td> </tr> <tr> <td>BSL2 &amp; 3 (Non- Sprinkled)</td> <td>6</td> <td>12</td> </tr> <tr> <td>CDSL 1, 2, 3</td> <td>Minimum opening for fume hood(s)</td> <td>Maintain minimum 0.5m/s airflow for fume hood(s) at working position. Reasonable diversity to be considered.</td> </tr> </tbody> </table> <p>*ACH baseline for BSL4 / CDSL4 to be discussed with assessor(s) on case-by-case basis if baseline for BSL3/CDSL3 are not suitable.</p>	x	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	Fan ratio	0.068	0.128	0.206	0.300	0.410	0.536	0.676	0.831	1.000	Laboratories	ACH* for unoccupied hours	ACH* for occupied hours	BSL1	3	4	BSL2 & 3 (Sprinkled)	4	8	BSL2 & 3 (Non- Sprinkled)	6	12	CDSL 1, 2, 3	Minimum opening for fume hood(s)	Maintain minimum 0.5m/s airflow for fume hood(s) at working position. Reasonable diversity to be considered.
x	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1																													
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2.6	Mechanical Ventilation Fan Systems	<p>SS 553 - Code of Practice for Air-conditioning and Mechanical Ventilation in Buildings</p> <p>ASHRAE 90.1- Energy Standard for Buildings Except Low-Rise Residential Buildings</p>	<p>The ratio of fan system power to the supply fan air flow rate (main fan) of each ventilation system at design conditions shall not exceed the allowable fan system power.</p> <p><u>Fan system design criteria</u></p> <p>(a) Mechanical ventilation systems having a total fan system power <math>\geq 4\text{kW}</math> shall refer to SS 553, Table 8 – Fan Power Limitation in Mechanical Ventilation Systems.</p> <p>(b) For fan system with a motor nameplate power <math>&lt; 4\text{ kW}</math>, the allowable fan system input power shall not exceed <math>0.6\text{ kW/m}^3/\text{s}</math> (or <math>0.17\text{ W/CMH}</math>) of supply air. For cases where the proposed fan power exceeds the reference power limitation, the energy consumption of the reference model is to be the same as that of the proposed fan systems.</p> <p>(c) Reference fan power limitation for mechanical ventilation system shall be considered to be of constant volume and the fan system input shall not exceed <math>0.3\text{ W/CMH} + A</math>.</p> <p>(d) Fan power limitation pressure drop adjustment (A) shall refer to SS 553, Table 2b- Fan power limitation pressure drop adjustment. Pressure drop adjustment is applicable to particulate filtration credit MERV 14, MERV 15 and filters with higher MERV ratings, but not applicable to particulate filtration credit MERV 9 to MERV 13.</p> <p>(e) Exceptions can be considered for activities where higher fan power are expected to overcome the high static pressure of the specialized hardware such as kitchen exhaust, heap filter or high-pressure exhaust system used in the clean room and hospital. There is no exception to the Reference Model for cases when proposed fan power exceeds the baseline power limitation.</p> <p>(f) Transit Station and Underground Structures / Spaces - Pressure adjustment can be considered for horizontal long ducts of 70m or more at <math>2\text{Pa/m}</math> run.</p>																																			

S/N	Component	Baseline Standard	Minimum Requirement
2.7	Design Airflow Rates	<i>ASHRAE 90.1 Section G3.1.2.9.1</i>	For systems serving laboratory spaces, use a supply-air-to-room-air temperature difference of 9°C or the required ventilation air or makeup air, whichever is greater.
2.8	Exhaust Air	<i>ASHRAE 90.1 Section 6.5.7.2</i>	Buildings with laboratory exhaust systems having a total exhaust rate greater than 2360 L/s shall adopt at least one of the energy efficient features as stated in <i>ASHRAE 90.1 Section 6.5.7.2</i> .
2.9	Lighting Systems	<i>SS 530 – Code of Practice for Energy Efficiency Standard for Building Services and Equipment</i>  <i>ASHRAE 90.1- Energy Standard for Buildings Except Low-Rise Residential Buildings</i>	(a) The maximum design lighting power (including ballast loss) for a building's interior lighting shall not exceed the sum of maximal power for various areas calculated in accordance with SS 530, Table 7A- <i>Maximum Building Interior Lighting Power Density for Compliance (Space-By Space Method)</i> . Particularly, the maximum design lighting power (including ballast loss) for laboratories shall be 16W/m <sup>2</sup> . The allowable lighting power density stated in ASHRAE 90.1 can be considered if the lighting power budget for the types of usage is not available in SS 530.  (b) The allowable building exterior and outdoor (uncovered area) lighting power shall be the combined total of the sum of the general hardscape lighting allowance determined in according to SS 530, Table 7D and the sum of the additional lighting power allowance for specific applications determined in accordance with Table 7E. The maximal power density requirements specified in Table 7D are tradable but those specified in Table 7E are not, unless stated otherwise.
2.10	Hot Water generation	<i>SS 530 – Code of Practice for Energy Efficiency Standard for Building Services and Equipment</i>  <i>SS 553 - Code of Practice for Air-conditioning and Mechanical Ventilation in Buildings</i>	(a) For the generation of hot water ≤ 60°C, the baseline shall be a heat pump with COP of 3.2.  (b) Control of indoor thermal environment via reheat of the air shall not be allowed except for energy source from site-recovered energy (including condenser heat) or site-solar energy, referring to <i>SS 553, Section 8.14</i> . The baseline for this case will be heat pump with COP of 3.2.
2.11	Energy Recovery Systems	<i>SS 553 - Code of Practice for Air-conditioning and Mechanical Ventilation in Buildings</i>	(a) Exhaust air of 2.5 m <sup>3</sup> /s or greater from conditioned space in a single location shall have energy recovery system with at least 60% recovery effectiveness. 60% recovery effectiveness shall mean a change of enthalpy of the outdoor air supply equal to 60% of the difference between the outdoor air and return air at design conditions when tested under AHRI standard 1060.  (b) Control of indoor thermal environment by reheating the air shall not be allowed except for energy source from site-recovered energy (including condenser heat) or site-solar energy, refer to <i>SS553, Section 8.14</i> . The baseline for this case will be heat pump with COP of 3.2

S/N	Component	Baseline Standard	Minimum Requirement																					
3.0	Others																							
3.1	Receptacle & Process loads	ASHRAE Handbook – Fundamentals  ASHRAE 90.4 Energy Standards for Data Centers	<p>In general, the default figures of receptacle value for Reference Model are as below:</p> <table border="1"> <thead> <tr> <th>Receptacle Loads</th> <th>Standard</th> <th>Nominal Values</th> </tr> </thead> <tbody> <tr> <td>a. Computer intensive offices</td> <td></td> <td>22.0 W/m<sup>2</sup></td> </tr> <tr> <td>b. General office areas</td> <td>Source: ASHRAE</td> <td>16.0 W/m<sup>2</sup></td> </tr> <tr> <td>c. Large conference areas</td> <td>90.1.2013</td> <td>11 W/m<sup>2</sup></td> </tr> <tr> <td>d. Schools (Tertiary/IHLs)</td> <td></td> <td>8 W/m<sup>2</sup></td> </tr> <tr> <td>e. Schools (Primary/Secondary)</td> <td></td> <td>5 W/m<sup>2</sup></td> </tr> <tr> <td>f. Computer rooms (Information Technology Equipment -ITE)</td> <td>Source: ASHARE 90.4 2016</td> <td>215 W/m<sup>2</sup></td> </tr> </tbody> </table> <p>Other receptacle loads that are not listed shall be assumed to have the same value as the proposed design.</p>	Receptacle Loads	Standard	Nominal Values	a. Computer intensive offices		22.0 W/m <sup>2</sup>	b. General office areas	Source: ASHRAE	16.0 W/m <sup>2</sup>	c. Large conference areas	90.1.2013	11 W/m <sup>2</sup>	d. Schools (Tertiary/IHLs)		8 W/m <sup>2</sup>	e. Schools (Primary/Secondary)		5 W/m <sup>2</sup>	f. Computer rooms (Information Technology Equipment -ITE)	Source: ASHARE 90.4 2016	215 W/m <sup>2</sup>
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3.2	Occupancy Load		<p>For office buildings, the occupancy load provided in Table 1 under Section D6 of this Appendix shall be used in both reference and proposed model.</p> <p>For other building categories, the occupancy load provided will be the same as the proposed design.</p>																					
3.3	Operation Schedules		<p>For office buildings, the operation schedules for the different spaces within the building provided in Table 2 to 11 under Section D6 of this Appendix shall be used in both reference and proposed model.</p> <p>For other building categories, the baseline operation schedules will be the same as the proposed design.</p> <p>Note that for car parks that are equipped with Carbon Monoxide (CO) sensors, jet fans if provided shall be considered to operate at 100% at all time in both reference and proposed model.</p>																					
3.4	Indoor Thermal Comfort Conditions	SS554– Code of Practice for Indoor Air Quality for Air-conditioned Buildings	Same as proposed design																					
3.5	Minimum Ventilation Rates	SS 553 - Code of Practice for Air-conditioning and Mechanical Ventilation in Buildings	<p>Same as proposed design. The ventilation rates for specific usages based on international/ Singapore recognised guidelines can be considered.</p> <p>For car parks, the baseline air change rate shall be based on SS 553- Section 14.1 Car parks. The ventilation rates for proposed model shall also comply to the requirement in the same standard unless a waiver is obtained from relevant authorities.</p> <p><i>Exception: This section is not applicable for laboratories</i></p>																					
3.6	Heat Exchanger		Same as proposed design																					
3.7	Lift & Escalator without Regenerative Drive	ASHRAE 90.1	<p>Same as proposed design</p> <p>Both the reference and proposed lift design shall incorporate with A/C VVVF features. Energy consumption of the lift motor, ventilation fans, and lights shall be included in reference and proposed model where the ventilation fans and lights shall be modelled with the same schedule as the lift motor.</p>																					

S/N	Component	Baseline Standard	Minimum Requirement																																																																					
3.7	Lift & Escalator without Regenerative Drive	ASHRAE 90.1 Energy Standard for Buildings Except Low-Rise Residential Buildings	<p><i>Cont'd</i></p> <p>If the lift car ventilation fans and lighting power density are unknown, default figures may be used. That is, the default lift car ventilation fan shall be 0.69 W/L-s and the lighting power density shall be 33.79 W/m<sup>2</sup>; both operate continuously.</p> <p>The lift peak motor power shall be calculated as follows:  <math>kW = (\text{weight of lift car} + \text{rated load} - \text{counterweight}) \times \text{speed of lift car} \times 0.00981/h_{\text{mechanical}}</math></p> $P_m = kW/h_{\text{motor}}$ <p>where  Weight of Lift Car = the proposed design lift car weight, kg  Rated Load = the proposed design lift load at which to operate, kg  Counterweight of Lift Car = the lift car counterweight, from Table G3.9.2, kg  Speed of Lift Car = the speed of the proposed elevator, m/s  <math>h_{\text{mechanical}}</math> = the mechanical efficiency of the lift from Table, Lift Motor  <math>h_{\text{motor}}</math> = the motor efficiency from Table, Hydraulic Lift Motor Efficiency  <math>P_m</math> = peak lift motor power, kW</p> <p><b>Lift Motor</b></p> <table border="1"> <thead> <tr> <th>Number of Stories (Including Basement)</th> <th>Motor Type</th> <th>Counterweight</th> <th>Mechanical Efficiency</th> <th>Motor Efficiency*</th> </tr> </thead> <tbody> <tr> <td>&lt; 4</td> <td>Hydraulic</td> <td>None</td> <td>58%</td> <td>Hydraulic Lift Motor Efficiency</td> </tr> <tr> <td>&gt; 4</td> <td>Traction</td> <td>Proposed design counterweight, if not specified use weight of the car plus 40% of the rated load</td> <td>64%</td> <td>Traction Lift Motor Efficiency</td> </tr> </tbody> </table> <p><sup>a</sup> Use the efficiency for the next motor size greater than the calculated kW</p> <p><b>Hydraulic Lift Motor Efficiency</b></p> <table border="1"> <thead> <tr> <th>Motor (KW)</th> <th>7.5</th> <th>15</th> <th>22</th> <th>30</th> <th>75</th> </tr> </thead> <tbody> <tr> <td>Full-Load Efficiency (%)</td> <td>72</td> <td>75</td> <td>78</td> <td>78</td> <td>80</td> </tr> </tbody> </table> <p><b>Traction Lift Motor Efficiency</b></p> <table border="1"> <thead> <tr> <th>Motor (KW)</th> <th>0.8</th> <th>1.1</th> <th>1.5</th> <th>2.2</th> <th>3.7</th> <th>5.6</th> <th>7.5</th> <th>11.1</th> <th>14.9</th> <th>18.7</th> </tr> </thead> <tbody> <tr> <td>Full-Load Efficiency (%)</td> <td>82.5</td> <td>84.0</td> <td>84.0</td> <td>87.5</td> <td>87.5</td> <td>89.5</td> <td>89.5</td> <td>91.0</td> <td>91.0</td> <td>92.4</td> </tr> <tr> <th>Motor (KW)</th> <th>22.4</th> <th>29.8</th> <th>37.3</th> <th>44.8</th> <th>56</th> <th>74.6</th> <th>93.3</th> <th>111.9</th> <th>149.2</th> </tr> <tr> <td>Full-Load Efficiency (%)</td> <td>92.4</td> <td>93.0</td> <td>93.0</td> <td>93.6</td> <td>94.1</td> <td>94.5</td> <td>94.5</td> <td>95.0</td> <td>95.0</td> </tr> </tbody> </table>	Number of Stories (Including Basement)	Motor Type	Counterweight	Mechanical Efficiency	Motor Efficiency*	< 4	Hydraulic	None	58%	Hydraulic Lift Motor Efficiency	> 4	Traction	Proposed design counterweight, if not specified use weight of the car plus 40% of the rated load	64%	Traction Lift Motor Efficiency	Motor (KW)	7.5	15	22	30	75	Full-Load Efficiency (%)	72	75	78	78	80	Motor (KW)	0.8	1.1	1.5	2.2	3.7	5.6	7.5	11.1	14.9	18.7	Full-Load Efficiency (%)	82.5	84.0	84.0	87.5	87.5	89.5	89.5	91.0	91.0	92.4	Motor (KW)	22.4	29.8	37.3	44.8	56	74.6	93.3	111.9	149.2	Full-Load Efficiency (%)	92.4	93.0	93.0	93.6	94.1	94.5	94.5	95.0	95.0
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3.8	Modelling Limitation or Simulation Program		Same as proposed design																																																																					

S/N	Component	Baseline Standard	Minimum Requirement
3.9	Passive Design Features		<p>The energy saving contribution from passive design features that could reduce the energy consumption of air conditioning system can be considered. For example, the introduction of air well or slopes to facilitate the provision of natural ventilated car parks which otherwise would have to be mechanically ventilated. Similarly, in the case of circulation spaces such as atria, plaza and corridor spaces where naturally ventilated design is adopted instead of having to air-condition these spaces can be considered as part of passive design strategies.</p> <p>This does not apply to features that would normally be regarded as common such as non-airconditioned spaces for warehouses, car parks, school classrooms and pantries.</p> <p>A written justification detailing the design strategies with due consideration for ventilation requirements and thermal comfort of the designated non air-conditioned spaces provided is to be submitted for evaluation. The details can include Computational Fluid Dynamics (CFD) simulation and/or Energy Modelling (EM) simulation of the energy consumption of the reference air-conditioned space and the proposed designated non air-conditioned spaces with fan provision. No cap on energy savings.</p>
<p><i>Note: Refer to ASHRAE 90.1 Appendix G when there is no baseline standard for energy related features such as chilled beams, underfloor air distribution systems, receptacle loads, lifts and escalators, hot water systems and etc. If baseline is unavailable for building with special requirements, reference can be made to similar building type completed after 2005. Detailed calculations shall be provided to justify energy savings from the use of salient energy efficient features /equipment. Where justification cannot be provided, same input parameters for good design practice shall apply to both the Reference and Proposed Model.</i></p>			

## (ii) Default Chiller Efficiency Curve

The minimum system efficiency of the chiller plant shall be based on the recommendations stipulated in SS 530 and AHRI 551/591. The standard rating conditions are to be based on chilled water supply temperature at 7.0°C, chilled water return temperature at 12.0°C, condenser water entering temperature at 30.0°C and condenser water leaving temperature at 35.0°C as stipulated in AHRI 551/591. The default part-load performance curves derived from the DOE 2.2 and IESVE software 2014 and in compliance with the California's TM24 requirement presented in the following table shall be used for the reference model.

Equipment Type	Size Category	COP									
		10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Rotary Screw and Scroll	< 263kW	3.125	3.581	3.809	3.970	4.105	4.228	4.345	4.461	4.576	4.694
	≥ 264 kW and < 528 kW	3.255	3.730	3.967	4.135	4.276	4.403	4.526	4.646	4.767	4.889
	≥ 528 kW and < 1055 kW	3.551	4.069	4.328	4.511	4.665	4.804	4.938	5.069	5.200	5.334
	≥ 1,055 kW and < 2110 kW	3.842	4.403	4.683	4.881	5.047	5.198	5.342	5.484	5.626	5.771
	≥ 2,110 kW	4.185	4.796	5.100	5.317	5.497	5.662	5.819	5.974	6.129	6.286
Centrifugal	< 1,055 kW	1.676	2.914	3.821	4.478	4.949	5.279	5.504	5.648	5.732	5.771
	≥ 1,055kW and < 1,407 kW	1.826	3.174	4.162	4.878	5.391	5.750	5.995	6.152	6.244	6.286
	≥ 1,407kW	1.826	3.174	4.162	4.878	5.391	5.750	5.995	6.152	6.244	6.286

## D6 Default Occupancy and Operation Schedules for Office Buildings

Default schedules correspond to a week of operation and occupancy for office buildings is as stipulated in the following Table 1.

