BUILDING ENERGY MODELING & THERMAL SIMULATION





Organised by:

BCA ACADEMY
of the built environment

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Important Notes to Course Participants

On Attendance/Examination/Assessment/Assignment

Please remember to sign on the attendance sheet daily and promptly upon arriving at the class. Course participants are **not allowed** to sign for lesson(s) not attended or for someone else. Participants are to monitor their attendance throughout the whole course.

Participants must achieve at least **75% class attendance for lessons (excluding exam attendance)** to qualify to sit for all the assessment(s). Participants who do not achieve at least 75% class attendance may be debarred from all the assessment(s). In this case, the participant will also not be allowed to sit for the supplementary assessment(s). The participant would be deemed to have failed the course and will not be issued the Certificate of Successful Completion.

Submission of assignment/project report (if any) will have to be made by the given deadline. Failure to do so, will result in incompetency/unsuccessful completion of the course.

Late submission of assignment will not be accepted.

BCA Academy

GREEN MARK PROFESSIONAL CORE MODULE :

BUILDING ENERGY MODELING & THERMAL SIMULATION

YONG PING QUEN
(CERTIFIED GMP, LEED AP, GBIF, CEM, BCA-REGISTERED ENERGY AUDITOR)

BUILDING SYSTEM & DIAGNOSTICS PTE LTD

Presented by :
Environmentally Sustainable Development (ESD) Consultant,
Building System and Diagnostics | BSD Pte Ltd. © 2015

Overview

- 4 days course
- Lecture & discussion session
- Practical sessions
- Exams & Assessment
  - Group energy simulation assignment
  - Individual exams

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.
- Hand-on experience with the simulation software.
- Understand Energy Modeling Framework and its Green Mark submission requirement

Overview – Day 1

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

- Introduction to Simulation Software
- Hand-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

Methodology of simulation – App E
Simulation Structure

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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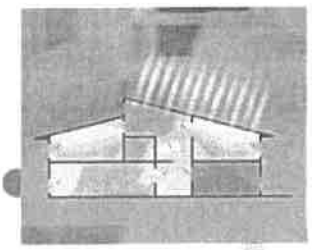
ENERGY MODELING & GREEN MARK



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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
- Update version in progress for V5.0

Objectives

- To adopt an *integrated approach* to building design so as to improve energy efficiency and achieve a superior performance in energy consumption.

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 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

Source: BCA

Part 1-1 – Building Envelope ETTV

Envelope Thermal Transfer Value (ETTV) Formula

The ETTV formula is given as follows:

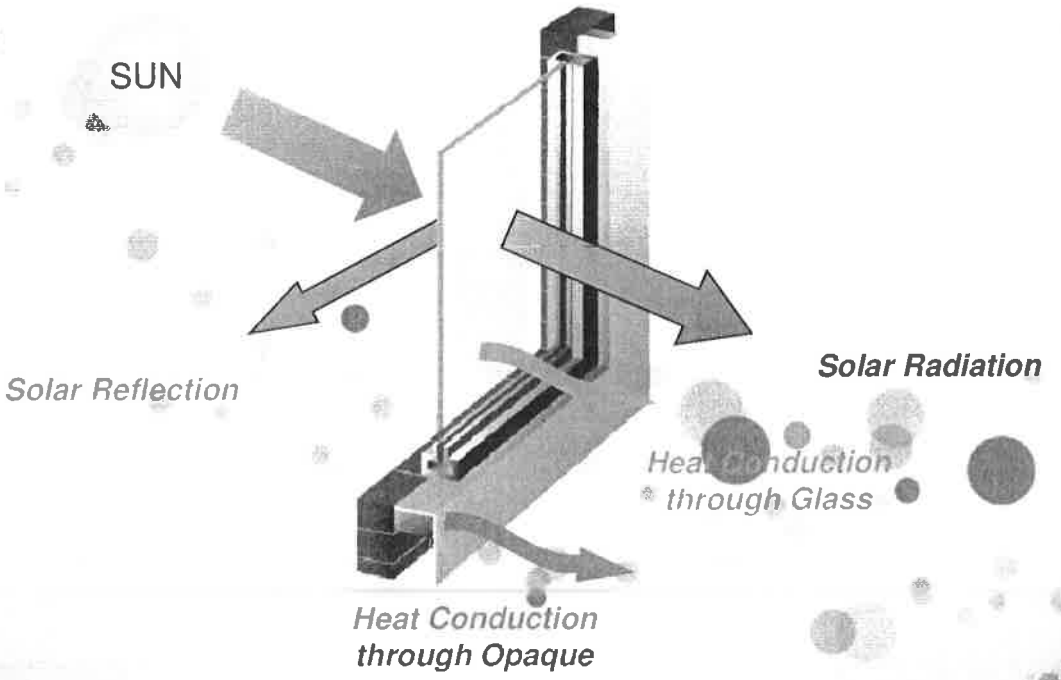
$$ETTV = 12(1-WWR)U_w + 3.4(WWR)U_f - 211(WWR)(CF)(SC)$$

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

Source: BCA

Heat Transfer through Facade

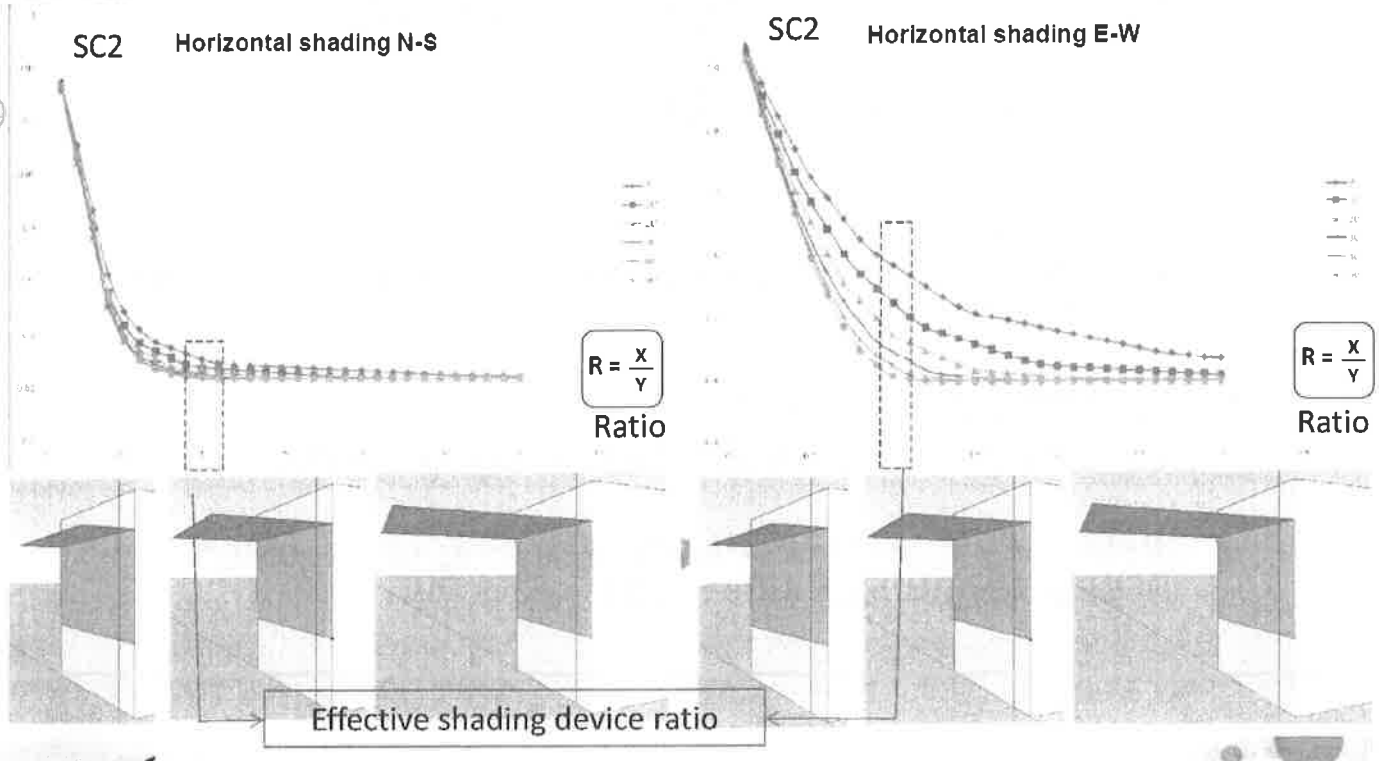


Factors that affect facade performance

- 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

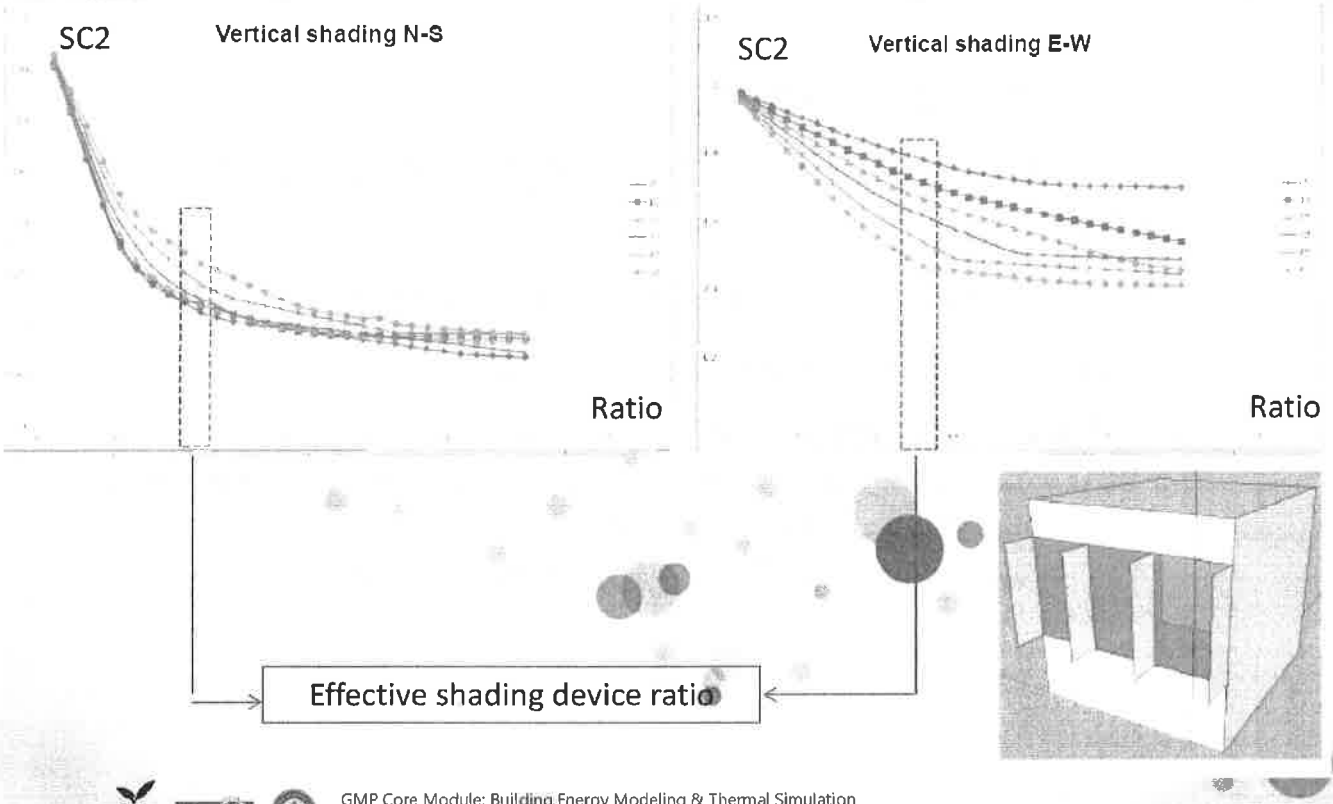
Effective Shading Device (SC2 value)

