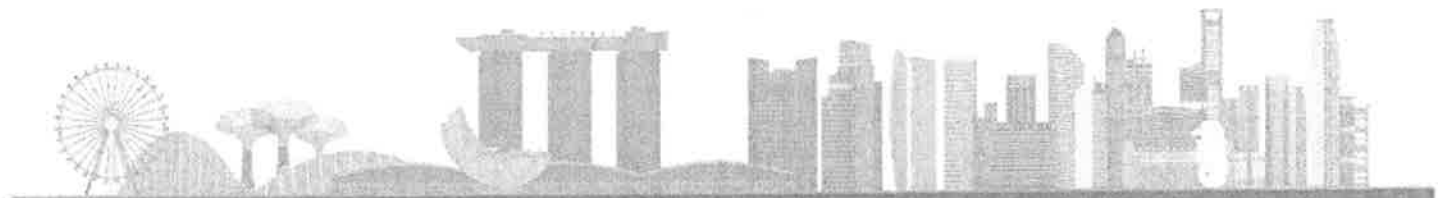
BCA ACADEMY

Building Energy Modeling & Thermal Simulation

(21st Intake)

School of Graduate Development and Management



The Education and Research arm of the Building and Construction Authority

Green Mark Professional core module : Building Energy Modeling & Thermal Simulation

Yong Ping Quen

Director and Partner
MSc. (Bdg Sci), BEng (Hons), LEED AP, GMP, GBIF.
BCA-Registered Energy Auditor

BSD
building system & diagnostics

Building System & Diagnostics Pte Ltd
No. 18, Boon Lay Way #07-107
Tradehub 21, Singapore 609966
Telephone : (65) 6560 0702
Website : www.bsd.com.sg



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Overview

- 4 days course
- Lecture & dis session
- Practical sessions
- Exams & Assessment

  - Group energy simulation assignment

  - Individual exams

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Objectives

- Better understanding on the basics of building energy modeling.
- Appreciate energy modeling as a design tool for building delivery process.
- Understand the fundamental concept behind the energy modeling.
- Hands-on experience with the simulation software.
- Understand Energy Modeling Framework and its Green Mark submission requirement

The Education and Research arm of the Building and Construction Authority

Overview – Day 1

- Energy Modeling & Green Mark
- Energy Modeling Theory (Cooling Load)

- Introduction to Simulation Software
- Hands-on experience on the Software

Overview – Day 2

- Thermal Simulation

- Practical Session on Energy Modeling I: Passive Design
  - Building orientation
  - Façade design
  - Building material selections
  - Internal conditions setting
  - Cooling load saving re-iteration

  ...

Overview – Day 3

- Practical Session on Energy Modeling II: Active Design
  - Air conditioning system
  - Lighting system
  - Ventilation system
  - Vertical transportation system
  - Energy efficient features ....

Overview – Day 4

- Individual Exams
- Energy Modeling & Submission

- Group project presentation

Individual Exams– 50%

- 1 ½ hours paper
- Close Book Exams
- 10 Multiple Choice Questions (40%)
- 2 Short Essay Questions (60%)
- Answer all questions

Group Project Assignment – 50%

- Develop the reference model during practical sessions.
- Study and recommend three Energy Conservation Opportunities (ECO) for proposed model.
- Present comparative study for ECO
- Result finding and discussion

Thank you

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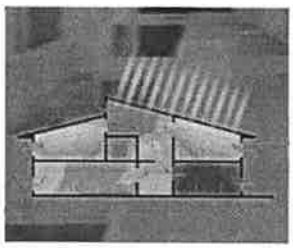
Green Mark Professional core module : Building Energy Modeling & Thermal Simulation

2.0 Energy Modeling & Green Mark



Energy Modeling & Green Mark

Objectives:

Understand

- Building energy modeling and its use
- Software tools – their structures, solution method and features
- Energy modeling and Green Mark Requirement

Energy Modelling

What is Building Energy Model

- A computer model to simulate the way a building consumes energy to meet the demands of services to maintain the temperature, humidity within the building.

- It provides users with the key performance indicators of demand, energy use, space conditions and costs

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Energy Modelling

Why is Building Energy Model Important?

- Buildings consume roughly one-third of all the energy consumed nationally every year
  - Much of this energy is consumed maintaining the thermal conditions inside the building and lighting.

- Simulation can and has played a significant role in reducing the energy consumption of buildings.
  - Answers "What if..." on Scientific Basis
  - Provides comprehensive data not easily obtainable from experimental tests
  - Allows alternatives to be studied before optimum designs are confirmed
  - Reduce time and expense

Energy Modelling

When Should I Start?

early, early, early

"When just 1% of a project's up front cost are spent....
Up to 70% of its life-cycle costs may already be committed."

Energy Modelling

Energy Model as a Design Tool

Pre-Design	•Climatic analysis; •Identify strategies; •Goal setting
Schematic Design	•Shape, Massing, Building Envelope; •Daylighting, HVAC options; •Load reduction iterations
Design Development	•HVAC systems comparisons; •Fine-tune details – system optimization
Construction/ O&M	•Calibrate model; •Troubleshoot operation; •Measurement and verification

Energy Modelling

Energy Model as a Design Tool

- Thermal insulation
- Thermal capacity ("thermal mass")
- Glazing properties
- Built form and orientation
- Shading from nearby buildings and self-shading
- Solar heat gain & Cooling Load
- Gains from lights, occupants and equipment (both sensible and latent)
- Air conditioning system design & optimization
- Mechanical ventilation system design & optimization
- Available plant capacities for heating and cooling
- Artificial lighting system design

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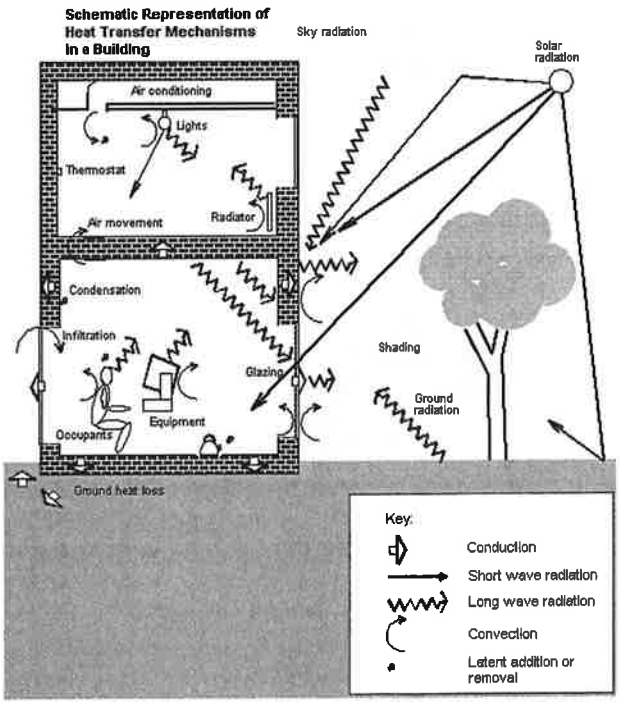
Energy Modelling

Understand the Loads

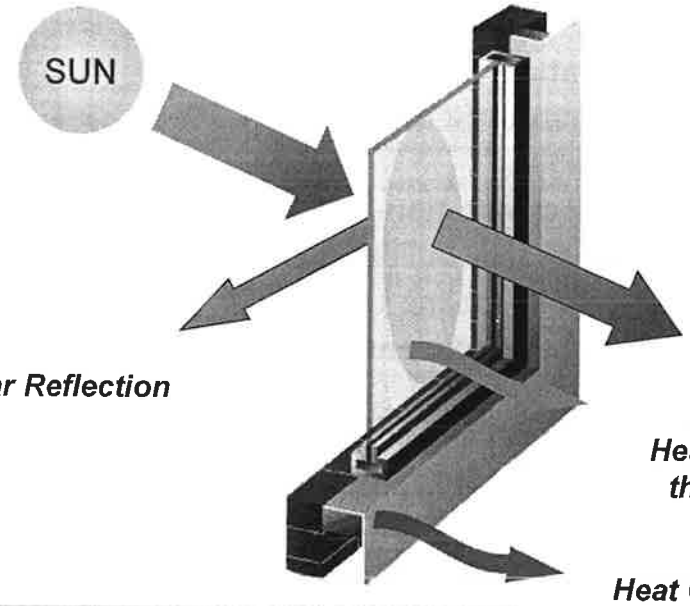
Building loads:

- Solar heat gains
- Human
- Lighting
- Equipment
- Receptacle
- Infiltration
- Others



Energy Modelling

Understand the Loads: Solar Heat Gains



ETTV = 12 (1-WWR)Uw + 3.4 (WWR)Uf + 211(WWR)(CF)(SC)

Building Envelope ETTV

Envelope Thermal Transfer Value (ETTV) Formula

The ETTV formula is given as follows:

$$ETTV = 12(1-WWR)U_w + 3.4(WWR)U_f + 211(WWR)(CF)(SC)$$

where

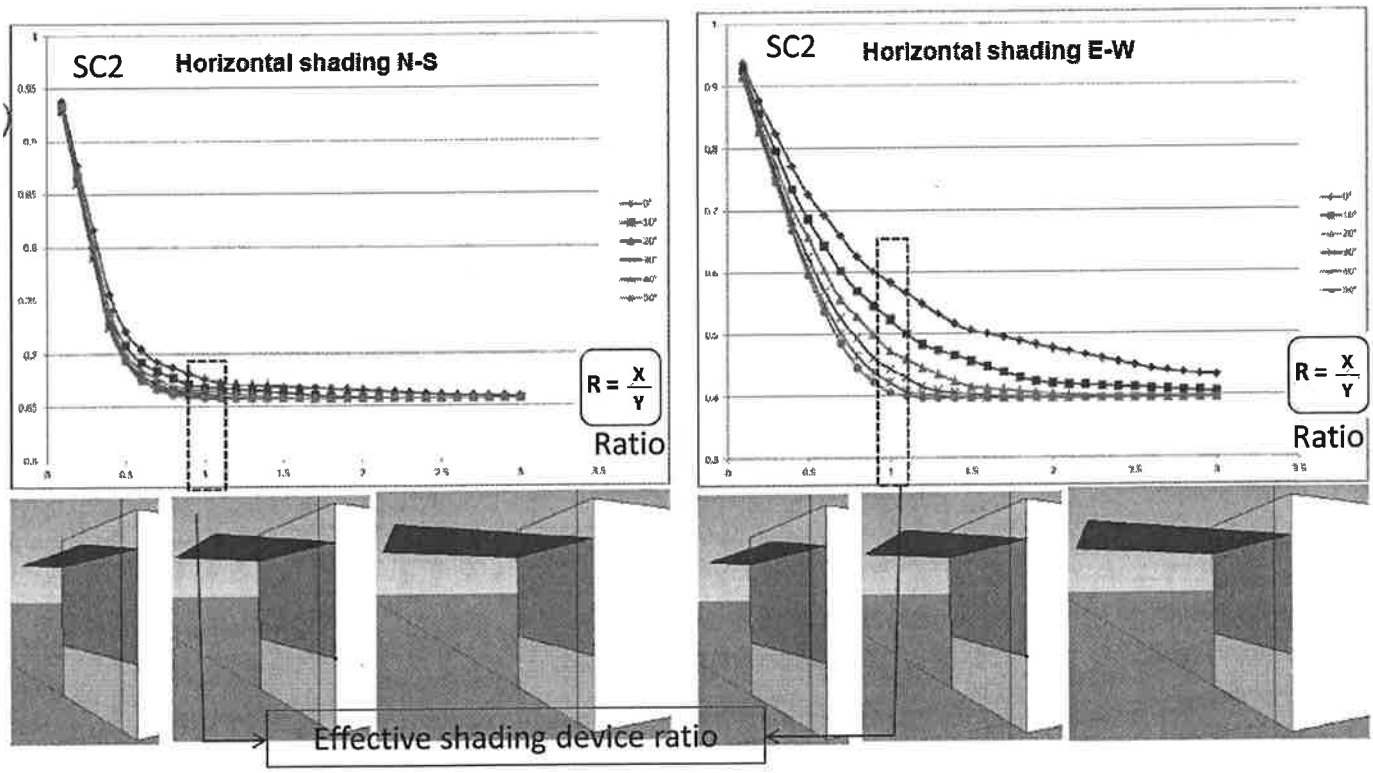
ETTV	:	envelope thermal transfer value (W/m^2)
WWR	:	window-to-wall ratio (fenestration area / gross area of exterior wall)
U_w	:	thermal transmittance of opaque wall ($W/m^2\,^oK$)
U_f	:	thermal transmittance of fenestration ($W/m^2\,^oK$)
CF	:	correction factor for solar heat gain through fenestration
SC	:	shading coefficients of fenestration

Factors that affect facade performance

- Orientation of the façade.
- Window to wall ratio – Percentage of openings vs. solid mass areas
- Amount of self shading and actual shading provided
- Material composition of the facade
  - Material properties
    - Thermal properties – Thermal capacity, conductivity, density, time lag and decrement factor
    - Visual properties – Opacity of the facade, SC values

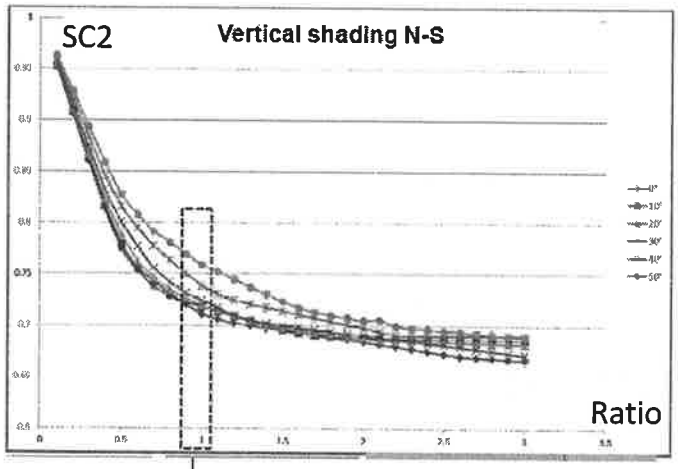
Effective Shading Device (SC2 value)

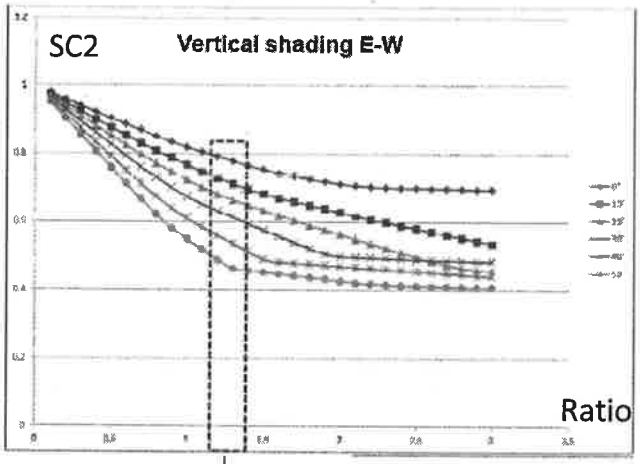
Effective shading device ratio based on Horizontal Shading

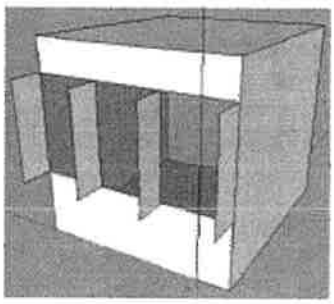


Effective Shading Device (SC2 value)

Effective shading device ratio based on Vertical Shading







Effective shading device ratio

Energy Modelling

Understand the Loads: Human (sensible heat + latent heat)

Table 1 Representative Rates at Which Heat and Moisture Are Given Off by Human Beings in Different States of Activity

Degree of Activity		Total Heat, W		Sensible Heat, W	Latent Heat, W
		Adult Male	Adjusted, M/F[a]		
Seated at theater	Theater, matinee	115	95	65	30
Seated at theater, night	Theater, night	115	105	70	35
Seated, very light work	Offices, hotels, apartments	130	115	70	45
Moderately active office work	Offices, hotels, apartments	140	130	75	55
Standing, light work; walking	Department store; retail store	160	130	75	55
Walking, standing	Drug store, bank	160	145	75	70
Sedentary work	Restaurant[c]	145	160	80	80
Light bench work	Factory	235	220	80	140
Moderate dancing	Dance hall	265	250	90	160
Walking 4.8 km/h; light machine work	Factory	295	295	110	185
Bowling[d]	Bowling alley	440	425	170	255
Heavy work	Factory	440	425	170	255
Heavy machine work; lifting	Factory	470	470	185	285
Athletics	Gymnasium	585	525	210	315

Energy Modelling

Understand the Loads: Artificial Lighting

Energy Efficient Light + Fixtures + Control (Motion Detector, Timer)

Lamp power + ballast loss = Total load

Lamp	Ballast type	Lamp power	Ballast loss	Total power
TL 40W	EM	40W	9W	49W
TLD 36W	EM	36W	9W	45W
TLD 36W	EM Low-Loss type	36W	6W	42W
TLD 36W	EL	**32W**	4W	**36W**
TL5 28W	EL	28W	3W	31W

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Energy Modelling

Understand the Loads: Receptacle or Plug Loads

Table 11 Recommended Load Factors for Various Types of Offices

Load Density of Office	Load Factor, W/m²	Description
Light	5.4	Assumes 15.5 m²/workstation (6.5 workstations per 100 m²) with computer and monitor at each plus printer and fax. Computer, monitor, and fax diversity 0.67, printer diversity 0.33.
Medium	10.8	Assumes 11.6 m²/workstation (8.5 workstations per 100 m²) with computer and monitor at each plus printer and fax. Computer, monitor, and fax diversity 0.75, printer diversity 0.50.
Medium/ Heavy	16.1	Assumes 9.3 m²/workstation (11 workstations per 100 m²) with computer and monitor at each plus printer and fax. Computer and monitor diversity 0.75, printer and fax diversity 0.50.
Heavy	21.5	Assumes 7.8 m²/workstation (13 workstations per 100 m²) with computer and monitor at each plus printer and fax. Computer and monitor diversity 1.0, printer and fax diversity 0.50.

Source: Wilkins and McGaffin (1994).

Receptacle loads

Table 12 Cooling Load Estimates for Various Office Load Densities

	Number	Each, W	Total, W	Diversity	Load, W
Light Load Density[a]					
Computers	6	55	330	0.67	220
Monitors	6	55	330	0.67	220
Laser printer—small desk top	1	130	130	0.33	43
Fax machine	1	15	15	0.67	10
Total Area Load					494
Recommended equipment load factor = 5.4 W/m²					
Medium Load Density[a]					
Computers	8	65	520	0.75	390
Monitors	8	70	560	0.75	420
Laser printer—desk	1	215	215	0.5	108
Fax machine	1	15	15	0.75	11
Total Area Load					929
Recommended equipment load factor = 10.8 W/m²					
Medium/Heavy Load Density[a]					
Computers	10	65	650	1	650
Monitors	10	70	700	1	700
Laser printer—small office	1	320	320	0.5	160
Facsimile machine	1	30	30	0.5	15
Total Area Load					1525
Recommended equipment load factor = 16.1 W/m²					
Heavy Load Density[a]					
Computers	12	75	900	1	900
Monitors	12	80	960	1	960
Laser printer-small office	1	320	320	0.5	160
Facsimile machine	1	30	30	0.5	15
Total Area Load					2035
Recommended equipment load factor = 21.5 W/m²					

Source: Wilkins and McGaffin (1994).
[a] See Table 11 for descriptions of load densities.

Energy Modelling

Understand the Loads: Fresh Air/ Outdoor Air Rate

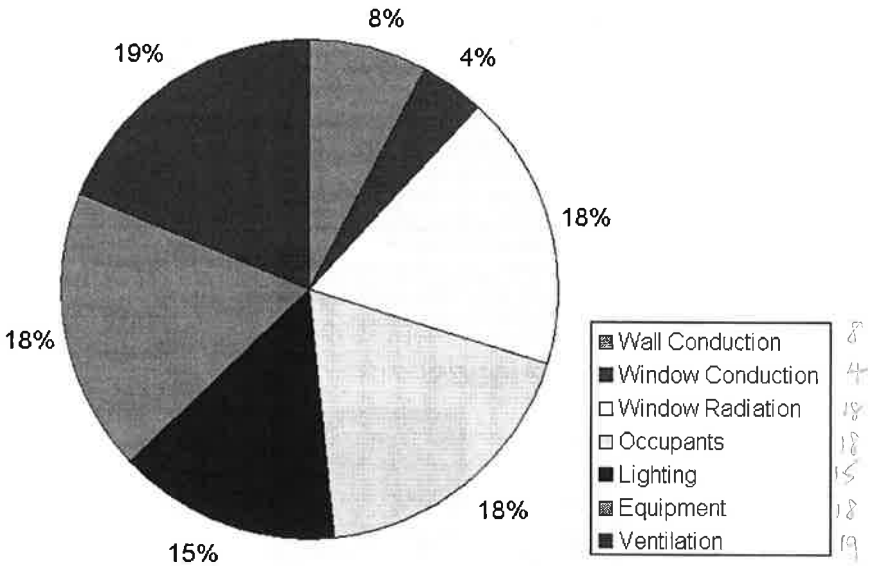
Type	l/s/m2	l/s/person	Occupancy Density m2/person
Offices	0.6	5.5	10.0
Restaurants	3.4	5.1	1.5
Shops, supermarkets & department stores	1.1	5.5	5.0
Lobbies & corridors	0.3	3.3	25
Theatres/ cinemas	2.0	3.0	1.5

100m² office ⇒ people 10 × 2.5 + area 100 × 0.3 = 55 l/s

Energy Modelling

Understand the Loads:
Commercial Office Building Distribution

- Solar heat gains
- Human
- Lighting
- Receptacle
- Ventilation
- Other



façade = 30% wall

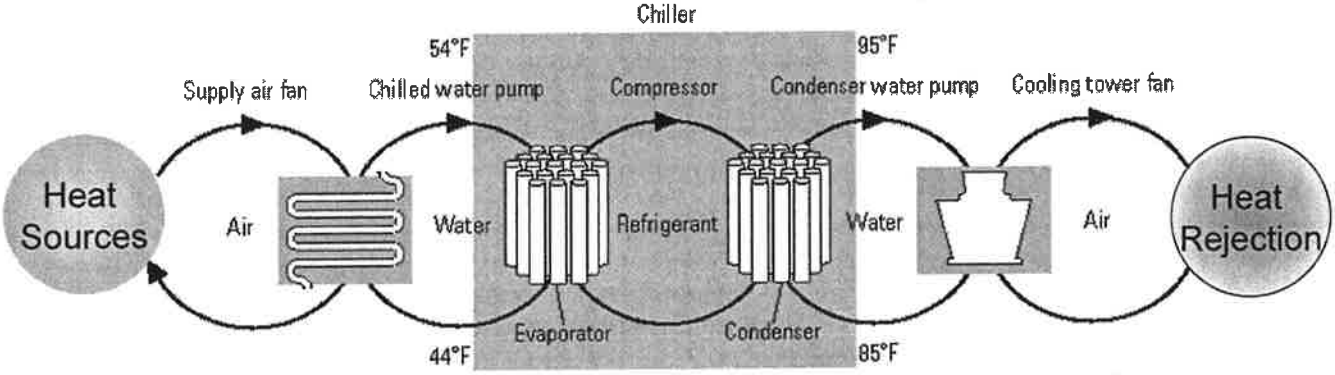
Air Conditioning System

Air-conditioned equipments:

- Central Cooling Plant
  - Chiller, Chilled water pump, Condenser water pump, Cooling Tower etc.
- Air Distribution System
  - Air Handling Units (AHUs), Fan Coil Unit (FCU) etc.
- Unitary Air-Conditioners/ Condensing units which include single-split units, VRF units etc.

Air Conditioning System





Source: NCCC

Air Conditioning System Efficiency

a) Air Cooled Chilled-Water System/ Unitary Air-Conditioning System

Relevant equipment: *Air-cooled chillers, chilled-water pumps, variable refrigerant flow (VRF) systems, single-split units, multi-split units, air distribution system (e.g. AHUs, PAHUs, FCUs)*

Green Mark Rating	Peak Building Cooling Load (RT)		Remarks
	<500 RT	≥500RT	(η_c, η_a) shall meet their respective thresholds.
	Minimum DSE η_t (kW/RT)		η_c: System kW/ton excluding the air distribution equipment
Gold	NA *(0.9, N.A.)*	NA *(to be assessed on case by case basis)*	η_a: Air distribution equipment kW/ton
Gold^{PLUS}	1.10 *(0.85, 0.25)*		$\eta_t = \eta_c + \eta_a$
Platinum	1.03 *(0.78, 0.25)*		

b) Water Cooled Chilled Water System

Relevant equipment: *Water-cooled chillers, chilled-water pumps, condenser water pumps, cooling towers, air distribution system*

Green Mark Rating	Peak Building Cooling Load (RT)		Remarks
	<500 RT	≥500RT	(η_c, η_a) shall meet their respective thresholds.
	Minimum DSE η_t (kW/RT)		η_c: System kW/ton excluding the air distribution equipment
Gold	NA *(0.75, N.A.)*	NA *(0.68, NA)*	η_a: Air distribution equipment kW/ton
Gold^{PLUS}	0.95 *(0.7, 0.25)*	0.9 *(0.65, 0.25)*	$\eta_t = \eta_c + \eta_a$
Platinum	0.93 *(0.68, 0.25)*		

Energy Modelling

Strategies towards Low Energy Building:

Take Advantage of Climate

- Solar exposure
- Daylighting
- Natural Ventilation

Optimize Systems

- Lightings – Lighting Power Density, Lighting control
- HVAC – Air-side, water-side Systems

Use on-site Energy System

- Renewable energy – PV, Solar thermal
- Combined Heat and Power

Energy Modelling

Understanding the limitations:

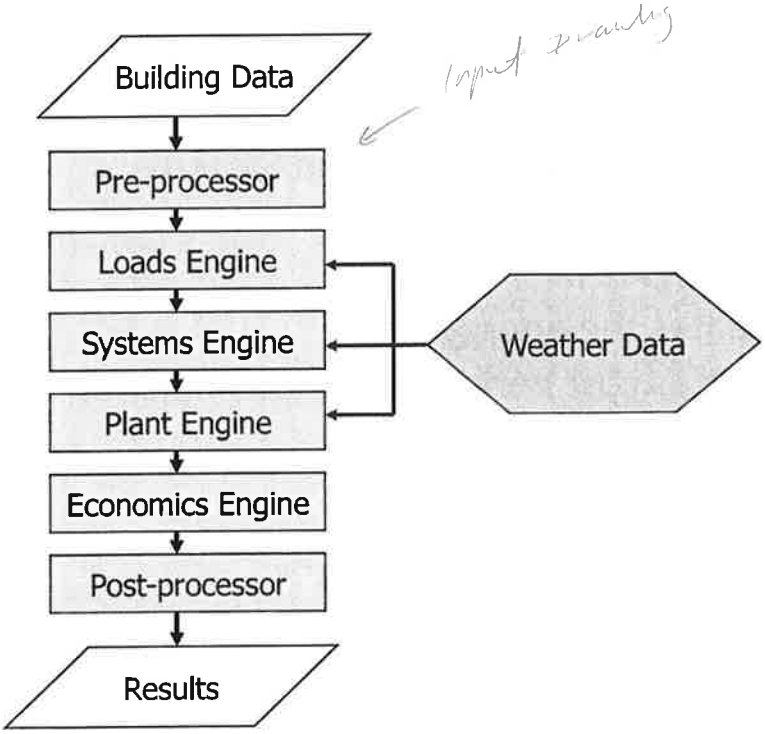
Energy models can't directly model everything

- Air flows study
- Light Quality
- Certain Technologies – Strategies
  - Natural ventilation
  - Phase-change materials
  - Electro-chromic window

Work Arounds...

Energy Modelling

Energy Software Structure:



Energy Modelling

Energy Software Structure:

Loads engine

- Calculates heating and cooling loads for each space taking account of weather and building use schedules.
- For each period simulated, a heat balance of space surfaces and room air is performed.

Systems engine

- Based on the system described for building model, calculates the energy and utilities demand to satisfy the space loads computed in Loads Engine

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Energy Modelling

Energy Software Structure:

Plant engine

- Calculates the central plant energy needed to supply the utilities demand computed in Systems.

Economics engine

- Calculates the energy cost
- Calculates cost benefit of various building systems design

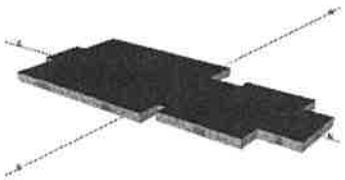
Applicable Green Mark Criteria

Green Mark Non-Residential New Buildings v4.1

Green Mark New Healthcare Facilities v1.0

Green Mark New Data Centres v1.1

Green Mark NRB: 2015



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Green Mark Non-Residential New Buildings v4.1

Elective Requirement for Energy Improvement
(Combination of the following items to meet 30 points)

Part 1 - Energy Efficiency

Air-con
- 1-1 Thermal Performance of Building Envelope - ETTV
- 1-2 Air-Conditioning System

Non Air-con
- 1-3 Building Envelope – Design/Thermal Parameter
- 1-4 Natural Ventilation / Mechanical Ventilation

General
- 1-5 Daylighting
- 1-6 Artificial Lighting
- 1-7 Ventilation in Carparks
- 1-8 Ventilation in Common Areas
- 1-9 Lifts and Escalators
- 1-10 Energy Efficient Practices & Features
- 1-11 Renewable Energy

Elective Requirement from Other Areas
(Combination of the following items to meet 20 points)

Part 2 - Water Efficiency
- 2-1 Water Efficient Fittings
- 2-2 Water Usage and Leak Detection
- 2-3 Irrigation System and Landscaping
- 2-4 Water Consumption of Cooling Towers

Part 3 – Environmental Protection
- 3-1 Sustainable Construction
- 3-2 Sustainable Products
- 3-3 Greenery Provision
- 3-4 Environmental Management Practice
- 3-5 Green Transport
- 3-6 Refrigerants
- 3-7 Stormwater Management

Part 4 - Indoor Environmental Quality
- 4-1 Thermal Comfort
- 4-2 Noise Level
- 4-3 Indoor Air Pollutants
- 4-4 Indoor Air Quality (IAQ) Management
- 4-5 High Frequency Ballasts

Part 5 – Other Green Features
- 5-1 Green Features and Innovations

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Green Mark New Healthcare Facilities v1.0

Elective Requirement for Energy Improvement
(Combination of the following items to meet 30 points)

Part 1 - Energy Efficiency

Air-con
- 1-1 Thermal Performance of Building Envelope - ETTV
- 1-2 Air-Conditioning System

Non Air-con
- 1-3 Building Envelope – Design/Thermal Parameters
- 1-4 Natural Ventilation

General
- 1-5 Electrical Services
- 1-6 Artificial Lighting
- 1-7 Ventilation in Carparks
- 1-8 Lifts and Escalators
- 1-9 Airside Energy Recovery
- 1-10 Local Energy Generation for Centralised Service Hot Water Heating
- 1-11 Renewable Energy
- 1-12 Energy Efficient Practices & Features

Elective Requirement from Other Areas
(Combination of the following items to meet 20 points)

Part 2 - Water Efficiency

- 2-1 Water Efficient Fittings
- 2-2 Water Usage and Leak Detection
- 2-3 Irrigation System and Landscaping
- 2-4 Water Consumption of Cooling Towers

Part 3 – Environmental Protection

- 3-1 Sustainable Construction
- 3-2 Sustainable Products
- 3-3 Airborne Contaminant Prevention
- 3-4 Greenery Provision and Healing Environment
- 3-5 Green and Universal Connectivity
- 3-6 Refrigerants

Part 4 - Indoor Environmental Quality

- 4-1 Thermal Comfort and Control for A/C Spaces
- 4-2 Thermal Comfort for N/V Spaces
- 4-3 Noise Level
- 4-4 Indoor Air Pollutants
- 4-5 Indoor Air Quality
- 4-5 High Frequency Ballasts & PBT-reduced Lamps
- 4-6 Daylighting and Glare
- 4-7 View out & Access to Indoor Places of Respite

Part 5 – Sustainable Practices and Green Innovation

- 5-1 Environmental Management Practice
- 5-2 Conservation of Existing Structures and Adoption of Demolition Protocol
- 5-3 Other Green Practices and Innovative Features

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Green Mark New Data Centres v1.1

Part 1 - Energy Efficiency

- 1-1 Overall Energy Efficiency
- 1-2 Systems Energy Efficiency
  - Cooling System
  - Electrical System
  - IT Equipment
- 1-3 Energy Efficiency and Performance Verification
- 1-4 Data Centre Design and Energy Management
- 1-5 Energy Efficient Features and Innovations

Use a **computer simulation model** to assess the energy performance of the **proposed data centre** facility and systems (Proposed DC Model) to achieve the most effective energy efficient design.

Quantify Proposed DC Model energy performance operating under Singapore climatic conditions, at Full Design Load, 66% of the Design Load, and 33% of the Design Load and express them in terms of improvement in **Power Utilization Effectiveness (PUE)** over a Reference DC Model.

Part 2 - Water Efficiency

- 2-1 Water Efficient Design
- 2-2 Alternative Water Sources
- 2-3 Cooling Tower Water Use

Part 3 – Sustainable Construction & Management

- 3-1 Refrigerants and Fire Suppressants
- 3-2 Sustainable Construction
- 3-3 Sustainability Policy

Part 4 - Indoor Environmental Quality

- 4-1 Indoor Air Quality Performance
- 4-2 Lighting Quality and Management
- 4-3 Thermal Comfort and Noise Level

Part 5 – Other Green Features

- 5-1 Other Green Features & Innovations

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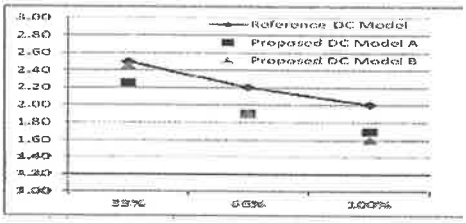

Green Mark NRB:2015



Energy Modelling

Green Mark Energy Modelling - Background

- Nov 2006 – Learning experience from USGBC's GreenBuild Conference at Denver.
- Formation of Energy Modeling Technical Committee to draw up the EM frame work and guidelines.
- Members from private sector, public agencies and tertiary institutes.
- Final EM frame work come effective 15 March 2007.
- Second revision launched Aug 2010, together with Green Mark version 4.0.
- Minor revision of requirements with effective from 15 Jan 2013, in line with Green Mark v4.1
- Third Revision for GM NRB:2015.

Energy Modelling

Green Mark Energy Modelling - Framework & Methodologies

- Models
  - Reference Model
  - Proposed Model
- Reference model: Building that complies to all minimum requirements prescribes in codes and standards.
- Proposed model: Building that being designed for – more than meets code requirements, incorporating innovative energy efficient systems.

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Energy Modelling

Green Mark Energy Modelling - Framework & Methodologies

- Total annual energy consumption between proposed and reference model must
  - Achieve > 25% savings for Gold Plus award.
  - Achieve > 30% savings for Platinum award.
- Use of accredited software and endorsement by QP (Mechanical & Electrical).

Energy Modelling

Green Mark Energy Modelling - Framework & Methodologies

- If proposed model is supplied with District Cooling System (DCS) for which plant data is not available,
  - Energy modelling may exclude the energy consumption on DCS plant, but shall include those on the ACMV components dedicated to the design building; and
  - energy modelling shall demonstrate compliance with the 2 following criteria.

S/N	Criteria	Gold Plus	Platinum
1	Cooling Load Savings	10%	15%
2	Energy Consumption Savings (excluding the Air-Conditioned Plant);	27%	33%

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Energy Modelling

Green Mark Energy Modelling - Framework & Methodologies for NRBv4.1

Compliance with Singapore Standards

- SS530:2006 – Energy efficiency standard for building services and equipment.
- SS 553:2009 -Code of Practice for Air-conditioning and mechanical ventilation in buildings. *(replaced CP 13)*
- SS 531: Part 1: 2006 - Code of Practice for Lighting of work places *(replaced CP 38)*
- ETTV requirements: Guidelines on Envelope Thermal Transfer Value for Buildings.

Others references: ASHRAE std 90.1, std 62.1

Energy Modelling

Green Mark Energy Modelling
- Framework & Methodologies for GMNRB: 2015

Compliance with Singapore Standards

- SS530:2014 – Energy efficiency standard for building services and equipment. *(replace SS530: 2006)*
- SS553:2015 -Code of Practice for Air-conditioning and mechanical ventilation in buildings. *(replace SS553:2009)*
- SS531:2013 Part 1: 2006 - Code of Practice for Lighting of work places *(replace SS531:2006)*
- ETTV requirements: Guidelines on Envelope Thermal Transfer Value for Buildings.

Others references: ASHRAE std 90.1, std 62.1

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Energy Modelling

Green Mark Energy Modelling - Reference Model

SS530: Energy efficiency standard for building services and equipment.

Provides minimum energy efficiency requirements for:

- Air Conditioning equipment
- Heat rejection equipment
- Water Heaters
- Electric Motor Drives
- High Efficiency Lighting

Energy Modelling

Green Mark Energy Modelling - Reference Model

SS530: Energy efficiency standard for building services and equipment.

Air Conditioning equipment

- Unitary air conditioners and condensing units
- Water chilling packages

Equipment Type	Size category	Min Efficiency
Air-conditioners, Air cooled	> 40 kW & < 70 kW	3.22 COP
Air-conditioners, water cooled	> 40 kW & < 70 kW	3.66 COP
Water-cooled, electrically operated, Rotary screw	< 1055 kW	5.33 COP
	> 1055 kW & < 2110 kW	5.77 COP
	>2110 kW	6.28 COP
Water-cooled, electrically operated, centrifugal	< 1055 kW	5.77 COP
	> 1055 kW & < 2110 kW	6.28 COP
	>2110 kW	6.28 COP

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Energy Modelling

Green Mark Energy Modelling - Reference Model

SS530: Energy efficiency standard for building services and equipment.

Max Lighting Power Budget (including ballast loss)

Type of usage	Max Lighting Power Density (W/m2)
Office	12
Retail	25
Restaurants	12
Car parks	3
Corridors	7
Lobbies	7
Stairs	6
...	...

Design service illuminance, lamp efficacies, light output ratios of luminaries in accordance with SS531

Energy Modelling

Green Mark Energy Modelling - Reference Model

SS530: Energy efficiency standard for building services and equipment.

Permanently wired electric motor (0.75 ~ 185kW)

Power (kW)	Minimum nominal full-load efficiency (%)			
	Continuous use [a]		Occasional use [b]	
	2-pole	4-pole	2-pole	4-pole
	IE3 [c]		IE2 [c]	
11	91.2	91.4	89.4	89.8
15	91.9	92.1	90.3	90.6
18.5	92.4	92.6	90.9	91.2
22	92.7	93.0	91.3	91.6
30	93.3	93.6	92.0	92.3
37	93.7	93.9	92.5	92.7
45	94.0	94.2	92.9	93.1
55	94.3	94.6	93.2	93.5

Continuous use: at least 2900hrs/ year

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Green Mark Energy Modelling - Reference Model

SS530: Energy efficiency standard for building services and equipment.

Building with standalone Cooling Plant (non-DCS)

Reference system to be used will be based on the peak building cooling load:

a. Peak building load of 500Rton or more, the reference chiller will be centrifugal.
b. Peak building load of less than 500Rton, the reference chiller will be screw type.
c. Peak building load of less than 500Rton and AC floor area is <5,000m2, the reference system will be the same as proposed system. For VRF, baseline COP = 3.7.

Size	Baseline Configuration
Cooling load < 500 RT A/C areas < 5000 m^2	Same as proposed
Cooling load < 500 RT A/C areas ≥ 5000 m^2	1 x screw chiller (size = peak cooling load) (for peak cooling load ≤ 300 RT) 2 x screw chiller equally sized (total size = peak cooling load) (for peak cooling load >300 RT)
Cooling load ≥ 500 RT	n x centrifugal chillers equally sized (total size = peak cooling load) (capped at 800RT per chiller)

Energy Modelling

Green Mark Energy Modelling - Reference Model

SS530: Energy efficiency standard for building services and equipment.

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

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Energy Modelling

Green Mark Energy Modelling - Reference Model

SS553: CP for air conditioning and mechanical ventilation in buildings.

Components	Minimum Requirement
Air Conditioning Hydronic System	For AC system having pump power exceeding 7.5kW, the pump power limitation for chilled water systems shall be 349 kW/m3/s. The pump power limitation for condensing water system is 301 kW/m3/s.
CHWP	Motor exceeding 3.7 kW shall have control that will result in pump motor demand of no more than 30% of design wattage at 50% of design water flow.
CWP	Condenser water pump shall be equivalent to a constant speed pump.

Notes:

- *349 kW/1000 L/s (equal to a pump operating against a 23 m head, 65% combined impeller and motor efficiency).*
- *301 kW/1000 L/s (equal to a pump operating against a 18 m head, 60% combined impeller and motor efficiency).*

Energy Modelling

Green Mark Energy Modelling - Reference Model

SS553: CP for air conditioning and mechanical ventilation in buildings.

Chilled water pump			
Minimum CHWP performance	349	kW/m3/s	The m3/s refers to CHW flow
CHW supply	7	deg C	
CHW return	12	deg C	
Delta T	5		
Cooling kW per l/s	20.950		Cooling kW = l/s x DT x 4.19
Minimum CHWP performance	0.0586	kWi/ton	kW/ton = 349 / (20.95 x 1000) x 3.5172
Condenser water pump			
Minimum CNWP performance	301	kW/m3/s	The m3/s refers to CNW flow
CNW in	30	deg C	
CNW out	35	deg C	
Delta T	5		
Heat rejection tons per cooling tons	1.25		Based on AHRI ratio of 3gmp/ 2.4gmp
Heat rejection kW per l/s	20.950		Heat rejection kW = l/s x DT x 4.19
Cooling kW per l/s	16.760		Cooling = Rejection /1.25
Minimum CHWP performance	0.0632	kwi/ton	kW/ton = 301 / (16.76 x 1000) x 3.5172

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Energy Modelling

Green Mark Energy Modelling - Reference Model

SS553: CP for air conditioning and mechanical ventilation in buildings.

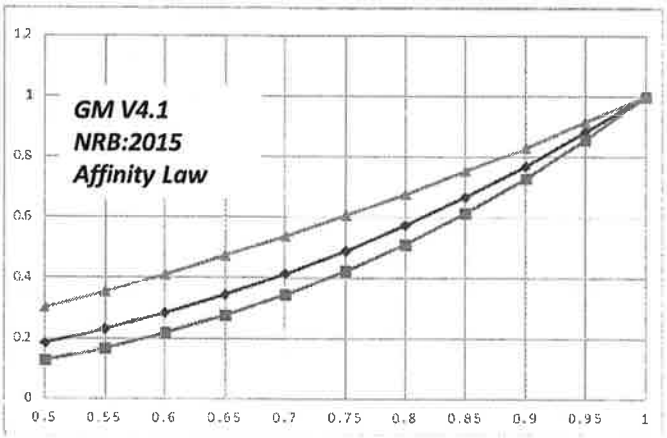
i. Chilled water Pump

Part load efficiency of pump with VSD shall follow the following table and the minimum operating load shall be cap at 25 Hz.

Coefficient a: 0.0000
Coefficient b: 0.0205
Coefficient c: 0.4101
Coefficient d: 0.5753

Power ratio = $a + bx + cx^2 + dx^3$
where x is the flow ratio.

Flow Ratio	Power Ratio
1	1.00590
0.95	0.88284
0.9	0.77002
0.85	0.66703
0.8	0.57342
0.75	0.48876
0.7	0.41263
0.65	0.34458
0.6	0.28420
0.55	0.23105
0.5	0.18469



Energy Modelling

Green Mark Energy Modelling - Reference Model

SS530: Energy efficiency standard for building services and equipment.

Components	Minimum Requirement
Cooling Towers	Performance requirement for heat rejection equipment: a) Propeller or axial fan cooling towers: Cooling tower performance shall not be less than 3.23 L/s/kW. b) Centrifugal fan cooling towers: Cooling tower performance shall not be less than 1.7 L/s/kW.
	Part load performance of Cooling tower with VSD and the minimum operating load shall be capped at 50% (25 Hz) of the equipment capacity. Cooling tower fan power ratio = 0.331629 -0.885676 x + 0.605565 x2 + 0.948482 x3 where x is the part load ratio. Affinity law is not recommended as it does not take into account of loss in actual operating conditions

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Energy Modelling

Green Mark Energy Modelling - Reference Model

SS553: CP for air conditioning and mechanical ventilation in buildings.

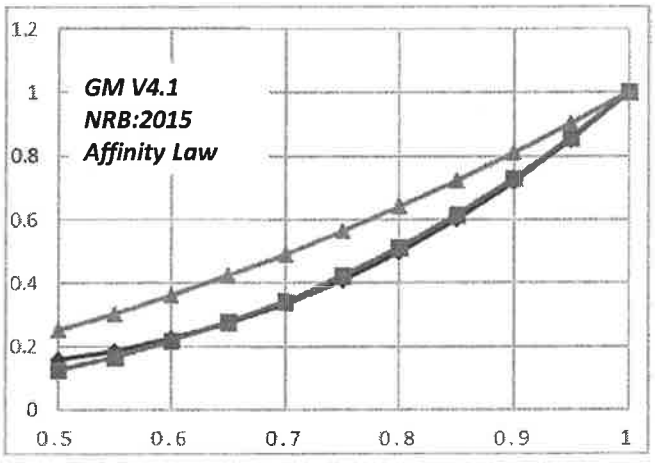
ii. Cooling Tower:

Part load efficiency of cooling tower with VSD shall follow the following table and the minimum operating load shall be cap at 25 Hz.

Coefficient a: 0.331629
Coefficient b: -0.885676
Coefficient c: 0.605565
Coefficient d: 0.948482

Power ratio = a + bx + cx2 + dx3
where x is the flow ratio.

Flow Ratio	Power Ratio
1	1.0000
0.95	0.8500
0.9	0.7165
0.85	0.5988
0.8	0.4963
0.75	0.4081
0.7	0.3337
0.65	0.2723
0.6	0.2231
0.55	0.1855
0.5	0.1587



The Education and Research arm of the Building and Construction Authority

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Energy Modelling

Green Mark Energy Modelling - Reference Model

SS530: Energy efficiency standard for building services and equipment.

Building with District Cooling Plant

For buildings with chilled water supplied/ to be supplied by a District Cooling System (DCS) company:

Path A: The DCS information for the building served by district chilled water are available. All ACMV components dedicated to the DCS plant and building designed shall be included and considered.

Path B: The energy consumption contribution from the DCS plant may be excluded from the energy modeling provided the two criteria as follows are complied with:

Level of Green Mark Award	Cooling Load Savings	Energy Consumption Savings (exclude DCS plant)
Gold^{PLUS}	10%	27%
Platinum	15%	33%

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Energy Modelling

Green Mark Energy Modelling - Reference Model

SS553: CP for air conditioning and mechanical ventilation in buildings.

Components	SS530:2006 and SS553:2009 (referenced to AHRI 550/590)	SS530:2014 and SS553:2016 (referenced to AHRI 551/591)
Chiller (> 300Rton)	0.5766 kW/ton	0.5595 kW/ton
Chilled Water Pump	0.0534 kW/ton	0.05866 kW/ton
Condenser Water Pump	0.0575 kW/ton	0.06323 kW/ton
Cooling Tower	0.0591 kW/ton	0.06504 kW/ton
Total	0.7465 kW/ton	0.7465 kW/ton
Rating: CHW temperature	CHW: 6.7 to 12.2 deg C	CHW: 12 to 7 deg C
Rating: CW temperature	CW: 29.4 to 34.6 deg C	CW: 30 to 35 deg C

Energy Modelling

Green Mark Energy Modelling - Reference Model

SS553: CP for air conditioning and mechanical ventilation in buildings.

MECHANICAL FAN EFFICIENCY

Fan System	2006 [w/cmh]	2015 [w/cmh]	Tightening of Code Percentage
Fan power limitation in mechanical ventilation systems [CAV & VAV]	0.42	0.30	28.5%

AIR – CONDITIONING FAN EFFICIENCY

No change in Air – Con Fan system Efficiency from pervious version

	Limit	Constant Volume	Variable Volume
Option 1: Fan system motor nameplate kW	Allowable nameplate motor kW	kW ≤ L/Ss x 0.0017	kW ≤ L/Ss x 0.0024
Option 2: Fan system input kWi	Allowable fan system input kWi	kWi ≤ L/Ss x 0.0015 + A	kWi ≤ L/Ss x 0.0021 + A

Notes:

All VAV system shall have VSD control regardless of fan motor is less than 7.5 kW

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Energy Modelling

Green Mark Energy Modelling - Reference Model

SS553: CP for air conditioning and mechanical ventilation in buildings.

Fan System Design Criteria

(c) For fan systems with a motor nameplate power ≥ 4 kW, the fan power limitation in air-conditioning system (the allowable fan system input power) shall be as follows:

(i) Constant volume shall not exceed 1.5 kW/m^3/s (or 0.42 W/CMH + A) of supply air. Reference control strategy for CAV system shall be constant speed.

(ii) Variable volume shall not exceed 2.1 kW/m^3/s (or 0.58 W/CMH + A) of supply air.

(d) For fan system having a motor nameplate power < 4 kW, the allowable fan system input power shall be ≤ 0.6 kW/m^3/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 proposed fan can be applied to the Reference Model.

Energy Modelling

Device	Adjustment
Fully ducted return and/or exhaust air systems	125 Pa (535 Pa for laboratory and vivarium systems)
Return and/or exhaust airflow control devices	125 Pa
Exhaust filters, scrubbers, or other exhaust treatment	The pressure drop of device calculated at fan system design condition
Particulate filtration credit: MERV 9 – 12	125 Pa
Particulate filtration credit: MERV 13 – 15	225 Pa
Particulate filtration credit: MERV 16 and greater and electronically enhanced filters	Pressure drop calculated at 2× clean filter pressure drop at fan system design condition
Carbon and other gas-phase air cleaners	Clean filter pressure drop at fan system design condition
Biosafety cabinet	Pressure drop of device at fan system design condition
Energy recovery device, other than coil runaround loop	(550 × Energy Recovery Effectiveness) – 125 Pa for each airstream
Coil runaround loop	150 Pa for each airstream
Evaporative humidifier/cooler in series with another cooling coil	Pressure drop of device at fan system design condition
Sound attenuation section (fans serving spaces with design background noise goals below NC35)	38 Pa
Exhaust system serving fume hoods	85 Pa
Laboratory and vivarium exhaust systems in high-rise buildings	60 Pa/30 m of vertical duct exceeding 25 m

CMH = maximum design supply airflow rate to conditioned spaces served by the system in cubic metre per hour

Wi = maximum combined fan input W

A = sum of (PD / 2340)

PD = each applicable pressure drop adjustment

Energy Modelling

Green Mark Energy Modelling - Reference Model

SS553: CP for air conditioning and mechanical ventilation in buildings.

Note: Fan power limitation pressure drop adjustment is not applicable for the following devices:

- *Return and/or exhaust air systems*
- *Return and/or exhaust airflow control devices*
- *Exhaust filters or other exhaust treatment*
- *Particulate Filtration Credit: MERV 9 – 14*

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 : 2015

Energy Modelling

Green Mark Energy Modelling - Reference Model

Move towards Passive Design Approach:

+ Passive Design Enhancement

- Projects that demonstrate considerable efforts to reduce air-conditioning energy consumption, a cap of **3%** of additional energy savings from passive design features over its Reference Model can be considered.
- Justification by demonstrating design strategies can enhance the ventilation and thermal comfort of the designated non air-conditioned spaces

  - Simulations and/or calculations

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Energy Modelling

Green Mark Energy Modelling - Reference Model

Move towards Passive Design Approach:

Passive Design Enhancement

Examples

- Circulation spaces such as atria, can be considered if these spaces are largely designed to be non-air-conditioned and sizeable. This is not applicable to areas that would normally be non-air-conditioned, such as warehouses, school classrooms and pantries.
- The introduction of air well or slopes to convert a mechanical ventilated car park to a code compliant natural ventilated car park is also acceptable. However, open air naturally ventilated carparks cannot be considered for energy savings.

Energy Modelling

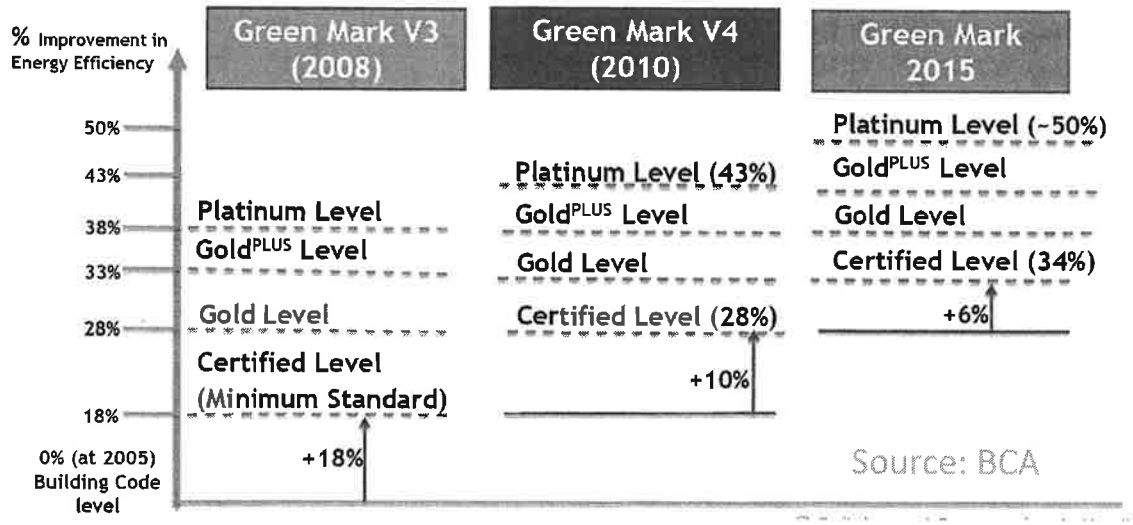
Green Mark Energy Modelling - Reference Model

- Where no Baseline Standard is available, the basis for deriving the overall energy consumption and potential savings must be made clear and justifiable for consideration.
- Notwithstanding this, the potential energy savings for the following system/devices are subject to the cap based on the following norm:

List of Systems/Devices		Energy Savings Cap
Escalator		30%
Lifts	With VVVF and Sleep mode	10%
	Regenerative features	18%
CO sensors		15%
Occupancy Sensors		15%
Photo Sensors		15%

Energy Modelling

Green Mark NRB4.1 & GM NRB:2015



Energy Saving Requirements

Baseline has increased but target 30% remained the same for Platinum award

Energy Modelling

Green Mark NRB4.1 & GM NRB:2015

CHILLER EFFICIENCY

Typology Of Chiller .	2006 [COP]	2014 [COP]	Changes to Code [Percentage]
Water – cooled centrifugal ≥ 528kW to <1055kW	5.5	5.771	4.7% (tighten)
Water – cooled centrifugal ≥ 2110 kW	6.10	6.286	2.9% (tighten)
Rotary Screw & Scroll <263kW	4.45	4.694	5.2% (tighten)
Rotary Screw & Scroll ≥ 264kW to < 528 kW	4.45	4.889	9.0% (tighten)
Rotary Screw & Scroll ≥528 kW to <1055 kW	4.90	5.334	8.2% (tighten)
Rotary Screw & Scroll ≥1055 kW to <2100 kW	5.50	5.771	4.7% (tighten)
Rotary Screw & Scroll ≥2100 kW	5.50	6.286	12.5% (tighten)
VRF ≥17.6 kW to < 40 kW	3.37 (GM Ref)	3.28	2.7% (relax in standard)
VRF ≥40 kW to < 70 kW	3.37 (GM Ref)	3.22	4.7% (relax in standard)
VRF ≥70 kW	3.37 (GM Ref)	2.93	15% (relax in standard)

Note: SS 530 was launched in 2015

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Energy Modelling

Green Mark NRB4.1 & GM NRB:2015

LIGHTING POWER BUDGET

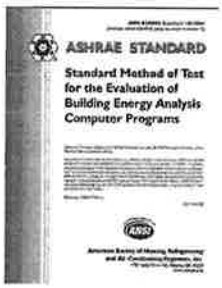
Spaces	2006 [COP]	2014 [COP]	Tightening of Code [Percentage]
Office / Classroom /	15	12	20%
Car Park	5	3	40%
Corridors	10	7	30%
Warehouse	10	7	30%
Restaurants	15	12	20%
Laboratories	-	16	-
Lobbies/ Auditorium	10	10	0%
Supermarket/ Departmental Store	25	20	20%
Lift Lobby	10	7	30%
Toilet and M&E	-	10	-
Hotel Guestrooms	-	12	-

Note: SS 530 was launched in 2015

Energy Modelling

Green Mark Energy Modelling - Software Selection

- The software must be able 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.
- The software must be tested by a recognized institution in accordance to the Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs - **ANSI/ASHRAE STD 140** or other international equivalent, such as **IEA HVAC BESTEST**.



Energy Modelling

Green Mark Energy Modelling - Software Options

- DOE-2*
- Energy-10
- EnergyPlus*
- eQUEST*
- HAP (E-20)
- IES VE
- PowerDOE
- TAS
- TRACE
- TRNSYS
- VisualDOE 4.1

- Note: * Free software

Energy Modelling

Green Mark Energy Modelling - Methodology

Create massing model ← Layout, shape, size, orientation

⇩

Define roof, windows, floors, openings, shading, walls, etc ← U-value, color, dimensions, transmission, etc

⇩

Define zones having different ACMV ⇨ **For each zone, define heat loads, lighting systems, operating schedules, etc** ⇨

Energy Modelling

Green Mark Energy Modelling - Methodology

⇨ **Define ACMV details for each zone** ← COP, flow rates, set-points, etc for pumps, fans, dehumidifiers, chillers, etc

← Sensors & other efficient features may reduce operating times, energy consumptions

⇩

Run simulation ← Local weather data files

⇩

Peak load, Part load, Annual power consumption data

Energy Modelling

Green Mark Energy Modelling - Methodology

- Extract relevant data from the building plans or other project documentations as inputs for **Proposed Model.**

  - Building design layout in terms of shape, size and orientation.

  - Materials for walls, windows, roofs, floors, doors and permanent shading devices.

  - Internal loads such as levels and schedules for occupancy, lighting systems, equipment, appliances and machinery within the building.

  - HVAC equipment, controls and other associated components selected for use in the building.

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Energy Modelling

Green Mark Energy Modelling - Methodology

- Perform hourly simulation for **proposed model.**

- Compute the overall energy consumption of the model, using the building envelope and all energy-consuming equipment that are selected during the design stage.

- These include chillers, air handling systems, plant equipment, and non-HVAC systems such as lightings, lifts, escalators, and receptacle loads from equipment.

Energy Modelling

Green Mark Energy Modelling - Methodology

- Extract relevant data from the Codes and Singapore standards or other project documentations as inputs for **reference model.**

  - Building design layout in terms of shape, size and orientation.

  - Materials for walls, windows, roofs, floors, doors and permanent shading devices.

  - Internal loads such as levels and schedules for occupancy, lighting systems, equipment, appliances and machinery within the building.

  - HVAC equipment, controls and other associated components selected for use in the building.

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Energy Modelling

Green Mark Energy Modelling - Methodology

- Perform hourly simulation for **reference model.**

- Compute the overall energy consumption of the model, using the building envelope and all energy-consuming equipment that are selected during the design stage.

- Compare the overall energy consumption of the Reference Model against the Proposed Model.

Energy Modelling

Green Mark Energy Modelling - Methodology

The simulations for both the Proposed Model and Reference Model shall use:

- the same software,
- the same weather data,
- the same operating schedules,
- the same occupancy rates,
- the same building design in terms of shape, size and orientation,
- the same receptacle loads,
- the same indoor environmental conditions in terms of thermal comfort level, and
- the same internal illuminance levels (lux) for space lightings.

Energy Modelling

Green Mark Energy Modelling Submission

- Energy Model Submission in two stages:

  1. At the Green Mark Certification Stage

  2. At the validation stage when building is in steady operation.

continuously 12 months

Energy Modelling

Green Mark Energy Modelling - Methodology

- Completed building
  - Compile monthly whole-building energy use utility data for 12 months.

- Reference building model
  - Revise schedules and occupancy data
  - Simulate annual energy consumption and compare with actual performance
  - Explain any differences

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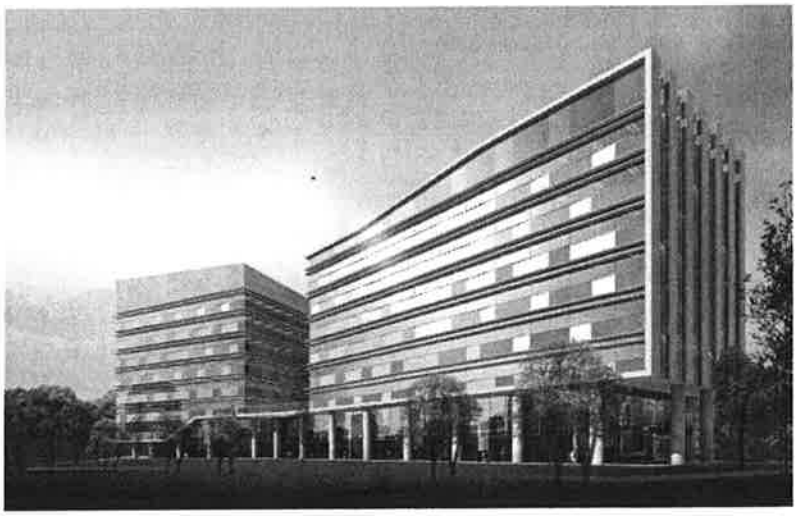
Energy Modelling

Case Study – Tampines Grande



Proposed Erection of 2 Blocks of **8-Storey** Office Building with One Level of **Basement Carpark** on HDB Land Parcel P15 Lot 2559K Mk 29 at Tampines Grande (Tampines Planning Area)

Energy Modelling

Case Study – Tampines Grande
Methodology- Simplified Floor Plans

- The building thermal zones had been modified into **Simple Zones** based on the occupancy type, operating hours and ACMV system
- Ensure that no significant differences in
  - ✓ Floor Area,
  - ✓ Exterior Wall Area,
  - ✓ Window area &
  - ✓ Orientation.