Table 1: Occupancy Load for Office Building

Functional Spaces	Occupancy Load (m <sup>2</sup> /person)
Reception Areas	3
Lobby/Corridors	0
Waiting Areas/ Visitors Lounge	3
Admin Office	10
Business Centre	10
Meeting/ Seminar Room	1.5
Archive/ Library - Stack Area	10
Archive/ Library - Reading Area	5
Filling Room/ Store	10
Computer Room	5
Design Studio	5
Drafting Office	5
Trading Floor	2
Trading Gallery	1.5
Banking Hall	3
Deposit/ Storage Room	30
Machine/ Printing Room	10
Restaurant	1.5
Canteen	1.5
Staff Canteen	1.5
Shop	5
Toilets	0
Storage Area	30
Mechanical Plant Room	30

Note:

- (i) Occupancy load reference from Singapore Fire Code Chapter 1 – Schedule 4
- (ii) The default occupancy load density for the reference model and proposed model shall be the same.

Table 2: Schedules for Office Space in Office Building (include meeting room, workspaces, waiting areas, business centre, filling room, banking and trading floor)

Hour of Day/Time		Occupancy Schedule Percentage of Maximum load			Lighting Schedule Percentage of Maximum load			Receptacle Schedule Percentage of Maximum load			ACMV Schedule On/Off		
		Weekday	Sat	Sun	Weekday	Sat	Sun	Weekday	Sat	Sun	Weekday	Sat	Sun
1	12 - 1 am	0	0	0	0	0	0	5	5	5	Off	Off	Off
2	1 - 2 am	0	0	0	0	0	0	5	5	5	Off	Off	Off
3	2 - 3 am	0	0	0	0	0	0	5	5	5	Off	Off	Off
4	3 - 4 am	0	0	0	0	0	0	5	5	5	Off	Off	Off
5	4 - 5 am	0	0	0	0	0	0	5	5	5	Off	Off	Off
6	5 - 6 am	0	0	0	0	0	0	5	5	5	Off	Off	Off
7	6 - 7 am	0	0	0	0	0	0	5	5	5	Off	Off	Off
8	7 - 8 am	0	0	0	0	0	0	5	5	5	On	Off	Off
9	8 - 9 am	50	0	0	100	0	0	50	5	5	On	Off	Off
10	9 - 10 am	95	0	0	100	0	0	90	5	5	On	Off	Off
11	10 - 11am	95	0	0	100	0	0	90	5	5	On	Off	Off
12	11 - 12 pm	95	0	0	100	0	0	90	5	5	On	Off	Off
13	12 - 1 pm	50	0	0	50	0	0	50	5	5	On	Off	Off
14	1 - 2 pm	95	0	0	100	0	0	90	5	5	On	Off	Off
15	2 - 3 pm	95	0	0	100	0	0	90	5	5	On	Off	Off
16	3 - 4 pm	95	0	0	100	0	0	90	5	5	On	Off	Off
17	4 -5 pm	95	0	0	100	0	0	90	5	5	On	Off	Off
18	5 - 6 pm	95	0	0	100	0	0	90	5	5	On	Off	Off
19	6 - 7 pm	50	0	0	100	0	0	50	5	5	On	Off	Off
20	7 - 8 pm	0	0	0	0	0	0	5	5	5	Off	Off	Off
21	8 - 9 pm	0	0	0	0	0	0	5	5	5	Off	Off	Off
22	9 - 10 pm	0	0	0	0	0	0	5	5	5	Off	Off	Off
23	10 - 11 pm	0	0	0	0	0	0	5	5	5	Off	Off	Off
24	11 - 12 pm	0	0	0	0	0	0	5	5	5	Off	Off	Off

The above schedules are to be adopted as the default profile of office building for the reference model and proposed model. Adjustment to the proposed model to account for the contributing factors from energy efficient systems or devices can be considered.

Table 3: Schedules for Restaurant and Retail in Office Building

Hour of Day/Time		Occupancy Schedule Percentage of Maximum load			Lighting Schedule Percentage of Maximum load			Receptacle Schedule Percentage of Maximum load			ACMV Schedule On/Off		
		Weekday	Sat	Sun	Weekday	Sat	Sun	Weekday	Sat	Sun	Weekday	Sat	Sun
1	12 - 1 am	0	0	0	0	0	0	10	10	10	Off	Off	Off
2	1 - 2 am	0	0	0	0	0	0	10	10	10	Off	Off	Off
3	2 - 3 am	0	0	0	0	0	0	10	10	10	Off	Off	Off
4	3 - 4 am	0	0	0	0	0	0	10	10	10	Off	Off	Off
5	4 - 5 am	0	0	0	0	0	0	10	10	10	Off	Off	Off
6	5 - 6 am	0	0	0	0	0	0	10	10	10	Off	Off	Off
7	6 - 7 am	0	0	0	0	0	0	10	10	10	Off	Off	Off
8	7 - 8 am	0	0	0	0	0	0	10	10	10	Off	Off	Off
9	8 - 9 am	0	0	0	0	0	0	10	10	10	Off	Off	Off
10	9 - 10 am	0	0	0	0	0	0	10	10	10	Off	Off	Off
11	10 - 11am	50	0	0	100	0	0	100	10	10	On	Off	Off
12	11 - 12 pm	90	0	0	100	0	0	100	10	10	On	Off	Off
13	12 - 1 pm	90	0	0	100	0	0	100	10	10	On	Off	Off
14	1 - 2 pm	50	0	0	100	0	0	100	10	10	On	Off	Off
15	2 - 3 pm	50	0	0	100	0	0	100	10	10	On	Off	Off
16	3 - 4 pm	50	0	0	100	0	0	100	10	10	On	Off	Off
17	4 - 5 pm	50	0	0	100	0	0	100	10	10	On	Off	Off
18	5 - 6 pm	50	0	0	100	0	0	100	10	10	On	Off	Off
19	6 - 7 pm	90	0	0	100	0	0	100	10	10	On	Off	Off
20	7 - 8 pm	90	0	0	100	0	0	100	10	10	On	Off	Off
21	8 - 9 pm	50	0	0	100	0	0	100	10	10	On	Off	Off
22	9 - 10 pm	20	0	0	100	0	0S	100	10	10	On	Off	Off
23	10 - 11 pm	0	0	0	0	0	0	10	10	10	Off	Off	Off
24	11 - 12 pm	0	0	0	0	0	0	10	10	10	Off	Off	Off

The above schedules are to be adopted as the default profile of Restaurant and Retail for the reference model and proposed model. Except for lighting provision, adjustment to the proposed model can be made to account for the contributing factors from energy efficient systems or devices.

Note that the proposed receptacle load density for these spaces must be reasonably expected. For energy modelling, the receptacle load density for the reference model and proposed model shall be the same.

Table 4: Schedules for Canteen, Staff Canteen, Food court, Café and Pantry in Office Building

Hour of Day/Time		Occupancy Schedule Percentage of Maximum load			Lighting Schedule Percentage of Maximum load			Receptacle Schedule Percentage of Maximum load			ACMV Schedule On/Off		
		Weekday	Sat	Sun	Weekday	Sat	Sun	Weekday	Sat	Sun	Weekday	Sat	Sun
1	12 - 1 am	0	0	0	0	0	0	10	10	10	Off	Off	Off
2	1 - 2 am	0	0	0	0	0	0	10	10	10	Off	Off	Off
3	2 - 3 am	0	0	0	0	0	0	10	10	10	Off	Off	Off
4	3 - 4 am	0	0	0	0	0	0	10	10	10	Off	Off	Off
5	4 - 5 am	0	0	0	0	0	0	10	10	10	Off	Off	Off
6	5 - 6 am	0	0	0	0	0	0	10	10	10	Off	Off	Off
7	6 - 7 am	0	0	0	0	0	0	10	10	10	Off	Off	Off
8	7 - 8 am	20	0	0	100	0	0	100	10	10	On	Off	Off
9	8 - 9 am	50	0	0	100	0	0	100	10	10	On	Off	Off
10	9 - 10 am	40	0	0	100	0	0	100	10	10	On	Off	Off
11	10 - 11am	50	0	0	100	0	0	100	10	10	On	Off	Off
12	11 - 12 pm	90	0	0	100	0	0	100	10	10	On	Off	Off
13	12 - 1 pm	90	0	0	100	0	0	100	10	10	On	Off	Off
14	1 - 2 pm	80	0	0	100	0	0	100	10	10	On	Off	Off
15	2 - 3 pm	50	0	0	100	0	0	100	10	10	On	Off	Off
16	3 - 4 pm	50	0	0	100	0	0	100	10	10	On	Off	Off
17	4 - 5 pm	20	0	0	100	0	0	100	10	10	On	Off	Off
18	5 - 6 pm	50	0	0	100	0	0	100	10	10	On	Off	Off
19	6 - 7 pm	80	0	0	100	0	0	100	10	10	On	Off	Off
20	7 - 8 pm	60	0	0	100	0	0	100	10	10	On	Off	Off
21	8 - 9 pm	20	0	0	100	0	0	10	10	10	Off	Off	Off
22	9 - 10 pm	0	0	0	0	0	0	10	10	10	Off	Off	Off
23	10 - 11 pm	0	0	0	0	0	0	10	10	10	Off	Off	Off
24	11 - 12 pm	0	0	0	0	0	0	10	10	10	Off	Off	Off

The above schedules are to be adopted as the default profile of Canteen, Staff Canteen, Food court, Café and Pantry for reference model and proposed model. Except for lighting provision, adjustment to the proposed model can be made to account for the contributing factors from energy efficient systems or devices.

Note that the proposed receptacle load density for these spaces must be reasonably expected. For energy modelling, the receptacle load density for the reference model and proposed model shall be the same.

Table 5: Schedules for Main Lobby in Office Building

Hour of Day/Time		Occupancy Schedule Percentage of Maximum load			Lighting Schedule Percentage of Maximum load			Receptacle Schedule Percentage of Maximum load			ACMV Schedule On/Off		
		Weekday	Sat	Sun	Weekday	Sat	Sun	Weekday	Sat	Sun	Weekday	Sat	Sun
1	12 - 1 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
2	1 - 2 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
3	2 - 3 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
4	3 - 4 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
5	4 - 5 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
6	5 - 6 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
7	6 - 7 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
8	7 - 8 am	100	0	0	100	0	0	100	0	0	On	Off	Off
9	8 - 9 am	100	0	0	100	0	0	100	0	0	On	Off	Off
10	9 - 10 am	100	0	0	100	0	0	100	0	0	On	Off	Off
11	10 - 11am	100	0	0	100	0	0	100	0	0	On	Off	Off
12	11 - 12 pm	100	0	0	100	0	0	100	0	0	On	Off	Off
13	12 - 1 pm	100	0	0	100	0	0	100	0	0	On	Off	Off
14	1 - 2 pm	100	0	0	100	0	0	100	0	0	On	Off	Off
15	2 - 3 pm	100	0	0	100	0	0	100	0	0	On	Off	Off
16	3 - 4 pm	100	0	0	100	0	0	100	0	0	On	Off	Off
17	4 -5 pm	100	0	0	100	0	0	100	0	0	On	Off	Off
18	5 - 6 pm	100	0	0	100	0	0	100	0	0	On	Off	Off
19	6 - 7 pm	100	0	0	100	0	0	100	0	0	On	Off	Off
20	7 - 8 pm	0	0	0	100	0	0	0	0	0	Off	Off	Off
21	8 - 9 pm	0	0	0	100	0	0	0	0	0	Off	Off	Off
22	9 - 10 pm	0	0	0	100	0	0	0	0	0	Off	Off	Off
23	10 - 11 pm	0	0	0	0	0	0	0	0	0	Off	Off	Off
24	11 - 12 pm	0	0	0	0	0	0	0	0	0	Off	Off	Off

The above schedules are to be adopted as default profile of Main Lobby for the reference model and proposed model. Adjustment to the proposed model to account for the contributing factors from energy efficient systems or devices can be considered.

Table 6: Schedules for Toilet, Common Corridor in Office Building

Hour of Day/Time		Occupancy Schedule Percentage of Maximum load			Lighting Schedule Percentage of Maximum load			Receptacle Schedule Percentage of Maximum load			ACMV Schedule On/Off		
		Weekday	Sat	Sun	Weekday	Sat	Sun	Weekday	Sat	Sun	Weekday	Sat	Sun
1	12 - 1 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
2	1 - 2 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
3	2 - 3 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
4	3 - 4 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
5	4 - 5 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
6	5 - 6 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
7	6 - 7 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
8	7 - 8 am	0	0	0	100	0	0	0	0	0	On	Off	Off
9	8 - 9 am	0	0	0	100	0	0	0	0	0	On	Off	Off
10	9 - 10 am	0	0	0	100	0	0	0	0	0	On	Off	Off
11	10 - 11am	0	0	0	100	0	0	0	0	0	On	Off	Off
12	11 - 12 pm	0	0	0	100	0	0	0	0	0	On	Off	Off
13	12 - 1 pm	0	0	0	100	0	0	0	0	0	On	Off	Off
14	1 - 2 pm	0	0	0	100	0	0	0	0	0	On	Off	Off
15	2 - 3 pm	0	0	0	100	0	0	0	0	0	On	Off	Off
16	3 - 4 pm	0	0	0	100	0	0	0	0	0	On	Off	Off
17	4 - 5 pm	0	0	0	100	0	0	0	0	0	On	Off	Off
18	5 - 6 pm	0	0	0	100	0	0	0	0	0	On	Off	Off
19	6 - 7 pm	0	0	0	100	0	0	0	0	0	On	Off	Off
20	7 - 8 pm	0	0	0	0	0	0	0	0	0	Off	Off	Off
21	8 - 9 pm	0	0	0	0	0	0	0	0	0	Off	Off	Off
22	9 - 10 pm	0	0	0	0	0	0	0	0	0	Off	Off	Off
23	10 - 11 pm	0	0	0	0	0	0	0	0	0	Off	Off	Off
24	11 - 12 pm	0	0	0	0	0	0	0	0	0	Off	Off	Off

The above schedules are to be adopted as default profile for Toilet, Common Corridor for the reference model and proposed model. Adjustment to the proposed model to account for the contributing factors from energy efficient systems or devices can be considered.

Table 7: Schedules for Server room and Computer Room in Office Building

Hour of Day/Time		Occupancy Schedule Percentage of Maximum load			Lighting Schedule Percentage of Maximum load			Receptacle Schedule Percentage of Maximum load			ACMV Schedule On/Off		
		Weekday	Sat	Sun	Weekday	Sat	Sun	Weekday	Sat	Sun	Weekday	Sat	Sun
1	12 - 1 am	0	0	0	0	0	0	100	100	100	On	On	On
2	1 - 2 am	0	0	0	0	0	0	100	100	100	On	On	On
3	2 - 3 am	0	0	0	0	0	0	100	100	100	On	On	On
4	3 - 4 am	0	0	0	0	0	0	100	100	100	On	On	On
5	4 - 5 am	0	0	0	0	0	0	100	100	100	On	On	On
6	5 - 6 am	0	0	0	0	0	0	100	100	100	On	On	On
7	6 - 7 am	0	0	0	0	0	0	100	100	100	On	On	On
8	7 - 8 am	0	0	0	0	0	0	100	100	100	On	On	On
9	8 - 9 am	0	0	0	0	0	0	100	100	100	On	On	On
10	9 - 10 am	0	0	0	0	0	0	100	100	100	On	On	On
11	10 - 11am	0	0	0	0	0	0	100	100	100	On	On	On
12	11 - 12 pm	0	0	0	0	0	0	100	100	100	On	On	On
13	12 - 1 pm	0	0	0	0	0	0	100	100	100	On	On	On
14	1 - 2 pm	0	0	0	0	0	0	100	100	100	On	On	On
15	2 - 3 pm	0	0	0	0	0	0	100	100	100	On	On	On
16	3 - 4 pm	0	0	0	0	0	0	100	100	100	On	On	On
17	4 - 5 pm	0	0	0	0	0	0	100	100	100	On	On	On
18	5 - 6 pm	0	0	0	0	0	0	100	100	100	On	On	On
19	6 - 7 pm	0	0	0	0	0	0	100	100	100	On	On	On
20	7 - 8 pm	0	0	0	0	0	0	100	100	100	On	On	On
21	8 - 9 pm	0	0	0	0	0	0	100	100	100	On	On	On
22	9 - 10 pm	0	0	0	0	0	0	100	100	100	On	On	On
23	10 - 11 pm	0	0	0	0	0	0	100	100	100	On	On	On
24	11 - 12 pm	0	0	0	0	0	0	100	100	100	On	On	On

The above schedules are to be adopted as default profile of Server room and Computer Room for the reference model and proposed model. Adjustment to the proposed model to account for the contributing factors from energy efficient systems or devices can be considered.

Note that the proposed receptacle load density for these spaces must be reasonably expected. The receptacle load density for the reference model and proposed model shall be the same for modelling.