Effective shading device ratio based on Horizontal Shading

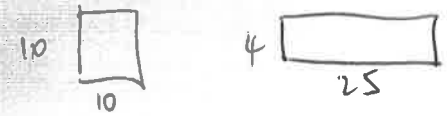


Effective Shading Device (SC2 value)

Effective shading device ratio based on Vertical Shading



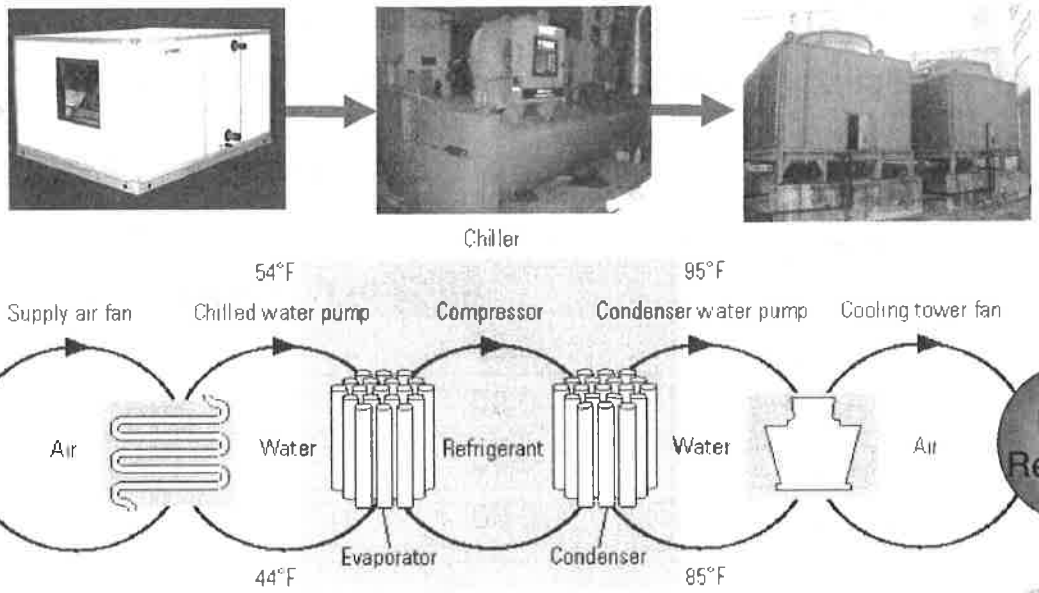
Same foot print, diff bldg shape generate diff facade area



Part 1-2 – 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.

Part 1-2 – Air Conditioning System



Source: NCCC

GM Score –Air Conditioning

NRB 1-2 Air-Conditioning System

Encourage the use of better energy efficient air-conditioned equipment to minimise energy consumption.

(a) Water-Cooled Chilled-Water Plant :

- Water-Cooled Chiller
- Chilled-Water Pump
- Condenser Water Pump
- Cooling Tower

Baseline	Peak Building Cooling Load	
	≥ 500 RT	< 500 RT
Prerequisite Requirements Minimum central chilled-water plant efficiency	0.70 kW/RT	0.80 kW/RT

Prerequisite Requirements for Higher Green Mark Rating : Green Mark Gold^{Plus} & Platinum : Minimum central chilled water plant efficiency of 0.65 kW/RT for peak building cooling load ≥ 500 RT and 0.7 kW/RT for peak building cooling load < 500 RT

(a) Water-Cooled Chilled-Water Plant

Peak building cooling load ≥ 500 RT

15 points for meeting the prescribed chilled-water plant efficiency of 0.70 kW/RT

0.25 point for every percentage improvement in the chilled-water plant efficiency over the baseline

Points scored = 0.25 x (% improvement)

Peak building cooling load < 500 RT

12 points for meeting the prescribed chilled-water plant efficiency of 0.80 kW/RT

0.45 point for every percentage improvement in the chilled-water plant efficiency over the baseline

Points scored = 0.45 x (% improvement)

(Up to 20 points)

GM Score –Air Conditioning

Prescribed system efficiency of air–conditioning system to be as follows:

(i) For Buildings using Water Cooled Chilled-Water Plant:

Green Mark Rating	Peak Building Cooling Load (RT)	
	< 500	≥ 500
	Efficiency[1] (kW/RT)	
Certified	0.80	0.70
Gold	0.80	0.70
Gold^{Plus}	0.70	0.65
Platinum	0.70	0.65

GM Score –Air Conditioning

(b) Air Cooled Chilled-Water Plant / Unitary Air-Conditioners

Air Cooled Chilled-Water Plant :

- Air-Cooled Chiller
- Chilled-water pump

Unitary Air-Conditioners :

- Variable Refrigerant Flow (VRF) system
- Single-Spilt Unit
- Multi-Spilt Unit

(b) Air Cooled Chilled-Water Plant/ Unitary Air-Conditioners

Peak building cooling load ≥ 500 RT

12 points for meeting the prescribed air-conditioning system efficiency of 0.80 kW/RT

1.3 points for every percentage improvement in the air-conditioning system efficiency over the baseline

Points scored = 1.3 x (% improvement)

GM Score –Air Conditioning

(b) Air Cooled Chilled-Water Plant / Unitary Air-Conditioners – *Cont'd*

Baseline	Peak Building Cooling Load	
	≥ 500 RT	< 500 RT
Prerequisite Requirements Minimum system efficiency of air cooled chilled-water plant or unitary conditioners	0.80 kW/RT	0.90 kW/RT

Prerequisite Requirements for Higher Green Mark Rating :

Green Mark Gold^{Plus} : Minimum system efficiency of 0.85kW/RT for peak building cooling load < 500 RT

Green Mark Platinum: Minimum system efficiency of 0.78kW/RT for peak building cooling load < 500 RT

Note (1) : Where there is a combination of central chilled water plant with unitary conditioners, the points scored will only be based on the air-conditioning system with a larger aggregate capacity

Peak building cooling load < 500 RT

10 points for meeting the prescribed air-conditioning system efficiency of 0.90 kW/RT

0.6 point for every percentage improvement in the air-conditioning system efficiency over the baseline

Points scored = 0.6 x (% improvement)

(Up to 20 points)

Source: BCA

GM Score –Air Conditioning

(ii) For Buildings using Air Cooled Chilled-Water Plant or Unitary Air-Conditioners:

Green Mark Rating	Peak Building Cooling Load (RT)	
	< 500	≥ 500
	Efficiency[1] (kW/RT)	
Certified	0.90	0.80
Gold	0.90	Not applicable[2]
Gold^{plus}	0.85	
Platinum	0.78	

Source: BCA

GM Score –Air Conditioning

(c) Air Distribution System :

- Air Handling Units (AHUs)
- Fan Coil Units (FCUs)

Option 1 – Fan System Motor Nameplate Power

Baseline : SS553:2009 Table 2 – Fan power limitation and as prescribed below :

Baseline Air Distribution System Type	Allowable Motor Nameplate Power	
	($kW/m^3/s$)	(W/CMH)
AHUs/FCUs ≥ 4kW (Constant Volume)	1.7	0.47
AHUs ≥ 4kW (Variable Volume)	2.4	0.67
Fan systems with nameplate motor power < 4 kW	No baseline	

Option 2 – Fan System Input Power

Baseline : ASHRAE 90.1.2010 Clause 6.5.3.1 and as prescribed below :

Baseline Air Distribution System Type	Allowable Fan System Input Power*	
	($kW/m^3/s$)	(W/CMH)
AHUs/FCUs ≥ 4kW (Constant Volume)	1.5	0.42
AHUs ≥ 4kW (Variable Volume)	2.1	0.58
Fan systems with nameplate motor power < 4 kW	0.6	0.17

* Applicable pressure drop adjustments can be considered based on ASHRAE 90.1 Table 6.5.3.1 1B and are subject to BCA's evaluation

Note (2) For buildings with cooling provision from a licensed District Cooling System (DCS) supplier where the plant efficiency data is not available, the point scored for NRB 1-2(a) and (b) will be pro-rated based on the air distribution system efficiency under NRB 1-2(c).

Source: BCA

Part 1-3 – Building Envelope – Design/ Thermal parameters

NRB 1-3 Building Envelope – Design / Thermal Parameters

Enhance the overall thermal performance of building envelope to minimise heat gain which would improve indoor thermal comfort and encourage natural ventilation or mechanical ventilation.

(a) Minimum direct west facing façade through building design orientation.

Note (3) : Orientation of façade that falls within the range of 22.5° N of W and 22.5° S of W will be defined as west facing facade. Core walls for lifts or staircases and toilets that are located within this range are exempted in computation.

Points scored = 15 – 0.3 x (% of west facing facade areas over total façade areas)

(Up to 15 points)

Where there is no west facing façade, the total points scored for this item will be 30 points; the NRB 1-3 b(i), b(ii) and (c) as listed below will not be applicable.

(b)(i) Minimum west facing window openings.