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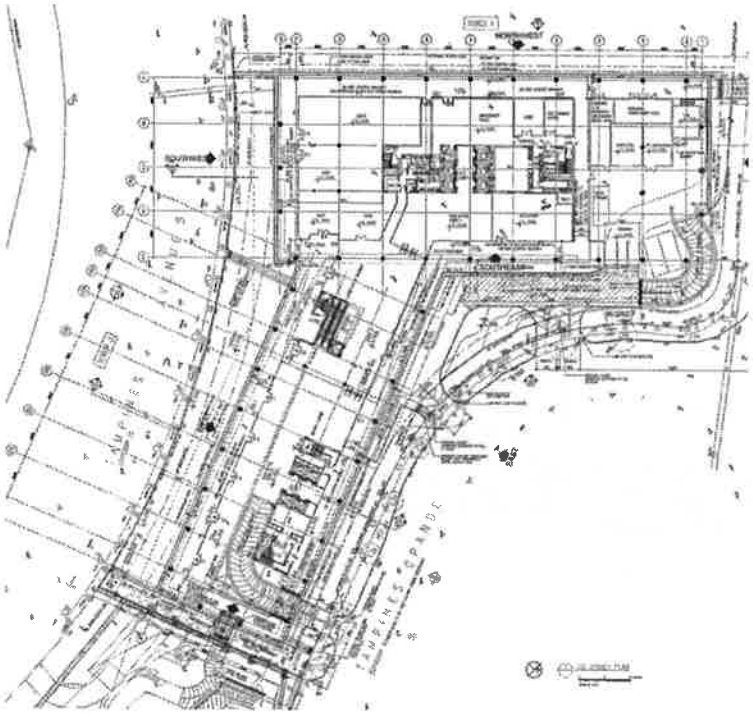
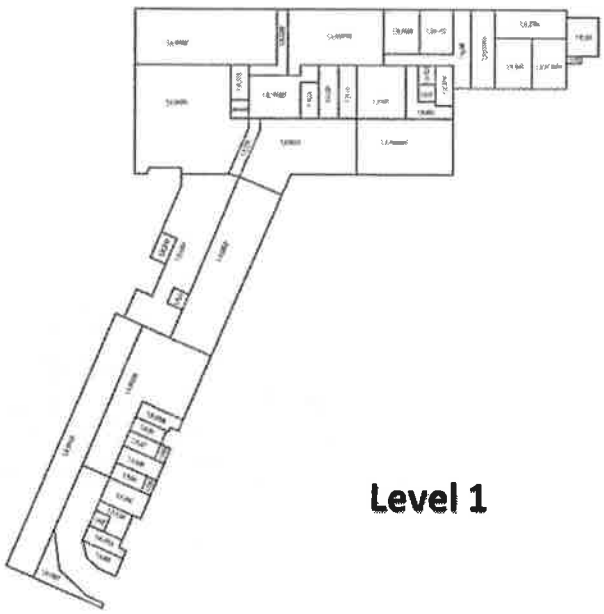
Energy Modelling

Case Study – Tampines Grande
Methodology- Simplified Floor Plans

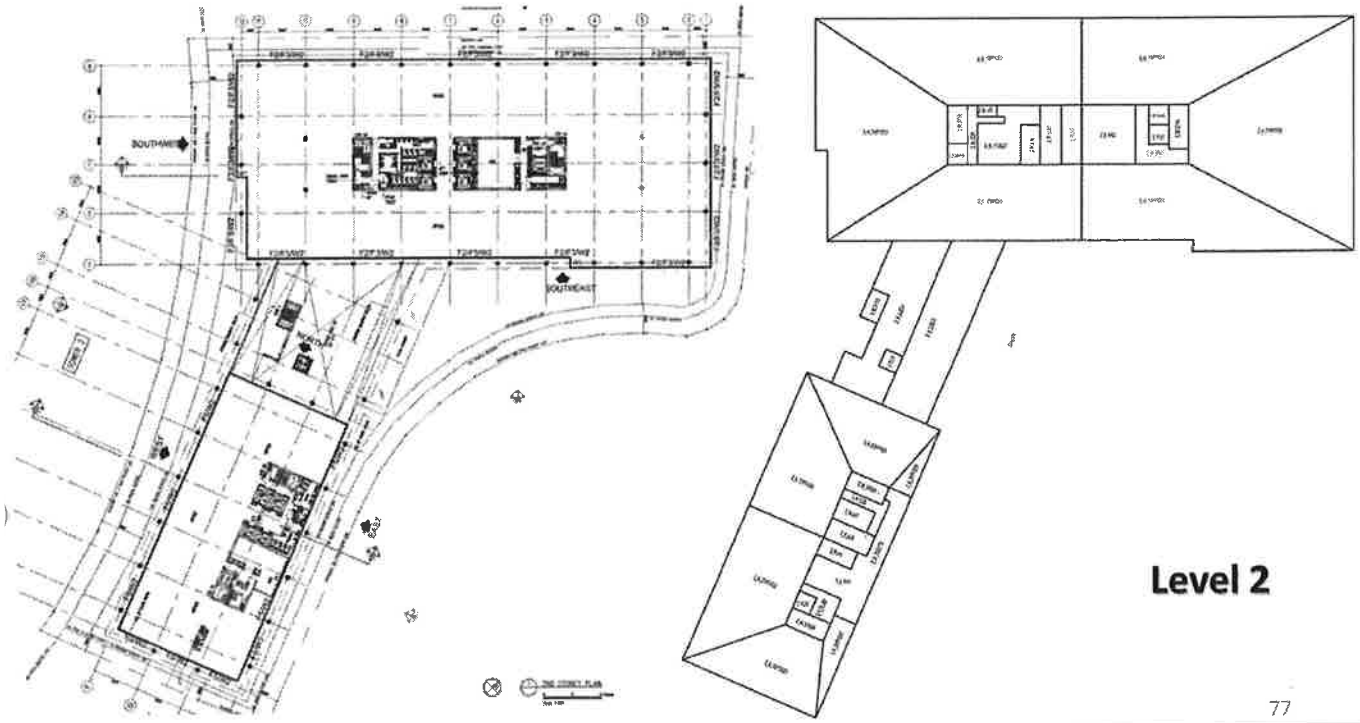




Level 1

Energy Modelling

Case Study – Tampines Grande
Methodology- Simplified Floor Plans



Level 2

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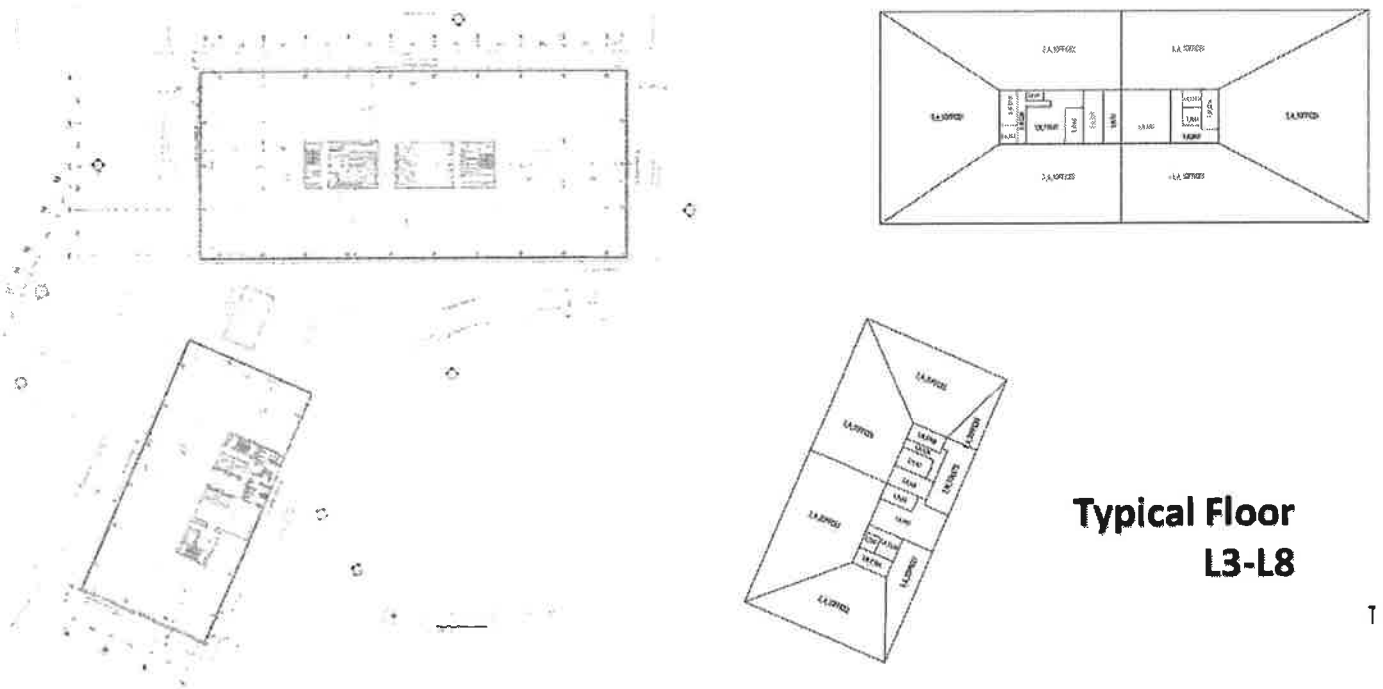
Energy Modelling

Case Study – Tampines Grande
Methodology- Simplified Floor Plans



Typical Floor
L3-L8

Energy Modelling

Case Study – Tampines Grande
Simulation Inputs – Building Envelope (example)

BUILDING ELEMENT	REFERENCE MODEL	PROPOSED MODEL
Wall Construction	Glass, Air gap, cement plaster, light weight wall, Rockwool insulation, Alum Cladding; U = 2.72 W/m2K	Glass, Air gap, cement plaster, light weight wall, Rockwool insulation, Alum Cladding, U = 0.83 W/m2K; south façade U=0.54 W/m2K
Windows	Same as Proposed Model	12mm Single glaze U = 4.1, SC = 0.7 Double glaze U = 1.7, SC = 0.32
Skylight	Same as Proposed Model	RC slab
Floor	Medium construction, U = 0.8 W/m2K	RC roof , U = 0.49 W/m2K
Roof	Same as Proposed Model	0.54
Window to Wall Ratio (WWR)	ETTV = 50 W/m2	ETTV = 39.5 W/m2

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Energy Modelling

Case Study – Tampines Grande
Simulation Inputs – Lighting Power Budget (example)

BUILDING ELEMENT	REFERENCE MODEL	PROPOSED MODEL
Lighting Power Density (W/m^2)	Office = 15 W/m2 Circulation = 10 W/m2 Main Lobby = 10 W/m2 Mgt Office = 15 W/m2 Restaurant = 15 W/m2 Retail = 25 W/m2 Stairs = 6 W/m2 Car Park = 5 W/m2 Utilities = 10 W/m2 Toilet = 10 W/m2	Office = 10 W/m2 Circulation = 8 W/m2 Main Lobby = 10 W/m2 Mgt Office = 10 W/m2 Restaurant = 15 W/m2 Retail = 25 W/m2 Stairs = 4 W/m2 Car Park = 3 W/m2 Utilities = 10 W/m2 Toilet = 10 W/m2

Energy Modelling

Case Study – Tampines Grande
Simulation Inputs – ACMV (example)

BUILDING ELEMENTS	REFERENCE MODEL	PROPOSED MODEL
AHU Fan Properties	AHU VAV Fan with 0.67 W/cmh	AHU Fan with average 0.36W/cmh
Central Plant Efficiency	Auto-sizing based on peak load CHW pump = 0.053 kW/ton CW pump = 0.057 kW/ton Cooling Tower = 0.059 kW/ton	2 x 600 Rton Cent Chillers, COP = 7.25 2 x 300 Rton Screw Chillers, COP = 6.94 CHW pump = 0.04 kW/ton CW pump = 0.03 kW/ton Cooling Tower = 0.03 kW/ton
HVAC Circulation Properties	CHW pump 2.85 (l/m)/ikW, head: 25 m CHW pump efficiency = 51.93 x 94.2 CW pump 3.23 (l/m)/ikW, head: 15m CW pump efficiency = 29.2 x 93.2	CHW pump 2.85 (l/m)/ikW, head: 25 m CHW pump efficiency = 89.42 x 94.5 CW pump 3.23 (l/m)/ikW, head: 15 m CW pump efficiency = 85.19 x 93.9

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Energy Modelling

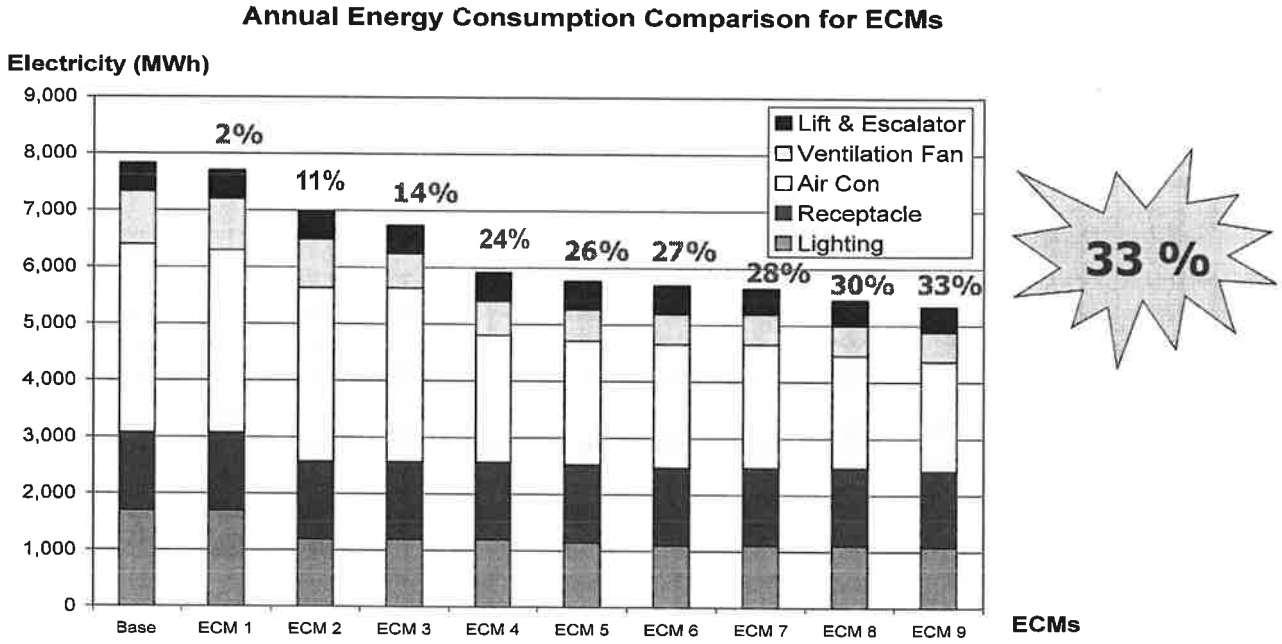
Case Study – Tampines Grande
Energy Conservation Measures (ECM)

BASE: Building design to comply with Code of Practices & BCA approved documents.

ECM1: Improve ETTV from 50 W/m2 to 39 W/m2
ECM2: Select T5 lighting solution that reduces 30% from BASE case.
ECM3: Improve air ventilation efficiency by 45% from BASE case.
ECM4: Chilled water plant Optimization and efficiency improvement by 25%.
ECM5: Incorporate motion sensor & CO2 sensor in building design.
ECM6: Introduce perimeter lighting control with photo sensor.
ECM7: Energy Efficient AC VVVF lift & escalator with slow down feature.
ECM8: Incorporate energy recovery solution for fresh air pre-cool AHU
ECM9: Integrate Solar Photovoltaic Panel at roof top of development.

Energy Modelling

Case Study – Tampines Grande
Energy Conservation Measures (ECM)



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Thank you

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GMP : Energy Modeling Theories (Cooling load)

How should we understand process of cooling load calculation?

Presented by : Yong Ping Quen
Environmentally Sustainable Development (ESD) Consultant,
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GMP : Energy Modeling Theories (Cooling load)
How should we understand process of cooling load calculation?



CONTENTS

1. Introduction of cooling load calculation in EM
2. Internal Heat Gain in cooling load calculation
3. Infiltration Heat Gain in cooling load calculation
4. Fenestration Heat Gain in cooling load calculation
5. Heat Balance Method in cooling load calculation

Presented by : Yong Ping Quen
Environmentally Sustainable Development (ESD) Consultant,
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1. Introduction of cooling load calculation in EM

Understanding for cooling load calculation : Load calculations should be accurately described because these calculation affect the size of piping, duck work, diffusers, air handlers, chillers, coils, fans and every component of systems that condition indoor environment.

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1. Introduction of cooling load calculation in EM

Cooling Load Calculation Principles

Load calculations should be accurately described because these calculation affect the size of piping, duck work, diffusers, air handlers, chillers, coils, fans and every component of systems that condition indoor environment.

Cooling loads result from many conduction, convection, and radiation, heat transfer processes through the building envelope and from internal sources and system components. Building components or contents that may affect cooling loads include the following:

1) External : Walls, roofs, windows, skylights, doors, partitions, ceilings, and floors
2) Internal : Lights, people, appliances, and equipment
3) Infiltration : Air leakage and moisture migration
4) System : Outside air, duct leakage and heat gain, reheat, fan and pump energy, and energy recovery

In GMP course, we will look into theories related to cooling load calculation in energy modeling based on ASHRAE Fundamental 2009. It includes two methods of heating and cooling load estimation: heat balance (HB) and radiant time series (RTS). We will check heat balance method.

Generally, heat balance is used for cooling load calculation in EM.

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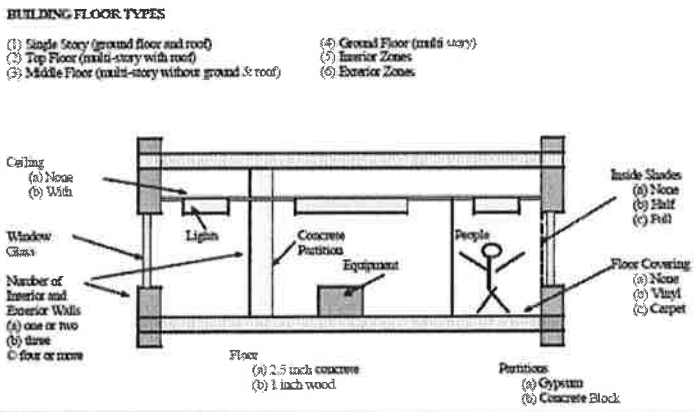
1. Introduction of cooling load calculation in EM

Cooling Load Calculation Principles

This instantaneous rate of heat gain is the rate at which heat enters into and/or is generated within a space. Heat gain is classified by its mode of entry into the space and whether it is sensible or latent.

(1) Solar radiation through transparent surfaces;
(2) Heat conduction through exterior walls and roofs;
(3) Heat conduction through ceilings, floors, and interior partitions;
(4) Heat generated in the space by occupants, lights, and appliances;
(5) Energy transfer through direct-with-space ventilation and infiltration of outdoor air
(6) Miscellaneous heat gains.



- Sensible heat is added directly to the conditioned space by conduction, convection, and/or radiation.
- Latent heat gain occurs when moisture is added to the space (e.g., from vapor emitted by occupants and equipment).

1. Introduction of cooling load calculation in EM

Cooling Load Calculation Principles

Radiant Heat Gain. Radiant energy must first be absorbed by surfaces that enclose the space (walls, floor, and ceiling) and objects in the space (furniture, etc.). When these surfaces and objects become warmer than the surrounding air, some of their heat transfers to the air by convection.

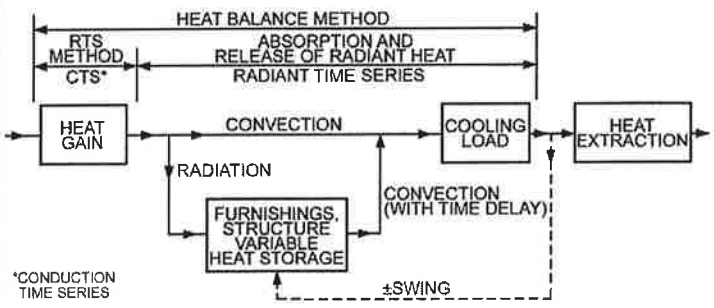


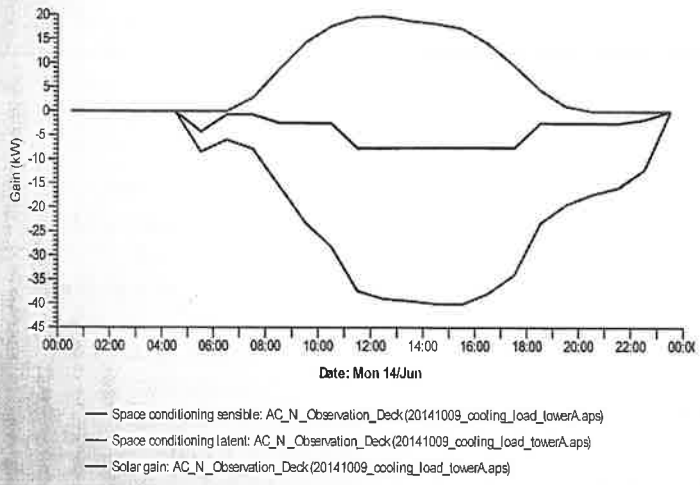
Fig. 1 Origin of Difference Between Magnitude of Instantaneous Heat Gain and Instantaneous Cooling Load

The composite heat storage capacity of these surfaces and objects determines the rate at which their respective surface temperatures increase for a given radiant input. Some of portion of absorbed heat by radiation will release after some time lag. It is called to "Time delay effect".

1. Introduction of cooling load calculation in EM

Cooling Load Calculation Principles

Space Cooling Load This is the rate at which sensible and latent heat must be removed from the space to maintain a constant space air temperature and humidity. The sum of all space instantaneous heat gains at any given time does not necessarily (or even frequently) equal the cooling load for the space at that same time because of the time delay effect.



For example, to maintain design temperature, about 35kW need to be removed at 4pm in left profile.

As can be seen in green profile, solar heat gain profile is different with sensible cooling load profile because of the time delay effect.

The peak cooling load occurs after 3-4hours later than peak when solar heat gain happens.

The space cooling load is what cooling system have to remove from zone to maintain design temperature.

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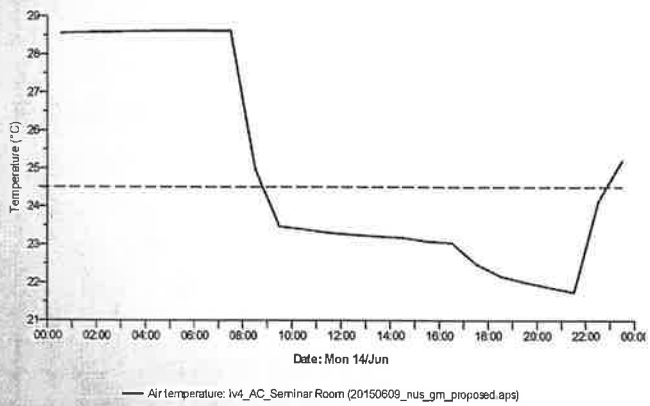
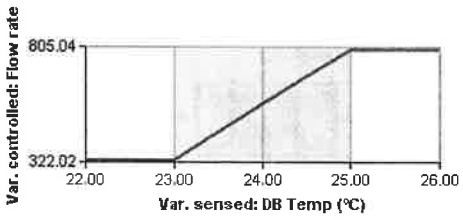
1. Introduction of cooling load calculation in EM

Cooling Load Calculation Principles

Space Heat Extraction Rate Basically, cooling load amount is not same as the rate at which sensible and latent heat are removed from the conditioned space by cooling equipment due to control of the systems. The control systems usually allow a minor cyclic variation or swing in room temperature.

This means that the different control strategy of cooling system affect the room air temperature or humidity profiles. For example, below profiles shows 21.5C after 10pm due to fixed minimum flow rate of AHU. It shows more realistic result of zone temperature.





Therefore, proper simulation of the control system gives a more realistic value of energy removal over a fixed period than using values of the space cooling load.

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1. Introduction of cooling load calculation in EM

Cooling Load Calculation Principles

Time delay effect Energy absorbed by walls, floor, furniture, etc., contributes to space cooling load only after a time lag. Some of this energy is still present and reradiating even after the heat sources have been switched off or removed, as shown in Figure 2.

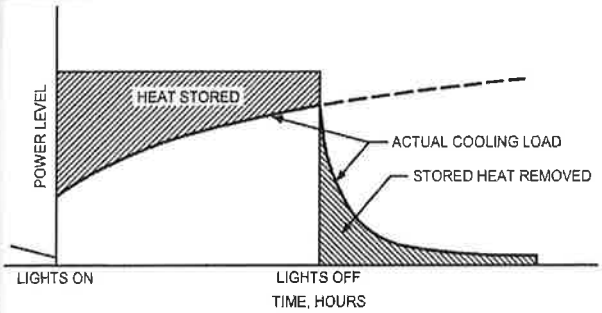

Fig. 2 Thermal Storage Effect in Cooling Load from Lights

There is always significant delay between the time a heat source is activated, and the point when reradiated energy equals that being instantaneously stored. This time lag must be considered when calculating cooling load, because the load required for the space can be much lower than the instantaneous heat gain being generated, and the space's peak load may be significantly affected.

Energy modeling software consider this time delay effect to calculate more accurate cooling load result.

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1. Introduction of cooling load calculation in EM

What information do we need for cooling load calculation?

Calculating space cooling loads requires detailed building design information and weather data at design conditions. Generally, the following information should be compiled.

1) Building Characteristics : Building materials, external surface colours, and shape are usually determined from building plans and specifications.
2) Configuration : Determine building location, orientation, and external shading from building plans and specifications. Shading from adjacent buildings can be determined from a site plan. Shading from adjacent buildings can be determined from a site plan or by visiting the proposed site.
3) Outdoor design condition : Weather data.
4) Indoor design condition : Select indoor dry-bulb temperature, indoor relative humidity, and ventilation rate. Include permissible variations and control limits. Consult ASHRAE Standard 90.1 for energy-savings conditions, and Standard 55 for ranges of indoor conditions needed for thermal comfort.
5) Internal Heat Gains and Operating Schedules : Obtain planned density and a proposed schedule of lighting, occupancy, internal equipment, appliances, and processes that contribute to the internal thermal load.
6) Area : Use consistent methods for calculation of building areas.

Based on the above information, cooling load calculation can be conducted.

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2. Internal Heat Gains

Internal Heat Gains and Operating Schedules : Obtain planned density and a proposed schedule of lighting, occupancy, internal equipment, appliances, and processes that contribute to the internal thermal load.

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2. Internal Heat Gains

People Heat gain in Cooling load calculation

People heat gain : Table 1 gives representative rates at which sensible heat and moisture are emitted by humans in different states of activity. In high-density spaces, such as auditoriums, these sensible and latent heat gains comprise a large fraction of the total load.

Table 1 Representative Rates at Which Heat and Moisture Are Given Off by Human Beings in Different States of Activity

Degree of Activity		Total Heat, W		Sensible Heat, W	Latent Heat, W
		Adult Male	Adjusted, M/F[a]		
Seated at theater	Theater, matinee	115	95	65	30
Seated at theater, night	Theater, night	115	105	70	35
Seated, very light work	Offices, hotels, apartments	130	115	70	45
Moderately active office work	Offices, hotels, apartments	140	130	75	55
Standing, light work; walking	Department store; retail store	160	130	75	55
Walking, standing	Drug store, bank	160	145	75	70
Sedentary work	Restaurant[c]	145	160	80	80
Light bench work	Factory	235	220	80	140
Moderate dancing	Dance hall	265	250	90	160
Walking 4.8 km/h; light machine work	Factory	295	295	110	185
Bowling[d]	Bowling alley	440	425	170	255
Heavy work	Factory	440	425	170	255
Heavy machine work; lifting	Factory	470	470	185	285
Athletics	Gymnasium	585	525	210	315

Heat gain from adult female is 85% of adult male and one of a child is 75% of adult male.

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2. Internal Heat Gains

Lighting Heat gain in Cooling load calculation

Lighting Heat Gain : Because lighting is often a major space cooling load component, an accurate estimate of the space heat gain it imposes is needed. Calculation of this load component is not straightforward; the rate of cooling load from lighting at any given moment can be quite different from the heat equivalent of power supplied instantaneously to those lights, because of heat storage.

$$q_{el} = WF_{ul}F_{sa}$$

where

q_{el} = heat gain, W
W = total light wattage, W
F_{ul} = lighting use factor
F_{sa} = lighting special allowance factor

The total light wattage (Installed lighting wattage without ballast loss) is obtained from the ratings of all lamps installed, both for general illumination and for display use.

The lighting use factor is the ratio of wattage in use, for the conditions under which the load estimate is being made, to total installed wattage.

The special allowance factor (To include ballast loss) is the ratio of the lighting fixtures' power consumption, including lamps and ballast, to the nominal power consumption of the lamps.

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2. Internal Heat Gains

Lighting Heat gain in Cooling load calculation

Lighting Heat Gain : An alternative procedure is to estimate the lighting heat gain on a per square foot basis. Such an approach may be required when final lighting plans are not available. Table 2 shows the maximum lighting power density (LPD) (lighting heat gain per square metre) allowed by ASHRAE Standard 90.1-2007 for a range of space types.

Table 2 Lighting Power Densities Using Space-by-Space Method

Common Space Types[a]	LPD, W/m²	Building-Specific Space Types	LPD, W/m²
Office—enclosed	12	Gymnasium/exercise center	
Office—open plan	12	Playing Area	15
Conference/meeting/multipurpose	14	Exercise Area	10
Classroom/lecture/training	15	Courthouse/police station/penitentiary	
For penitentiary	14	Courtroom	20
Lobby	14	Confinement cells	10
For hotel	12	Judges' chambers	14
For performing arts theater	36	Fire Stations	
For motion picture theater	12	Engine room	9
Audience/seating Area	10	Sleeping quarters	3
For gymnasium	4	Post office—sorting area	13
For exercise center	3	Convention center—exhibit space	14
For convention center	8	Library	
For penitentiary	8	Card file and cataloging	12
For religious buildings	18	Stacks	18
For sports arena	4	Reading area	13
For performing arts theater	28	Hospital	
For motion picture theater	13	Emergency	29
For transportation	5	Recovery	9
Atrium—first three floors	6	Nurses' station	11
Atrium—each additional floor	2	Exam/treatment	16
Lounge/recreation	13	Pharmacy	13
For hospital	9	Patient room	8
Dining Area	10	Operating room	24
For penitentiary	14	Nursery	6
For hotel	14	Medical supply	15
For motel	13	Physical therapy	10
For bar lounge/leisure dining	15	Radiology	4
For family dining	23	Laundry—washing	6
Food preparation	13	Automotive—service/repair	8

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2. Internal Heat Gains

Lighting Heat gain in Cooling load calculation

Lighting Heat Gain : In addition to determining the lighting heat gain, the fraction of lighting heat gain that enters the conditioned space may need to be distinguished from the fraction that enters an unconditioned space; of the former category, the distribution between radiative and convective heat gain must be established.

Table 3 Lighting Heat Gain Parameters for Typical Operating Conditions

Luminaire Category	Space Fraction	Radiative Fraction	Notes
Recessed fluorescent luminaire without lens	0.64 to 0.74	0.48 to 0.68	• Use middle values in most situations • May use higher space fraction, and lower radiative fraction for luminaire with side-slot returns • May use lower values of both fractions for direct/indirect luminaire • May use higher values of both fractions for ducted returns
Recessed fluorescent luminaire with lens	0.40 to 0.50	0.61 to 0.73	• May adjust values in the same way as for recessed fluorescent luminaire without lens
Downlight compact fluorescent luminaire	0.12 to 0.24	0.95 to 1.0	• Use middle or high values if detailed features are unknown • Use low value for space fraction and high value for radiative fraction if there are large holes in luminaire's reflector
Downlight incandescent luminaire	0.70 to 0.80	0.95 to 1.0	• Use middle values if lamp type is unknown • Use low value for space fraction if standard lamp (i.e. A-lamp) is used • Use high value for space fraction if reflector lamp (i.e. BR-lamp) is used
Non-in-ceiling fluorescent luminaire	1.0	0.5 to 0.57	• Use lower value for radiative fraction for surface-mounted luminaire • Use higher value for radiative fraction for pendant luminaire

Source: Fisher and Chantrasrisalai (2006).

The space fraction in the table is the fraction of lighting heat gain that goes to the room and the rest of fraction goes to the plenum. The radiative fraction is the radiative part of the lighting heat gain that goes to the room. The rest of fraction will be convective fraction of the lighting heat gain.

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2. Internal Heat Gains

Equipment Heat gain in Cooling load calculation

Equipment Heat Gain : A cooling load estimate should take into account heat gain from all appliances (electrical, gas, or steam). ASHRAE fundamental provides the reference number for the equipment heat gain for office, medical and laboratory equipment. Nameplate data rarely reflect the actual power consumption of office equipment. Actual power consumption is assumed to equal total (radiant plus convective) heat gain

(1) Office Equipment : Computers, printers, copiers, etc., can generate very significant heat gains, sometimes greater than all other gains combined.

A. Computer Equipment heat gain

Table 8 Recommended Heat Gain from Typical Computer Equipment

Equipment	Description	Nameplate Power Consumption, W	Average Power Consumption, W
Desktop computer[a]	Manufacturer A (model A); 2.8 GHz processor, 1 GB RAM	480	73
	Manufacturer A (model B); 2.6 GHz processor, 2 GB RAM	480	49
	Manufacturer B (model A); 3.0 GHz processor, 2 GB RAM	690	77
	Manufacturer B (model B); 3.0 GHz processor, 2 GB RAM	690	48
	Manufacturer A (model C); 2.3 GHz processor, 3 GB RAM	1200	97
Laptop computer[b]	Manufacturer 1; 2.0 GHz processor, 2 GB RAM, 430 mm screen	130	36
	Manufacturer 1; 1.8 GHz processor, 1 GB RAM, 430 mm screen	90	23
	Manufacturer 1; 2.0 GHz processor, 2 GB RAM, 355 mm screen	90	31
	Manufacturer 2; 2.13 GHz processor, 1 GB RAM, 355 mm screen, tablet PC	90	29
	Manufacturer 2; 366 MHz processor, 130 MB RAM, 355 mm screen)	70	22
	Manufacturer 3; 900 MHz processor, 256 MB RAM (265 mm screen)	50	12
Flat-panel monitor[c]	Manufacturer X (model A); 760 mm screen	383	90
	Manufacturer X (model B); 560 mm screen	360	36
	Manufacturer Y (model A), 480 mm screen	288	28
	Manufacturer Y (model B), 430 mm screen	240	27
	Manufacturer Z (model A), 430 mm screen	240	29
	Manufacturer Z (model C), 380 mm screen	240	19

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2. Internal Heat Gains

Equipment Heat gain in Cooling load calculation

B. Monitor Equipment heat gain : Based on monitors tested by Hosni et al. (1999), heat gain for cathode ray tube (CRT) monitors correlates approximately with screen size as

$$q_{mon} = 0.2S - 20$$

where

q_{mon} = sensible heat gain from monitor, W
S = nominal screen size, mm

C. Laser Printers and copiers Equipment heat gain : Hosni et al. (1999) found that power consumption, and therefore the heat gain, of laser printers depended largely on the level of throughput for which the printer was designed. Table 9 presents data on laser printers.

Table 9 Recommended Heat Gain from Typical Laser Printers and Copiers

Equipment	Description	Nameplate Power Consumption, W	Average Power Consumption, W
Laser printer, typical desktop, small-office type[a]	Printing speed up to 10 pages per minute	430	137
	Printing speed up to 35 pages per minute	890	74
	Printing speed up to 19 pages per minute	508	88
	Printing speed up to 17 pages per minute	508	98
	Printing speed up to 19 pages per minute	635	110
	Printing speed up to 24 page per minute	1344	130
Multifunction (copy, print, scan)[b]	Small, desktop type	600	30
		40	15
	Medium, desktop type	700	135
Scanner[b]	Small, desktop type	19	16
Copy machine[c]	Large, multiuser, office type	1750	800 (idle 260 W)
		1440	550 (idle 135 W)
		1850	1060 (idle 305 W)
Fax machine	Medium	936	90
	Small	40	20
Plotter	Manufacturer A	400	250
	Manufacturer B	456	140

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2. Internal Heat Gains

Equipment Heat gain in Cooling load calculation

D. Others : Table 10 presents data on miscellaneous office equipment such as vending machines and mailing equipment.

Table 10 Recommended Heat Gain from Miscellaneous Office Equipment

Equipment	Maximum Input Rating, W	Recommended Rate of Heat Gain, W
Mail-processing equipment		
Folding machine	125	80
Inserting machine, 3600 to 6800 pieces/h	600 to 3300	390 to 2150
Labeling machine, 1500 to 30 000 pieces/h	600 to 6600	390 to 4300
Postage meter	230	150
Vending machines		
Cigarette	72	72
Cold food/beverage	1150 to 1920	575 to 960
Hot beverage	1,725	862
Snack	240 to 275	240 to 275
Other		
Bar code printer	440	370
Cash registers	60	48
Check processing workstation, 12 pockets	4800	2470
Coffee maker, 10 cups	1500	1050 sens., 450 latent
Microfiche reader	85	85
Microfilm reader	520	520
Microfilm reader/printer	1150	1150
Microwave oven, 28 L	600	400
Paper shredder	250 to 3000	200 to 2420
Water cooler, 30 L/h	700	350

E. Other recommendation : **(Heat Gain per Unit Area)** Table 11 presents a range of load factors with a subjective description of the type of space to which they would apply.

Table 11 Recommended Load Factors for Various Types of Offices

Load Density of Office	Load Factor, W/m^2	Description
Light	5.4	Assumes 15.5 m^2/workstation (6.5 workstations per 100 m^2) with computer and monitor at each plus printer and fax. Computer, monitor, and fax diversity 0.67, printer diversity 0.33.
Medium	10.8	Assumes 11.6 m^2/workstation (8.5 workstations per 100 m^2) with computer and monitor at each plus printer and fax. Computer, monitor, and fax diversity 0.75, printer diversity 0.50.
Medium/ Heavy	16.1	Assumes 9.3 m^2/workstation (11 workstations per 100 m^2) with computer and monitor at each plus printer and fax. Computer and monitor diversity 0.75, printer and fax diversity 0.50.
Heavy	21.5	Assumes 7.8 m^2/workstation (13 workstations per 100 m^2) with computer and monitor at each plus printer and fax. Computer and monitor diversity 1.0, printer and fax diversity 0.50.

Generally, 16.0W/m2 is used for energy modeling for Green mark certification.

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2. Internal Heat Gains

Equipment Heat gain in Cooling load calculation

(3) Medical Equipment : It is more difficult to provide generalized heat gain recommendations for medical equipment than for general office equipment because medical equipment is much more varied in type and in application. Table 6 is just reference only.

Table 6 Recommended Heat Gain from Typical Medical Equipment

Equipment	Nameplate, W	Peak, W	Average, W
Anesthesia system	250	177	166
Blanket warmer	500	504	221
Blood pressure meter	180	33	29
Blood warmer	360	204	114
ECG/RESP	1440	54	50
Electrosurgery	1000	147	109
Endoscope	1688	605	596
Harmonical scalpel	230	60	59
Hysteroscopic pump	180	35	34
Laser sonics	1200	256	229
Optical microscope	330	65	63
Pulse oximeter	72	21	20
Stress treadmill	N/A	198	173
Ultrasound system	1800	1063	1050
Vacuum suction	621	337	302
X-ray system	968		82
	1725	534	480
	2070		18

Data presented for medical equipment in Table 6 are relevant for portable and bench-top equipment. Medical equipment is very specific and can vary greatly from application to application. The data are presented to provide guidance in only the most general sense. For large equipment, such as MRI, heat gain must be obtained from the manufacturer.

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2. Internal Heat Gains

Equipment Heat gain in Cooling load calculation

(4) Equipment in laboratories : laboratory equipment items are major sources of sensible and latent heat gains in conditioned spaces. Equipment in laboratories is similar to medical equipment in that it varies significantly according to the type of the equipment and from space to space.

Table 7 Recommended Heat Gain from Typical Laboratory Equipment

Equipment	Nameplate, W	Peak, W	Average, W
Analytical balance	7	7	7
Centrifuge	138	89	87
	288	136	132
	5500	1176	730
Electrochemical analyzer	50	45	44
	100	85	84
Flame photometer	180	107	105
Fluorescent microscope	150	144	143
	200	205	178
Function generator	58	29	29
Incubator	515	461	451
	600	479	264
	3125	1335	1222
Orbital shaker	100	16	16
Oscilloscope	72	38	38
	345	99	97
Rotary evaporator	75	74	73
	94	29	28
Spectronics	36	31	31
Spectrophotometer	575	186	104
	200	122	121
	N/A	127	125
Spectro fluorometer	340	405	395
Thermocycler	1840	965	641
	N/A	233	198
Tissue culture	475	132	46
	2346	1178	1146

Source: Hosni et al. (1999).

Chapter 14 of the 2007 ASHRAE Handbook—HVAC Applications discusses heat gain from equipment, which may range from 50 to 270 W/m2 in highly automated laboratories.

As mentioned in medical equipment, it is just reference only for the sizing calculation. According to type or purpose of equipment, heat gain must be obtained from the manufacturer.

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3. Infiltration Heat Gain

Infiltration Heat Gain : It is load components which contribute to space cooling load directly without time delay from building mass.

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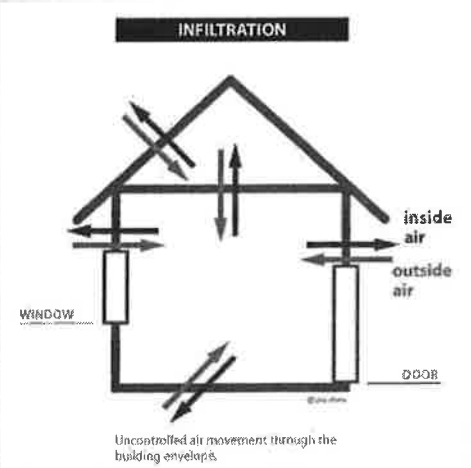
3. Infiltration Heat Gains

Infiltration heat gain in cooling load calculation

Infiltration heat gain : Infiltration is uncontrolled air movement from the outside of the building to the inside (infiltrated air moves through the building envelope passing chemically treated timber, dust, dirt).

When positive air pressure is assumed, most designers do not include infiltration in cooling load calculations for commercial buildings. However, Infiltration also depends on wind direction and speed, façade direction, temperature differences, and occupant use of exterior doors and operable windows.



Uncontrolled air movement through the building envelope.

It is impossible to accurately predict infiltration rates. Designers usually predict overall rates of infiltration using the number of air changes per hour (ach).

However, ASHRAE Fundamental doesn't provide any reference number for infiltration. We generated how to consider infiltration from crack area in energy modeling based on other reference.

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3. Infiltration Heat Gains

Infiltration heat gain in cooling load calculation

(1) Infiltration flow rate based on crack length method : With the consideration for total crack length, infiltration flow rate can be calculated based on the pressure difference between outdoor and indoor.

For a crack the dependence of flow on pressure difference is assumed to take the form

$$q = CL(\rho_{ref} / \rho)^{0.5} \Delta p^{0.6}$$

where

q is the air flow through the crack (l/s)

C is the Crack Flow Coefficient (l s^{-1} m^{-1} $Pa^{-0.6}$)

L is the length of the crack (m)

ρ is the density of air entering the crack (kg/m^3)

ρ_{ref} = 1.21 kg/m^3 is a reference air density

Δp is the pressure difference across the crack (Pa).

Table 3 Crack Flow Coefficients (l s^{-1} m^{-1} $Pa^{-0.6}$) – Windows

	Lower Quartile	Median	Upper Quartile
Windows (Weatherstripped)			
Hinged	0.086	0.13	0.41
Sliding	0.079	0.15	0.21
Windows (Non-weatherstripped)			
Hinged	0.39	0.74	1.1
Sliding	0.18	0.23	0.37

Table 4 Crack Flow Coefficients (l s^{-1} m^{-1} $Pa^{-0.6}$) – Doors

	Lower Quartile	Median	Upper Quartile
External Doors (Weatherstripped)			
Hinged	0.082	0.27	0.84
Revolving	1.0	1.5	2.0
External Doors (Non-weatherstripped)			
Hinged	1.1	1.2	1.4
Sliding		0.2	
Internal Doors (Non-weatherstripped)	1.1	1.3	2.0
Loft Hatches (Non-weatherstripped)	0.64	0.68	0.75

This equation represents a best fit to a large range of experimental data analysed by the Air Infiltration and Ventilation Centre. Representative measured values of the Crack Flow Coefficient for windows and doors are given in Table 3 and Table 4.

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3. Infiltration Heat Gains

Infiltration heat gain in cooling load calculation

(1) Infiltration flow rate based on crack length method : With the consideration for total crack length, infiltration flow rate can be calculated based on the pressure difference between outdoor and indoor.

Difference of pressure between outdoor and indoor can be calculated as in the below.

The air pressure in a room is thus a linear function of height:

$$p_n(h) = p_n(0) - h\rho_n g \quad (5)$$

where

$p_n(h)$ is the pressure (Pa) in room n at height h above ground level

h is height above ground level (m)

ρ_n is the air density in room n

g = 9.81 m/s^2 is the acceleration due to gravity

Indoor pressure should include the positive pressure due to supply fresh air. It can be generated based on the fresh air amount into zone.

For the outside air mass, both wind and buoyancy-induced pressure must be included:

$$p_{0,i}(h) = p_{w,i} - h\rho_0 g \quad (6)$$

where

$p_{0,i}(h)$ is the external pressure (Pa) experienced by opening i

$p_{w,i}$ is the wind pressure (Pa) experienced by opening i

ρ_0 is the outside air density

Outdoor pressure depends on wind direction and wind speed in weather file and building geometry.

In addition, energy modeling software considers "exposure type" and "wind turbulence" effect as well.

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3. Infiltration Heat Gains

Infiltration heat gain in cooling load calculation

(2) Infiltration heat gain calculation: Air-conditioning design often requires the following process to calculate infiltration heat gain in cooling load calculation.

When we have the volume of infiltration, we can use general approach to calculate heat gain as in the below.

1. Total heat

Total heat gain q_t corresponding to the change of a given standard flow rate Q_s through an enthalpy difference Δh is

$$q_t = 1.2 Q_s \Delta h \quad (8)$$

where 1.2 = kg_{da}/m^3.

This total heat equation can also be expressed as

$$q_t = C_t Q_s \Delta h$$

where C_t = 1.2 is the air total heat factor, in W/(L/s) per kJ/kg enthalpy h.

2. Sensible heat

Sensible heat gain q_s corresponding to the change of dry-bulb temperature Δt for given airflow (standard conditions) Q_s is

$$q_s = 1.23 Q_s \Delta t \quad (10)$$

This sensible heat equation can also be expressed as

$$q_s = C_s Q_s \Delta t$$

where C_s = is the air sensible heat factor, in W/(L·s·K).

3. Latent heat

This latent heat equation can also be expressed as

$$q_l = C_l Q_s \Delta W$$

where C_l = 3010 is the air latent heat factor, in W/(L/s).

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4. Fenestration Heat Gain

Fenestration Heat Gain : Fenestration can serve as a physical and/or visual connection to the outdoors, as well as a means to admit solar radiation for natural lighting (day-lighting), and for heat gain to a space.

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4. Fenestration Heat Gain

Fenestration heat gain in Cooling load calculation

Fenestration heat gain : Fenestration affects building energy use through four basic mechanisms : Thermal heat transfer, Solar heat gain, Air leakage, and day-lighting.

The energy effects of fenestration can be minimized by

(1) Using daylight to offset lighting requirements,
(2) Using glazing and shading strategies to control solar heat gain to supplement heating through passive Solar gain and minimize cooling requirements,
(3) Using glazing to minimize conductive heat loss,
(4) Specifying low-air-leakage fenestration products,
(5) Integrating fenestration into natural ventilation strategies that can reduce energy use for cooling and fresh air requirements.

As we are discussing fenestration heat gain for cooling load calculation, we will check following in more detail.

(1) Energy flow through fenestration.
(2) Two components of fenestration solar heat gain.
(3) Solar optical properties of window.

Infiltration from glazing already has been discussed in "Infiltration heat gain".

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4. Fenestration Heat Gain

Fenestration heat gain in Cooling load calculation

(1) Energy flow through Fenestration : Energy flows through fenestration via

- Conductive and convective heat transfer caused by the temperature difference between outdoor and indoor air.
- Direct solar radiation : Net long-wave (above 2500 nm) radiative exchange between the fenestration and its surroundings and between glazing layers.
- Direct diffuse radiation : Short-wave (below 2500 nm) solar radiation incident on the fenestration product, either directly from the sun or reflected from the ground or adjacent objects.

Basic equation for the steady-state energy flow Q through fenestration is,

$$Q = UA_{pf}(t_{out} - t_{in}) + (\mathrm{SHGC})A_{pf}E_t \qquad (1)$$

where

Q = instantaneous energy flow, W
U = overall coefficient of heat transfer (U-factor), W/(m^2·K)
A_{pf} = total projected area of fenestration (the product's rough opening in the wall or roof less installation clearances), m^2
t_{in} = indoor air temperature, °C
t_{out} = outdoor air temperature, °C
SHGC = solar heat gain coefficient, dimensionless
E_t = incident total irradiance, W/m^2

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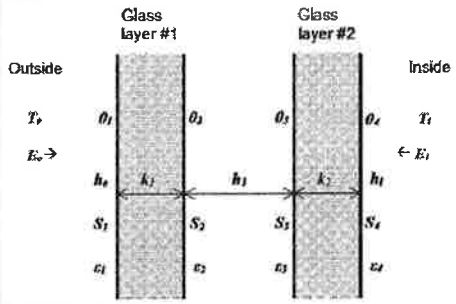
4. Fenestration Heat Gain

Fenestration heat gain in Cooling load calculation

(1) Energy flow through Fenestration : Conductive and convective heat transfer (Detail approach)

As the additional information, energy modeling software uses the heat balance calculation to generate the heat gain from Conductive and convective heat transfer from window as much more detail approach.



$$E_o\varepsilon_1 - \varepsilon_1\sigma\theta_1^4 + k_1(\theta_2-\theta_1) + h_o(T_o-\theta_1) + S_1 = 0 \quad (180)$$

$$k_1(\theta_1-\theta_2) + h_1(\theta_3-\theta_2) - \sigma\frac{\varepsilon_2\varepsilon_3}{1-(1-\varepsilon_2)(1-\varepsilon_3)}\left(\theta_3^4-\theta_2^4\right) + S_2 = 0 \quad (181)$$

$$h_1(\theta_2-\theta_3) + k_2(\theta_4-\theta_3) + \sigma\frac{\varepsilon_2\varepsilon_3}{1-(1-\varepsilon_2)(1-\varepsilon_3)}\left(\theta_2^4-\theta_3^4\right) + S_3 = 0 \quad (182)$$

$$E_i\varepsilon_4 - \varepsilon_4\sigma\theta_4^4 + k_2(\theta_3-\theta_4) + h_i(T_i-\theta_4) + S_4 = 0 \quad (183)$$

Each equations mean the heat balance of each surface of window layers. It shows more detail level of calculations and it is adapted in energy modeling software and includes (1) Absorbed radiation heat to window layers, (2) conductive heat to window layers, (3) long wave radiation heat gain from indoors.

It will finally generate the surface temperature for window layers.

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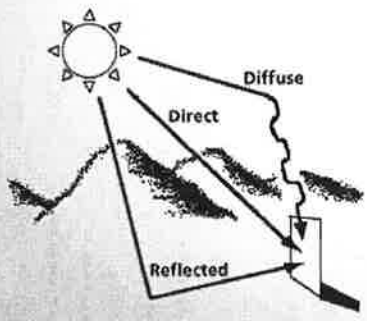
4. Fenestration Heat Gain

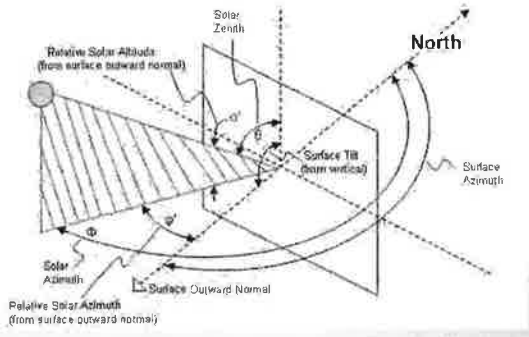
Fenestration heat gain in Cooling load calculation

(2) Solar radiation : Direct solar radiation and diffuse solar radiation generates difference thermal properties of window due to different incident angle.

Direct Solar Radiation is also sometimes called "beam radiation" or "direct beam radiation". It is used to describe solar radiation traveling on a straight line from the sun down to the surface of the earth. (Has incident angle)

Diffuse Solar Radiation on the other hand, describes the sunlight that has been scattered by molecules and particles in the atmosphere but that has still made it down to the surface of the earth. (Inclusive of reflected radiation from ground or other building as well)





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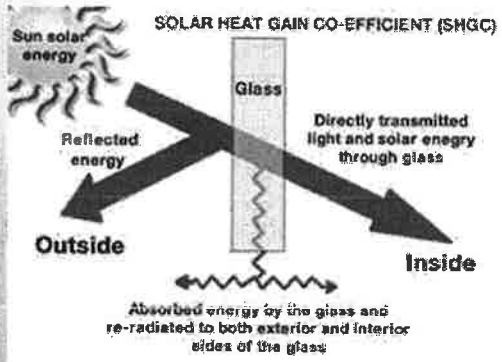
4. Fenestration Heat Gain

Fenestration heat gain in Cooling load calculation

(3) Two components of Fenestration Solar Heat Gain

Directly transmitted solar radiation : The quantity of radiation entering the fenestration directly by the solar transmittance of the glazing system. It is determined by multiplying the incident irradiance by the glazing area and its solar transmittance.

Inward flowing fraction of absorbed solar radiation : The radiation that is absorbed in the glazing and framing materials of the window, some of which is subsequently conducted, convected, or radiated to the interior of the building.



A. Directly transmitted solar radiation is result of solar transmittance and reflectance of window.

B. Inward flowing fraction is result of solar absorption and emissivity of window.

4. Fenestration Heat Gain

Fenestration heat gain in Cooling load calculation

(3) Optical Properties of Single Glazing Layers : If solar radiation incident on glazing is considered, the transmittance T, reflectance R, and absorptance A of the glazing layer contain the effects of multiple reflections between the two interfaces of the layer as well as the effects of absorption during the passage through the layer of each inter reflection (Figure 6).

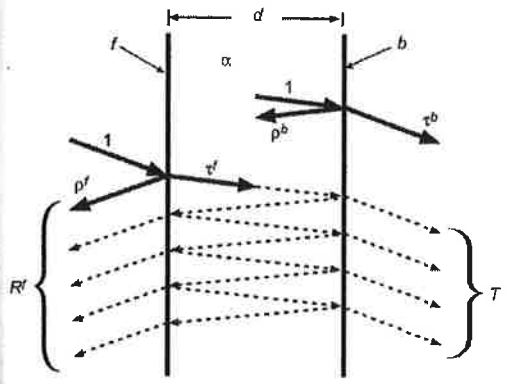


Fig. 6 Optical Properties of a Single Glazing Layer

The transmittance, reflectance, and absorptance of a layer are formally defined as the fractions of incident flux that transmit, reflect, and are absorbed by the layer, respectively, including the effects of interreflection. Their sum equals unity, as shown in Equation (10).

$$T + R + A = 1 \qquad (10)$$

In window specification, Solar transmittance are reflectance are provided. It can be referred in cooling load calculation and input in energy modeling software.

Basically, energy modeling software includes the effect of inner reflection between layer and layer in glazing system. If user input transmittance and reflectance, program generates effect of inner reflection.

4. Fenestration Heat Gain

Fenestration heat gain in Cooling load calculation

(3) Optical Properties of Single Glazing Layers : The interfacial properties τ and ρ, and consequently layer properties T, R, and A, also depend on the incident angle θ of the radiation incident on the layer.

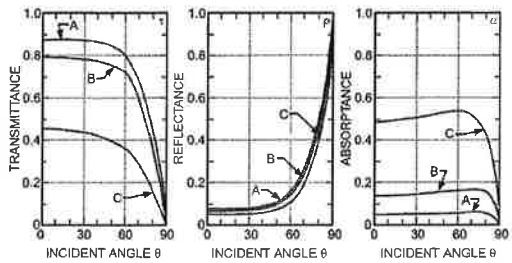
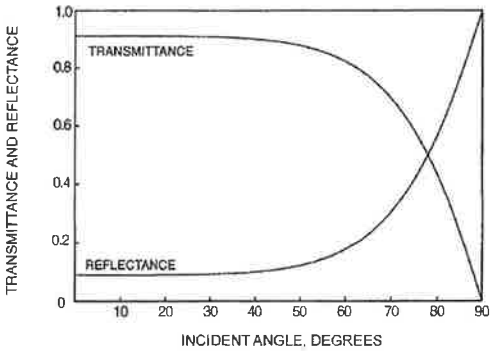


Fig. 8 Variations with Incident Angle of Solar-Optical Properties for (A) Double-Strength Sheet Glass, (B) Clear Plate Glass, and (C) Heat-Absorbing Plate Glass



Basically, incident angle of solar radiation will affect the transmittance, reflectance and absorptance of glazing as in the above. It will generate different solar heat gain according to different solar position according to the data and hours.

Basically, energy modeling software includes the effect of different incident angle when calculating solar heat profile from glazing system.

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4. Fenestration Heat Gain

Fenestration heat gain in Cooling load calculation

(4) SOLAR HEAT GAIN COEFFICIENT: Normally energy modelling software ask user to define or generate SC or SHGC as input of window properties. It can be confirmed by window specification.

Because the optical properties $\mathcal{A}$ and T vary with the angle of incidence and wavelength, the solar heat gain coefficient is also a function of these variables. In the most general way, the solar heat gain $q(\theta)$ and the solar heat gain coefficient SHGC(θ,λ) are defined as

$$q(\theta) = \int_{\lambda} E_D(\lambda)[T(\theta,\lambda) + N\mathcal{A}(\theta,\lambda)]d\lambda = \int_{\lambda} E_D(\lambda)\mathrm{SHGC}(\theta,\lambda)d\lambda \quad (15)$$

where

$E_D(\lambda)$ = incident solar spectral irradiance
$T(\theta,\lambda)$ = spectral transmittance of glazing system
$\mathcal{A}(\theta,\lambda)$ = total spectral absorptance of glazing system

Here, the angle- and wavelength-dependent solar heat gain coefficient is given by

$$\mathrm{SHGC}(\theta,\lambda) = T(\theta,\lambda) + N\mathcal{A}(\theta,\lambda) \quad (16)$$

Combined with Equation (11), this becomes the wavelength-averaged solar heat gain coefficient:

$$\mathrm{SHGC}(\theta) = \frac{\int_{\lambda_{min}}^{\lambda_{max}} E_D(\lambda)[T(\theta,\lambda) + N(\lambda)\mathcal{A}(\theta,\lambda)]d\lambda}{\int_{\lambda_{min}}^{\lambda_{max}} E_D(\lambda)d\lambda} \quad (17)$$

SHGC means "Total solar heat gain from window divided by total solar radiation from outdoor". Total solar heat gain includes transmitted solar radiation and inward flowing fraction due to absorbed solar in layer.

Basically, SHGC from window specification in based on 0 degree of incident angle. It is able to be used for simple calculation of solar heat gain manually, but energy modeling software will capture more detail information such as inner reflection and impact of incident angle of solar.

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5. Heat Balance Method

Heat Balance Method : Cooling load estimation involves calculating a surface-by-surface conductive, convective, and radiative heat balance for each room surface and a convective heat balance for the room air.

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5. Heat Balance Method

Heat Balance Method in Cooling load calculation

(1) Heat Balance Method: The heat balance method solves the problem directly instead of introducing transformation-based procedures such as RTS (Radiant Time Series Method). It is the methodology to decide the result what we want based on the relationship between heat gain components.

It is based on the assumption in the below.

(1) Uniform surface temperature : Each surface such as window, wall, ground and roof has uniform temperature.
(2) Uniform long-wave (LW) and short-wave (SW) irradiation
(3) Diffuse radiating surfaces : Each surface such as window, wall, ground and roof has uniform diffuse radiation
(4) One-dimensional heat conduction within

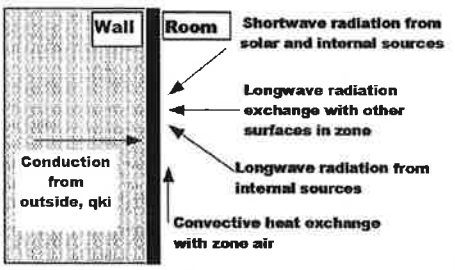

Figure 18. Inside Heat Balance Control Volume Diagram

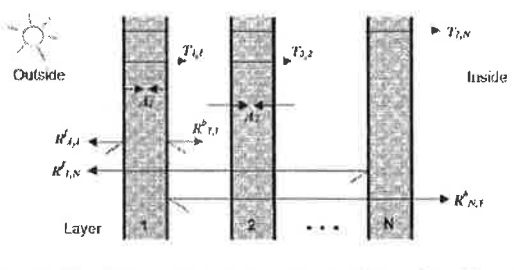

Figure 73. Schematic of transmission, reflection and absorption of solar radiation within a multi-layer

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5. Heat Balance Method

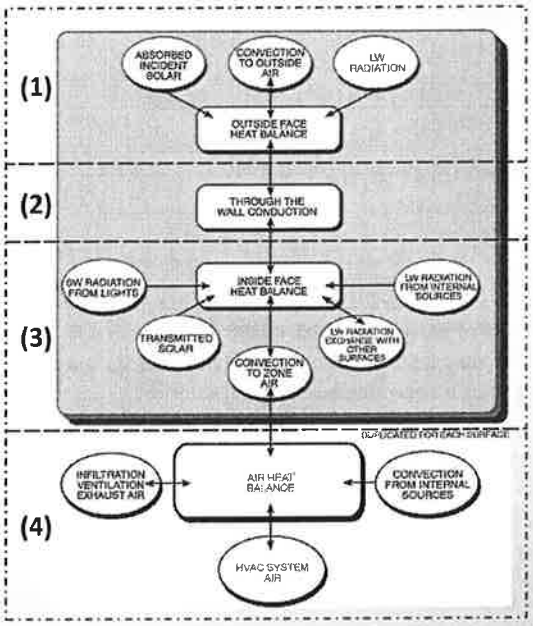
Heat Balance Method in Cooling load calculation

(2) Framework of Heat Balance Method : Within the framework of the assumptions, the HB can be viewed as four distinct processes.

It shows the relationship between all processes for a single opaque surface.

(1) Outside-face heat balance : Absorbed by incident solar, convection to outside air and long wave radiation.
(2) Wall conduction process : Through the wall conduction.
(3) Inside-face heat balance : Short wave radiation from lights, transmitted solar, long wave from internal sources and exchange with other surfaces, and convention to zone air.
(4) Air heat balance : Infiltration/ventilation/exhaust air, HVAC system air, and convection from internal sources.

The process for transparent surfaces is similar.



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5. Heat Balance Method

Heat Balance Method in Cooling load calculation

(3-1) Outside-Face Heat Balance : The heat balance on the outside face of each surface is,

The heat balance on the outside face of each surface is

$$q''_{\alpha sol} + q''_{LWR} + q''_{conv} - q''_{ko} = 0 \qquad (17)$$

where

$q''_{\alpha sol}$ = absorbed direct and diffuse solar radiation flux (q/A), W/m^2
q''_{LWR} = net long-wave radiation flux exchange with air and surroundings, W/m^2
q''_{conv} = convective exchange flux with outside air, W/m^2
q''_{ko} = conductive flux (q/A) into wall, W/m^2

All terms are positive for net flux to the face except q''_{ko}, which is traditionally taken to be positive from outside to inside the wall.

Each term in Equation (17) has been modeled in several ways, and in simplified methods the first three terms are combined by using the sol-air temperature.

Outdoor surface will (1) take solar radiation, long wave radiation, (2) release heat flux as convective heat flux to outdoor. The rest of energy is going into wall.

It is calculated based on "square meters".

(1) Absorbed direct and diffuse solar radiation : This is based on solar radiation amount and absorbtance of external wall.
(2) Net long-wave radiation with air and surrounding : This is based on long wave radiation from surroundings.
(3) Convective exchange flux with outside air: Based on surface temperature of outside, it can be calculated with outdoor air and conductive heat transfer coefficient.
(4) Conductive flux into wall : The rest of energy will go into wall as conductive heat transfer.

The heat balance method is based on energy cannot destroyed or created.

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5. Heat Balance Method

Heat Balance Method in Cooling load calculation

(3-2) Wall conduction process : It requires more complicated calculation.

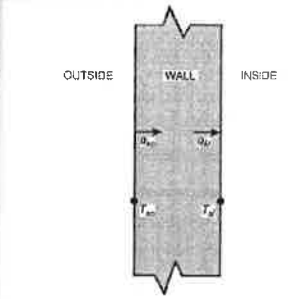

Fig. 6 Schematic of Wall Conduction Process

Because it links the outside and inside heat balances, the wall conduction process regulates the **cooling load's time dependence.**

For the HB procedure presented here, wall conduction is formulated using **conduction transfer functions (CTFs)**, which relate conductive heat fluxes to current and past surface temperatures and past heat fluxes.

The general form for the inside heat flux is

$$q''_{ki}(t) = -Z_o T_{si,\theta} - \sum_{j=1} Z_j T_{si,\theta-j\delta} + Y_o T_{so,\theta} + \sum_{j=1}^{nz} Y_j T_{so,\theta-j\delta} + \sum_{j=1}^{nq} \Phi_j q''_{ki,\theta-j\delta}$$

For outside heat flux, the form is

$$q''_{ko}(t) = -Y_o T_{si,\theta} - \sum_{j=1}^{nz} Y_j T_{si,\theta-j\delta} + X_o T_{so,\theta} + \sum_{j=1}^{nz} X_j T_{so,\theta-j\delta} + \sum_{j=1}^{nq} \Phi_j q''_{ko,\theta-j\delta}$$

After wall has heat energy from outside and inside, absorbed energy will be released based on time dependence based on thermal capacity of wall.

In this process, how much heat is going to internal zone which reflected time delay effect.

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5. Heat Balance Method

Heat Balance Method in Cooling load calculation

(3-3) Inside-Face Heat Balance : The heart of the HB method is the internal heat balance involving the inside faces of the zone surfaces.

$$q''_{LWX} + q''_{SW} + q''_{LWS} + q''_{ki} + q''_{sol} + q''_{conv} = 0 \qquad (18)$$

where

q''_{LWX} = net long-wave radiant flux exchange between zone surfaces, W/m^2
q''_{SW} = net short-wave radiation flux to surface from lights, W/m^2
q''_{LWS} = long-wave radiation flux from equipment in zone, W/m^2
q''_{ki} = conductive flux through wall, W/m^2
q''_{sol} = transmitted solar radiative flux absorbed at surface, W/m^2
q''_{conv} = convective heat flux to zone air, W/m^2

Inner surface will (1) take long wave radiation from other surface and other equipment, short wave radiation from lights, conductive heat flux from wall and transmitted solar radiation absorbed at surface and (2) release heat flux as convective heat flux to zone air.

It is calculated based on "square meters".

(1) LW Radiation exchange among zone surface: All surface generates long wave radiation.
(2) SW Radiation from lights: The short-wavelength radiation from lights is usually assumed to be distributed over the surfaces.
(3) LW Radiation exchange from internal sourse: This source defines a radiative/convective split for heat from equipment.
(4) Transmitted Solar heat gain : Solar heat gain from window. It is explained in previous chapter.
(5) Convection to zone air : All heat absorbed in wall transform to surface temperature. Based on this, the convective heat will be calculated.

The heat balance method is based on energy cannot destroyed or created.

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5. Heat Balance Method

Heat Balance Method in Cooling load calculation

(3-4) Air Heat Balance : Four factors contribute to the air heat balance .

$$q_{conv} + q_{CE} + q_{IV} + q_{sys} = 0 \quad (22)$$

where

q_{conv} = convective heat transfer from surfaces, W
q_{CE} = convective parts of internal loads, W
q_{IV} = sensible load caused by infiltration and ventilation air, W
q_{sys} = heat transfer to/from HVAC system, W

It is process to decide the cooling load requirement which includes heat gain for convective part of internal loads and infiltration heat gain. HVAC system loads have to meet this requirement.

It is calculated based on "Watts".

(1) Convection from zone surfaces : Total cooling load from convection from zone surface calculated in "inside face heat balance".
(2) Convective parts of internal loads: Radiative part is considered in "inside face heat balance" and it is heat gain for convective part of internal loads.
(3) Infiltration or ventilation: Infiltration heat gain is explained in chapter of "Infiltration Heat Gain".
(4) Heat transfer to/from HVAC system : Conditioned air that enters the zone from the HVAC system. This is finally what we want to get from this calculation.

The "Wall conduction process" is the most difficult part in heat balance calculation because it reflects time delay effect in cooling load calculation. In addition, it is available to use Radiant time series method (RTS) as more simplified way.

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5. Heat Balance Method

Heat Balance Method in Cooling load calculation

(4-1) Input requirement : For heat balance, we need following inputs.

(Weather data and 3D model)

Global Information. Because the procedure incorporates a solar calculation, some global information is required, including latitude, longitude, time zone, month, day of month, directional orientation of the zone, and zone height (floor to floor). Additionally, to take full advantage of the flexibility of the method to incorporate, for example, variable outside heat transfer coefficients, things such as wind speed, wind direction, and terrain roughness may be specified. Normally, these variables and others default to some reasonable set of values, but the flexibility remains.

(Window properties)

Window Information (Each Window). The situation for windows is similar to that for walls, but the windows require some additional information because of their role in the solar load. Necessary parameters include

- Area
- Normal solar transmissivity
- Normal SHGC
- Normal total absorptivity
- Long-wave emissivity outside
- Long-wave emissivity inside
- Surface-to-surface thermal conductance
- Reveal (for solar shading)
- Overhang width (for solar shading)
- Distance from overhang to window (for solar shading)

(Wall properties)

Wall Information (Each Wall). Because the walls are involved in three of the fundamental processes (external and internal heat balance and wall conduction), each wall of the zone requires a fairly large set of variables. They include

- Facing angle with respect to solar exposure
- Tilt (degrees from horizontal)
- Area
- Solar absorptivity outside
- Long-wave emissivity outside
- Short-wave absorptivity inside
- Long-wave emissivity inside
- Exterior boundary temperature condition (solar versus nonsolar)
- External roughness
- Layer-by-layer construction information

Again, some of these parameters can be defaulted, but they are changeable, and they indicate the more fundamental character of the HB method because they are related to true heat transfer processes.

(Roof and Floor properties)

Roof and Floor Details. The roof and floor surfaces are specified similarly to walls. The main difference is that the ground outside boundary condition will probably be specified more often for a floor.

This is same as what energy modeling software requires for energy modeling works.

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5. Heat Balance Method

Heat Balance Method in Cooling load calculation

(4-2) Input requirement : For heat balance, we need following inputs.

(Thermal mass surface details)

Thermal Mass Surface Details. An "extra" surface, called a thermal mass surface, can serve several functions. It is included in radiant heat exchange with the other surfaces in the space but is only exposed to the inside air convective boundary condition. As an example, this surface would be used to account for movable partitions in a space. Partition construction is specified layer by layer, similar to specification for walls, and those layers store and release heat by the same conduction mechanism as walls. As a general definition, the extra thermal mass surface should be sized to represent all surfaces in the space that are exposed to the air mass, except the walls, roof, floor, and windows. In the formulation, both sides of the thermal mass participate in the exchange.

(Internal heat gain details)

Internal Heat Gain Details. The space can be subjected to several internal heat sources: people, lights, electrical equipment, and infiltration. Infiltration energy is assumed to go immediately into the air heat balance, so it is the least complicated of the heat gains. For the others, several parameters must be specified. These include the following fractions:

- Sensible heat gain
- Latent heat gain
- Short-wave radiation
- Long-wave radiation
- Energy that enters the air immediately as convection
- Activity level of people
- Lighting heat gain that goes directly to the return air

(Wall properties)

Radiant Distribution Functions. As mentioned previously, the generally accepted assumptions for the HB method include specifying the distribution of radiant energy from several sources to surfaces that enclose the space. This requires a distribution function that specifies the fraction of total radiant input absorbed by each surface. The types of radiation that require distribution functions are

- Long-wave, from equipment and lights
- Short-wave, from lights
- Transmitted solar

(Other required information)

Other Required Information. Additional flexibility is included in the model so that results of research can be incorporated easily. This includes the capability to specify such things as

- Heat transfer coefficients/convection models
- Solar coefficients
- Sky models

The amount of input information required may seem extensive, but many parameters can be set to default values in most routine applications. However, all parameters listed can be changed when necessary to fit unusual circumstances or when additional information is obtained.

In addition, some software have model to decide heat transfer coefficient for more detail calculation.

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THANK YOU



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GMP : Introduction of IES<VE> Software

What can we do with EM modules in IES<VE>?

Presented by : Yong Ping Quen
Environmentally Sustainable Development (ESD) Consultant,
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GMP : Introduction of IES<VE> Software

What can we do with EM modules in IES<VE>?

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2. General process of Model IT in IES<VE>
3. General process of Apache in IES<VE>
4. General process of Apache HVAC in IES<VE>
5. General process of Vista/Vista pro in IES<VE>

Presented by : Yong Ping Quen
Environmentally Sustainable Development (ESD) Consultant,
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Introduction for IES<VE>

Overview of the Energy Simulation Software

-General introduction for IES<VE>
-The modules in IES<VE> that are applicable for energy modeling.
-The energy modeling process using IES<VE>

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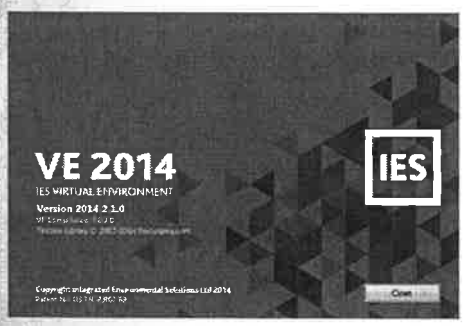
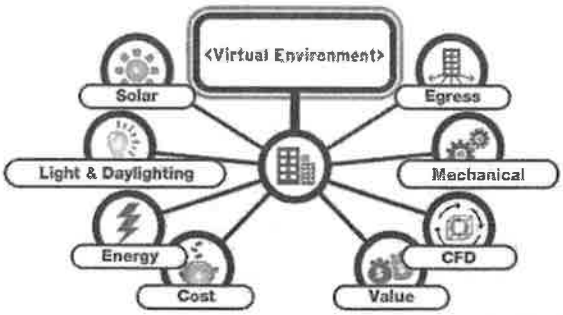
1.Introduction for IES<VE>

Integrated Analysis tool of Dynamic Building Energy Simulation

One of the dynamic simulation tools to analyze the building cooling load, air-flow, day-lighting, fire-escape, energy usages, etc on hourly, monthly and yearly basis. Many kind of options are provided in terms of the architectural, mechanical, and sustainable design aspects.

https://www.iesve.com/





1) Lighting & Day-lighting : Day-lighting, artificial lighting lux levels and lighting fittings.
2) Building Load Calculation : annual/monthly/hourly building cooling and heating load demands.
3) Building Energy : Calculate energy usage for energy components such as lighting, HVAC, central plant etc.
4) Value Engineering : Analyze the lift cycle cost and payback period for VE engineering.
5) Air Flow Simulation : CFD simulation and simplified air flow amount between space and space or outdoor.
6) Fire Escape: Egress simulation of people under fire situation.

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1.Introduction for IES<VE>

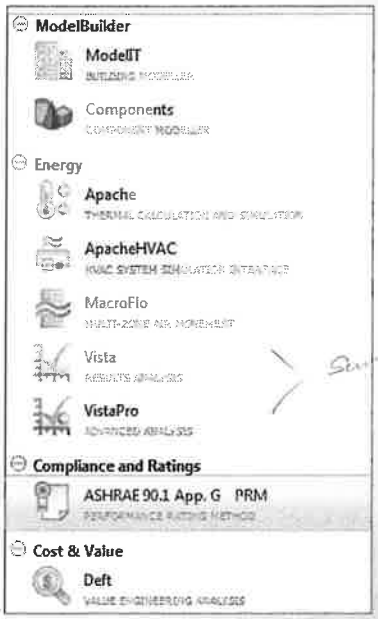
Integrated Analysis tool of Dynamic Building Energy Simulation

The mandatory modules related to the energy modeling:

1) Model IT : 3D Model (Geometry model)
2) Apache : Thermal Model such as internal condition and façade properties.
3) Apache HVAC: To model the air-side systems and chilled water plant (auto-sizing calculation).
4) Vista : Building load and energy result on hourly, monthly and yearly basis.
5) Vista Pro : Detail result for all of HVAC components such as the fan, chiller, pump, cooling tower etc.