Table 8: Schedules for FCC room or Security room in Office Building

Hour of Day/Time		Occupancy Schedule Percentage of Maximum load			Lighting Schedule Percentage of Maximum load			Receptacle Schedule Percentage of Maximum load			ACMV Schedule On/Off		
		Weekday	Sat	Sun	Weekday	Sat	Sun	Weekday	Sat	Sun	Weekday	Sat	Sun
1	12 - 1 am	100	100	100	100	100	100	100	100	100	On	On	On
2	1 - 2 am	100	100	100	100	100	100	100	100	100	On	On	On
3	2 - 3 am	100	100	100	100	100	100	100	100	100	On	On	On
4	3 - 4 am	100	100	100	100	100	100	100	100	100	On	On	On
5	4 - 5 am	100	100	100	100	100	100	100	100	100	On	On	On
6	5 - 6 am	100	100	100	100	100	100	100	100	100	On	On	On
7	6 - 7 am	100	100	100	100	100	100	100	100	100	On	On	On
8	7 - 8 am	100	100	100	100	100	100	100	100	100	On	On	On
9	8 - 9 am	100	100	100	100	100	100	100	100	100	On	On	On
10	9 - 10 am	100	100	100	100	100	100	100	100	100	On	On	On
11	10 - 11am	100	100	100	100	100	100	100	100	100	On	On	On
12	11 - 12 pm	100	100	100	100	100	100	100	100	100	On	On	On
13	12 - 1 pm	100	100	100	100	100	100	100	100	100	On	On	On
14	1 - 2 pm	100	100	100	100	100	100	100	100	100	On	On	On
15	2 - 3 pm	100	100	100	100	100	100	100	100	100	On	On	On
16	3 - 4 pm	100	100	100	100	100	100	100	100	100	On	On	On
17	4 - 5 pm	100	100	100	100	100	100	100	100	100	On	On	On
18	5 - 6 pm	100	100	100	100	100	100	100	100	100	On	On	On
19	6 - 7 pm	100	100	100	100	100	100	100	100	100	On	On	On
20	7 - 8 pm	100	100	100	100	100	100	100	100	100	On	On	On
21	8 - 9 pm	100	100	100	100	100	100	100	100	100	On	On	On
22	9 - 10 pm	100	100	100	100	100	100	100	100	100	On	On	On
23	10 - 11 pm	100	100	100	100	100	100	100	100	100	On	On	On
24	11 - 12 pm	100	100	100	100	100	100	100	100	100	On	On	On

The above schedules are to be adopted as the default profile of FCC room or Security room for the reference model and proposed model. Except for lighting provision, adjustment to the proposed model can be made to account for the contributing factors from energy efficient systems or devices.

Note that the proposed receptacle load density for these spaces must be reasonably expected. The receptacle load density for the reference model and proposed model shall be the same for modelling.

Table 9: Schedules for Storeroom, Storage room and Plant room in Office Building

Hour of Day/Time		Occupancy Schedule Percentage of Maximum load			Lighting Schedule Percentage of Maximum load			Receptacle Schedule Percentage of Maximum load			ACMV Schedule On/Off		
		Weekday	Sat	Sun	Weekday	Sat	Sun	Weekday	Sat	Sun	Weekday	Sat	Sun
1	12 - 1 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
2	1 - 2 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
3	2 - 3 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
4	3 - 4 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
5	4 - 5 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
6	5 - 6 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
7	6 - 7 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
8	7 - 8 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
9	8 - 9 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
10	9 - 10 am	0	0	0	0	0	0	0	0	0	Off	Off	Off
11	10 - 11am	0	0	0	0	0	0	0	0	0	Off	Off	Off
12	11 - 12 pm	0	0	0	0	0	0	0	0	0	Off	Off	Off
13	12 - 1 pm	0	0	0	0	0	0	0	0	0	Off	Off	Off
14	1 - 2 pm	100	0	0	100	0	0	0	0	0	On	On	On
15	2 - 3 pm	100	0	0	100	0	0	0	0	0	On	On	On
16	3 - 4 pm	0	0	0	0	0	0	0	0	0	Off	Off	Off
17	4 - 5 pm	0	0	0	0	0	0	0	0	0	Off	Off	Off
18	5 - 6 pm	0	0	0	0	0	0	0	0	0	Off	Off	Off
19	6 - 7 pm	0	0	0	0	0	0	0	0	0	Off	Off	Off
20	7 - 8 pm	0	0	0	0	0	0	0	0	0	Off	Off	Off
21	8 - 9 pm	0	0	0	0	0	0	0	0	0	Off	Off	Off
22	9 - 10 pm	0	0	0	0	0	0	0	0	0	Off	Off	Off
23	10 - 11 pm	0	0	0	0	0	0	0	0	0	Off	Off	Off
24	11 - 12 pm	0	0	0	0	0	0	0	0	0	Off	Off	Off

The above schedules are to be adopted as the default profile of Storeroom, Storage room and Plant room for the reference model and proposed model. Except for lighting provision, adjustment to the proposed model can be made to account for the contributing factors from energy efficient systems or devices.

Table 10: Schedules for Car Park Lighting and Car Park Mechanical Ventilation System in Office Building

Hour of Day/Time		Lighting Schedule Percentage of Maximum load			Receptacle Schedule Percentage of Maximum load			ACMV Schedule Percentage of Maximum Power			MV Schedule Percentage of Maximum Power (With CO Sensors)		
		Weekday	Sat	Sun	Weekday	Sat	Sun	Weekday	Sat	Sun	Weekday	Sat	Sun
1	12 - 1 am	50	50	50	0	0	50	100	100	100	50	50	50
2	1 - 2 am	50	50	50	0	0	50	100	100	100	50	50	50
3	2 - 3 am	50	50	50	0	0	50	100	100	100	50	50	50
4	3 - 4 am	50	50	50	0	0	50	100	100	100	50	50	50
5	4 - 5 am	50	50	50	0	0	50	100	100	100	50	50	50
6	5 - 6 am	50	50	50	0	0	50	100	100	100	50	50	50
7	6 - 7 am	50	50	50	0	0	50	100	100	100	50	50	50
8	7 - 8 am	100	50	50	0	0	100	100	100	100	100	50	50
9	8 - 9 am	100	50	50	0	0	100	100	100	100	100	50	50
10	9 - 10 am	100	50	50	0	0	100	100	100	100	100	50	50
11	10 - 11am	100	50	50	0	0	100	100	100	100	100	50	50
12	11 - 12 pm	100	50	50	0	0	100	100	100	100	100	50	50
13	12 - 1 pm	100	50	50	0	0	100	100	100	100	100	50	50
14	1 - 2 pm	100	50	50	0	0	100	100	100	100	100	50	50
15	2 - 3 pm	100	50	50	0	0	100	100	100	100	100	50	50
16	3 - 4 pm	100	50	50	0	0	100	100	100	100	100	50	50
17	4 - 5 pm	100	50	50	0	0	100	100	100	100	100	50	50
18	5 - 6 pm	100	50	50	0	0	100	100	100	100	100	50	50
19	6 - 7 pm	100	50	50	0	0	100	100	100	100	100	50	50
20	7 - 8 pm	50	50	50	0	0	50	100	100	100	50	50	50
21	8 - 9 pm	50	50	50	0	0	50	100	100	100	50	50	50
22	9 - 10 pm	50	50	50	0	0	50	100	100	100	50	50	50
23	10 - 11 pm	50	50	50	0	0	50	100	100	100	50	50	50
24	11 - 12 pm	50	50	50	0	0	50	100	100	100	50	50	50

The above schedules are to be adopted as the default profile of Car Park Lighting and Mechanical Ventilation System of an office building for the reference model and proposed model. Except for jet fan provision, adjustment to the proposed model can be made to account for the contributing factors from energy efficient systems or devices.

Note that the MV schedule will be relevant to mechanical ventilation fans with CO sensors (supply and/or exhaust fans). It does not apply to jet fans system which would need to be in operation at 100%, 24/7 to ensure good air circulation within the car parks.

Table 11: Schedules for Escalator and Lift in Office Building

Hour of Day/Time		Escalator Schedule Percentage of Maximum load			Lift Schedule Percentage of Maximum load		
		Weekday	Sat	Sun	Weekday	Sat	Sun
1	12 - 1 am	0	0	0	0	0	0
2	1 - 2 am	0	0	0	0	0	0
3	2 - 3 am	0	0	0	0	0	0
4	3 - 4 am	0	0	0	0	0	0
5	4 - 5 am	0	0	0	0	0	0
6	5 - 6 am	0	0	0	0	0	0
7	6 - 7 am	0	0	0	0	0	0
8	7 - 8 am	100	0	0	35	0	0
9	8 - 9 am	100	0	0	69	0	0
10	9 - 10 am	100	0	0	43	0	0
11	10 - 11am	100	0	0	37	0	0
12	11 - 12 pm	100	0	0	43	0	0
13	12 - 1 pm	100	0	0	58	0	0
14	1 - 2 pm	100	0	0	48	0	0
15	2 - 3 pm	100	0	0	37	0	0
16	3 - 4 pm	100	0	0	37	0	0
17	4 -5 pm	100	0	0	46	0	0
18	5 - 6 pm	100	0	0	62	0	0
19	6 - 7 pm	100	0	0	20	0	0
20	7 - 8 pm	100	0	0	12	0	0
21	8 - 9 pm	0	0	0	0	0	0
22	9 - 10 pm	0	0	0	0	0	0
23	10 - 11 pm	0	0	0	0	0	0
24	11 - 12 pm	0	0	0	0	0	0

The above schedules are to be adopted as the default profile of Escalator and Lift operation for the reference model and proposed model. Adjustment to the proposed model can be made to account for the contributing factors from energy efficient systems or devices such as motion sensors, sleep mode, regenerative feature and the like.

## Appendix E

# Daylight Availability Tables and Methodology



# Daylight Availability Tables and Methodology

## E1 General

E1.1 In general, daylighting simulation should be carried out using computational modelling to quantify and demonstrate the availability of natural daylighting that could provide a proper and comfortable lighting level for building occupants. However, for buildings/spaces that come with standard designs and have the following building characteristics and urban parameters, the quality and availability of daylight can be quantified using the Daylight Availability Tables provided in this Appendix.

- (a) Spaces that are side lit and located adjacent to the vertical fenestration.
- (b) Spaces with typical room floor-to-ceiling heights between 2.5 m and 3.1 m.
- (c) Simple horizontal overhang shading devices or no shading devices adopted for vertical fenestration.
- (d) Relatively unobstructed by surrounding buildings and with average urban obstruction angles (AUOA)  $\leq 57.25^\circ$ . More explanation on the derivation of the AUOA can be found in para E3 of this Appendix.
- (e) The daylight availability tables were developed using the annual climate-based daylighting metrics and take into consideration potential visual discomfort in evaluating the effectiveness of daylighting in the local context. The following terms and requirements, which describe the lighting quality of building spaces will be of relevance.

E1.2 **Daylight Autonomy ( $DA_{Nlx,x\%}$ )** is a daylight availability metric that defines the percentage of the occupied hours of the year when the desired illuminance level can be provided by daylight alone. It is expressed as  $DA_{Nlx,x\%}$  where N lx represents the illuminance requirement in lux for a specific space and x% represents the percentage of occupied sunlit hours. For example, in the case of residential buildings, the daylight autonomy requirement set is  $DA_{200lx,50\%}$  which is translated to having 200 lux (or greater) of illuminance for 50% of the occupied sunlit hours (from 7:00 am to 10:00 am and from 4:00 pm to 7:00 pm) for a specific space of interest.

E1.3 **Useful Daylight Illuminance Exceeded ( $UDle_{3000lx,10\%}$ )** is a daylight availability metric that describes the frequency at which daylight illuminance levels exceed an acceptable daylight illuminance threshold of 3000 lux for more than 10% of occupied hours in a year.

E1.4 **Daylit area** refers to the floor area that is illuminated by sufficient daylight that meets the daylight autonomy requirement set for indoor spaces. For example, in the context of residential buildings, daylit areas refer to the floor areas where daylight autonomy,  $DA_{200lx,50\%}$  are met.

E1.5 **Overlit area** refers to the floor area that is illuminated by high levels of daylight that would potentially result in visual discomfort (glare) for occupants. In this requirement, the area of a space where daylight illuminance level is equal to or greater than 3000 lx for more than 10% of occupied hours in a year is denoted by  $UDle_{3000lx,10\%}$ , are considered overlit,

**Specific Daylight Autonomy Requirements** for the various types of occupied spaces are as follows:

S/N	Space Occupancy Type	Daylight Autonomy requirement	Occupied sunlit hours every day of the year for analysis
1	Offices and Institutional spaces	$DA_{500lx,50\%}$	8:00 am to 5:00 pm
2	Industrial, sports facilities, retail areas	$DA_{300lx,50\%}$	8:00 am to 5:00 pm
3	Hotel and residential style occupancy	$DA_{200lx,50\%}$	7:00 am to 10:00 pm 4:00 pm to 7:00 pm
4	Residential Buildings – Dwelling Units	$DA_{200lx,50\%}$	7:00 am to 10.00 am 4:00 pm to 7:00 pm

Note (1) – For all cases, the overlit areas with Useful Daylight Illuminance Exceeded (UDLe<sub>3000lx,10%</sub>) are to be accounted for in determining the quality of daylight provision.

Note (2) – As the DA<sub>Nlx</sub> and UDLe<sub>3000lx</sub> are defined as a percentage of occurrence over an occupied period of a building, this period must be explicitly defined and use for daylight analysis as stated in this table.

Note (3) – Daylight availability tables will not be applicable for buildings or spaces with unusual occupancy schedules.

## E2 Daylight Availability Tables and Methodology for Standard Designs

E2.1 The Daylight Availability tables were derived from more than 13,000 different combinations of building characteristics and urban parameters with a conglomeration of 4,000 simulated results using a reference shoebox model. The simulation results provided in these tables can be used to determine the effective daylighting for buildings/spaces with standard designs as highlighted in para E1.

E2.2 There are three (3) Daylight Availability tables for each space occupancy type. The specific Daylight Autonomy and respective occupied hours are as stipulated below:

Daylight Availability Table Reference	Space Occupancy Type	Daylight Autonomy requirement	Occupied sunlit hours
DT1-1 to DT1-3	Offices and Institutional spaces including schools	DA <sub>500lx,50%</sub>	8:00 am to 5:00 pm
DT2-1 to DT2-3	Industrial, Sports facilities, Retail areas	DA <sub>300lx,50%</sub>	8:00 am to 5:00 pm
DT3-1 to DT 3-3	Residential, Hotel and Service Apartments	DA <sub>200lx,50%</sub>	7:00 am to 10:00 pm 4:00 pm to 7:00 pm

E2.3 These tables provide information on the daylight availability expressed in term of the depth of the effective daylit areas (in blue shade) and highlights the areas that have potential risks of overlit (in red and pink shade). The daylight availability results shown in the table have considered the overlit areas with UDLe<sub>3000 lx, 10 %</sub> and if the percentage of these areas takes up more than 15% of the occupied spaces before deriving the effective daylit areas.

*In short,*

**Effective daylit areas** = Daylit areas with DA<sub>Nlx,50%</sub> - Overlit areas with UDLe<sub>3000 lx,10 %</sub>

*where the overlit areas must be less than 15% of the occupied spaces.*

### E2.4 Average Urban Obstructing Angle (AUOA)

The Average Urban Obstructing Angle (AUOA) describes the average portion of the sky blocked by surrounding obstructions such as neighbouring buildings. It can be determined by considering the height of the surrounding obstructions and the height of the specific floor level with reference to the ground level as well as the distance apart and can be expressed in the following formula.

$$AUOA = \arctan\left(\frac{H - h}{W}\right)$$

where

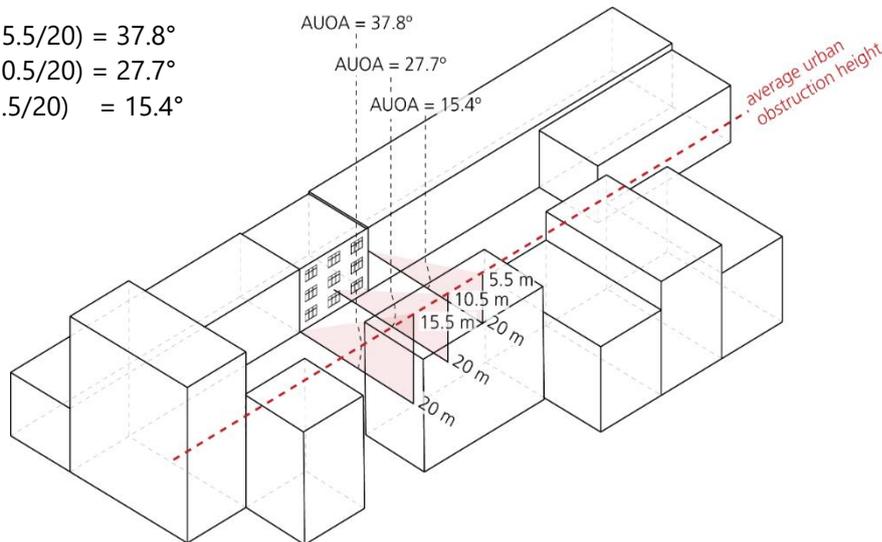
*H: Average urban height of the surrounding obstructions in meters measured from the ground*

*h: The height of the respective space's floor level above ground*

*W: Width of the street or the distance between the building and its surrounding obstructions.*

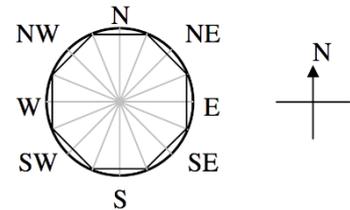
E2.5 The following diagram shows an example of the derivation of the average urban obstruction angle for three floors of a building. For example, based on the average urban obstruction height of 15.5 m, the building-to-building distance of 20 m with respect to the height of the respective floor level above ground, the AUOA is 37.8° and so forth. Spaces with AUOA of more than 57.25° are not likely to have quality daylighting and hence, there is no daylight availability table for such spaces. Other than AUOA, there are four other parameters that are important and pertinent before the Daylight Availability Tables can be used to determine the depth of the daylight areas and as listed in para E2.6 to E2.9.

$$\begin{aligned} \text{AUOA} &= \arctan (15.5/20) = 37.8^\circ \\ \text{AUOA} &= \arctan (10.5/20) = 27.7^\circ \\ \text{AUOA} &= \arctan (5.5/20) = 15.4^\circ \end{aligned}$$



**E2.6 Orientation** (refers to vertical axis on the right-hand side of daylight availability table)

The daylight availability expressed in terms of the depth of the daylit areas is grouped based on the eight (8) major cardinal directions in which the façade is orientated. The selection of the façade orientation should be within 11.25° of the given orientation shown in the tables.