Points scored = 10 - 0.1 x (% of west facing window areas over total west facing façade areas)

Source: BCA

Part 1-3 – Building Envelope – Design/ Thermal parameters

(b)(ii) Effective sunshading provision for windows on the west façade with minimum shading of 30%.

Points scored = 0.1 x (% of west facing window areas with sunshading devices over total west facing façade areas)

(Up to 10 points for NRB 1-3 b(i) & b(ii))

(c) Better thermal transmittance (U-value) of external west facing walls.

The U-value of external west facing walls should be equal or less than 2 W/m^{2}K.

Points scored = 0.05 x (% of the external west facing walls areas with U value of 2 W/m^{2}K or less over total west facing facades areas)

(Up to 5 points)

(d) Better thermal transmittance (U-value) of roof.

Baseline: U-value for roof stated below depending on the weight range of roof structure:

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

1 point for every 0.1 W/m^{2}K reduction from the baseline roof U-value

(Up to 5 points)

Source: BCA

Part 1-4 – Natural Ventilation/ Mechanical Ventilation

NRB 1-4 Natural Ventilation / Mechanical Ventilation

(a) Natural Ventilation

Encourage building design that facilitates good natural ventilation.

(i) Proper design of building layout that utilises prevailing wind conditions to achieve adequate cross ventilation.

(ii) Use of ventilation simulation modeling and analysis or wind tunnel testing to identify the most effective building design and layout to ensure good natural ventilation.

Prerequisite Requirement :

Green Mark Platinum : Ventilation simulation modeling and analysis are to be carried out to ensure good natural ventilation with minimum weighted average wind velocity of 0.6 m/s within the functional spaces or units.

1 point for every 10% of units/rooms with window openings facing north and south directions
Points scored = 1 x (% of units/10)
(Up to 10 points)

5 points

Additional 5 points
if the recommendations are implemented and meet the air-flow requirement
(Up to 10 points)

Source: BCA

Part 1-4 – Natural Ventilation/ Mechanical Ventilation

(b) Mechanical Ventilation

Encourage energy efficient mechanical ventilation system design as the preferred ventilation mode to minimise air-conditioned spaces.

Option 1 – Fan System Motor Nameplate Power

Baseline : SS553:2009 Table 8 – Fan power limitation and as prescribed below :

Baseline Air Distribution System Type	Allowable Motor Nameplate Power	
	($kW/m^3/s$)	(W/CMH)
AHUs/FCUs ≥ 4kW (Constant Volume)	1.7	0.47
Fan systems with nameplate motor power < 4 kW	No baseline	

0.6 point for every percentage improvement in the mechanical ventilation system efficiency over the baseline

Points scored = 0.6 x (% improvement)

(Up to 15 points)

Option 2 – Fan System Input Power

Baseline : ASHRAE 90.1 2010 Clause 6.5.3.1 and as prescribed below :

Baseline Air Distribution System Type	Allowable Fan System Input Power *	
	($kW/m^3/s$)	(W/CMH)
AHUs/FCUs ≥ 4kW (Constant Volume)	1.5	0.42
Fan systems with nameplate motor power < 4 kW	0.6	0.17
* Applicable pressure drop adjustments can be considered based on ASHRAE 90.1 Table 6.5.3.1.1B and are subject to BCA's evaluation		

Source: BCA

Part 1-5 – Daylighting

NRB 1-5 Daylighting

Encourage design that optimises the use of effective daylighting to reduce energy use for artificial lighting.

(a) Use of daylighting and glare simulation analysis to verify the adequacy of ambient lighting levels in meeting the illuminance level and Unified Glare Rating (UGR) stated in SS 531:Part 1:2006 – Code of Practice for Lighting of Work Places.

Extent of coverage: At least 75% of the units with daylighting provisions meet the minimum illuminance level and are within the acceptable glare exposure.

Points scored based on the extent of perimeter daylight zones

Distance from the Façade Perimeters (m)	Points Allocation
≥ 3.0	1
4.0 – 5.0	2
> 5.0	3

(Up to 3 points)

(b) Daylighting for the following common areas:

(i) Toilets
(ii) Staircases
(iii) Corridors
(iv) Lift Lobbies
(v) Atriums
(vi) Carparks

Extent of Coverage : At least 60 % of each applicable area

0.5 point each

(Up to 3 points)

Note (5) All daylit areas must be integrated with automatic electric lighting control system.

Source: BCA

GM Score –Artificial Lighting

NRB 1-6 Artificial Lighting

Encourage the use of energy efficient lighting to minimise energy consumption from lighting usage while maintaining proper lighting level.

Baseline = Maximum lighting power budget stated in SS 530

0.3 point for every percentage improvement in lighting power budget

Points scored = 0.3 x (% improvement)
(Including tenant lighting provision)
(Up to 12 points)

(Excluding tenant lighting provision)

(Up to 5 points)

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

Source: BCA

Part 1-7 – Ventilation in Car Park

Encourage energy efficient design and control of ventilation systems in carparks

- Fully Naturally Ventilated
- CO sensors to regulate ventilation requirement
- Ductless MV jet fan

Part 1-8 – Ventilation in Common Area

- Encourage energy efficient design and control of ventilation systems in Common Area
  - Toilets, Staircases, Corridors, Lift Lobbies, Atrium
  - Naturally Ventilated
  - Mechanical Ventilated
  - Avoid Air-conditioning

Part 1-9 – Lifts & Escalators

- Encourage the use of energy efficient lifts & Escalator
  - Lifts with AC Variable Voltage Variable Frequency (VVVF) motor drive.
  - Lifts with sleep mode features.
  - Escalators with motion sensors to regulate usage.
  - Lifts with Regenerative-drive

Part 1-10 – Energy Efficient Features

Encourage the use of energy efficient features

- Heat Recovery Devices
- Light Shelves
- Photo sensors to maximize the use of daylighting
- Motion sensors for staircases and toilet
- Heat Pump
- Sun pipes for natural lighting
- Etc ...

Part 1-11 – Renewable Energy

NRB 1-11 Renewable Energy

Encourage the application of renewable energy sources in buildings.

Point scored based on the expected energy efficiency index (EEI) and % replacement of electricity by renewable energy source

Expected Energy Efficiency Index (EEI)	Every 1 % replacement of electricity (based on total electricity consumption) by renewable energy source	
	Include tenant's usage	Exclude tenant's usage
≥ 30 kWh/m^2/yr	5 points	3 points
< 30 Wh/m^2/yr	3 points	1.5 points

(Up to 20 Points)

Source: BCA

Green Mark Assessment Criteria

- Meet minimum total points for the specific criteria.
- Platinum and GoldPlus projects to demonstrate 30% and 25% energy saving respectively.

Green Mark Rating	Points
Platinum	≥ 90
GoldPlus	85 ≤ 90
Gold	75 ≤ 85
Certified	50 ≤ 75

Energy Modeling

DCS energy modeling methodology

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%

Pre-requisites for higher Green Mark award

Air-Conditioned Buildings

(1) Building envelope design with Envelope Thermal Transfer Value (ETTV) computed based on the methodology and guidelines stipulated in the Code on Envelope Thermal Performance for Buildings and this Standard.

Green Mark Gold^{Plus} – ETTV of 42 W/m^2 or lower
Green Mark Platinum – ETTV of 40 W/m^2 or lower

(2) To demonstrate the stipulated energy savings over its reference model using an energy modeling framework set out. Details and submission requirements on energy modeling can be found in Appendix E of the Certification Standard.

Green Mark Gold^{Plus} – At least 25% energy savings
Green Mark Platinum – At least 30% energy savings

Source: BCA

Office Ref Prop
DC 50% 30
Light 17% 8
Fan 15% 8
Plug 18% 18
100% 64% ≈ 36% saving.

Pre-requisites for higher Green Mark award

(3) Prescribed system efficiency of air–conditioning system to be as follows:

(i) For Buildings using Water-Cooled Chilled-Water Plant:

Green Mark Rating	Peak Building Cooling Load (RT)	
	< 500	≥ 500
	Efficiency (kW/RT)	
Certified	0.80	0.70
Gold	0.80	0.70
Gold^{Plus}	0.70	0.65
Platinum	0.70	0.65

Source: BCA

Pre-requisites for higher Green Mark award

(ii) For Buildings using Air-Cooled Chilled-Water Plant or Unitary Air-Conditioners:

Green Mark Rating	Peak Building Cooling Load (RT)	
	< 500	≥ 500
	Efficiency[1] (kW/RT)	
Certified	0.90	0.80
Gold	0.90	Not applicable[2]
Gold^{plus}	0.85	
Platinum	0.78	

Note [1] The performance of the overall air-conditioning system for the building can either be based on the efficiency at full installed capacity (exclude standby) of the system or

Source: BCA

Pre-requisites for higher Green Mark award

expected operating efficiency of the system at part-load condition during the normal building operation hours as defined below:

Office Building:
Monday to Friday: 9 am to 6 pm
Saturday: 9 am to 11 pm

Retail Mall:
Monday to Sunday: 10 am to 10 pm

Institutional:
Monday to Friday: 9 am to 6 pm

Hotel and Hospital:
24-hour

Industrial and Other Building Types:
To be determined based on the operating hours

Note [2] For building with peak building cooling load of more than 500 RT, the use of air-cooled central chilled-water plant or other unitary air-conditioners are not applicable for Gold and higher ratings. In general, the system efficiency of the air-cooled central chilled-water plant and other unitary air-conditioners are to be comparable with the stipulated efficiency for water-cooled central chilled-water plant. Buildings that are designed with air-cooled systems and for higher Green Mark rating will be assessed on a case by case basis.

Source: BCA

Pre-requisites for higher Green Mark award

(4) Instrumentation for monitoring the water cooled chilled-water plant efficiency is to be provided in accordance with the requirement set in the criteria.

Instrumentation Accuracy

As instrumentation accuracies stated in calibration certificates and technical specifications are based on controlled conditions in a laboratory, it is necessary to allow for onsite deviations and measurements. The following instrumentation accuracy listed can be considered for the monitoring central water-cooled chilled-water plant efficiency.

Item	Description	Measurement Error
01	Temperature Sensors - 10K/30K Thermistor - Platinum Resistance Thermometers	±0.03°C – 0.05°C @ 0°C
02	Flow Sensor / Meter - Ultrasonic - Full bore magnetic	±0.5 - 1% over entire measurement range
03	Power Meter	ANSI C12.1-2008, Class 1 ±1%

Source: BCA

Pre-requisites for higher Green Mark award

(5) Minimum score under NRB 3-1 Sustainable Construction

- Green Mark Gold^{Plus} ≥ 3 points
  Green Mark Platinum ≥ 5 points

(a) Use of Sustainable and Recycled Materials

(i) Green Cements with approved industrial by-product (such as Ground Granulated Blastfurnace Slag (GGBS), silica fume, fly ash) to replace Ordinary Portland Cement (OPC) by at least 10% by mass for superstructural works.