Addition modules for more detail simulation

1) Sun cast : Detail analysis of the solar impact to the building from external and internal shading devices.
2) Macro flow : Simplified air flow simulation (Air volume calculation) between space and space, and between indoor space and outdoor, instead of detail CFD simulation.
3) Green Mark Navigator : Easier tool to find the function and follow the process related to requirement of Green Mark.



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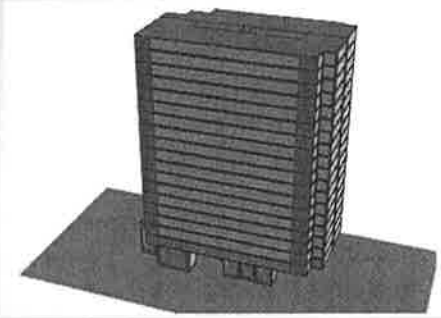
1.Introduction for IES<VE>

Integrated Analysis tool of Dynamic Building Energy Simulation

IES<VE> Modules applicable for energy modeling.

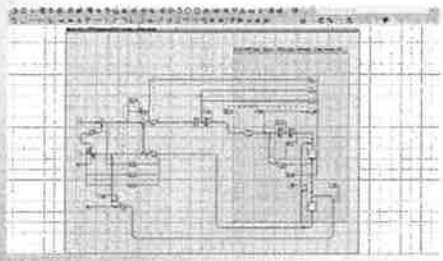
1. Model IT is for Geometry model (plan and elevation).



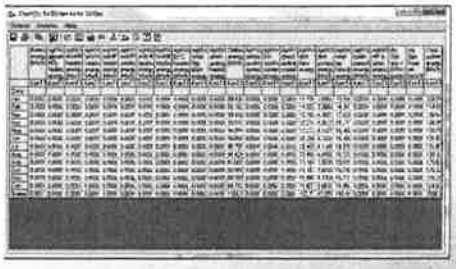
2. Apache-Sim is for physical model (internal condition and facade).



3. Apache HVAC is for mechanical modeling (ACMV, plant).



4. Vista/Vista pro is for result file (building load, energy and carbon).



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General process of Model IT in IES<VE>

Geometry Modeling tool (3D Model)

-Easy to create spaces based on imported drawings
-Standard weather data for variable place
-Design Weather condition
-Easy to assign category for spaces
-3D model Viewer

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2.General understanding of Model IT in IES<VE>

To create 3D model based on architectural plan and elevation drawings.

Model IT module has following functions.

(1) Create each rooms based on the drawings.



Draw Arc
Draw Extruded Shape
Draw Prism
Draw Pyramid
Draw Sphere
Draw Hemisphere
Draw Cylinder
Draw Partition

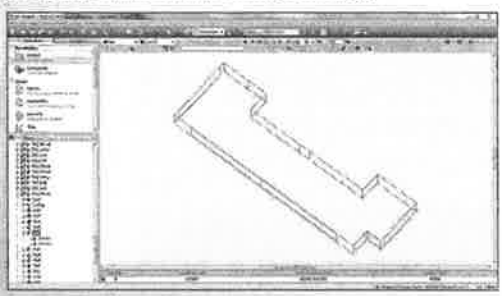
Based on the imported drawings, 3D model can be created in Model IT.

It is possible to draw different shapes of the spaces in model tool bar and combine or separated space and space if needed.

It allows to create the complicated shape of building easily compared with other software.

Please note that only DXF file is available to be imported in Model IT.

(2) Create window based on the drawings.



Add Door
Add Window
Add Hole Between Adjacent Zones

Based on the elevation drawing, it is possible to create window and door on façade of building. In addition, it has function to define "Hole" between adjacent zone. It is useful to create space which has high height.

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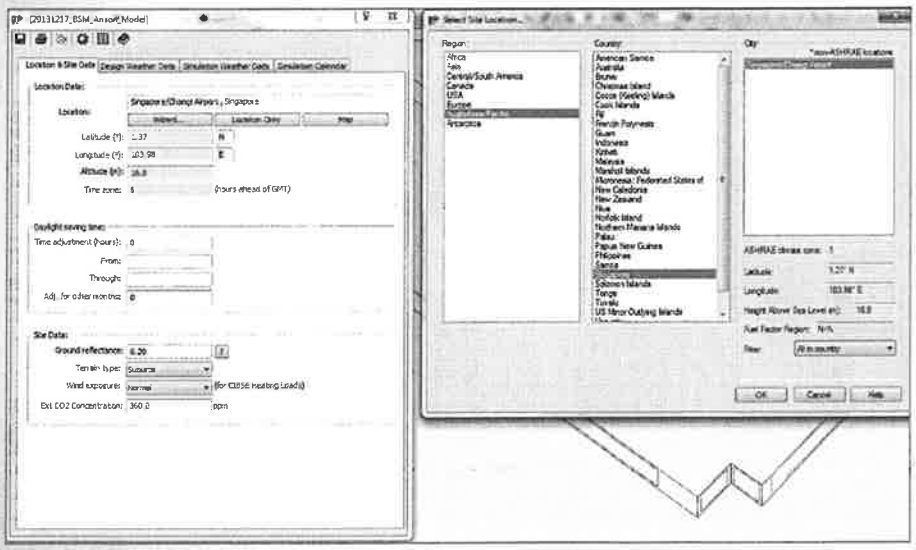
2.General understanding of Model IT in IES<VE>

To create 3D model based on architectural plan and elevation drawings.

Model IT module has following functions.

(3-1) Assign the weather file in IES<VE>



In Model IT in IES<VE>,
We can define a location of a project building.

It includes following functions.

Site data
Daylighting condition
Design weather condition
Weather file (8,760hrs)
Simulation calendar

In addition, site data also relates to load and energy simulation because it is used for the diffuse solar calculation (Ground reflectance) and wind speed calculation (Wind exposure).

International weather data is available in IES<VE> website. (http://www.iesve.com/support/weatherfiles)

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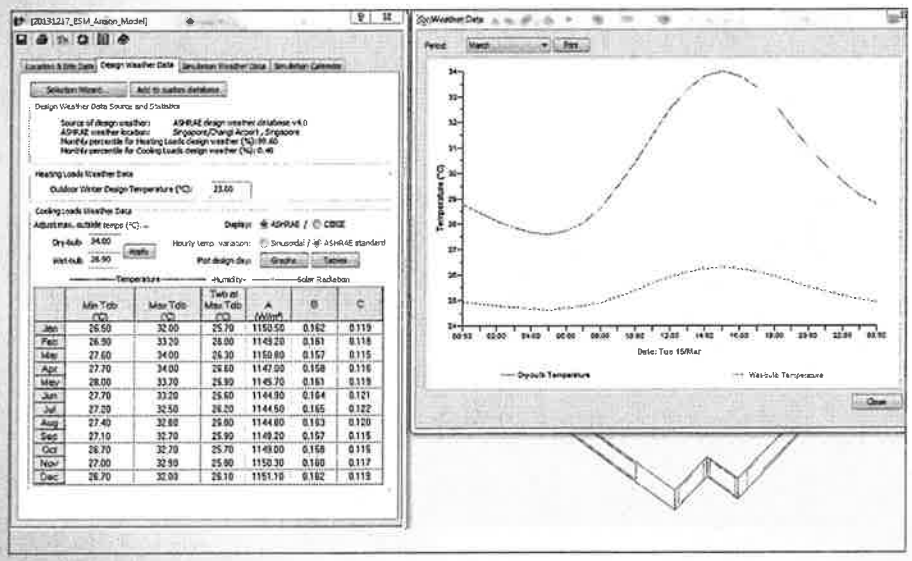
2.General understanding of Model IT in IES<VE>

To create 3D model based on architectural plan and elevation drawings.

Model IT module has following functions.

(3-2) Assign the weather file in IES<VE>



In Model IT in IES<VE>,
As the additional information, project team also can define the design weather condition in Model IT.

It will used for the sizing calculation of the pump, chiller and fans to decide the capacity or flow rate.

Based on the ASHRAE Fundamental Design water data, the Model IT generate the design weather data for 12months.

International weather data is available in IES<VE> website. (http://www.iesve.com/support/weatherfiles)

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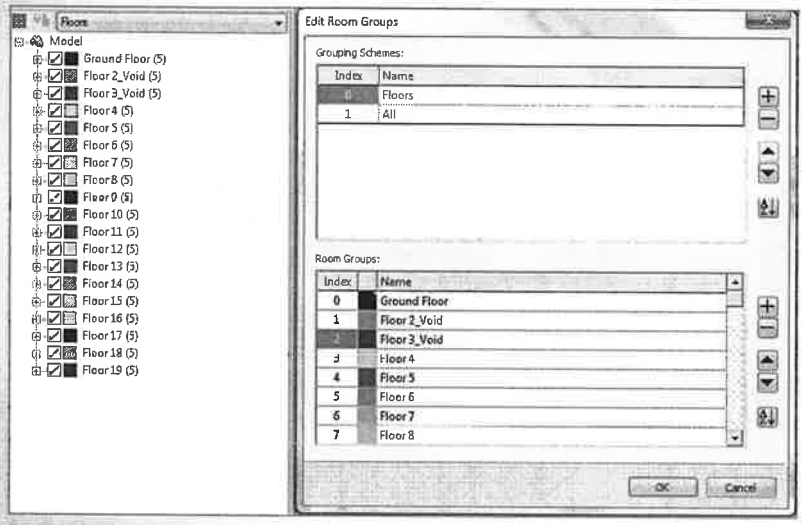
2.General understanding of Model IT in IES<VE>

To create 3D model based on architectural plan and elevation drawings.

Model IT module has following functions.

(4) Edit Room Group in IES<VE>



In Model IT in IES<VE>,
In Model IT, we can define room groups based on different categories.

Floor by floor
Space type
System type
AC and Non AC zone

This "Edit room group" is useful when we check the area according to the type of space and floor by floor.

Function of "Edit Room Groups " is useful to check total area of the window and plan according to the different category of the space.

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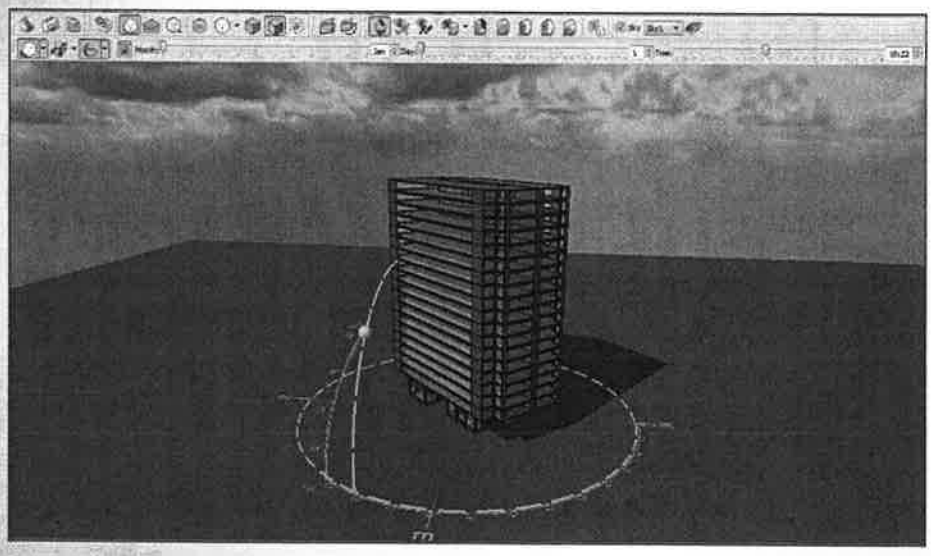
2.General understanding of Model IT in IES<VE>

To create 3D model based on architectural plan and elevation drawings.

Model IT module has following functions.

(4) Viewer of 3D model in IES<VE>



In Model IT in IES<VE>,
Viewer of 3D model is provided as well in Model IT and it can be used for the followings.

To check whether 3D model is correct or not.

To provide the Screen capture of the building.

To study Solar position and shade by building according to hour and date.

It provides variable options to the building view.

Visual function in IES<VE> is useful to check if 3D model is correct and to provide image of the building in supporting documents.

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General process of Apache in IES<VE>

Thermal properties of building (Hourly/Monthly building load profile)

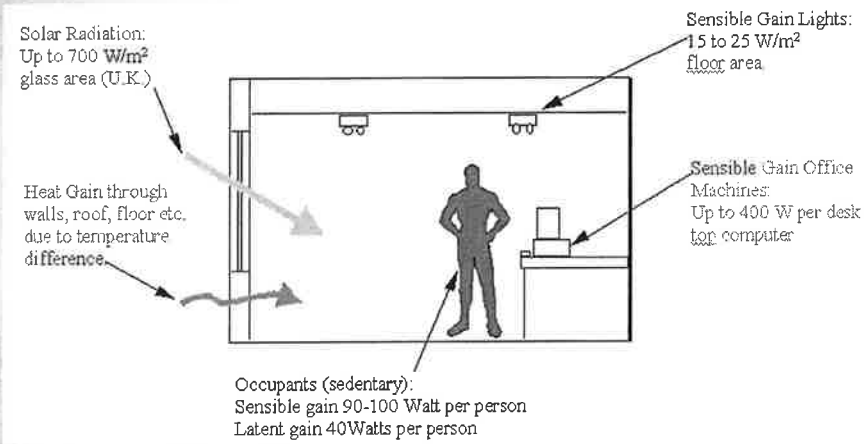
-Internal condition
-Operating schedule of lighting, equipment, people, system etc
-Thermal properties of façade
-Report generator for room level
-Simple HVAC model in early stage of project
-Hot water system and solar hot water system

3. General understanding of Apache in IES<VE>

To define the thermal properties of the building (Internal condition and façade).

After creating 3D model, we can define thermal properties of building such as the internal condition and façade.

(1) What is internal and external heat gain?



In terms of the cooling load, space heat gain can be summarized as in the below.

(Internal heat gain)
Lighting heat gain
Equipment heat gain
People heat gain
etc

(External heat gain)
Infiltration heat gain
Solar heat gain
Wall heat gain
Roof heat gain
Floor heat gain
etc

Internal heat gain : LPD (Lighting Power Density), EPD (Equipment Power Density), Occupancy heat gain in 'Thermal conditions' tap. It should be created space by space such as office, corridor, meeting room etc.

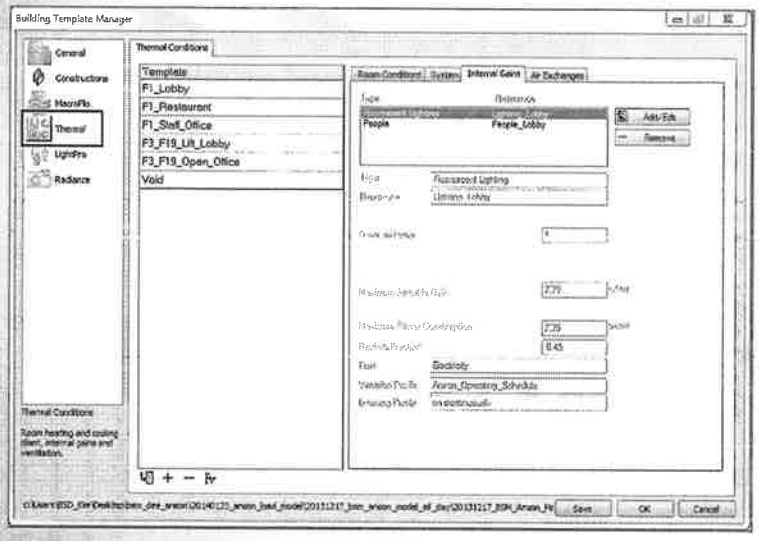
External heat gain : Thermal properties of façade can be defined in 'construction' tap. The IES<VE> will calculate the cooling load from the facade based on the hourly weather data .

3. General understanding of Apache in IES<VE>

To define the thermal properties of the building (Internal condition and façade).

After creating 3D model, we can define thermal properties of building such as the internal condition and façade.

(1-1) Internal condition in Apache Module (Building Template Manager)



Based on the space type, the user can define the internal heat gain from lighting, equipment and occupancy (inclusive of ACH of infiltration)

(Lighting, Equipment)
Sensible heat gain (W/m2)
Power consumption (W/m2)
Operating hours

(Occupancy)
Sensible heat gain (W)
Latent heat gain (W)
Occupancy density (m2/person)
Occupancy schedule

(Infiltration)
Max flow (ACH)
Infiltration schedule

Based on this template, IES<VE> will generate cooling or heating load for internal heat gain components and it will be referred for the calculation of the energy consumption from lighting and equipment as well.

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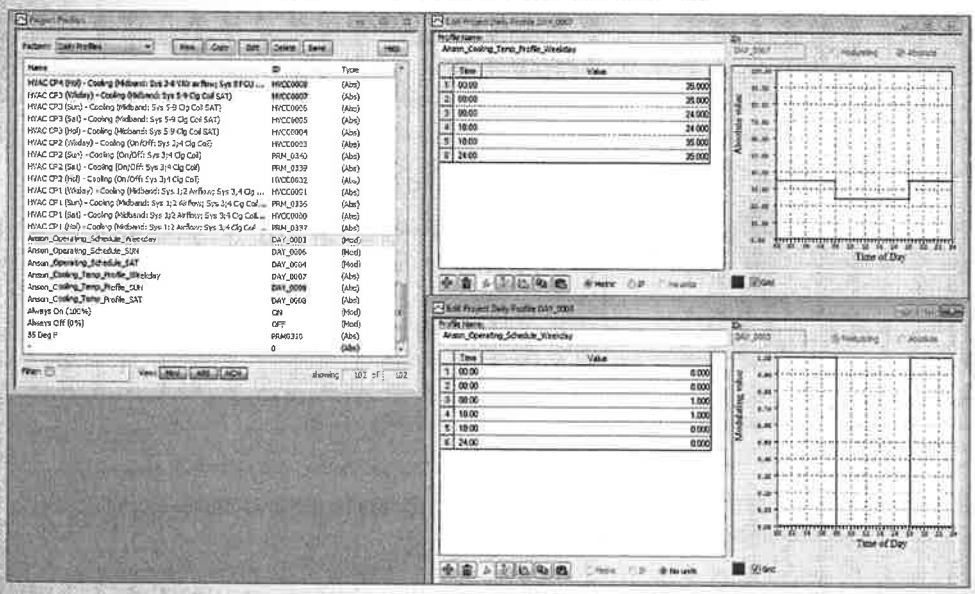
3. General understanding of Apache in IES<VE>

To define the thermal properties of the building (Internal condition and façade).

After creating 3D model, we can define thermal properties of building such as the internal condition and façade.

(1-2) Operating schedule in Apache Module (Building Template Manager)



User can define the hourly operating profile for lighting , equipment, occupancy, fan, chiller etc. The profile will be used in the "Building Template Manager" and "Apache-HVAC".

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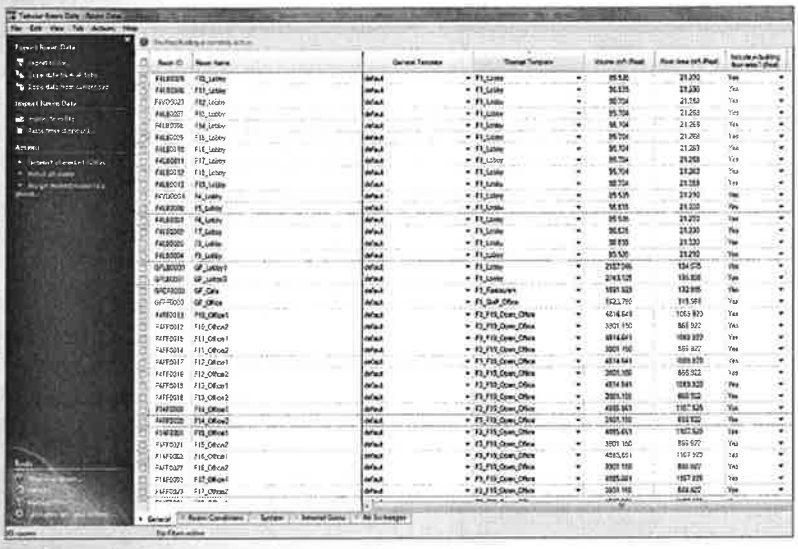
3. General understanding of Apache in IES<VE>

To define the thermal properties of the building (Internal condition and façade).

After creating 3D model, we can define thermal properties of building such as the internal condition and façade.

(1-3) Assign Internal condition to correspond zones (Tabular Room Data)



Based on defined thermal templates in Building Template Manger, user can assign internal conditions to correspond zones in Tabular room data.

If using Tabular room data, it is easier to change the room name, make a groups and define templates, and check volume of room and floor area.

This table can be extracted to excel.

Based on this template, IES<VE> will generate cooling or heating load for internal heat gain components and it will be referred for the calculation of the energy consumption from lighting and equipment as well.

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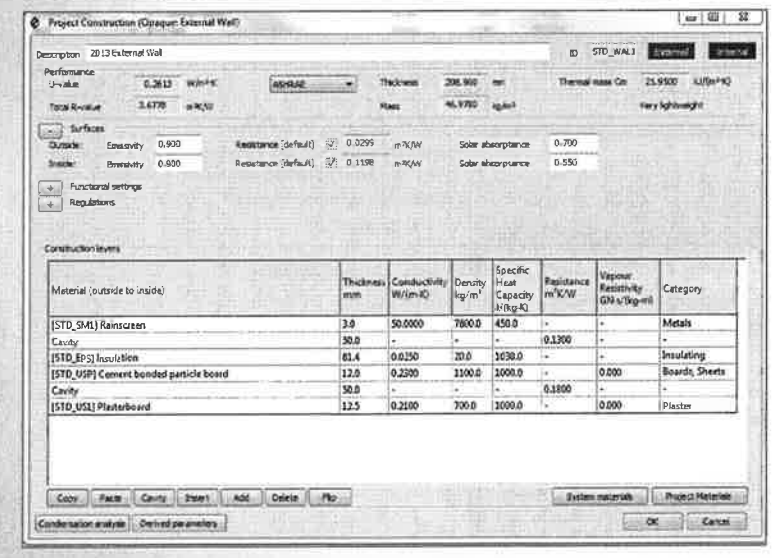
3. General understanding of Apache in IES<VE>

To define the thermal properties of the building (Internal condition and façade).

After creating 3D model, we can define thermal properties of building such as the internal condition and façade.

(2-1) Thermal properties of façade in Apache Module (External Wall)



Thermal properties of façade can be defined in Apache module.

(External Wall, Roof, Internal wall, Ground floor)
U-value (W/m2K)
Solar absorptance
Surface Resistance
Conductivity
Thickness
Density
Vapour Resistivity
Specific Heat Capacity
Resistance

Based on this template, IES<VE> will generate cooling or heating load for external heat gain components based on 8,760hrs weather profile inclusive of the solar profile, solar radiation, wet-bulb temp, dry-bulb temp, wind speed, etc

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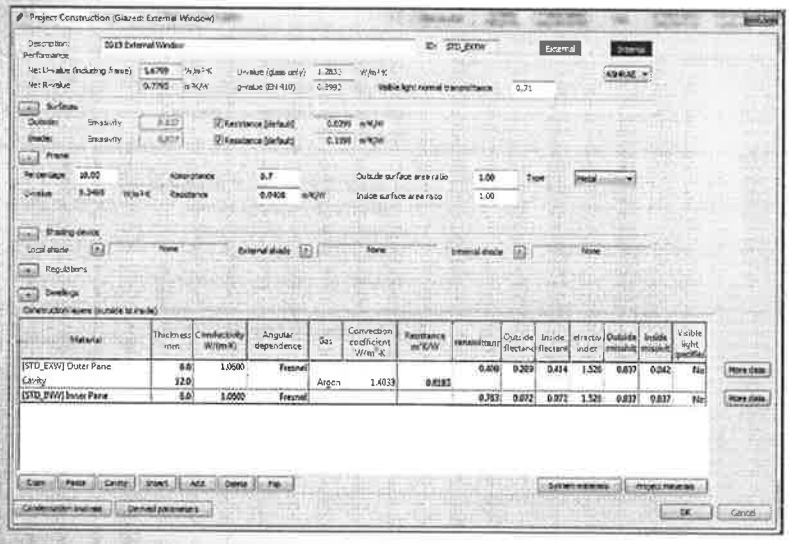
3. General understanding of Apache in IES<VE>

To define the thermal properties of the building (Internal condition and façade).

After creating 3D model, we can define thermal properties of building such as the internal condition and façade.

(2-2) Thermal properties of façade in Apache Module (External Window)



Thermal properties of façade can be defined in Apache module.

(Window)
U-value (W/m2K)
Surface Resistance
Transmittance
Reflectance
Conductivity
Thickness
Gas Convection coefficient
Emissivity
SHGC
SC

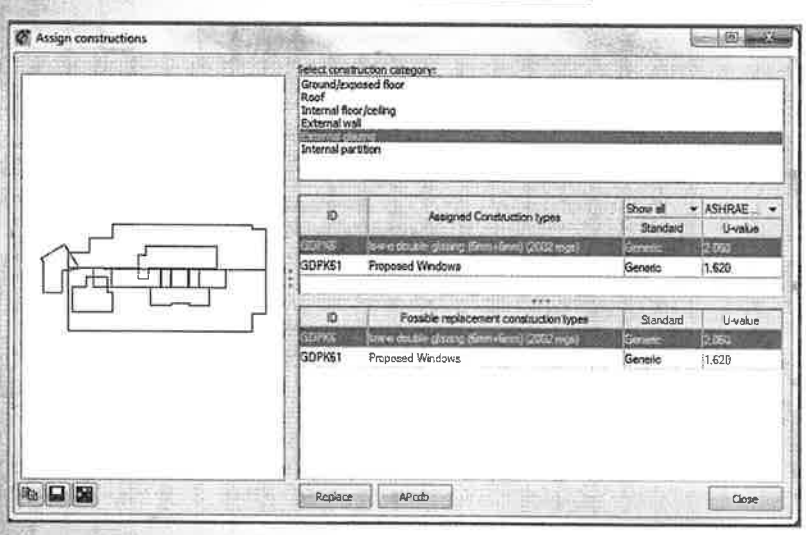
Based on different calculation methodologies from ASHRAE, CIBSE and EN-ISO standard, thermal properties of external window and external wall are generated differently.

3. General understanding of Apache in IES<VE>

To define the thermal properties of the building (Internal condition and façade).

After creating 3D model, we can define thermal properties of building such as the internal condition and façade.

(3) Assign thermal properties of façade to correspond facade



We can define the thermal properties of façade to correspond facade.

After selecting space where users want to define, window and wall construction can be assigned by using "Assign construction".

Ground / exposed floor
Roof
Internal floor / Ceiling
External wall
Internal partition

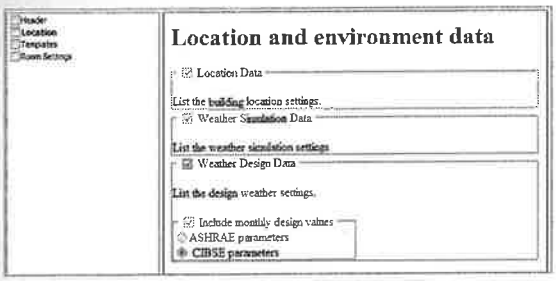
By using "Assign constructions", the project team can define the type of the façade or floor to correspond space.

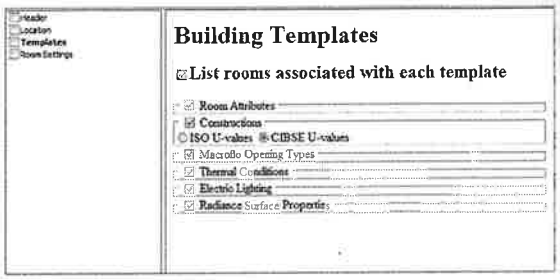
3. General understanding of Apache in IES<VE>

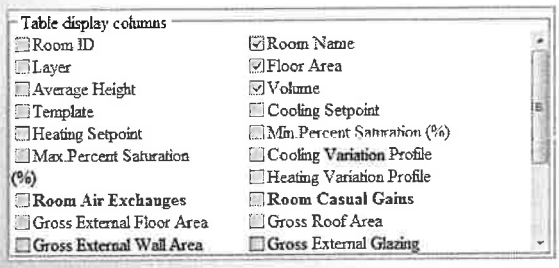
To define the thermal properties of the building (Internal condition and façade).

After creating 3D model, we can define thermal properties of building such as the internal condition and façade.

(4) Report Generator (Room level)







Apache Module in IES<VE> also provides the PDF report format for the following information as in the below.

Location data
Design weather condition
Construction list defined in model
Thermal condition defined in model
Room name, area, volume (Geometry information)

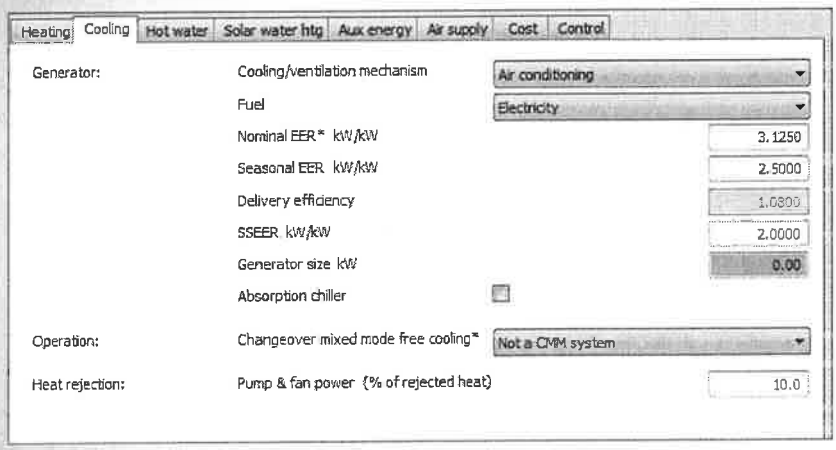
It can be used as the supporting document in certification.

3. General understanding of Apache in IES<VE>

To define the thermal properties of the building (Internal condition and façade).

After creating 3D model, we can define thermal properties of building such as the internal condition and façade.

(5) Simplified HVAC system study in early stage of project (ApacheSim)



It is simplified calculation of the energy consumption of HVAC systems.

Instead of part load performance of ACMV systems, nominal COP and Seasonal COP is used for the analysis of annual energy consumption of systems.

This function is used in very early stage of design to estimate energy consumption of system.

Nominal EER (=COP) is efficiency of system at full load condition.

Seasonal EER (=COP) is efficiency of system to represent the performance of units over season and year. (Include the effect of weather condition)

SEER is the efficiency of system to take into account losses.

Fresh air amount also can be defined in "Thermal condition" tap.

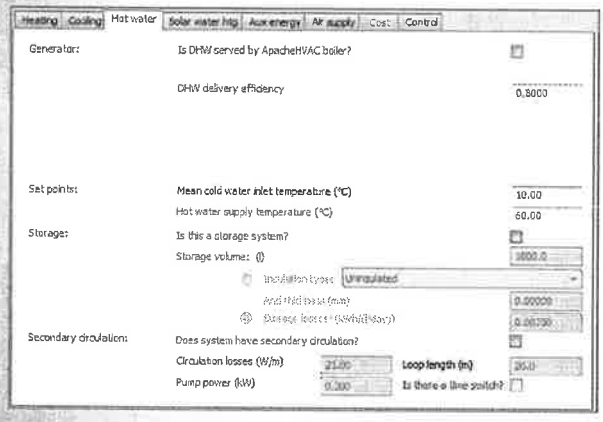
3. General understanding of Apache in IES<VE>

To define the thermal properties of the building (Internal condition and façade).

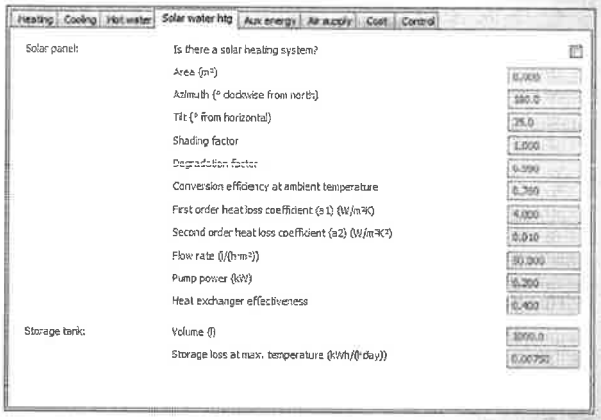
After creating 3D model, we can define thermal properties of building such as the internal condition and façade.

(5) Hot water system and solar hot water modeling (ApacheSim)

A. Hot water system



B. Solar Hot water system



As the additional information, Hot water system and solar hot water system can be modeled in Apache Module.

Basically, Apache HVAC is to model detail ACMV system such as air-side fans, chiller, pump, cooling tower, VRV unit etc based on part load performance of system and doesn't include modeling tool for hot water system and solar hot water system.

Both hot water system and solar hot water system can be defined only in Apache Module.

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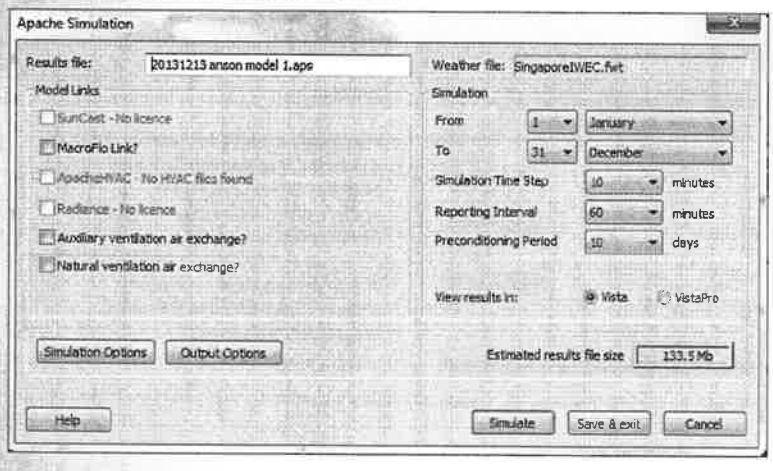
3. General understanding of Apache in IES<VE>

To define the thermal properties of the building (Internal condition and façade).

After creating 3D model, we can define thermal properties of building such as the internal condition and façade.

(6) Building Load Simulation (ApacheSim)



After creating all of internal conditions and thermal properties of façade, project team can simulate the cooling and heating load based on weather data. Hourly building load profiles and space load profile will be provided in Vista Module and be able to be used for design of building and systems.

Please note that it still is able to run simulation of building load based on thermal properties defined in Apache module without input in Apache HVAC module.

BSD building system & diagnostics

General process of Apache HVAC in IES<VE>

To model HVAC systems in detail for energy model

-Advantage of Apache HVAC module
-Prototype of systems in Apache HVAC
-Airside system modeling in Apache HVAC
-Water side system modeling in Apache HVAC

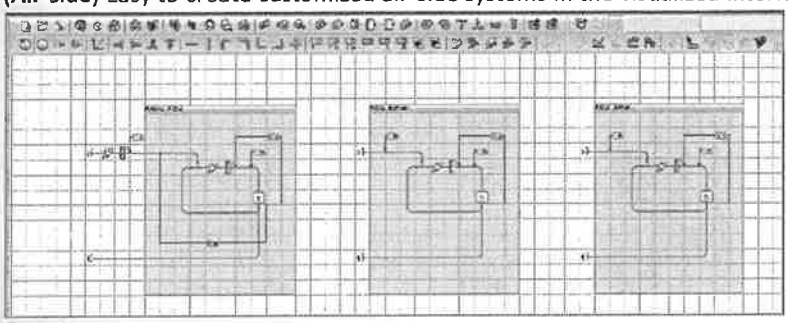
4. General process of Apache HVAC in IES<VE>

To define detail ACMV system in energy model

Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

(1) What is advantage of Apache HVAC module?

- Variable prototype system : User can select many pre-defined system from the prototype library.
- **(Air-side)** Easy to create customized air-side systems in the visualized interface.



A. User can draw duct lines according to duct layout design.
B. User can define location of inlet and outlet, fan and cooling/heating coil.
C. User can define properties of system such as capacity, flow rate, control etc.

Easy to understand defined systems in Apache HVAC interface.

- **(Water-side)** Easy to define the part load performance of chilled water plant : Normally, part load performance of chilled water plant is defined based on many coefficients to define cooling capacity curve, water temperature dependence curve and part load dependence curve. However, Apache HVAC provides easier interface to define performance curves which has similar data format with technical specification from supplier.

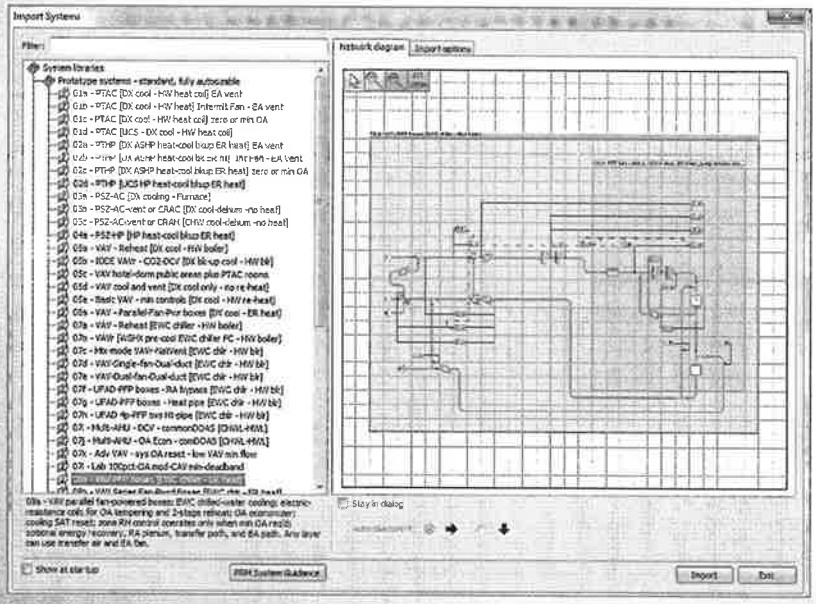
4. General process of Apache HVAC in IES<VE>

To define detail ACMV system in energy model

Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

(2-1) Prototype of systems in Apache HVAC

The standard and fully auto-sizable prototype systems are provided from system libraries.



Prototype can be used for following purposes.

User can refer libraries when they define some customized system.

User can use prototype when they need auto-sizing calculation.

Please note that auto-sizing is available only in prototype systems in Apache HVAC.

Packaged terminal air conditioner
Packaged terminal heat pump
VAV with PFP boxes
VAV with reheat
DOAS (Dedicated Outdoor Air System)
Active chilled beam
etc

BSD building system & diagnostics

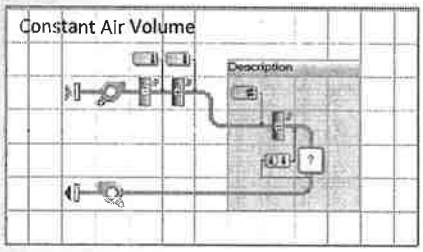
4. General process of Apache HVAC in IES<VE>

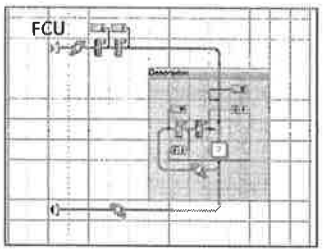
To define detail ACMV system in energy model

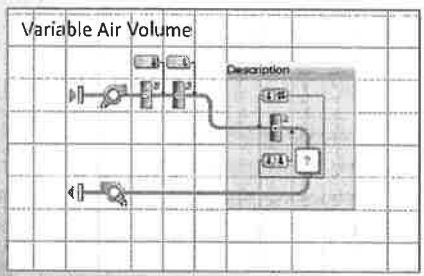
Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

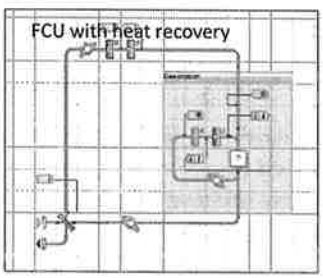
(2-2) Prototype of systems in Apache HVAC

The simplified HVAC systems also are provided from system libraries.









Simplified prototype systems also are provided in Apache HVAC.

Constant air volume with economizer
Constant air volume with heat recovery
Constant air volume
Fan coil units with heat recovery
Fan coil units
Variable air volume with economizer
Variable air volume with heat recovery
Variable air volume

We can delete component related to heating in simplified prototype systems to use for project building in Singapore.

BSD building system & diagnostics

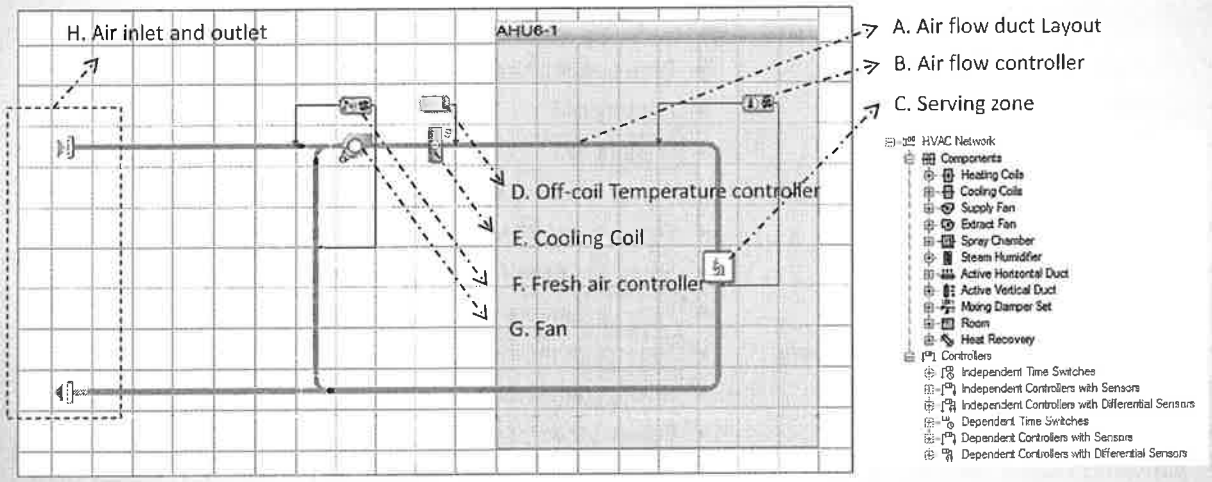
4. General process of Apache HVAC in IES<VE>

To define detail ACMV system in energy model

Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

(3-1) Airside system modeling in Apache HVAC

We can summarize components of systems as in the below.



The simplified AHU loop is provided as example as in the above. There are total 8 components (3 of controllers, duct layout, fan system, cooling coil, serving zone and air inlet/outlet).

4. General process of Apache HVAC in IES<VE>

To define detail ACMV system in energy model

Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

(3-2) Airside system modeling in Apache HVAC

We can draw duct layout by using tool bar on grid in Apache HVAC as in the below.

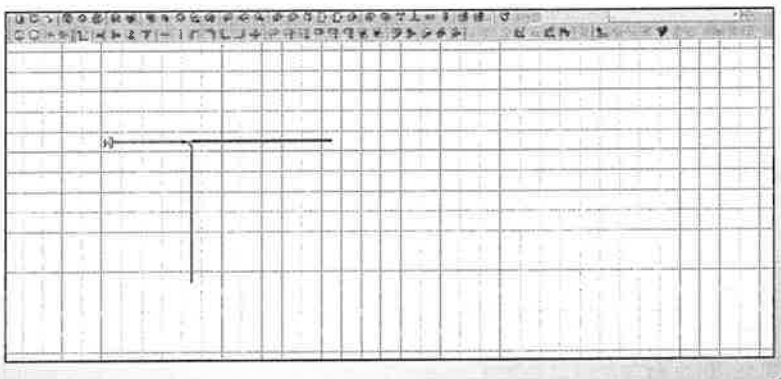


- Room or thermal zone component
- Air inlet
- Air outlet
- Network drawing tool
- Junction / flow splitters (four)
- Straight connectors (two)
- Elbow connectors (four)
- Crossover connector

In this tool bar, we can define below components from example AHU loop.

A. Air flow duct Layout
C. Serving zone
H. Air inlet and outlet





4. General process of Apache HVAC in IES<VE>

To define detail ACMV system in energy model

Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

(3-3) Airside system modeling in Apache HVAC

We can define system components from tool bar in Apache HVAC.



- Hot water loops
- Generic heat sources
- Air-to-air heat pump types
- Heat transfer loops → Chilled Water Plant
- Water-to-air heat pump types
- Chilled water loops
- Generic cooling sources → DX unit
- Dedicated waterside economizer types
- DX Cooling types
- Unitary cooling system types
- Radiator / radiant panel types
- Chilled ceiling /radiant panel types
- Direct-acting heater/cooler types
- Heating coil
- Cooling coil
- Air-to-air heat / enthalpy exchanger
- Steam humidifier
- Spray chamber / evaporative cooler
- Fan – left intake
- Fan – right intake
- Mixing damper set
- Return air damper set
- Duct heat gain / loss – horizontal
- Duct heat gain / loss – vertical

In addition, duct heat gain also can be considered in Apache HVAC module.

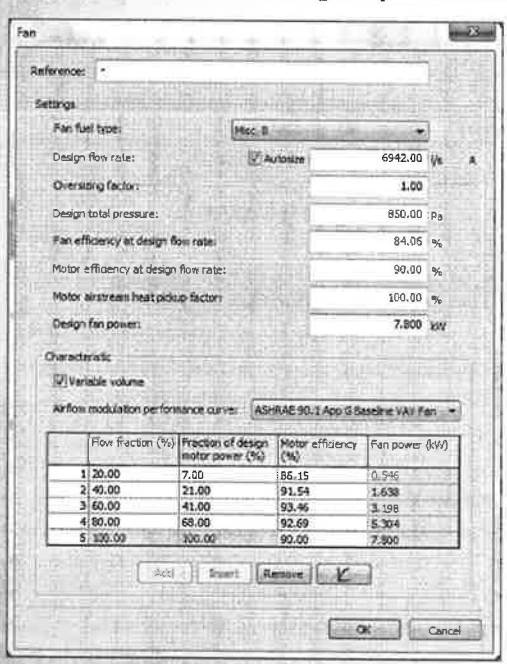
BSD building system & diagnostics

4. General process of Apache HVAC in IES<VE>

To define detail ACMV system in energy model

Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

(3-4) Airside system modeling in Apache HVAC



Based on technical specification or equipment schedule, User can define fan specification.

Design Flow rate (l/s)
Over-sizing Factor (When auto-sizing calculation)
Design total pressure (Pa)
Motor airstream heat pickup factor
(to consider heat gain from motor)
Fan performance curve

Please note that Apache HVAC module provides several fan curves as references.

Fan efficiency (%) and Motor efficiency
Or Design fan power (kW)

Please note that Apache HVAC module calculate fan power based on flow rate, pressure and efficiency or calculate efficiency based on flow rate, pressure and fan power. Either fan power or efficiency has to be inputted.

BSD building system & diagnostics

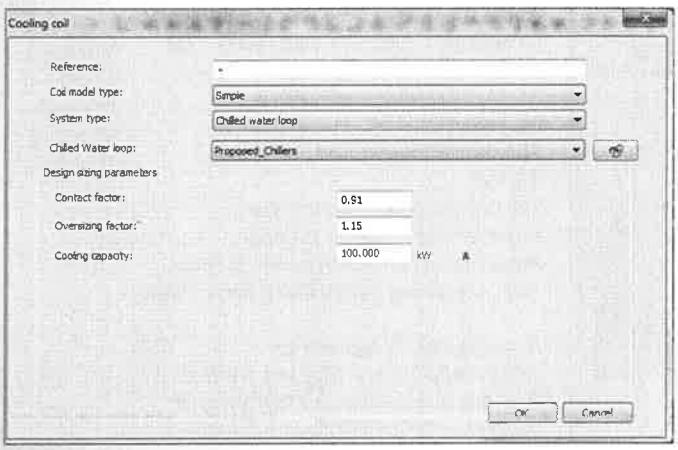
4. General process of Apache HVAC in IES<VE>

To define detail ACMV system in energy model

Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

(3-5) Airside system modeling in Apache HVAC

Cooling Coil specification can be defined in tap of "cooling coil".



Contact factor (%)
Over-sizing Factor (%)
(When auto-sizing calculation)
Cooling Coil (kW)
System type
(DX unit or chilled water plant)
Chilled water loop
(to define corresponding chilled water plant from chilled water loops)

Please note that there are two options to define cooling coil in Apache HVAC. If having detail information of fan, detail mode can be used.

4. General process of Apache HVAC in IES<VE>

To define detail ACMV system in energy model

Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

(3-6) Airside system modeling in Apache HVAC

The controllers will define the operation of the system and the behavior of devices such as coils, mixing dampers, flow splitters, heat exchanger, etc.



- Independent time switch controller
- Independent controller with sensor
- Independent differential controller
- Dependent time switch controller
- Dependent controller with sensor
- Dependent differential controller
- AND connection
- OR connection

Mainly, 4 controllers highlighted in red in the above are used for the HVAC model.

- Independent time switch : Normally, it is used for constant off-coil temperature control or constant flow rate of fresh air and fan flow rate.
- Independent controller with sensor : According to the detected number from sensor, airflow or temperature is controlled. It is used for Variable air volume control, off-coil temperature reset control, and fresh air demand control by CO2 sensor.
- And connection : This is connection between controller and other controller. When own switch operates, another switch will operate together. (Identical operating schedule)
- OR connection : When own switching operate, another switch will operate together, but another switch will operate according to own operating schedule as well. All connections will be explained in actual practice session.

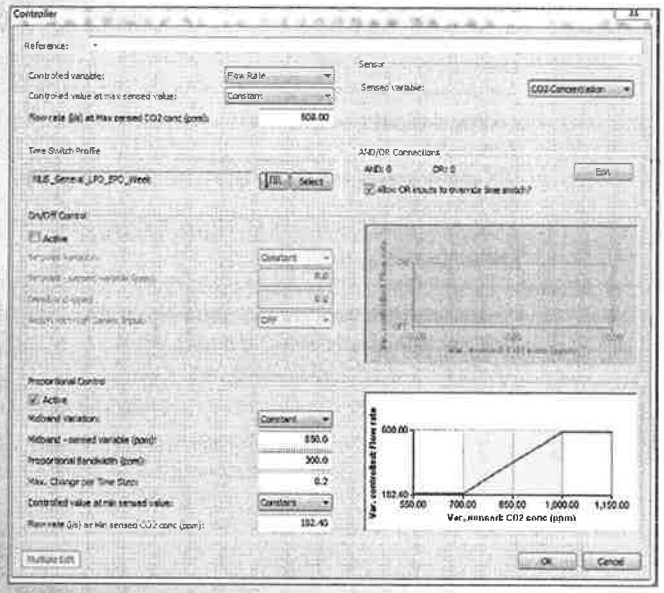
4. General process of Apache HVAC in IES<VE>

To define detail ACMV system in energy model

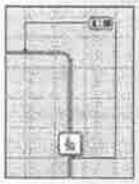
Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

(3-7) Airside system modeling in Apache HVAC

Independent controller with sensor1



As the example of fresh air control by using independent controller with sensor, CO2 demand controller is provided.



For example,
Flow rate at max sensed CO2 (ppm) : 1000l/s
Time switch profile : 8am to 6pm
Sensed variable (ppm) : 850ppm
Proportional Bandwidth(ppm) : 300ppm
Flow rate at min sensed CO2 (ppm) : 500l/s

It means that "At higher than 1000ppm(850ppm + 150ppm), fresh air flow rate is maximum at 1000l/s and at lower than 700ppm(850ppm – 150ppm), fresh air flow rate is minimum at 500l/s. between 700ppm and 1000ppm, fresh air flow rate is linearly varied from 8am to 6pm".

BSD building system & diagnostics

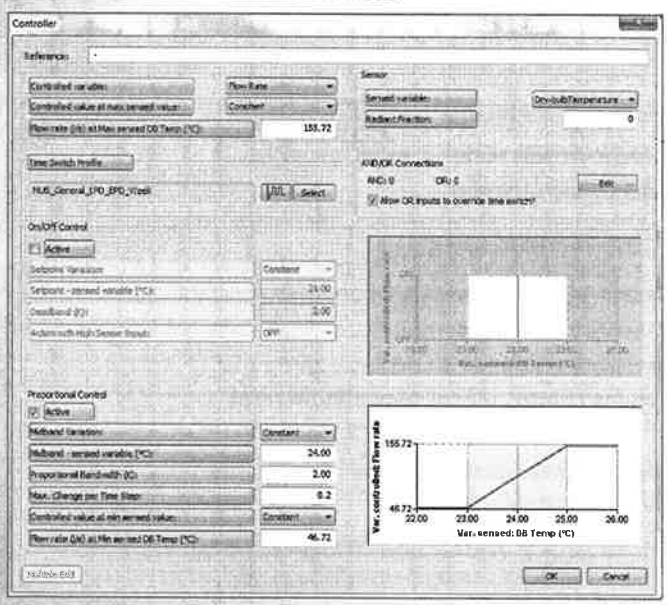
4. General process of Apache HVAC in IES<VE>

To define detail ACMV system in energy model

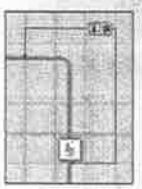
Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

(3-8) Airside system modeling in Apache HVAC

Independent controller with sensor2



As the example of VAV flow rate control by using independent controller with sensor, VAV box controller is provided.



For example,
Flow rate at max sensed CO2 (ppm) : 1000l/s
Time switch profile : 8am to 6pm
Sensed variable (ppm) : 24C
Proportional Bandwidth(ppm) : 2C
Flow rate at min sensed CO2 (ppm) : 500l/s

It means that "At higher than 25C (24C + 1C), Supply air flow rate is maximum at 1000l/s and at lower than 23C(24C – 1C), Supply air flow rate is minimum at 500l/s. between 23C and 25C, Supply air flow rate is linearly varied from 8am to 6pm".

BSD building system & diagnostics

4. General process of Apache HVAC in IES<VE>

To define detail ACMV system in energy model

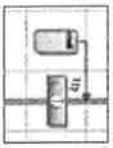
Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

(3-8) Airside system modeling in Apache HVAC

Independent time switch controller



As the example of constant off coil temperature control by using independent time switch controller, Off-coil temperature controller is provided.



For example,
Controlled variable : Dry-bulb temp
Max signal variation: Constant
(We can define hourly profile of off-coil temp)
Dry-bulb : 10.9C
Time switch profile : 8am to 6pm

It means that "Off-coil temperature will be maintain at 10.9C from 8am to 6pm".

Please note that all controllers has to be positioned at proper location. Off-coil temperature controller has to be located after cooling coil.

BSD building system & diagnostics

4. General process of Apache HVAC in IES<VE>

To define detail ACMV system in energy model

Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

(4-1) Water side system modeling in Apache HVAC

There are two options to define part load performance of chilled water plant in Apache HVAC.

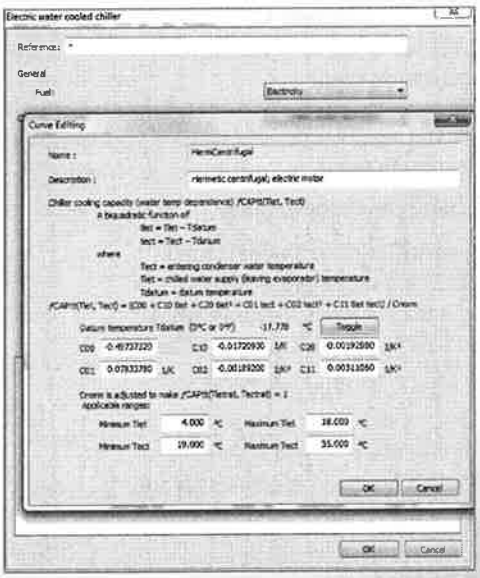
A. Part load curve (by equation and coefficients)

Chiller part load curve : It is defined based on three equations

- Cooling capacity curve
- Water temperature dependence
- Part load dependence

CHWP part load curve : Based on equations
CWP : Only for constant speed
Cooling tower : One speed/two speed/VSD

In this option, many pre-defined chiller part load curve can be selected based on type of chillers. It is useful to be used for 4 seasons country which has several control strategies of chiller according to different weather condition (Supply chilled water temp reset and entering condenser water temp reset etc) But, it is difficult to generate all coefficients manually.



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4. General process of Apache HVAC in IES<VE>

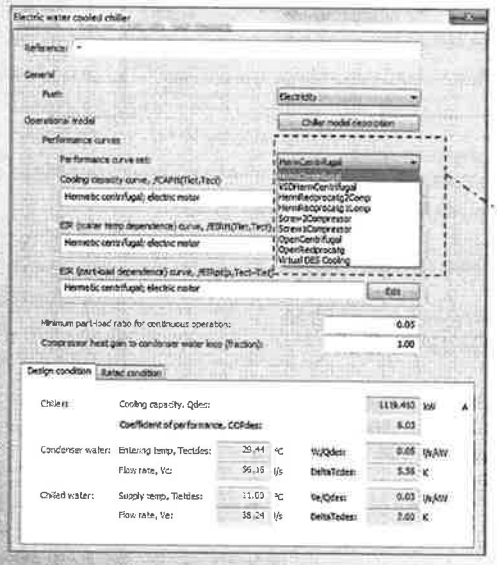
To define detail ACMV system in energy model

Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

(4-1) Water side system modeling in Apache HVAC

There are two options to define part load performance of chilled water plant in Apache HVAC.

A. Part load curve (by equation and coefficients)



Apache HVAC provides the default curve according to the type of chillers.

Herm Centrifugal
VSD Herm Centrifugal
Herm Reciprocatg2Comp
Herm Reciprocatg1Comp
Screw2Compressor
Screw1Compressor
Open Centrifugal
Open Reciprocatg
Virtual DES Cooling

User can define chiller type, chiller capacity and COP at full load condition and part load performance will be generated based on pre-defined coefficients in three equations.

BSD building system & diagnostics

4. General process of Apache HVAC in IES<VE>

To define detail ACMV system in energy model

Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

(4-1) Water side system modeling in Apache HVAC

There are two options to define part load performance of chilled water plant in Apache HVAC.

B. Part load curve (by table)

Chiller part load curve : User can just input COP of part load for chiller in table.

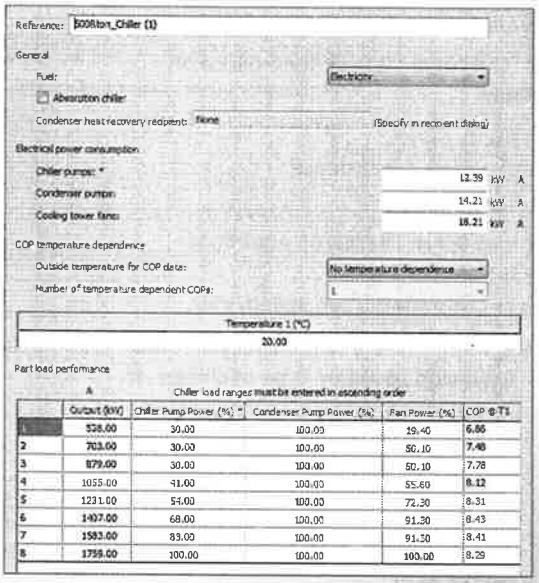
CHWP part load curve : User can input in table

CWP : User can input in table

Cooling tower : User can input in table

In this option, it is easier to define part load performance of chilled water plant than previous option because it has similar format with general technical specification of chiller.

In tropical countries, it seldom use "Supply chilled water temp reset control" because weather condition is quite constant through a year. We will study this way in practice session.



BSD building system & diagnostics

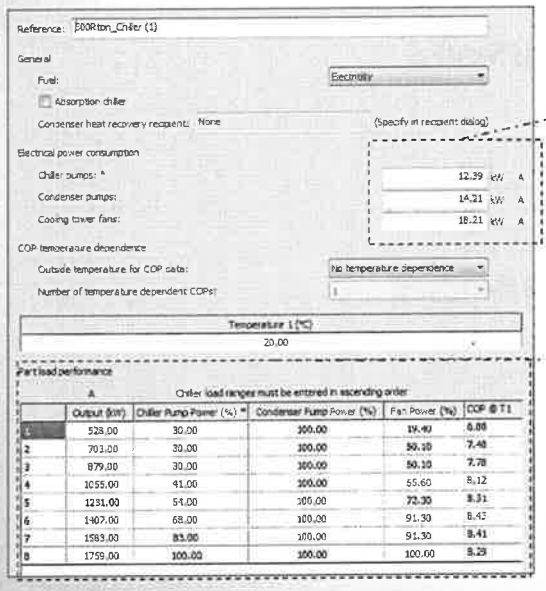
4. General process of Apache HVAC in IES<VE>

To define detail ACMV system in energy model

Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

(4-2) Water side system modeling in Apache HVAC

There are two options to define part load performance of chilled water plant in Apache HVAC.


Reference: 500Rton_Chiller (1)

General

Fuel: Electricity

Absorption chiller

Condenser heat recovery recipient: None (Specify in recipient dialog)

Electrical power consumption

Chiller pumps: 12.39 kW A

Condenser pumps: 14.21 kW A

Cooling tower fans: 18.21 kW A

COP temperature dependence

Outside temperature for COP data: No temperature dependence

Number of temperature dependent COPs: 1

Temperature 1 (°C)
20.00

Part load performance

A — Chiller load ranges must be entered in ascending order

	Output (kW)	Chiller Pump Power (%) *	Condenser Pump Power (%)	Fan Power (%)	COP @ T1
1	528.00	30.00	100.00	19.40	6.86
2	703.00	30.00	100.00	50.10	7.48
3	879.00	30.00	100.00	50.10	7.78
4	1055.00	41.00	100.00	55.60	8.12
5	1231.00	54.00	100.00	72.30	8.31
6	1407.00	68.00	100.00	91.30	8.43
7	1583.00	83.00	100.00	91.30	8.41
8	1759.00	100.00	100.00	100.00	8.29

Input power of pumps and cooling tower at full load condition

Chilled water pump power (kW)
Condenser water pump power (kW)
Cooling tower fan power (kW)

Part load performance for pumps, cooling tower and chiller.

Chilled water pump part load performance
Condenser water part load performance
Cooling tower fan part load performance
Chiller part load performance

4. General process of Apache HVAC in IES<VE>

To define detail ACMV system in energy model

Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

(4-2) Water side system modeling in Apache HVAC

Part load performance table in excel format

		Cooling load (kW)	Cooling load (Rton)	kW/Rton	Input power (kW)	COP	Chiller Operation: CHWP1 Power1 (kW)	CW Power (kW)	CT power (kW)	Plant input power (kW)	Plant (kW/Rton)
1	100%	1,759	500	0.424	212	8.29	12.39	14.21	18.21	256.81	0.514
2	90%	1,583	450	0.418	188	8.41	10.28	14.21	16.63	229.23	0.509
3	80%	1,407	400	0.417	167	8.43	8.43	14.21	16.63	206.07	0.515
4	70%	1,231	350	0.423	148	8.31	6.69	14.21	13.16	182.11	0.520
5	60%	1,055	300	0.433	130	8.12	5.08	14.21	10.13	159.31	0.531
6	50%	879	250	0.452	113	7.78	3.72	14.21	9.13	140.06	0.560
7	40%	703	200	0.470	94	7.48	3.72	14.21	9.13	121.06	0.605
8	30%	528	150	0.513	77	6.86	3.72	14.21	3.53	98.41	0.656

Part load performance table in Apache HVAC

Part load performance

A — Chiller load ranges must be entered in ascending order

	Output (kW)	Chiller Pump Power (%) *	Condenser Pump Power (%)	Fan Power (%)	COP @ T1
1	528.00	30.00	100.00	19.40	6.86
2	703.00	30.00	100.00	50.10	7.48
3	879.00	30.00	100.00	50.10	7.78
4	1055.00	41.00	100.00	55.60	8.12
5	1231.00	54.00	100.00	72.30	8.31
6	1407.00	68.00	100.00	91.30	8.43
7	1583.00	83.00	100.00	91.30	8.41
8	1759.00	100.00	100.00	100.00	8.29

Excel table to indicate part load performance can be converted into part load performance table.

General process of Vista/Vista pro in IES<VE>

To check detail results of energy modeling in IES<VE>

-Difference of Vista and Vista pro
-Weather profile in Vista Module.
-Result of Room Level in Vista Module
-Building Load Result of Building Level in Vista Module
-Results in Vista Pro Module (Air-side)
-Results in Vista Pro Module (Water-side)

BSD building system & diagnostics

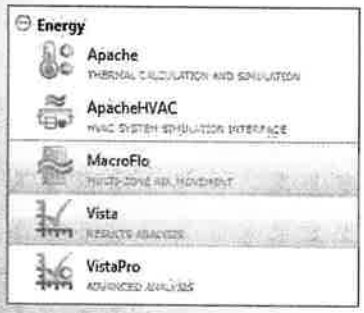
5. General process of Vista and Vista pro in IES<VE>

To check result of energy models in detail in terms of building and system components

There are two modules to check results for energy model in IES<VE>

(1) Difference of Vista and Vista pro

- Vista module : It is to check results related to many kind of information for building/room level such as cooling load profile, room temperature etc and some information of system level such as flow rate, off-coil temperature etc.
- Vista-pro module : It includes all results in Vista module and also provides detail information of systems such as operating power of chiller, pump, cooling tower and fans, part load ratio etc.



How to use result from Vista and Vista pro module

- **Excel format :** Basically, Vista provides results of energy model on hourly, monthly and yearly basis and they can be copied into excel table. The project team can analyze performance of building and systems in excel format.
- **Graph format :** Vista provides graphs for results as well. Project team can choose period on calendar and choose what kind of data they want to see. Vista automatically generates graphs as format which can be copied in excel or word file.

Please note that this module provides cooling and heat load report as well and weather profile can be checked as well.

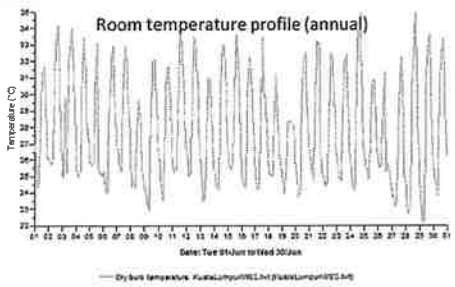
BSD building system & diagnostics

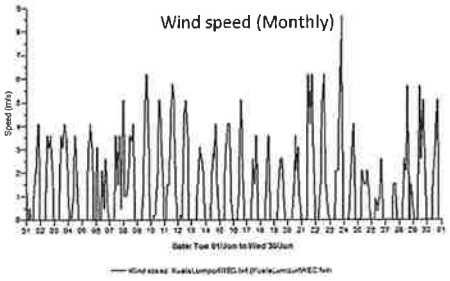
5. General process of Vista and Vista pro in IES<VE>

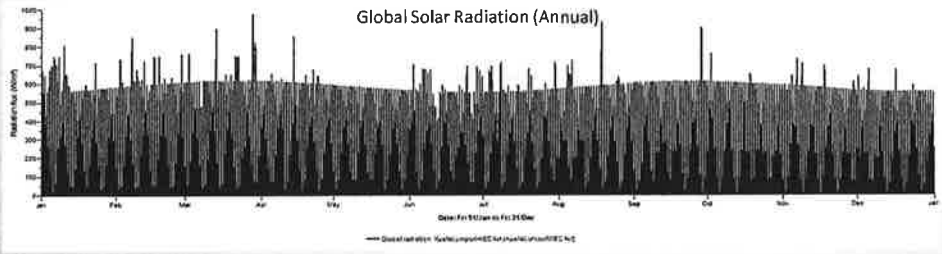
To check result of energy models in detail in terms of building and system components

There are two modules to check results for energy model in IES<VE>

(2-1) Weather profile in Vista Module







For weather profile in Vista module, project team can see the results in the below.

- Dry-bulb Temp
- Wet-bulb Temp
- Wind speed
- Direct Radiation
- Diffuse Radiation
- Global Radiation
- Solar altitude
- Solar azimuth
- etc

Weather file can be used as supporting document of system design.

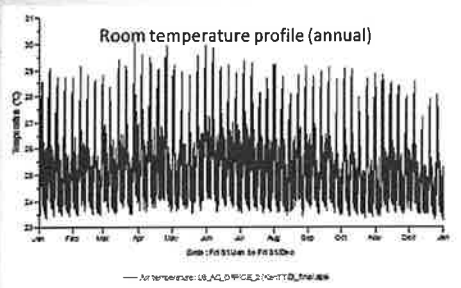
BSD building system & diagnostics

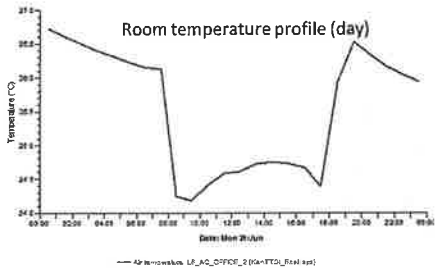
5. General process of Vista and Vista pro in IES<VE>

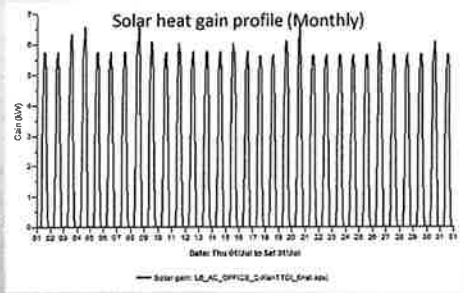
To check result of energy models in detail in terms of building and system components

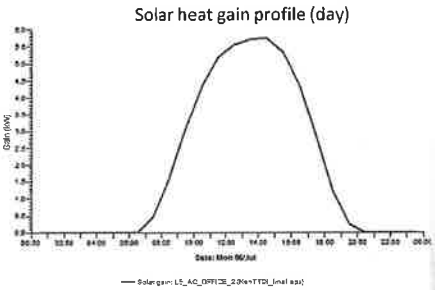
There are two modules to check results for energy model in IES<VE>

(2-2) Result of Room Level in Vista Module









For room level result, project team can see the results in the below.