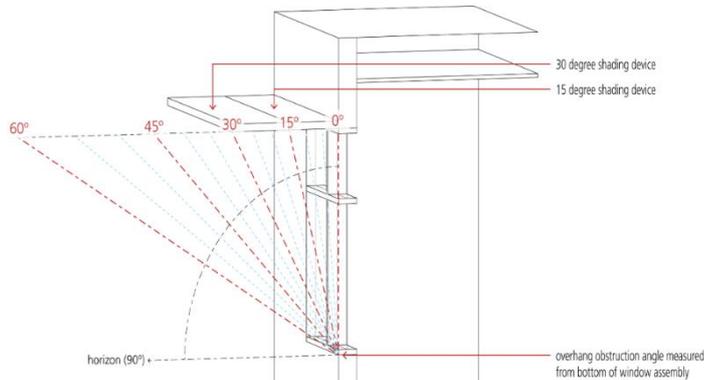
**E2.7 Overhang Obstruction Angle (OOA)** (refers to horizontal axis on the top of daylight availability table)

The OOA is the angle describing the portion of the sky blocked by a horizontal overhang. The angle is measured from the bottom of the window assembly, i.e. from the zenith (directly overhead) to the outside edge of the shading device.

$$\text{OOA} = \arctan \left( \frac{H_w}{P} \right)$$

$H_w$  is the height of the windows of the space, while  $P$  is the length of the shading device.

The diagram below depicts the measurement of the overhang obstruction angle from the bottom of window sill:



Within each table, the daylight availability results are broadly classified by the Overhang Obstruction Angle (OOA) in three groupings that are 0°, 15° and 30°. The selection of the OOA will be based on the nearest value to the OOA of the overhang design.

### E2.8 Visible Light Transmittance ( $T_{vis}$ ) (refers to vertical axis on the left-hand side of daylight availability table)

Visible light transmittance ( $T_{vis}$ ) is the percentage of visible light that passes through a glazing surface such as a window at normal incidence. A higher value of  $T_{vis}$  represents greater visible light transmittance. There are six (6) options of Visible Light Transmittance ( $T_{vis}$ ) for selection (that is 25%, 35%, 45%, 55%, 65% and 75%). In general, the  $T_{vis}$  can be obtained from the glazing specification and the selection of  $T_{vis}$  would be based on the nearest value to the specification or design intent.

### E2.9 Window-to-Wall Ratio (refers to horizontal axis at the bottom of daylight availability table)

Window-to-wall Ratio (WWR) in this context is the percentage of glazing areas relative to its exterior wall envelope areas.

$$WWR = \frac{\sum \text{Area of Glazing Panes}}{\text{Total Exterior Wall Envelope Areas}} \times 100$$

There is a list of 10 WWRs included in the Daylight Availability Tables (that is 10%, 20%, 26%, 32%, 39%, 43%, 52%, 60%, 70%, and 87%). The selection of WWR would be based on the nearest value to the designed WWR from this list.

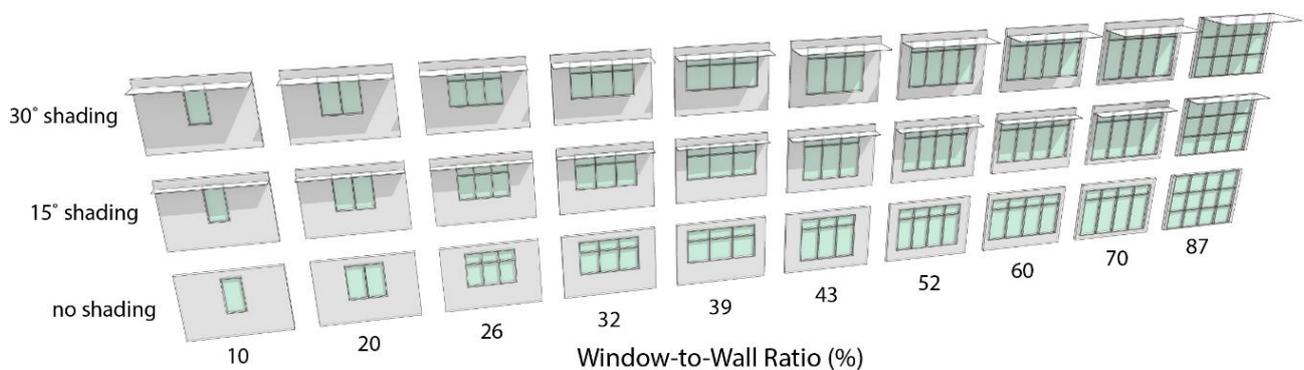


Illustration of the façade geometric parameters of various WWR and Shading provision with the respective OOA

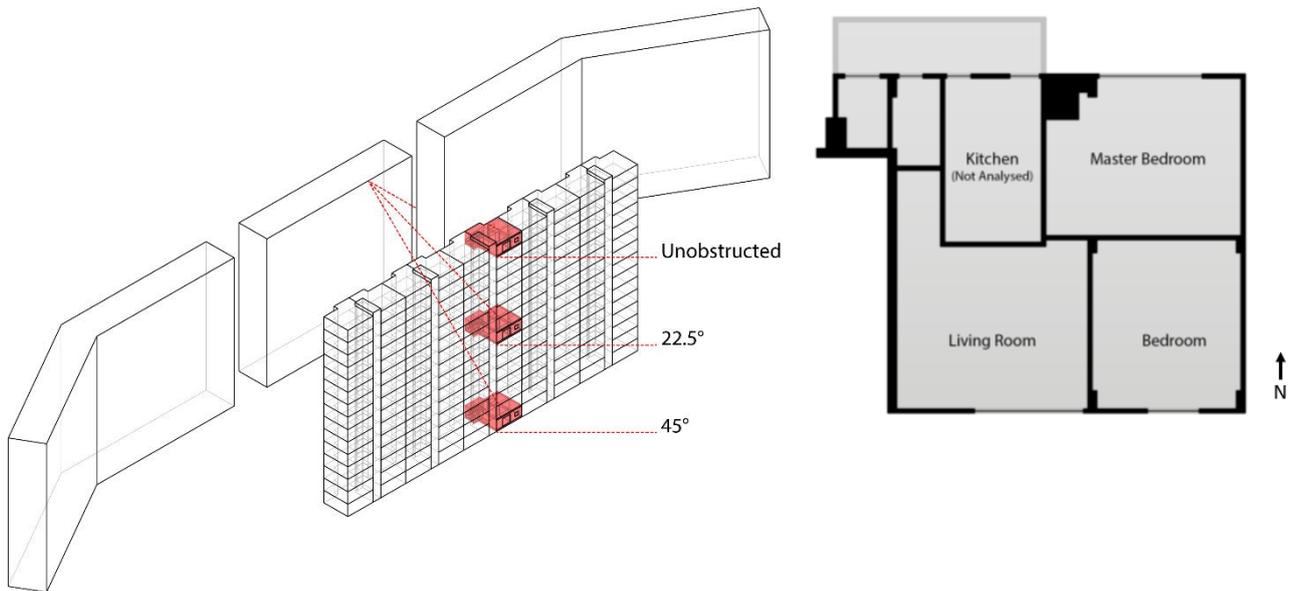
## E3 Guidance and Limitation on the Use of Daylight Availability Tables

While the Daylight Availability tables can help eliminate the need for daylight simulations for standard designs, there are limitations that should be considered and are as follows:

- **Potential underestimation of the daylighting provision in spaces with more than one glazed façade or window openings** - As the daylight availability tables document only the daylit area for single-sided lit spaces, there would be added daylighting sources which are not accounted for. In such a situation, there would be a need to consider daylight availability by way of daylighting simulation to ensure proper and comfortable lighting levels for building occupants. For spaces that are located adjacent to two glazed facades abutting at corners, the daylight availability for such spaces could be discounted for simplicity.
- **Applicability limited to stipulated floor-to-ceiling heights** - As the daylight availability tables are derived based on the floor-to-ceiling height of spaces that are within 2.5 m - 3.1m, these tables would not be suitable means in determining effective daylighting if the floor-to-ceiling height is not within the stipulated range.

## Worked Example for Residential Building Development

Proposed residential development with one block of 15-storey residential apartments with sky obstruction from neighbouring building at its south-facing façade. The typical floor layout of the apartment units is as shown below.



In this instance, the Daylight Availability Tables can be used as the respective sky obstructions posed by neighbouring buildings fall within the limit (i.e. the AUOA is 57.25). Three (3) unit types representing the different urban contexts are selected for analysis.

In summary,

Unit Type 1 can represent the units from Level 1 to 5 with Significant Obstruction Urban Context that is AUOA of 45° (i.e. ranging from 33.75° to 57.25°);

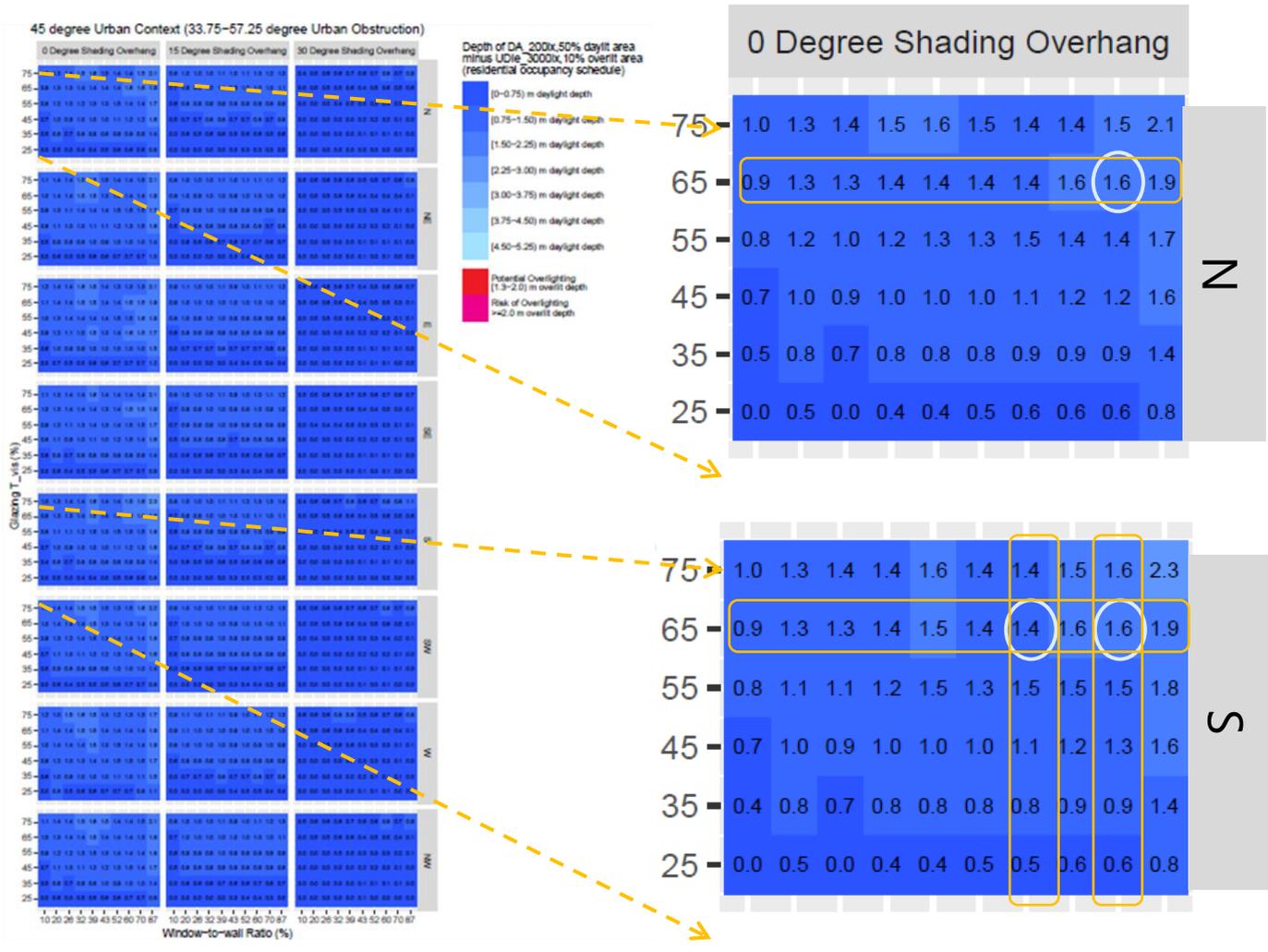
Unit Type 2 can represent the units from Level 6 to 10 with Moderate Obstruction Urban Context that is AUOA of 22.5° (i.e. ranging from 11.25° to < 33.75°); and

Unit Type 3 can represent the units from Level 11 to 15 which are Unobstructed Urban Context (i.e. ranging from 0° to < 11.25°).

Based on building and façade design, the key parameters of these typical units are as follows:

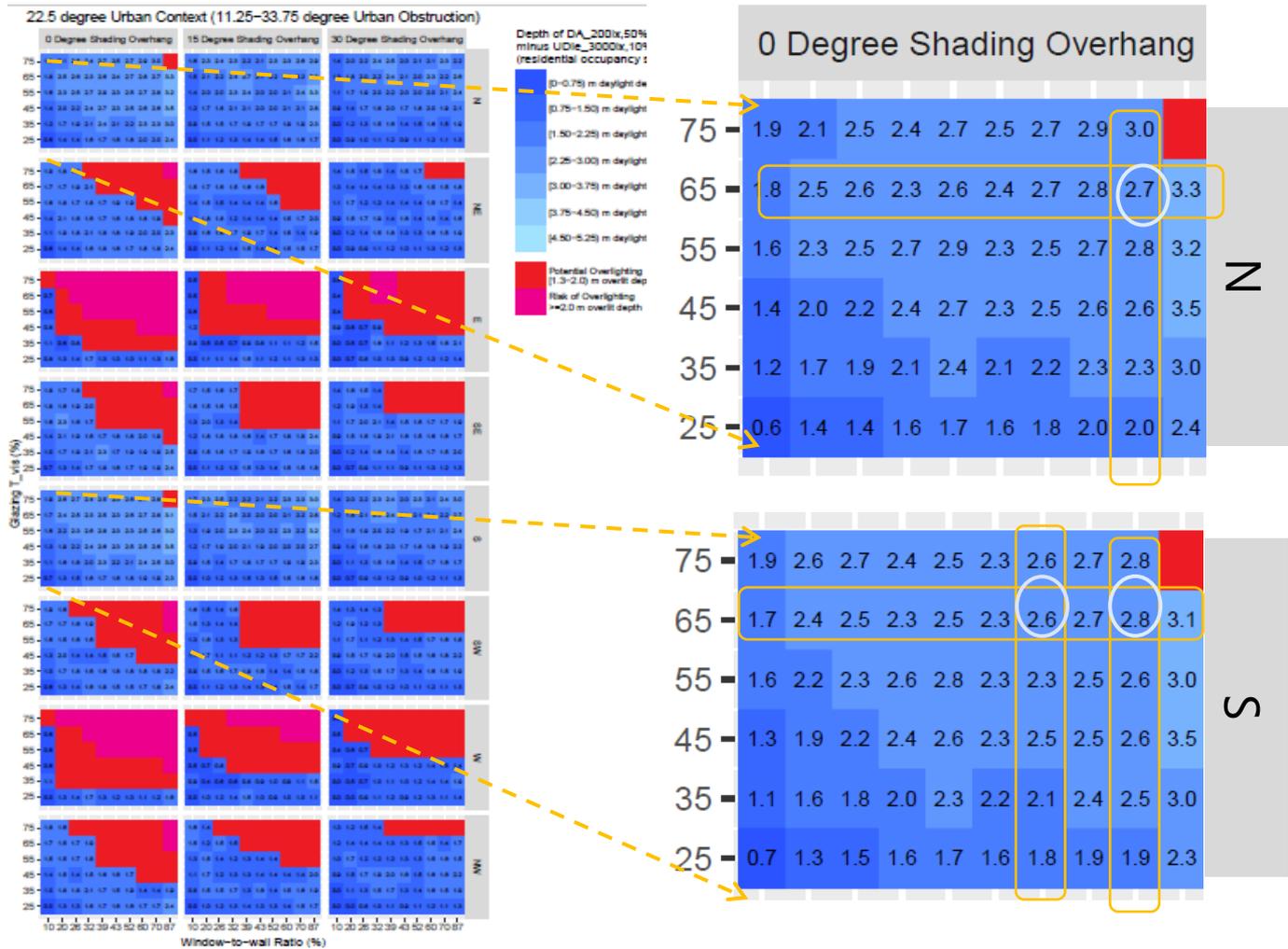
Habitable Spaces	Floor Areas (m <sup>2</sup> )	Room Width (m)	Orientation of Vertical Fenestration adjacent to the space	Overhang Obstruction Angle (OOA)	Visible Light Transmittance (T <sub>vis</sub> ) (%)	Window to Wall Ratio (WWR) (m <sup>2</sup> )
Master Bedroom	14.7	4.2	North-facing	0°	65	0.7
Living Room	16.4	4.1	South-facing	0°	65	0.7
Bedroom	11.2	3.2	South-facing	0°	65	0.5