(ii) Recycled Concrete Aggregates (RCA) and Washed Copper Slag (WCS) from approved sources to replace coarse and fine aggregates for concrete production of main building elements.

(b) Concrete Usage Index (CUI)

Encourage designs with efficient use of concrete for building components.

Project CUI (m^3/m^2)	Points Allocation
≤ 0.70	1 point
≤ 0.60	2 points
≤ 0.50	3 points
≤ 0.40	4 points
≤ 0.35	5 points

Source: BCA

Energy Simulation Models

- 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.

BC Codes & Singapore Standards

FOL BASELINE MODEL

- The Energy Model must adopt the acceptable solutions on energy efficiency, lighting and ventilation in the BCA's Approved Documents:

- SS530:2006 – Energy efficiency standard for building services and equipment.

- SS 553:2009 – Code of Practice for mechanical ventilation and air conditioning in buildings.

- SS531:2006 – Code of Practice for lighting of work places.

- ETTV requirements: Guidelines on Envelope Thermal Transfer Value for Buildings.

Others references: ASHRAE std 90.1, std 62.1

Energy Modeling & Green mark

Building development with more than 30% Non AC Spaces

Aggregate Non Air-Conditioned Spaces (m^2)	Aggregate Air-Conditioned Spaces (m^2)	Ventilation Simulation Requirement See Note (a)	Energy Modeling Requirement See Note (b)	Justification on Energy Savings See Note (c)
≥ 2000	≥ 5000	Yes	Yes	No
< 2000	≥ 5000	No	Yes	No
≥ 2000	< 5000	Yes	No	Yes
< 2000	< 5000	No	No	Yes

Important Notes

(a) Ventilation requirement stated paragraph (12) is a pre-requisite requirement to attain Green Platinum rating.

(b) The stipulated energy savings and Design System Efficiency (DSE) of cooling system stated in paragraph (7) and (8) are pre-requisites to attain Green Mark Gold^{Plus} and Platinum rating.

(c) Detailed calculations to be provided to justify the savings in energy consumption from the use of salient energy efficient features /equipment. Energy savings will be based on the energy efficiency measures and improvements over the reference model established for similar building types. The reference ACMV system will be of the same type as the proposed system. The baseline used for the equipment will be in accordance with the minimum efficiency requirement stipulated in SS 530. For VRF system, the baseline COP of 3.37 shall be adopted. The stipulated energy savings stated in paragraph (7) are pre-requisites to attain Green Mark Gold^{Plus} and Platinum rating.

Reference Model: What?

Components	Code	Minimum Requirement
Building Envelope	ETTV Guide	ETTV = 50W/m2
	BCA Approved Doc	Roof with Skylight, RTTV = 50W/m2
		Roof Without Skylight, the average U value of the gross area of roof:

Maximum Thermal Transmittance for Roof of Air-Conditioned Buildings

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

Reference Model: What?

Components	Code	Minimum Requirement
Building Shape, Size & Configuration	NIL	Reference Model to be the same as proposed model
Building Zoning & Thermal Block	NIL	Reference Model to be the same as proposed model ; Zoning of air-conditioned & Non AC areas shall be modeled based on the approved building plan; ACMV zones are defined on the ACMV drawings, each zone shall be modeled as a separate thermal block.

Reference Model: What?

Components	Code	Minimum Requirement
ACMV	NIL	Building with standalone Cooling Plant: 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.

Reference Model: What?

ASHRAE 60.1

TABLE G3.1.3.7 Type and Number of Chillers

Building Peak Cooling Load	Number and Type of Chiller(s)
≤1055 kW	1 water-cooled screw chiller
>1055 kW, ≤2110 kW	2 water-cooled screw chillers sized equally
≥2110 kW	2 water-cooled centrifugal chillers minimum with chillers added so that no chiller is larger than 2813 kW, all sized equally

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)

Reference Model: What?

Components	Code	Minimum Requirement
ACMV	NIL	Building with cooling provision from licensed District Cooling System (DCS) supplier: a. The energy consumption contribution from DCS plant may be excluded in the energy modeling. b. All ACMV components dedicated to the building designed shall be included and considered c. Comply with below:

S/No.	Criteria	Gold^{Plus}	Platinum
1	Cooling Load Savings	10%	15%
2	Energy Consumption Savings (exclude air-conditioned plant) and from energy efficiency improvements that reduce the cooling load requirement	27%	33%

Reference Model: What?

Components	Code	Minimum Requirement
Air Conditioning Hydronic System	SS553-2009	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. Motor exceeding 15kW shall have control that will result in pump motor demand of no more than 30% of design wattage at 50% of design water flow.

Notes:

349 kW/1000 L/s (equal to a pump operating against a 23 m head, 65% combined impeller and motor efficiency). head on At 5.6°C

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

Reference Model: What?

Exceptional case	Minimum Requirement
CHWP system for very tall building?	VPF Chilled Water Primary Pump = 349 kW/m^3/s After heat exchanger: Chilled Water Secondary + Tertiary Pumps = Same as proposed model, no savings
CHWP after HEX of licensed DCS	Chilled Water Pump after heat exchanger = 349 kW/m3/s No savings for heat exchanger, reference energy consumption is same propose.
CWP for Chiller	Constant (reference condenser loop is constant flow)

Notes:

Minimum unloading for VSD application is 25Hz

Reference Model: What?

Components	Code	Minimum Requirement
Cooling Tower	SS530-2006	Propeller or Axial fan Cooling Towers Performance shall not be less than 3.23 L/s/KW Centrifugal fan Cooling Towers Performance shall not be less than 1.70 L/s/KW

Notes:

Reference Model: What?

Components	Code	Minimum Requirement
Air Fan system	SS553-2009 ASHRAE 90.1-2010	Option 1 – Fan System Motor Nameplate Power Baseline : SS553 2009 Table 2 – Fan power limitation and as prescribed below :

Baseline Air Distribution System Type	Allowable Motor Nameplate Power	
	($kW \cdot m^3 \cdot s$)	(W/CMH)
AHUs/FCUs ≥ 4kW (Constant Volume)	1.7	0.47
AHUs ≥ 4kW (Variable Volume)	2.4	0.67
Fan systems with nameplate motor power < 4 kW	No baseline	

Notes:

Reference Model: What?

Components	Code	Minimum Requirement
Air Fan system	SS553-2009 ASHRAE 90.1-2010	Option 2 – Fan System Input Power Baseline ASHRAE 90.1:2010 Clause 6.5.3.1 and as prescribed below :

Baseline Air Distribution System Type	Allowable Fan System Input Power*	
	($kW/m^3/s$)	(W/CMH)
AHUs/FCUs ≥ 4kW (Constant Volume)	1.5	0.42
AHUs ≥ 4kW (Variable Volume)	2.1	0.58
Fan systems with nameplate motor power < 4 kW	0.6	0.17
* Applicable pressure drop adjustments can be considered based on ASHRAE 90.1 Table 6.5.3.1.1B and are subject to BCA's evaluation		

Notes

Reference Model: What?

Components	Code	Minimum Requirement
Air Fan system	ASHRAE 90.1-2010	VAV Baseline System partload curve shall follow:

Method 2—Part-Load Fan Power Equation

$$P_{fan} = 0.0013 + 0.1470 \times PLR_{fan} + 0.9506 \times (PLR_{fan})^2 - 0.0998 \times (PLR_{fan})^3$$

where

P_{fan} = fraction of full-load fan power and

PLR_{fan} = fan part-load ratio (current L/s/design L/s)

Minimum unloading curve is at 25Hz

ASHRAE 90.1-2010	Air flow for AHU system for Reference Model shall be auto-sized based on the cooling load for zones served in Reference Model, with the off-coil setting of 11.1 Deg C different from the space design temperature.

Reference Model: What?

Components	Code	Minimum Requirement
Lighting Power Density	SS530-2006 ASHRAE 90.1-2010	Maximum Lighting power budget stated in Table 7 of SS530.

Type of Usage	Maximum Lighting Power Budgets (W/m^2)
Hotel guestroom	15 W/m^2 *(including decorative and task lighting)*
Hotel Lobby	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*

For spaces not listed, may adopt ASHRAE 90.1

Reference Model: What?

Components	Code	Minimum Requirement
Fresh Air Rates/ Minimum Ventilation Rates	SS553-2009	Same as Proposed Design
Receptacle & Process Loads	ASHRAE 90.1	Same as Proposed Design
Occupancy Rates	Fire Code	Same as Proposed Design
Operation Schedules	NIL	Same as Proposed Design
Indoor Thermal Comfort Conditions	SS553-2009	Same as Proposed Design
Internal illuminance level (lux)	SS531-2006	Same as Proposed Design

Reference Model: What?

Components	Code	Minimum Requirement
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.

Reference Model: What?

- 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%

Exception

- Where no Baseline Standard is available, e.g. receptacles loads, lift & escalators, sanitary & plumbing,

  - The same input parameters for good design practices should apply to both the reference and proposed models.

  - Must provide detail calculations to justify the savings in energy consumption by salient energy efficient features/ equipment, eg sensor or VVVF motors are used in the proposed models.

Case by case basis for exemplary cases.

Receptacle loads

- Reasonable assumptions for simulation

  2. For receptacle loads. Table A below is for reference.

Table A: Receptacle Loads	Source:-	Nominal Values
a. Computer intensive Offices	ASHRAE STD	22.0 W/m^2
b. General Office Areas	90.1:1989	16.0 W/m^2
c. Large Conference areas		11.0 W/m^2
d. Server/Computer rooms		540.0 W/m^2

Title 24, California's energy efficiency standards for residential and nonresidential buildings.

Acceptable Software Options

- 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 Modeling Methodologies

- 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.

Energy Modeling Methodologies

- 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 Modeling Methodologies

- 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.

Energy Modeling Methodologies

- 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 Modeling Methodologies

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 Modeling submission

- Energy Model Submission in two stages:

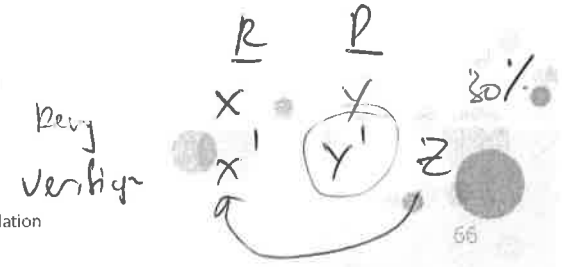
1. At the Green Mark Certification Stage

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

Submission stage 2

- Completed building
  - Gather building operation data through Building Management System (BMS) and utility data for 12 months.
  - Compile actual monthly whole-building energy use utility data for 12 months.