- Room temperature
- Relative humidity
- Room CO2 concentration
- Internal gain
- Lighting gain
- Equipment gain
- People gain
- Solar gain
- Infiltration
- Predicted Mean Vote
- Mean Radiant Temp
- etc

BSD building system & diagnostics

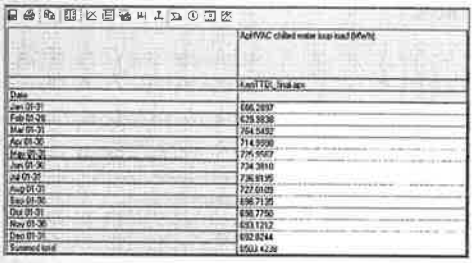
5. General process of Vista and Vista pro in IES<VE>

To check result of energy models in detail in terms of building and system components

There are two modules to check results for energy model in IES<VE>

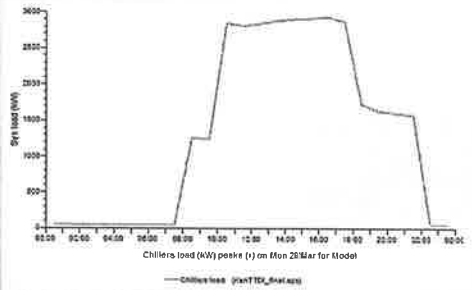
(2-3) Building Load Result of Building Level in Vista Module

Chilled water plant load (annual)

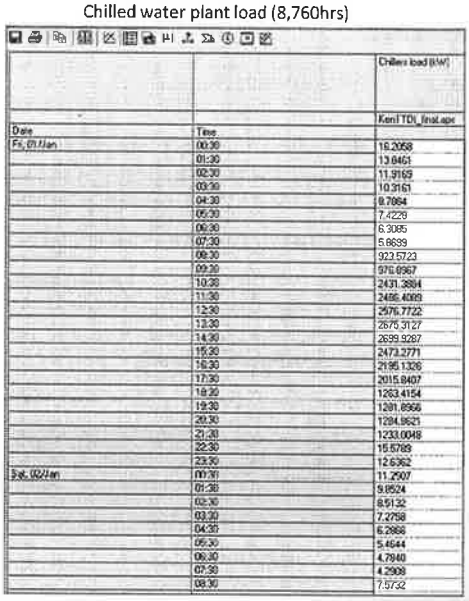


	ApHVAC chilled water loop load (MWh)
	KenTTDI_final.aps
Date	
Jan 01-31	666.2697
Feb 01-28	626.9838
Mar 01-31	764.5492
Apr 01-30	714.9990
May 01-31	795.9567
Jun 01-30	734.3810
Jul 01-31	736.8135
Aug 01-31	727.0103
Sep 01-30	696.7135
Oct 01-31	698.7750
Nov 01-30	653.1212
Dec 01-31	692.8244
Summed load	8500.4238

Chilled water plant load profile



Chilled water plant load (8,760hrs)



		Chillers load (kW)
		KenTTDI_final.aps
Date	Time	
Fri, 01/Jan	00:30	16.2058
	01:30	13.6461
	02:30	11.3169
	03:30	10.3161
	04:30	8.7864
	05:30	7.4229
	06:30	6.3085
	07:30	5.8639
	08:30	923.5723
	09:30	976.6967
	10:30	2431.3894
	11:30	2486.4089
	12:30	2576.7722
	13:30	2675.3127
	14:30	2699.9287
	15:30	2473.2771
	16:30	2195.1326
	17:30	2015.8407
	18:30	1263.4154
	19:30	1281.8966
	20:30	1284.8621
	21:30	1233.0048
	22:30	15.5789
	23:30	12.6362
Sat, 02/Jan	00:30	11.2907
	01:30	9.9524
	02:30	8.5132
	03:30	7.2758
	04:30	6.2866
	05:30	5.4644
	06:30	4.7840
	07:30	4.2908
	08:30	7.5732

For building level result, project team can see the results in the below.

- Heating Load (Boiler, DX units, etc)
- Cooling Load (Chiller, DX units, etc)
- Apache Sim load
- Apache HVAC load
- etc

Please note that all numbers in the tables can be copied in excel format.

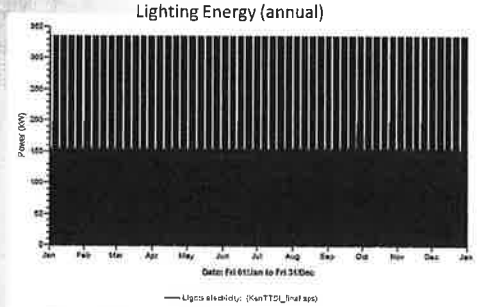
5. General process of Vista and Vista pro in IES<VE>

To check result of energy models in detail in terms of building and system components

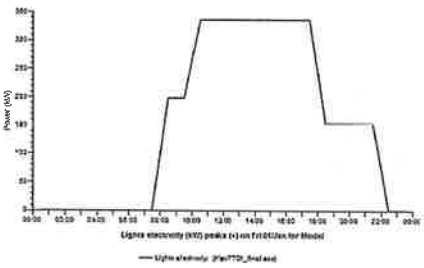
There are two modules to check results for energy model in IES<VE>

(2-4) Building Load Result of Building Level in Vista Module

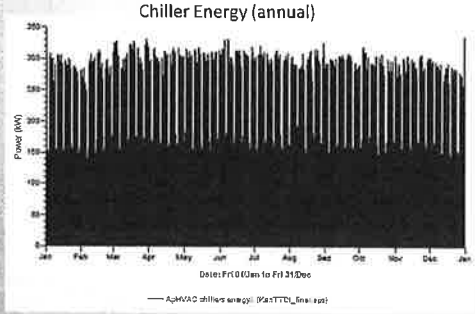
Lighting Energy (annual)



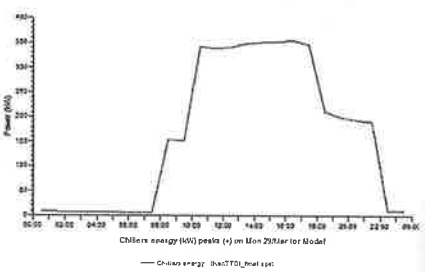
Lighting Energy profile at peak day



Chiller Energy (annual)



Chiller Energy profile at peak day



For room Building result, project team can see the results in the below.

- Chiller Energy
- CHWP Energy
- Heat Rejection Energy
- Fan Energy
- DX unit Energy
- Lighting Energy
- Equipment Energy
- etc

5. General process of Vista and Vista pro in IES<VE>

To check result of energy models in detail in terms of building and system components

There are two modules to check results for energy model in IES<VE>

(2-5) Building Load Result of Building Level in Vista Module

		ApHVAC chilled water loop load (kW)				ApHVAC d	ApHVAC h	ApHVAC chillers energy (kW)		
		KenTTDI_final.aps				KenTTDI_	KenTTDI_	KenTTDI_final.aps		
Date	Time		Rton	Date	Time				input(kW)	kW/Rton
Fri, 01/Jar	0:30	0	0	Fri, 01/Jar	0:30	0	0	0	0	0.000
	1:30	0	0		1:30	0	0	0	0	0.000
	2:30	0	0		2:30	0	0	0	0	0.000
	3:30	0	0		3:30	0	0	0	0	0.000
	4:30	0	0		4:30	0	0	0	0	0.000
	5:30	0	0		5:30	0	0	0	0	0.000
	6:30	0	0		6:30	0	0	0	0	0.000
	7:30	0	0		7:30	0	0	0	0	0.000
	8:30	901.9218	256.4468		8:30	5.0799	24.3348	105.1191	134.5338	0.525
	9:30	941.9075	267.8156		9:30	5.0799	24.3348	109.7794	139.1941	0.520
	10:30	2349.751	668.1122		10:30	12.4092	52.7127	278.1059	343.2278	0.514
	11:30	2389.755	679.4867		11:30	12.7931	53.7503	282.2061	348.7495	0.513
	12:30	2469.255	702.0914		12:30	13.583	55.1335	290.7711	359.4876	0.512
	13:30	2559.957	727.8807		13:30	14.5395	55.1705	301.7224	371.4324	0.510
	14:30	2583.874	734.6813		14:30	14.7921	55.1705	304.6215	374.5841	0.510
	15:30	2366.421	672.8523		15:30	12.5701	53.2192	279.7913	345.5806	0.514
	16:30	2101.533	597.5355		16:30	10.1332	48.9421	252.3809	311.4562	0.521
	17:30	1934.763	550.1175		17:30	8.8543	47.7101	235.9895	292.5539	0.532
	18:30	1196.412	340.1797		18:30	6.3741	26.7782	144.6223	177.7746	0.523
	19:30	1219.905	346.8595		19:30	6.59	27.1873	147.019	180.7963	0.521
	20:30	1224.8	348.2514		20:30	6.6352	27.2734	147.5201	181.4287	0.521
	21:30	1177.503	334.8033		21:30	6.201	26.4515	142.6855	175.338	0.524
	22:30	0	0		22:30	0	0	0	0	0.000
	23:30	0	0		23:30	0	0	0	0	0.000
Sat, 02/Ja	0:30	0	0	Sat, 02/Ja	0:30	0	0	0	0	0.000
	1:30	0	0		1:30	0	0	0	0	0.000
	2:30	0	0		2:30	0	0	0	0	0.000
	3:30	0	0		3:30	0	0	0	0	0.000

As discussed, hourly cooling load profile can be imported in excel table to be used for calculation what user want.

For example,
Hourly operating efficiency of chilled water plant can be generated based on results from Vista module.

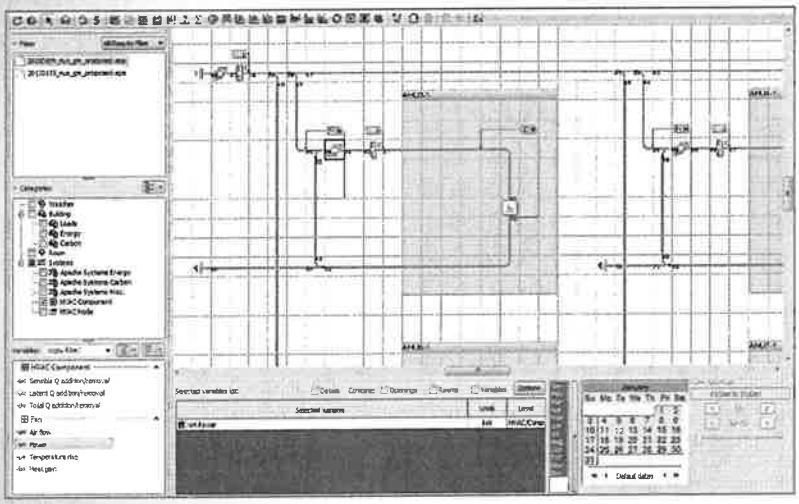
BSD building system & diagnostics

5. General process of Vista and Vista pro in IES<VE>

To check result of energy models in detail in terms of building and system components

There are two modules to check results for energy model in IES<VE>

(3-1) Results in Vista Pro Module (Air-side)



For Fan, user can check the below.

- Fan Power
- Operating air flow
- Heat Gain
- Temperature rise
- etc

For Coil, user can check the below

- Coil load (Sensible and Latent)
- Entering temperature
- Leaving temperature
- Water flow
- On/Off coil temperature
- etc

Please note that air flow rate and temperature can be checked in Vista module as well, Vista pro provides more detail information than vista module such as fan power, heat gain etc in system level.

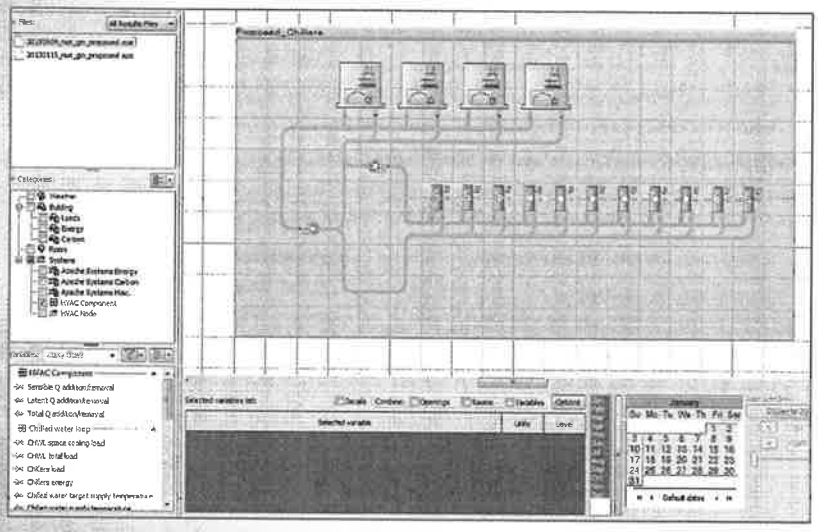
BSD building system & diagnostics

5. General process of Vista and Vista pro in IES<VE>

To check result of energy models in detail in terms of building and system components

There are two modules to check results for energy model in IES<VE>

(3-2) Results in Vista Pro Module (Water-side)



For Chilled water plant, user can check the below.

- Part Load ratio (each chiller)
- Operating COP (each chiller)
- Operating CHWP power (each pump)
- Operating CWP power (each pump)
- Operating CT power (each CT)
- Pump temperature rise
- Pump temperature heat gain
- Heat rejection load
- Ambient dry/wet bulb temp (CT)
- etc

Please note that Vista module provides overall performance for chilled water plant and Vista pro provides individual equipment information in chilled water plant in detail. Vista pro allow us to understand detail level of behavior of chilled water plant and air-side system.

BSD building system & diagnostics

THANK YOU

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BCA GREEN MARK AWARDS IN 2013/14

BSD building system & diagnostics

Green Mark Professional core module : Building Energy Modeling & Thermal Simulation

Yong Ping Quen

Director and Partner
MSc. (Bdg Sci), BEng (Hons), LEED AP, GMP, GBIF.
BCA-Registered Energy Auditor

BSD
building system & diagnostics

Building System & Diagnostics Pte Ltd
No. 18, Boon Lay Way #07-107
Tradehub 21, Singapore 609966
Telephone : (65) 6560 0702
Website : www.bsd.com.sg

BCA ACADEMY

Green Mark Professional core module : Building Energy Modeling & Thermal Simulation

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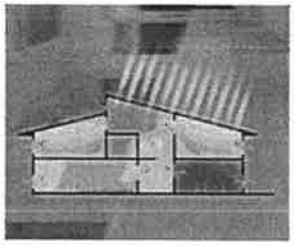
Green Mark Professional core module : Building Energy Modeling & Thermal Simulation

5.0 Thermal Simulation



Thermal Simulation Application

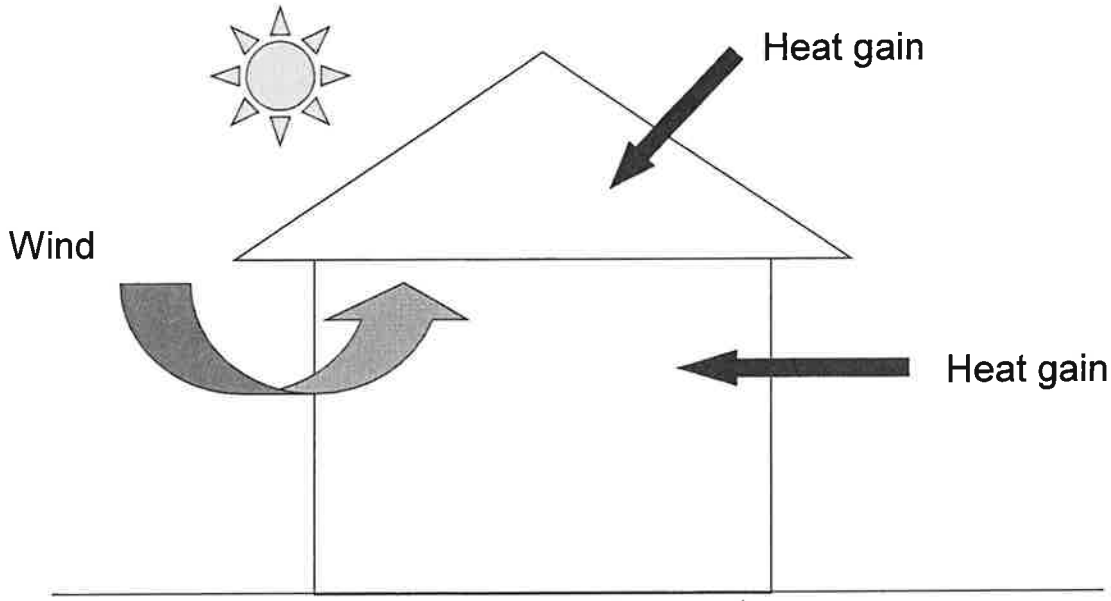
- Study & investigate building material thermal performances.
- Evaluate the environmental performance and thermal comfort of occupants for Non-Air conditioning spaces

ASHRAE - 55.

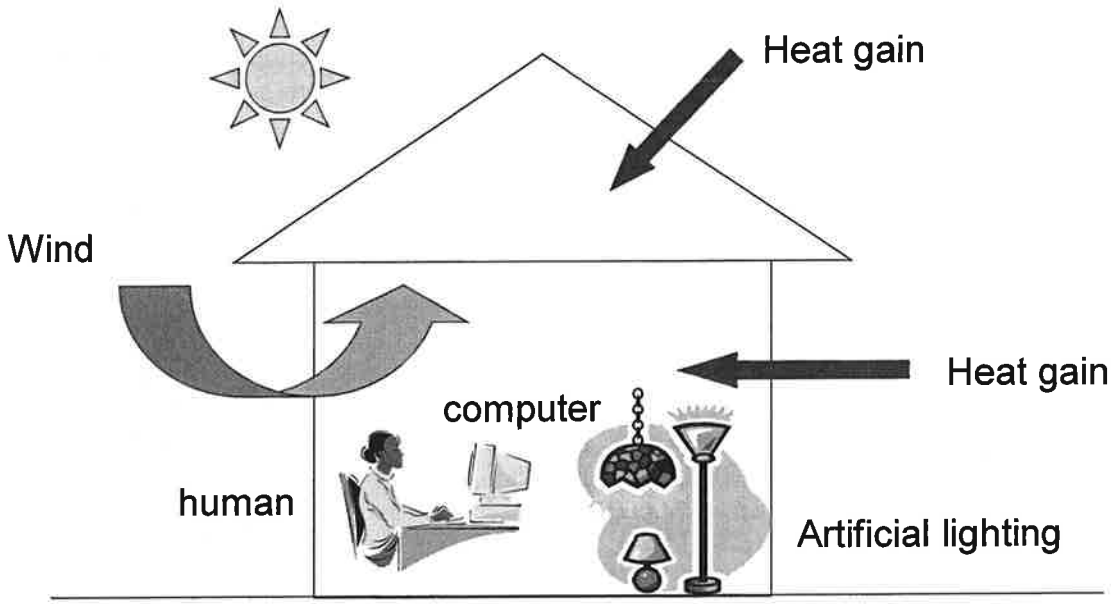
1. Air temp
2. Air speed / velocity 0.25 to 0.3
3. RH 65%
4. Mean Radiant temp
5. Metabolic (MET)
6. Clothing.

NRR 4.1 24 - 26 °C operating temp - not air temp

Heat Gain (External)



Heat Gain (External and Internal)

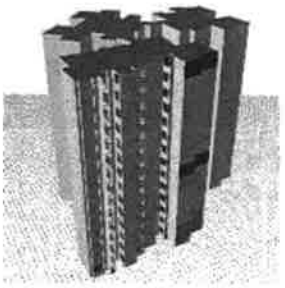


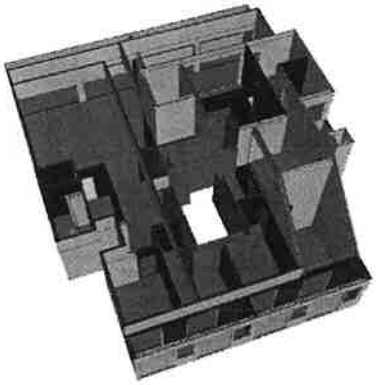
Factors that can be considered

- Thermal insulation of materials
- Thermal capacity ("thermal mass")
- Reflectivity of materials
- Emissivity of materials
- Shading coefficient of glazing
- Infiltration & Exfiltration
- Solar heat gain
- Cooling load

Output

- Air temperature
- Mean radiant temperature
- Resultant temperature
- Surface temperatures
- Humidity
- Condensation risk
- Sensible and latent loads
- Energy consumption



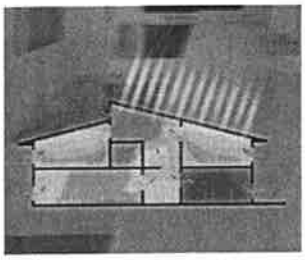


COMMERCIAL SOFTWARES

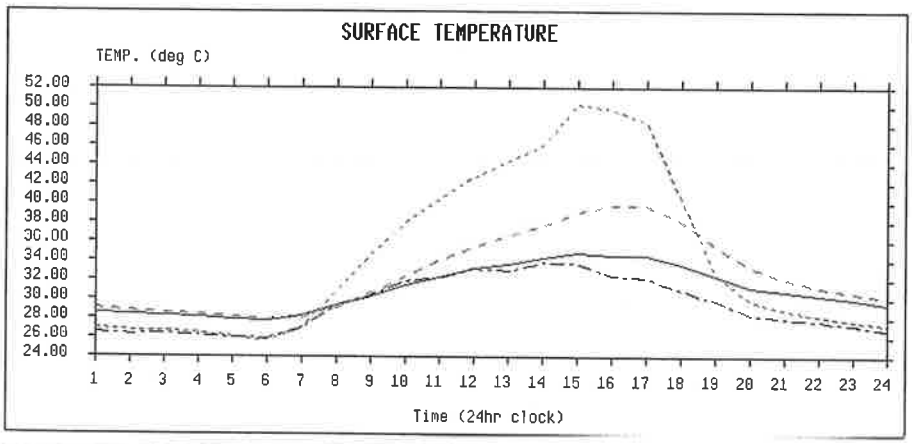
- Thermal Analysis Software (TAS)
- DOE2 (Visual DOE, Power DOE)
- eQUEST
- TRNSYS
- ESP-r
- IES<VE>

Source: US DOE http://www.eere.energy.gov/buildings/tools_directory/

TAS



- A-Tas is a software tool which simulates the thermal performance of buildings. The main applications of the program are in assessment of environmental performance, prediction of energy consumption, plant sizing, analysis of energy conservation options and energy targeting.



	Line Type
Internal Air	———
Internal Surface	- - - - -
External Surface	.....
External Air	-.-.-.-

Time (24 hr clock)	Internal Surface Temp. (deg C)	External Surface Temp. (deg C)
1	29.0	26.9
2	28.8	26.7
3	28.6	26.7
4	28.4	26.5
5	28.2	26.1
6	27.9	25.7
7	28.0	27.0
8	29.1	30.0
9	30.6	34.6
10	32.4	37.9
11	34.0	40.4
12	35.4	42.7

Time (24 hr clock)	Internal Surface Temp. (deg C)	External Surface Temp. (deg C)
13	36.6	44.3
14	37.6	46.0
15	39.0	50.3
16	39.7	49.7
17	39.8	48.4
18	38.1	40.3
19	35.5	32.6
20	33.3	29.8
21	32.0	28.9
22	31.2	28.2
23	30.6	27.7
24	30.1	27.3

LOCATION

Zone: 21. BEDROOM1F10W

Surface: 10

Building Element: 5
External Wall

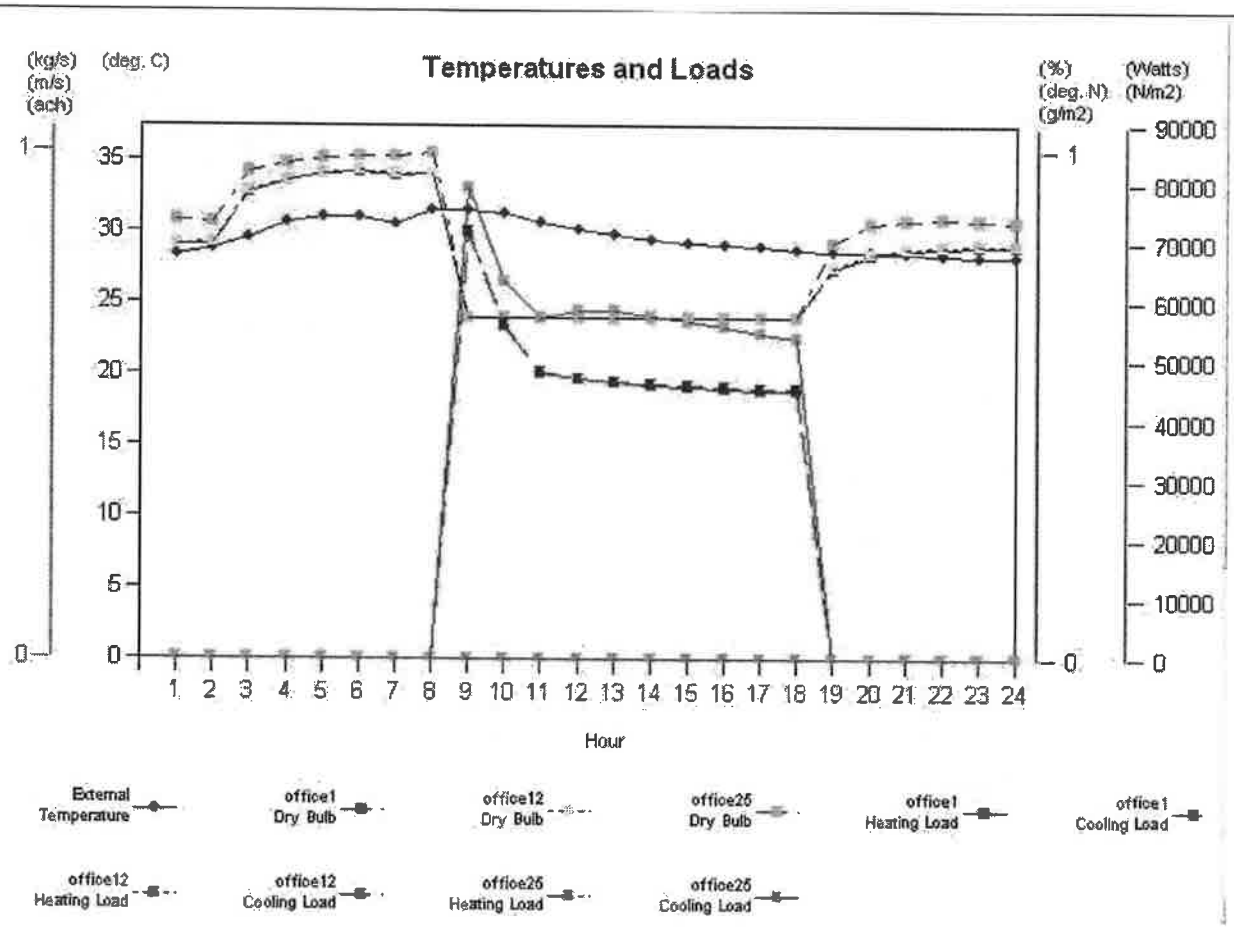
Building Feature: Exposed

Orientation: 261 (W)

Area (m2): 6.53

Day 286: Saturday, Oct 13 (SATURDAY)
Weather: sin2001.wfl

Print
Previous
Next
Exit



Simulation Study

Thermal Performance of Facade Materials and Design and the Impacts on Indoor and Outdoor Environment

Joint Research Collaboration between
National Environmental Agency (NEA)
and
Department of Building, NUS

Research objectives

- To determine the thermal performance of the commonly used façade materials in Singapore specifically for non air-conditioned buildings.
- To study the impacts of the thermal performance of the façade materials on both the indoor and outdoor environment.
- To examine the effects of parameters such as the orientation, colour, provision of shading and types of construction on the thermal performance.
- To develop criteria which can be used to determine the acceptable U value of materials for non air-conditioned buildings.

Research background

- U-value of building façade is important for naturally ventilated buildings in Singapore:
  - ❖Thermal comfort
  - ❖Energy savings
- Current U-value provision for naturally ventilated building façade in Singapore:
  - ❖Wall: $U \leq 3.5 W/K \cdot m^2$
  - ❖ Roof:$U \leq 1.5 W/K \cdot m^2$

Research background

- Façade U-value regulation in other countries

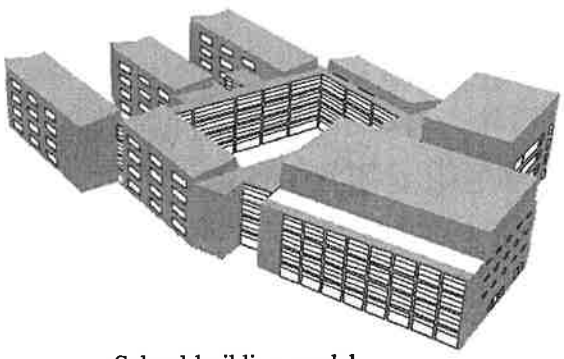
Country	Roofs ($W/K \cdot m^2$)	Walls ($W/K \cdot m^2$)	Windows ($W/K \cdot m^2$)
UK	0.16-0.25	0.35	2.0-2.2
Canada	0.14-0.29	0.37	1.4-2.7
China	0.4	0.52	2

- It is hard to follow other countries' experience since the weather condition is quite different

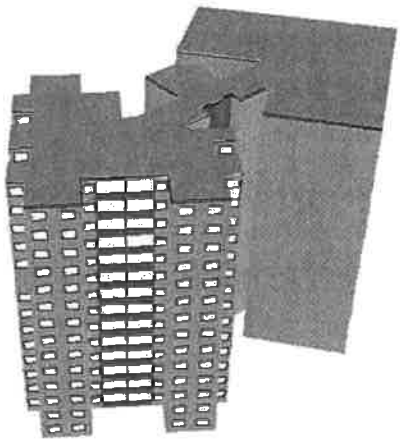
Methodology

- Field measurement
  - *6 naturally ventilated residential and school buildings --- thermal performance of façade and indoor thermal environment*
- Computer simulation
  - *TAS simulation program --- acceptable U-value, effects of façade colour, adoption of window shading device and façade construction*
- Laboratory test
  - *Spectrophotometer --- reflectance and transmittance of commonly used façade materials*

Computer simulations



School building model



HDB building model

Computer simulation --- finding acceptable Façade U-value

- Method:
  - Criterion: good indoor thermal comfort

  Mean radiant temperature – ambient temperature ≤2° C

CHRENKO, F.A: Heated ceilings and comfort. Journ. of the Inst. of Heating and Ventilating Engineers,(1953) 20: 375-396, and 21:145-154.

BCA ACADEMY

Computer simulation --- finding acceptable Façade U-value

- Measurement position:

  Height: occupant level

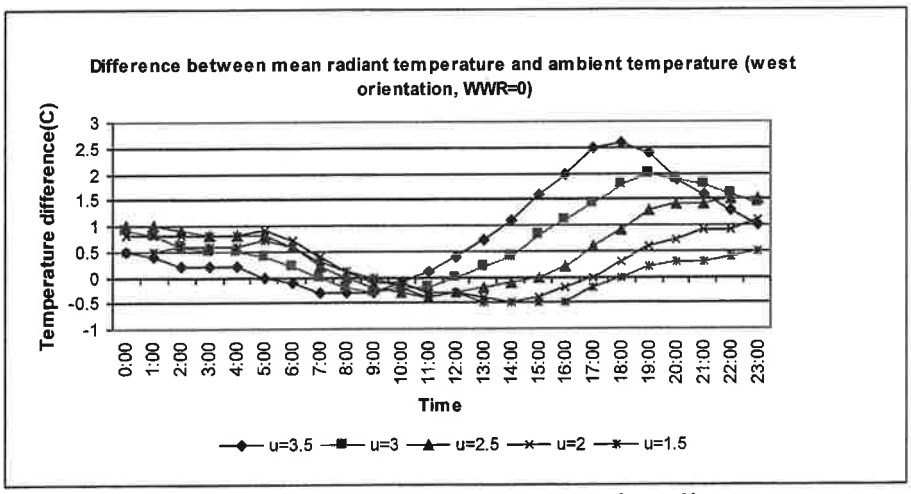
  Distance to the external wall: 200mm

Finding acceptable Façade U-value

orientation	West, East, North/South
U-value for wall($W/K \cdot m^2$)	1.5, 2, 2.5, 3, 3.5
U-value for roof($W/K \cdot m^2$)	0.5, 1, 1.5, 2, 2.5
Window to wall ratio	0, 0.1, 0.2, 0.3, 0.4, 0.5
Window shading device	Horizontal shading device 300mm, 450mm, 600mm, 900mm

Computer simulation --- finding acceptable external wall U-value

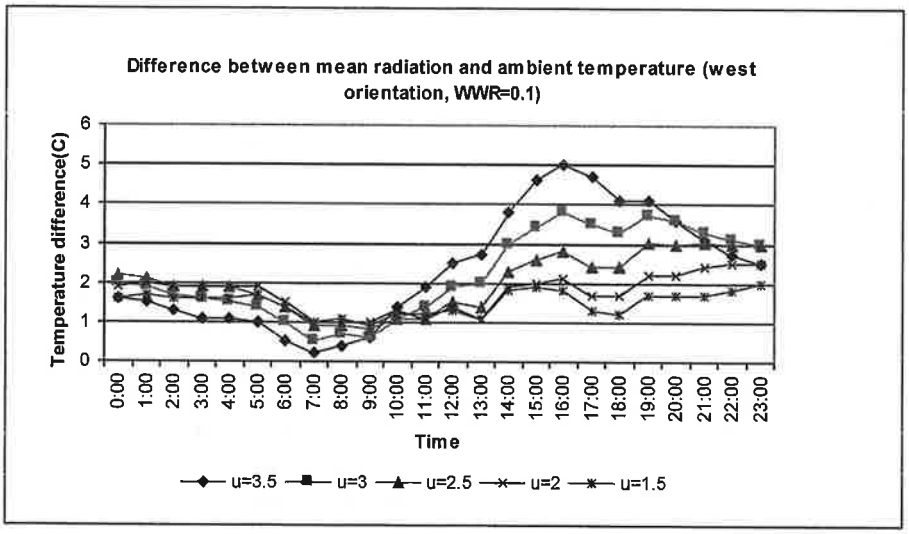
- **West orientation**
  - Window to wall ratio=0 (Condition I: Without window)



Acceptable U-value for west external wall without window is $3W/K \cdot m^2$

Computer simulation --- finding acceptable external wall U-value

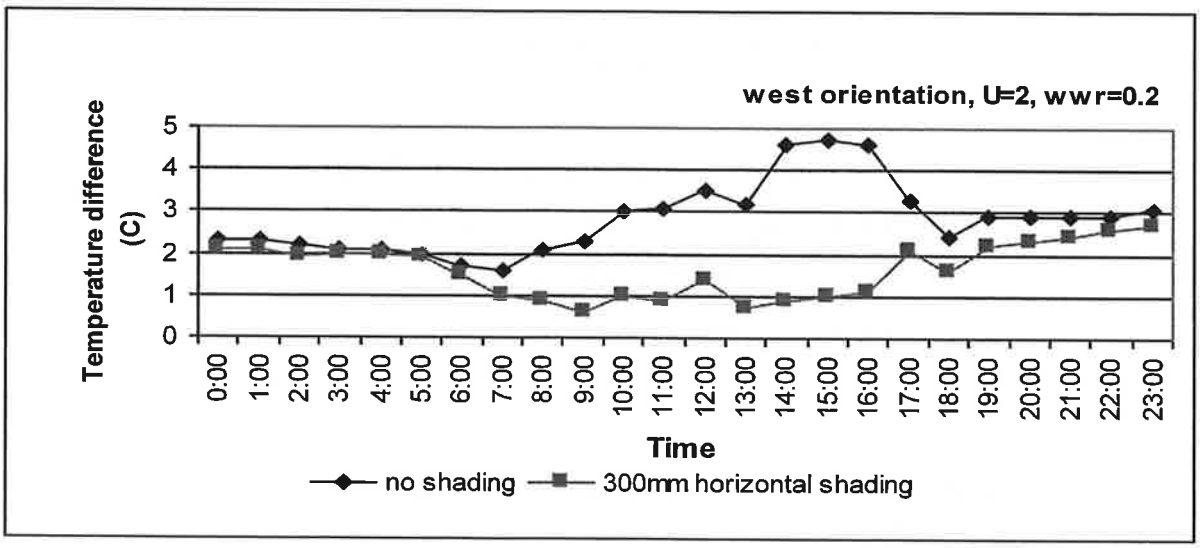
- **West orientation**
  - Window to wall ratio=0.1 (Condition II: With window)



Acceptable U-value is 2W/K·m^2 .

Computer simulation --- finding acceptable external wall U-value

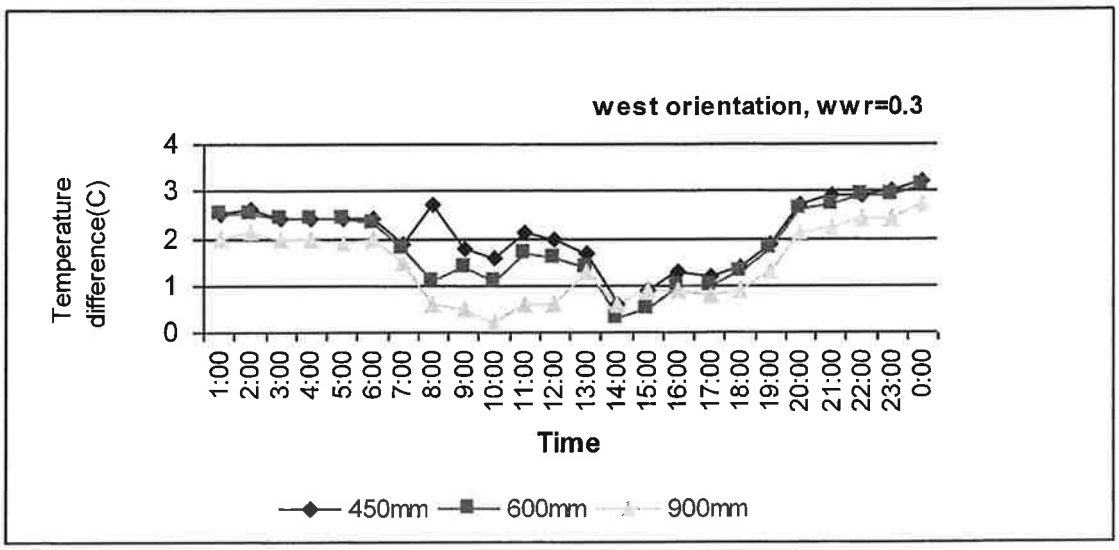
- **West orientation** --- effect of window shading device
  WWR=0.2, with 300mm horizontal shading devices



Computer simulation --- finding acceptable external wall U-value

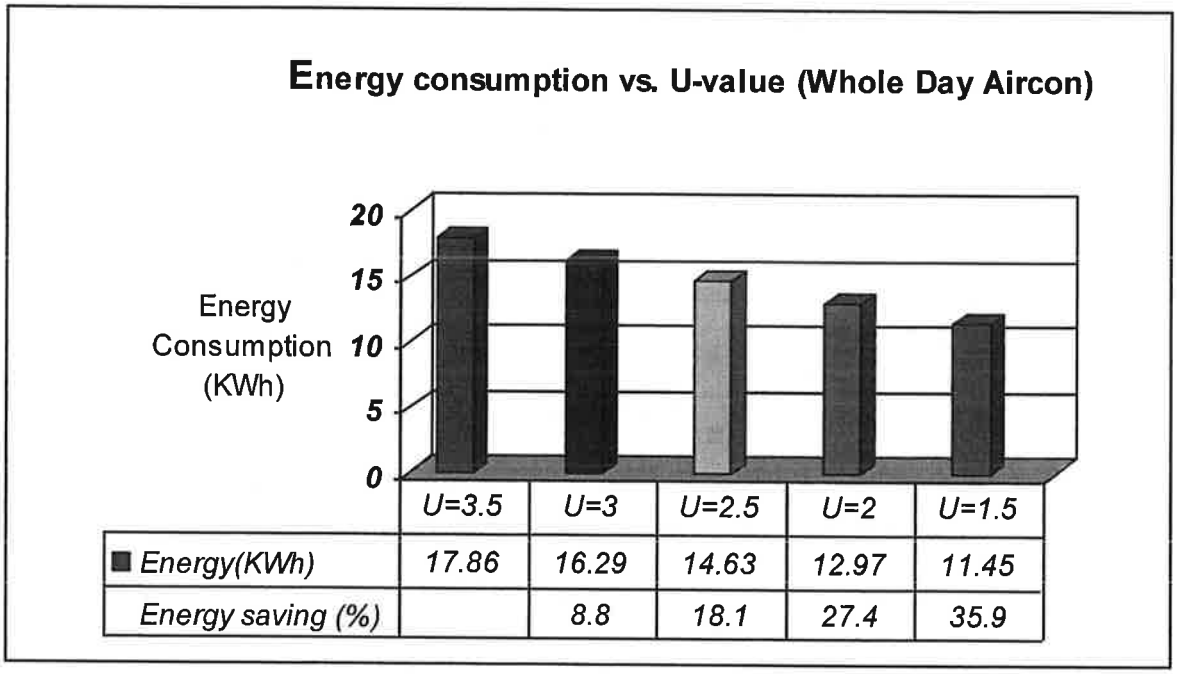
- **West orientation** --- effect of window shading device

  WWR=0.3, with 450mm, 600mm and 900mm horizontal shading devices (450mm is suitable)



	East	West	North	South
WWR=0	U=3W/K·m²	U=3W/K·m²	U=3.5W/K·m²	U=3.5W/K·m²
WWR=0.1	U=2W/K·m² 300mm horizontal shading or or U=1.5W/K·m²	U=2W/K·m² 300mm horizontal shading or or U=1.5W/K·m²	U=2.5W/K·m²	U=2.5W/K·m²
WWR=0.2	U=2W/K·m² 300mm horizontal shading	U=2W/K·m² 300mm horizontal shading	U=2.5W/K·m² 300mm horizontal shading or U=2.0W/K·m²	U=2.5W/K·m² 300mm horizontal shading or U=2.0W/K·m²
WWR=0.3	U=2W/K·m² 450mm horizontal shading	U=2W/K·m² 450mm horizontal shading	U=2.5W/K·m² 300mm horizontal shading	U=2.5W/K·m² 300mm horizontal shading
WWR=0.4	U=2W/K·m² 600mm horizontal shading	U=2W/K·m² 900mm horizontal shading	U=2.5W/K·m² 300mm horizontal shading	U=2.5W/K·m² 300mm horizontal shading
WWR=0.5	U=2W/K·m² 600mm horizontal shading	U=2W/K·m² 900mm horizontal shading	U=2.5W/K·m² 600mm horizontal shading	U=2.5W/K·m² 600mm horizontal shading

The Impact of U values on cooling energy consumptions



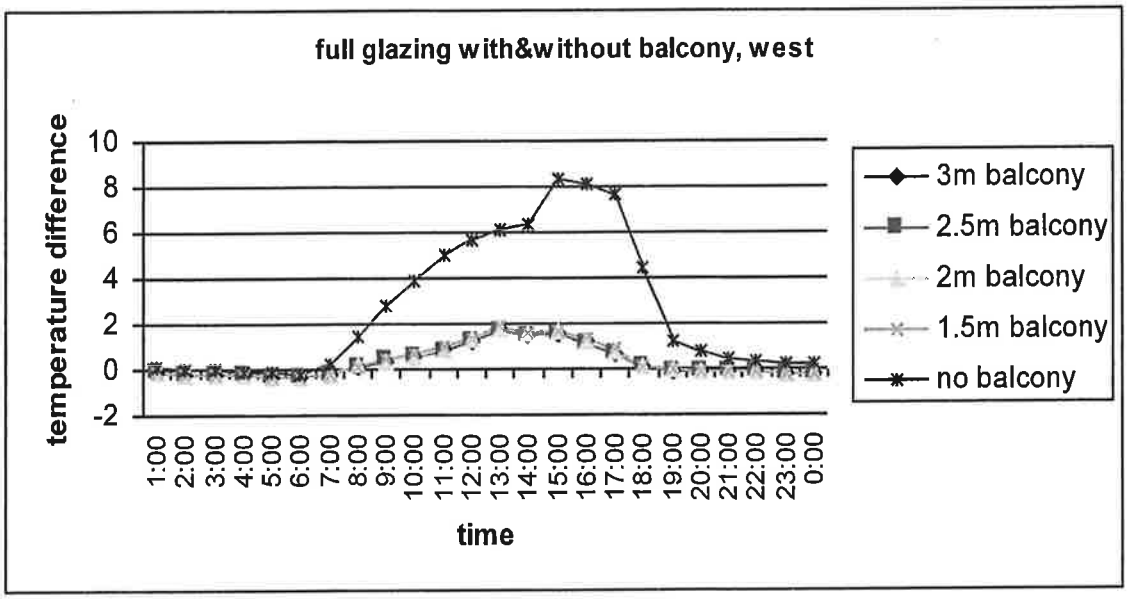
	U=3.5	U=3	U=2.5	U=2	U=1.5
Energy(KWh)	17.86	16.29	14.63	12.97	11.45
Energy saving (%)		8.8	18.1	27.4	35.9

Full glazing wall

- The full glazing wall is adopted in more and more residential buildings for the aesthetics and daylighting.
- At the same time, the problem of thermal comfort is brought by the strong direct solar radiation.
- Is there any way to resolve the problem besides the adoption of special glazing material?
- Is balcony helpful?

Full glazing wall

- West orientation



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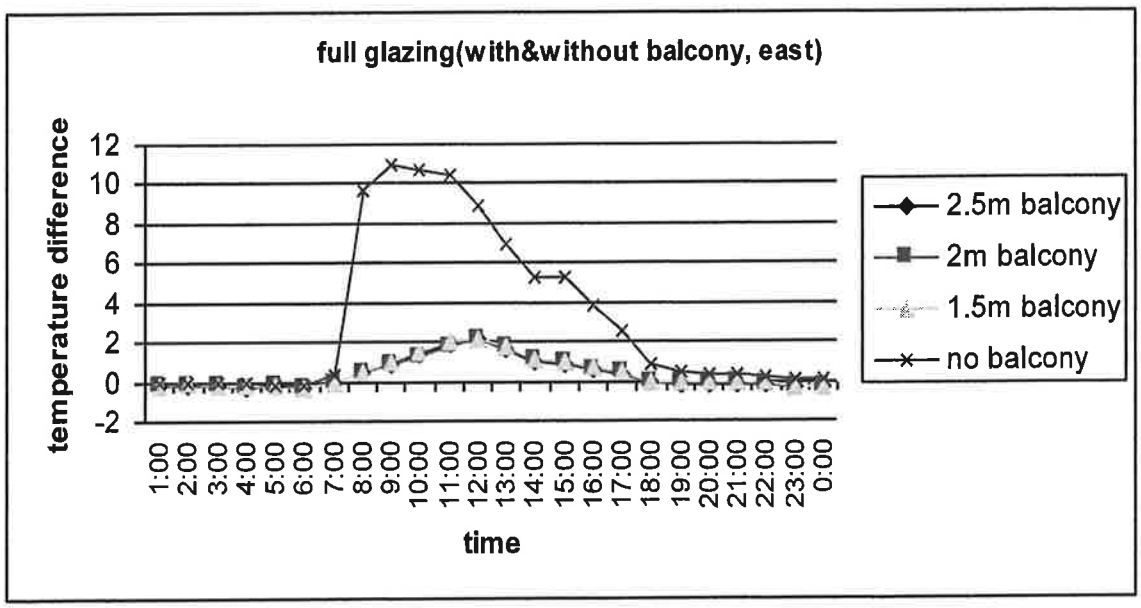
Full glazing wall

- East orientation



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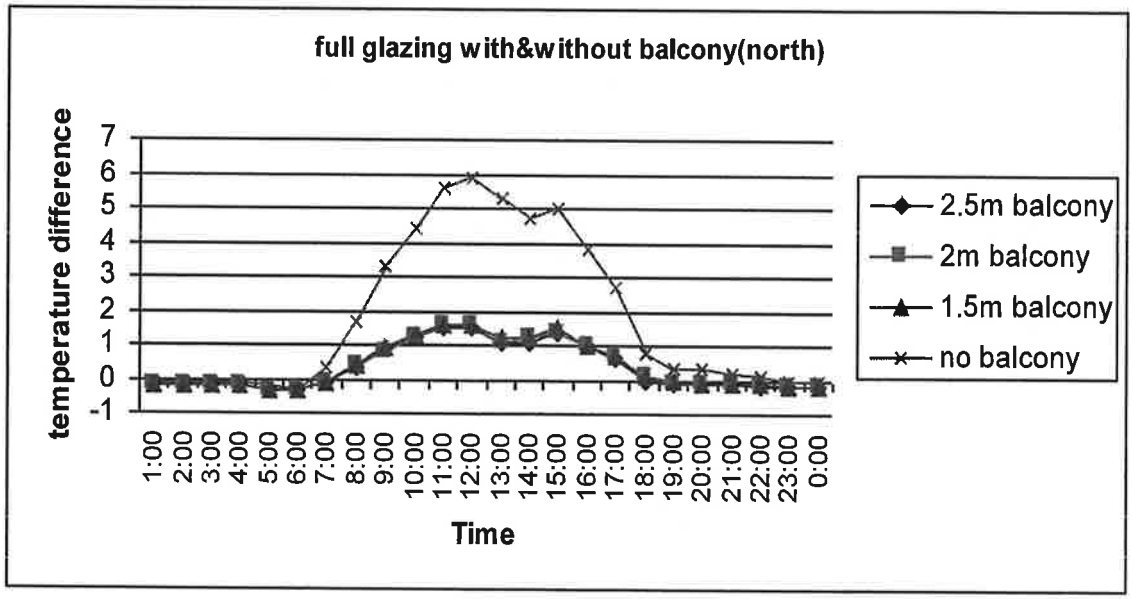
Full glazing wall

- North and South orientation

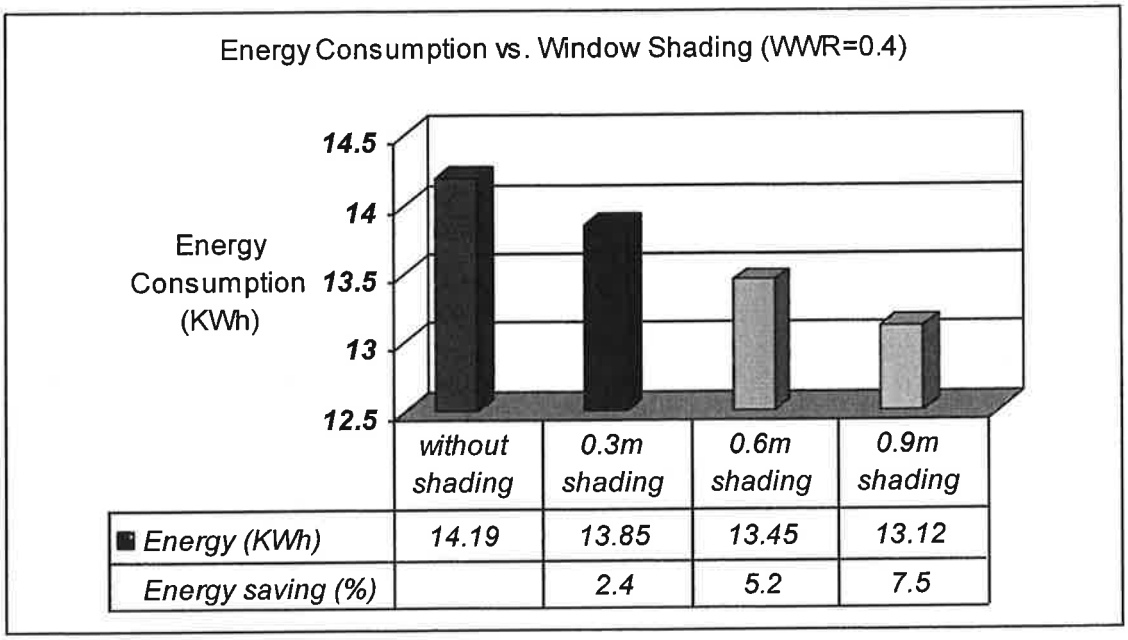


Full glazing wall

- Conclusion:

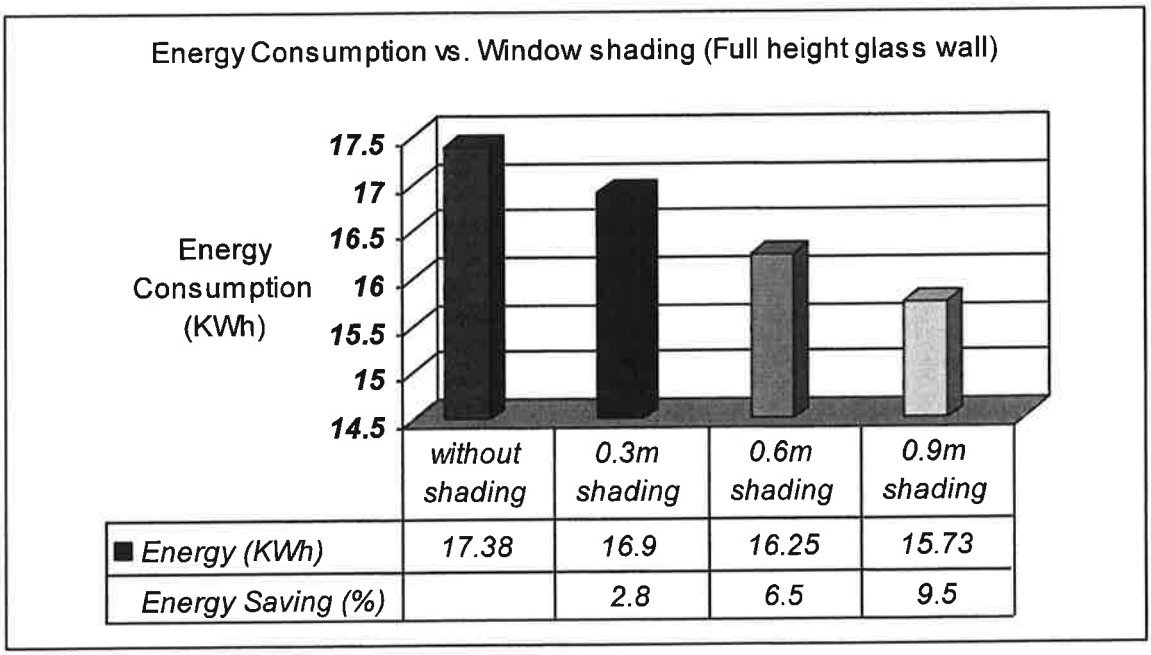
  As long as there is a balcony (width≥1.5m), the problem of direct solar radiation can be resolved and the indoor thermal comfort can be ensured.

The Impact of Window Shading on cooling energy consumptions



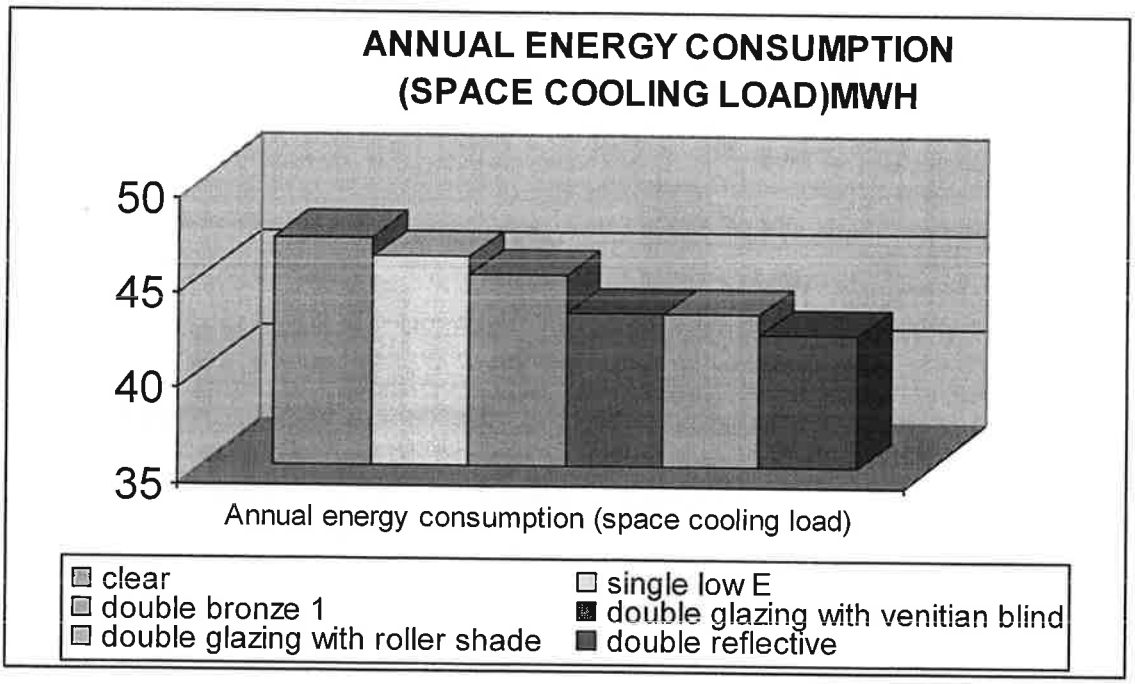
	without shading	0.3m shading	0.6m shading	0.9m shading
Energy (KWh)	14.19	13.85	13.45	13.12
Energy saving (%)		2.4	5.2	7.5

The Impact of Window Shading on cooling energy consumptions

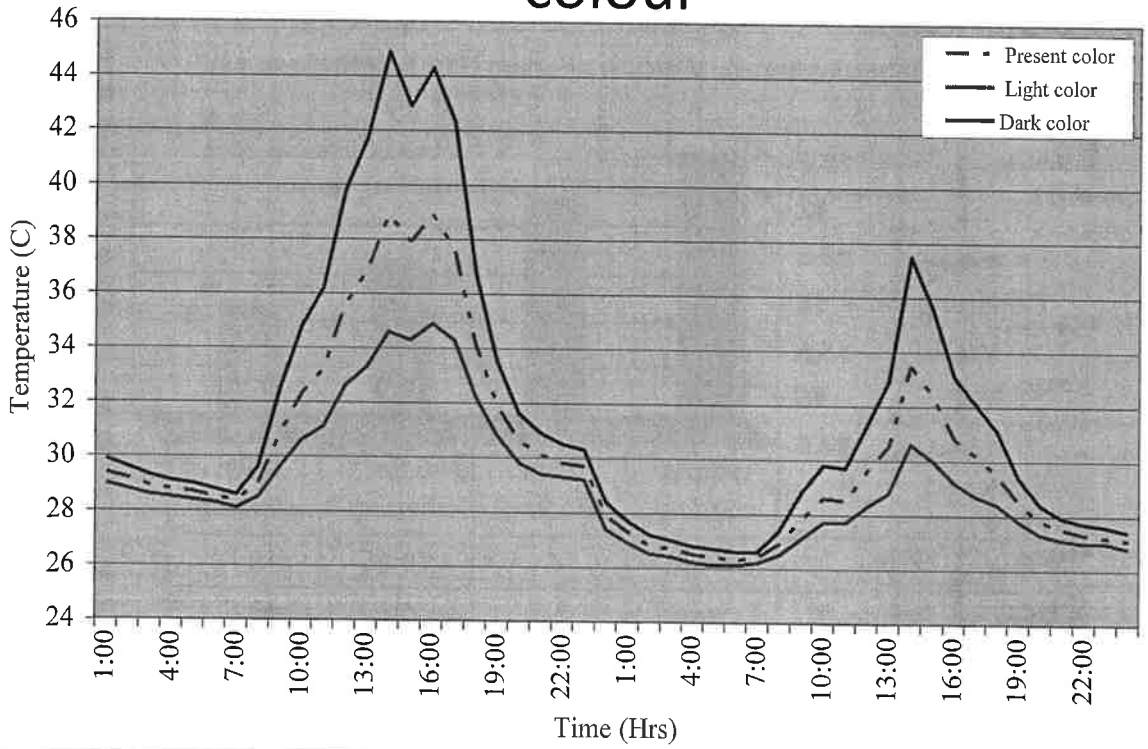


	without shading	0.3m shading	0.6m shading	0.9m shading
Energy (KWh)	17.38	16.9	16.25	15.73
Energy Saving (%)		2.8	6.5	9.5

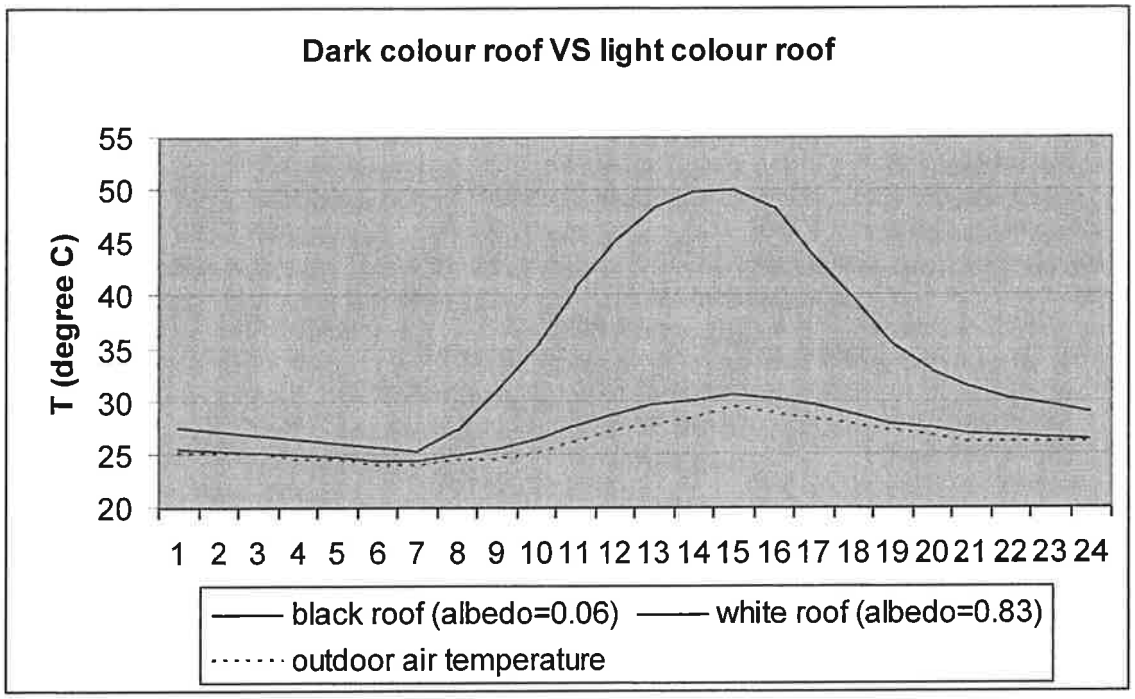
Types of Glazings



Computer simulation - effects of façade colour



Effect of facade colour (Roof)



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Thank you

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Green Mark Professional core module : Building Energy Modeling & Thermal Simulation

Yong Ping Quen

Director and Partner
MSc. (Bdg Sci), BEng (Hons), LEED AP, GMP, GBIF.
BCA-Registered Energy Auditor

BSD
building system & diagnostics

Building System & Diagnostics Pte Ltd
No. 18, Boon Lay Way #07-107
Tradehub 21, Singapore 609966
Telephone : (65) 6560 0702
Website : www.bsd.com.sg

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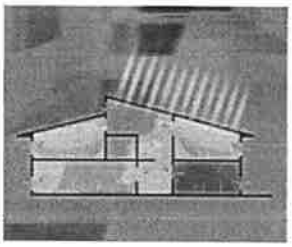
Green Mark Professional core module : Building Energy Modeling & Thermal Simulation

5.0 Thermal Simulation Case Study



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Case Study - 1

- Thermal Comfort Study of Central Walkway in Retail Mall

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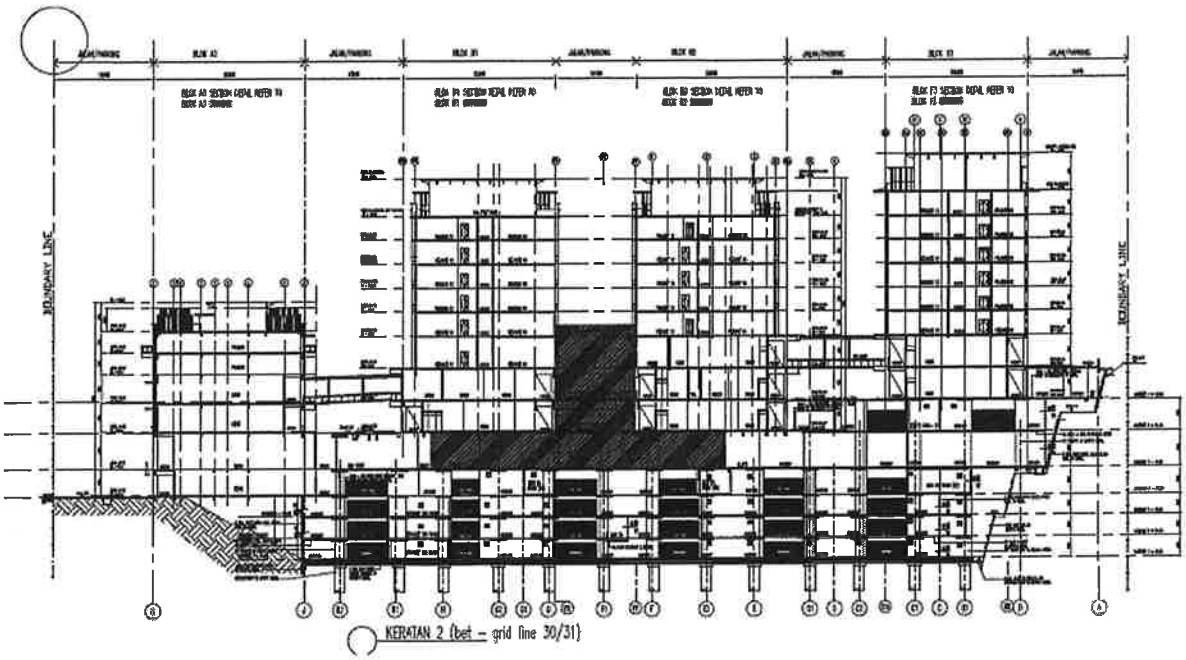
Case Study - 1



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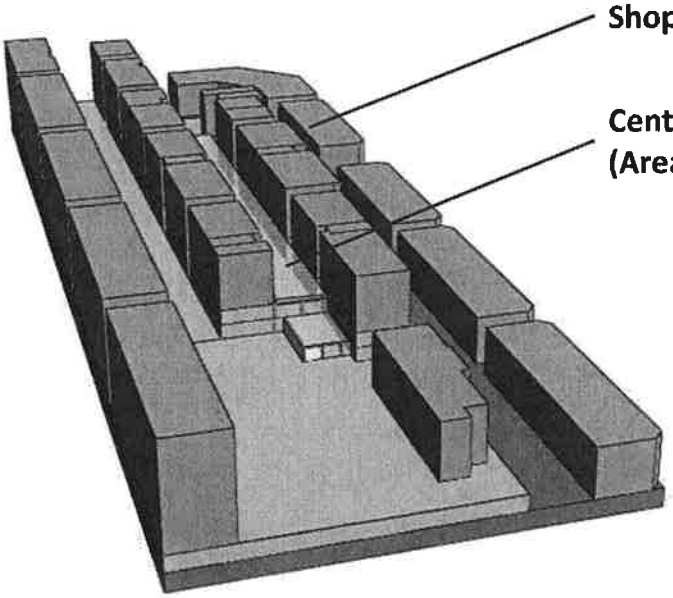
Case Study - 1

- Thermal Comfort Study of Enclosed Pedestrian Walkway in Shopping Mall



Overall 3D View

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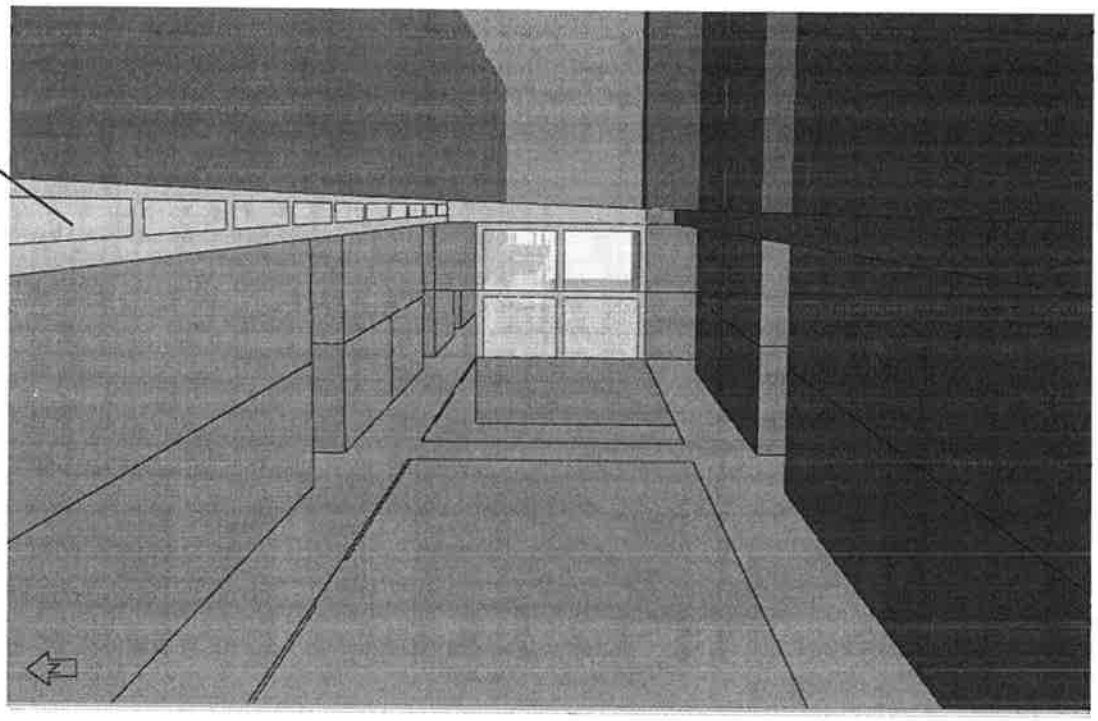
Case Study - 1



Interior view of the Central walkway

Case Study – 1
Simulation Assumptions

BUILDING ELEMENT	DESCRIPTION
Façade Glazing	10mm ASG Clear Annealed Float Glass U-Value = 5.6 W/m²K; SC = 0.89; visible light transmittance = 86%
Floor	RC Slab
Skylight Glazing	17.52 mm thk. Glass (8mm ASG tempered float glass + 1.52mm clear PVB + 8mm ASG clear tempered float glass) U-Value = 5.2 W/m²K; SC = 0.78; visible light transmittance = 84%

Case Study – 1
Simulation Assumptions

ITEMS	DESCRIPTION
Occupancy Load	5 m^2 / Person
Operating Hours	10:00 am to 10:00 pm
Lighting Power Density	25 W/m^2
Indoor design Temp	24 degree C
Indoor Design RH	50%

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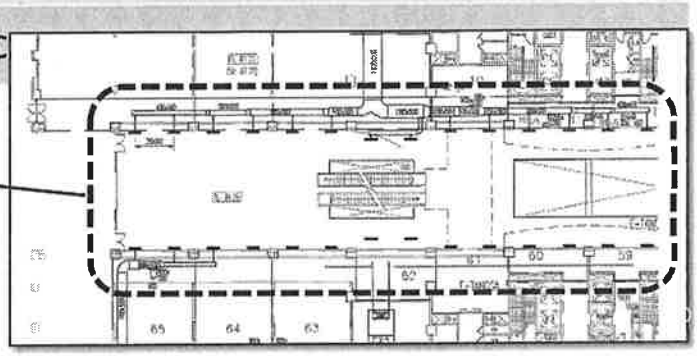
Case Study – 1
Simulation Assumptions

DIFFUSERS	
Type & Size	: 1200mm x 150 mm linear diffusers
Location	: 3.3m above ground level 4m apart from centre to centre
Flow rate	: 200 l/s
Supply air temp	: Leaving DB/WB: 13 degree C/ 11.9 degree C
Indoor Design Temp	: 24 degree C

Location of Diffusers



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Simulation Assumptions

Transmitted Solar Gain from Glazed Façades

- March 22 was chosen as a typical day for airflow study
- The peak solar gain occurs at 13:30 hr

Peak Solar gain through glazing at different orientations on March 22, 13:30 hr

ORIENTATION	SOLAR GAIN (W/m^2)
Skylight	292.0
North facing façade	92.2
East facing façade	115.0
South facing façade	102.5
West facing façade	115.8

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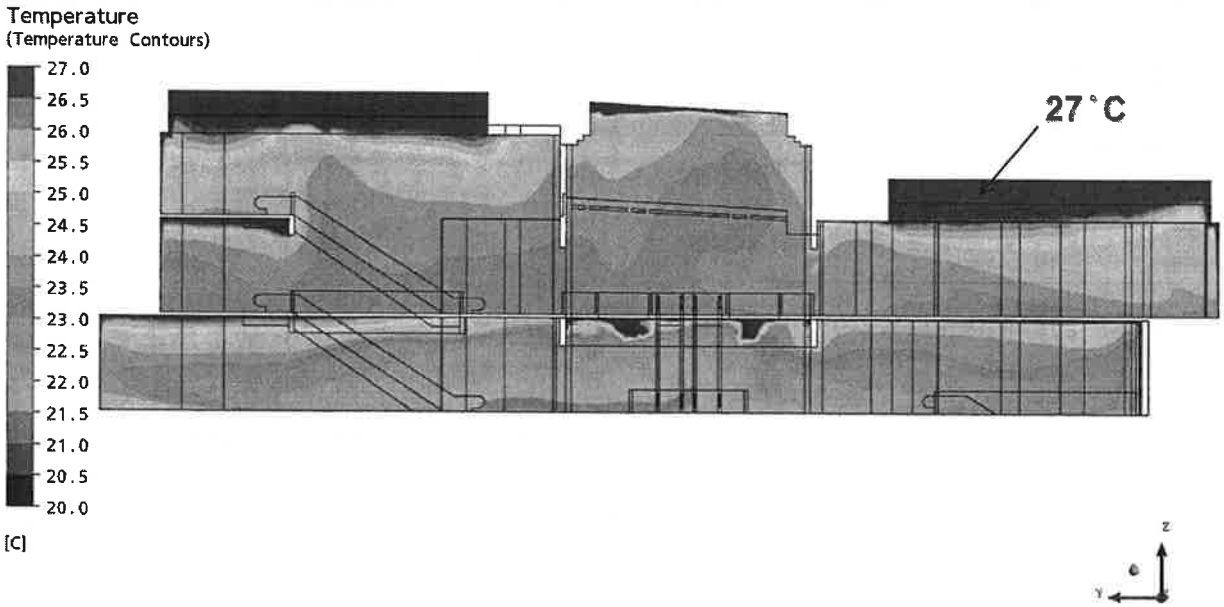
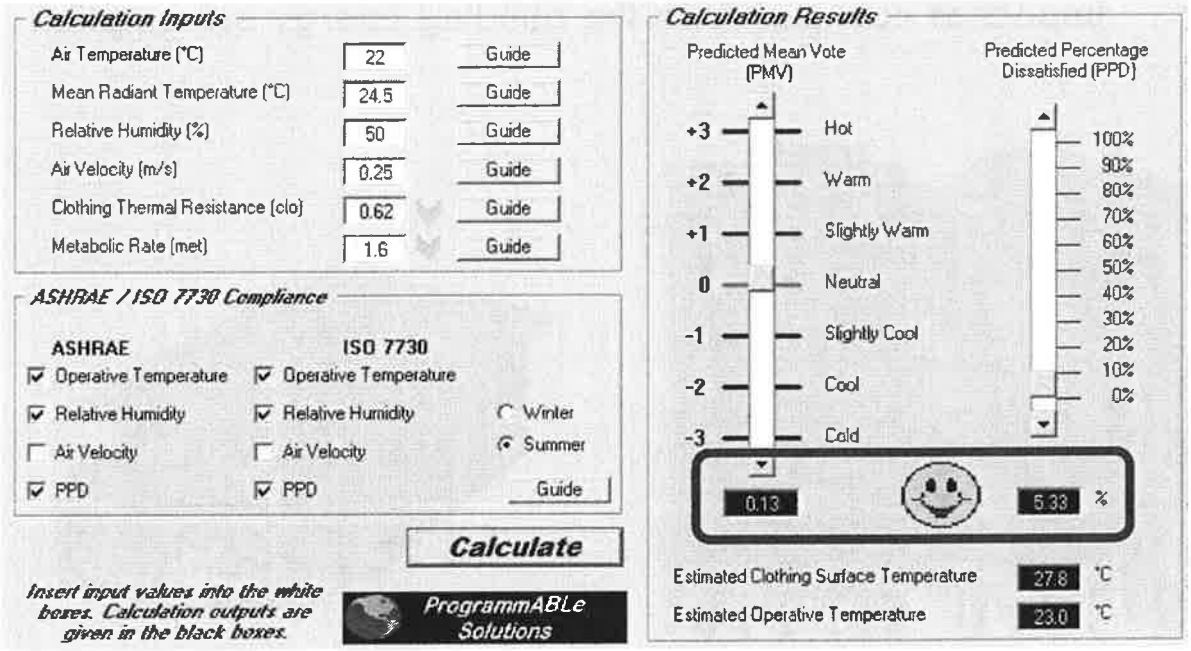
Case Study – 1: Simulation Results



Temp Contours @ East Link Corridor

Case Study – 1: Simulation Results



Assumption: the occupants wear the long sleeve shirts/blouses and long pants.