(a) Unit Type 1 representing the Units from Level 1 to 5 with Significant Obstruction Urban Context that is AUOA of 45° (i.e. ranging from 33.75° to 57.25°), the depth of effective daylight areas can be derived from Daylight Availability Table DT3-3 as illustrated below:



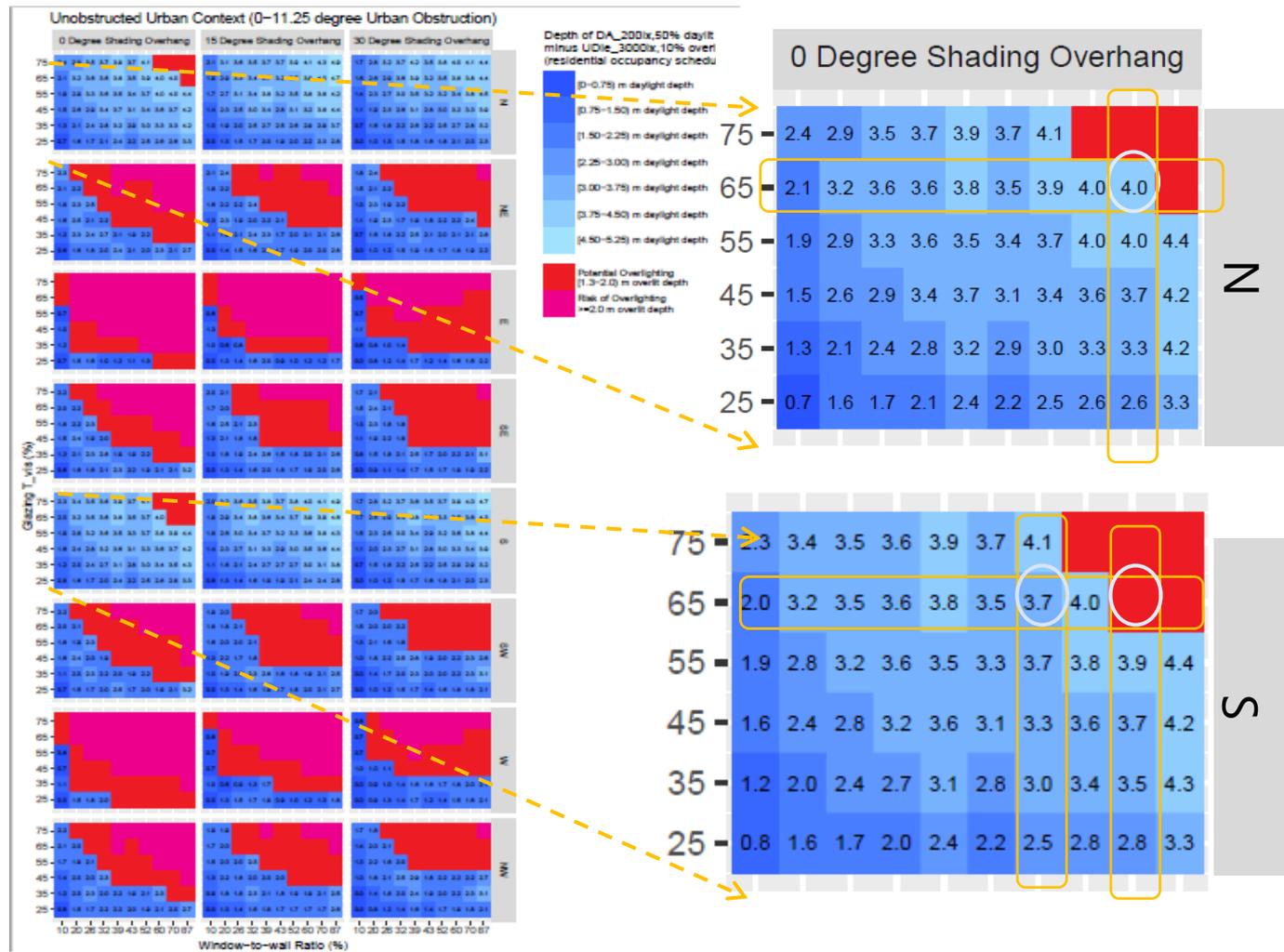
Unit Type 1 representing Level 1 to 5 (50 Units) (with Significant Obstruction Urban Context that is AUOA of 45° )				
Habitable Spaces	Floor Areas (m <sup>2</sup> )	Room Width (m <sup>2</sup> )	Depth of Effective Daylit Areas from Daylight Availability Table (m)	Effective Daylit Areas (m <sup>2</sup> )
Master Bedroom	14.7	4.2	1.6	6.7
Living Room	16.4	4.1	1.6	6.6
Bedroom	11.2	3.2	1.4	4.5
<b>Total Areas :</b>	<b>42.3</b>		<b>Total Effective Daylit areas:</b>	<b>17.8</b>
$\text{Total Daylit Area for each dwelling unit} = \frac{\text{DaylitArea}_{\text{Room1}} + \text{DaylitArea}_{\text{Room2}} + \dots + \text{DaylitArea}_{\text{RoomN}}}{\sum \text{FloorAreas of each dwelling}}$			Percentage of effective daylit areas: 42.1% < min 60% requirement	

(b) Unit Type 2 can represent the units from Level 6 to 10 with Moderate Obstruction Urban Context that is AUOA of 22.5° (i.e. ranging from 11.25° to < 33.75°), the depth of effective daylight areas can be derived from Daylight Availability Table DT3-2 as illustrated below.



Unit Type 2 representing Level 6 to 10 (50 Units) (with Moderate Obstruction Urban Context that is AUOA of 22.5° )				
Habitable Spaces	Floor Areas (m <sup>2</sup> )	Room Width (m <sup>2</sup> )	Depth of Effective Daylit Areas from Daylight Availability Table (m)	Effective Daylit Areas (m <sup>2</sup> )
Master Bedroom	14.7	4.2	2.7	11.3
Living Room	16.4	4.1	2.8	11.5
Bedroom	11.2	3.2	2.6	8.3
<b>Total Areas:</b>	<b>42.3</b>		<b>Total Effective Daylit areas:</b>	<b>31.1</b>
Percentage of effective daylit areas: 73.5% > min 60% requirement				

(c) Unit Type 3 representing the units at Level 11 to 15 that are relatively unobstructed, the depth of effective daylight areas can be derived from the Daylight Availability Table DT3-1 as illustrated below:



Unit Type 3 representing Level 11 to 15 (50 Units) (with Unobstructed Urban Context)				
Habitable Spaces	Floor Areas (m <sup>2</sup> )	Room Width (m <sup>2</sup> )	Depth of Effective Daylit Areas from Daylight Availability Table (m)	Effective Daylit Areas (m <sup>2</sup> )
Master Bedroom	14.7	4.2	4.0	16.8
Living Room	16.4	4.1	Not qualified as daylit areas as there is potential risks of overlit of more than 15% of room areas	0
Bedroom	11.2	3.2	3.7	11.8
<b>Total Areas :</b>	<b>42.3</b>		<b>Total Effective Daylit areas:</b>	<b>28.6</b>
Percentage of effective daylit areas: 67.6% > min 60% requirement				

Note that for residential building development, the effective daylight provision should at least cover 25% of the total number of dwelling units where 60% of the habitable spaces within these units are effective daylight.

In summary,

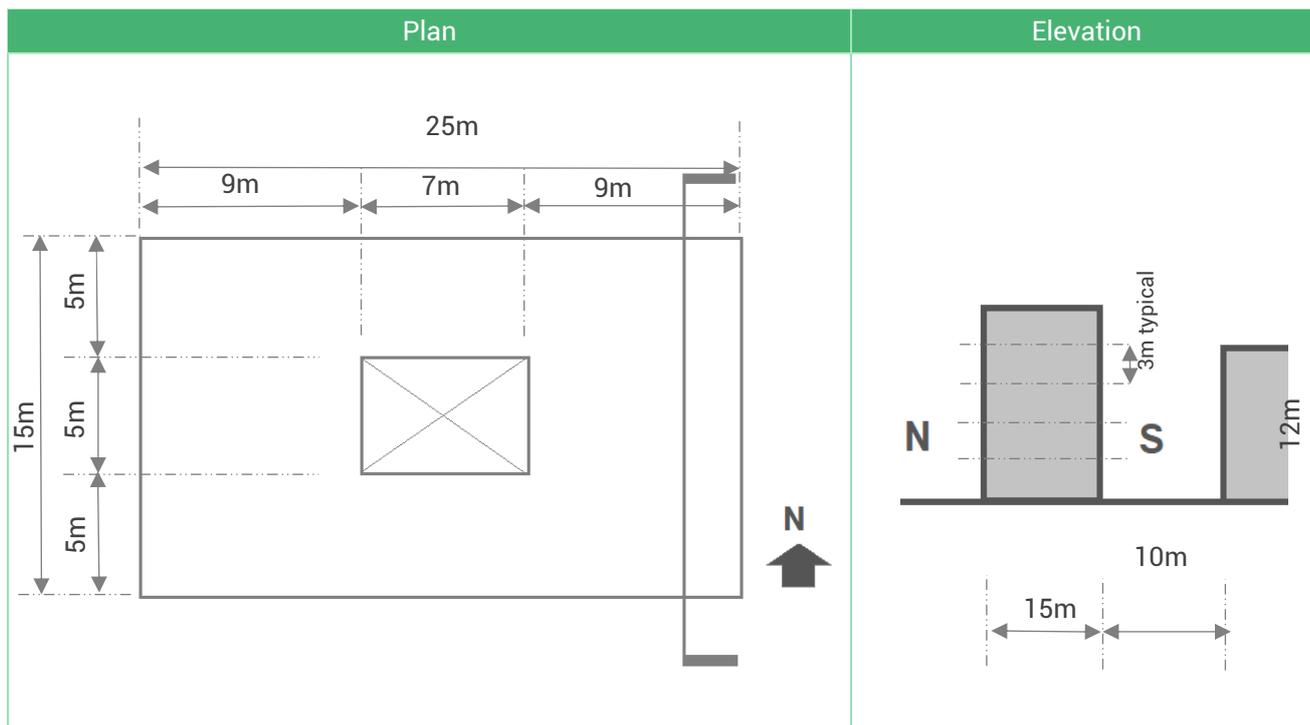
Unit Description	No. of Dwelling Units	% of effective daylight areas	No. of dwelling units with 60% of habitable spaces with effective daylighting
Unit Type 1 representing Level 1 to 5 <i>(with Significant Obstruction Urban Context that is AUOA of 45°)</i>	50	42.1% < min 60% requirement	0
Unit Type 2 representing Level 6 to 10 <i>(with Moderate Obstruction Urban Context that is AUOA of 22.5°)</i>	50	73.5% > min 60% requirement	50
Unit Type 3 representing Level 11 to 15 <i>(with Unobstructed Urban Context )</i>	50	67.6% > min 60% requirement	50
<b>Total</b>	<b>150</b>		<b>100</b>

Percentage of dwelling units with 60% of habitable spaces with effective daylighting =  $\frac{100 \text{ units}}{150 \text{ units}} = 66.7\% > 25\% \text{ min ok}$

### Worked Example for Non-Residential Building

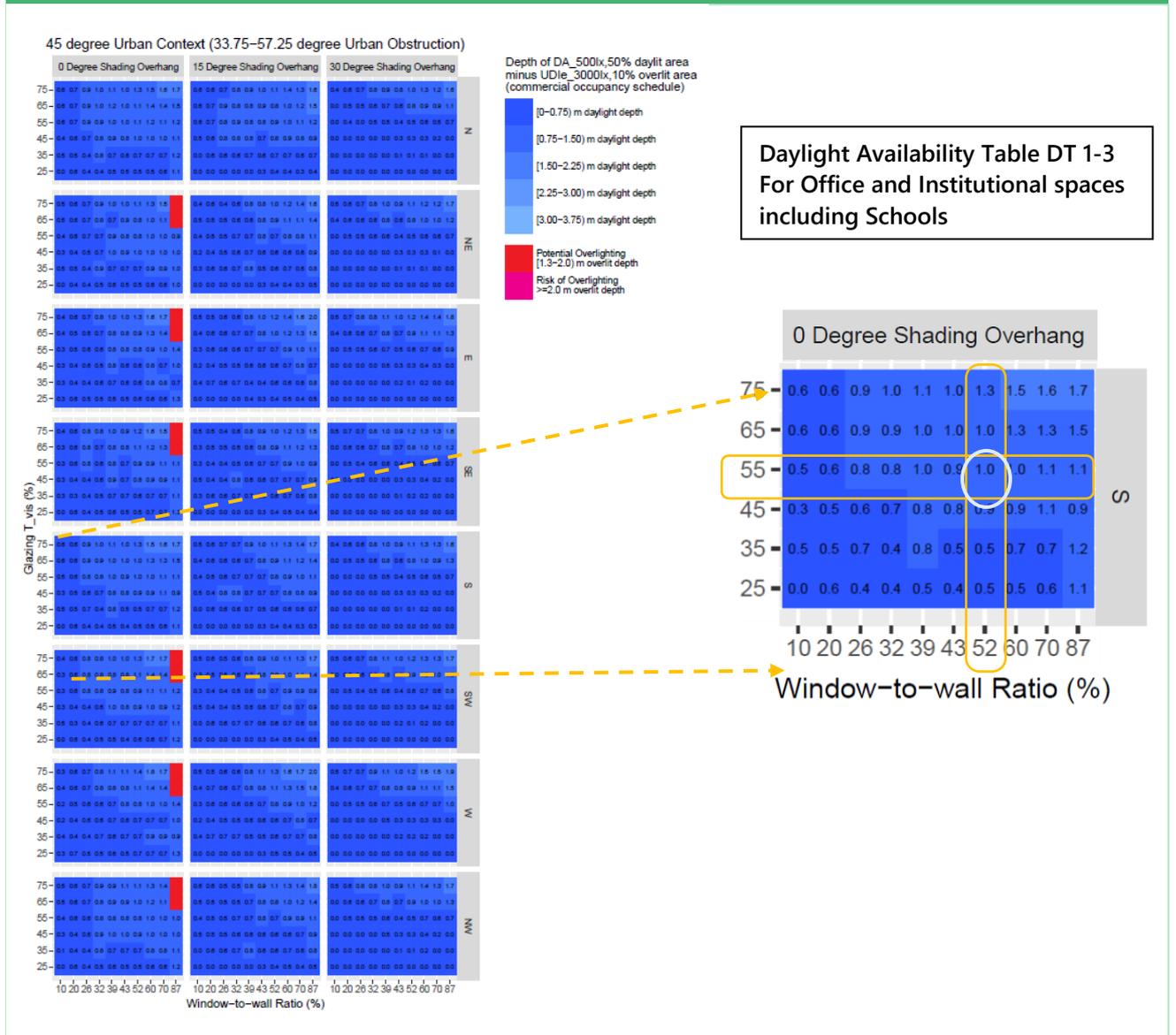
Proposed non-residential development with one block of 5-Storey office with sky obstruction from neighbouring building at its south-facing façade. The simplified elevation, typical floor layout and façade design parameters of the office are as shown below.

In this example, daylight from the air well and non-applicable area are excluded for simplicity.