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



Thank you

Introduction to Energy Modeling

Presented by : Yong Ping Quen
Environmentally Sustainable Development (ESD) Consultant,
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Overview

- Introduction to Energy Modelling
  - What is building energy model?
  - Why building simulation (BS) tools?
  - BS as design tool
  - Available BS Tools
- Methodologies for Energy Modelling
- Case Studies

Objectives

Understand

- Building energy modeling and its use
- Software tools – their structures, solution method and features
- Energy Modeling Methodologies

What is Building Energy Model

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 energy use, space conditions and costs

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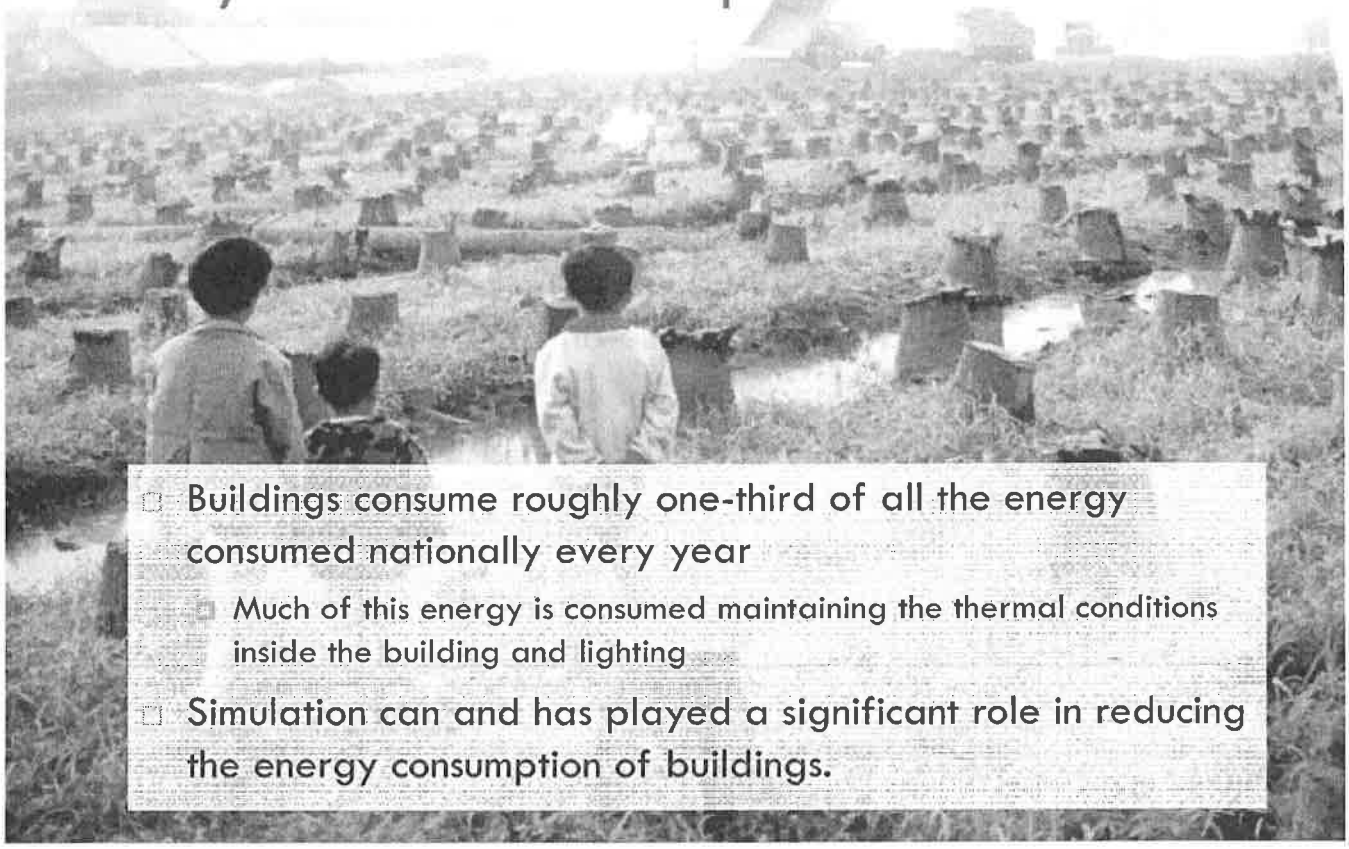
Why is Simulation Important?



- 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.

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How does Simulation save Energy?



- Answers "What if..." on Scientific Basis
- Reduce time and expense
- Provides comprehensive data not easily obtainable from experimental tests
- Allows alternatives to be studied before optimum designs are confirmed

Application of BS Tools

- Building heating/cooling load calculation (peak energy Demand and its profile)
- Building energy performance analysis,
- Building energy management and control system design,
- Building regulations/codes/standards compliance checking
- Life Cycle Cost analysis

When?

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."

BS 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

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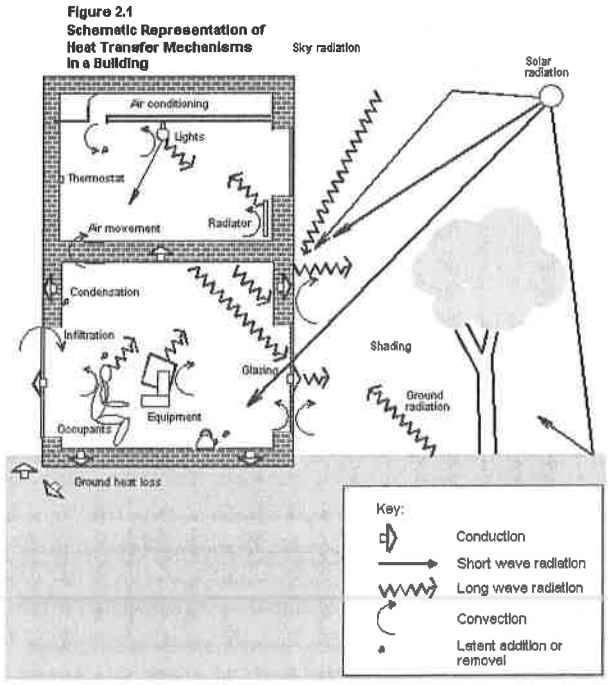
Understand the loads

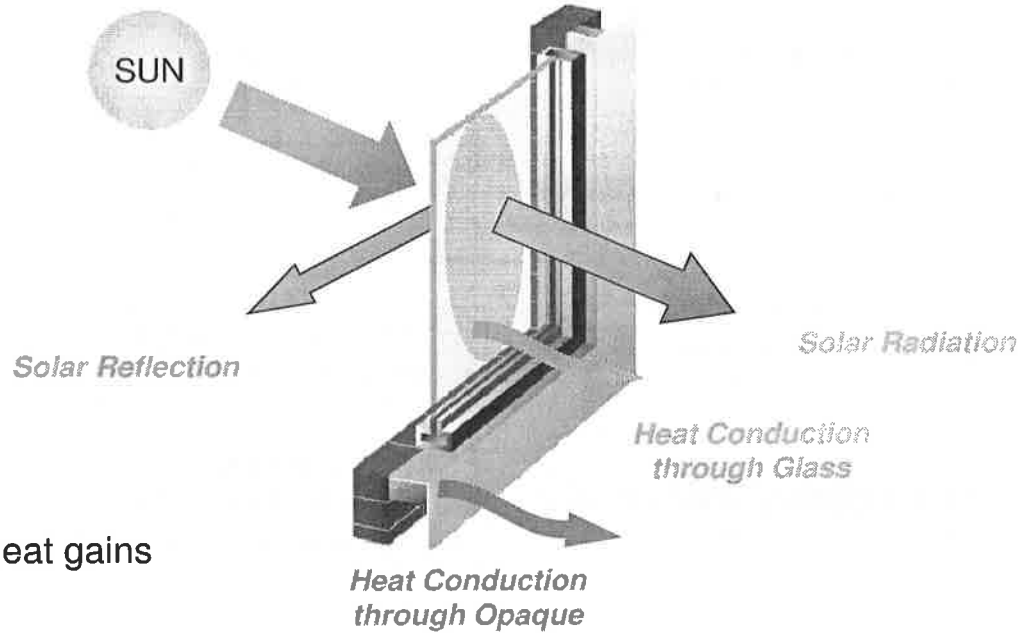


Building loads:

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

Understand the loads

OTTV = 15 α(1-WWR)Uw + 6 (WWR)Uf + 194(WWR)(CF)(SC)



- Solar heat gains

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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: Adult Male	Total Heat, W: Adjusted, M/F[a]	Sensible Heat, W	Latent Heat, W	% Sensible Heat that is Radiant[b]: Low V	% Sensible Heat that is Radiant[b]: High V
Seated at theater	Theater, matinee	115	95	65	30		
Seated at theater, night	Theater, night	115	105	70	35	60	27
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	58	38
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	49	33
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	54	19
Heavy machine work; lifting	Factory	470	470	185	285		
Athletics	Gymnasium	585	525	210	315		

Notes:
1. Tabulated values are based on 24°C room dry-bulb temperature. For 27°C room dry bulb, the total heat remains the same, but the sensible heat values should be decreased by approximately 20%, and the latent heat values increased accordingly.
2. Also refer to Table 4, Chapter 8, for additional rates of metabolic heat generation.
3. All values are rounded to nearest 5 W.

[a] Adjusted heat gain is based on normal percentage of men, women, and children for the application listed, with the postulate that the gain from an adult female is 85% of that for an adult male, and that the gain from a child is 75% of that for an adult male.

[b] Values approximated from data in Table 6, Chapter 8, where V is air velocity with limits shown in that table.

[c] Adjusted heat gain includes 18 W for food per individual (9 W sensible and 9 W latent).

[d] Figure one person per alley actually bowling, and all others as sitting (117 W) or standing or walking slowly (231 W).