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Case Study - 2

- Impact of Cool Paint on Building Energy Consumption

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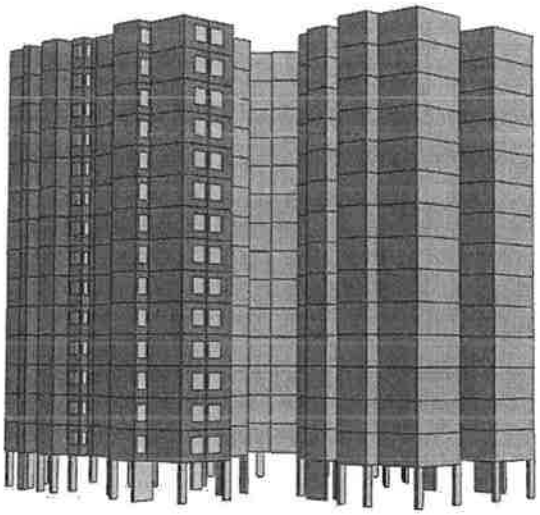
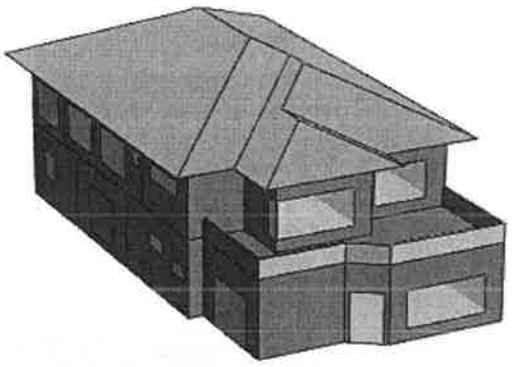
Case Study - 2

- Impact of cool paints on the building energy consumption





Case Study 2: Assumptions

BUILDING ELEMENT	DESCRIPTION
Glazing	Double glazing
Floor	RC slab
Wall Construction	Brick wall with plaster on both sides Case 1. CRCW – with conventional emulsion paint Case 2. DRDW – with Dulux Weathershield wall paint Case 3. CRDW – with Dulux Weathershield wall paint Case 4. DRCW - with conventional emulsion paint
Roof	Metal Roof with insulation Case 1. CRCW – with conventional roof paint Case 2. DRDW – with Dulux Weathershield roof paint Case 3. CRDW – with conventional roof paint Case 4. DRCW - with Dulux Weathershield roof paint

Case Study 2: Assumptions

- Test Results

ITEMS		DESCRIPTION	E	TSR
Roof Paint	**CR**	Conventional Roof Paint – Dark Blue	0.82	7.04
	DR	Dulux Weathershield (for Roof) – Light Blue	0.82	81.82
Wall Paint	**CW**	Conventional Emulsion Paint – Dark Brown	0.83	12.24
	DW	Dulux Weathershield – Light Brown	0.84	77.78

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Case Study 2: Assumptions

CR: Metal Roof with Conventional Roof Paint (Dark Blue)

ID SROOF2 Description ICI_Metal Roof_CP01(Dark Blue) Standard Generic

Outside surface

Emissivity 0.820 Resistance (m²K/W) 0.0400 default Solar absorptance 0.920

Inside surface

Emissivity 0.900 Resistance (m²K/W) 0.1000 default Solar absorptance 0.550

Metal Cladding

Construction layers (outside to inside)

Material	Thickness m	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m	Category
ALUMINIUM	0.0070	160.0000	2800.0	896.0			Metals
Cavity	0.0100				0.0900		
ROOFING FELT	0.0050	0.1900	960.0	837.0			Asphalts & Other Roofing
GLASS-FIBRE QUILT	0.0500	0.0400	12.0	840.0			Insulating Materials
Cavity	0.5000				0.1800		
GYPSUM PLASTERBOARD	0.0130	0.1600	950.0	840.0			Plaster

Copy Paste Cavity Insert Add Delete Flip System Materials Project Materials

Construction thickness 0.5651 m

Total R-value 1.6296 m²K/W

U-value (W/m²·K)

U-value method EN-ISO

U-value 0.5651 W/m²·K

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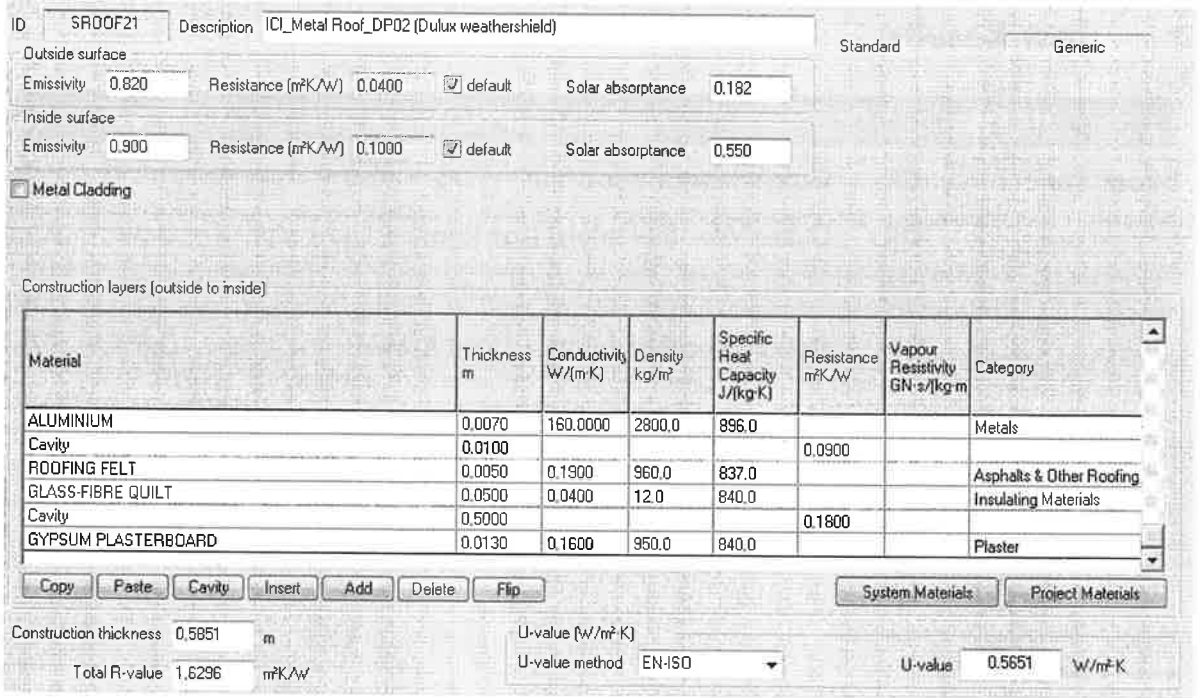
Case Study 2: Assumptions

DR: Metal Roof with Dulux Weathershield (Light Blue)



ID SROOF21 Description ICI_Metal Roof_DP02 (Dulux weathershield) Standard Generic

Outside surface: Emissivity 0.820 Resistance (m²K/W) 0.0400 default Solar absorptance 0.182

Inside surface: Emissivity 0.900 Resistance (m²K/W) 0.1000 default Solar absorptance 0.550

Metal Cladding

Construction layers (outside to inside)

Material	Thickness m	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m	Category
ALUMINIUM	0.0070	160.0000	2800.0	896.0			Metals
Cavity	0.0100				0.0900		
ROOFING FELT	0.0050	0.1900	960.0	837.0			Asphalts & Other Roofing
GLASS-FIBRE QUILT	0.0500	0.0400	12.0	840.0			Insulating Materials
Cavity	0.5000				0.1800		
GYPSUM PLASTERBOARD	0.0130	0.1600	950.0	840.0			Plaster

Copy Paste Cavity Insert Add Delete Flip System Materials Project Materials

Construction thickness 0.5851 m Total R-value 1.6296 m²K/W

U-value (W/m²·K) U-value method EN-ISO U-value 0.5651 W/m²·K

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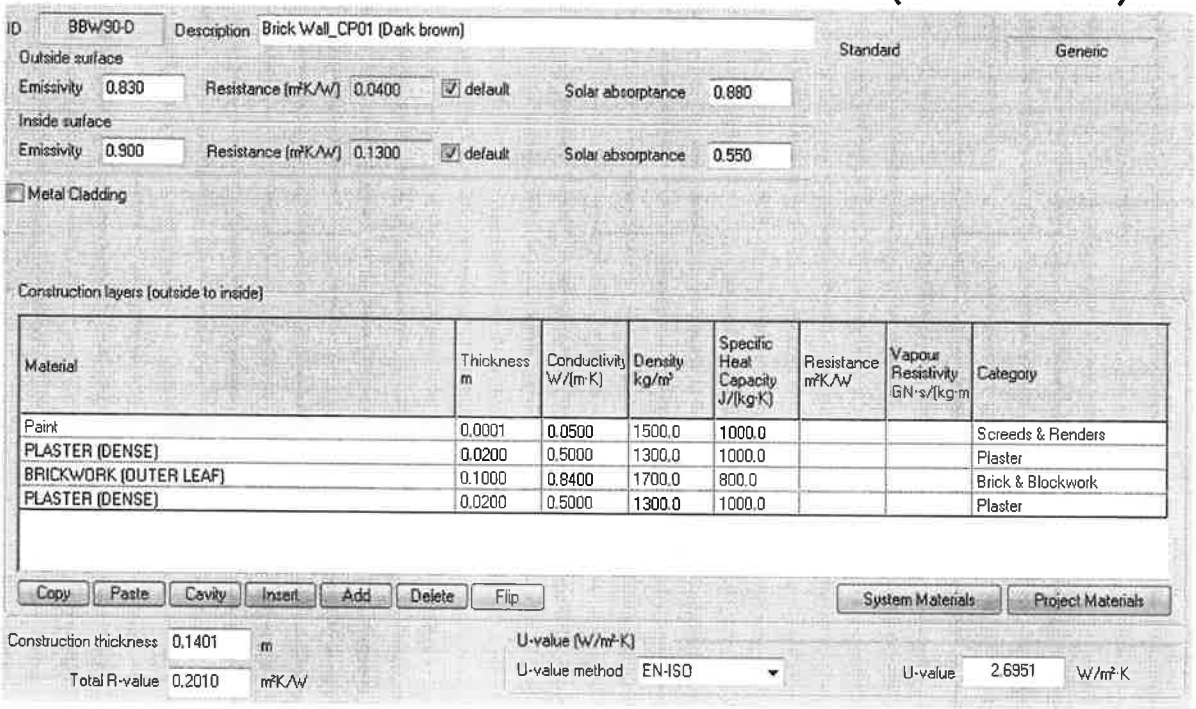
Case Study 2: Assumptions

CW: Brick wall with Conventional Emulsion Paint (Dark Brown)



ID BBW90-D Description Brick Wall_CP01 (Dark brown) Standard Generic

Outside surface: Emissivity 0.830 Resistance (m²K/W) 0.0400 default Solar absorptance 0.880

Inside surface: Emissivity 0.900 Resistance (m²K/W) 0.1300 default Solar absorptance 0.550

Metal Cladding

Construction layers (outside to inside)

Material	Thickness m	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m	Category
Paint	0.0001	0.0500	1500.0	1000.0			Screeds & Renders
PLASTER (DENSE)	0.0200	0.5000	1300.0	1000.0			Plaster
BRICKWORK (OUTER LEAF)	0.1000	0.8400	1700.0	800.0			Brick & Blockwork
PLASTER (DENSE)	0.0200	0.5000	1300.0	1000.0			Plaster

Copy Paste Cavity Insert Add Delete Flip System Materials Project Materials

Construction thickness 0.1401 m Total R-value 0.2010 m²K/W

U-value (W/m²·K) U-value method EN-ISO U-value 2.6951 W/m²·K

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Case Study 2: Assumptions

DW: Brick wall with Dulux Weathershield Paint (Light Brown)

ID B8W90-D1 Description Brick Wall_DP02 (Dulux) Standard Generic

Outside surface
Emissivity 0.850 Resistance (m²K/W) 0.0400 ☑ default Solar absorptance 0.222

Inside surface
Emissivity 0.900 Resistance (m²K/W) 0.1300 ☑ default Solar absorptance 0.550

☐ Metal Cladding

Construction layers (outside to inside)

Material	Thickness m	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN s/(kg·m	Category
Paint	0.0001	0.0500	1500.0	1000.0			Screeds & Renders
PLASTER (DENSE)	0.0200	0.5000	1300.0	1000.0			Plaster
BRICKWORK (OUTER LEAF)	0.1000	0.8400	1700.0	800.0			Brick & Blockwork
PLASTER (DENSE)	0.0200	0.5000	1300.0	1000.0			Plaster

Copy Paste Cavity Insert Add Delete Flip System Materials Project Materials

Construction thickness 0.1401 m
Total R-value 0.2010 m²K/W

U-value (W/m²·K)
U-value method EN-ISO
U-value 2.6951 W/m²·K

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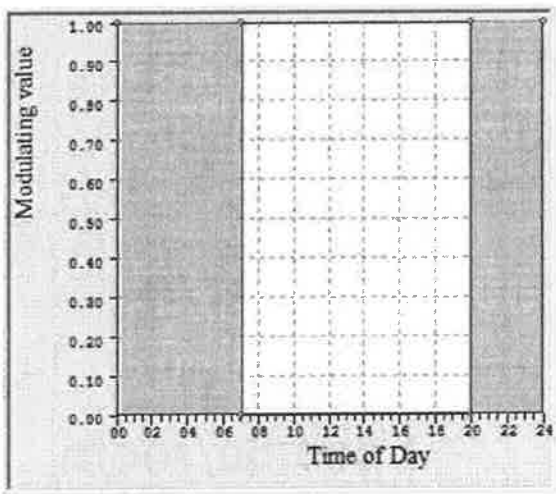
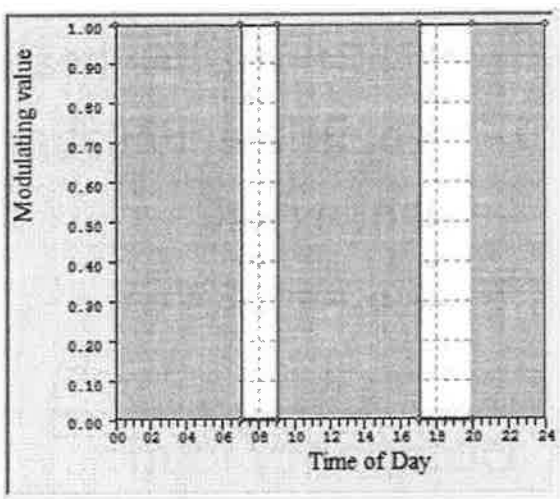
Case Study 2: Assumptions

Bedrooms





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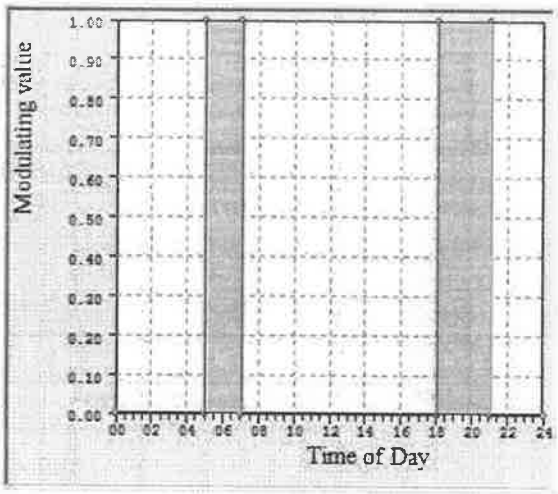
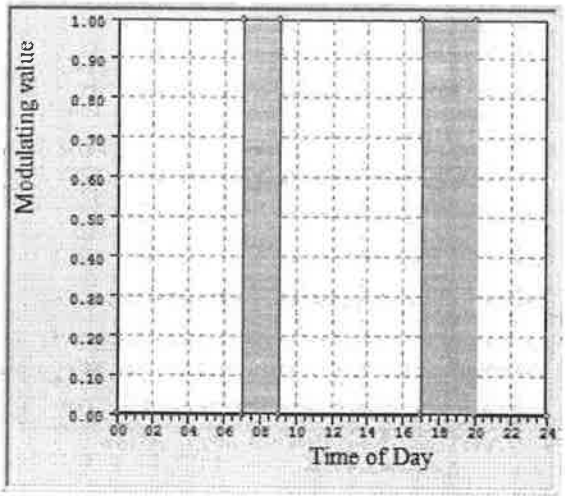
Case Study 2: Assumptions

Living





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Case Study 2: Assumptions

- Simulation Assumptions
  - People sensible heat gains - 75 W/person
  - People latent heat gain - 55 W/person
  - Lighting gain - 10 W/m2
  - Equipment gain - 5 W/m2

- Occupancy load - 2 people/room

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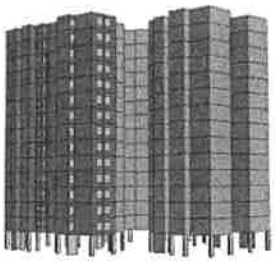
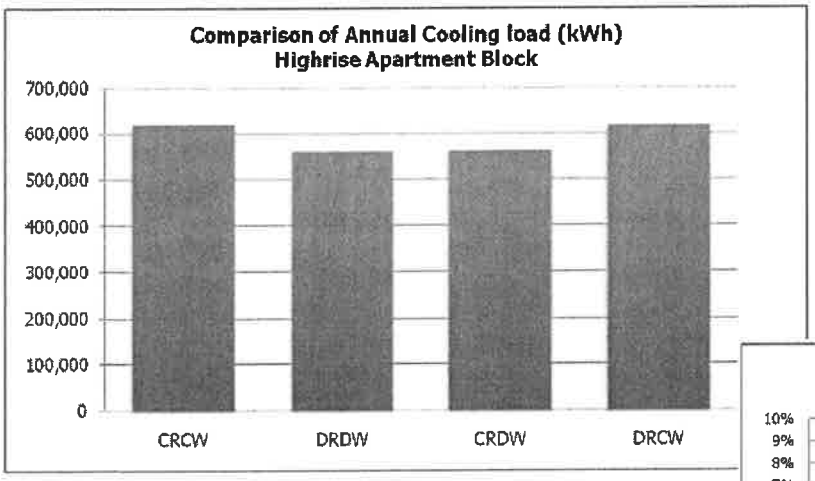
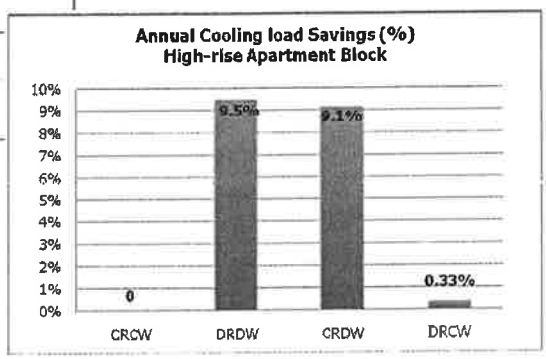
Case Study 2: Results

- Comparison of Annual cooling load







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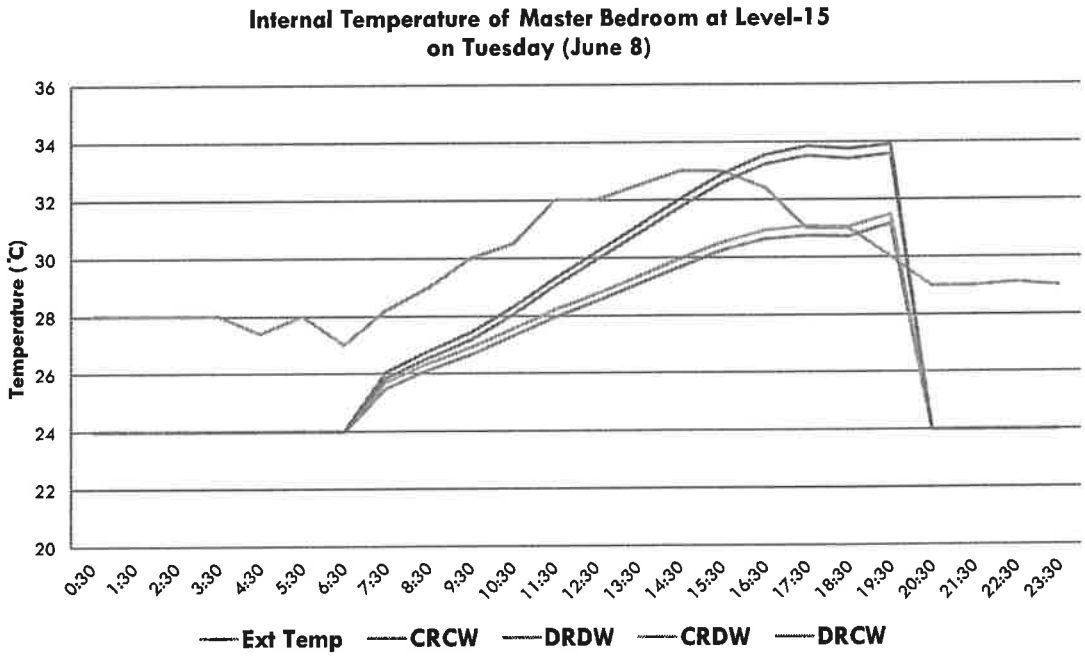
Case Study 2: Results

Internal room temperature of Master Bedroom at L15



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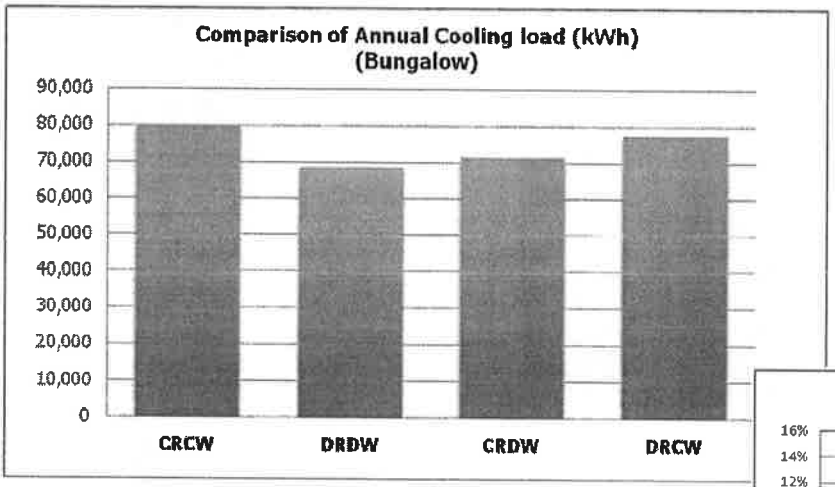
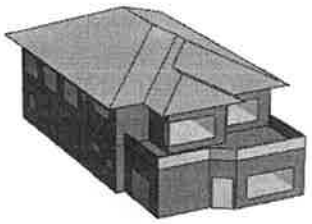
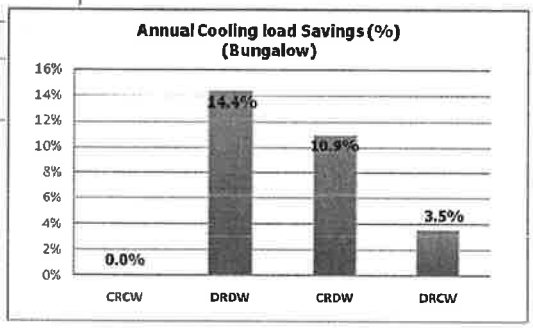
Case Study 2: Results

- Comparison of Annual cooling load







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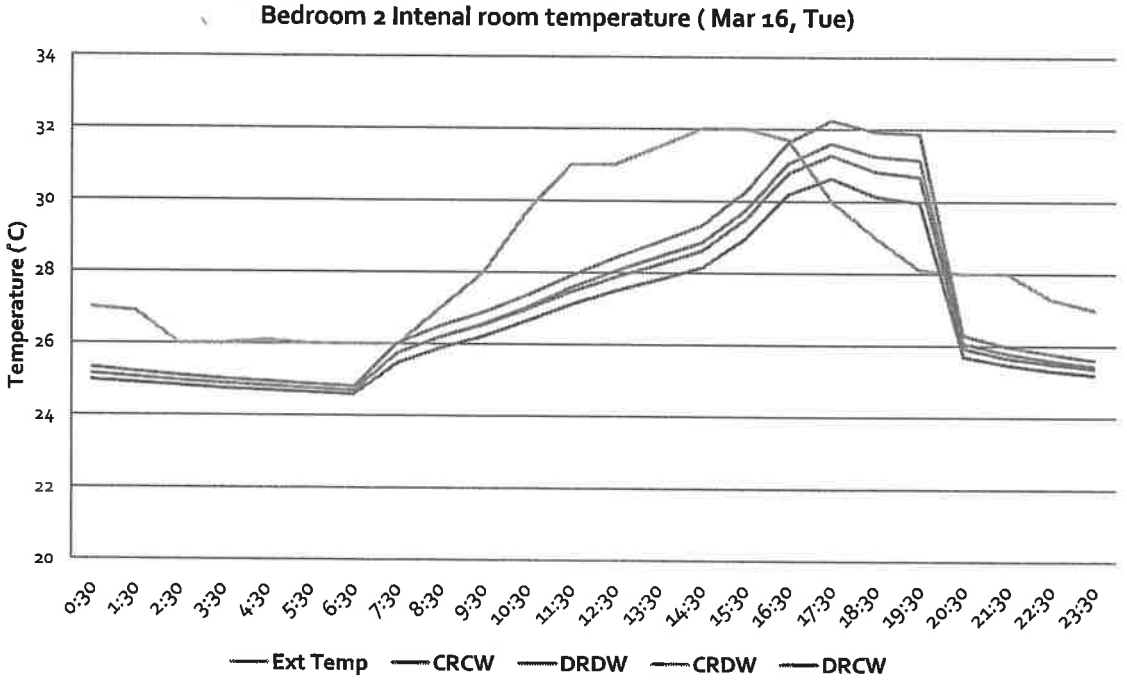
Case Study 2: Results

Internal room temperatures at Bedroom 2



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Thank You

Green Mark Professional core module : Building Energy Modeling & Thermal Simulation

Yong Ping Quen

Director and Partner
MSc. (Bdg Sci), BEng (Hons), LEED AP, GMP, GBIF.
BCA-Registered Energy Auditor

BSD
building system & diagnostics

Building System & Diagnostics Pte Ltd
No. 18, Boon Lay Way #07-107
Tradehub 21, Singapore 609966
Telephone : (65) 6560 0702
Website : www.bsd.com.sg



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3.0 1.03a Tropical Façade Performance

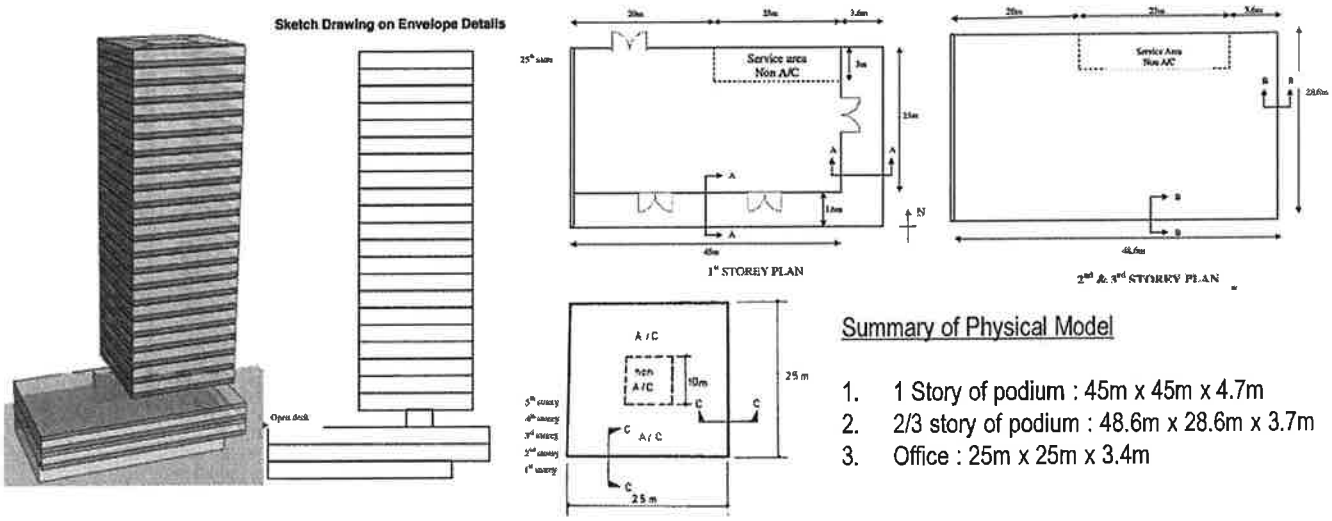
1.03a Tropical Façade Performance

Simulation Method: 1 point can be scored for every 5% heat load reduction of the envelope & solar insolation reduction of the fenestrations against the notional façade - By conducting building simulations

Overall Weighted Values	Industrial Buildings	Other building types
Weighted Window U-Value	5.4 W/m²K	2.8 W/m²K
Weighted Wall U-Value	1.5 W/m²K	0.7 W/m²K
Overall Envelope U-value	2.4 W/m²K	1.6 W/m²K
Window-to-Wall Ratio (Each façade)	0.2	0.4
Total Effective Glass Shading Coefficient ($SC_1 \times SC_2$)	0.6	0.4
Roof U-Value	1.1 W/m²K	0.8 W/m²K
Sky light/ Roof window U-Value	4.3 W/m²K	2.2 W/m²K
RTTV (where there are sky lights for AC areas)	50 W/m²K	50 W/m²K

1.03a Tropical Façade Performance

The example building: in Appendix D of the BCA ETTV Code. The proposed building is a 25-storey office building, consisting of a 4-storey rectangular podium and 21-storey square office tower. The front façade is chosen to be facing south. A neighboring building will be joined on the west façade of the podium.



Summary of Physical Model

1. 1 Story of podium : 45m x 45m x 4.7m
2. 2/3 story of podium : 48.6m x 28.6m x 3.7m
3. Office : 25m x 25m x 3.4m

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1.03a Tropical Façade Performance

METHODOLOGY

THERMAL MODEL AND SIMULATION RESULT

Various simulations for each of the different fenestrations are performed for 4,380 hours a year (7am to 7pm) based on Singapore's weather data.

The simulation results of the different case studies were collected and separated as follows:

- External wall conductive heat gain
- External fenestration conductive heat gain
- External roof conductive heat gain
- External fenestration solar heat gain
- Ground floor conductive heat gain
- Internal conductive heat gain between AC and non-AC zone

These heat gain results takes into account the time delay effect which occurs in materials. The results were separated as such in order to understand the contribution of each of these gains, as well as to check for any unexpected trends and anomalies.

The proposed fenestrations were graded according to their respective cooling load reductions, for a maximum of 4 points in 1.03a on Tropical Façade Performance.

1.03a Tropical Façade Performance

SIMULATION ASSUMPTIONS

6 different case studies, yielding a total of 20 different scenarios .
"Fenestration" refers to "Frame" and "Glazing" and "Window U-value and SC" means the "U-value and SC of Fenestration" which includes "Frame and Glazing".

CASE 1 – BASED ON BCA ETTV CODE APPEDIX D STUDY

TABLE 4.1: FAÇADE INPUT PARAMETERS FOR CASE 1

	Area	Case 1-1 (Glazing Only)	Case 1-2 (Frame + Glazing)	Case 1-3 (Thermally Broken Frame + Glazing)
Wall U-value (W/m²·K)	All Area	2.02	2.02	2.02
Roof U-value (W/m²·K)	All Area	0.50	0.50	0.50
Win U-value (F1) South (W/m²·K)	Podium	**5.60**	**6.53**	**5.83**
Win SC (F1) South	Podium	**0.39**	**0.37**	**0.36**
Win U-value (F1) East (W/m²·K)	Podium	**5.60**	**6.53**	**5.83**
Win SC (F1) East	Podium	**0.33**	**0.32**	**0.31**
Win U-value (F2) (W/m²·K)	Office	**1.88**	**3.61**	**2.56**
Win SC (F2)	Office	**0.33**	**0.32**	**0.30**
WWR	All Area	0.44	0.44	0.44

The window types of F1 refer to those used for the podium levels from 1st floor to 3rd floor, whereas F2 refers to the office windows from 5th floor to 25th floor. Note that the windows used for the south and east façade of the podium floors are different.

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1.03a Tropical Façade Performance

SIMULATION ASSUMPTIONS

CASE 2A – NOTIONAL FAÇADE U-VALUE STUDY

Notional façade proposed in Green Mark Ver 5.0. The U-values of the fenestrations were then adjusted in order to determine their significance in cooling load reduction.

TABLE 4.2: FAÇADE INPUT PARAMETERS FOR CASE 2A

	Notional Building	Case 2A-1	Case 2A-2	Case 2A-3
	Notional Façade U-value Study			
Wall U-value (W/m²·K)	0.70	0.70	0.70	0.70
Roof U-value (W/m²·K)	0.80	0.80	0.80	0.80
Window U-value (W/m²·K)	2.80	**2.40**	**2.00**	**1.60**
Window Shading Coefficient	0.40	0.40	0.40	0.40
WWR	0.40	0.40	0.40	0.40

CASE 2B – NOTIONAL FAÇADE U-VALUE STUDY

Similar to the previous case, this time only the shading coefficient was adjusted.

TABLE 4.3: FAÇADE INPUT PARAMETERS FOR CASE 2B

	Notional Building	Case 2B-1	Case 2B-2	Case 2B-3
	Notional Façade Shading Coefficient Study			
Wall U-value (W/m²·K)	0.70	0.70	0.70	0.70
Roof U-value (W/m²·K)	0.80	0.80	0.80	0.80
Window U-value (W/m²·K)	2.80	2.80	2.80	2.80
Window Shading Coefficient	0.40	**0.35**	**0.30**	**0.25**
WWR	0.40	0.40	0.40	0.40

1.03a Tropical Façade Performance

SIMULATION ASSUMPTIONS

CASE 3A – INDUSTRY STATUS QUO STUDY (U-VALUE AND SC)

Window-wall-ratio (WWR) has been increased from 40% in the notional building to 60% in the "industry status quo building". The wall and roof U-values are also altered to 0.30 W/m2·K and 0.50 W/m2·K respectively.

TABLE 4.4: FAÇADE INPUT PARAMETERS FOR CASE 3A

	Notional Building	Case3A-1 (Alu)	Case3A-2 (TB-1)	Case3A-3 (TB-2)	Case3A-4 (TB-3)
	Industry Status Quo Study (U-value & SC)				
Wall U-value (W/m²·K)	0.70	0.30	0.30	0.30	0.30
Roof U-value (W/m²·K)	0.80	0.50	0.50	0.50	0.50
Window U-value (W/m²·K)	2.80	3.00	2.40	2.00	1.60
Window Shading Coefficient	0.40	0.289	0.279	0.269	0.259
WWR	0.40	0.60	0.60	0.60	0.60

CASE 3B – INDUSTRY STATUS QUO STUDY (U-VALUE)

In Case 3A, both U-values and shading coefficients were changed together, making it difficult to separate the contribution of each alteration. Thus in this case study, using the "industry status quo" façade properties, only U-value of the fenestration systems was changed.

TABLE 4.5: FAÇADE INPUT PARAMETERS FOR CASE 3B

	Notional Building	Case3B-1 (Alu)	Case3B-2 (TB-1)	Case3B-3 (TB-2)	Case3B-4 (TB-3)
	Industry Status Quo Study (U-value)				
Wall U-value (W/m²·K)	0.70	0.30	0.30	0.30	0.30
Roof U-value (W/m²·K)	0.80	0.50	0.50	0.50	0.50
Window U-value (W/m²·K)	2.80	3.00	2.40	2.00	1.60
Window Shading Coefficient	0.40	0.289	0.289	0.289	0.289
WWR	0.40	0.60	0.60	0.60	0.60

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SIMULATION ASSUMPTIONS

CASE 3C – INDUSTRY STATUS QUO STUDY (SC)

Similar to Case 3B, except that instead of altering U-value, the shading coefficient of the fenestrations was altered.

TABLE 4.6: FAÇADE INPUT PARAMETERS FOR CASE 3C

	Notional Building	Case 3C-1 (Alu)	Case 3C-2 (TB-1)	Case 3C-3 (TB-2)	Case 3C-4 (TB-3)
	Industry Status Quo Study (SC)				
Wall U-value (W/m²·K)	0.70	0.30	0.30	0.30	0.30
Roof U-value (W/m²·K)	0.80	0.50	0.50	0.50	0.50
Window U-value (W/m²·K)	2.80	3.00	3.00	3.00	3.00
Window Shading Coefficient	0.40	0.289	0.279	0.269	0.259
WWR	0.40	0.60	0.60	0.60	0.60

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SIMULATION ASSUMPTIONS

CASE 3C – INDUSTRY STATUS QUO STUDY (SC)

Similar to Case 3B, except that instead of altering U-value, the shading coefficient of the fenestrations was altered.

TABLE 4.6: FAÇADE INPUT PARAMETERS FOR CASE 3C

	Notional Building	Case 3C-1 (Alu)	Case 3C-2 (TB-1)	Case 3C-3 (TB-2)	Case 3C-4 (TB-3)
	Industry Status Quo Study (SC)				
Wall U-value ($W/m^2 \cdot K$)	0.70	0.30	0.30	0.30	0.30
Roof U-value ($W/m^2 \cdot K$)	0.80	0.50	0.50	0.50	0.50
Window U-value ($W/m^2 \cdot K$)	2.80	3.00	3.00	3.00	3.00
Window Shading Coefficient	0.40	**0.289**	**0.279**	**0.269**	**0.259**
WWR	0.40	0.60	0.60	0.60	0.60

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SIMULATION RESULTS

CASE 1 – BASED ON BCA ETTV CODE APPEDIX D STUDY

For Green Mark Version 5, BCA looks at total cooling load from the facade. This includes additional gains such as ground floor conduction gain (gain from the ground) and internal conduction gain (gain from the non-air-conditioned zones within the building), on top of the gains described above. Thus in order to accurately score each fenestration's performance, the annual heat gain calculation would have to include these additional load.

TABLE 5.1: SIMULATION RESULTS FOR CASE 1

	Notional Building	Case 1-1 (Glazing Only)	Case 1-2 (Frame + Glazing)	Case 1-3 (Thermally Broken Frame + Glazing)
External Wall Conduction Gain (MWh)	143.0	365.8	364.7	368.6
External Fenestration Conduction (MWh)	192.5	105.4	220.7	184.2
External Roof Conduction Gain (MWh)	75.5	48.4	48.3	48.6
Solar Radiation Gain (MWh)	691.4	654.3	615.8	544.5
Ground Floor Conduction Gain (MWh)	9.0	8.9	8.7	9.0
Internal Conduction Gain (MWh)	26.2	36.6	36.1	36.7
Total Cooling Load (MWh)	1,137.7	1,219.5	1,294.3	1,191.5
ETTV (W/m^2)	41.97	46.84	48.82	45.43
Average Cooling Load (W/m^2)	15.5	16.6	17.6	16.2
Savings (%)	-	-7.2%	-13.6%	-4.7%
Point Calculation	-	**0.0**	**0.0**	**0.0**

1.03a Tropical Façade Performance

SIMULATION RESULTS

CASE 1 – BASED ON BCA ETTV CODE APPEDIX D STUDY

FIGURE 5.1: SIMULATION RESULTS FOR EACH HEAT COMPONENT FOR CASE 1

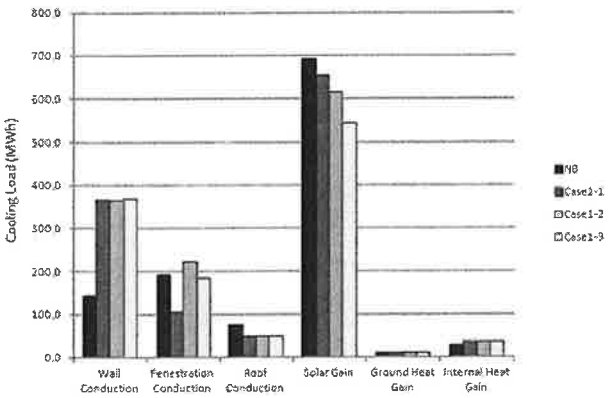
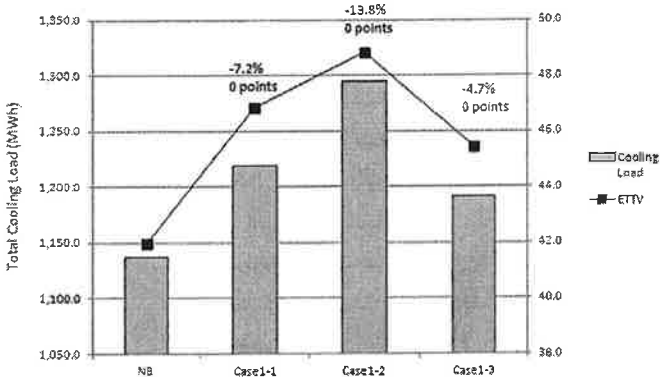


FIGURE 5.2: SIMULATION RESULTS FOR TOTAL COOLING LOAD FOR CASE 1



The ETTV is calculated for the reference to validate the total cooling load result.
Case 1-1 : -7.2% and 0 points achieved
Case 1-2 : -13.8% and 0 points achieved
Case 1-3 : -4.7% and 0 points achieved

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SIMULATION RESULTS

CASE 2A – NOTIONAL FAÇADE U-VALUE STUDY

In this case study, only the fenestration U-values were decreased incrementally. Intuitively, the fenestration conduction gain is expected to decrease.

TABLE 5.2: SIMULATION RESULTS FOR CASE 2A

	Notional Building	Case 2A-1	Case 2A-2	Case 2A-3
	Notional Façade U-value Study			
Fenestration U-value (W/m²K)	2.80	2.40	2.00	1.60
External Wall Conduction Gain (MWh)	143.0	143.4	143.8	144.2
External Fenestration Conduction (MWh)	192.5	**171.9**	**150.9**	**129.6**
External Roof Conduction Gain (MWh)	75.5	75.5	75.6	75.6
Solar Radiation Gain (MWh)	691.4	687.0	682.8	678.3
Ground Floor Conduction Gain (MWh)	9.0	9.1	9.1	9.1
Internal Conduction Gain (MWh)	26.2	26.2	26.2	26.2
Total Cooling Load (MWh)	1,137.7	1,113.1	1,088.5	1,063.1
ETTV (W/m²)	41.97	41.43	40.88	40.34
Average Cooling Load (W/m²)	15.5	15.1	14.8	14.5
Savings (%)	-	2.2%	4.3%	6.6%
Point Calculation	-	**1.0**	**1.0**	**2.0**

1.03a Tropical Façade Performance

SIMULATION RESULTS

CASE 2A – NOTIONAL FAÇADE U-VALUE STUDY

FIGURE 5.3: SIMULATION RESULTS FOR EACH HEAT COMPONENT FOR CASE 2A

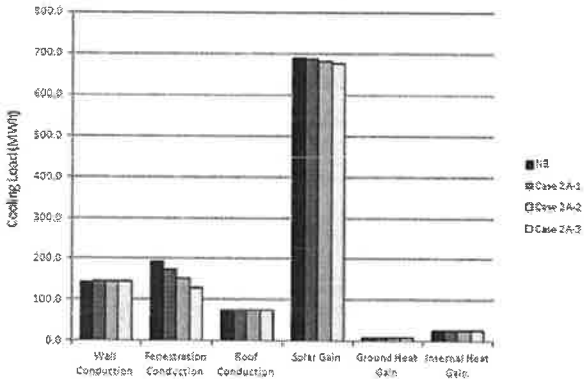
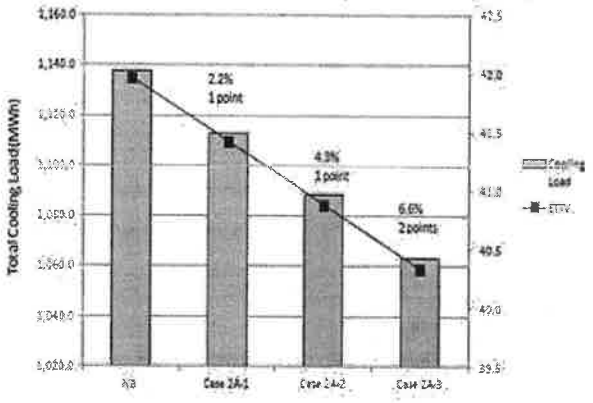


FIGURE 5.4: SIMULATION RESULTS FOR TOTAL COOLING LOAD FOR CASE 2A



When the fenestration U-value is improved, the conduction heat gain is reduced as shown in Figure 5.3 and it contributes overall cooling load reduction as in Figure 5.4. Once again, it can be seen that the ETTV varies in a similar fashion as the total cooling load.

Case 2A-1 : 2.2% and 1 point achieved
Case 2A-2 : 4.3% and 1 point achieved
Case 2A-3 : 6.6% and 2 points achieved

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SIMULATION RESULTS

CASE 2B – NOTIONAL FAÇADE SHADING COEFFICIENT (SC) STUDY

Similar to Case 2A, except that now instead of U-value, the shading coefficients were decreased by a fixed interval. The solar gain would be expected to decrease significantly.

TABLE 5.3: SIMULATION RESULTS FOR CASE 2B

	Notional Building	Case 2B-1	Case 2B-2	Case 2B-3
	Notional Façade SC Study			
Fenestration SC	0.400	0.350	0.300	0.250
External Wall Conduction Gain (MWh)	143.0	144.9	146.6	148.2
External Fenestration Conduction (MWh)	192.5	196.8	200.9	204.7
External Roof Conduction Gain (MWh)	75.5	76.0	76.5	76.9
Solar Radiation Gain (MWh)	691.4	**604.1**	**518.6**	**435.5**
Ground Floor Conduction Gain (MWh)	9.0	9.3	9.6	9.8
Internal Conduction Gain (MWh)	26.2	26.4	26.7	26.9
Total Cooling Load (MWh)	1,137.7	1,057.6	978.9	902.0
ETTV (W/m²)	41.97	37.8	33.7	29.5
Average Cooling Load (W/m²)	15.5	14.4	13.3	12.3
Savings (%)	-	7.0%	14.0%	20.7%
Point Calculation	-	**2.0**	**3.0**	**4.0**

1.03a Tropical Façade Performance

SIMULATION RESULTS

CASE 2B – NOTIONAL FAÇADE SHADING COEFFICIENT (SC) STUDY

FIGURE 5.5: SIMULATION RESULTS FOR EACH HEAT COMPONENT FOR CASE 2B

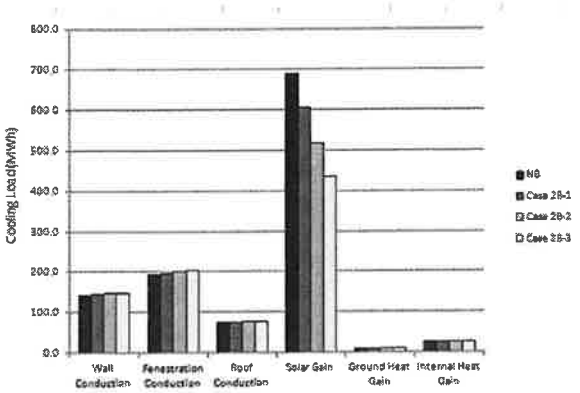
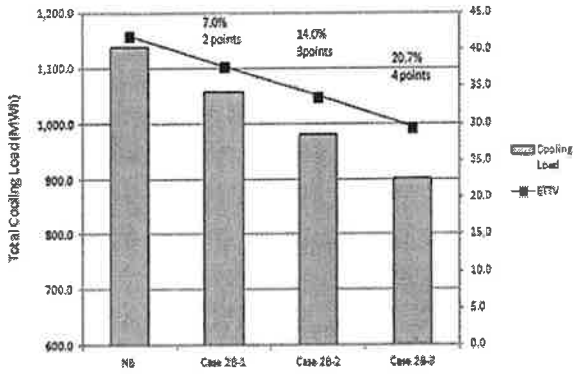


FIGURE 5.6: SIMULATION RESULTS FOR TOTAL COOLING LOAD FOR CASE 2B



Compared with Figure 5.4 in Case 2A, it can be observed that there is higher overall savings when the shading coefficient is improved (Case 2B), as compared to improving the U-value as in Case 2A. This is because the solar gain is the largest contributor to the overall cooling load when compared to the other façade gains.

Case 2B-1 : 7.0% and 2 points achieved
Case 2B-2 : 14.0% and 3 points achieved
Case 2B-3 : 20.7% and 4 points achieved

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SIMULATION RESULTS

CASE 3A – INDUSTRIAL STATUS QUO STUDY (U-value and SC)

For Cases 3A to 3C, it is important to note that the WWR has increased to 60%; external wall and roof U-values are changed to 0.30W/m^{2}K and 0.50W/m^{2}K respectively. In Case 3A, both the U-value and shading coefficient values were decreased concurrently. Intuitively one would expect a large improvement as these values drop. However it would be difficult to separate their individual contributions.

TABLE 5.4: SIMULATION RESULTS FOR CASE 3A

	Notional Building	Case 3A-1 (Alu)	Case 3A-2 (TB-1)	Case 3A-3 (TB-2)	Case 3A-4 (TB-3)
	Industry Status Quo Study (U-value and SC)				
Fenestration U-value (W/m^{2}K)	2.80	3.00	2.40	2.00	1.60
Fenestration SC	0.400	0.289	0.279	0.269	0.259
External Wall Conduction Gain (MWh)	143.0	41.0	41.4	41.7	42.0
External Fenestration Conduction (MWh)	192.5	**306.5**	**262.7**	**232.6**	**201.4**
External Roof Conduction Gain (MWh)	75.5	50.0	50.2	50.3	50.5
Solar Radiation Gain (MWh)	691.4	**754.8**	**714.6**	**678.8**	**643.0**
Ground Floor Conduction Gain (MWh)	9.0	9.7	9.8	9.9	10.0
Internal Conduction Gain (MWh)	26.2	18.5	18.6	18.7	18.7
Total Cooling Load (MWh)	1,137.7	1,180.6	1,097.3	1,032.0	965.6
ETTV (W/m^2)	41.97	43.66	41.18	39.12	37.05
Average Cooling Load (W/m^2)	15.5	16.1	14.9	14.0	13.1
Savings (%)	-	-3.8%	3.5%	9.3%	15.1%
Point Calculation	-	0.0	1.0	2.0	4.0

1.03a Tropical Façade Performance

SIMULATION RESULTS

CASE 3A – INDUSTRIAL STATUS QUO STUDY (U-value and SC)

FIGURE 5.7: SIMULATION RESULTS FOR EACH HEAT COMPONENT FOR CASE 3A

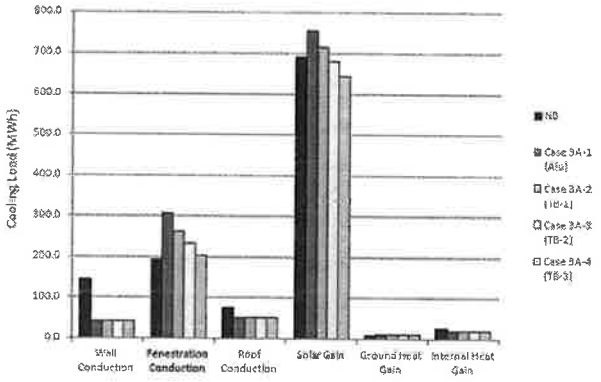
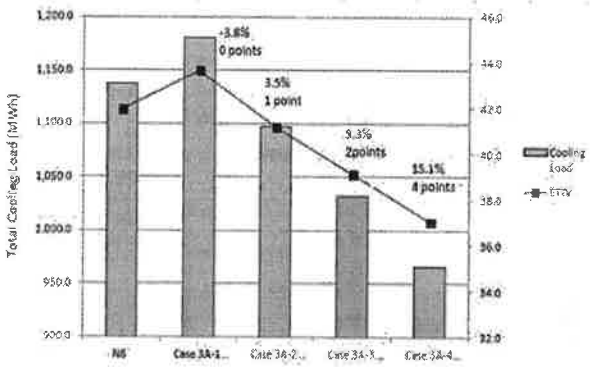


FIGURE 5.8: SIMULATION RESULTS FOR TOTAL COOLING LOAD FOR CASE 3A



When fenestration U-value and shading coefficient were improved, fenestration conduction and solar gain were reduced, as shown in Figure 5.7 and those reductions contribute to the overall cooling load reduction as in Figure 5.8. Case 3A-4 shows the maximum score of 4 points.

Case 3A-1 : -3.8% and 0 points achieved
Case 3A-2 : 3.5% and 1 point achieved
Case 3A-3 : 9.3% and 2 points achieved
Case 3A-3 : 15.1% and 4 points achieved

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1.03a Tropical Façade Performance

SIMULATION RESULTS

CASE 3B – INDUSTRIAL STATUS QUO STUDY (U-value)

In Case 3B, using the similar façade properties as in Case 3A, the U-values of the fenestrations were scaled down accordingly. Just like in Case 2A, we would expect the fenestration conduction gain to decrease.

TABLE 5.5: SIMULATION RESULTS FOR CASE 3B

	Notional Building	Case 3B-1 (Alu)	Case 3B-2 (TB-1)	Case 3B-3 (TB-2)	Case 3B-4 (TB-3)
	Industry Status Quo Study (U-Value)				
Fenestration U-value (W/m^2K)	2.80	3.00	2.40	2.00	1.60
External Wall Conduction Gain (MWh)	143.0	41.0	41.3	41.4	41.6
External Fenestration Conduction (MWh)	192.5	306.5	261.2	230.0	198.0
External Roof Conduction Gain (MWh)	75.5	50.0	50.1	50.2	50.2
Solar Radiation Gain (MWh)	691.4	754.8	739.8	730.2	720.6
Ground Floor Conduction Gain (MWh)	9.0	9.7	9.7	9.8	9.8
Internal Conduction Gain (MWh)	26.2	18.5	18.6	18.6	18.6
Total Cooling Load (MWh)	1,137.7	1,180.6	1,120.7	1,080.2	1,038.9
ETTV (W/m^2)	41.97	43.66	42.43	41.62	40.80
Average Cooling Load (W/m^2)	15.5	16.1	15.2	14.7	14.1
Savings (%)	-	-3.8%	1.5%	5.1%	8.7%
Point Calculation	-	0.0	1.0	1.0	2.0

1.03a Tropical Façade Performance

SIMULATION RESULTS

CASE 3B – INDUSTRIAL STATUS QUO STUDY (U-value)

FIGURE 5.9: SIMULATION RESULTS FOR EACH HEAT COMPONENT FOR CASE 3B

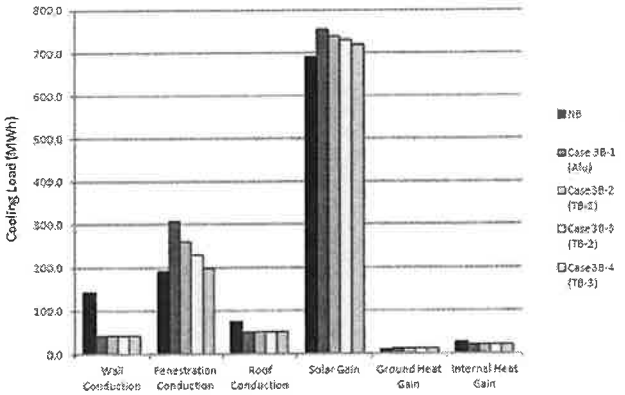
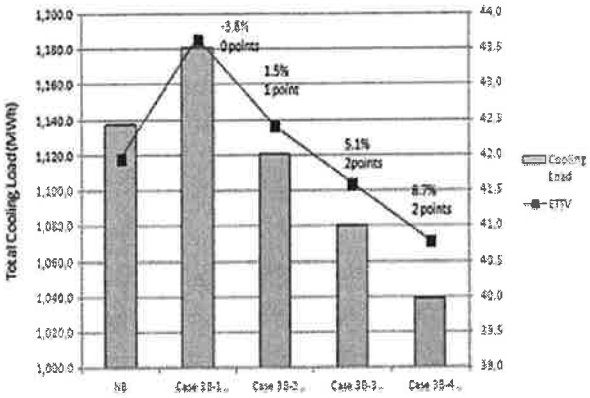


FIGURE 5.10: SIMULATION RESULTS FOR TOTAL COOLING LOAD FOR CASE 3B



When the fenestration U-value was improved based on industrial status quo building, fenestration conduction heat gain was reduced as shown in Figure 5.9 and its contribution to the overall cooling load reduction can be seen in Figure 5.10.

Case 3B-1 : -3.8% and 0 points achieved
Case 3B-2 : 1.5% and 1 point achieved
Case 3B-3 : 5.1% and 2 points achieved
Case 3B-3 : 8.7% and 2 points achieved

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SIMULATION RESULTS

CASE 3C – INDUSTRIAL STATUS QUO STUDY (SC)

For the last case, instead of U-values, the shading coefficients of the fenestrations were decreased slightly by a fixed interval. This will serve to improve the solar gain into the air-conditioned zones.

TABLE 5.6: SIMULATION RESULTS FOR CASE 3C

	Notional Building	Case 3C-1 (Alu)	Case 3C-2 (TB-1)	Case 3C-3 (TB-2)	Case 3C-4 (TB-3)
	Industry Status Quo Study (SC)				
Fenestration SC	0.400	0.289	0.279	0.269	0.259
External Wall Conduction Gain (MWh)	143.0	41.0	41.1	41.3	41.4
External Fenestration Conduction (MWh)	192.5	305.5	308.4	310.2	311.9
External Roof Conduction Gain (MWh)	75.5	50.0	50.1	50.2	50.3
Solar Radiation Gain (MWh)	691.4	754.8	730.3	705.6	681.2
Ground Floor Conduction Gain (MWh)	9.0	9.7	9.7	9.8	9.8
Internal Conduction Gain (MWh)	26.2	18.5	18.6	18.6	18.6
Total Cooling Load (MWh)	1,137.7	1,180.6	1,158.3	1,135.7	1,113.2
ETTV (W/m²)	41.97	43.66	42.41	41.16	39.91
Average Cooling Load (W/m²)	15.5	16.1	15.7	15.4	15.1
Savings (%)	-	-3.8%	-1.8%	0.2%	2.1%
Point Calculation	-	0.0	0.0	1.0	1.0

1.03a Tropical Façade Performance

SIMULATION RESULTS

CASE 3C – INDUSTRIAL STATUS QUO STUDY (SC)

FIGURE 5.11: SIMULATION RESULTS FOR EACH HEAT COMPONENT FOR CASE 3C

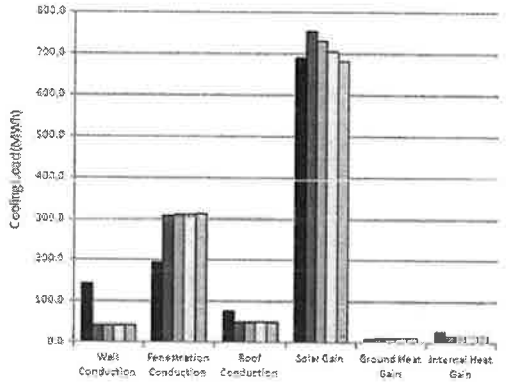
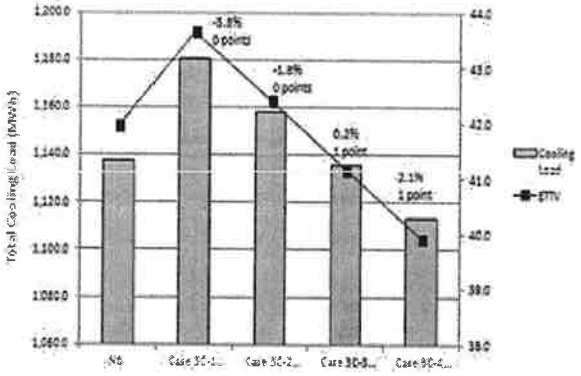


FIGURE 5.12: SIMULATION RESULTS FOR TOTAL COOLING LOAD FOR CASE 3C



The reduction of the shading coefficients serve to reduce solar radiation. Although solar gain is the largest contributor to the overall cooling load, in Case 3C, the effect of reducing shading coefficient is not as pronounced as the shading coefficient is only reduced by a small amount (0.01) per interval.