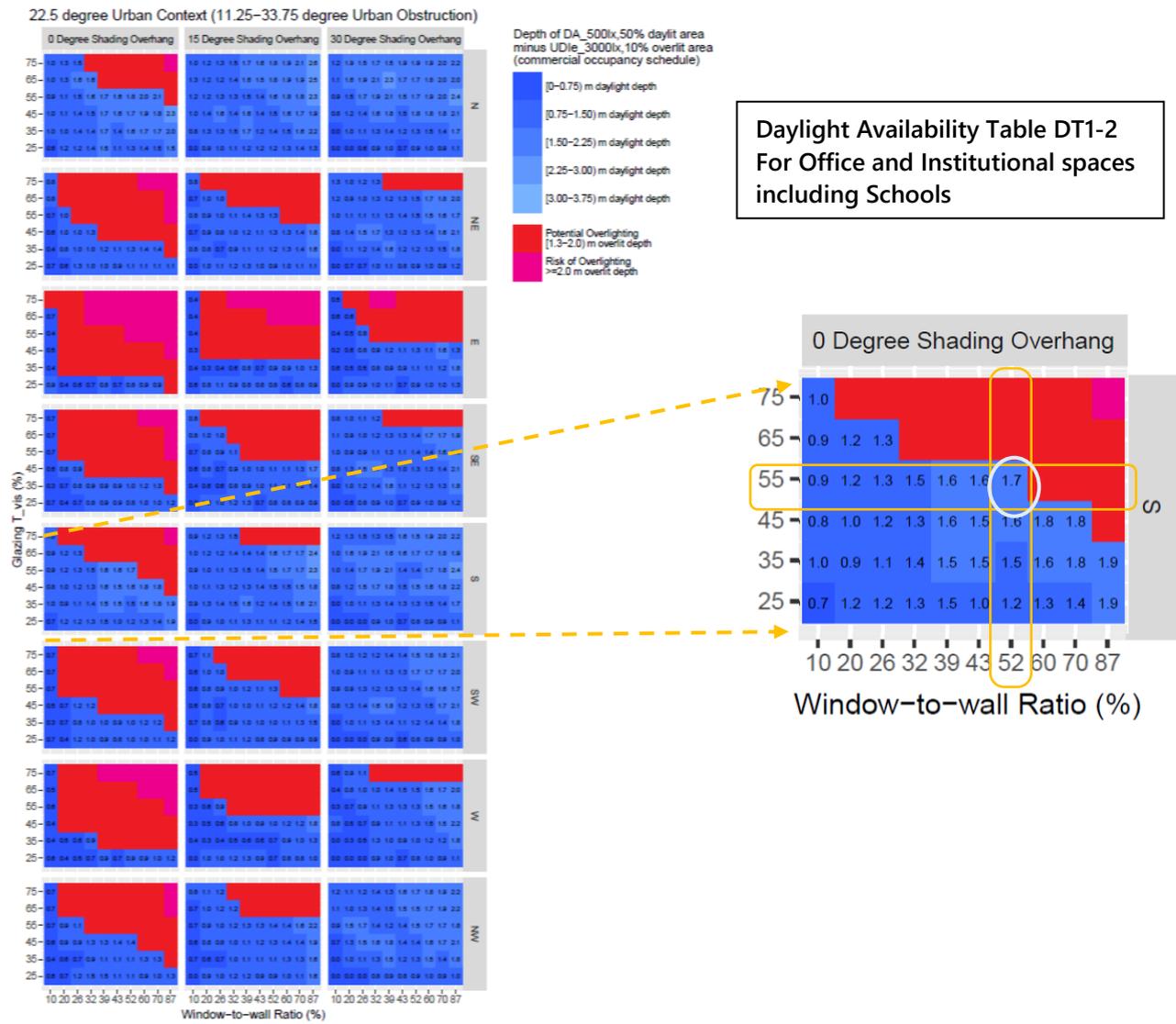


Level	Orientation of Vertical Fenestration	Overhang Obstruction Angle (OOA)	Visible Light Transmittance (Tvis) (%)	Window to Wall Ratio (WWR) (%)	Obstruction angle from adjoining block
1	South	0	55	52	50
2	South	0	55	52	42
3	South	0	55	52	31
4	South	0	55	52	17
5	South	0	55	52	0
1 to 5	North	15	55	52	0
1 to 5	East	15	55	10	0
1 to 5	West	15	45	20	0

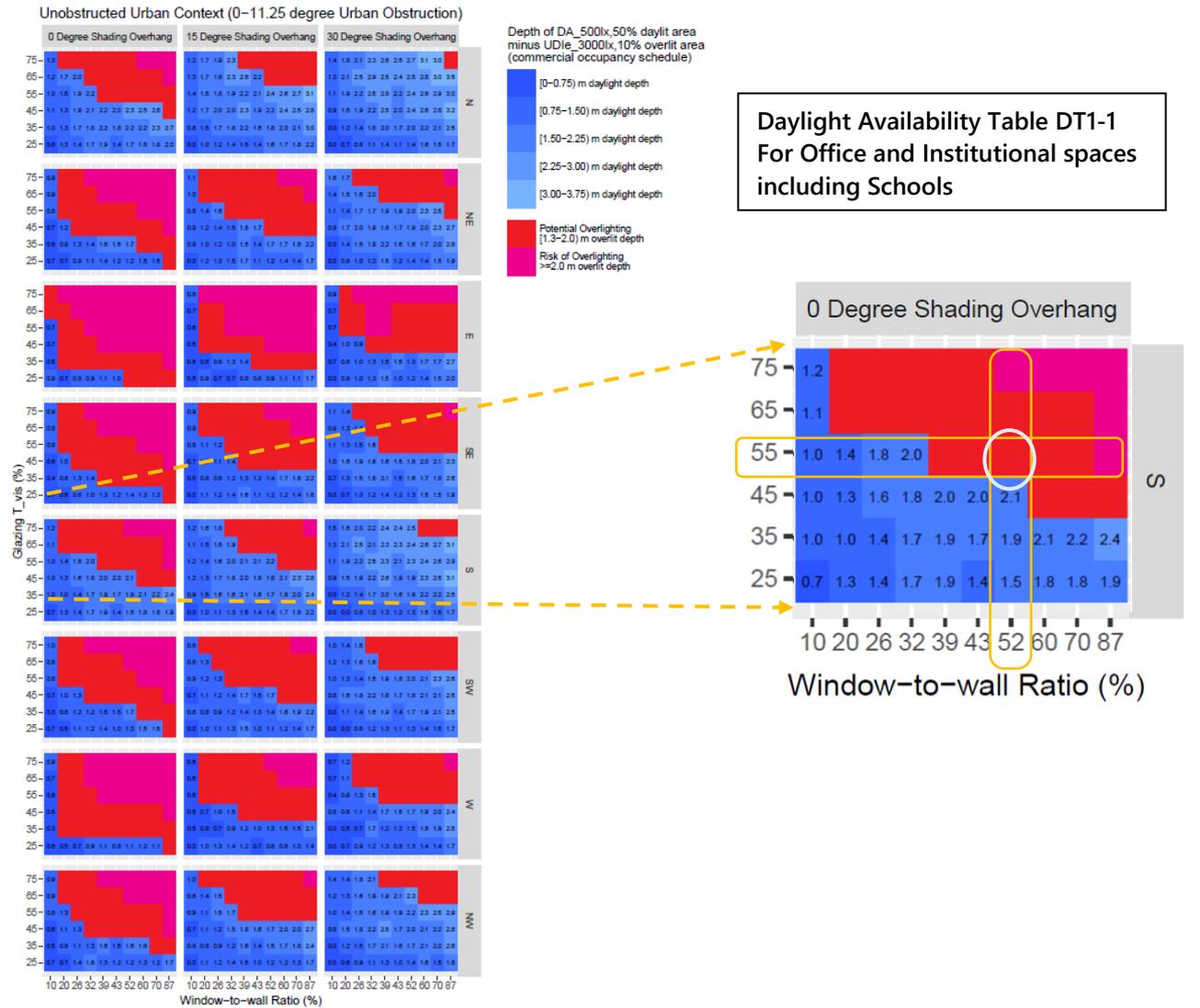
Level 1 & 2- South-facing fenestration- Average Urban Obstruction Angle (AUOA) of 45°



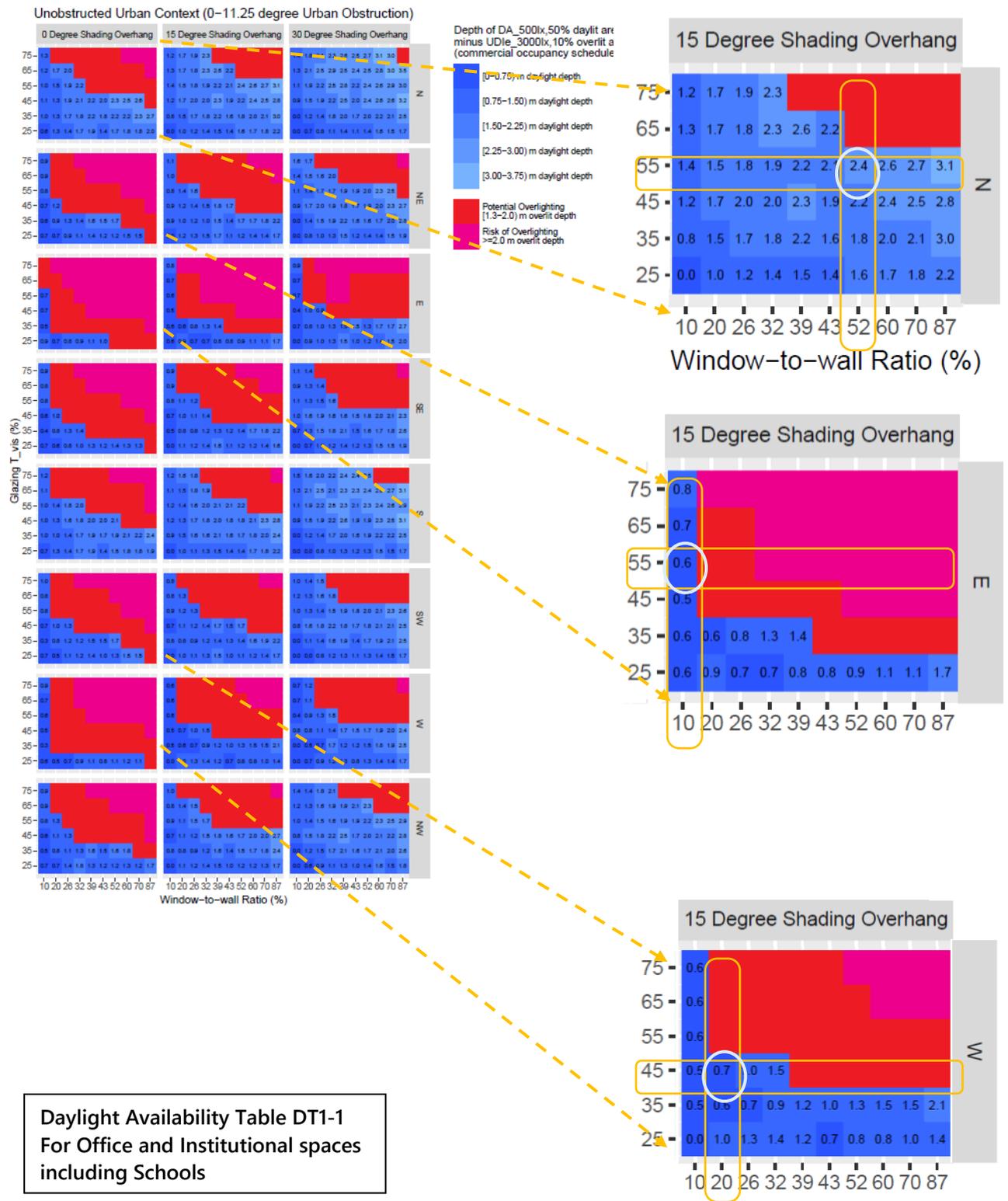
Level 3 & 4- South-facing fenestration- Average Urban Obstruction Angle (AUOA) of 22.5°



# Level 5- South-facing fenestration- Average with Unobstructed Urban Context



Level 1 to 5- North, East & West facing fenestration- Average Urban Obstruction Angle (AUOA) of 22.5°



Level 1- Office area (with Significant Obstruction Urban Context that is AUOA of 45°)				
Orientation of Vertical Fenestration	Floor Areas (m <sup>2</sup> )	Daylit Room Width (m)	Depth of Effective Daylit Areas from Daylight Availability Table (m)	Effective Daylit Areas (m <sup>2</sup> )
N	340	9.92	2.4	23.81
S		9.92	1.0	9.92
W		11.6	0.7	8.12
E		11.6	0.6	6.96
Area daylit				48.81

Level 2- Office area (with Significant Obstruction Urban Context that is AUOA of 45°)				
Orientation of Vertical Fenestration	Floor Areas (m <sup>2</sup> )	Daylit Room Width (m)	Depth of Effective Daylit Areas from Daylight Availability Table (m)	Effective Daylit Areas (m <sup>2</sup> )
N	340	9.92	2.4	23.81
S		9.92	1.0	9.92
W		11.6	0.7	8.12
E		11.6	0.6	6.96
Area daylit				48.81

Level 3- Office area (with Significant Obstruction Urban Context that is AUOA of 45°)				
Orientation of Vertical Fenestration	Floor Areas (m <sup>2</sup> )	Daylit Room Width (m)	Depth of Effective Daylit Areas from Daylight Availability Table (m)	Effective Daylit Areas (m <sup>2</sup> )
N	340	23.7	2.4	56.88
S		23.7	1.7	40.29
W		10.9	0.7	7.63
E		10.9	0.6	6.54
Area daylit				111.34

Level 4- Office area (with Significant Obstruction Urban Context that is AUOA of 45°)				
Orientation of Vertical Fenestration	Floor Areas (m <sup>2</sup> )	Daylit Room Width (m)	Depth of Effective Daylit Areas from Daylight Availability Table (m)	Effective Daylit Areas (m <sup>2</sup> )
N	340	23.7	2.4	56.88
S		23.7	1.7	40.29
W		10.9	0.7	7.63
E		10.9	0.6	6.54
Area daylit				111.34

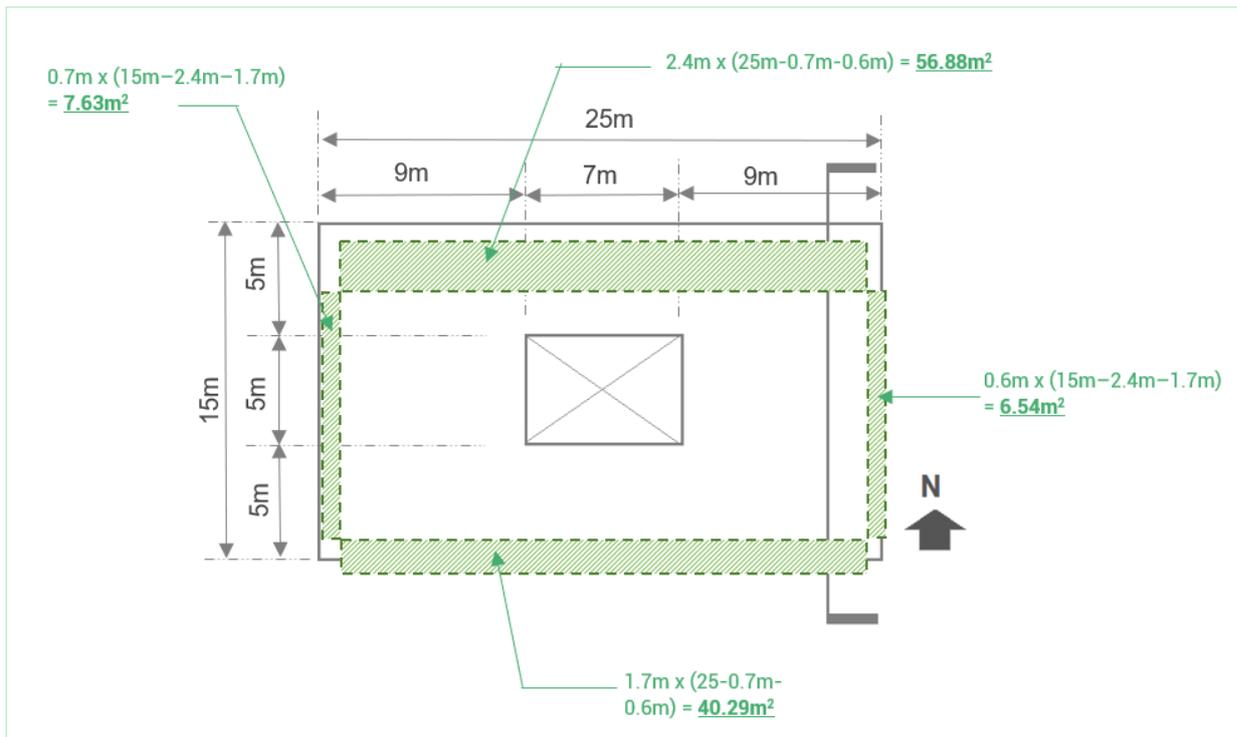
Level 5- Office area (with Significant Obstruction Urban Context that is AUOA of 45° )				
Orientation of Vertical Fenestration	Floor Areas (m <sup>2</sup> )	Daylit Room Width (m)	Depth of Effective Daylit Areas from Daylight Availability Table (m)	Effective Daylit Areas (m <sup>2</sup> )
N	340	25	2.4	56.88
S		25	0	0.00
W		12.6	0.7	7.42
E		12.6	0.6	6.36
Area daylit				70.66

In Summary

Total daylit area for the block: 390.96m<sup>2</sup>

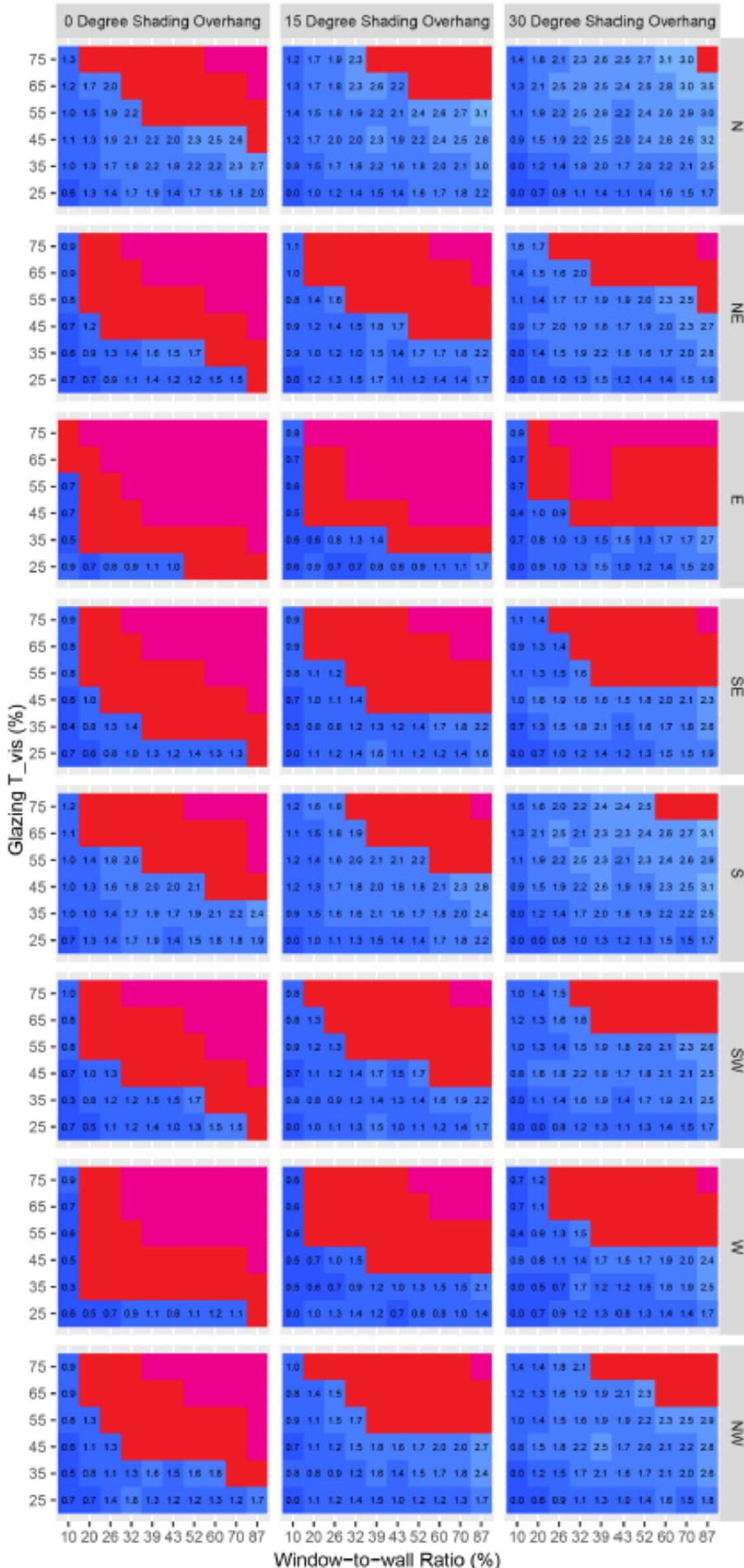
Total floor area: 1700.0m<sup>2</sup>

Percentage daylit floor area: 23%



Marking out example for the calculation for Level 3 (Level 4 has similar results)