Understand the loads

- Energy Efficient Light + Fixtures (Efficacy vs Lamp Wattage)
- Photo sensor + motion sensor

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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Understand the 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





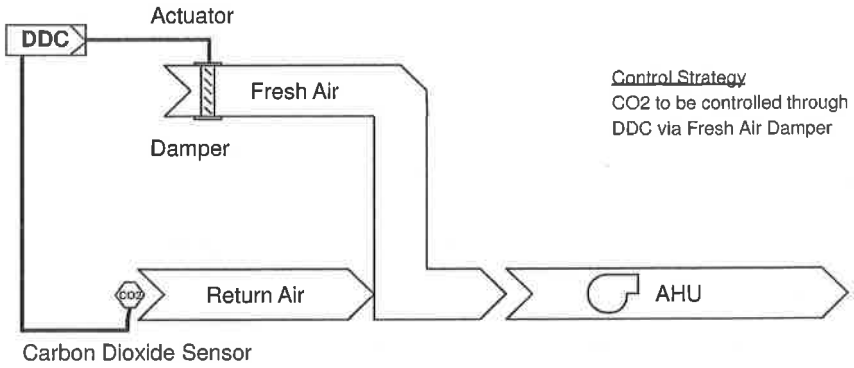
Table 12 Cooling Load Estimates for Various Office Load Densities

	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

Understand the loads

- Ventilation load
- Fresh Air local minimum 5.5 l/s person for Office
- Reduce fresh air rate through CO2 demand control ventilation.



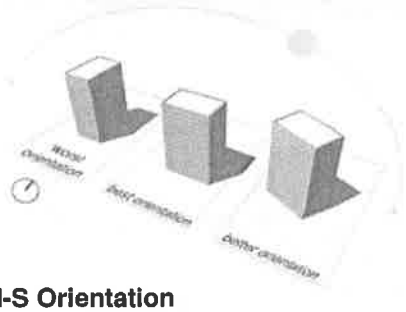
Reduce the loads



- Size, Form
- Orientation
- Envelope
  - Insulation
  - Fenestration
  - Shading
- Lighting Systems
- Internal Loads

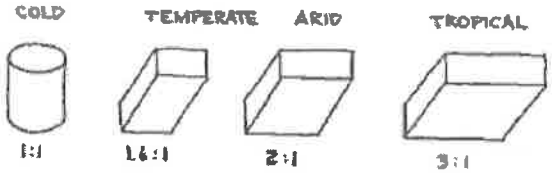
Schematic Design

Orientation



N-S Orientation

Building shape



Length to Width Ration 3:1 or more

Space planning



Non AC Space as buffer zones on W-E of Building

Window position

Minimize the window on W-E Facade

Efficient site usage

Create more spaces for Greenery

Circulation space

Minimization of circulation and travel spaces

Common area

Natural Ventilation mode for common areas

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Schematic Design

Orientation | **Building Shape** | **Space planning**

Assumptions

-3 different shape ratio with the same footprint (1,600m²)



Building A
40m x 40m

1 : 1



Building B
28.28m x 56.57m

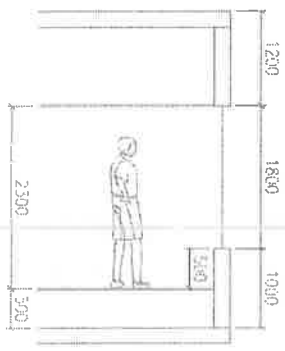
1 : 2



Building C
23.09m x 69.28m

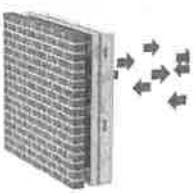
1 : 3

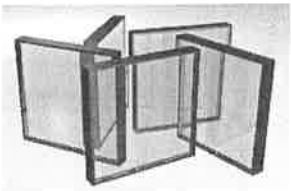
-WWR 60%



-External Constructions

Wall U-Value 0.5
(brickwall with insulation)
Window U-Value 2 SC 0.35
(DGU with Low-E)





$$OTTV = 15\,\alpha(1\text{-}WWR)Uw + 6\,(WWR)Uf + 194(WWR)(CF)(SC)$$

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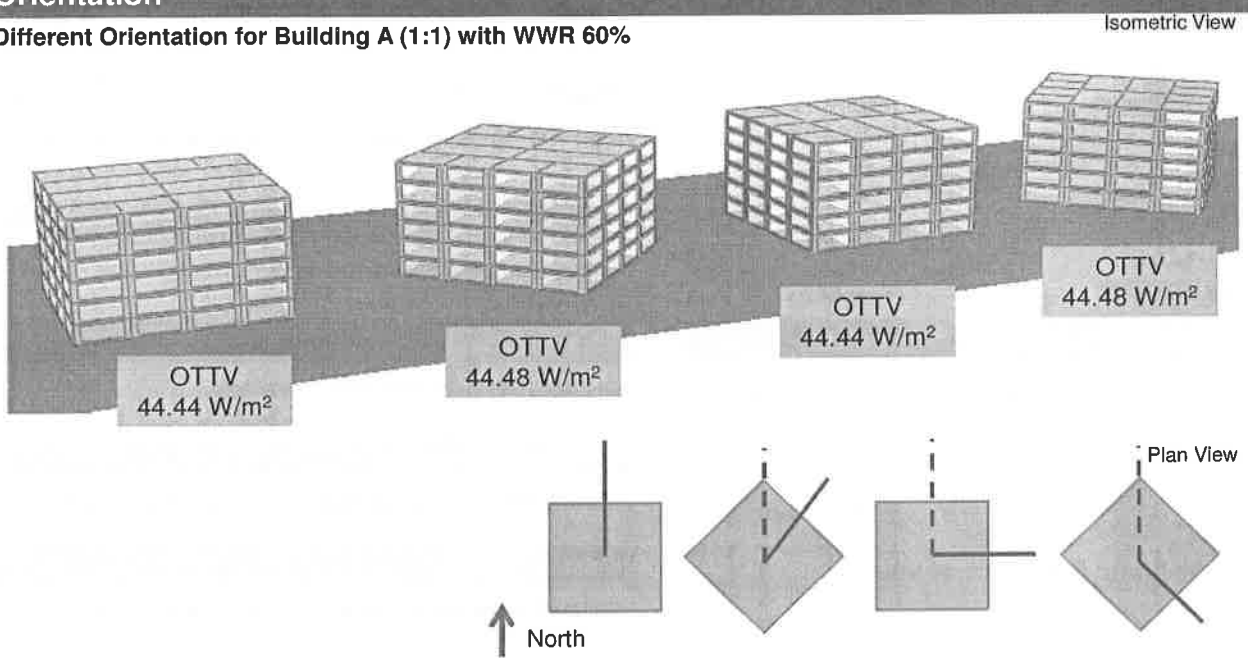
Schematic Design

Orientation

Different Orientation for Building A (1:1) with WWR 60%



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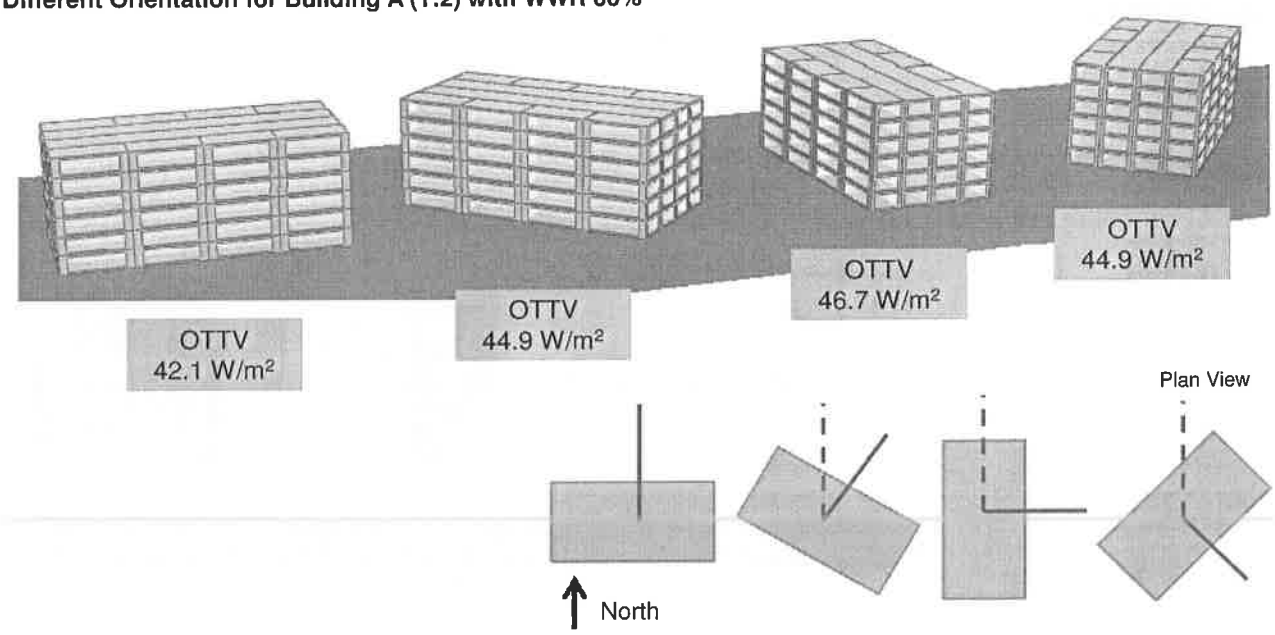
Schematic Design

Orientation

Different Orientation for Building A (1:2) with WWR 60%

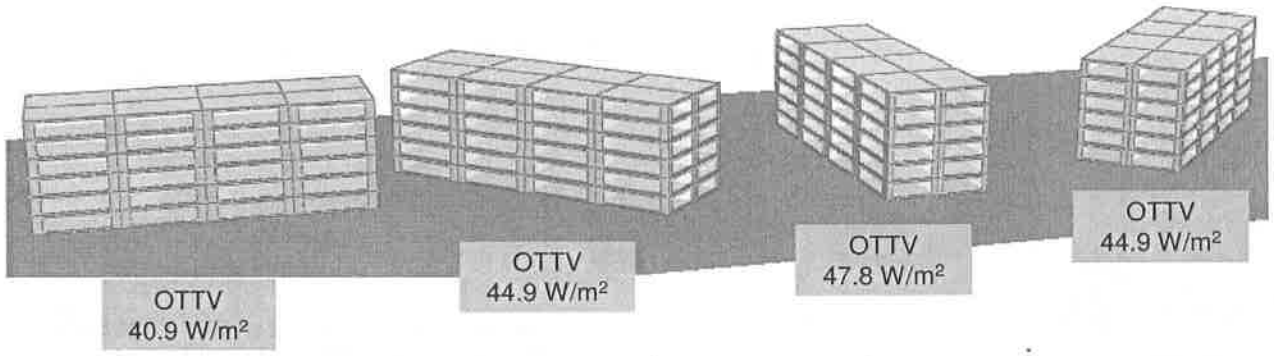


Schematic Design

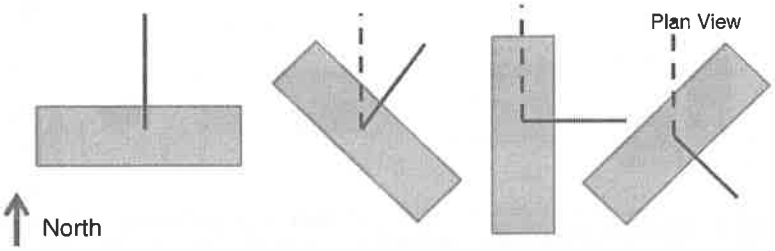
Orientation

Different Orientation for Building C (1:3) with WWR 60%

Isometric View



Changing the building orientation can help to reduce the OTTV from 47.8 W/m² to 40.9 W/m²