Case 3C-1 : -3.8% and 0 points achieved
Case 3C-2 : -1.8% and 0 points achieved
Case 3C-3 : 0.2% and 1 point achieved
Case 3C-3 : 2.1% and 1 point achieved

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5. SUMMARY OF RESULTS

ETTV Calculation for all cases

	Unit	Notional Building	Case 1-1 (Window Only)	Case 1-2 (Frame + Glazing)	Case 1-3 (Thermally Broken Frame + Glazing)	Case 2A-1	Case 2A-2	Case 2A-3	Case 2B-1	Case 2B-2	Case 2B-3	Case 3A-1 (Alv)	Case 3A-2 (TB-1)	Case 3A-3 (TB-2)	Case 3A-4 (TB-3)	Case 3B-1 (Alv)	Case 3B-2 (TB-1)	Case 3B-3 (TB-2)	Case 3B-4 (TB-3)	Case 3C-1 (Alv)	Case 3C-2 (TB-1)	Case 3C-3 (TB-2)	Case 3C-4 (TB-3)
			Appendix D Study			Notional Façade U-value Study			Notional Façade SC Study			Industry Status Quo Study (U-value & SC)				Industry Status Quo Study (U-value)				Industry Status Quo Study (SC)			
Wall U-value	W/m2K	0.70	2.02	2.02	2.02	0.70	0.70	0.70	0.70	0.70	0.70	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Roof U-value	W/m2K	0.50	0.50	0.50	0.50	0.80	0.80	0.80	0.80	0.80	0.80	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Win U-value (Fl)_S	W/m2K	2.80	5.60	6.53	5.63	2.40	2.00	1.60	2.80	2.80	2.80	3.00	2.40	2.00	1.60	3.00	2.40	2.00	1.60	3.00	2.00	3.00	3.00
Win SC (Fl)_S	SC	0.400	0.390	0.375	0.350	0.400	0.400	0.400	0.390	0.300	0.250	0.269	0.279	0.269	0.259	0.269	0.269	0.269	0.269	0.269	0.279	0.269	0.259
Win U-value (Fl)_E	W/m2K	2.80	5.60	6.53	5.63	2.40	2.00	1.60	2.80	2.80	2.80	3.00	2.40	2.00	1.60	3.00	2.40	2.00	1.60	3.00	3.00	3.00	3.00
Win SC (Fl)_E	SC	0.400	0.390	0.375	0.350	0.400	0.400	0.400	0.390	0.300	0.250	0.269	0.279	0.269	0.259	0.269	0.269	0.269	0.269	0.269	0.279	0.269	0.259
Win U-value (F2)	W/m2K	2.80	5.60	6.53	5.63	2.40	2.00	1.60	2.80	2.80	2.80	3.00	2.40	2.00	1.60	3.00	2.40	2.00	1.60	3.00	3.00	3.00	3.00
Win SC (F2)	SC	0.400	0.390	0.375	0.350	0.400	0.400	0.400	0.390	0.300	0.250	0.269	0.279	0.269	0.259	0.269	0.269	0.269	0.269	0.269	0.279	0.269	0.259
WWR	%	40.0%	44.0%	44.0%	44.0%	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	60.0%	60.0%	60.0%	60.0%	60.0%	60.0%	60.0%	60.0%	60.0%	60.0%	60.0%	60.0%
Win Height (Office)	m	1.34	1.50	1.50	1.50	1.34	1.34	1.34	1.34	1.34	1.34	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13	2.13
Wall Area (Building)	m2	4,577	4,645	4,645	4,645	4,577	4,577	4,577	4,577	4,577	4,577	3,318	3,318	3,318	3,318	3,318	3,318	3,318	3,318	3,318	3,318	3,318	3,318
Win Area (Office)	m2	2,614	3,146	3,146	3,146	2,614	2,614	2,614	2,614	2,614	2,614	4,473	4,473	4,473	4,473	4,473	4,473	4,473	4,473	4,473	4,473	4,473	4,473
Win Area (Podium2/3)	m2	262	262	262	262	262	262	262	262	262	262	262	262	262	262	262	262	262	262	262	262	262	262
Win Area (Podium)_S	m2	162	162	162	162	162	162	162	162	162	162	162	162	162	162	162	162	162	162	162	162	162	162
Win Area (Podium)_E	m2	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79
Total Façade Area	m2	8,235	8,295	8,295	8,295	8,235	8,235	8,235	8,235	8,235	8,235	8,295	8,295	8,295	8,295	8,295	8,295	8,295	8,295	8,295	8,295	8,295	8,295

Cooling Load from façade and Point calculations for all cases

	Unit	Notional Building	Case 1-1 (Window Only)	Case 1-2 (Frame + Glazing)	Case 1-3 (Thermally Broken Frame + Glazing)	Case 2A-1	Case 2A-2	Case 2A-3	Case 2B-1	Case 2B-2	Case 2B-3	Case 3A-1 (Alv)	Case 3A-2 (TB-1)	Case 3A-3 (TB-2)	Case 3A-4 (TB-3)	Case 3B-1 (Alv)	Case 3B-2 (TB-1)	Case 3B-3 (TB-2)	Case 3B-4 (TB-3)	Case 3C-1 (Alv)	Case 3C-2 (TB-1)	Case 3C-3 (TB-2)	Case 3C-4 (TB-3)
			kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh
ETTV	kWh	41.81	48.34	48.52	45.43	41.43	40.80	40.34	41.81	33.65	29.15	43.86	41.19	38.12	37.05	43.86	42.42	41.62	40.86	43.86	42.41	41.16	39.91
Total Heat Gain	Jan	92.98	98.11	101.93	94.57	91.49	89.85	88.23	85.78	78.71	71.80	95.53	89.41	84.50	79.53	95.53	91.59	88.01	86.10	95.53	92.53	91.51	89.51
	Feb	91.16	96.87	101.34	94.19	89.34	87.54	85.68	84.31	77.98	71.59	94.26	87.82	82.73	77.60	94.26	89.76	86.14	83.69	94.26	92.40	90.53	88.67
	Mar	96.19	103.15	110.24	101.25	93.96	91.72	89.42	93.67	83.26	76.55	100.07	92.78	87.13	81.38	100.07	94.63	91.06	87.56	100.07	98.25	96.40	94.57
	Apr	99.96	107.90	116.48	106.57	97.42	94.97	92.24	93.44	87.04	80.78	104.45	96.40	90.34	84.09	104.45	98.38	94.27	90.97	104.45	102.62	100.78	98.95
	May	104.57	113.56	121.92	112.02	101.96	99.32	96.60	97.72	91.00	84.42	109.16	100.32	94.34	88.03	109.16	102.52	98.61	94.32	109.16	107.24	105.31	103.39
	Jun	102.24	111.47	120.10	110.25	99.56	96.96	94.06	95.71	89.30	83.00	107.06	98.79	92.42	85.91	107.06	100.71	96.91	91.91	107.06	105.22	103.08	101.14
	Jul	99.37	107.13	114.28	105.09	97.08	94.78	92.41	92.56	85.92	79.42	103.53	96.00	90.10	84.15	103.53	97.99	94.23	90.39	103.53	101.63	99.71	97.81
	Aug	98.05	106.01	112.63	103.92	96.11	93.87	91.54	91.62	85.01	78.54	102.36	94.99	89.23	83.37	102.36	96.96	93.29	89.54	102.36	100.48	98.57	96.68
	Sep	93.91	91.99	97.43	93.80	84.11	82.20	80.43	73.06	73.95	68.14	89.06	82.90	78.06	73.14	89.06	84.67	81.70	78.67	89.06	87.37	85.66	83.86
	Oct	95.59	102.51	109.14	100.10	93.20	91.17	89.08	88.13	82.19	75.38	99.00	91.95	86.43	80.82	99.00	93.85	90.43	86.91	99.00	97.14	95.26	93.40
	Nov	96.39	91.59	95.88	88.18	84.92	83.30	82.01	78.69	73.10	66.67	88.90	83.25	78.72	74.14	88.90	85.20	82.14	80.25	88.90	87.03	85.14	83.27
	Dec	85.14	89.42	92.27	85.56	83.91	82.71	81.45	78.25	71.49	64.67	87.25	82.01	77.74	73.44	87.25	84.01	81.87	79.72	87.25	85.33	83.40	81.48
Cooling Load (kWh)	Total	1,137.1	1,210.5	1,294.8	1,191.2	1,103.1	1,068.3	1,033.1	1,037.6	972.3	902.0	1,180.6	1,091.9	1,032.0	965.6	1,180.6	1,120.7	1,080.2	1,038.9	1,180.6	1,156.3	1,136.1	1,115.2
Average Cooling Load	kW	259.7	276.4	295.5	272.0	254.1	246.3	242.7	241.5	223.3	203.3	269.6	250.5	236.6	220.5	269.6	255.9	246.6	237.2	269.6	264.4	259.5	254.7
AC Area	m^2	16,734.3	16,734.3	16,734.3	16,734.3	16,734.3	16,734.3	16,734.3	16,734.3	16,734.3	16,734.3	16,734.3	16,734.3	16,734.3	16,734.3	16,734.3	16,734.3	16,734.3	16,734.3	16,734.3	16,734.3	16,734.3	16,734.3
Average Cooling Load	W/m^2	15.5	16.5	17.6	16.3	15.1	14.8	14.5	14.4	13.3	12.2	16.1	14.9	14.0	13.1	16.1	15.2	14.7	14.1	16.1	15.7	15.4	15.1
Savings	%		-1.2%	-10.8%	-4.7%	2.2%	4.2%	6.5%	1.0%	14.0%	20.7%	-2.0%	5.5%	10.9%	16.6%	-2.0%	1.3%	3.1%	5.7%	-2.0%	-0.8%	0.2%	2.1%
Point Calculation			0.0	0.0	0.0	1.0	1.0	2.0	2.0	3.0	4.0	0.0	1.0	2.0	4.0	0.0	1.0	2.0	2.0	0.0	0.0	1.0	1.0

ASSIGNMENT FOR BUILDING ENERGY MODELNG

PART A - BASE CASE Run

Prepare a building model in IES<VE> ("input file") for the building input data to represent the BASE CASE. The general information of the building is provided in Appendix. You may assume any hypothetical info for information not provided. Determine the building peak cooling load, Cooling load distribution percentage, annual cooling load and annual energy consumption for the base case.

PART B - PARAMETRIC VARIATIONS - Energy Conservation Opportunities

You are required to perform 3 different simulations (parametric variations), each of which represents one of several energy conservation opportunities (ECOs) in passive design and in active design. By a comprehensive comparison of the results of the simulation, and subsequent analysis that includes both peak and part load performance of the major components, suggest a suitable energy conservation strategy for your building and highlight the expected potential for energy savings. Your analysis must also include compliance requirements to prevailing local and international standards such as SS 530, SS 531, SS553 etc.

Presentation and Report Submission

Each group is required to make a 20 mins formal presentation on the study. Participants are encourage participate to learn from each other.

Outline for Presentation

1. Building descriptions
2. Reference Model (Base case) building peak cooling, cooling load distribution
3. Reference Model (Base case) building annual cooling load, energy consumption
4. ECO 1: Description of ECO, provide illustration how to achieve its design target
5. ECO 2: Description of ECO, provide illustration how to achieve its design target
6. ECO 3: Description of ECO, provide illustration how to achieve its design target
7. For each ECO, describe the corresponding peak cooling, cooling load distribution, annual energy consumption & analyse the results
8. For the final Proposed model, compute the building peak cooling, cooling load distribution, and the final energy consumption
9. Comparison of Reference Model vs Proposed Model
10. Comparison of Energy Efficiency Index (EEI)

Group Project Submission

1. Simulation input and output files for Reference Model
2. Simulation input and output files for Proposed Model
3. Completed Energy Modelling Form
4. Power point presentation slide

Annex C: Energy Modeling Methodology and Requirements

General

The energy modeling for evaluating the energy performance of a building shall be carried out in a prescribed manner to quantify the potential savings based on energy efficiency measures and improvements that reduce cooling load requirement over the Reference Model. The energy savings shall be measured by comparing the annual energy consumption of the Proposed Model (designed building) against the Reference Model (baseline building).

Simulation Software

The simulation software used for energy modeling 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 with *ANSI/ASHRAE Standard 140 – Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs* (or other equivalent standards).

Reference Model

(i) Baseline Standards

The simulation model for calculating the baseline building performance (known as Reference Model) shall be developed in accordance with the requirements in the following table on Baseline Standards. The requirements are applicable to all buildings, including building served by new/ existing DCS plants.

<table>
<tr><th>S/N</th><th>Component</th><th>Baseline Standard</th><th>Minimum Requirement</th></tr>
<tr><td>1</td><td colspan="3">Building Description</td></tr>
<tr><td>1.1</td><td>Building Envelope Design</td><td>BCA Approved Document
Code on Envelope Thermal Performance for buildings

SS 212 : 2007 – Specification for Aluminium Alloy Windows</td><td>(a) ETTV shall not exceed 50 W/m^2
(b) For roof with skylight, RTTV shall not exceed 50 W/m^2
For roof without skylight, the average U value of the gross area of the roof shall not exceed the limits below:
<table><tr><th>Weight Group</th><th>Weight range (kg/m^2)</th><th>Maximum Thermal Transmittance (W/m^{2}k)</th></tr><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></table>(c) All windows on the building envelope shall not exceed the air leakage rates specified in SS 212 : 2007.
(d) Where the door opening of any commercial unit is located along the perimeter of the building envelope, that unit shall:
(i) Be completely separated from the other parts of the building</td></tr>
</table>

<table>
<tr><td></td><td></td><td></td><td>(ii) Have its air-conditioning system separated from and independent of the central system.</td></tr>
<tr><td>1.2</td><td>Building Shape, Size and Configuration</td><td></td><td>Reference Model to be the same as Proposed Model</td></tr>
<tr><td>1.3</td><td>Building Zoning & Thermal Block</td><td></td><td>Reference Model to be the same as Proposed Model.

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 Passive Design Features 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.</td></tr>
<tr><td>2</td><td colspan="3">System Description</td></tr>
<tr><td>2.1</td><td>Air-conditioning System Types</td><td>SS 530 : 2014 – Code of Practice for Energy efficiency Standard for Building Services and Equipment

ASHRAE 90.1: 2013 – Energy Standard for Buildings Except Low-Rise Residential Buildings</td><td>(a) Based on the peak building cooling load, the reference system shall be as follows:
(i) Peak building cooling load ≥ 500RT: Centrifugal chiller.
- Peak cooling load ≤ 800 RT: 1 number of centrifugal chiller
- Peak cooling load > 800 RT: N numbers of centrifugal chillers equally sized with each chiller ≤ 800 RT
(ii) Peak building cooling load < 500RT and air-conditioned area ≥ 5,000m^2: Screw chiller
- Peak cooling load ≤ 300 RT: 1 number of screw chiller
- Peak cooling load > 300 RT: 2 numbers of screw chillers sized equally sized with each chiller ≤ 300 RT
(iii) Peak building cooling load < 500RT and air-conditioned area < 5,000m^2: The reference system shall be of the same type as the proposed system.
(iv) For VRF systems, the baseline of constant COP of 3.28, 3.22 and 2.93 shall be adopted, with reference to SS 530 : 2014, Table 1B.

(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.

(c) For buildings with chilled water supplied/ to be supplied by a District Cooling System (DCS) company:
(i) Path A: The above item (a) and (b) are applicable to building with chilled water supplied by DCS company under Path A. All ACMV components dedicated to the DCS plant and building designed shall be included and considered. The energy efficiency and chilled water system of the Proposed Model shall be that of the DCS plant.
(ii) Path B: The energy consumption contribution from the DCS plant may be excluded from the energy modeling provided the two criteria as follows are complied with:

<table>
<tr><th>Level of Green Mark Award</th><th>Cooling Load Savings</th><th>Energy Consumption Savings (exclude DCS plant)</th></tr>
<tr><td>Gold^{PLUS}</td><td>10%</td><td>27%</td></tr>
<tr><td>Platinum</td><td>15%</td><td>33%</td></tr>
</table>
</td></tr>
</table>

			Paths A and B shall be as per defined in the Technical Guide and *Requirements for P.04 Air Conditioning Total System and Component Efficiency.*
2.2	Chiller Efficiency	SS 530 : 2014	Minimum energy efficiency standard stated in *SS 530 : 2014.* Please refer below for the default chiller efficiency curve.
2.3	Air-Conditioning Hydronic Systems	*SS 553 : 2015* - *Code of Practice for Air-conditioning and Mechanical Ventilation in Buildings* *California Energy Commission Non-Residential Alternative Calculation Method Reference Manual 2013 Appendix 5.7*	(a) Pumping system design criteria (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^3/s. The pump power limitation for condensing water systems is 301 kW/m^3/s. (ii) For motors > 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. (iii) For motors ≤ 3.7 kW: The chilled water pump shall be the equivalent of a constant speed pump if motor is less than 3.7 kW. (iv) Condenser water pump shall be the equivalent of a constant speed pump. The above item (i) to (iv) are applicable to buildings with chilled water supplied by DCS companiess. For Path B, only the customer building pumps shall be considered. (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. Pump power ratio = $0.0205x + 0.4101x^2 + 0.5753x^3$ *where x is the part load ratio* *Project team can propose other equivalent methodology but affinity law is not recommended as it does not take into account of loss in actual operating conditions.*
2.4	Cooling Tower	*SS 530: 2014* *California Energy Commission Non-Residential Alternative Calculation Method Reference Manual 2013 Appendix 5.7*	Performance requirement for heat rejection equipment: a) Propeller or axial fan cooling towers: Cooling tower performance shall not be less than 3.23 L/s/kW. b) Centrifugal fan cooling towers: Cooling tower performance shall not be less than 1.7 L/s/kW. 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. Cooling tower fan power ratio = $0.331629 - 0.885676\ x + 0.605565\ x^2 + 0.948482\ x^3$ *where x is the part load ratio* *Project team can propose other equivalent methodology but affinity law is not recommended as it does not take into account of loss in actual operating conditions.*
2.5	Air Conditioning Fan Systems	*SS 553 : 2015* *ASHRAE 90.1: 2013* *Non-domestic Building Services Compliance*	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. Airflow Rate for Reference Model (a) The airflow rate for the Reference Model shall be based on the auto-sizing function of the energy modeling software used.

		Guide 2013 Edition	(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 modeling software. For hotel guest room FCUs where the airflow rate simulated is less than that of the smallest FCU available in the market, the airflow rate of the proposed FCU can be adopted for the Reference Model. <u>Fan System Design Criteria</u> (c) For fan systems with a motor nameplate power ≥ 4 kW, the fan power limitation in air-conditioning system (the allowable fan system input power) shall be as follows: (i) Constant volume shall not exceed 1.5 kW/m^3/s (or 0.42 W/CMH + A) of supply air. Reference control strategy for CAV system shall be constant speed. (ii) Variable volume shall not exceed 2.1 kW/m^3/s (or 0.58 W/CMH + A) of supply air. *Note: Fan power limitation pressure drop adjustment is not applicable for the following devices:* - *Return and/or exhaust air systems* - *Return and/or exhaust airflow control devices* - *Exhaust filters or other exhaust treatment* - *Particulate Filtration Credit: MERV 9 – 14* *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 : 2015* (d) For fan system having a motor nameplate power < 4 kW, the allowable fan system input power shall be ≤ 0.6 kW/m^3/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 proposed fan can be applied to the Reference Model. <u>Part load fan power limitation</u> (e) The reference control strategy for VAV system shall come with VSD without exemption, applicable to all fans including small fan motors ≤ 7.4 kW. (f) Individual VAV fans with motors of ≥ 7.4 kW shall meet one of the following requirements: - Be driven by an electrical variable speed drive. - 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. - 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. 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)
2.6	Mechanical Ventilation Fan Systems	*SS 553 : 2015* *ASHRAE 90.1: 2013* *Non-domestic Building Services Compliance Guide 2013 Edition*	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. <u>Fan system design criteria</u> (a) Mechanical ventilation systems having a total fan system power ≥ 4kW shall refer to *SS 553 : 2015, Table 8 – Fan Power Limitation in Mechanical Ventilation Systems.* (a) Reference fan power limitation for mechanical ventilation system shall be constant volume type and the fan system input shall not exceed 0.3 W/CMH + A. *Note: The fan power limitation pressure drop adjustment is not applicable for the following devices:* - *Exhaust air systems* - *Exhaust airflow control devices* - *Exhaust filters* *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 clean room, and hospital. There is no exception to the Reference Model for cases when proposed fan power exceeds the baseline power limitation.* (b) For fan system with a motor nameplate power < 4 kW, the allowable fan system input power shall not exceed 0.6 kW/m3/s (or 0.17 W/CMH) of supply air. For cases where the proposed fan power exceeds the reference power limitation, the energy consumption of the proposed fan can be applied to the Reference Model.
2.7	Design Airflow Rates	*ASHRAE 90.1:2013 Section G3.1.2.9.1*	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	*ASHRAE 90.1:2013 Section 6.5.7.2*	Buildings with laboratory exhaust systems having a total exhaust rate greater than 2360 L/s should adopt at least one of the energy efficient features as stated in *ASHRAE 90.1 Section 6.5.7.2.*
2.9	Lighting Systems	*SS 530 : 2014* *ASHRAE 90.1:2013*	(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 : 2014, Table 7A- Maximum Building Interior Lighting Power Density for Compliance (Space-By Space Method).* Particularly, the maximum design lighting power (including ballast loss) for laboratories shall be 16W/m^2. The allowable lighting power density stated in *ASHRAE 90.1:2013* 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

<table>
<tr><td></td><td></td><td></td><td>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.</td></tr>
<tr><td>2.10</td><td>Hot Water generation</td><td>SS 530 : 2014

SS 553 : 2015</td><td>(a) For 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 SS 553, Section 8.14. The baseline for this case will be heat pump with COP of 3.2.</td></tr>
<tr><td>2.11</td><td>Energy Recovery Systems</td><td>SS 553 : 2015</td><td>(a) Exhaust air of 2.5 m^3/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 SS553, Section 8.14. The baseline for this case will be heat pump with COP of 3.2.</td></tr>
<tr><td>3</td><td>Others</td><td></td><td></td></tr>
<tr><td>3.1</td><td>Receptacle & Process loads</td><td>ASHRAE 2013 ASHRAE Fundamentals Handbook (SI)</td><td>In general, the receptacle value for both the Reference Model and proposed design shall be the same. Some default figures are as mentioned:

<table>
<tr><th>Receptacle Loads</th><th>Standard</th><th>Nominal Values</th></tr>
<tr><td>a. Computer intensive offices
b. General office areas
c. Large conference areas
d. Server/ Computer rooms</td><td>Source: ASHRAE 90.1.2013</td><td>22.0 W/m^2
16.0 W/m^2
11 W/m^2
540.0 W/m^2</td></tr>
</table>

<u>Office Receptacle Loads</u>

Energy savings is allowed in the form of a lower W/m^2 for the proposed design (as compared to 16 W/m^2 for the Reference Model) if the project can commit to deliver lower receptacle density at verification. The project team must provide a green lease, dedicated energy meters and tenant engagement programme as evidences for Green Mark assessment.

<u>Data Centres</u>

Energy consumed by data centres must be included as receptacle loads in the model. The scope and the calculation methodology must take reference from the BCA-IDA Green Mark for New Data Centre Criteria. The PUE of data centres must be ≤ 2. The building owner is encouraged to apply for the BCA-IDA Green Mark for New Data Centre scheme if the share of the energy consumed by the data centre is substantial compared to the building's total energy consumption.

<u>Laboratories</u>

Project could take reference from the receptacle load values stated in the ASHRAE Fundamentals Handbook (SI) or other international recognised guides with diversity and should consider existing measured data.</td></tr>
</table>

3.2	Occupancy Rates		Same as proposed design
3.3	Operation Schedules		Same as proposed design
3.4	Indoor Thermal Comfort Conditions	*SS554 :2015 – Code of Practice for Indoor Air Quality for Air-conditioned Buildings*	Same as proposed design
3.5	Minimum Ventilation Rates	*SS 553 : 2015* *NFPA 45* *EPA*	Same as proposed design except for laboratories. For laboratories, baseline air change rate would be: • 8 ACH (Occupied) • 4 ACH (Non-occupied) The project team can propose values for specific usages based on international/ Singapore recognised guidelines.
3.6	Heat Exchanger		Same as proposed design
3.7	Lift and Escalator without Regenerative Drive		Same as proposed design Both the reference and proposed design baseline should incorporate A/C VVVF features.
3.8	Modeling Limitation or Simulation Program		Same as proposed design
3.9	Passive Design Features		For projects that demonstrate considerable efforts to reduce air-conditioning energy consumption, a cap of 3% of additional energy savings from passive design features over its Reference Model can be considered. For savings to be justified, design strategies that enhance the ventilation and thermal comfort of the designated non air-conditioned spaces must be demonstrated. A written justification detailing the design strategies used and evidences accompanied with simulation and/or calculation of the energy saving estimate would be required for evaluation. <u>Examples</u> • Circulation spaces such as atria, can be considered if these spaces are largely designed to be non-air-conditioned and sizeable. This is not applicable to areas that would normally be non-air-conditioned, such as warehouses, school classrooms and pantries. • The introduction of air well or slopes to convert a mechanical ventilated car park to a code compliant natural ventilated car park is also acceptable. However, open air naturally ventilated carparks cannot be considered for energy savings.
4.0	Renewable Energy		Energy generated from renewable sources, such as solar photovoltaic (PV) systems, could be used to offset the 25% and 30% energy savings requirement for Gold^{PLUS} and Platinum projects respectively, up to a

			maximum of 3% energy savings against the annual energy consumption from the Reference Model. For example, if a project has annual energy consumption of 100 MWh simulated from the Reference Model and 72 MWh from the Proposed Model, the project can attain 28% energy savings. However, if it has solar PV installed to produce 2 MWh annually, it could offset a further 2% of the energy savings. This brings its total energy savings to 30%.

Note:
Where there is no baseline standard for certain energy related features such as chilled beams, underfloor air distribution systems, receptacle loads, lifts and escalators, hot water systems, reference can be made to ASHRAE 90.1:2013 Appendix G. For buildings with special requirements where there is no reference based on ASHRAE 90.1:2013 Appendix G, the baseline set for similar building type completed after 2005 can be considered. Detailed calculations must be provided to justify the savings in energy consumption from the use of salient energy efficient features /equipment. Where justification cannot be provided, the same input parameters for good design practice shall apply to both the Reference and Proposed Model.

(ii) Default Chiller Efficiency Curve

The default Chiller Curve and Chiller Configuration, references to *SS 530 : 2014, AHRI 551/591, Path A, Full Load Conditions*. The standard rating conditions are based on chilled water entering temperature at 7.0°C, chilled water leaving temperature at 12.0°C, condenser water entering temperature at 30.0°C and condenser water leaving temperature at 35.0°C. The default part load performance curves below are provided in DOE 2.2 and IESVE software 2014 which are compliant with California's TM24 requirement:

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

Energy Modeling Methodology

The simulation model of the Proposed Model, as well as the Reference Model shall be:

(a) Developed in accordance with the design parameters of the building. This includes:

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

(b) Calculated using the same:

- Software
- Weather data: Appropriate up-to-date weather set should be used for energy modeling such as ASHRAE's International Weather for Energy Calculation data for Singapore.
- Operating schedules
- Occupancy rates
- Building design in terms of shape, size and orientation
- Receptacle loads (exception for office, see *3.1* under Table 1 for requirements)
- Indoor environmental conditions in terms of thermal comfort level: If 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.
- Internal illuminance levels (lux) for space lightings

(c) Based on the overall energy consumption computed over a period of 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 (e.g. water pumps, cooling towers, tube cleaning devices, chillers, etc.), and non-ACMV systems such as lighting, lifts, escalators, ceiling fans and receptacle loads from equipment (e.g. photo-copiers, printers, fax machines, computers, laptops, fridges, projectors, audio-cum video systems, water heaters, dryers, washers, etc.).

The basis for deriving the overall energy consumption and potential energy savings must be made clear and justifiable for consideration. Notwithstanding this, the potential energy savings for the following systems/devices shall be capped as follows:

List of Systems/Devices	Cap on Energy Savings Devices
Escalator	30%
Lift with regenerative features	18%
CO Sensors	15%
Occupancy sensors	15%
Photo sensors	15%
Renewable energy (e.g. solar energy)	3%

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

Calculation of Energy Efficiency Index (EEI) and Energy Use Intensity (EUI)

The normalised EEI based on the proposed model result shall be computed using the formula:

$$EEI_{Normalised,model} = \frac{TBEC - DCEC - CPEC}{GFA - DCA} \times \frac{NF}{OH}$$

The EEI shall be computed as follows:

$$EEI_{model} = \frac{TBEC - DCEC - CPEC}{GFA - DCA}$$

The building overall EUI, excluding car park shall be calculated as follows:

$$EUI_{model} = \frac{TBEC - CPEC}{GFA}$$

The car park EUI shall be calculated as follows

$$EUI_{Carpark,model} = \frac{CPEC}{CPFA}$$

TBEC: Total building energy consumption (kWh/year)
DCEC: Data centre energy consumption (kWh/year)
CPEC: Car park energy consumption (kWh/year)
CPFA: Total floor area for car park (m^2)
DCA: Data centre areas (m^2)
GFA: Gross floor area (m^2)
OH: Weighted weekly operating hours (hours/week)
NF: Normalising factor based on typical weekly operating hours of the following building types:
Office: 55 hours/week
Retail: 84 hours/week
Hotel and Industrial: 168 hours/week
Institutions: 60 hours/week
Carpark: 168 hours/week

Documentation Requirements

(A) Design Stage

The name and company of the Energy Modeling consultant, details of software used and its limitations, building type and complexity shall be submitted to BCA. The *Energy Modeling Form for Green Mark Scheme (Finalisation of Building Design)* following shall be submitted, of which the template may be found at the following link: *http://www.bca.gov.sg/GreenMark/others/Energy_Modelling_Form_Template_(GM_NRB2015).doc*

The Qualified Person (QP) and the appropriate practitioners shall certify that the energy modeling for the building has been carried out in accordance with the requirements using the energy modeling methodology. The appropriate practitioner shall ensure that the assumptions and inputs used for energy modeling are bona fide. The energy modeling specialist shall certify and be responsible for the correctness of the modeling included proper usage of the relevant software.

The QP and the appropriate practitioners shall ensure the following documents and records are available as evidences to demonstrate compliance with the energy modeling framework and validation of the potential energy savings during final assessment. They are:

(a) Certification showing that the simulation software is tested and meet the criteria in accordance with the ANSI/ASHRAE Standard 140

(b) Detailed drawings and other necessary information of proposed design

(c) Detailed system design calculation

(d) Summary of Space and Envelope Thermal Transfer Value (ETTV) of the Building Envelope as in *Energy Modeling Form for Green Mark Scheme (Finalisation of Building Design)*

(e) List of data such as:

- Space input data for all zones comprising detail 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, receptacles loads, outdoor ventilation rates, misc. loads etc.). Schedules for each individual operating zone (e.g. lighting, occupants, mechanical fans, AHUs, other mechanical and electrical equipment, etc.)

- Executable input data files used in the generation of the energy estimates for the Proposed and Reference Models
- 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.)
- 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 vs Time
- Detailed computation of the ETTV for both Reference and Proposed Models
- Comparison of Reference Model versus Proposed Model as in Form: Energy Modeling Form (Finalisation of Building Design)
- Summary of Energy of End Use including Efficiency Indicators for both Reference and Proposed Models as in *Energy Modeling Form (Finalisation of Building Design)*
- Summary printouts of energy modeling software for the Reference Model including summary of weather data results Monthly energy consumption of mechanical and electrical system components such as air-conditioned system, lighting systems, receptacle equipment's, lift and escalator etc.
- Assumptions and limitations in modeling with rectifications

(f) Executable file of the EM simulation for both the Proposed and Reference Models

(g) Recommendations (if any)

(B) Verification Stage 2

For Gold^{PLUS} and Platinum projects, when the building starts to operate in a steady state, the developer shall within 2 years after TOP, commence to gather data on actual site operation for the next 12 months period. Appropriate and adequate power meters shall be installed to measure and record the breakdown on the energy consumption from the utilities bills. Sub-meters are required to capture the annual consumption of data centre and car park lighting and mechanical ventilation. Separate meters shall be provided during design stage to record the annual energy consumption generated by renewable energy e.g. solar photovoltaic (PV) and energy savings claimed by energy saving devices, e.g. escalators, lifts, CO sensors and occupancy sensors and photo sensors. Adequate meters shall be installed to data log and monitor and extract the necessary information, e.g. monthly and annual energy generated (kWh) from the Solar PV. Dedicated meters shall be installed to measure the operational energy consumption and intensities of receptacle load (W/m^2) of office space to verify on the energy savings claimed in energy modeling. Using the data on actual site operation, a revised energy modeling shall be performed to compare the annual energy consumption of the Reference Model with the actual consumption of the building.

The project developer or building owner shall submit a Stage 2 Verification Audit Report of at least, but not be limited to, the following content:

a) Form for *Energy Modeling Form for Green Mark Scheme (Validation After Project Completion)* - the template may be found at the following link:
http://www.bca.gov.sg/GreenMark/others/Energy_Modelling_Form_Template_(GM_NRB2015).doc
b) Electricity bills: Building landlord/ tenants/ DCS company bills for 12 months if applicable. Building cooling provision from DCS company (Path A and Path B) shall provide energy efficiency information (kW/RT) of the plant to facilitate the computation of EEI and EUI of the customer building. Monthly bills paid to DCS company shall be provided to facilitate EEI and EUI computation at verification stage.
c) Energy Audit (GM NRB: 2015) Report (the template may be found the following link: http://www.bca.gov.sg/GreenMark/others/Energy_Audit_Report_(GM_NRB2015).doc)
d) As-built electrical single-line schematics drawings
e) Description of deviations of the building operations to the Proposed Energy Model which was submitted for Green Mark Certification e.g. monthly building occupancy rate, receptacle loads, data centre addition etc.
f) BMS data log for the individual energy end use as in the actual energy breakdown under the Form for Energy Modeling for Green Mark Scheme (Validation After Project Completion); kWh raw data in softcopy Microsoft Excel file format and categorized according to the meters as-built schematics design.
g) Temporary logging of energy end use as in Form for Energy Modeling for Green Mark Scheme (Validation After Project Completion); kWh raw data in softcopy Microsoft Excel file format.
h) Data Centre Monthly Energy Consumption - kWh raw data in softcopy (if applicable).
i) BMS data log and monitoring of monthly and annual energy generated (kWh) from renewable energy
j) For actual building operations, state:
    (i) Operation hours for the spaces using the cooling load profiles
    (ii) Operation of chiller plant
    - Operating hours
    - Installed capacity
    - Duty and standby
    - Latest 1- week building cooling load
    - Latest 1-week chiller plant efficiency profile
    (iii) Operation hours of other air-con systems e.g. unitary system for after office hours cooling demand
    - Spaces with after office hours demand

(iv) Human load schedules
(v) Lighting schedules

k) EEI and EUI Calculation
(i) The operational hours of the building and car park
(ii) Area of the car park
(iii) EUI information must tally with submission to BCA BESS system.

l) For Reference Energy Model, state:
(i) Operation hours for the spaces (Must be similar to actual operation)
(ii) Operation of chiller plant
- Capacity and configuration in simulation
- Simulated 1- week building cooling load
- Simulated 1-week chiller plant efficiency profile
(iii) Operation hours of other air-con systems e.g. unitary system for after office hours cooling demand (Must be similar to actual operation)
- Spaces with after office hours demand
(iv) Human load schedules (Must be similar to actual operation)
(v) Simulation file in softcopy

A project will have deemed to have met the pre-requisite where the key energy consuming components are operating to their designed efficiencies. A calibrated reference model shall not be required except for circumstances including:

(a) A significant discrepancy in comparison with the energy model results
(b) Change of primary use
(c) A change of functional area distribution
(d) Changes in equipment specifications and performance
(e) Changes in GFA
(f) Change in ventilation modes

Guidance Notes

To assist in the generation of satisfactory results from the energy modeling simulation, the EM consultant should adhere to the following self-assessment checklist before the energy modeling assessment.

Checklist Item	Notes
A. **Overview**	1) Verify if Energy Modeling is required. 2) Verify the key performance indicators (KPI) a. EEI b. W/m^2 c. kW/RT
B. **Input Checks (for both proposed and reference model)**	1) General Setting a. Weather b. Elevation c. Orientation d. Area summary (discrepancies within 5%)

	2) Façade a. Select at least 3 areas to verify façade selection b. Construction c. SC value of glass and U-Value of walls and windows. 3) Thermal Zoning 4) HVAC design a. Typical space W/m^2 and whole building W/m^2 b. Cooling load profile c. Cooling system • Compressor (e.g. chiller if applicable) • Condenser (e.g. cooling tower if applicable) • Pumps (if applicable) • Overall and individual efficiency (kW/RT) d. Air distribution (baseline - provide oversizing factor) • Individual W/CMH • Typical CMH/m^2 and whole building CMH/m^2 • Overall air distribution kW/RT e. Overall – Provide unmet hours (Should not exceed 300 unmet hours) 5) Lighting 6) Receptacle load 7) MV fans 8) Schedule and diversity (including non-A/C areas like car park) 9) Energy saving items, eg heat recovery 10) Non-modelled items by alternative calculation
C. Output checks	1) Indoor thermal parameters for three typical indoor spaces 2) Daily, weekly, and monthly building cooling load 3) Energy breakdown proportion
D. Consistency checks	1) Proposed model and reference model consistency 2) Input data and output data consistency 3) Assumption verification 4) Exception calculation method

Appendix E

ENERGY MODELING METHODOLOGY AND REQUIREMENTS

E1 General

The energy modeling for evaluating the energy performance of a building shall be carried out in a prescribed manner to quantify the potential savings based on energy efficiency measures and improvements that reduce cooling load requirement over the Reference Model.

E2 Simulation Software

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

(a) It must have the capability to model the thermal performance of buildings in a mult-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 with ANSI/ASHRAE Standard 140 – Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs or other equivalent standard.

E3 Reference Model

The simulation model for calculating the baseline building performance (known as Reference Model) shall be developed in accordance with the requirements in the following Table E3.

Table E3 – Baseline Standard

<table>
<tr><th>S/No.</th><th>Component</th><th>Baseline Standard</th><th>Minimum Requirement</th></tr>
<tr><td>1</td><td colspan="3">Building Description</td></tr>
<tr><td>1.1</td><td>Building Envelope Design</td><td>BCA Approved Document
Code on Envelope Thermal Performance for buildings</td><td>(a) ETTV shall not exceed 50 W/m^2
(b) For roof with skylight, RTTV shall not exceed 50 W/m^2
(c) For roof without skylight, the average U value of the gross area of the roof shall not exceed the limit below :
Maximum Thermal Transmittance for Roof of Air-Conditioned Buildings
<table>
<tr><th>Weight Group</th><th>Weight range (kg/m^2)</th><th>Maximum Thermal Transmittance (W/m^{2}k)</th></tr>
<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>
</table>
(d) All windows on the building envelope shall not exceed the air leakage rates specified in SS 212 – Specification for Aluminium Alloy Windows.
(e) Where the door opening of any commercial unit is located along the perimeter of the building envelope, that unit shall : -
(i) be completely separated from the other parts of the building; and
(ii) has its air-conditioning system separated from and independent of the central system.</td></tr>
</table>

<table>
<tr><th>S/No.</th><th>Component</th><th>Baseline Standard</th><th>Minimum Requirement</th></tr>
<tr><td>1</td><td colspan="3">Building Description (cont'd)</td></tr>
<tr><td>1.2</td><td>Building Shape, Size and Configuration</td><td></td><td>Reference model to be the same as proposed model</td></tr>
<tr><td>1.3</td><td>Building Zoning & Thermal Block</td><td></td><td>Reference model to be the same as proposed model.

Zoning of air-conditioned and non-air conditioned areas shall be modeled based on the approved building plan except for floor areas that conform to the provisions for Passive Design Enhancement to reduce air-conditioned spaces. (Refer to Para 3.7 for more details)

Where ACMV zones are defined on the ACMV design drawings, each ACMV zone shall be modeled as a separate thermal block.</td></tr>
<tr><td>2</td><td colspan="3">System Description</td></tr>
<tr><td>2.1</td><td>Air-conditioning and Mechanical Ventilation (ACMV) System Types</td><td></td><td>(a) Reference system to be used will be based on the peak building cooling load :

(i) For buildings with peak building cooling load of 500 RT or more, the reference system will be centrifugal chiller.

(ii) For buildings with peak building cooling load of less than 500RT, the reference system will be screw chiller.

(iii) For buildings with peak building cooling load of less than 500RT and the air-conditioned floor areas is less than 5000 m^2, the reference system will be of the same type as the proposed system. For VRV system, the baseline COP of 3.37 shall be adopted.

(b) For buildings with cooling provision from a District Cooling System (DCS) supplier that is authorised by a licence to carry out all or any of the functions of providing district cooling services to the services areas.

(i) the energy consumption contribution from DCS plant may be excluded in the energy modeling

(ii) all ACMV components dedicated to the building designed shall be included and considered

(iii) the following two criteria are to be complied with
<table>
<tr><th>S/No.</th><th>Criteria</th><th>Gold^{Plus}</th><th>Platinum</th></tr>
<tr><td>1</td><td>Cooling Load Savings</td><td>10%</td><td>15%</td></tr>
<tr><td>2</td><td>Energy Consumption Savings (exclude air-conditioned plant) and from energy efficiency improvements that reduce the cooling load requirement</td><td>27%</td><td>33%</td></tr>
</table></td></tr>
<tr><td>2.2</td><td>Chiller Efficiency</td><td>SS 530: 2006 – Code of Practice for Energy efficiency Standard for Building Services and Equipment</td><td>Minimum energy efficiency standard stated in SS 530</td></tr>
</table>

S/No.	Component	Baseline Standard	Minimum Requirement
2	*System Description (cont'd)*		
2.3	Air-Conditioning Hydronic Systems	SS 553 : 2009 – Code of Practice for Air-conditioning and Mechanical Ventilation in Buildings	<u>Pumping system design criteria</u> 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^3/s. The pump power limitation for condensing water systems is 301 kW/m^3/s. Motors exceeding 15 kW shall have controls/ and/or devices that will result in pump motor demand of no more than 30% of design wattage at 50% of design water flow.
2.4	Cooling Tower	SS 530 : 2006 – Code of Practice for Energy Efficiency Standard for Building Services and Equipment	Performance requirement for heat rejection equipment. <u>*Propeller or axial fan cooling towers*</u> Cooling Tower performance shall not be less than 3.23 L/s/kW. <u>*Centrifugal fan cooling towers*</u> Cooling Tower performance shall not be less than 1.7 L/s/kW.
2.5	Air Conditioning Fan Systems	ASHRAE 90.1:2010 – Energy Standard for Buildings Except Low-Rise Residential Buildings Non-domestic Building Services Compliance Guide 2010 Edition SS 553:2009– Code of Practice for Air-conditioning and Mechanical Ventilation in Buildings	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 allowable fan system power. <u>Fan System design criteria</u> (a) For fan system having a motor nameplate power exceeding 4 kW, the fan power limitation in air-conditioning system that is the allowable fan system input power shall be as follows : (i) Constant volume shall not exceed 1.5 kW/m^3/s (or 0.42 W/CMH) of supply air (ii) Variable volume shall not exceed 2.1 kW/m^3/s (or 0.58 W/CMH) of supply air (b) For fan system having a motor nameplate power not exceeding 4 kW, the allowable fan system input power shall not exceed 0.6 kW/m^3/s (or 0.17 W/CMH) of supply air. <u>Part load fan power limitation</u> (c) Individual VAV fans with motors 11 kW and larger shall meet one of the following requirements: (i) Be driven by a mechanical or electrical variable speed drive or the fan shall be vane-axial fan with variable pitch blades; (ii) 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 setpoint equals one-third of the total design static pressure based on manufacturer's certified fan data.

<table>
<tr><th>S/No.</th><th>Component</th><th>Baseline Standard</th><th>Minimum Requirement</th></tr>
<tr><td>2</td><td colspan="3">System Description (cont'd)</td></tr>
<tr><td>2.6</td><td>Mechanical Ventilation Fan Systems</td><td>ASHRAE 90.1:2010 – Energy Standard for Buildings Except Low-Rise Residential Buildings

Non-domestic Building Services Compliance Guide 2010 Edition

SS 553 : 2009 – Code of Practice for Air-conditioning and Mechanical Ventilation in Buildings</td><td>The ratio of fan system to the supply fan air flow rate (main fan) of each mechanical ventilation system at design conditions shall not exceed allowable fan system power.

<u>Fan system design criteria</u>

(a) For fan system having a motor nameplate power exceeding 4 kW, the fan power limitation in air-conditioning system that is the allowable fan system input power shall not exceed 1.5 kW/m^3/s (or 0.42 W/CMH) of supply air

(b) For fan system having a motor nameplate power not exceeding 4 kW, fan system input power shall not exceed 0.6 kW/m^3/s (or 0.17 W/CMH) of supply air.

<u>Part load fan power limitation</u>

(c) Individual VAV fans with motors 11 kW and larger shall meet one of the following requirements:

(i) Be driven by a mechanical or electrical variable speed drive or the fan shall be vane-axial fan with variable pitch blades;

(ii) 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 setpoint equals one-third of the total design static pressure based on manufacturer's certified fan data.</td></tr>
<tr><td>2.7</td><td>Lighting Systems</td><td>SS530: 2006 – Code of Practice for Energy Efficiency Standard for Building Services and Equipment

The allowable lighting power density stated in ASHRAE 90.1:2010 can be considered if the lighting power budget for the types of usage are not made available in SS 530</td><td>Maximum lighting power budget stated in SS 530 - Table 7 and as prescribed below :

<table><tr><th>Type of Usage</th><th>Maximum Lighting Power Budgets (W/m^2)</th></tr><tr><td>Hotel guestroom</td><td>15 W/m^2 (including decorative and task lighting)</td></tr><tr><td>Hotel Lobby</td><td>10 W/m^2 (including reception lobby, lift lobby and lounge)

15 W/m^2 (for localized areas with special lighting). However, the overall baseline for energy modeling remains as 10 W/m^2</td></tr></table></td></tr>
</table>

S/No.	Component	Baseline Standard	Minimum Requirement
2	*System Description (cont'd)*		
2.8	Water Heaters	SS530:2006 – Code of Practice for Energy Efficiency Standard for Building Services and Equipment	Water heating equipment efficiency and performance stated in SS 530
2.9	Energy Recovery Systems	SS 553:2009 – Code of Practice for Air-conditioning and Mechanical Ventilation in Buildings	Energy recovery from conditioned space exhaust air Exhaust air of 2.5m^3/s or greater from conditioned space in a single location shall have energy recovery system with at least 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 ARI Standard 1060
3	*Others*		
3.1	Receptacle & Process loads		Same as proposed design
3.2	Occupancy Rates		Same as proposed design
3.3	Operation Schedules		Same as proposed design
3.4	Indoor Thermal Comfort Conditions	SS554 :2009 – Code of Practice for Indoor Air Quality for Air-conditioned Buildings	Same as proposed design
3.5	Minimum Ventilation Rates	SS 553 : 2009 – Code of Practice for Air-conditioning and Mechanical Ventilation in Buildings	Same as proposed design
3.6	Modeling Limitation or Simulation Program		Same as proposed design
3.7	Passive Design Enhancement		For projects that demonstrate considerable efforts to reduce air-conditioned spaces, a cap of 2% additional energy savings over its referenced model can be considered. This would not apply to areas that would normally be non air-conditioned such as warehouses, carparks, school classrooms, staircases, toilets and pantries. Circulation spaces such as atria, plaza and corridors can be considered if these spaces are largely designed to be non air-conditioned and sizeable. For savings to be justified, design strategies that enhance the ventilation and thermal comfort of the designated non air-conditioned spaces must be demonstrated. A written justification detailing the design strategies used and the energy saving estimate would be required for evaluation.

Important notes :

1. Where there is no baseline standard for certain energy related features such as such as chilled beams, underfloor air distribution systems, receptacle loads, lifts & escalators, hot water systems, the following shall apply :

   (a) Reference can be made to ASHRAE 90.1:2010 Appendix G.

   (b) For buildings with special requirements where there is no reference based on ASHRAE 90.1:2010 Appendix G, the baseline set for similar building type completed after 2005 can be considered.

   (c) Detailed calculations to be provided to justify the savings in energy consumption from the use of salient energy efficient features /equipment. Where justification could not be provided, the same input parameters for good design practice shall apply to both the Reference and Proposed Models.

2. For receptacle loads, Table A below is for reference.

Table A: Receptacle Loads	Standard	Nominal Values
a. Computer intensive offices	Source:-	22.0 W/m^2
b. General office areas	ASHRAE STD	16.0 W/m^2
c. Large conference areas	90.1:2010	11.0 W/m^2
d. Server/Computer rooms		540.0 W/m^2

E4 Energy Modeling Methodology

E4.1 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 equipments, controls and other associated components selected for use in the building.

E4.2 The Reference Model shall be developed using similar data as stated in paragraph E4.1.

E4.3 The simulations for the Proposed Model and Reference Model shall be calculated using

(i) the same software
(ii) the same weather data[1]
(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[2], and
(viii) the same internal illuminance levels (lux) for space lightings

E4.4 The overall energy consumption of the Reference Model is 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 (eg. 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 (eg. photo-copiers, printers, fax machines, computers, laptops, fridges, projectors, audio-cum video

[1] Appropriate up-to-date weather set should be used for energy modeling such as ASHRAE's International Weather for Energy Calculation data for Singapore.

[2] If 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.

systems, water heaters, dryers, washers, etc). Similarly, the overall energy consumption of the Proposed Model can be computed over a period of one (1) year.

E4.5 The basis for deriving the overall energy consumption and potential energy savings must be made clear and justifiable for consideration. Notwithstanding this, the potential energy savings for the following systems/devices are subject to the cap based on the following norm.

List of Systems/Devices		Energy Savings Cap
Escalator		30%
Lifts	With VVVF and Sleep mode	10%
	Regenerative features	18%
CO sensors		15%
Occupancy Sensors		15%
Photo Sensors		15%

E4.6 The improved performance of the proposed building design can then be obtained by making comparison of the overall energy consumption of the Reference Model against the Proposed Model.

E4.7 The normalized Energy Efficiency Index for both the Proposed and Reference Models shall also be computed. The details are as follows :

Calculation of EEI :

EEI = [(TBEC - DCEC) / (GFA – DCA)] x (NF/OH)

where:

(a) TBEC : Total building energy consumption (kWh/year)
(b) DCEC : Data centre energy consumption (kWh/year)
(c) GFA : Gross floor area (for info, carpark areas not included) (m^2)
(d) DCA : Data centre areas (m^2)
(e) NF : Normalising factor based on typical weekly operating hours that is 55 hrs/week
(f) OH : Weighted weekly operating hours (hrs/week)

Reference : [1] NUS Centre for Total Building Performance:
http://www.bdg.nus.edu.sg/buildingenergy/e_energy/audit_results.html

E5 Documentation Requirements

E5.1 The Qualified Person (QP) and the appropriate practitioners shall certify that the energy modeling for the building has been carried out in accordance with the requirements using the Energy Modeling methodology. The appropriate practitioner shall ensure that the assumptions and inputs used for energy modeling are bona fide. Whilst the energy modeling specialist shall certify and be responsible for the correctness of the modeling included proper usage of the relevant software.

E5.2 The QP and the appropriate practitioners shall ensure the following documents and records are available as evidences to demonstrate compliance with the energy modeling framework and validation of the potential energy savings during assessment. They are :

(a) Certification showing that the simulation software is tested and meet the criteria in accordance with the ANSI/ASHRAE Standard 140

(b) Detailed drawings and other necessary information of proposed design

(c) Detailed system design calculation

(d) Summary of Space and Envelope Thermal Transfer Value (ETTV) of the Building Envelope as in Table E5.2-1(a) and Table E5.2-2(a)

(e) List of data such as

(i) Space input data for all zones comprising detail 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, receptacles loads, outdoor ventilation rates, misc. loads etc)

(ii) Schedules for each individual operating zone (eg. 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 (eg. 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.

(f) Detailed computation of the ETTV for both Reference and Proposed Models

(g) Comparison of Reference Model versus Proposed Model as in Table E5.2-1(b)

(h) Summary of Energy of End Use including Efficiency Indicators for both Reference and Proposed Models as in Table E5.2-1(c) and Table E5.2-2(b).

(i) Summary printouts of energy modeling software for the Reference Model including summary of weather data results

(j) Monthly energy consumption of mechanical and electrical system components such as air-conditioned system, lighting systems, receptacle equipments, lift and escalator etc.

E5.3 Similar documentation requirements as above will also be required to reflect the as-built condition upon project completion for validation.

Table E5.2-1(a) Summary of Space and ETTV of the Building Envelope

(A) Space Summary			
Building Use	Air-Conditioned Area (m^2)	Non Air-Conditioned Area (m^2)	Total Area (m^2)
1. Office	1897.5942		
2. Toilets	85	25.5090	
3. Storage			
4. Corridor	89.0037		
5. Atrium			
6. Foodcourt			
7. Mechanical / Electrical		85.3/14/9=769.63	
8. Staircase			
9. Conference			
10.Retail Outlets			
11.Carpark			
12. Others		80.5673×9= 725.0607	
Total			
Note: The building use 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^2)	Reference Model ETTV (W/m^2)	Proposed Model ETTV (W/m^2)
North			
North-East			
East			
South-East			
South			
South-West			
West			
North-West			
Average ETTV of the Building Envelope (W/m^2)		50 W/m^2	

Table E5.2-1(b) Comparison of Reference Model versus Proposed Model

BUILDING ELEMENT	REFERENCE MODEL	PROPOSED MODEL
BUILDING ENVELOPE		
Wall Construction		
Opaque Doors		
Windows		
Floor		
Roof		
Window to Wall Ratio (WWR)		
Others		
ELECTRICAL SYSTEMS		
Lighting Power Density (W/m^2)		
Lighting Occupant Sensor Controls		
Lighting Daylighting Controls		
Receptacle Power (W/m^2)		
Lifts & Escalators		
Others		
Note: The Receptacle Loads for both the Reference and Proposed Models must be the same.		
RENEWABLE ENERGY SYSTEMS		
Photovoltaics		
Note: To include a description of renewable energy systems used to reduce Proposed Model energy consumption.		

BUILDING ELEMENT	REFERENCE MODEL	PROPOSED MODEL
SCHEDULES		
Occupancy, Lighting & Equipment		
HVAC		
Note: The Occupancy Rates and Operating Schedules for both the Reference and Proposed Models must be the same.		
MECHANICAL & PLUMBING SYSTEMS		
HVAC System Type		
AHU Fan Properties		
Boiler Efficiency		
Central Plant Efficiency		
Note: Central plant efficiencies and capacities for chillers and cooling towers shall be listed whenever the central plant is included as part of the energy model.		
HVAC Circulation Loop Properties		
Domestic Water System		
Mechanical Ventilation Fans		
OTHERS		

Description of differences between the Reference Model and Proposed Model not documented on other forms:

☐☐Not Applicable ☐ Attached

Table E5.2-1(c) : 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)			
[3]Air-Conditioned Plant			
[4]Air System Fans			
Mechanical Ventilation Fans			
Lifts			
Escalators			
Receptacle Equipment			
Domestic Water Systems			
Others			
Total Building Energy Consumption			

Note : The stipulated energy savings required to attain the Green Mark Gold^{Plus} and Platinum rating to be based on the savings derived from energy efficiency measures and improvements over its reference model as listed above.

Renewable Energy Sources

End Use	Energy Produced (kWh)	Reference Model Energy Consumption (kWh)	Proposed Building Energy Consumption (kWh)	Energy Consumption Savings (%)
Photovoltaics		Not Applicable		
Others				
Total Building Energy Consumption including Renewable Energy Sources				

Efficiency Indicators

Efficiency Indicators	Reference Model	Proposed Model
Energy Efficiency Index, EEI (kWh/m^2/yr)		
System Efficiency of Air-Conditioned Plant (ikW/kW)		

[3] Chilled Water System (chillers, water pumps and cooling towers)
[4] Chilled Water Air Handling and Fan Coil Units

Table E5.2-2(a) : Summary of Space and ETTV of the Building Envelope
(required if there is a change)

(A) Space Summary			
Building Use	Air-Conditioned Area (m^2)	Non Air-Conditioned Area (m^2)	Total Area (m^2)
1. Office			
2. Toilets			
3. Storage			
4. Corridor			
5. Atrium			
6. Foodcourt			
7. Mechanical / Electrical			
8. Staircase			
9. Conference			
10.Retail Outlets			
11.Carpark			
12. Others			
Total			
Note: The building use floor areas for both the Reference and Actual Models must be the same.			

(B) Building Envelope Summary – ETTV			
Orientation of Façade	Gross Area of External Walls (m^2)	Reference Model ETTV (W/m^2)	Actual Model ETTV (W/m^2)
North			
North-East			
East			
South-East			
South			
South-West			
West			
North-West			
Average ETTV of the Building Envelope (W/m^2)		50 W/m^2	

Table E5.2-2(b) : Summary of Actual Energy by End Use including Efficiency Indicators

End Use	Reference Model Energy Consumption (kWh)	Actual Building Energy Consumption (kWh)	Energy Consumption Savings (%)
Lighting – (Air-Conditioned Space)			
Lighting- (Non Air-Conditioned Space)			
[5]Air-Conditioned Plant			
[6]Air System Fans			
Mechanical Ventilation Fans			
Lifts			
Escalators			
Receptacle Equipment			
Domestic Water Systems			
Others			
Total Building Energy Consumption			
Note : The stipulated energy savings required to attain the Green Mark Gold[Plus] and Platinum rating to be based on the savings derived from energy efficiency measures and improvements over its reference model as listed above.			

Renewable Energy Sources

End Use	Energy Produced (kWh)	Reference Model Energy Consumption (kWh)	Actual Building Energy Consumption (kWh)	Energy Consumption Savings (%)
Photovoltaics		Not Applicable		
Others				
Total Building Energy Consumption including Renewable Energy Sources				

Efficiency Indicators

Efficiency Indicators	Reference Model	Actual Building Model
Energy Efficiency Index, EEI (kWh/m^2/yr)		
System Efficiency of Air-Conditioned Plant (ikW/kW)		

[5] Chilled Water System (chillers, water pumps and cooling towers)
[6] Chilled Water Air Handling and Fan Coil Units

Building and Construction Authority

CODE ON

ENVELOPE THERMAL PERFORMANCE

FOR

BUILDINGS

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GENERAL

1 Aim

The aim of this Code is to assist architects and professional engineers to comply with the envelope thermal performance standards prescribed in the Building Regulations.

2 Scope

This Code covers the following Envelope Thermal Performance Standards:

i. Envelope Thermal Transfer Value (ETTV) for air-conditioned non-residential buildings

ii. Roof Thermal Transfer Value (RTTV) for air-conditioned non-residential buildings (with skylight)

iii. Residential Envelope Transmittance Value (RETV) for residential buildings

iv. Roof insulation for air-conditioned non-residential buildings (without skylight) and residential buildings

3 Background

3.1. Since 1979, the Building Control Regulations had prescribed an envelope thermal performance standard know as Overall Thermal Transfer Value (OTTV). The OTTV standard applied only to air-conditioned non-residential buildings.

3.2. A major review of the OTTV formula was carried out in the early 2000 to provide a more accurate measure of the thermal performance of building envelope. The new formula is given the name 'Envelope Thermal Transfer Value' (ETTV) to differentiate it from the original OTTV formula.

3.3. A similar review of the OTTV formula for roof was also conducted and a new formula, known as 'Roof Thermal Transfer Value' (RTTV), replaces the Roof OTTV formula.

3.4. The ETTV requirement does not apply to non air-conditioned buildings such as residential buildings that are designed to be naturally ventilated. However, as it becomes increasingly common for residential buildings to be air-conditioned, there is a need to regulate the design of their envelopes so that heat gain into the interior spaces and hence air-conditioning energy used can be minimised.

3.5. Based on the results of a NUS study commissioned by BCA, the ETTV concept was extended in 2008 to cover residential buildings. As the air-conditioners in residential buildings are usually turned on in the night, the

envelope thermal performance standard for residential buildings is given the name Residential Envelope Transmittance Value (RETV) so as to differentiate it from ETTV, which is meant for buildings that operate the air-conditioning system during the day.

4 Envelope Thermal Transfer Value (ETTV)

4.1 The ETTV takes into account the three basic components of heat gain through the external walls and windows of a building. These are:

heat conduction through opaque walls,
heat conduction through glass windows,
solar radiation through glass windows.

4.2 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 the purpose of energy conservation, the maximum permissible **ETTV has been set at 50 W/m^2.**

5 Envelope Thermal Transfer Value (ETTV) Formula

5.1 The ETTV formula is given as follows:

$$ETTV = 12(1 - WWR)U_w + 3.4(WWR)U_f + 211(WWR)(CF)(SC)$$

where

ETTV	:	envelope thermal transfer value (W/m^2)
WWR	:	window-to-wall ratio (fenestration area / gross area of exterior wall)
U_w	:	thermal transmittance of opaque wall (W/m^2 K)
U_f	:	thermal transmittance of fenestration (W/m^2 K)
CF	:	correction factor for solar heat gain through fenestration
SC	:	shading coefficients of fenestration

5.2 Where more than one type of material and/or fenestration is used, the respective term or terms shall be expanded into sub-elements as shown:

$$ETTV = \frac{12(A_{w1} \times U_{w1} + A_{w2} \times U_{w2} + \ldots + A_{wn} \times U_{wn})}{A_o} + \frac{3.4(A_{f1} \times U_{f1} + A_{f2} \times U_{f2} + \ldots + A_{fn} \times U_{fn})}{A_o} + \frac{211(A_{f1} \times SC_{f1} + A_{f2} \times SC_{f2} + \ldots + A_{fn} \times SC_{fn})(CF)}{A_o}$$

where

A_{w1}, A_{w2}, A_{wn}	:	areas of different opaque wall (m^2)
A_{f1}, A_{f2}, A_{fn}	:	areas of different fenestration (m^2)
A_o	:	gross area of the exterior wall (m^2)
U_{w1}, U_{w2}, U_{wn}	:	thermal transmittances of opaque walls (W/m^2 K)

U_{f1}, U_{f2}, U_{fn} : thermal transmittances of fenestrations ($W/m^2 K$)
SC_{f1}, SC_{f2}, SC_{fn} : shading coefficients of fenestrations
CF : correction factor for solar heat gain through fenestration

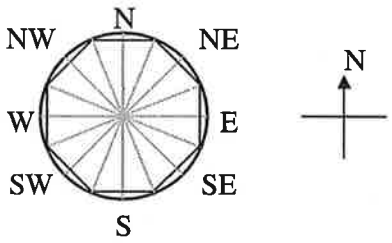
5.3 As walls at different orientations receive different amounts of solar radiation, it is necessary in general to first compute the ETTVs of individual walls, then the ETTV of the whole building envelope is obtained by taking the weighted average of these values. To calculate the ETTV for the envelope of the whole building, the following formula shall be used:

$$ETTV = \frac{A_{o1} \times ETTV_1 + A_{o2} \times ETTV_2 + \ldots + A_{on} + ETTV_n}{A_{o1} + A_{o2} + \ldots + A_{on}}$$

where
A_{o1}, A_{o2}, A_{on} : gross areas of the exterior wall for each orientation (m^2)

5.4 The solar correction factors for eight primary orientations of the walls have been determined for the Singapore climate. They are given in Table C1.

5.4.1 If the wall is curved, the eight primary orientations are segmented as follows:



6 Roof Thermal Transfer Value (RTTV)

6.1 If the roof of an air-conditioned building is provided with skylight, the ETTV concept is also applicable to its roof. To differentiate between the walls and the roof, the term Roof Thermal Transfer Value (RTTV) is used instead. Similarly, RTTV takes into consideration the three basic components of heat gain through the opaque roof and skylight. These are:

heat conduction through opaque roof,
heat conduction through skylight,
solar radiation through skylight.

6.2 The maximum permissible **RTTV has also been set at 50 W/m^2.**

7 Roof Thermal Transfer Value (RTTV) Formula

7.1 The RTTV formula is given as follows:

$$RTTV = 12.5(1-SKR)U_r + 4.8(SKR)U_s + 485(SKR)(CF)(SC)$$

where

RTTV : roof thermal transfer value (W/m^2)
SKR : skylight ratio of roof (skylight area / gross area of roof)
U_r : thermal transmittance of opaque roof (W/m^2 K)
U_s : thermal transmittance of skylight area (W/m^2 K)
CF : solar correction factor for roof
SC : shading coefficient of skylight portion of the roof

7.2 Similarly, when more than one type of material and or skylight is used, the respective term or terms shall be expanded into sub-elements, such as;

$$RTTV = \frac{12.5(A_{r1}\times U_{r1} + A_{r2}\times U_{r2} + ... + A_{rn}\times U_{rn})}{A_o} + \frac{4.8(A_{s1}\times U_{s1} + A_{s2}\times U_{s2} + ... + A_{sn}\times U_{sn})}{A_o} + \frac{485(A_{s1}\times SC_{s1} + A_{s2}\times SC_{s2} + ... + A_{sn}\times SC_{sn})(CF)}{A_o}$$

where

A_{r1}, A_{r2}, A_{rn} : areas of different opaque roof (m^2)
A_{s1}, A_{s2}, A_{sn} : areas of different skylight (m^2)
A_o : gross area of roof (m^2)

U_{r1}, U_{r2}, U_{rn} : thermal transmittances of opaque roofs ($W/m^2 K$)
U_{s1}, U_{s2}, U_{sn} : thermal transmittances of skylights ($W/m^2 K$)
SC_{s1}, SC_{s2}, SC_{sn} : shading coefficient of skylights

7.3 If a roof consists of different sections facing different orientations or pitched at different angles, the RTTV for the whole roof shall be calculated as follows:

$$RTTV = \frac{A_{o1} \times RTTV_1 + A_{o2} \times RTTV_2 + \ldots A_{on} \times RTTV_n}{A_{o1} + A_{o2} + \ldots + A_{on}}$$

where

A_{o1}, A_{o2}, A_{on} :gross areas of the roof for each section (m^2)

7.4 The solar correction factors for roof are given in Table C2.

RESIDENTIAL ENVELOPE TRANSMITTANCE VALUE (RETV)

8 Residential Envelope Transmittance Value (RETV)

8.1 The RETV is similar to ETTV in that it takes into consideration the three basic components of heat gain through the external walls and windows of a building. These are:

i. heat conduction through opaque walls,
ii. heat conduction through glass windows, and
iii. solar radiation through glass windows.

8.2 These three components of heat input are averaged over the whole envelope area of the building to give an RETV that represents the thermal performance of the whole envelope. For the purpose of energy conservation, the maximum permissible **RETV has been set at 25 W/m^2.**

9 Residential Envelope Transmittance Value (RETV) Formula

9.1 The RETV formula is given as follows:

$$RETV = 3.4(1-WWR)U_w + 1.3(WWR)U_f + 58.6(WWR)(CF)(SC)$$

where

RETV	:	residential envelope transmittance value (W/m^2)
WWR	:	window-to-wall ratio (fenestration area/gross area of exterior wall)
U_w	:	thermal transmittance of opaque wall (W/m^2 K)
U_f	:	thermal transmittance of fenestration (W/m^2 K)
CF	:	correction factor for solar heat gain through fenestration
SC	:	shading coefficients of fenestration

9.2 Where more than one type of material and/or fenestration is used, the respective term or terms shall be expanded into sub-elements as shown:

$$RETV = \frac{3.4(A_{w1}\times U_{w1} + A_{w2}\times U_{w2} + \ldots + A_{wn}\times U_{wn})}{A_o} +$$

$$\frac{1.3(A_{f1}\times U_{f1} + A_{f2}\times U_{f2} + \ldots + A_{fn}\times U_{fn})}{A_o} +$$

$$\frac{58.6(A_{f1}\times SC_{f1} + A_{f2}\times SC_{f2} + \ldots + A_{fn}\times SC_{fn})(CF)}{A_o}$$

where

A_{w1}, A_{w2}, A_{wn} : areas of different opaque walls (m^2)
A_{f1}, A_{f2}, A_{fn} : areas of different fenestrations (m^2)
A_o : gross area of the exterior wall (m^2)
U_{w1}, U_{w2}, U_{wn} : thermal transmittances of opaque walls ($W/m^2 K$)
U_{f1}, U_{f2}, U_{fn} : thermal transmittances of fenestrations ($W/m^2 K$)
SC_{f1}, SC_{f2}, SC_{fn} : shading coefficients of fenestrations

9.3 The external façades of the living, dining, study and bedrooms are considered in the RETV computation. As walls at different orientations receive different amounts of solar radiation, it is necessary in general to first compute the RETVs of individual walls, then the RETV of the whole building envelope is obtained by taking the weighted average of these values. To calculate the RETV for the envelope of the whole building, the following formula shall be used:

$$RETV = \frac{A_{o1} \times RETV_1 + A_{o2} \times RETV_2 + \ldots + A_{on} + RETV_n}{A_{o1} + A_{o2} + \ldots + A_{on}}$$

where
A_{o1}, A_{o2}, A_{on} : gross areas of the exterior wall for each orientation (m^2)

9.4 The solar correction factors for walls are given in Table C3. For an example of the orientation of the wall, please refer to section 5.4.1.

10 Deem-to-Satisfy Criteria for RETV

10.1 Should the building's WWR and SC[1] fall within any one of the following sets of criteria, the building is deemed to have complied with RETV and; hence, is exempted from computing RETV.