### Unobstructed Urban Context (0-11.25 degree Urban Obstruction)

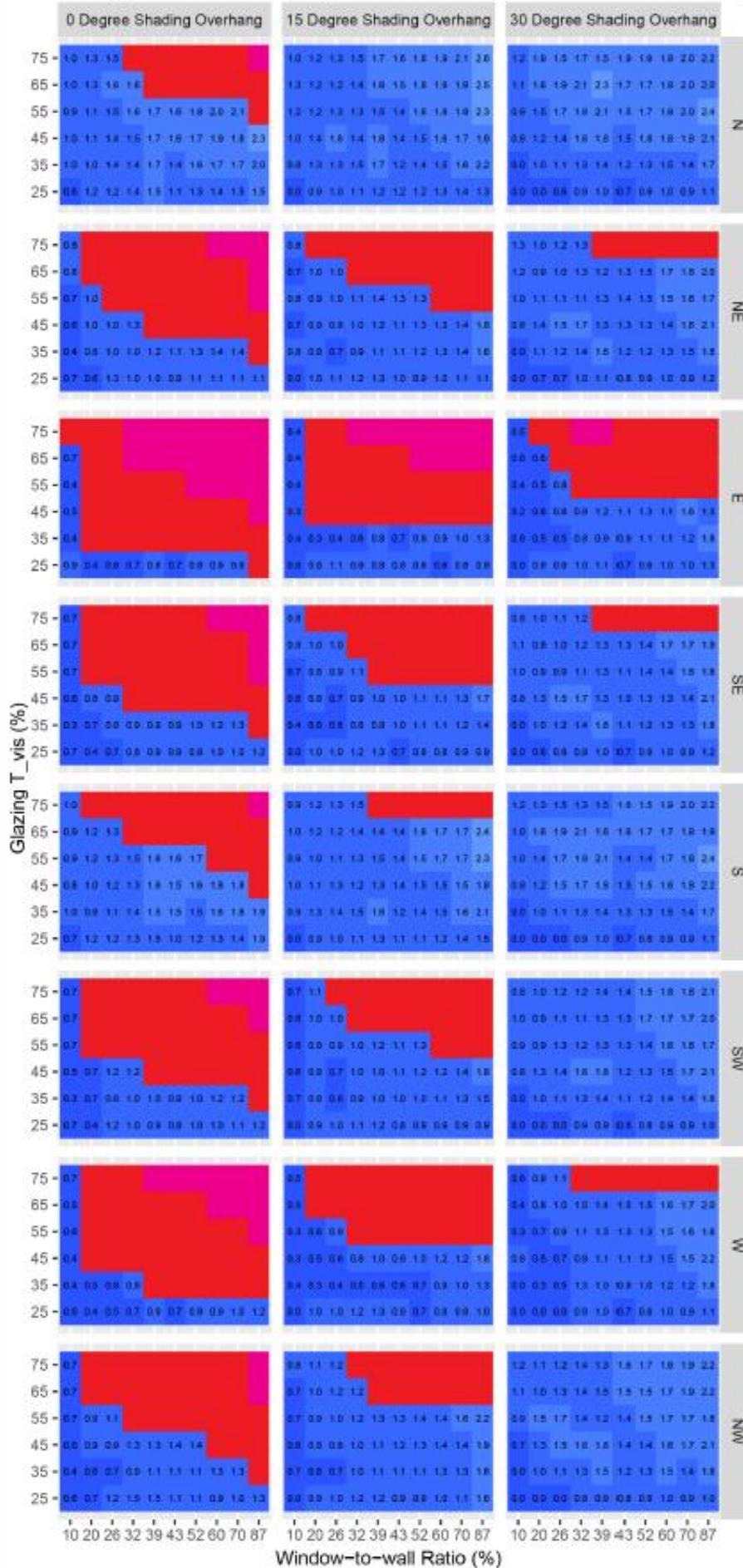


Depth of DA\_500lx,50% daylit area minus UDIe\_3000lx,10% overlit area (commercial occupancy schedule)



**Daylight Availability Table DT1-1**  
for Offices and Institutional spaces including schools

## 22.5 degree Urban Context (11.25–33.75 degree Urban Obstruction)

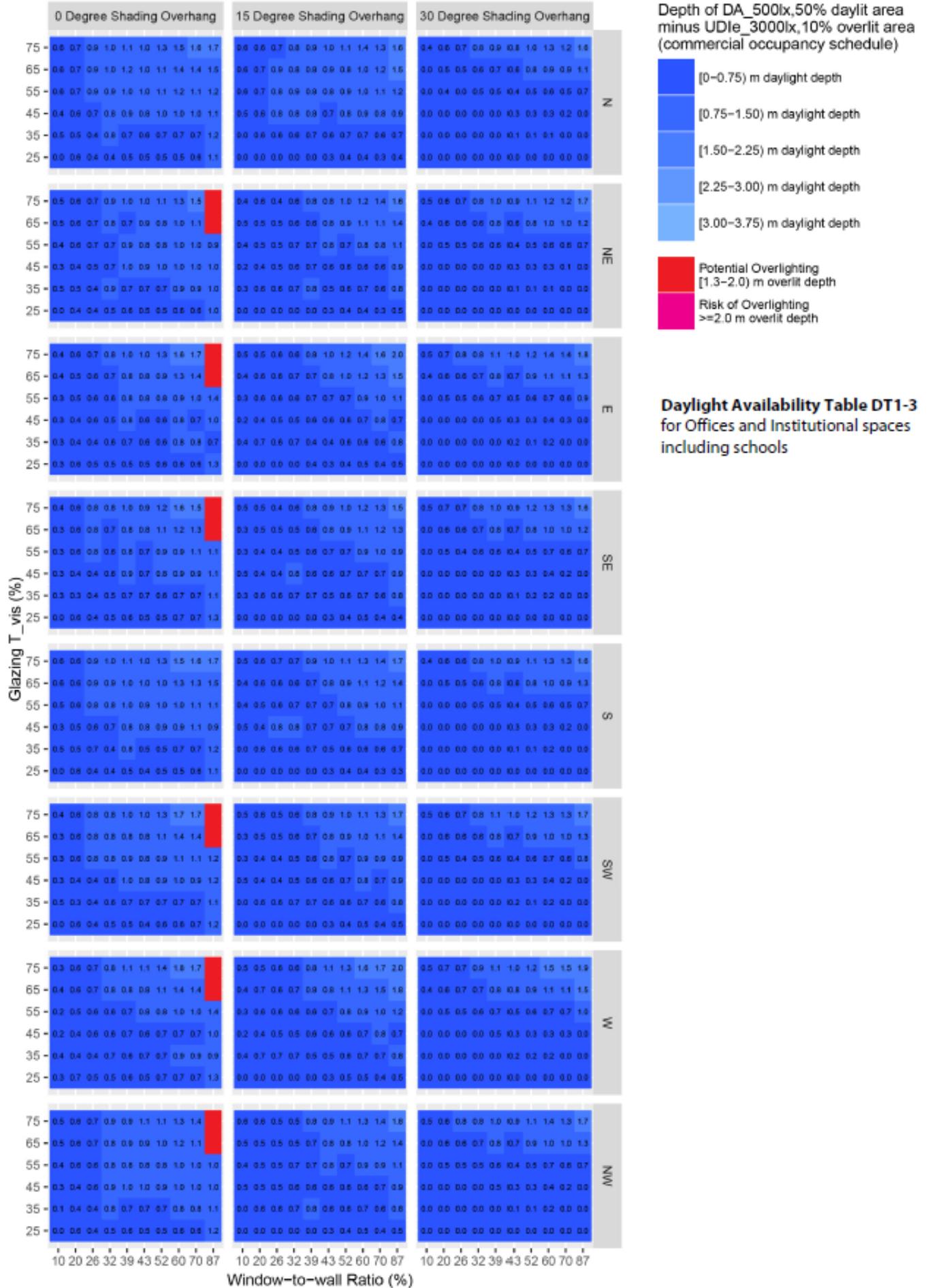


Depth of DA\_500lx, 50% daylit area minus UDe\_3000lx, 10% overlit area (commercial occupancy schedule)

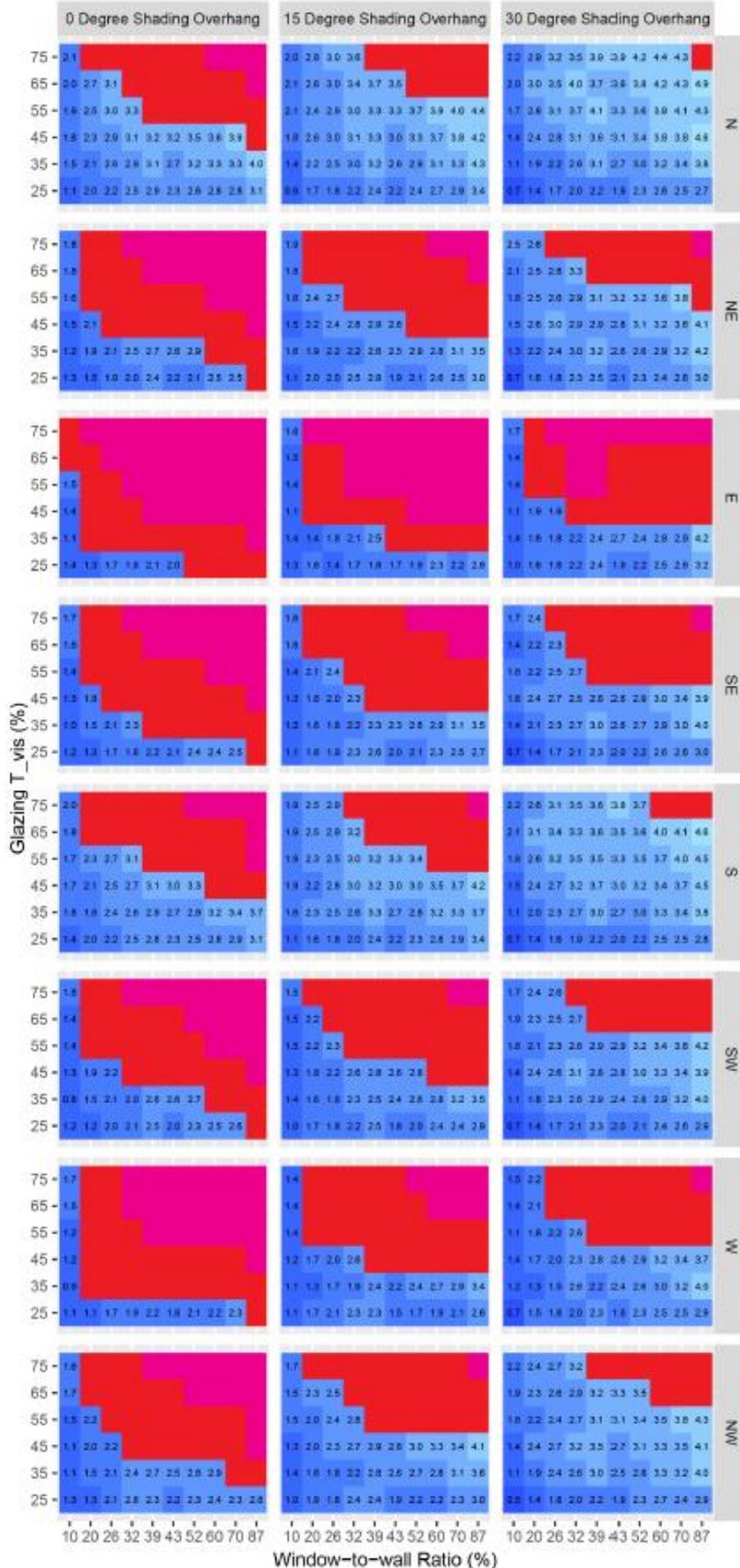


**Daylight Availability Table DT1-2**  
for Offices and Institutional spaces including schools

### 45 degree Urban Context (33.75–57.25 degree Urban Obstruction)



### Unobstructed Urban Context (0–11.25 degree Urban Obstruction)



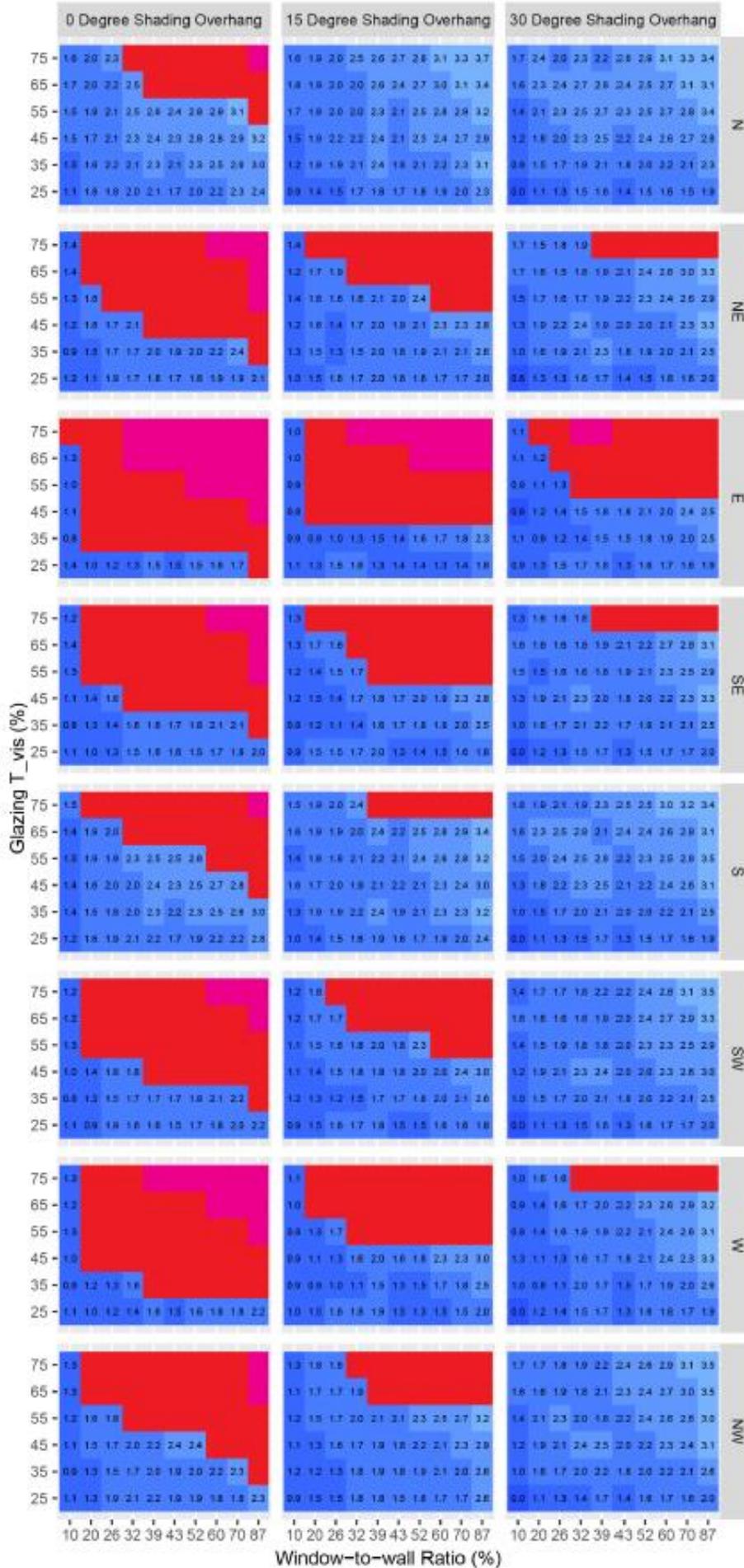
Depth of DA\_3000lx,50% daylight area minus UDle\_3000lx,10% overlit area (commercial occupancy schedule)



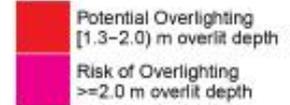
Potential Overlighting [1.3–2.0) m overlit depth  
 Risk of Overlighting >=2.0 m overlit depth