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Schematic Design

Building Shape

Assumptions

-3 different shape ratio with the same footprint (1,600m²)

North



Building A
40m x 40m

1 : 1



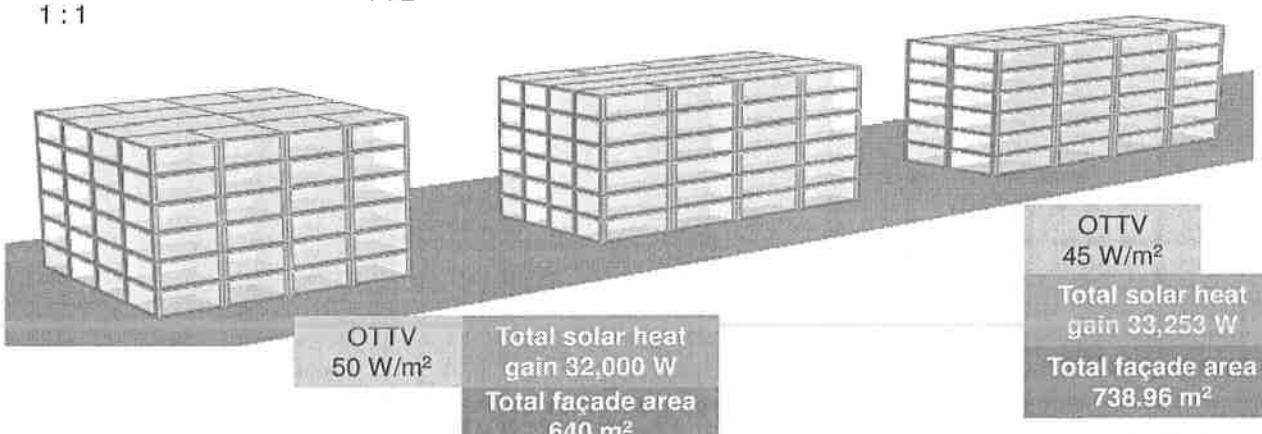
Building B
28.28m x 56.57m

1 : 2



Building C
23.09m x 69.28m

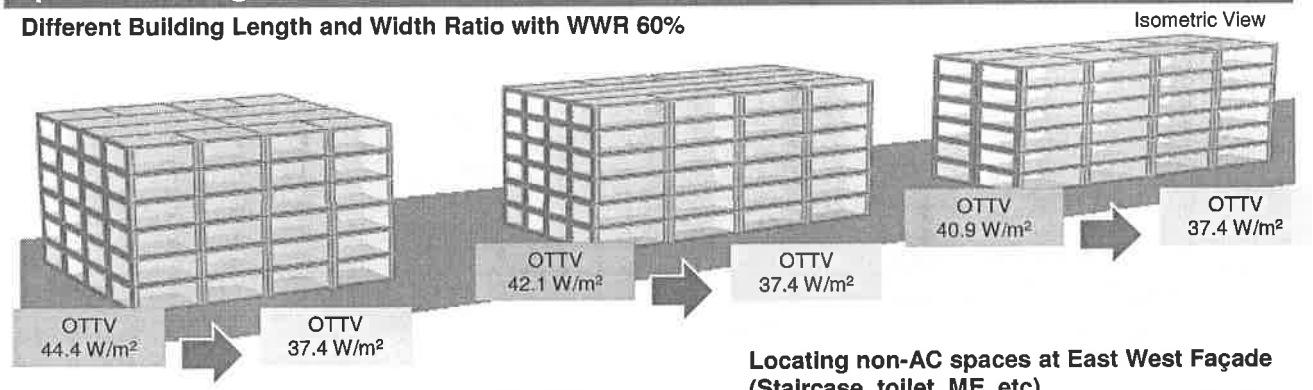
1 : 3



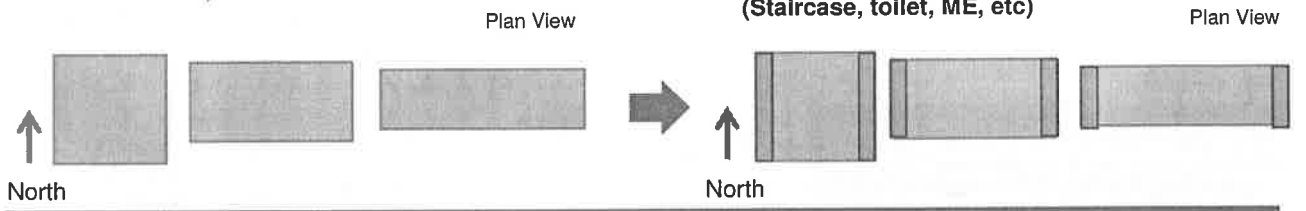
Schematic Design

Space Planning

Different Building Length and Width Ratio with WWR 60%



Locating non-AC spaces at East West Façade (Staircase, toilet, ME, etc)



Good space planning helps to reduce ETTV from 44.44 W/m² to 37.4 W/m²

Design Development

Hourly Cooling Demand for 24x 365 = 8,760 data points

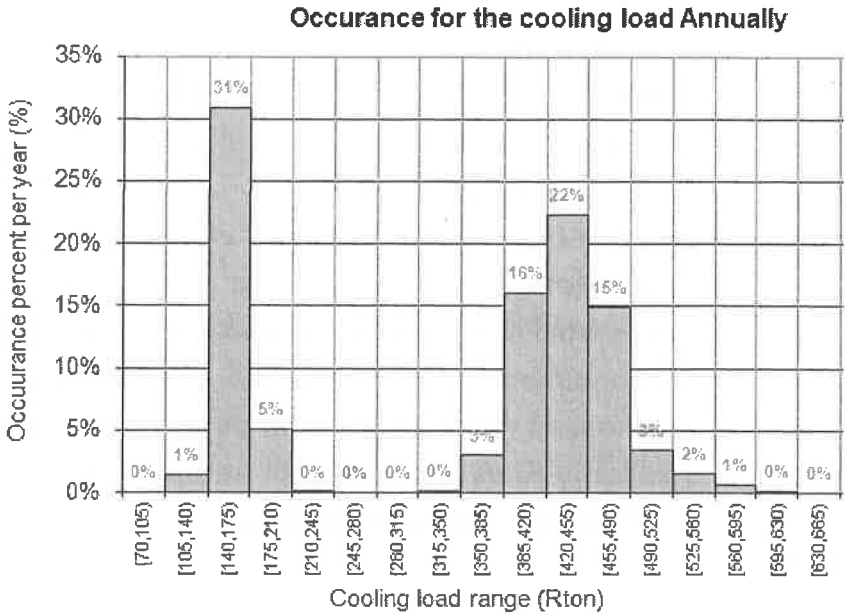
Month	Day	Hours	Rton	Month	Day	Hours	Rton	Month	Day	Hours	Rton	Month	Day	Hours	Rton
1	1	1	0	6	27	21	0	8	11	17	420.287	12	30	19	405.35
1	1	2	0	6	27	22	0	8	11	18	402.862	12	30	20	150.98
1	1	3	0	6	27	23	0	8	11	19	429.122	12	30	21	149.931
1	1	4	0	6	27	24	0	8	11	20	162.391	12	30	22	150.219
1	1	5	0	6	28	1	0	8	11	21	157.396	12	30	23	0
1	1	6	0	6	28	2	0	8	11	22	155.774	12	30	24	0
1	1	7	0	6	28	3	0	8	11	23	0	12	31	1	0
1	1	8	0	6	28	4	0	8	11	24	0	12	31	2	0
1	1	9	441.296	6	28	5	0	8	12	1	0	12	31	3	0
1	1	10	380.456	6	28	6	0	8	12	2	0	12	31	4	0
1	1	11	384.66	6	28	7	0	8	12	3	0	12	31	5	0
1	1	12	383.318	6	28	8	0	8	12	4	0	12	31	6	0
1	1	13	376.343	6	28	9	601.812	8	12	5	0	12	31	7	0
1	1	14	368.306	6	28	10	495.252	8	12	6	0	12	31	8	0
1	1	15	368.875	6	28	11	493.498	8	12	7	0	12	31	9	478.989
1	1	16	376.135	6	28	12	492.278	8	12	8	0	12	31	10	406.945
1	1	17	383.822	6	28	13	455.582	8	12	9	508.452	12	31	11	411.286
1	1	18	385.858	6	28	14	456.644	8	12	10	447.873	12	31	12	422.57
1	1	19	378.806	6	28	15	495.108	8	12	11	448.906	12	31	13	411.362
1	1	20	141.908	6	28	16	485.514	8	12	12	448.715	12	31	14	411.912
1	1	21	140.09	6	28	17	472.11	8	12	13	448.354	12	31	15	414.647
1	1	22	138.379	6	28	18	452.958	8	12	14	438.469	12	31	16	412.501
1	1	23	0	6	28	19	445.131	8	12	15	434.293	12	31	17	415.061
1	1	24	0	6	28	20	170.469	8	12	16	429.267	12	31	18	404.628
1	2	1	0	6	28	21	171.972	8	12	17	438.446	12	31	19	391.388
1	2	2	0	6	28	22	170.1	8	12	18	432.78	12	31	20	146.226
1	2	3	0	6	28	23	0	8	12	19	416.903	12	31	21	146.036
1	2	4	0	6	28	24	0	8	12	20	157.351	12	31	22	145.503
1	2	5	0	6	29	1	0	8	12	21	156.478	12	31	23	0
1	2	6	0	6	29	2	0	8	12	22	155.027	12	31	24	0
1	2	7	0	6	29	3	0	8	12	23	0				
1	2	8	0	6	29	4	0	8	12	24	0				

Design Development

Min	0.0
Max	623.1
Round up Max	700.0

How to Design my Chiller plant ?