$WWR_{Bldg} < 0.3$ and $SC^1_{facade} < 0.7$
or
$WWR_{Bldg} < 0.4$ and $SC^1_{facade} < 0.5$
or
$WWR_{Bldg} < 0.5$ and $SC^1_{facade} < 0.43$

where
WWR : Window to wall ratio
SC : Shading coefficient of fenestration = SC_{Glass} X $SC_{shading\ device}$
Note: This is applicable to buildings with external masonry walls.

[1] Each SC of the facade must not exceed the prescribed value.

Otherwise detailed RETV computation is required.

ROOF INSULATION FOR AIR-CONDITIONED NON-RESIDENTIAL (WITHOUT SKYLIGHT) AND RESIDENTIAL BUILDINGS

11 Thermal Transmittance of Roof

11.1 Solar heat gain into a building through an uninsulated roof increases air temperature indoor. In all buildings, directional radiation received on the roof can be one of the main causes of thermal discomfort.

11.2 For an air-conditioned building, solar heat gain through the roof also constitutes a substantial portion of the cooling load. From on-site solar radiation measurements taken in Singapore, the intensity of radiation on a horizontal surface can be as much as 3 times of that on a vertical surface.

11.3 The purpose of roof insulation is therefore to conserve energy in airconditioned buildings. The building regulations require that the average thermal transmittance (U-value) for the gross area of the roof shall not exceed the limit in the Table C4 for the corresponding weight group.

11.4 If the roof of an air-conditioned non-residential building is provided with skylight then RTTV computation is required.

APPENDIX A
THERMAL TRANSMITTANCE (U-VALUE) CALCULATION

A1 Thermo-Physical Properties of Building Materials

A1.1 Thermal conductivity (k-value)

The ability of a material to transmit heat is measured by its thermal conductivity or k-value. The k-value of a material is defined as the quantity of heat transmitted under steady-state conditions through unit area of the material of unit thickness in unit time when unit temperature difference exists between its opposite surfaces. It is expressed in W/m K. Table C5 gives the k-values of some commonly used building materials.

A1.2 Thermal resistivity (r)

The thermal resistivity of a material is the reciprocal of its thermal conductivity, i.e.

$$r = \frac{1}{k}$$

It may be defined as the time required for one unit of heat to pass through unit area of a material of unit thickness when unit temperature difference exists between opposite faces. It is expressed as m K/W.

A1.3 Thermal conductance (C)

Thermal conductance refers to specific thickness of a material or construction. It is the thermal transmission through unit area of a material per unit temperature difference between the hot and cold faces. It is expressed in W/m^2 K and is given by:

$$C = \frac{k}{b}$$

where b is the thickness of the material (m)

A1.4 Thermal resistance (R)

The thermal resistance of a material or construction is the reciprocal of its thermal conductance. It refers to the thermal resistance of any section or assembly of building components and is particularly useful in computing the overall transfer of heat across the building section. It is expressed as m^2 K/W and is given by:

$$R = \frac{1}{C} = \frac{b}{k}$$

A2 Thermal Transmittance (U-value)

The thermal transmittance or U-value of a construction is defined as the quantity of heat that flows through a unit area of a building section under steady-state conditions in unit time per unit temperature difference of the air on either side of the section. It is expressed in $W/m^2 K$ and is given by:

$$U = \frac{1}{R_T}$$

where R_T is the total thermal resistance and is given by:

$$R_T = R_o + \frac{b_1}{k_1} + \frac{b_2}{k_2} + \ldots + \frac{b_n}{k_n} + R_i$$

where

R_o	:	air film resistance of external surface ($m^2 K/W$)
R_I	:	air film resistance of internal surface ($m^2 K/W$)
k_1, k_2, k_n	:	thermal conductivity of basic material (W/m K)
b_1, b_2, b_n	:	thickness of basic material (m)

A3 Surface Air Film Resistance

A3.1 The transfer of heat to and from a surface of a body through air is impeded by the presence of a thin layer of relatively motionless air at the surface of the body. This offers resistance to the heat flow and results in a temperature drop across the layer of air.

A3.2 Surface air film resistance is affected by wind velocity and therefore different resistance values for outside and inside air films are given. These are defined as follows:

R_o : outside surface air film resistance (moving air)
R_i : inside surface air film resistance (still air)

A3.3 Table C6 gives the values of surface resistances for walls and roofs at different positions of surface and for different surface emissivity values.

A4 Air Space Resistance

A4.1 Air is a relatively poor conductor of heat. Its presence as a gap between two layers of materials contributes further thermal resistance to the whole construction. The U-value of a building section can therefore be modified as follows:

$$U = \frac{1}{R_T}$$

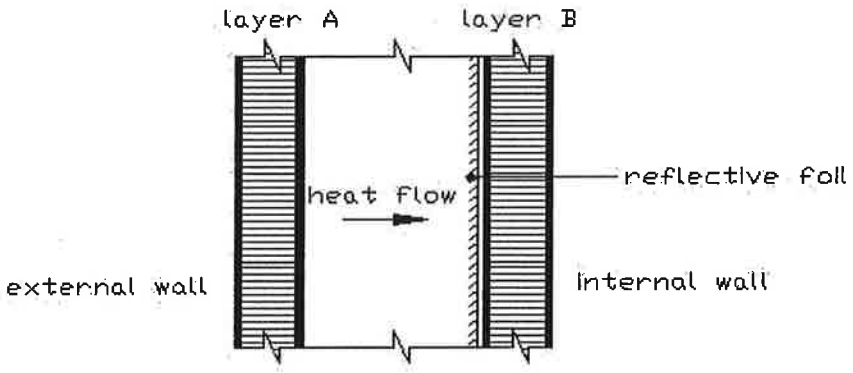
and

$$R_T = R_o + \frac{b_1}{k_1} + \ldots + R_a + \ldots + \frac{b_n}{k_n} + R_i$$

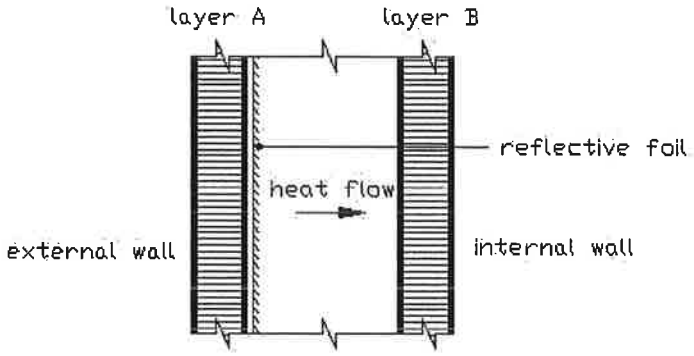
where

R_a : thermal resistance of air space

A4.2 Reflective materials such as aluminium foil have high surface reflectivity and low surface emissivity. If a reflective foil is inserted in an air space with its reflective surface facing the space and against the direction of heat flow as shown below, approximately 95% of the radiation will be reflected. This increases the thermal resistance of the air space.



A4.3 If the heat flow is reversed as shown below, the result would be the same, as in this case, the low emissivity of the reflective surface emits only about 5% of the absorbed heat as radiant energy.



A4.4 Table C7 gives the values of air space resistances for walls and roofs at different positions and for different surface emissivity values in the air space.

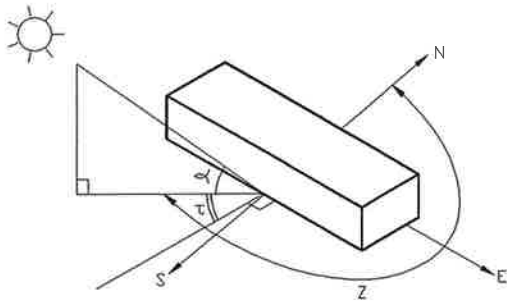
APPENDIX B

SHADING COEFFICIENT OF SUN SHADING DEVICES

B1 Basic Solar Data

B1.1 Solar geometry

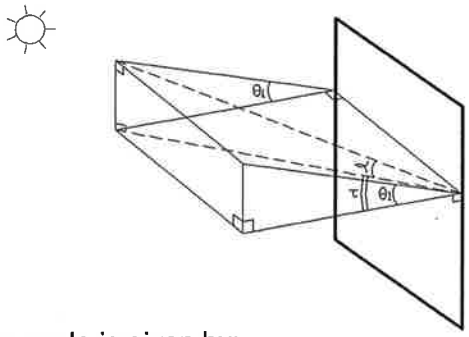
The position of the sun can be specified by the angles illustrated below:



These angles are (i) altitude (α, angle above the horizon) and (ii) azimuth (z, compass orientation of a vertical plane through the sun, measured clockwise from north). The orientation of a wall is the angle measured clockwise from north of a plane normal to the wall and the wall-solar azimuth (τ) is the angle between the two planes.

B1.2 Shadow angles

For the purpose of finding the shading effect of horizontal projections, fins, louvers, or canopies, the vertical shadow angle (VSA) is required. This is the angle (θ_1) between two planes viz, the horizontal plane and an inclined plane projected through the sun as illustrated in the diagram below:



The vertical shadow angle is given by:

$$\tan\theta_1 = \tan\alpha \sec\tau$$

where

θ_1 : the vertical shadow angle
α : the altitude of the sun
τ : the wall-solar azimuth

To calculate the shading coefficient of vertical fins and projections, the horizontal shadow angle (HSA) has to be determined and it is given by the wall-solar azimuth angle (τ), i.e.

$$\theta_2 = \tau$$

where

θ_2 : the horizontal shadow angle

B1.3 Intensity of solar radiation

To facilitate the calculation of the effective shading coefficient of external shading devices, the intensities of diffuse, direct and total radiation transmitted through a standard 3mm clear glass sheet are tabulated in Tables C8 to C11 together with the horizontal and vertical shadow angles for March, June, September and December.

B2 Shading Coefficient

B2.1 Basic concept

In the RETV formula, the solar factor has been derived from the annual average of solar radiation transmitted through a 3mm clear glass window. For other system of fenestration, the rate of solar heat gain is modified by the shading coefficient of the fenestration system which is defined as the ratio of solar heat gain through the fenestration system having combination of glazing and shading device to the solar heat gain through an unshaded 3mm clear glass. This ratio is a unique characteristic of each type of fenestration system and is represented by the equation:

$$SC = \frac{\text{Solar heat gain of any glass and shading combination}}{\text{Solar heat gain through a 3mm unshaded clear glass}}$$

In general, the shading coefficient of any fenestration system can be obtained by multiplying the shading coefficient of the glass (or effective shading coefficient of glass with solar control film where a solar control film is used on the glass) and the shading coefficient of the sun-shading devices as follows:

$$SC = SC_1 \times SC_2$$

where

SC : shading coefficient of the fenestration system
SC_1 : shading coefficient of glass or effective shading coefficient of glass with solar control film where a solar control film is used on the glass
SC_2 : effective shading coefficient of external shading devices

Note: 1. For the purpose of RETV calculation, the shading effect offered by internal blind and curtain should be ignored.

The shading coefficient of the glass or effective shading coefficient of glass with solar control film should be based on the manufacturer's recommended value.

The effective shading coefficient of external shading devices as given in Tables C12 to C23 shall be used unless the type of shading device in question is not included in the tables. In that case, the effective shading coefficient shall be calculated from the basic solar data given in Tables C8 to C11 in accordance with the method specified in Section B2.2.

B2.2 Method of calculating effective shading coefficient of external sun-shading device

B2.2.1 When a window is partially shaded by an external shading device, it is assumed (for simplicity and for the purpose of RETV computation) that the exposed portion receives the total radiation, I_T, and the shaded portion receives only the diffuse radiation, I_d.

The instantaneous heat gain due to solar radiation can then be expressed as follows:

$$Q = A_e \times I_T + A_s \times I_d$$
$$= A_e \times I_D + (A_e + A_s) \times I_d$$

where

Q : solar heat gain
A_e : exposed area of window
A_s : shaded area of window
I_T : total radiation
I_D : direct radiation
I_d : diffused radiation

Since

$$A = A_e + A_s$$

Therefore

$$Q = A_e \times I_D + A \times I_d$$

For an unshaded 3mm clear glass, the solar heat gain is given by A x I_T. By definition, the hourly Shading Coefficient, SC, of a shading device can be expressed as:

$$SC = \frac{A_e \times I_D + A \times I_d}{A \times I_T}$$

$$= \frac{G \times I_D \times I_d}{I_T}$$

where

$G = \frac{A_e}{A}$ the fraction of area exposed to direct solar radiation

B2.2.2 To calculate the shading coefficient (SC) of a shading device for the whole day, the hourly solar heat gain shall be computed and summed up for the 12 daylight hours. The total solar heat gain is then divided by the sum of the total radiation, I_T, through an unshaded 3mm clear glass for the same hours of the day, to obtain the SC for the day. Mathematically, the computation can be expressed as follows:

$$SC_{day} = \frac{\sum_{h=1}^{h=12}(A_e \times I_D + I_d)_h}{\sum_{h=1}^{h=12}(A \times I_T)_h}$$

where subscript 'day' and 'h' refers to daily & hourly respectively.

B2.2.3 For simplicity, the SC of a shading device for a particular month can be worked out basing on the solar data for a representative day of the month.

B2.2.4 To determine the effective SC of a shading device, theoretically, the computation has to be carried out for 12 months of the year. However, as the computation involved is rather tedious and the degree of accuracy required is not a critical factor, it is deemed sufficient to base the SC computation on 4 representative months of the year, viz. March, June, September and December. The representative days of these 4 months are March 21, June 22, September 23 and December 22.

B2.2.5 Further, since the solar data for March 21 and September 23 are almost identical, it suffices to compute the solar heat gain for March and double it to take account of the heat gain for September. Mathematically, the effective SC of a shading device is given by:

$$\text{Effective SC} = \frac{\Sigma_M(G \times I_D + I_d) + \Sigma_J(G \times I_D + I_d)\Sigma_S(G \times I_D + I_d) + \Sigma_D(G \times I_D + I_d)}{\Sigma_M I_T + \Sigma_J I_T + \Sigma_S I_T + \Sigma_D I_T}$$

Where

M denotes March
J denotes June
S denotes September
D denotes December

B2.2.6 The relevant solar data are given in Tables C8 to C11.

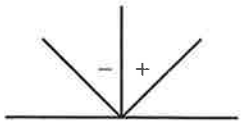
B2.3 Determination of 'G' factor

The fraction of window area exposed to the sun (G) at any time for a given orientation can be determined using solar geometry. With the VSA and HSA given, the G factor can be worked out graphically. For simple design, the

G factor can also be calculated using plane trigonometry. In the following examples of calculating the G factor for simple horizontal overhangs, vertical fins and egg-crate sun-shades using trigonometry, the following convention is used:

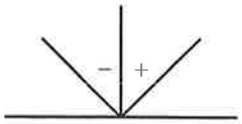
θ1 = VSA (always positive)

θ2 = HSA (positive, if to the right of wall orientation; negative, if to the left of wall orientation).

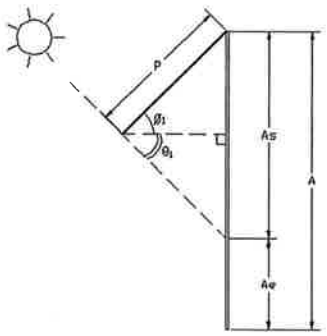


ϕ_1 = projection angle of horizontal projections with respect to horizontal plane (assume positive for practical reason).

ϕ_2 = projection angle of vertical fin with respect to wall orientation (positive, if to the right of wall orientation; negative, if to the left of wall orientation)



B2.3.1 For continuous horizontal projection fixed at window head level



$$A_s = P\cos\phi_1 \tan\theta_1 + P\sin\phi_1$$

$$= P(\cos\phi_1 \tan\theta_1 + \sin\phi_1)$$

$$\frac{A_e}{A_s} = A - As$$

$$\frac{A_e}{A} = 1 - \frac{P}{A}(\cos\phi_1 \tan\theta_1 + \sin\phi_1)$$

or

$$G_1 = 1 - R_1(\cos\phi_1 \tan\phi_1 + \sin\phi_1)$$

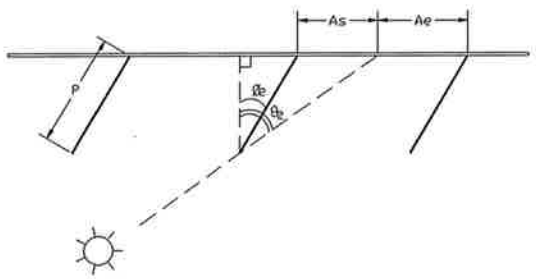
Where

$G_1 = \frac{A_e}{A}$ and $R_1 = \frac{P}{A}$ for horizontal projections.

Notes: 1. $G_1 \geq 0$

2. Table C12 to Table C15 give the SC of horizontal projections for a range of R_1 values with ϕ_1 ranging from 0° to 50°.

B2.3.2 For continuous vertical fins in an array



$$A_s = |P\cos\phi_2 \tan\phi_2 - P\sin\phi_2|$$

$$= P|\cos\phi_2 \tan\theta_2 - \sin\phi_2|$$

$$\frac{A_e}{A} = A - A_s$$

$$\frac{A_e}{A} = 1 - \frac{P}{A} \times |\cos\phi_2 \tan\phi_2 - \sin\phi_2|$$

or

$$G_2 = 1 - R_2 \left| \cos\phi_2 \tan\phi_2 - \sin\phi_2 \right|$$

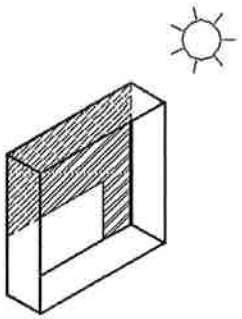
where

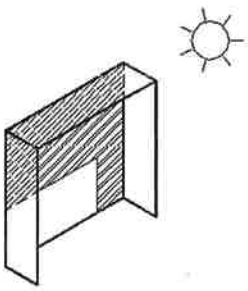
$$G_2 = \frac{A_e}{A} \text{ and } R_2 = \frac{P}{A} \text{ for vertical fins}$$

Notes: 1. $G_2 \geq 0$

2. Table C16 to Table C19 give the SC of vertical fins for a range of R_2 *values with* $|\phi_2|$ *ranging from* 0° *to* 50°. ϕ_2 *is chosen for the situation which gives the lower SC of the two possible values, viz positive or negative* ϕ_2.

B2.3.3 For egg-crate and combination fins made up of horizontal and vertical components for which the horizontal component may be sloped.





$$G_1 = 1 - R_1(\cos\phi_1 \tan\phi_1 - \sin\phi_1)$$

$$G_2 = 1 - R_2 \left| \tan\theta_2 \right|$$

Since G_1 and G_2 are independent of each other, the combined effect of the two components can be expressed as follows:

$$G_3 = G_1 \times G_2$$

Notes: 1. $G_3 \geq 0$

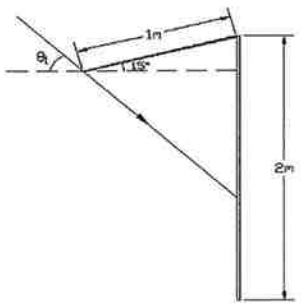
2. Table C20 to Table C23 give the SC of combination fins for a range of R_1 *and* R_2 *values with* ϕ_1 *ranging from* 0° *to* 40°.

B3 Examples

The following examples are meant to illustrate how the SC of a shading device is calculated from first principle.

B3.1 Example A

Find the effective shading coefficient (SC) of a sloping horizontal projection 1m in length, inclined at 15° and located over a window of 2m in height, in a North-East facing direction.



$\phi_1 = 15^\circ$

$R_1 = 1/2 = 0.5$

NE	March 21 / September 23					June 22					December 22				
Item	θ_1	(1-G)	I_D	I_d	Q	θ_1	(1-G)	I_D	I_d	Q	θ_1	(1-G)	I_D	I_d	Q
7 am	6	0.180	94	23	100	6	0.180	159	33	163	15	0.260	52	20	58
8 am	26	0.365	293	76	262	21	0.315	387	86	351	46	0.630	111	63	104
9 am	44	0.600	336	106	240	34	0.455	462	116	368	67	—	87	83	83
10 am	59	0.933	278	126	144	47	0.647	435	133	286	81	—	28	98	98
11 am	72	—	154	136	136	58	0.902	345	141	175	—	—	0	109	109
12 noon	83	—	31	136	136	68	—	216	141	141	—	—	0	116	116
1 pm	—	—	0	133	136	78	—	98	110	110	—	—	0	116	116
2 pm	—	—	0	123	123	88	—	29	116	116	—	—	0	108	108
3 pm	—	—	0	104	104	—	—	0	93	93	—	—	0	93	93
4 pm	—	—	0	85	85	—	—	0	76	76	—	—	0	73	73
5 pm	—	—	0	60	60	—	—	0	53	53	—	—	0	50	50
6 pm	—	—	0	28	28	—	—	0	23	23	—	—	0	20	20
$\Sigma Q = \Sigma(G \times I_D + I_d)$			1554					1955					1028		
$\Sigma I_T = \Sigma(I_D + I_d)$			2322					3252					1227		
SC (day)			0.669					0.601					0.838		

$$\text{Effective SC (Annual)} = \frac{2\times\sum_M(G\times I_D + I_d)+\sum_J(G\times I_D + I_d)+\sum_D(G\times I_D + I_d)}{2\times\sum_M(I_T)+\sum_J(I_T)+\sum_D(I_T)}$$

$$= \frac{(2\times 1554)+1955+1028}{(2\times 2322)+3252+1227}$$

$$= \frac{6091}{9123}$$

$$= 0.67$$

B3.2 Example B

Find the effective SC of an egg-crate shading device having $R_1 = 0.4$, $\Phi_1 = 0$, $R_2 = 0.4$ in the North-facing direction.

June 22								
Item	θ_1	G_1	θ_2	G_2	G_3	I_D	I_d	**Q**
7 am	15	0.893	67	0.058	0.050	60	25	28
8 am	41	0.652	65	0.142	0.093	145	63	76
9 am	55	0.429	63	0.215	0.092	187	91	108
10 am	62	0.248	57	0.384	0.095	208	114	134
11 am	66	0.102	45	0.600	0.061	219	131	144
12 noon	68	0.010	21	0.846	0.000	222	141	141
1 pm	68	0.010	-14	0.900	0.000	225	141	141
2 pm	66	0.102	-41	0.652	0.067	219	134	149
3 pm	63	0.215	-55	0.429	0.092	209	119	138
4 pm	57	0.384	-62	0.248	0.095	195	98	116
5 pm	44	0.614	-65	0.142	0.087	156	71	85
6 pm	21	0.847	-66	0.102	0.086	81	33	40

$$\Sigma Q = \Sigma[(G_3 \times I_D) + I_d]$$

$$= 1300$$

$$\Sigma(I_T) = 3287$$

$$\text{Therefore SC (June 22)} = \frac{1300}{3287}$$

$$= 0.395$$

The same procedure is repeated for March 21, September 23 and December 22 in order to work out the effective SC for the whole year.

B3.3 Example C

Find the effective SC of a shading device parallel to the wall as shown in the diagram below. It is installed in a North-facing wall.

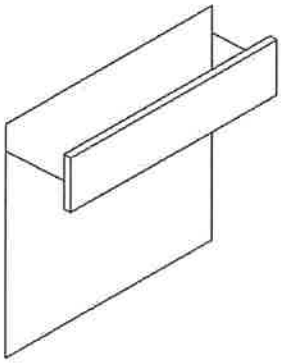
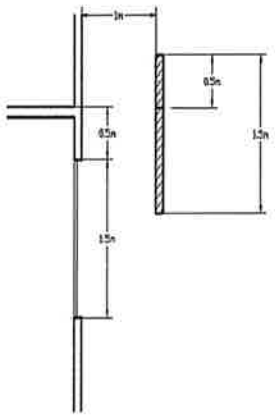


Fig (a)



The glass window is shaded by a panel parallel to the wall. The shadow cast on the window varies according to the time of the day depending on the sun's position and its vertical shadow angle (θ_1).

For $68.2^o < \theta_1 < 90^o$, the shading device is ineffective as sun rays strike the window directly. See figure (b). For $\theta_1 = 45^o$, the window is totally shaded. See figure (c).

For $\theta_1 < 45^o$, the window is partially shaded by the lower portion of the strip. See figure (d).

The shadow patterns for figure (c) and figure (d) can be worked out by simple geometry.

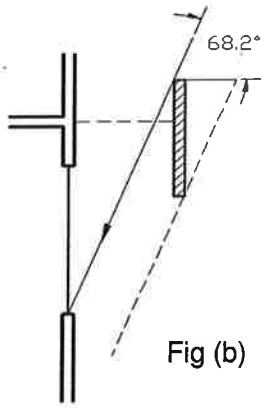


Fig (b)

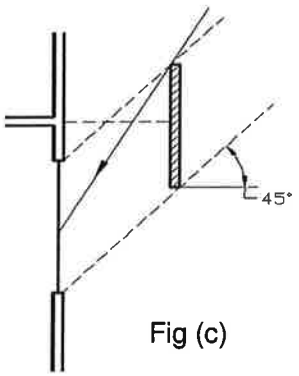


Fig (c)

JUNE 22						
Item	θ_1	G	I_D	I_d	$Q = G \times I_D + I_d$	$I_T = I_D + I_d$
7 am	15	0.488	60	25	54	85
8 am	41	0.087	145	63	76	208
9 am	55	0.285	187	91	144	278
10 am	62	0.587	208	114	236	322
11 am	66	0.831	219	131	313	350
12 noon	68	0.983	222	141	359	363
1 pm	68	0.983	225	141	362	366
2 pm	66	0.831	219	134	316	353
3 pm	63	0.642	209	119	253	328
4 pm	57	0.360	195	98	168	293
5 pm	44	0.023	156	71	75	227
6 pm	21	0.411	81	33	66	114

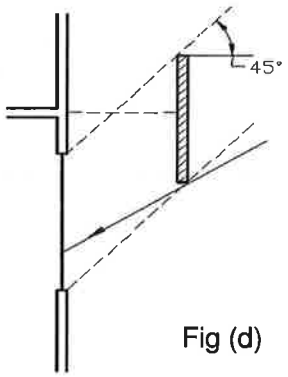


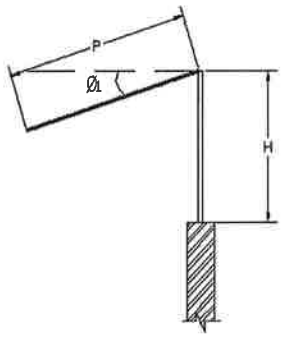
Fig (d)

B4 Keys for Tables of Effective Shading Coefficient of External Shading Devices

B4.1 Key 1 Horizontal Projections [Tables C12 to C15]

$$R_1 = \frac{P}{H}$$

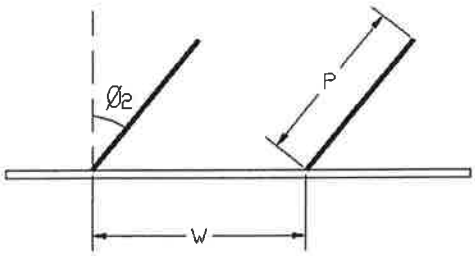
ϕ_1 = Angle of inclination



B4.2 Key 2 Vertical Projections [Tables C16 to C19]

$$R_2 = \frac{P}{W}$$

ϕ_2 = Angle of inclination

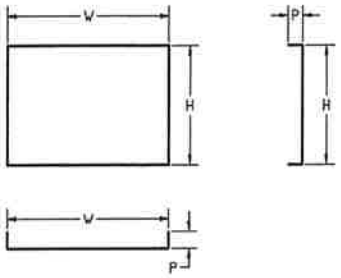


B4.3 Key 3 Egg-crate Louvers [Tables C20 to C23]

$$R_1 = \frac{P}{H}$$

$$R_2 = \frac{P}{W}$$

$\phi 1$ = Angle of inclination



B5 Examples

B5.1 Given : Window on South-West facing wall with a 0.3m horizontal overhang.

Find : The effective shading coefficient if (a) height of window is 0.6m; (b) height of window is 0.75m with the overhang inclined at 30° to the horizontal.

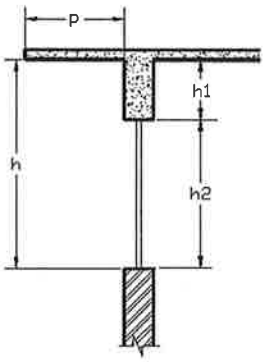
Solution : Refer to Table C15

a) $R_1 = 0.5$ SC = 0.698
b) $R_1 = 0.4$ SC = 0.669

B5.2 Given : Window on West facing wall with a 0.3m horizontal overhang and height of window is 0.75.

Find : The effective shading coefficient if the window is located 0.2m below the overhang.

Solution : Assuming the window has a height h and extends to the underside of the overhang, the solar heat gain into the window can be expressed as follows:



$SC \times h = (SC_1 \times h_1) + (SC_2 \times h_2)$

From Table C13 by interpolation

SC = 0.8123, h = 950(R_1 = 0.32)

$SC_1 = 0.5051$, $h_1 = 200$(R_1 = 1.5)

$$SC_2 = \frac{(SC \times h) - (SC_1 \times h_1)}{h_2}$$

$SC_2 = 0.894$

APPENDIX C

SCHEDULES OF TABLES

Table C1: Solar Correction Factors (CF) for Walls (ETTV)

Pitch Angle	Orientation							
	N	NE	E	SE	S	SW	W	NW
70°	1.17	1.33	1.47	1.35	1.21	1.41	1.56	1.38
75°	1.07	1.23	1.37	1.25	1.11	1.32	1.47	1.28
80°	0.98	1.14	1.30	1.16	1.01	1.23	1.39	1.20
85°	0.89	1.05	1.21	1.07	0.92	1.14	1.31	1.11
90°	0.80	0.97	1.13	0.98	0.83	1.06	1.23	1.03
95°	0.73	0.90	1.05	0.91	0.76	0.99	1.15	0.96
100°	0.67	0.83	0.97	0.84	0.70	0.92	1.08	0.89
105°	0.62	0.77	0.90	0.78	0.65	0.86	1.01	0.83
110°	0.59	0.72	0.83	0.72	0.61	0.80	0.94	0.78
115°	0.57	0.67	0.77	0.67	0.58	0.75	0.87	0.73
120°	0.55	0.63	0.72	0.63	0.56	0.71	0.81	0.69

Note: 1. The correction factors for other orientations and other pitch angles may be obtained by interpolation.

Table C2: Solar Correction Factors for Roofs

Pitch Angle	Orientation							
	N	NE	E	SE	S	SW	W	NW
0°	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5°	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10°	0.99	0.99	1.00	1.00	1.00	0.99	0.99	0.99
15°	0.98	0.98	0.99	0.99	0.99	0.98	0.98	0.98
20°	0.96	0.97	0.98	0.98	0.97	0.97	0.97	0.96
25°	0.93	0.95	0.96	0.96	0.95	0.95	0.95	0.94
30°	0.91	0.92	0.94	0.94	0.93	0.93	0.93	0.91
35°	0.88	0.90	0.92	0.91	0.90	0.90	0.90	0.89
40°	0.84	0.87	0.89	0.88	0.87	0.87	0.87	0.85
45°	0.80	0.83	0.86	0.85	0.83	0.84	0.84	0.82
50°	0.76	0.80	0.83	0.82	0.79	0.80	0.81	0.78
55°	0.72	0.76	0.80	0.78	0.75	0.76	0.78	0.75
60°	0.67	0.72	0.76	0.74	0.70	0.73	0.74	0.71
65°	0.63	0.68	0.73	0.70	0.66	0.69	0.71	0.67

Table C3 : Solar Correction Factors (CF) for Walls (RETV)

Pitch Angle	Orientation							
	N	NE	E	SE	S	SW	W	NW
90°	0.83	1.01	1.18	1.02	0.86	1.09	1.26	1.06
80°	0.98	1.15	1.34	1.18	1.01	1.23	1.41	1.21
70°	1.13	1.30	1.48	1.35	1.17	1.38	1.55	1.36

Note: 1. The correction factors for other orientations and other pitch angles may be obtained by interpolation.

Table C4: Maximum Thermal Transmittance of Roof of Air-Conditioned Building

Weight group	Weight range (kg/m^2)	Maximum thermal transmittance (W/m^2K)
Light	Under 50	0.5
Medium	50 to 230	0.8
Heavy	Over 230	1.2

Table C5: Thermal Conductivity Values (k-Values) of Basic Materials

S/No	Material	Density (kg/m^3)	k-value (W/m K)
1	Asphalt, roofing	2240	1.226
2	Bitumen	-	1.298
3	Brick		
	(a) dry (covered by plaster or tiles outside)	1760	0.807
	(b) common brickwall (brickwall directly exposed to weather outside).	-	1.154
4	Concrete	2400	1.442
		64	0.144
5	Concrete, lightweight	960	0.303
		1120	0.346
		1280	0.476
6	Cork board	144	0.042
7	Fibre board	264	0.052

8	Fibre glass (See Glass Wool and Mineral Wool)		
9	Glass, sheet	2512	1.053
10	Glass wool, mat or guilt (dry)	32	0.035
11	Gypsum plaster board	880	0.170
12	Hard board:		
	(a) Standard	1024	0.216
	(b) medium	640	0.123
13	Metals:		
	(a) Aluminium alloy, typical	2672	211
	(b) Copper, commercial	8784	385
	(c) Steel	7840	47.6
14	Mineral wool, felt	32 - 104	0.035 - 0.032
15	Plaster:		
	(a) gypsum	1216	0.370
	(b) perlite	616	0.115
	(c) sand / cement	1568	0.533
	(d) vermiculite	640 - 960	0.202 - 0.303
16	Polystyrene, expanded	16	0.035
17	Polyurethane, foam	24	0.024
18	PVC flooring	1360	0.713
19	Soil, loosely packed	1200	0.375
20	Stone, tile:		
	(a) sand stone	2000	1.298
	(b) granite	2640	2.927
	(c) marble / terrazzo / ceramic / mosaic	2640	1.298
21	Tile, roof	1890	0.836
22	Timber:		
	(a) across grain softwood	608	0.125
	(b) hardwood	702	0.138
	(c) plywood	528	0.138
23	Vermiculite, loose granules	80-112	0.065
24	Wood chipboard	800	0.144
25	Woodwool slab	400	0.086
		480	0.101

Table C6: Surface Film Resistances for Walls and Roofs

Type of Surface	Thermal Resistance (m^2 K /W)
A. Surface Film Resistances for Walls	
1. Inside Surface (R_i)	
(a) High emissivity	0.120
(b) Low emissivity	0.299
2. Outside surface (R_o) - High emissivity	0.044
B. Surface Film Resistances for Roofs	
1. Inside surface (R_i)	
(a) High Emissivity	
(i) Flat roof	0.162
(ii) Sloped roof 22½°	0.148
(iii) Sloped roof 45°	0.133
(b) Low Emissivity	
(i) Flat roof	0.801
(ii) Sloped roof 22½°	0.595
(iii) Sloped roof 45°	0.391
2. Outside surface (R_o) - High emissivity Flat or sloped	0.055

Notes: 1. Ordinarily, high emissivity is assumed for surfaces of building materials with reasonably smooth finishing. Low emissivity applies only to internal surface if the surface is very reflective, such as that of an aluminium foil.

2. Interpolation between the angle of slope from horizontal to 45° is permitted. For angle beyond 45°, the value for 45° can be used; no extrapolation is needed.

Table C7: Air Space Resistances for Walls and Roofs

Type of Air Space	Thermal Resistance (m^2K/W)		
	5mm	20mm	100mm
A. Air Space Resistances (R_a) for walls			
Vertical air space (Heat flows horizontally)			
(a) High emissivity	0.110	0.148	0.160
(b) Low emissivity	0.250	0.578	0.606
B. Air Space Resistances (R_a) for Roofs			
Horizontal or sloping air space (Heat flows downwards)			
(a) High emissivity			
(i) horizontal air space	0.110	0.148	0.174
(ii) sloped air space 22½°	0.110	0.148	0.165
(iii) sloped air space 45°	0.110	0.148	0.158
(b) Low emissivity			
(i) horizontal air space	0.250	0.572	1.423
(ii) sloped air space 22½°	0.250	0.571	1.095
(iii) sloped air space 45°	0.250	0.570	0.768
C. Attic space resistances (R attic)			
(a) High emissivity		0.458	
(b) Low emissivity		1.356	

Notes: 1. Ordinarily, high emissivity is assumed for air spaces bounded by building materials of moderately smooth surfaces. Low emissivity only applies where one or both sides of the air space are bounded by a reflective surface such as that of an aluminium foil.

2. Interpolation with the range of pitch angles from horizontal to 45° is permitted. For angles beyond 45°, the value for 45° can be used; no extrapolation is needed.

3. Interpolation within the range of thickness from 5mm to 100mm is permitted. For air spaces less than 5mm, extrapolation basing on R_a = 0 for zero thickness is allowed; otherwise R_a is assumed to be zero. For air spaces greater than 100mm, the R_a for 100mm should be used; i.e. extrapolation is not permitted.

4. In the case of air space in roof, reflective foil used should be installed with the reflective surface facing downward as dust deposit will render an upward-facing surface ineffective after a while.

Table C8: Solar Data

Orientation: North & South

TIME	MARCH 21 / SEPTEMBER 23					JUNE 22					DECEMBER 22				
	θ_1	θ_2	I_D	I_d	I_T	θ_1	θ_2	I_D	I_d	I_T	θ_1	θ_2	I_D	I_d	I_T
7 AM	90	+90	0	13	13	15	+67	60	25	85	—	—	0	15	15
8 AM	90	+90	0	48	48	41	+65	145	63	208	—	—	0	48	48
9 AM	—	—	0	76	76	55	+63	187	91	278	—	—	0	71	71
10 AM	—	—	0	98	98	62	+57	208	114	322	—	—	0	91	91
11 AM	—	—	0	118	118	66	+45	219	131	350	—	—	0	109	109
12 NOON	—	—	0	129	129	68	+21	222	141	363	—	—	0	117	117
1 PM	—	—	0	133	133	68	-14	225	141	366	—	—	0	116	116
2 PM	—	—	0	123	123	66	-41	219	134	353	—	—	0	108	108
3 PM	—	—	0	104	104	63	-55	209	119	328	—	—	0	93	93
4 PM	—	—	0	85	85	57	-62	195	98	293	—	—	0	73	73
5 PM	90	-90	0	60	60	44	-65	156	71	227	—	—	0	50	50
6 PM	90	-90	0	28	28	21	-66	81	33	114	—	—	0	20	20

Note: 1. For the purpose of calculating shading coefficient, the solar data for the North orientation can be used for the South orientation.

Table C9: Solar Data

Orientation: East & West

TIME	MARCH 21 / SEPTEMBER 23					JUNE 22					DECEMBER 22				
	θ_1	θ_2	I_D	I_d	I_T	θ_1	θ_2	I_D	I_d	I_T	θ_1	θ_2	I_D	I_d	I_T
7 AM	4	+0	136	25	161	7	-23	159	33	192	6	+24	159	30	189
8 AM	19	+0	429	88	517	21	-25	374	83	457	21	+25	394	86	480
9 AM	34	+1	504	121	625	36	-27	427	110	537	36	+29	445	114	559
10 AM	49	+2	435	139	574	51	-33	360	126	486	51	+36	373	129	502
11 AM	64	+3	282	146	428	66	-45	213	131	344	67	+49	216	134	350
12 NOON	79	+7	74	141	215	81	-69	44	126	170	82	+73	41	126	167
1 PM	—	—	0	133	133	—	—	0	116	116	—	—	0	116	116
2 PM	—	—	0	123	123	—	—	0	109	109	—	—	0	108	108
3 PM	—	—	0	104	104	—	—	0	93	93	—	—	0	93	93
4 PM	—	—	0	85	85	—	—	0	76	76	—	—	0	73	73
5 PM	—	—	0	60	60	—	—	0	53	53	—	—	0	50	50
6 PM	—	—	0	28	28	—	—	0	23	23	—	—	0	20	20

Note: 1. For the purpose of calculating shading coefficient, the solar data for the East orientation can be used for the West orientation.

Table C10: Solar Data

Orientation: North-East & North-West

TIME	MARCH 21 / SEPTEMBER 23					JUNE 22					DECEMBER 22				
	θ_1	θ_2	I_D	I_d	I_T	θ_1	θ_2	I_D	I_d	I_T	θ_1	θ_2	I_D	I_d	I_T
7 AM	6	+45	94	23	117	6	+22	159	33	192	15	+69	52	20	72
8 AM	26	+45	293	76	369	21	+20	387	86	473	46	+70	111	63	174
9 AM	44	+46	336	106	442	34	+18	462	116	578	67	+74	87	83	170
10 AM	59	+47	278	126	404	47	+12	435	133	568	81	+81	28	98	126
11 AM	72	+48	154	136	290	58	-0	345	141	486	—	—	0	109	109
12 NOON	83	+52	31	136	167	68	-24	216	141	357	—	—	0	116	116
1 PM	—	—	0	133	133	78	-59	98	110	208	—	—	0	116	116
2 PM	—	—	0	123	123	88	-86	29	116	145	—	—	0	108	108
3 PM	—	—	0	104	104	—	—	0	93	93	—	—	0	93	93
4 PM	—	—	0	85	85	—	—	0	76	76	—	—	0	73	73
5 PM	—	—	0	60	60	—	—	0	53	53	—	—	0	50	50
6 PM	—	—	0	28	28	—	—	0	23	23	—	—	0	20	20

Note: 1. For the purpose of calculating shading coefficient, the solar data for the North-East orientation can be used for the North-West orientation.

Table C11: Solar Data

Orientation: South-East & South-West

TIME	MARCH 21 / SEPTEMBER 23					JUNE 22					DECEMBER 22				
	θ_1	θ_2	I_D	I_d	I_T	θ_1	θ_2	I_D	I_d	I_T	θ_1	θ_2	I_D	I_d	I_T
7 AM	6	-45	94	23	117	16	-68	53	23	76	6	-21	162	30	192
8 AM	26	-45	321	48	369	46	-70	114	63	177	20	-20	417	88	505
9 AM	44	-44	382	76	458	65	-72	97	86	183	34	-16	496	119	615
10 AM	58	-43	325	98	423	79	-78	38	98	136	46	-9	470	136	606
11 AM	70	-42	180	136	316	—	—	0	106	106	57	+4	389	146	535
12 NOON	82	-38	47	139	186	—	—	0	116	116	67	+28	244	144	388
1 PM	—	—	0	133	133	—	—	0	116	116	76	+60	99	131	230
2 PM	—	—	0	123	123	—	—	0	109	109	86	+84	9	111	120
3 PM	—	—	0	104	104	—	—	0	93	93	—	—	0	93	93
4 PM	—	—	0	85	85	—	—	0	76	76	—	—	0	73	73
5 PM	—	—	0	60	60	—	—	0	53	53	—	—	0	50	50
6 PM	—	—	0	28	28	—	—	0	23	23	—	—	0	20	20

Note: 1. For the purpose of calculating shading coefficient, the solar data for the South-East orientation can be used for the South-West orientation.

Table C12: Effective Shading Coefficients of Horizontal Projection at Various Angles of Inclination

Orientation: North & South

R_1	0°	10°	20°	30°	40°	50°
0.1	0.9380	0.9330	0.9300	0.9291	0.9303	0.9336
0.2	0.8773	0.8674	0.8613	0.8595	0.8619	0.8685
0.3	0.8167	0.8017	0.7927	0.7899	0.7935	0.8033
0.4	0.7560	0.7392	0.7288	0.7245	0.7263	0.7382
0.5	0.7210	0.7080	0.7001	0.6950	0.6927	0.6938
0.6	0.7041	0.6921	0.6848	0.6804	0.6774	0.6760
0.7	0.6923	0.6842	0.6775	0.6723	0.6689	0.6672
0.8	0.6871	0.6779	0.6702	0.6661	0.6641	0.6626
0.9	0.6819	0.6718	0.6670	0.6643	0.6621	0.6604
1.0	0.6767	0.6690	0.6655	0.6625	0.6600	0.6583
1.1	0.6731	0.6678	0.6640	0.6607	0.6584	0.6577
1.2	0.6713	0.6667	0.6625	0.6589	0.6577	0.6577
1.3	0.6705	0.6656	0.6611	0.6582	0.6577	0.6577
1.4	0.6698	0.6644	0.6596	0.6577	0.6577	0.6577
1.5	0.6690	0.6633	0.6588	0.6577	0.6577	0.6577
1.6	0.6683	0.6622	0.6582	0.6577	0.6577	0.6577
1.7	0.6675	0.6610	0.6577	0.6577	0.6577	0.6577
1.8	0.6667	0.6599	0.6577	0.6577	0.6577	0.6577
1.9	0.6660	0.6594	0.6577	0.6577	0.6577	0.6577
2.0	0.6652	0.6589	0.6577	0.6577	0.6577	0.6577
2.1	0.6645	0.6585	0.6577	0.6577	0.6577	0.6577
2.2	0.6637	0.6581	0.6577	0.6577	0.6577	0.6577
2.3	0.6630	0.6577	0.6577	0.6577	0.6577	0.6577
2.4	0.6622	0.6577	0.6577	0.6577	0.6577	0.6577
2.5	0.6614	0.6577	0.6577	0.6577	0.6577	0.6577
2.6	0.6607	0.6577	0.6577	0.6577	0.6577	0.6577
2.7	0.6604	0.6577	0.6577	0.6577	0.6577	0.6577
2.8	0.6601	0.6577	0.6577	0.6577	0.6577	0.6577
2.9	0.6599	0.6577	0.6577	0.6577	0.6577	0.6577
3.0	0.6596	0.6577	0.6577	0.6577	0.6577	0.6577

Table C13: Effective Shading Coefficients of Horizontal Projection at Various Angles of Inclination

Orientation: East & West

R_1	0°	10°	20°	30°	40°	50°
0.1	0.9363	0.9268	0.9195	0.9147	0.9124	0.9129
0.2	0.8752	0.8565	0.8416	0.8309	0.8257	0.8257
0.3	0.8228	0.7947	0.7723	0.7563	0.7470	0.7448
0.4	0.7703	0.7330	0.7036	0.6820	0.6693	0.6664
0.5	0.7248	0.6842	0.6550	0.6231	0.6045	0.5946
0.6	0.6911	0.6424	0.6013	0.5691	0.5467	0.5349
0.7	0.6574	0.6006	0.5559	0.5249	0.5012	0.4851
0.8	0.6237	0.5693	0.5273	0.4923	0.4651	0.4467
0.9	0.5998	0.5463	0.4991	0.4608	0.4389	0.4237
1.0	0.5827	0.5232	0.4727	0.4442	0.4222	0.4062
1.1	0.5656	0.5002	0.4587	0.4296	0.4075	0.4010
1.2	0.5485	0.4828	0.4468	0.4151	0.4036	0.3969
1.3	0.5314	0.4739	0.4349	0.4089	0.3999	0.3963
1.4	0.5156	0.4650	0.4230	0.4059	0.3969	0.3963
1.5	0.5051	0.4561	0.4147	0.4029	0.3963	0.3963
1.6	0.4995	0.4472	0.4123	0.3999	0.3963	0.3963
1.7	0.4939	0.4383	0.4101	0.3974	0.3963	0.3963
1.8	0.4882	0.4294	0.4079	0.3963	0.3963	0.3963
1.9	0.4826	0.4237	0.4057	0.3963	0.3963	0.3963
2.0	0.4770	0.4204	0.4035	0.3963	0.3963	0.3963
2.1	0.4713	0.4190	0.4013	0.3963	0.3963	0.3963
2.2	0.4657	0.4176	0.3991	0.3963	0.3963	0.3963
2.3	0.4601	0.4163	0.3978	0.3963	0.3963	0.3963
2.4	0.4544	0.4149	0.3968	0.3963	0.3963	0.3963
2.5	0.4488	0.4135	0.3963	0.3963	0.3963	0.3963
2.6	0.4432	0.4122	0.3963	0.3963	0.3963	0.3963
2.7	0.4400	0.4108	0.3963	0.3963	0.3963	0.3963
2.8	0.4369	0.4094	0.3963	0.3963	0.3963	0.3963
2.9	0.4339	0.4081	0.3963	0.3963	0.3963	0.3963
3.0	0.4333	0.4067	0.3963	0.3963	0.3963	0.3963

Table C14: Effective Shading Coefficients of Horizontal Projection at Various Angles of Inclination

Orientation: North-East & North-West

R_1	0°	10°	20°	30°	40°	50°
0.1	0.9273	0.9193	0.9137	0.9106	0.9101	0.9122
0.2	0.8630	0.8471	0.8355	0.8285	0.8263	0.8291
0.3	0.8054	0.7820	0.7644	0.7533	0.7489	0.7515
0.4	0.7563	0.7278	0.7055	0.6895	0.6803	0.6799
0.5	0.7171	0.6824	0.6546	0.6345	0.6228	0.6198
0.6	0.6787	0.6443	0.6165	0.5946	0.5793	0.5710
0.7	0.6549	0.6166	0.5842	0.5587	0.5420	0.5320
0.8	0.6327	0.5889	0.5563	0.5360	0.5200	0.5088
0.9	0.6105	0.5681	0.5412	0.5184	0.5026	0.4919
1.0	0.5922	0.5560	0.5261	0.5051	0.4900	0.4826
1.1	0.5809	0.5440	0.5148	0.4939	0.4840	0.4790
1.2	0.5722	0.5321	0.5046	0.4877	0.4809	0.4759
1.3	0.5634	0.5243	0.4971	0.4850	0.4782	0.4759
1.4	0.5547	0.5165	0.4921	0.4825	0.4759	0.4759
1.5	0.5466	0.5086	0.4894	0.4802	0.4759	0.4759
1.6	0.5413	0.5037	0.4874	0.4780	0.4759	0.4759
1.7	0.5359	0.5001	0.4854	0.4759	0.4759	0.4759
1.8	0.5306	0.4965	0.4837	0.4759	0.4759	0.4759
1.9	0.5253	0.4949	0.4821	0.4759	0.4759	0.4759
2.0	0.5200	0.4936	0.4804	0.4759	0.4759	0.4759
2.1	0.5162	0.4923	0.4787	0.4759	0.4759	0.4759
2.2	0.5141	0.4909	0.4770	0.4759	0.4759	0.4759
2.3	0.5119	0.4897	0.4759	0.4759	0.4759	0.4759
2.4	0.5097	0.4886	0.4759	0.4759	0.4759	0.4759
2.5	0.5075	0.4876	0.4759	0.4759	0.4759	0.4759
2.6	0.5053	0.4865	0.4759	0.4759	0.4759	0.4759
2.7	0.5047	0.4855	0.4759	0.4759	0.4759	0.4759
2.8	0.5042	0.4844	0.4759	0.4759	0.4759	0.4759
2.9	0.5036	0.4834	0.4759	0.4759	0.4759	0.4759
3.0	0.5031	0.4823	0.4759	0.4759	0.4759	0.4759

Table C15: Effective Shading Coefficients of Horizontal Projection at Various Angles of Inclination

Orientation: South-East & South-West

R_1	0°	10°	20°	30°	40°	50°
0.1	0.9253	0.9167	0.9107	0.9072	0.9065	0.9086
0.2	0.8574	0.8405	0.8280	0.8203	0.8177	0.8204
0.3	0.7964	0.7715	0.7527	0.7406	0.7355	0.7377
0.4	0.7413	0.7100	0.6862	0.6692	0.6601	0.6597
0.5	0.6981	0.6615	0.6321	0.6109	0.5985	0.5951
0.6	0.6578	0.6179	0.5890	0.5663	0.5503	0.5417
0.7	0.6289	0.5891	0.5555	0.5289	0.5107	0.5004
0.8	0.6059	0.5604	0.5251	0.5044	0.4880	0.4765
0.9	0.5828	0.5372	0.5096	0.4863	0.4702	0.4592
1.0	0.5619	0.5248	0.4942	0.4727	0.4573	0.4493
1.1	0.5502	0.5124	0.4826	0.4613	0.4507	0.4459
1.2	0.5413	0.5003	0.4722	0.4551	0.4477	0.4429
1.3	0.5323	0.4923	0.4646	0.4516	0.4451	0.4429
1.4	0.5234	0.4843	0.4596	0.4492	0.4429	0.4429
1.5	0.5150	0.4763	0.4558	0.4471	0.4429	0.4429
1.6	0.5096	0.4714	0.4538	0.4449	0.4429	0.4429
1.7	0.5042	0.4678	0.4521	0.4429	0.4429	0.4429
1.8	0.4988	0.4642	0.4505	0.4429	0.4429	0.4429
1.9	0.4933	0.4610	0.4489	0.4429	0.4429	0.4429
2.0	0.4879	0.4598	0.4472	0.4429	0.4429	0.4429
2.1	0.4841	0.4585	0.4456	0.4429	0.4429	0.4429
2.2	0.4820	0.4572	0.4440	0.4429	0.4429	0.4429
2.3	0.4798	0.4562	0.4429	0.4429	0.4429	0.4429
2.4	0.4777	0.4552	0.4429	0.4429	0.4429	0.4429
2.5	0.4755	0.4542	0.4429	0.4429	0.4429	0.4429
2.6	0.4734	0.4532	0.4429	0.4429	0.4429	0.4429
2.7	0.4712	0.4521	0.4429	0.4429	0.4429	0.4429
2.8	0.4699	0.4511	0.4429	0.4429	0.4429	0.4429
2.9	0.4694	0.4501	0.4429	0.4429	0.4429	0.4429
3.0	0.4688	0.4491	0.4429	0.4429	0.4429	0.4429

Table C16: Effective Shading Coefficients of Vertical Projection at Various Angles of Inclination

Orientation: North & South

R_2	0°	10°	20°	30°	40°	50°
0.1	0.9526	0.9534	0.9549	0.9571	0.9606	0.9638
0.2	0.9066	0.9082	0.9110	0.9155	0.9225	0.9289
0.3	0.8605	0.8630	0.8672	0.8739	0.8844	0.8940
0.4	0.8144	0.8177	0.8236	0.8325	0.8463	0.8591
0.5	0.7752	0.7800	0.7892	0.8005	0.8159	0.8277
0.6	0.7540	0.7563	0.7632	0.7768	0.7950	0.8078
0.7	0.7379	0.7434	0.7464	0.7560	0.7771	0.7920
0.8	0.7290	0.7306	0.7348	0.7423	0.7637	0.7807
0.9	0.7202	0.7230	0.7269	0.7319	0.7507	0.7699
1.0	0.7114	0.7183	0.7190	0.7246	0.7388	0.7595
1.1	0.7060	0.7137	0.7144	0.7173	0.7308	0.7523
1.2	0.7022	0.7091	0.7098	0.7099	0.7251	0.7451
1.3	0.7000	0.7045	0.7053	0.7055	0.7206	0.7379
1.4	0.6977	0.6999	0.7007	0.7022	0.7173	0.7307
1.5	0.6954	0.6961	0.6981	0.7003	0.7141	0.7236
1.6	0.6932	0.6939	0.6960	0.6983	0.7109	0.7173
1.7	0.6909	0.6916	0.6940	0.6964	0.7077	0.7131
1.8	0.6886	0.6894	0.6919	0.6945	0.7044	0.7105
1.9	0.6864	0.6889	0.6899	0.6926	0.7012	0.7078
2.0	0.6841	0.6886	0.6878	0.6907	0.6980	0.7052
2.1	0.6818	0.6884	0.6858	0.6888	0.6948	0.7056
2.2	0.6796	0.6881	0.6853	0.6869	0.6915	0.7000
2.3	0.6773	0.6879	0.6849	0.6849	0.6910	0.6979
2.4	0.6750	0.6876	0.6845	0.6830	0.6909	0.6967
2.5	0.6728	0.6873	0.6841	0.6811	0.6908	0.6954
2.6	0.6705	0.6871	0.6837	0.6792	0.6908	0.6942
2.7	0.6695	0.6868	0.6833	0.6773	0.6907	0.6930
2.8	0.6686	0.6866	0.6829	0.6754	0.6906	0.6917
2.9	0.6677	0.6863	0.6826	0.6735	0.6905	0.6905
3.0	0.6668	0.6860	0.6822	0.6716	0.6904	0.6893

Table C17: Effective Shading Coefficients of Vertical Projection at Various Angles of Inclination

Orientation: East & West

R_2	0°	10°	20°	30°	40°	50°
0.1	0.9805	0.9751	0.9704	0.9653	0.9584	0.9520
0.2	0.9607	0.9499	0.9406	0.9302	0.9166	0.9038
0.3	0.9409	0.9247	0.9108	0.8952	0.8747	0.8555
0.4	0.9223	0.9007	0.8821	0.8614	0.8338	0.8078
0.5	0.9047	0.8774	0.8537	0.8275	0.7931	0.7606
0.6	0.8870	0.8543	0.8259	0.7939	0.7523	0.7133
0.7	0.8694	0.8313	0.7980	0.7616	0.7129	0.6671
0.8	0.8518	0.8090	0.7728	0.7312	0.6753	0.6227
0.9	0.8348	0.7884	0.7476	0.7014	0.6406	0.5823
1.0	0.8193	0.7678	0.7233	0.6747	0.6098	0.5493
1.1	0.8057	0.7471	0.7015	0.6511	0.5850	0.5184
1.2	0.7921	0.7287	0.6810	0.6320	0.5605	0.4880
1.3	0.7785	0.7120	0.6631	0.6135	0.5361	0.4633
1.4	0.7654	0.6960	0.6482	0.5949	0.5120	0.4577
1.5	0.7541	0.6826	0.6334	0.5764	0.4899	0.4526
1.6	0.7441	0.6696	0.6187	0.5579	0.4820	0.4474
1.7	0.7349	0.6589	0.6042	0.5397	0.4790	0.4422
1.8	0.7257	0.6485	0.5906	0.5220	0.4760	0.4371
1.9	0.7185	0.6381	0.5770	0.5065	0.4730	0.4319
2.0	0.7122	0.6276	0.5634	0.4982	0.4700	0.4268
2.1	0.7070	0.6172	0.5497	0.4966	0.4670	0.4221
2.2	0.7036	0.6076	0.5362	0.4950	0.4641	0.4185
2.3	0.7019	0.5987	0.5232	0.4934	0.4611	0.4158
2.4	0.7007	0.5897	0.5101	0.4918	0.4581	0.4145
2.5	0.6999	0.5808	0.4971	0.4902	0.4551	0.4132
2.6	0.6990	0.5718	0.4849	0.4886	0.4521	0.4119
2.7	0.6982	0.5629	0.4747	0.4870	0.4491	0.4105
2.8	0.6974	0.5539	0.4668	0.4859	0.4461	0.4092
2.9	0.6965	0.5450	0.4616	0.4850	0.4431	0.4082
3.0	0.6957	0.5360	0.4591	0.4841	0.4401	0.4080

Table C18: Effective Shading Coefficients of Vertical Projection at Various Angles of Inclination

Orientation: North-East & North-West

R_2	0°	10°	20°	30°	40°	50°
0.1	0.9517	0.9445	0.9389	0.9346	0.9317	0.9314
0.2	0.9074	0.8931	0.8819	0.8729	0.8670	0.8650
0.3	0.8646	0.8436	0.8268	0.8131	0.8036	0.8005
0.4	0.8262	0.7991	0.7770	0.7585	0.7449	0.7381
0.5	0.7912	0.7573	0.7297	0.7066	0.6895	0.6809
0.6	0.7562	0.7155	0.6824	0.6546	0.6342	0.6239
0.7	0.7230	0.6740	0.6356	0.6043	0.5832	0.5701
0.8	0.6899	0.6352	0.6038	0.5836	0.5643	0.5493
0.9	0.6575	0.6158	0.5921	0.5683	0.5465	0.5296
1.0	0.6359	0.6069	0.5806	0.5530	0.5288	0.5104
1.1	0.6300	0.5981	0.5691	0.5380	0.5125	0.5005
1.2	0.6240	0.5892	0.5576	0.5241	0.5038	0.4958
1.3	0.6181	0.5803	0.5461	0.5146	0.4984	0.4915
1.4	0.6121	0.5715	0.5348	0.5091	0.4946	0.4898
1.5	0.6061	0.5626	0.5257	0.5050	0.4908	0.4884
1.6	0.6002	0.5537	0.5201	0.5028	0.4881	0.4869
1.7	0.5942	0.5449	0.5161	0.5006	0.4874	0.4854
1.8	0.5883	0.5365	0.5120	0.4985	0.4867	0.4840
1.9	0.5823	0.5291	0.5094	0.4963	0.4860	0.4825
2.0	0.5763	0.5235	0.5079	0.4941	0.4853	0.4811
2.1	0.5704	0.5198	0.5064	0.4939	0.4846	0.4798
2.2	0.5644	0.5166	0.5050	0.4936	0.4839	0.4795
2.3	0.5590	0.5135	0.5035	0.4933	0.4831	0.4791
2.4	0.5541	0.5104	0.5020	0.4931	0.4824	0.4788
2.5	0.5494	0.5073	0.5005	0.4928	0.4817	0.4785
2.6	0.5452	0.5042	0.4991	0.4925	0.4810	0.4781
2.7	0.5410	0.5027	0.4976	0.4923	0.4803	0.4778
2.8	0.5376	0.5014	0.4961	0.4920	0.4796	0.4775
2.9	0.5349	0.5002	0.4946	0.4917	0.4788	0.4772
3.0	0.5323	0.4989	0.4941	0.4914	0.4781	0.4768

Table C19: Effective Shading Coefficients of Vertical Projection at Various Angles of Inclination

Orientation: South-East & South-West

R_2	0°	10°	20°	30°	40°	50°
0.1	0.9528	0.9457	0.9396	0.9351	0.9317	0.9304
0.2	0.9081	0.8938	0.8815	0.8724	0.8654	0.8624
0.3	0.8650	0.8437	0.8253	0.8113	0.8005	0.7955
0.4	0.8257	0.7988	0.7746	0.7555	0.7395	0.7307
0.5	0.7907	0.7570	0.7269	0.7029	0.6829	0.6715
0.6	0.7561	0.7153	0.6791	0.6504	0.6264	0.6127
0.7	0.7229	0.6743	0.6313	0.5978	0.5698	0.5539
0.8	0.6897	0.6342	0.5861	0.5629	0.5412	0.5242
0.9	0.6565	0.5987	0.5700	0.5474	0.5235	0.5045
1.0	0.6233	0.5863	0.5584	0.5324	0.5059	0.4850
1.1	0.6056	0.5771	0.5470	0.5185	0.4894	0.4737
1.2	0.5983	0.5685	0.5357	0.5046	0.4792	0.4670
1.3	0.5915	0.5599	0.5244	0.4946	0.4717	0.4627
1.4	0.5853	0.5513	0.5130	0.4882	0.4677	0.4586
1.5	0.5791	0.5427	0.5037	0.4831	0.4642	0.4572
1.6	0.5730	0.5341	0.4966	0.4790	0.4612	0.4557
1.7	0.5668	0.5255	0.4915	0.4771	0.4583	0.4543
1.8	0.5606	0.5169	0.4876	0.4752	0.4577	0.4528
1.9	0.5547	0.5096	0.4836	0.4734	0.4571	0.4514
2.0	0.5499	0.5043	0.4796	0.4715	0.4565	0.4499
2.1	0.5451	0.4990	0.4772	0.4696	0.4558	0.4485
2.2	0.5403	0.4938	0.4757	0.4677	0.4552	0.4471
2.3	0.5355	0.4909	0.4741	0.4662	0.4546	0.4456
2.4	0.5307	0.4879	0.4726	0.4661	0.4540	0.4446
2.5	0.5258	0.4850	0.4711	0.4660	0.4534	0.4443
2.6	0.5210	0.4820	0.4695	0.4659	0.4528	0.4439
2.7	0.5168	0.4790	0.4680	0.4658	0.4522	0.4435
2.8	0.5135	0.4761	0.4665	0.4657	0.4516	0.4432
2.9	0.5110	0.4735	0.4649	0.4656	0.4510	0.4429
3.0	0.5084	0.4715	0.4634	0.4655	0.4504	0.4429

Table C20: Effective Shading Coefficients of Egg-Crate Louvers with Inclined Horizontal Fins

Orientation: North & South

R_1	R_2	0°	10°	20°	30°	40°
0.2	0.2	0.8125	0.8053	0.8011	0.8002	0.8025
0.2	0.4	0.7476	0.7432	0.7409	0.7409	0.7431
0.2	0.6	0.7086	0.7059	0.7047	0.7050	0.7068
0.2	0.8	0.6945	0.6926	0.6917	0.6920	0.6934
0.2	1.0	0.6850	0.6836	0.6829	0.6832	0.6843
0.2	1.2	0.6802	0.6790	0.6785	0.6787	0.6796
0.2	1.4	0.6779	0.6768	0.6764	0.6766	0.6774
0.2	1.6	0.6756	0.6747	0.6743	0.6744	0.6752
0.2	1.8	0.6733	0.6725	0.6722	0.6723	0.6729
0.4	0.2	0.7184	0.7070	0.7002	0.6977	0.6995
0.4	0.4	0.6808	0.6747	0.6716	0.6709	0.6727
0.4	0.6	0.6631	0.6604	0.6593	0.6594	0.6605
0.4	0.8	0.6601	0.6586	0.6581	0.6581	0.6587
0.4	1.0	0.6587	0.6580	0.6578	0.6578	0.6580
0.4	1.2	0.6582	0.6577	0.6577	0.6577	0.6577
0.4	1.4	0.6581	0.6577	0.6577	0.6577	0.6577
0.4	1.6	0.6581	0.6577	0.6577	0.6577	0.6577
0.4	1.8	0.6581	0.6577	0.6577	0.6577	0.6577
0.6	0.2	0.6840	0.6769	0.6728	0.6703	0.6687
0.6	0.4	0.6638	0.6618	0.6608	0.6602	0.6599
0.6	0.6	0.6577	0.6577	0.6577	0.6577	0.6577
0.6	0.8	0.6577	0.6577	0.6577	0.6577	0.6577
0.6	1.0	0.6577	0.6577	0.6577	0.6577	0.6577
0.6	1.2	0.6577	0.6577	0.6577	0.6577	0.6577
0.6	1.4	0.6577	0.6577	0.6577	0.6577	0.6577
0.6	1.6	0.6577	0.6577	0.6577	0.6577	0.6577
0.6	1.8	0.6577	0.6577	0.6577	0.6577	0.6577

Table C20: Effective Shading Coefficients of Egg-Crate Louvers with Inclined Horizontal Fins (Continue)

Orientation: North & South

R_1	R_2	0°	10°	20°	30°	40°
0.8	0.2	0.6740	0.6688	0.6645	0.6622	0.6612
0.8	0.4	0.6609	0.6598	0.6589	0.6584	0.6583
0.8	0.6	0.6577	0.6577	0.6577	0.6577	0.6577
0.8	0.8	0.6577	0.6577	0.6577	0.6577	0.6577
0.8	1.0	0.6577	0.6577	0.6577	0.6577	0.6577
0.8	1.2	0.6577	0.6577	0.6577	0.6577	0.6577
0.8	1.4	0.6577	0.6577	0.6577	0.6577	0.6577
0.8	1.6	0.6577	0.6577	0.6577	0.6577	0.6577
0.8	1.8	0.6577	0.6577	0.6577	0.6577	0.6577
1.0	0.2	0.6681	0.6638	0.6619	0.6603	0.6590
1.0	0.4	0.6595	0.6586	0.6584	0.6581	0.6579
1.0	0.6	0.6577	0.6577	0.6577	0.6577	0.6577
1.0	0.8	0.6577	0.6577	0.6577	0.6577	0.6577
1.0	1.0	0.6577	0.6577	0.6577	0.6577	0.6577
1.0	1.2	0.6577	0.6577	0.6577	0.6577	0.6577
1.0	1.4	0.6577	0.6577	0.6577	0.6577	0.6577
1.0	1.6	0.6577	0.6577	0.6577	0.6577	0.6577
1.0	1.8	0.6577	0.6577	0.6577	0.6577	0.6577
1.2	0.2	0.6651	0.6626	0.6603	0.6584	0.6577
1.2	0.4	0.6588	0.6585	0.6581	0.6578	0.6577
1.2	0.6	0.6577	0.6577	0.6577	0.6577	0.6577
1.2	0.8	0.6577	0.6577	0.6577	0.6577	0.6577
1.2	1.0	0.6577	0.6577	0.6577	0.6577	0.6577
1.2	1.2	0.6577	0.6577	0.6577	0.6577	0.6577
1.2	1.4	0.6577	0.6577	0.6577	0.6577	0.6577
1.2	1.6	0.6577	0.6577	0.6577	0.6577	0.6577
1.2	1.8	0.6577	0.6577	0.6577	0.6577	0.6577

Table C20: Effective Shading Coefficients of Egg-Crate Louvers with Inclined Horizontal Fins (Continue)

Orientation: North & South

R_1	R_2	0°	10°	20°	30°	40°
1.4	0.2	0.6642	0.6613	0.6587	0.6577	0.6577
1.4	0.4	0.6587	0.6583	0.6579	0.6577	0.6577
1.4	0.6	0.6577	0.6577	0.6577	0.6577	0.6577
1.4	0.8	0.6577	0.6577	0.6577	0.6577	0.6577
1.4	1.0	0.6577	0.6577	0.6577	0.6577	0.6577
1.4	1.2	0.6577	0.6577	0.6577	0.6577	0.6577
1.4	1.4	0.6577	0.6577	0.6577	0.6577	0.6577
1.4	1.6	0.6577	0.6577	0.6577	0.6577	0.6577
1.4	1.8	0.6577	0.6577	0.6577	0.6577	0.6577
1.6	0.2	0.6634	0.6601	0.6580	0.6577	0.6577
1.6	0.4	0.6586	0.6581	0.6578	0.6577	0.6577
1.6	0.6	0.6577	0.6577	0.6577	0.6577	0.6577
1.6	0.8	0.6577	0.6577	0.6577	0.6577	0.6577
1.6	1.0	0.6577	0.6577	0.6577	0.6577	0.6577
1.6	1.2	0.6577	0.6577	0.6577	0.6577	0.6577
1.6	1.4	0.6577	0.6577	0.6577	0.6577	0.6577
1.6	1.6	0.6577	0.6577	0.6577	0.6577	0.6577
1.6	1.8	0.6577	0.6577	0.6577	0.6577	0.6577
1.8	0.2	0.6626	0.6589	0.6577	0.6577	0.6577
1.8	0.4	0.6584	0.6579	0.6577	0.6577	0.6577
1.8	0.6	0.6577	0.6577	0.6577	0.6577	0.6577
1.8	0.8	0.6577	0.6577	0.6577	0.6577	0.6577
1.8	1.0	0.6577	0.6577	0.6577	0.6577	0.6577
1.8	1.2	0.6577	0.6577	0.6577	0.6577	0.6577
1.8	1.4	0.6577	0.6577	0.6577	0.6577	0.6577
1.8	1.6	0.6577	0.6577	0.6577	0.6577	0.6577
1.8	1.8	0.6577	0.6577	0.6577	0.6577	0.6577