**Daylight Availability Table DT2-1**  
 for Industrial, Sports facilities, Retail areas

## 22.5 degree Urban Context (11.25–33.75 degree Urban Obstruction)

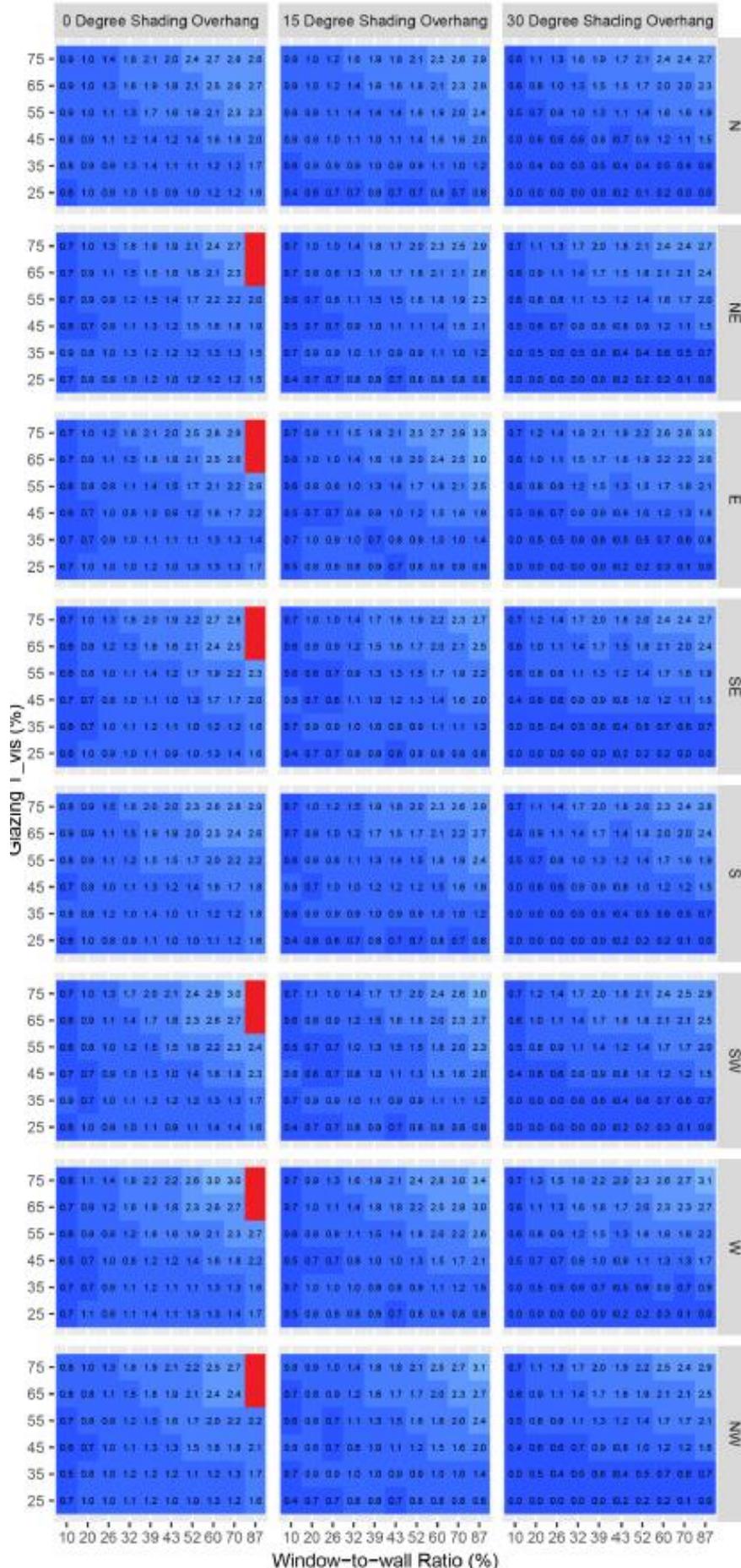


Depth of DA\_300lx,50% daylight area minus UDIe\_3000lx,10% overlit area (commercial occupancy schedule)

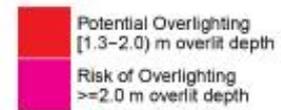
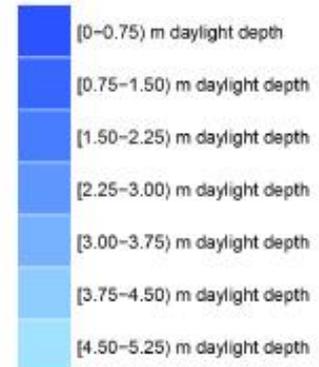


**Daylight Availability Table DT2-2**  
for Industrial, Sports facilities, Retail areas

### 45 degree Urban Context (33.75–57.25 degree Urban Obstruction)

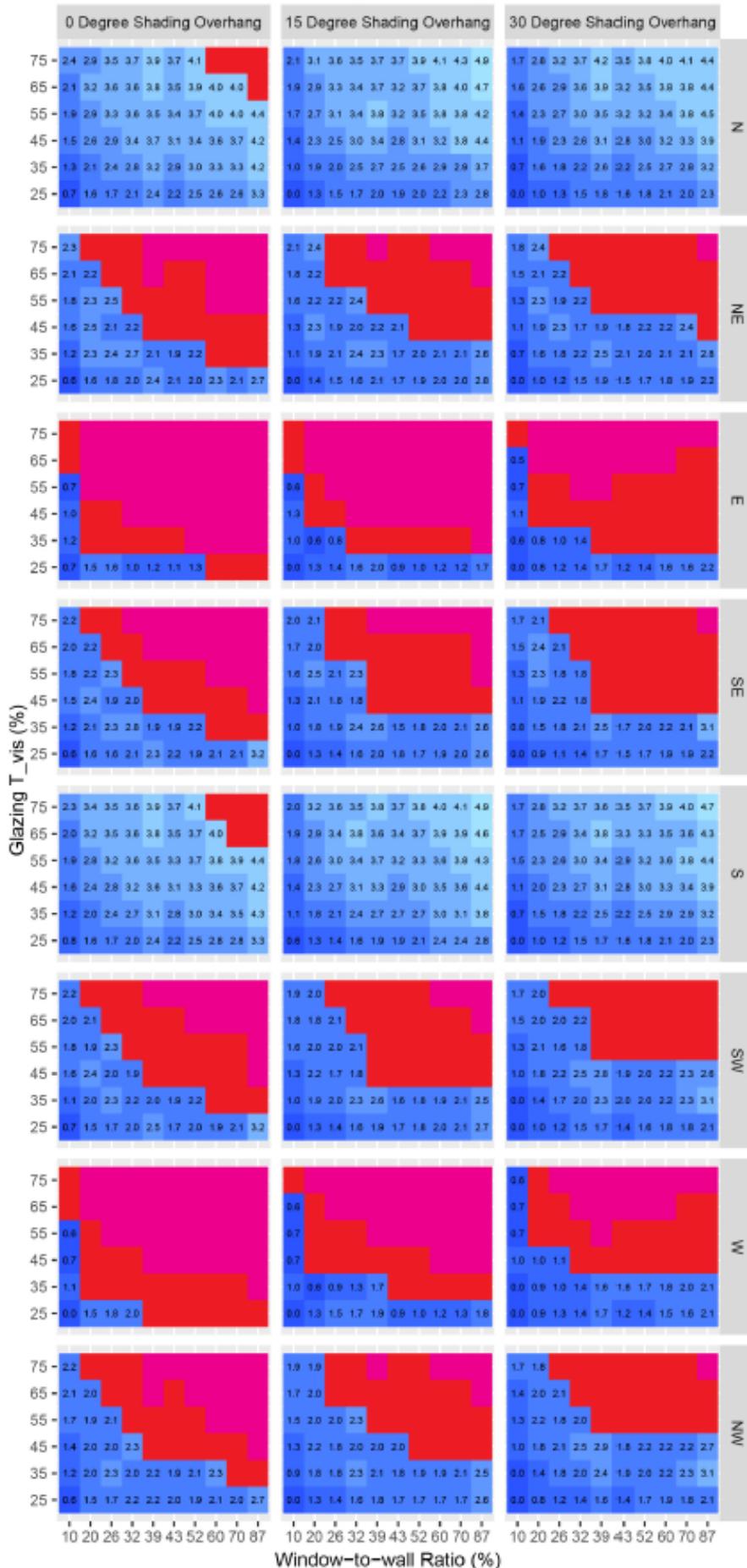


Depth of DA\_300lx,50% daylit area minus UDIe\_3000lx,10% overlit area (commercial occupancy schedule)

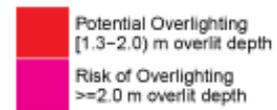
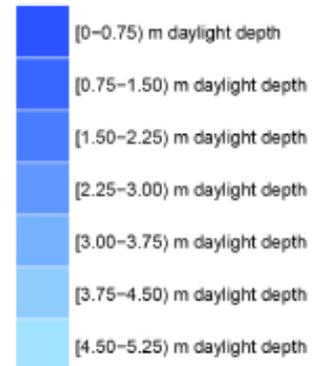


**Daylight Availability Table DT2-3**  
for Industrial, Sports facilities, Retail areas

### Unobstructed Urban Context (0–11.25 degree Urban Obstruction)

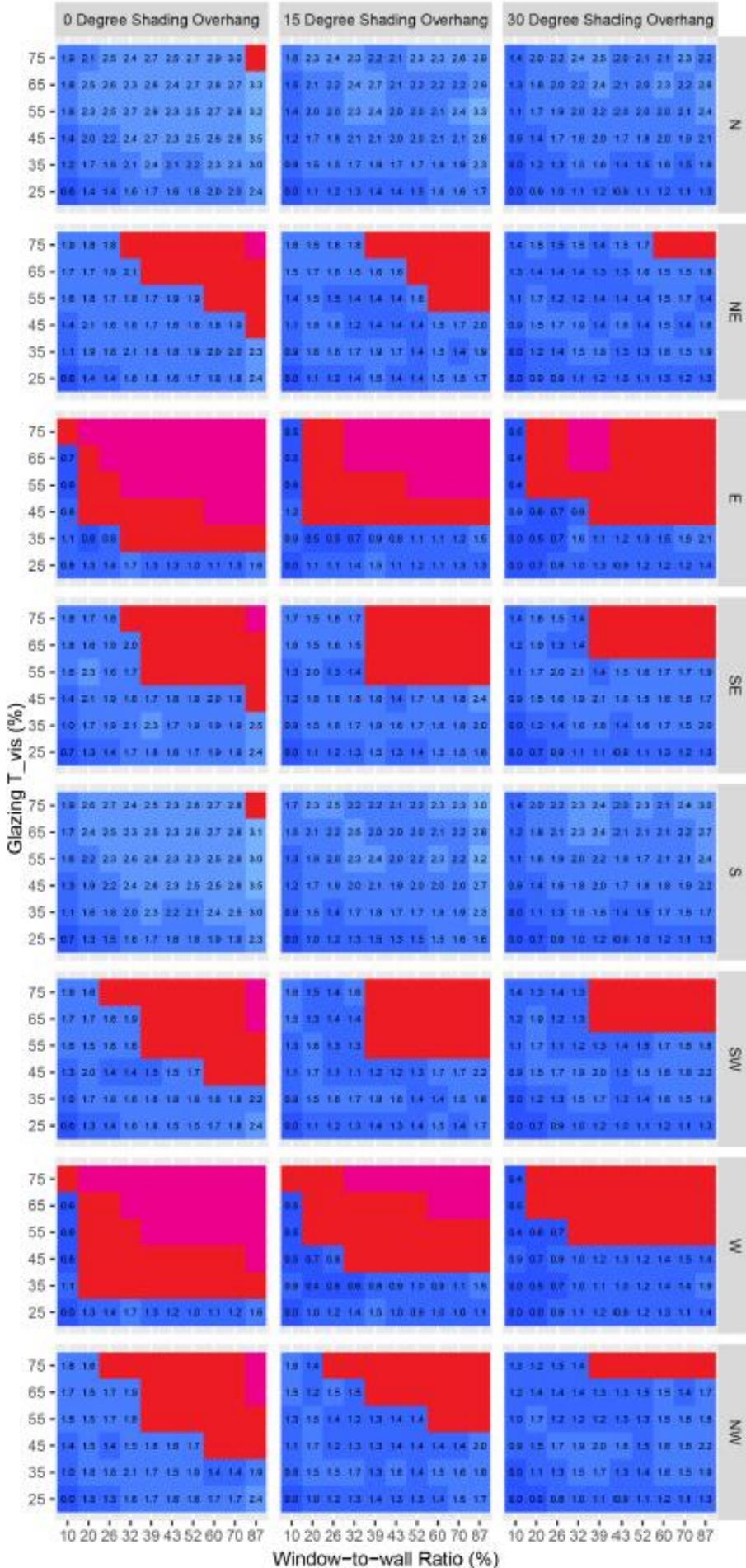


Depth of DA\_200lx,50% daylight area minus UDle\_3000lx,10% overlit area (residential occupancy schedule)

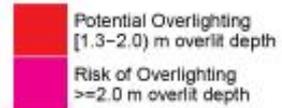


**Daylight Availability Table DT3-1**  
for Residential, Hotel and Service Apartments

22.5 degree Urban Context (11.25–33.75 degree Urban Obstruction)

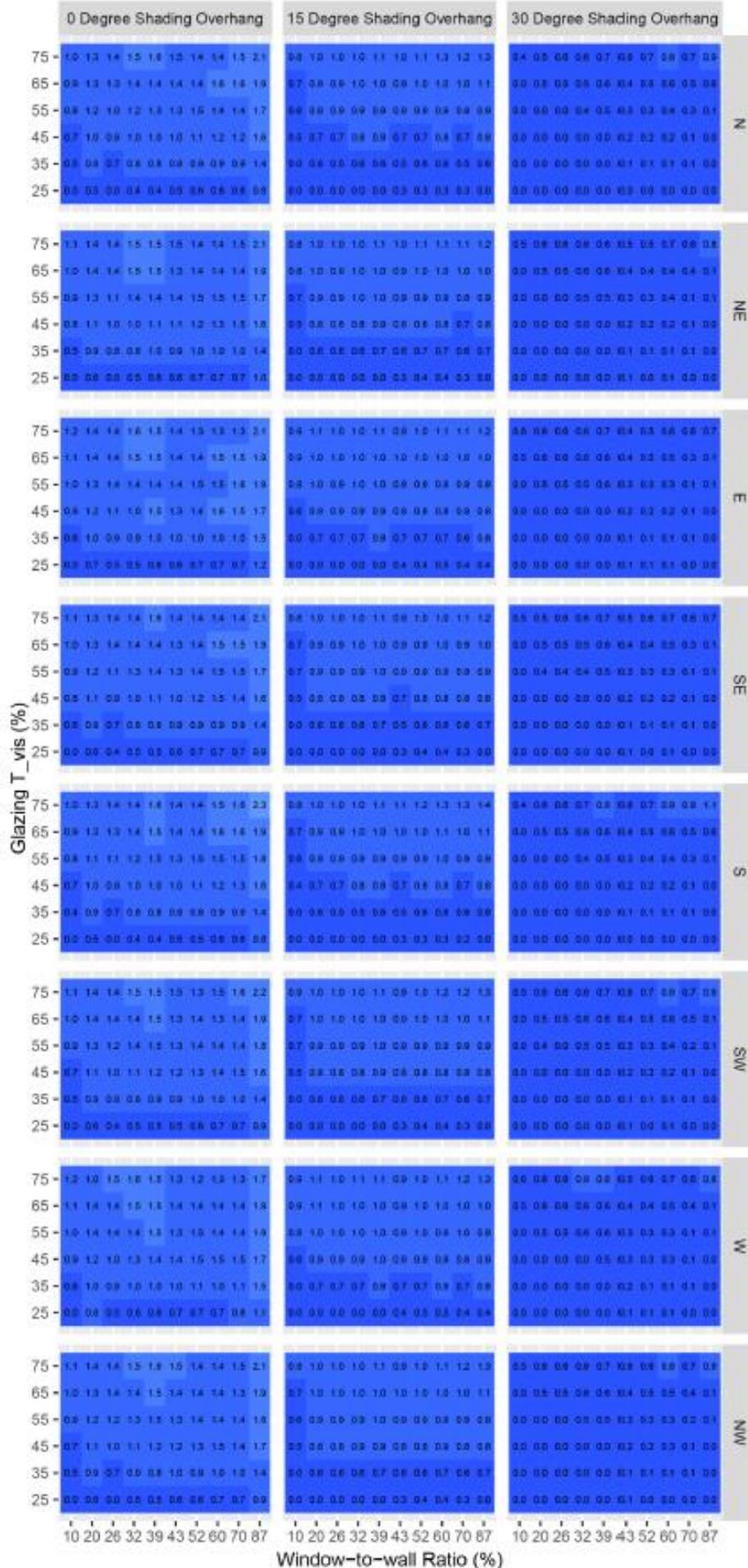


Depth of DA<sub>200lx,50%</sub> daylight area minus UDLe<sub>3000lx,10%</sub> overlit area (residential occupancy schedule)

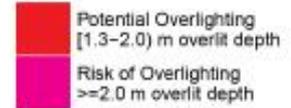


**Daylight Availability Table DT3-2**  
for Residential, Hotel and Service Apartments

### 45 degree Urban Context (33.75–57.25 degree Urban Obstruction)



Depth of DA<sub>200lx,50%</sub> daylit area minus UDI<sub>e,3000lx,10%</sub> overlit area (residential occupancy schedule)



**Daylight Availability Table DT3-3**  
for Residential, Hotel and Service Apartments