Table C21: Effective Shading Coefficients of Egg-Crate Louvers with Inclined Horizontal Fins

Orientation: East & West

R_1	R_2	0°	10°	20°	30°	40°
0.2	0.2	0.8482	0.8306	0.8165	0.8064	0.8013
0.2	0.4	0.8212	0.8047	0.7914	0.7818	0.7769
0.2	0.6	0.7942	0.7788	0.7663	0.7572	0.7525
0.2	0.8	0.7672	0.7529	0.7412	0.7327	0.7282
0.2	1.0	0.7417	0.7284	0.7175	0.7095	0.7052
0.2	1.2	0.7190	0.7066	0.6965	0.6890	0.6850
0.2	1.4	0.6968	0.6852	0.6758	0.6688	0.6652
0.2	1.6	0.6786	0.6677	0.6589	0.6524	0.6490
0.2	1.8	0.6626	0.6523	0.6440	0.6379	0.6348
0.4	0.2	0.7513	0.7162	0.6883	0.6678	0.6556
0.4	0.4	0.7323	0.6993	0.6730	0.6535	0.6418
0.4	0.6	0.7133	0.6825	0.6577	0.6393	0.6280
0.4	0.8	0.6943	0.6656	0.6424	0.6251	0.6143
0.4	1.0	0.6754	0.6488	0.6271	0.6108	0.6006
0.4	1.2	0.6570	0.6322	0.6118	0.5967	0.5871
0.4	1.4	0.6389	0.6158	0.5968	0.5827	0.5738
0.4	1.6	0.6235	0.6017	0.5840	0.5708	0.5625
0.4	1.8	0.6096	0.5890	0.5723	0.5599	0.5523
0.6	0.2	0.6768	0.6307	0.5917	0.5611	0.5398
0.6	0.4	0.6626	0.6190	0.5822	0.5532	0.5329
0.6	0.6	0.6483	0.6073	0.5726	0.5452	0.5260
0.6	0.8	0.6341	0.5956	0.5630	0.5372	0.5191
0.6	1.0	0.6198	0.5840	0.5535	0.5293	0.5121
0.6	1.2	0.6056	0.5723	0.5439	0.5213	0.5052
0.6	1.4	0.5915	0.5607	0.5344	0.5134	0.4984
0.6	1.6	0.5788	0.5500	0.5254	0.5058	0.4917
0.6	1.8	0.5668	0.5398	0.5167	0.4983	0.4852

Table C21: Effective Shading Coefficients of Egg-Crate Louvers with Inclined Horizontal Fins (Continue)

Orientation: East & West

R_1	R_2	0°	10°	20°	30°	40°
0.8	0.2	0.6135	0.5615	0.5215	0.4881	0.4622
0.8	0.4	0.6033	0.5537	0.5157	0.4839	0.4593
0.8	0.6	0.5931	0.5459	0.5099	0.4798	0.4564
0.8	0.8	0.5829	0.5381	0.5041	0.4756	0.4534
0.8	1.0	0.5727	0.5304	0.4983	0.4714	0.4505
0.8	1.2	0.5625	0.5226	0.4925	0.4673	0.4476
0.8	1.4	0.5523	0.5148	0.4867	0.4631	0.4447
0.8	1.6	0.5421	0.5070	0.4809	0.4589	0.4418
0.8	1.8	0.5320	0.4992	0.4751	0.4548	0.4389
1.0	0.2	0.5744	0.5178	0.4695	0.4422	0.4212
1.0	0.4	0.5661	0.5123	0.4663	0.4401	0.4201
1.0	0.6	0.5578	0.5068	0.4631	0.4381	0.4191
1.0	0.8	0.5495	0.5014	0.4599	0.4361	0.4180
1.0	1.0	0.5412	0.4959	0.4567	0.4341	0.4170
1.0	1.2	0.5329	0.4904	0.4535	0.4321	0.4159
1.0	1.4	0.5246	0.4849	0.4503	0.4301	0.4149
1.0	1.6	0.5163	0.4795	0.4471	0.4280	0.4138
1.0	1.8	0.5080	0.4740	0.4439	0.4260	0.4128
1.2	0.2	0.5420	0.4791	0.4447	0.4144	0.4033
1.2	0.4	0.5354	0.4754	0.4426	0.4137	0.4030
1.2	0.6	0.5289	0.4717	0.4405	0.4130	0.4027
1.2	0.8	0.5223	0.4680	0.4384	0.4123	0.4024
1.2	1.0	0.5158	0.4643	0.4363	0.4117	0.4021
1.2	1.2	0.5092	0.4606	0.4342	0.4110	0.4018
1.2	1.4	0.5027	0.4569	0.4321	0.4103	0.4015
1.2	1.6	0.4961	0.4532	0.4300	0.4096	0.4012
1.2	1.8	0.4896	0.4495	0.4279	0.4089	0.4009

Table C21: Effective Shading Coefficients of Egg-Crate Louvers with Inclined Horizontal Fins (Continue)

Orientation: East & West

R_1	R_2	0°	10°	20°	30°	40°
1.4	0.2	0.5107	0.4621	0.4220	0.4055	0.3969
1.4	0.4	0.5058	0.4592	0.4210	0.4051	0.3969
1.4	0.6	0.5008	0.4563	0.4200	0.4047	0.3969
1.4	0.8	0.4959	0.4535	0.4190	0.4043	0.3969
1.4	1.0	0.4910	0.4506	0.4180	0.4039	0.3969
1.4	1.2	0.4860	0.4477	0.4170	0.4035	0.3969
1.4	1.4	0.4811	0.4449	0.4160	0.4031	0.3969
1.4	1.6	0.4762	0.4420	0.4150	0.4028	0.3969
1.4	1.8	0.4712	0.4391	0.4140	0.4024	0.3969
1.6	0.2	0.4951	0.4451	0.4117	0.3998	0.3963
1.6	0.4	0.4907	0.4431	0.4110	0.3997	0.3963
1.6	0.6	0.4863	0.4410	0.4103	0.3996	0.3963
1.6	0.8	0.4820	0.4390	0.4096	0.3995	0.3963
1.6	1.0	0.4776	0.4369	0.4089	0.3994	0.3963
1.6	1.2	0.4732	0.4349	0.4083	0.3993	0.3963
1.6	1.4	0.4688	0.4329	0.4076	0.3992	0.3963
1.6	1.6	0.4644	0.4308	0.4069	0.3991	0.3963
1.6	1.8	0.4600	0.4288	0.4062	0.3990	0.3963
1.8	0.2	0.4844	0.4281	0.4075	0.3963	0.3963
1.8	0.4	0.4805	0.4269	0.4070	0.3963	0.3963
1.8	0.6	0.4767	0.4257	0.4065	0.3963	0.3963
1.8	0.8	0.4728	0.4245	0.4061	0.3963	0.3963
1.8	1.0	0.4690	0.4233	0.4056	0.3963	0.3963
1.8	1.2	0.4651	0.4221	0.4051	0.3963	0.3963
1.8	1.4	0.4613	0.4208	0.4047	0.3963	0.3963
1.8	1.6	0.4574	0.4196	0.4042	0.3963	0.3963
1.8	1.8	0.4536	0.4184	0.4037	0.3963	0.3963

Table C22: Effective Shading Coefficients of Egg-Crate Louvers with Inclined Horizontal Fins

Orientation: North-East & North-West

R_1	R_2	0°	10°	20°	30°	40°
0.2	0.2	0.8019	0.7886	0.7788	0.7727	0.7705
0.2	0.4	0.7439	0.7331	0.7250	0.7198	0.7178
0.2	0.6	0.6944	0.6857	0.6790	0.6746	0.6727
0.2	0.8	0.6452	0.6384	0.6332	0.6298	0.6281
0.2	1.0	0.6024	0.5973	0.5935	0.5909	0.5897
0.2	1.2	0.5926	0.5880	0.5844	0.5820	0.5809
0.2	1.4	0.5829	0.5786	0.5754	0.5732	0.5722
0.2	1.6	0.5732	0.5693	0.5663	0.5644	0.5635
0.2	1.8	0.5634	0.5599	0.5573	0.5555	0.5548
0.4	0.2	0.7138	0.6898	0.6709	0.6573	0.6494
0.4	0.4	0.6724	0.6527	0.6371	0.6258	0.6192
0.4	0.6	0.6369	0.6207	0.6079	0.5986	0.5933
0.4	0.8	0.6013	0.5887	0.5787	0.5715	0.5673
0.4	1.0	0.5688	0.5593	0.5519	0.5466	0.5436
0.4	1.2	0.5613	0.5524	0.5455	0.5407	0.5380
0.4	1.4	0.5537	0.5456	0.5392	0.5348	0.5325
0.4	1.6	0.5462	0.5387	0.5329	0.5290	0.5270
0.4	1.8	0.5386	0.5318	0.5266	0.5231	0.5214
0.6	0.2	0.6479	0.6186	0.5951	0.5766	0.5636
0.6	0.4	0.6178	0.5934	0.5741	0.5588	0.5481
0.6	0.6	0.5920	0.5718	0.5560	0.5435	0.5348
0.6	0.8	0.5663	0.5502	0.5379	0.5282	0.5214
0.6	1.0	0.5416	0.5294	0.5204	0.5134	0.5085
0.6	1.2	0.5353	0.5240	0.5159	0.5095	0.5051
0.6	1.4	0.5289	0.5186	0.5113	0.5056	0.5018
0.6	1.6	0.5225	0.5132	0.5067	0.5017	0.4984
0.6	1.8	0.5161	0.5078	0.5022	0.4978	0.4950

Table C22: Effective Shading Coefficients of Egg-Crate Louvers with Inclined Horizontal Fins (Continue)

Orientation: North-East & North-West

R_1	R_2	0°	10°	20°	30°	40°
0.8	0.2	0.6089	0.5719	0.5445	0.5270	0.5133
0.8	0.4	0.5855	0.5551	0.5328	0.5182	0.5067
0.8	0.6	0.5652	0.5403	0.5225	0.5104	0.5010
0.8	0.8	0.5449	0.5255	0.5122	0.5027	0.4952
0.8	1.0	0.5252	0.5109	0.5019	0.4949	0.4895
0.8	1.2	0.5199	0.5070	0.4989	0.4927	0.4879
0.8	1.4	0.5147	0.5030	0.4960	0.4905	0.4863
0.8	1.6	0.5095	0.4991	0.4930	0.4883	0.4847
0.8	1.8	0.5042	0.4952	0.4900	0.4861	0.4831
1.0	0.2	0.5750	0.5440	0.5183	0.5005	0.4878
1.0	0.4	0.5579	0.5321	0.5105	0.4960	0.4856
1.0	0.6	0.5429	0.5218	0.5039	0.4922	0.4839
1.0	0.8	0.5279	0.5114	0.4972	0.4884	0.4822
1.0	1.0	0.5129	0.5010	0.4905	0.4847	0.4805
1.0	1.2	0.5087	0.4981	0.4888	0.4836	0.4799
1.0	1.4	0.5045	0.4952	0.4870	0.4825	0.4793
1.0	1.6	0.5002	0.4922	0.4852	0.4814	0.4787
1.0	1.8	0.4960	0.4893	0.4834	0.4803	0.4781
1.2	0.2	0.5577	0.5232	0.5002	0.4857	0.4802
1.2	0.4	0.5434	0.5144	0.4958	0.4838	0.4795
1.2	0.6	0.5309	0.5069	0.4922	0.4822	0.4787
1.2	0.8	0.5185	0.4994	0.4886	0.4806	0.4780
1.2	1.0	0.5060	0.4919	0.4850	0.4789	0.4773
1.2	1.2	0.5025	0.4900	0.4839	0.4785	0.4771
1.2	1.4	0.4990	0.4880	0.4827	0.4781	0.4769
1.2	1.6	0.4955	0.4860	0.4816	0.4777	0.4767
1.2	1.8	0.4919	0.4840	0.4804	0.4773	0.4765

Table C22: Effective Shading Coefficients of Egg-Crate Louvers with Inclined Horizontal Fins (Continue)

Orientation: North-East & North-West

R_1	R_2	0°	10°	20°	30°	40°
1.4	0.2	0.5424	0.5101	0.4894	0.4815	0.4759
1.4	0.4	0.5303	0.5039	0.4868	0.4805	0.4759
1.4	0.6	0.5199	0.4987	0.4846	0.4796	0.4759
1.4	0.8	0.5095	0.4936	0.4825	0.4786	0.4759
1.4	1.0	0.4991	0.4884	0.4803	0.4777	0.4759
1.4	1.2	0.4963	0.4868	0.4797	0.4774	0.4759
1.4	1.4	0.4935	0.4853	0.4791	0.4772	0.4759
1.4	1.6	0.4907	0.4837	0.4785	0.4770	0.4759
1.4	1.8	0.4879	0.4821	0.4779	0.4767	0.4759
1.6	0.2	0.5310	0.4994	0.4856	0.4777	0.4759
1.6	0.4	0.5208	0.4952	0.4838	0.4774	0.4759
1.6	0.6	0.5122	0.4917	0.4822	0.4771	0.4759
1.6	0.8	0.5036	0.4883	0.4806	0.4768	0.4759
1.6	1.0	0.4949	0.4848	0.4790	0.4765	0.4759
1.6	1.2	0.4926	0.4837	0.4785	0.4764	0.4759
1.6	1.4	0.4902	0.4825	0.4781	0.4763	0.4759
1.6	1.6	0.4879	0.4814	0.4777	0.4762	0.4759
1.6	1.8	0.4855	0.4803	0.4773	0.4761	0.4759
1.8	0.2	0.5221	0.4930	0.4826	0.4759	0.4759
1.8	0.4	0.5137	0.4897	0.4815	0.4759	0.4759
1.8	0.6	0.5067	0.4869	0.4803	0.4759	0.4759
1.8	0.8	0.4997	0.4841	0.4792	0.4759	0.4759
1.8	1.0	0.4926	0.4813	0.4780	0.4759	0.4759
1.8	1.2	0.4906	0.4806	0.4777	0.4759	0.4759
1.8	1.4	0.4885	0.4798	0.4775	0.4759	0.4759
1.8	1.6	0.4864	0.4791	0.4772	0.4759	0.4759
1.8	1.8	0.4843	0.4784	0.4769	0.4759	0.4759

Table C23: Effective Shading Coefficients of Egg-Crate Louvers with Inclined Horizontal Fins

Orientation: South-East & South-West

R_1	R_2	0°	10°	20°	30°	40°
0.2	0.2	0.7951	0.7808	0.7702	0.7634	0.7608
0.2	0.4	0.7351	0.7233	0.7144	0.7087	0.7064
0.2	0.6	0.6842	0.6745	0.6672	0.6623	0.6602
0.2	0.8	0.6340	0.6264	0.6205	0.6167	0.6149
0.2	1.0	0.5838	0.5782	0.5739	0.5710	0.5696
0.2	1.2	0.5669	0.5620	0.5581	0.5555	0.5542
0.2	1.4	0.5570	0.5525	0.5489	0.5465	0.5453
0.2	1.6	0.5471	0.5430	0.5397	0.5375	0.5364
0.2	1.8	0.5372	0.5334	0.5305	0.5285	0.5275
0.4	0.2	0.6979	0.6713	0.6510	0.6365	0.6285
0.4	0.4	0.6555	0.6334	0.6165	0.6044	0.5977
0.4	0.6	0.6193	0.6008	0.5868	0.5768	0.5713
0.4	0.8	0.5831	0.5683	0.5572	0.5492	0.5449
0.4	1.0	0.5469	0.5358	0.5275	0.5216	0.5185
0.4	1.2	0.5361	0.5263	0.5188	0.5135	0.5107
0.4	1.4	0.5286	0.5196	0.5127	0.5078	0.5053
0.4	1.6	0.5212	0.5129	0.5066	0.5022	0.4999
0.4	1.8	0.5137	0.5063	0.5005	0.4965	0.4944
0.6	0.2	0.6266	0.5923	0.5677	0.5483	0.5347
0.6	0.4	0.5959	0.5670	0.5466	0.5305	0.5192
0.6	0.6	0.5694	0.5452	0.5283	0.5150	0.5057
0.6	0.8	0.5430	0.5235	0.5101	0.4996	0.4923
0.6	1.0	0.5166	0.5018	0.4919	0.4842	0.4788
0.6	1.2	0.5091	0.4957	0.4868	0.4798	0.4751
0.6	1.4	0.5030	0.4905	0.4824	0.4761	0.4718
0.6	1.6	0.4969	0.4853	0.4780	0.4723	0.4685
0.6	1.8	0.4907	0.4801	0.4736	0.4685	0.4652

Table C23: Effective Shading Coefficients of Egg-Crate Louvers with Inclined Horizontal Fins (Continue)

Orientation: South-East & South-West

R_1	R_2	0°	10°	20°	30°	40°
0.8	0.2	0.5821	0.5434	0.5133	0.4954	0.4814
0.8	0.4	0.5586	0.5264	0.5016	0.4865	0.4747
0.8	0.6	0.5381	0.5114	0.4912	0.4787	0.4689
0.8	0.8	0.5176	0.4964	0.4808	0.4709	0.4631
0.8	1.0	0.4971	0.4815	0.4705	0.4630	0.4573
0.8	1.2	0.4914	0.4773	0.4675	0.4609	0.4557
0.8	1.4	0.4863	0.4734	0.4646	0.4587	0.4541
0.8	1.6	0.4812	0.4695	0.4616	0.4565	0.4525
0.8	1.8	0.4761	0.4656	0.4587	0.4543	0.4509
1.0	0.2	0.5448	0.5129	0.4864	0.4682	0.4552
1.0	0.4	0.5277	0.5009	0.4786	0.4637	0.4531
1.0	0.6	0.5125	0.4904	0.4719	0.4599	0.4514
1.0	0.8	0.4973	0.4800	0.4652	0.4561	0.4497
1.0	1.0	0.4822	0.4695	0.4585	0.4523	0.4480
1.0	1.2	0.4779	0.4666	0.4566	0.4512	0.4474
1.0	1.4	0.4738	0.4637	0.4548	0.4501	0.4468
1.0	1.6	0.4696	0.4608	0.4530	0.4490	0.4461
1.0	1.8	0.4654	0.4579	0.4512	0.4478	0.4455
1.2	0.2	0.5269	0.4915	0.4679	0.4532	0.4471
1.2	0.4	0.5125	0.4827	0.4636	0.4513	0.4464
1.2	0.6	0.5000	0.4751	0.4600	0.4497	0.4457
1.2	0.8	0.4874	0.4675	0.4564	0.4481	0.4450
1.2	1.0	0.4748	0.4600	0.4528	0.4465	0.4443
1.2	1.2	0.4713	0.4579	0.4516	0.4461	0.4441
1.2	1.4	0.4678	0.4559	0.4504	0.4456	0.4439
1.2	1.6	0.4643	0.4539	0.4493	0.4452	0.4438
1.2	1.8	0.4608	0.4519	0.4481	0.4447	0.4436

Table C23: Effective Shading Coefficients of Egg-Crate Louvers with Inclined Horizontal Fins (Continue)

Orientation: South-East & South-West

R_1	R_2	0°	10°	20°	30°	40°
1.4	0.2	0.5112	0.4781	0.4571	0.4483	0.4429
1.4	0.4	0.4991	0.4719	0.4545	0.4474	0.4429
1.4	0.6	0.4886	0.4668	0.4524	0.4465	0.4429
1.4	0.8	0.4781	0.4616	0.4502	0.4456	0.4429
1.4	1.0	0.4676	0.4564	0.4481	0.4447	0.4429
1.4	1.2	0.4647	0.4548	0.4474	0.4445	0.4429
1.4	1.4	0.4619	0.4532	0.4468	0.4442	0.4429
1.4	1.6	0.4590	0.4516	0.4462	0.4440	0.4429
1.4	1.8	0.4562	0.4500	0.4455	0.4438	0.4429
1.6	0.2	0.4995	0.4672	0.4522	0.4446	0.4429
1.6	0.4	0.4893	0.4631	0.4506	0.4443	0.4429
1.6	0.6	0.4806	0.4597	0.4491	0.4440	0.4429
1.6	0.8	0.4719	0.4563	0.4475	0.4437	0.4429
1.6	1.0	0.4633	0.4529	0.4460	0.4435	0.4429
1.6	1.2	0.4608	0.4517	0.4456	0.4434	0.4429
1.6	1.4	0.4584	0.4505	0.4452	0.4433	0.4429
1.6	1.6	0.4560	0.4493	0.4448	0.4432	0.4429
1.6	1.8	0.4536	0.4481	0.4444	0.4432	0.4429
1.8	0.2	0.4904	0.4609	0.4494	0.4429	0.4429
1.8	0.4	0.4821	0.4576	0.4483	0.4429	0.4429
1.8	0.6	0.4750	0.4549	0.4472	0.4429	0.4429
1.8	0.8	0.4680	0.4521	0.4461	0.4429	0.4429
1.8	1.0	0.4610	0.4493	0.4451	0.4429	0.4429
1.8	1.2	0.4588	0.4485	0.4448	0.4429	0.4429
1.8	1.4	0.4567	0.4477	0.4445	0.4429	0.4429
1.8	1.6	0.4545	0.4470	0.4442	0.4429	0.4429
1.8	1.8	0.4524	0.4462	0.4440	0.4429	0.4429

APPENDIX D

D1 Example of ETTV Calculation for an office building

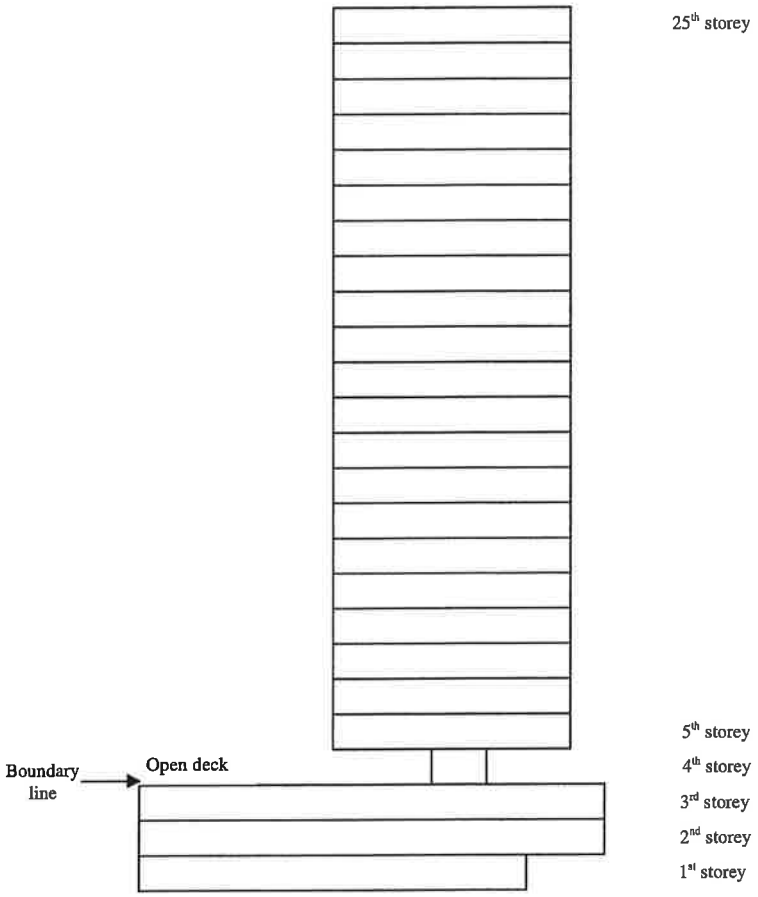
D1.1 Brief Description of Building

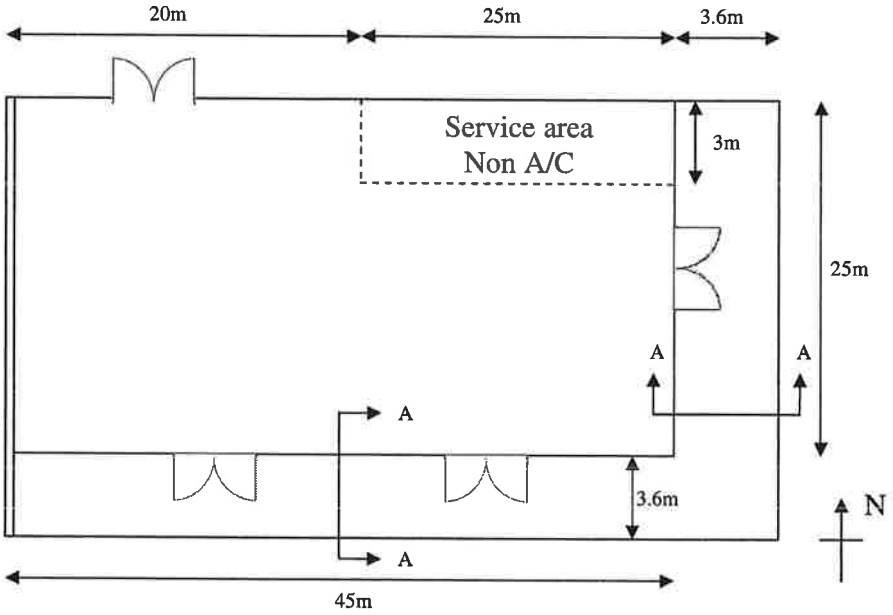
The 25-storey office building consists of a 4-storey rectangular podium and a 21-storey square tower. The building is orientated in the North, East, South and West directions with the front façade facing the south. While all the other façades are exposed to the weather, the west façade of the podium is joined to the neighbouring building by a 230mm brick party wall.

With the exception of the 4th storey open deck which is a landscaped roof garden-cum-café, the other storeys are all centrally air-conditioned. Hence the ETTV calculation covers only the 24 air-conditioned storeys. The basement which houses the car park and plant room is not included in the calculation as it is completely submerged.

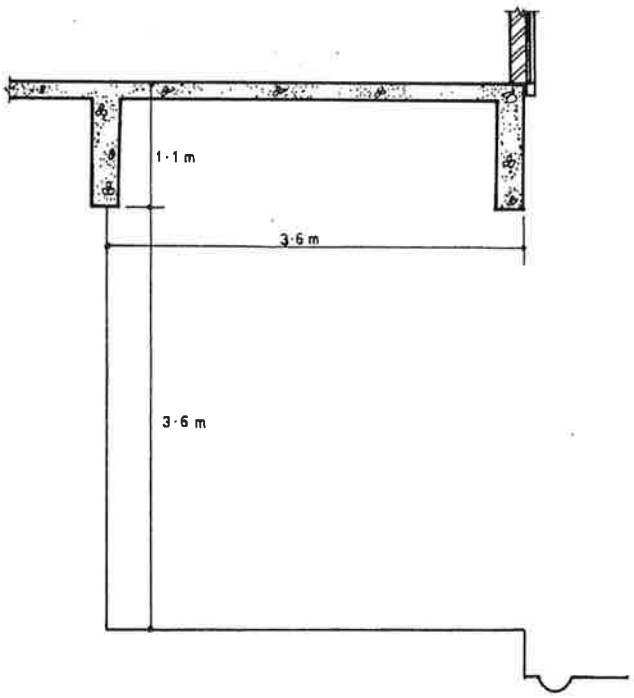
The envelope design consists essentially of a flush curtain wall construction with double glazing for the tower block as well as the east and south façades of the podium. The 1st storey facades on the east and south consist of an almost full height glass envelope shaded by a continuous overhang.

Sketch Drawing on Envelope Details

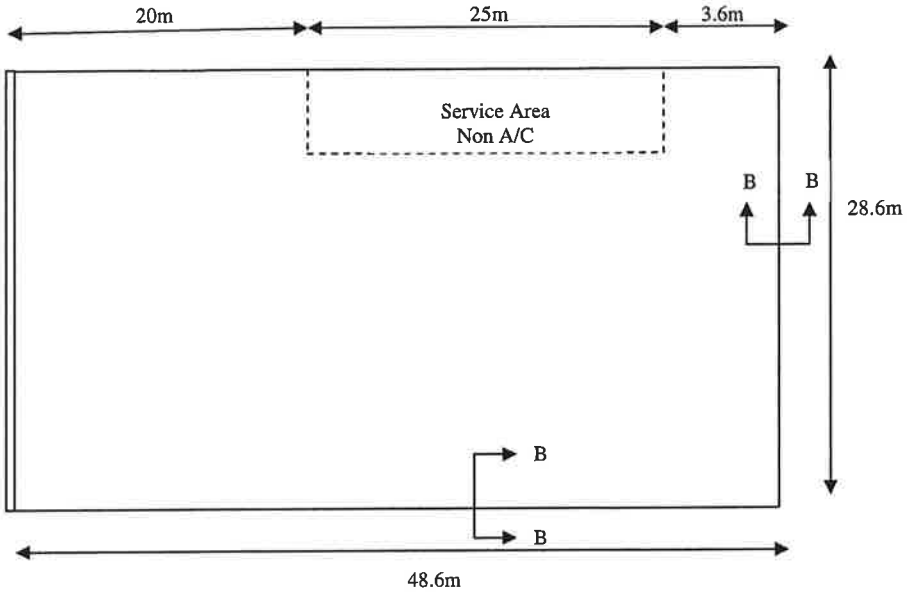




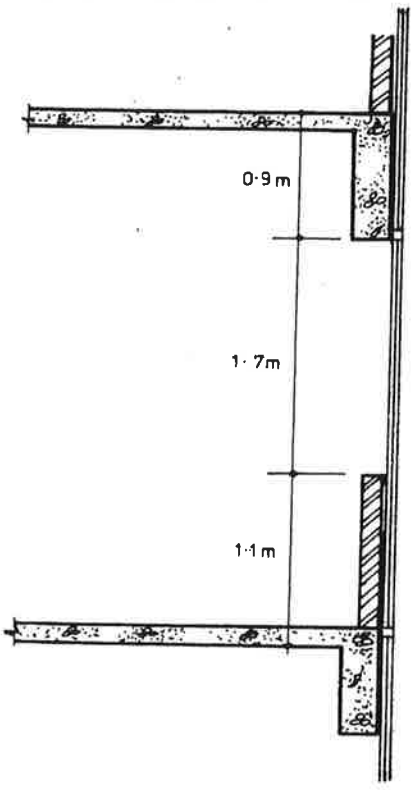
1st STOREY PLAN



SECTION A - A



2nd & 3rd STOREY PLAN



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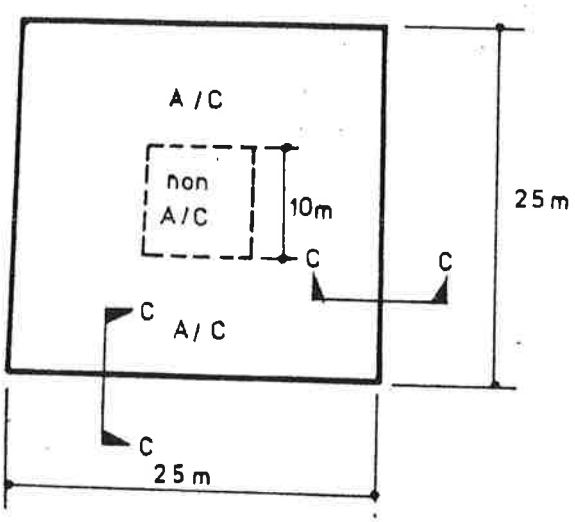
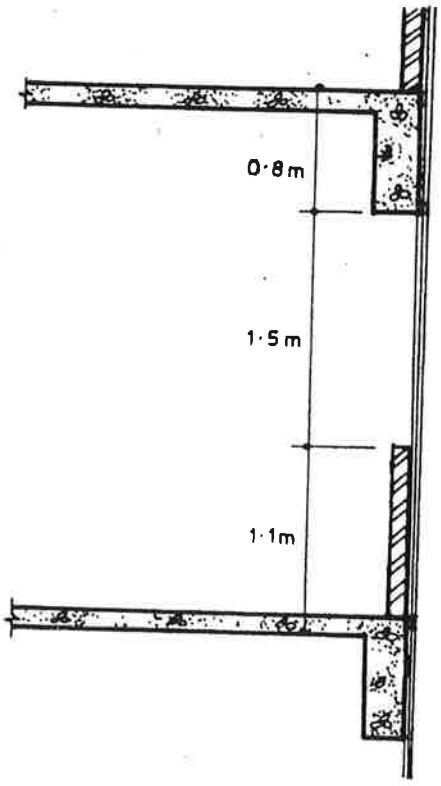


5th - 25th STOREY PLAN



SECTION C – C

D1.2 Envelope Area Calculation

D1.2.1 Podium: 1st Storey

(i) South façade:

(a) Single glazing Af_1 = 3.6 x 45 = 162.0m^2

(b) r.c beam Aw_1 = 1.1 x 45 = 49.5m^2

(ii) East façade:

(a) Single glazing Af_1 = 3.6 x (25 - 3) = 79.2m^2

(b) r.c beam Aw_1 = 1.1 x (25 - 3) = 24.2m^2

(iii) North façade:

(a) 200mm r.c wall Aw_2 = 4.7 x 20 = 94.0m^2

(iv) West façade:

As the 230mm thick brick-wall is a part wall which is not exposed to the outside, it is not included in the calculation.

D1.2.2 Podium: 2nd and 3rd Storeys (2 Storeys)

(i) South facade:

(a) Double glazing Af_2 = 1.7 x 48.6 x 2 = 165.2m^2

(b) r.c beam with glass cladding Aw_3 = 0.9 x 48.6 x 2 = 87.5m^2

(c) Brick parapet Aw_4 = 1.1 x 48.6 x 2 = 106.9m^2

(ii) East facade:

(a) Double glazing Af_2 = 1.7 x 28.6 x 2 = 97.2m^2

(b) r.c beam with glass cladding Aw_3 = 0.9 x 28.6 x 2 = 51.5m^2

(c) Brick parapet Aw_4 = 1.1 x 28.6 x 2 = 62.9m^2

(iii) North facade:

(a) 200mm r.c wall Aw_2 = 3.7 x (20 + 3.6) x 2 = 74.6m^2

(iv) West facade:

Similar to D1.2.1 (iv)

D1.2.3 Tower Block: 5th to 25th Storeys (21 Storeys)

(i) South facade:

(a) Double glazing Af_2 = 1.5 x 25 x 21 = 787.5m^2

(b) r.c beam with glass cladding Aw_3 = 0.8 x 25 x 21 = 420.0m^2

(c) Brick parapet Aw_4 = 1.1 x 25 x 21 = 577.5m^2

(ii) East facade:

Similar to D1.2.3 (i) above

(iii) North facade:

Similar to D1.2.3 (i) above

(iv) West facade:

Similar to D1.2.3 (i) above

Summary of Envelope Area

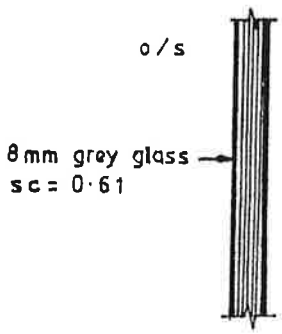
Facade Orientation	Podium 1st Storey	Podium 2nd and 3rd Storeys	Tower 5th - 25th Storeys	Total
South	Single glazing Af_1= 162.0m^2 r.c beam Aw_1=49.5m^2	Double glazing Af_2= 165.2m^2 r.c beam with glass cladding Aw_3 = 87.5m^2 Brick parapet with glass cladding Aw_4= 106.9m^2	Double glazing Af_2= 787.5m^2 r.c beam with glass cladding Aw_3= 420.0m^2 Brick parapet Aw_4= 577.5m^2	Af_1= 162.0m^2 Af_2= 952.7m^2 Aw_1=49.5m^2 Aw_3= 507.5m^2 Aw_4= 684.4m^2 **A_o=2356.1m^2**
East	Single glazing Af_1 =79.2m^2 r.c beam Aw_1= 24.2m^2	Double glazing Af_2= 97.2m^2 r.c beam with Aw_3=51.5m^2 glass cladding Brick parapet Aw_4= 62.9m^2	Double glazing Af_2= 787.5m^2 r.c beam with glass cladding Aw_3= 420.0m^2 Brick parapet Aw_4= 577.5m^2	Af_1= 79.2m^2 Af_2= 884.7m^2 Aw_1=24.2m^2 Aw_3= 471.5m^2 Aw_4= 640.4m^2 **A_o=2100m^2**

North	r.c wall Aw_2= 94m^2	r.c wall Aw_2= 174.6m^2	Double glazing Af_2= 787.5m^2 r.c beam with glass cladding Aw_3= 420.0m^2 Brick parapet Aw_4= 577.5m^2	Af_2= 787.5m^2 Aw_2=268.6m^2 Aw_3= 420.0m^2 Aw_4= 577.5m^2 **A_o=2053.6m^2**
West	-	-	Double glazing Af_2= 787.5m^2 r.c beam with glass cladding Aw_3= 420.0m^2 Brick parapet Aw_4= 577.5m^2	Af_2= 787.5m^2 Aw_3= 420.0m^2 Aw_4= 577.5m^2 **A_o=2356.1m^2**

D1.3 U-Value Calculation

D1.3.1 Podium: 1st Storey

(a) 8mm single glazing (South & East Facades)

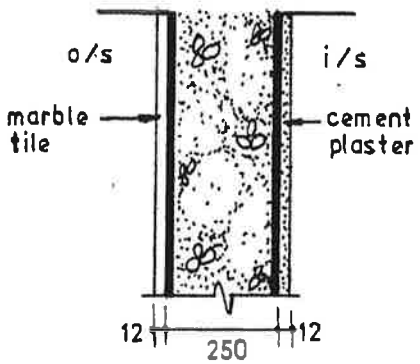


$$R = 0.044 + \frac{0.008}{1.053} + 0.12 = 0.172 m^2K/W$$

$$U = \frac{1}{R} = 5.82 W/m^2K$$

SC_g = 0.61 (by manufacturer)

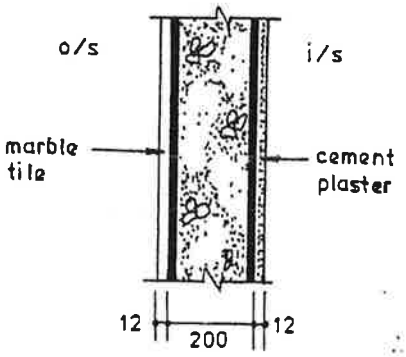
(b) 250mm r.c beam (South and East facades)



$$R = 0.044 + \frac{0.012}{1.298} + \frac{0.250}{1.442} + \frac{0.012}{0.533} + 0.12 = 0.369 m^2K/W$$

$$U = \frac{1}{R} = 2.71 W/m^2K$$

(c) 200mm r.c beam (North facades)

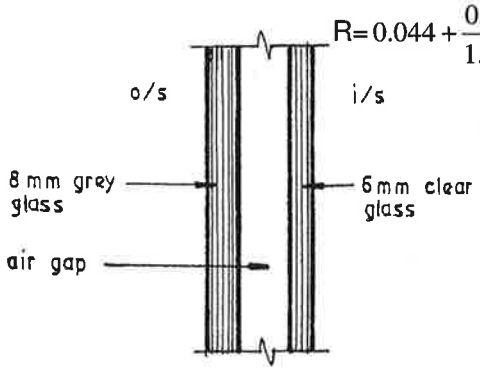


$$R = 0.044 + \frac{0.012}{1.298} + \frac{0.200}{1.442} + \frac{0.012}{0.533} + 0.12 = 0.334 m^2K/W$$

$$U = \frac{1}{R} = 2.99 W/m^2K$$

D1.3.2 Podium: 2nd & 3rd Storeys

(a) Double glazing (South & East Facades)

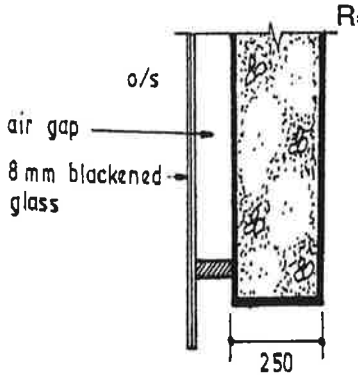


$$R = 0.044 + \frac{0.008}{1.053} + 0.16 + \frac{0.008}{1.053} + 0.12 = 0.337 m^2K/W$$

$$U = \frac{1}{R} = 2.96 W/m^2K$$

SC_g = 0.47 (by manufacturer)

(b) 250mm r.c beam with glass cladding (South and East facades)

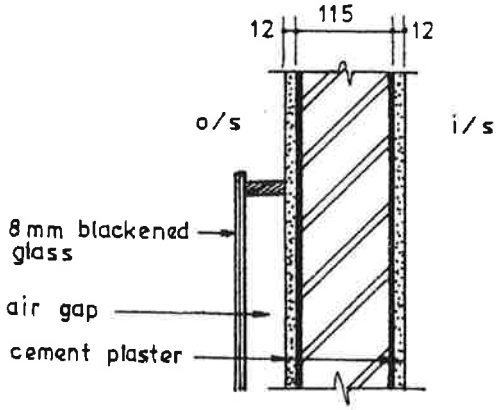


$$R = 0.044 + \frac{0.012}{1.053} + 0.16 + \frac{0.250}{1.442} + 0.12 = 0.505 m^2K/W$$

$$U = \frac{1}{R} = 1.98 W/m^2K$$

(c) 115mm brick parapet with glass cladding (South & East facades)

$$R = 0.044 + \frac{0.008}{1.053} + 0.16 + \frac{0.200}{1.442} + \frac{0.115}{0.807} + \frac{0.012}{0.533} + 0.12 = 0.519 m^2K/W$$



$$U = \frac{1}{R} = 1.93 W/m^2K$$

(d) 200mm r.c wall (North (c))

Same as D1.3.1 (c)

D1.3.3 Tower: 5th -25th Storeys

(a) Double glazing (all facades)

Same as D1.3.2 (a)

(b) 250mm r.c beam with glass cladding (all facades)

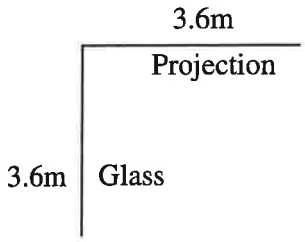
Same as D1.3.2 (b)

(c) 115mm brick parapet with glass cladding (all facades)

Same as D1.3.2 (c)

D1.4 Overhang

For 1st Storey only (South & East facades)



$$R_1 = \frac{P}{H} = \frac{3.6}{3.6} = 1.0$$

From Tables C12 & C13

SC_{ef} = 0.68 (South)
= 0.58 (East)

D1.5 ETTV Calculation

General Equation

$ETTV = 1/A_o\,[12(A_w \times U_w) + 3.4(A_f \times U_f) + 211 \times CF\,(A_f \times SC)]$

D1.5.1 South façade (CF =0.58)

$ETTV_S = 1/2356.1[12(49.5\times2.7+507.5\times1.98+684.4\times1.93) + 3.4 (162\times5.82 + 952.7\times2.96) +211\times0.58(162\times0.61\times0.68+ 952.7\times0.47)]$

$= 44.7\ W/m^2$

D1.5.2 East facade (CF =0.77)

$ETTV_E = 1/2100[12(24.2\times2.71+471.5\times1.98+640\times1.93) +3.4(79.2\times5.82+ 884.7\times2.96) +211\times0.77(79.2\times0.61\times0.58 + 884.7\times0.47)]$

$= 52.1W/m^2$

D1.5.3 North facade (CF =0.57)

$ETTV_N = 1/2053.6[12(268.6\times2.99+420\times1.98+577.5\times1.93) +3.4(787.5\times2.96) + 211\times0.57(787.5\times0.47)]$

$= 41.6W/m^2$

D1.5.4 West façade (CF =0.87)

$ETTV_W = 1/1785[12(420\times1.98+577.5\times1.93) +3.4(787.5\times2.96) + 211\times0.87(787.5\times0.47)]$

$= 55.6W/m^2$

D1.5.5 Overall for Whole Building

$ETTV = (44.7\times2356.1+52.1\times2100+41.6\times2053.6+55.6\times1785) / (2356.1+2100+2053.6+1785)$

$= 48.2\ W/m^2$

APPENDIX E

E1 Example of RETV Calculation

E1.1 Brief Description of Building

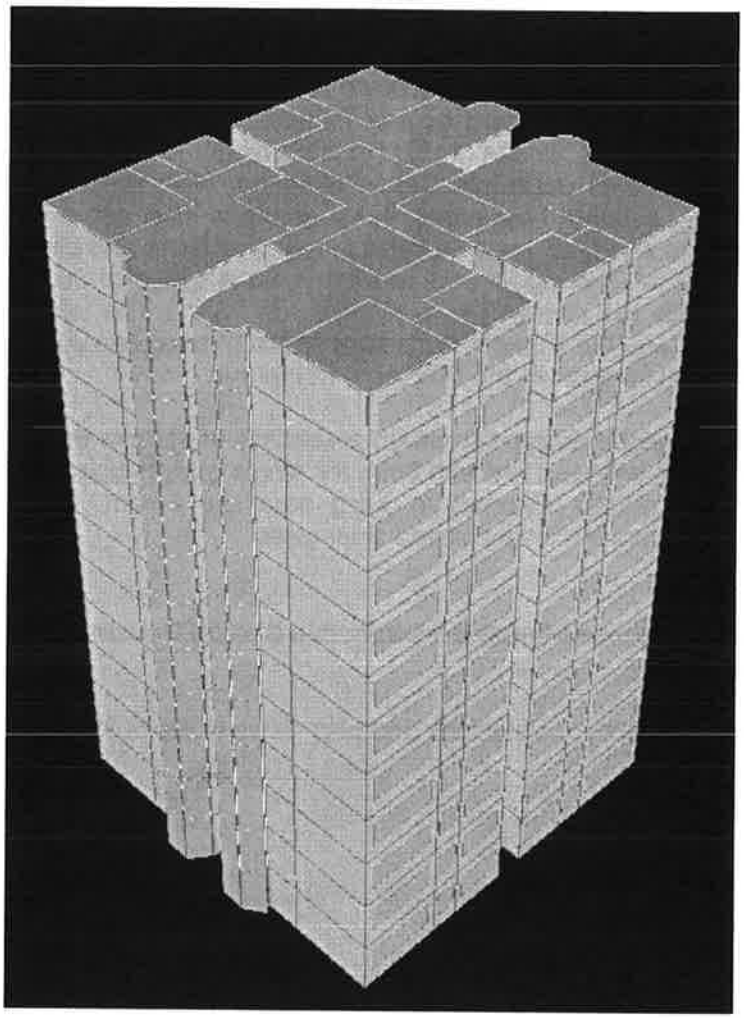
The 12-storey residential building is a point block. The block has a symmetrical cross section and its four facades face the North, South, East and West orientation. It has a floor-to-floor height of 3.2 m. Each storey houses 4 apartments, each with 150 m^2 of space. Within each apartment are 2 bedrooms of different floor areas, living, dining, a toilet and a kitchen. Both the toilet and the kitchen are non-conditioned. The living and dining occupies a space of 72 m^2.The bigger bedroom occupies a space of 36 m^2 within the apartment while the smaller bedroom occupies 16 m^2. The toilet occupies a space of 6 m^2 and the kitchen has a floor space of occupies 20 m^2. The floor plan is identical for each of the building's 12 storeys.

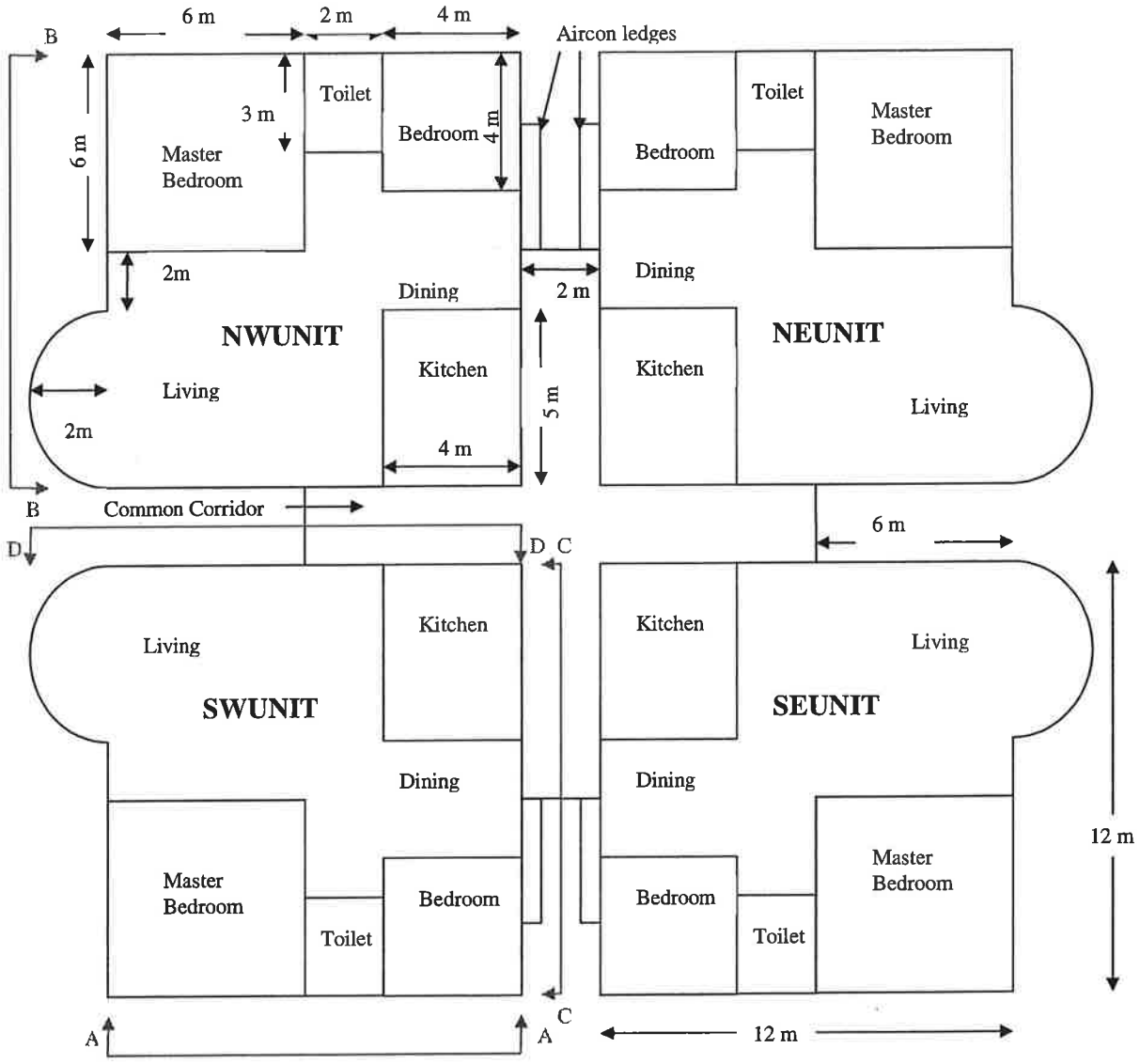
The envelope design makes up essentially of 150mm thk prefab walls. All the bedroom windows are with 8mm thk single glazed clear glass. The full height double glazed windows at living area are 24mm thk. The dining windows are 12mm thk single glazed clear glass.

E1.2 Building Floor Plan and Perspective Sketch Drawing on Envelope Details

The perspective, elevations and plan views of the building are shown in the figures below.

Perspective of Building

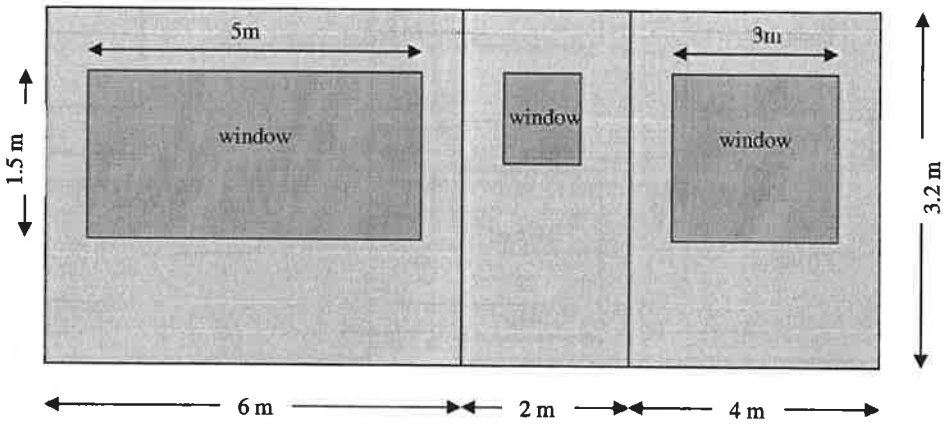




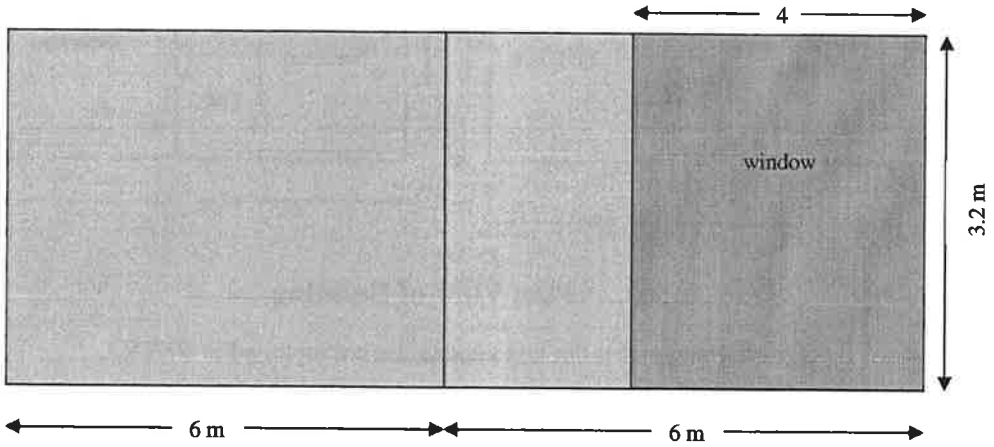
Plan View of Building

Exterior walls of toilet and kitchen are not included in RETV calculations

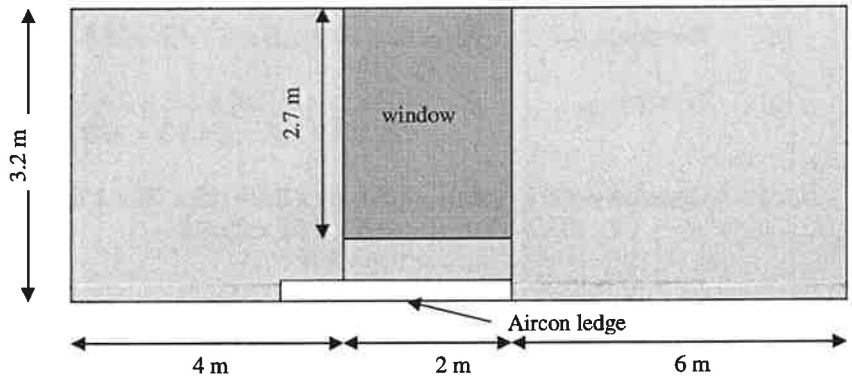
Elevation A-A
(For each typical apartment at each level)



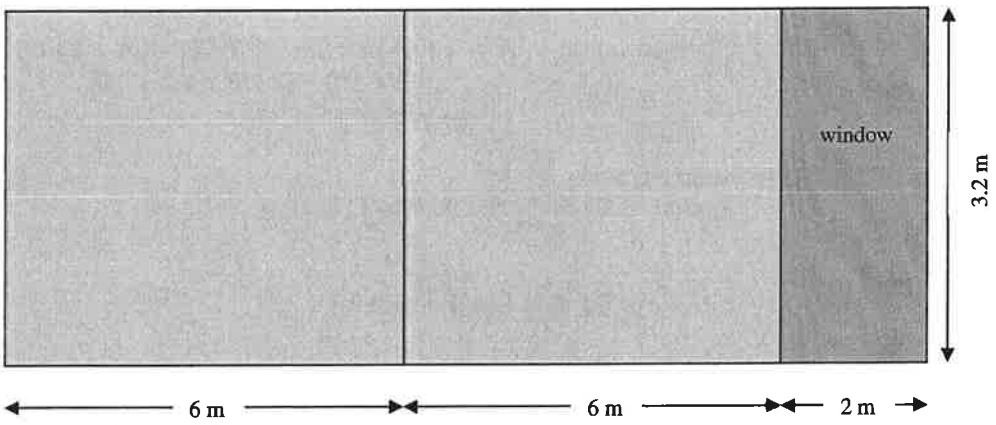
Elevation B-B
(For each typical apartment at each level)



Elevation C-C
(For each typical apartment at each level)



Elevation D-D
(For each typical apartment at each level)



E1.3 Envelope Area Calculation

Note: Exterior walls of toilet and kitchen are not included in RETV calculations.

(i) South Facade (*incls the south facade of unit NWUNIT & NEUNIT*):

(a) Window $_{bdrm}$ $Af_1 = (5 + 3) \times 1.5 \times 2 \times 12 = 288\ m^2$

(b) Window $_{Liv}$ $Af_2 = [(2 \times \pi \times 2)/16] \times 3.2 \times 2 \times 12 + [(2 \times \pi \times 2)/16] \times 3.2 \times 2 \times 12 = 120.64\ m^2$

(c) Opaque wall $Aw_1 = [(6 + 4) \times 3.2 - (5 + 3) \times 1.5] \times 2 \times 12 + (8 \times 3.2) \times 2 \times 12 = 1094.4\ m^2$

(ii) South-West Facade:

(a) Window $_{Liv}$ $Af_2 = [(2 \times \pi \times 2) \times 2/16] \times 3.2 \times 2 \times 12 = 120.64\ m^2$

(iii) West Facade *(incls the west facade of unit NEUNIT & SEUNIT)*:

(a) Window $_{Liv}$ $Af_2 = [(2 \times \pi \times 2) \times 2/16] \times 3.2 \times 2 \times 12 = 120.64\ m^2$

(b) Window $_{Din}$ $Af_3 = 2 \times 2.7 \times 2 \times 12 = 129.6\ m^2$

(c) Opaque wall $Aw_1 = [(6+2) \times 3.2 \times 2 \times 12] + [(4 + 3) \times 3.2 \times 2 \times 12] - (2 \times 2.7 \times 2 \times 12) = 1022.4\ m^2$

(vi) North-West Facade:
Similar to E1.3 (ii) South-West Facade

(iv) North Facade:
Similar to E1.3 (i) South Facade

(vi) North-East Facade:
Similar to E1.3 (ii) South-West Facade

(v) East Facade:
Similar to E1.3 (iii) West Facade

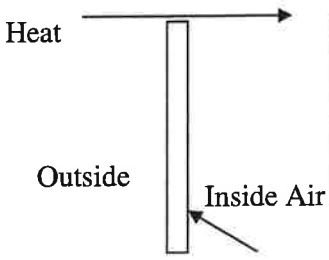
(vi) South-East Facade:
Similar to E1.3 (ii) South-West Facade

Summary of Envelope Area

Facade Orientation	1st to 12th Storeys		Total
South	Window $_{bdrm}$ Window $_{Liv}$ Opaque wall	$Af_1 = 288\ m^2$ $Af_2 = 120.64 m^2$ $Aw_1 = 1094.4\ m^2$	$Af_1 = 288\ m^2$ $Af_2 = 120.64 m^2$ $Aw_1 = 1094.4\ m^2$ $A_o = 1503.04\ m^2$
South-West	Window $_{Liv}$	$Af_2 = 120.64\ m^2$	$Af_2 = 120.64\ m^2$ $A_o = 120.64\ m^2$
West	Window $_{Liv}$ Window $_{Din}$ Opaque wall	$Af_2 = 120.64\ m^2$ $Af_3 = 129.6\ m^2$ $Aw_1 = 1022.4\ m^2$	$Af_2 = 120.64\ m^2$ $Af_3 = 129.6\ m^2$ $Aw_1 = 1022.4\ m^2$ $A_o = 1272.64\ m^2$
North-West	Glass wall	$Af_2 = 120.64\ m^2$	$Af_2 = 120.64\ m^2$ $A_o = 120.64\ m^2$
North	Window $_{bdrm}$ Window $_{Liv}$ Opaque wall	$Af_1 = 288\ m^2$ $Af_2 = 120.64\ m^2$ $Aw_1 = 1094.4\ m^2$	$Af_1 = 288\ m^2$ $Af_2 = 120.64\ m^2$ $Aw_1 = 1094.4\ m^2$ $A_o = 1503.04\ m^2$
North-East	Window $_{Liv}$	$Af_2 = 120.64\ m^2$	$Af_2 = 120.64\ m^2$ $A_o = 120.64\ m^2$
East	Window $_{Liv}$ Window $_{Din}$ Opaque wall	$Af_2 = 120.64\ m^2$ $Af_{1D} = 129.6\ m^2$ $Aw_1 = 1022.4\ m^2$	$Af_2 = 120.64\ m^2$ $Af_3 = 129.6\ m^2$ $Aw_1 = 1022.4\ m^2$ $A_o = 1272.64\ m^2$
South-East	Window $_{Liv}$	$Af_2 = 120.64\ m^2$	$Af_2 = 120.64\ m^2$ $A_o = 120.64\ m^2$

E1.4 U-Value Calculation

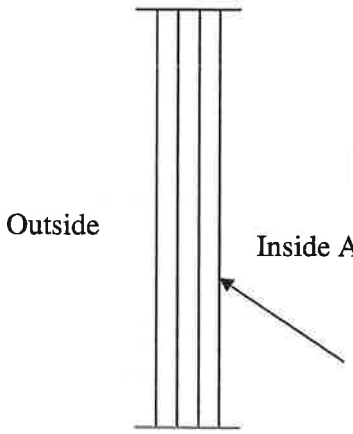
(a) 8mm single glazing (for all the bedroom's windows)



Component	b/k	R
Outside air film		0.044
8mm thk glass	0.008/1.053	0.0076
Inside air flim		0.12
Total R		0.172

$U = 1/R = 5.82\ W/m^2K$
SC = 0.7 (by manufacturer)

(b) 24mm tempered glass wall (for all living windows)

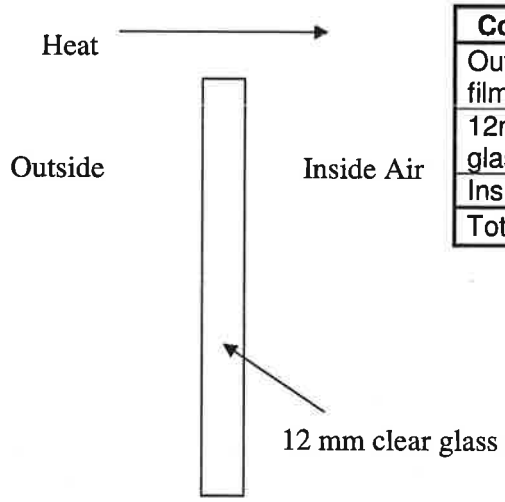


Component	b/k	R
Outside air film		0.044
8mm thk glass	0.008/1.053	0.0076
8mm air gap		0.118
8mm thk glass	0.008/1.053	0.0076
Inside air flim		0.12
Total R		0.290

$U = 1/R = 3.448\ W/m^2K$

SC = 0.5 (by manufacturer)

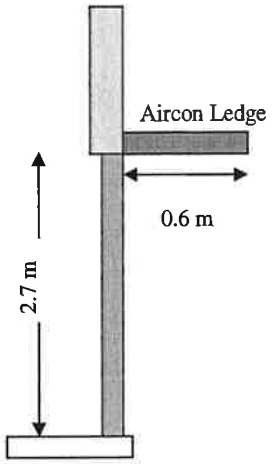
(c) 12mm single glazed tempered dining window with aircon ledge as shading device.



Component	b/k	R
Outside air film		0.044
12mm thk glass	0.012/1.053	0.0114
Inside air flim		0.12
Total R		0.175

$U = 1/R = 5.7\ W/\ m^2K$

SC = 0.61 (By manufacturer)



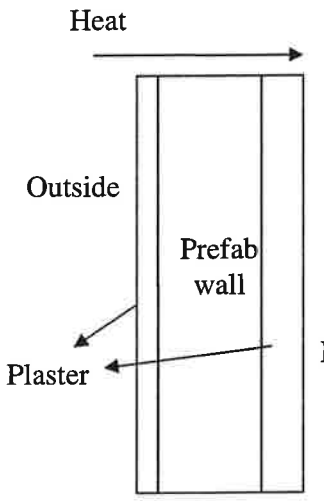
Since R_1 = P/H = 0.6/(2.7) = 0.2222
and $\Phi_1 = 0°$

For East or West orientation, from Table C13,

SC of external shading device = 0.8742

Overall SC for this window
with shading device = 0.61 x 0.8742 = 0.533

(d) 150mm thk prefab wall (2400kg/m3) with 5 mm thk plaster on outside and 15 mm thk on the inside



Component	b/k	R
Outside air film		0.044
5mm thk plaster	0.005/0.533	0.0094
150mm thk prefab	0.15/1.442	0.104
15mm thk plaster	0.015/0.533	0.0281
Inside air flim		0.12
Total R		0.306

U = 1/R = 3.27 W/ m^2K

E1.5 RETV Calculation

General Equation

$RETV = 3.4(A_w \times U_w)/A_o + 1.3(A_f \times U_f)/A_o + 58.6(A_f \times SC_f) \times CF/A_o$

E1.5.1 South facade (CF = 0.86)

RETV = 3.4(1094.4 x 3.27)/1503.04 + 1.3(288x5.83 + 120.64 x3.448)
/1503.04 + 58.6(288x0.7 + 120.64 x0.5) x 0.86/1503.04
= 8.095 + 1.812 + 8.782
= 18.69 W/ m^2

E1.5.2 South-West facade (CF = 1.09)

RETV = 0 + 1.3(120.64 x 3.448)/120.64 + 58.6(120.64
x0.5)x1.09/120.64
= 0+ 4.482 + 31.937
= 36.419 W/ m^2

E1.5.3 West facade (CF = 1.26)

RETV = 3.4(1022.4 x 3.27)/1272.64 + 1.3(120.64x3.448 + 129.6x5.7)/
1272.64 + 58.6(120.64 x 0.5 + 129.6x0.533)x1.26/1272.64
= 8.932 + 1.18 + 7.507
= 17.619 W/ m^2

E1.5.4 North-West facade (CF = 1.06)

RETV = 0 + 1.3(120.64 x 3.448)/120.64 + 58.6(120.64
x0.5)x1.06/120.64
= 0+ 4.482 + 31.058
= 35.54 W/ m^2

E1.5.5 North facade (CF = 0.83)

RETV = 3.4(1094.4 x 3.27)/1503.04 + 1.3(288x5.83 + 120.64 x3.448)
/1503.04 + 58.6(288x0.7 + 120.64 x0.5) x 0.83/1503.04
= 8.095 + 1.477 + 8.476
= 18.048 W/ m^2

E1.5.6 North-East facade (CF = 1.01)

RETV = 0 + 1.3(120.64 x 3.448)/ 120.64 + 58.6(120.64
x0.5)x1.01/120.64
= 0+ 4.482 + 29.593
= 34.075 W/ m^2

E1.5.7 East facade (CF = 1.18)

RETV = 3.4(1022.4 x 3.27)/1272.64 + 1.3(120.64x3.448 + 129.6x5.7)/
1272.64 + 58.6(120.64 x 0.5 + 129.6x0.533)x1.18/1272.64
= 8.932 + 1.18 + 7.031
= 17.143 W/ m^2

E1.5.8 South-East facade (CF = 1.02)

RETV = 0 + 1.3(120.64 x 3.448)/ 120.64 + 58.6(120.64
x0.5)x1.02/120.64
= 0+ 4.482 + 29.886
= 34.368 W/ m^2

E1.5.9 RETV for the whole residential building

$$RETV = \frac{A_{o1} \times RETV_1 + A_{o2} \times RETV_2 + \ldots + A_{on} + RETV_n}{A_{o1} + A_{o2} + \ldots + A_{on}}$$

where

A_{o1}, A_{o2}, A_{on} : gross areas of the exterior wall for each orientation (m^2)

RETV = (1503.04 x 18.69 + 120.64 x 36.419 + 1272.64 x 17.619 +
120.64 x 35.54 + 1503.04 x 18.048 + 120.64 x 34.075 +
1272.64 x 17.143 + 120.64 x 34.368)/ (1503.04 + 120.64 +
1272.64 + 120.64 + 1503.04 + 120.64 + 1272.64 + 120.64)
= 116396.29/6033.92
= 19.29 W/ m^2

APPENDIX F

F1 Bibliography

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