Range of Rton	Occurance	%
[0,35)	0	0%
[35,70)	0	0%
[70,105)	0	0%
[105,140)	64	1%
[140,175)	1418	31%
[175,210)	234	5%
[210,245)	3	0%
[245,280)	0	0%
[280,315)	0	0%
[315,350)	9	0%
[350,385)	139	3%
[385,420)	739	16%
[420,455)	1026	22%
[455,490)	687	15%
[490,525)	160	3%
[525,560)	71	2%
[560,595)	31	1%
[595,630)	9	0%
[630,665)	0	0%
[665,700)	0	0%
		1.0



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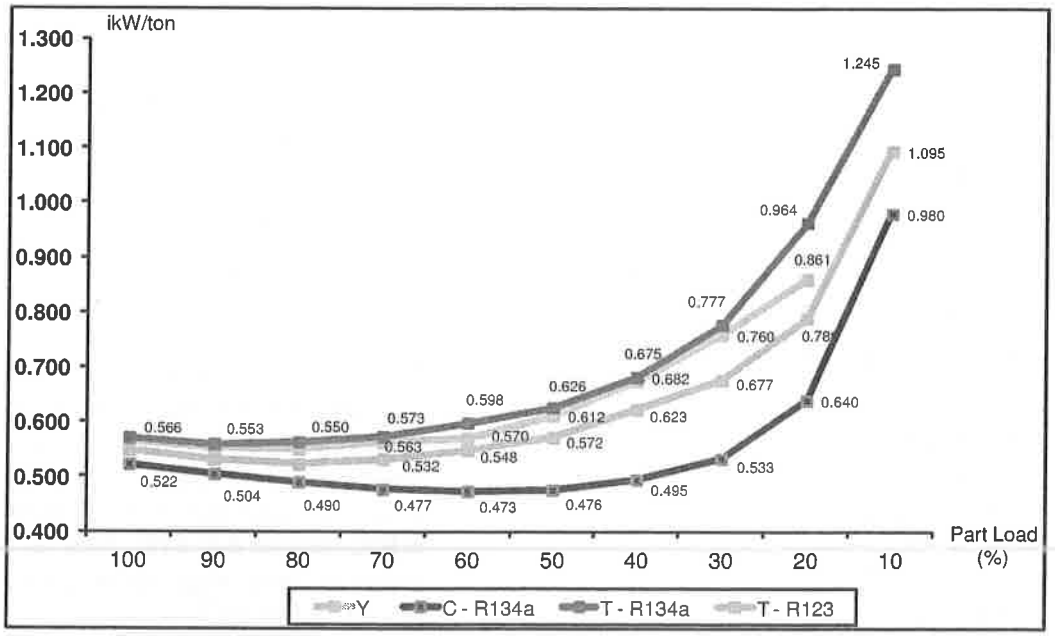
Design Development

How to Design my Chiller plant ?



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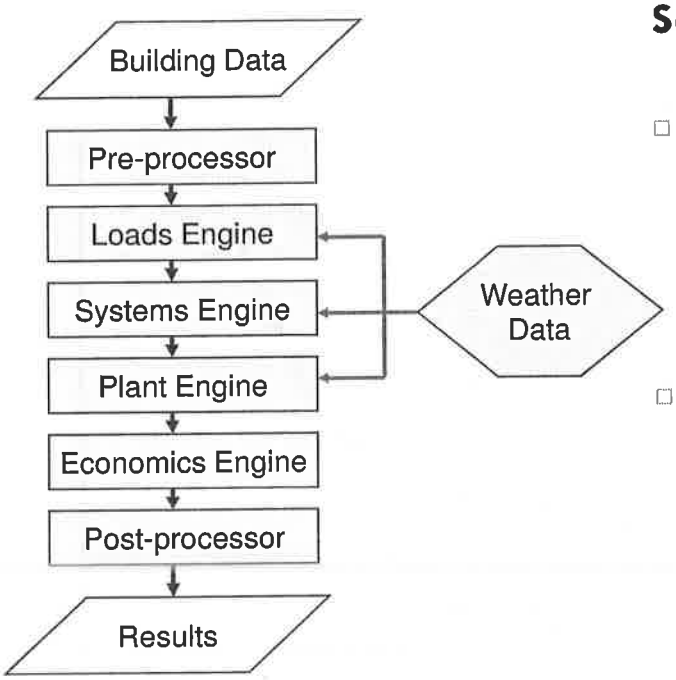
EM as a design tool

- 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

Energy Software Structure



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 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

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

Software Options

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

Note: * Free software

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** ⇨

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

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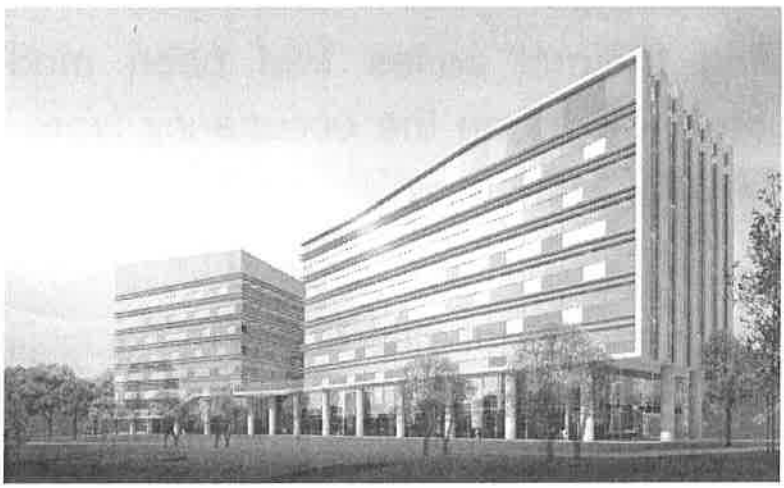
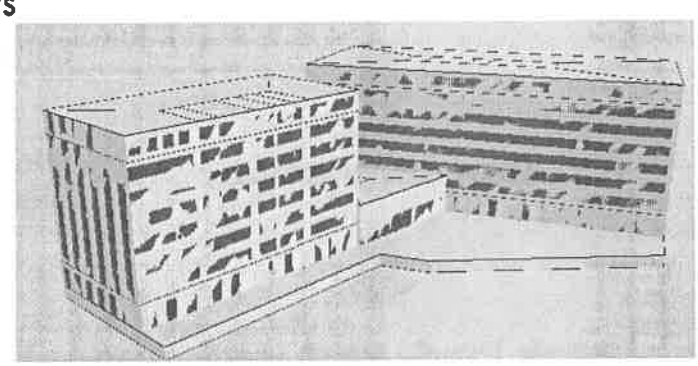
Case Study – Tampines Grande



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)

3 D Model

- 2 Blocks of 8-Storey Office Building connected with an atrium at L1 & L2
- One Level of Basement Carpark
- L3 to L8 – typical floors
- GFA of 35,000m2
- ETTV =39 W/m2



METHODOLOGY

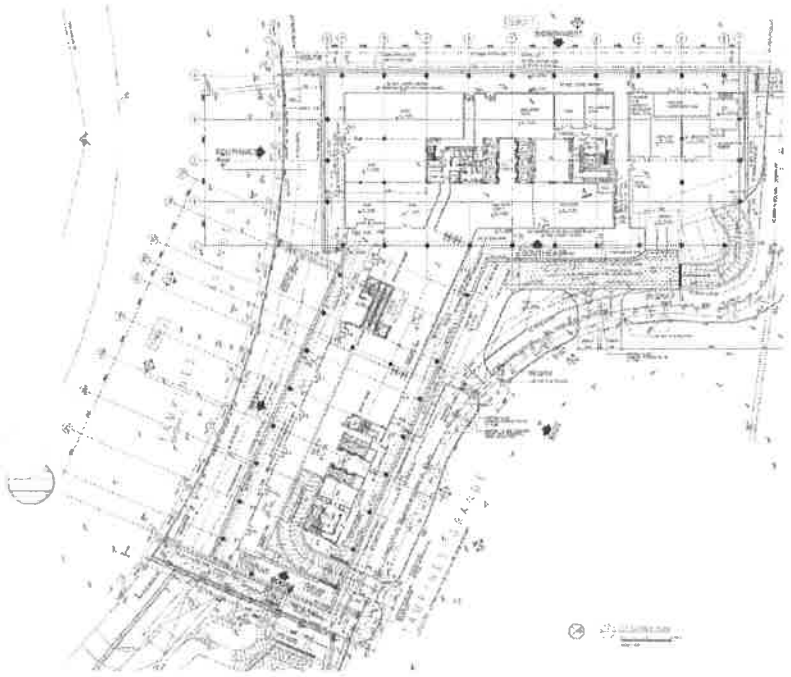
Simplified Floor Plans

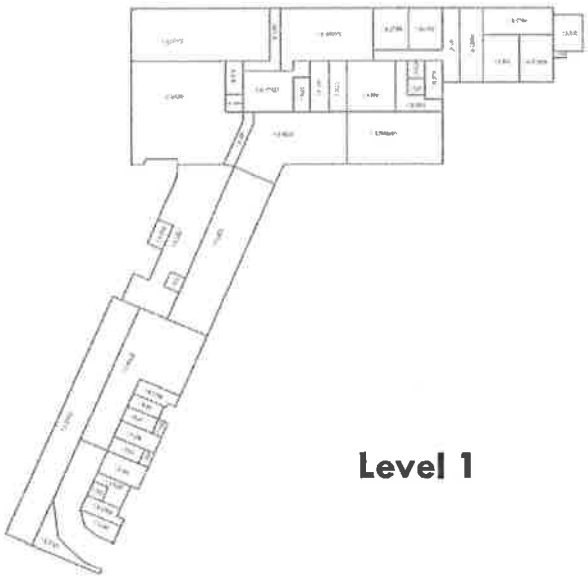
- The building thermal zones had been modified into **Simple Zones** based on the occupancy type, operating hours and ACMV system

- Ensure that no significant differences in
  - ✓ Floor Area,
  - ✓ Exterior Wall Area,
  - ✓ Window area &
  - ✓ Orientation.

METHODOLOGY

Simplified Floor Plans





Level 1

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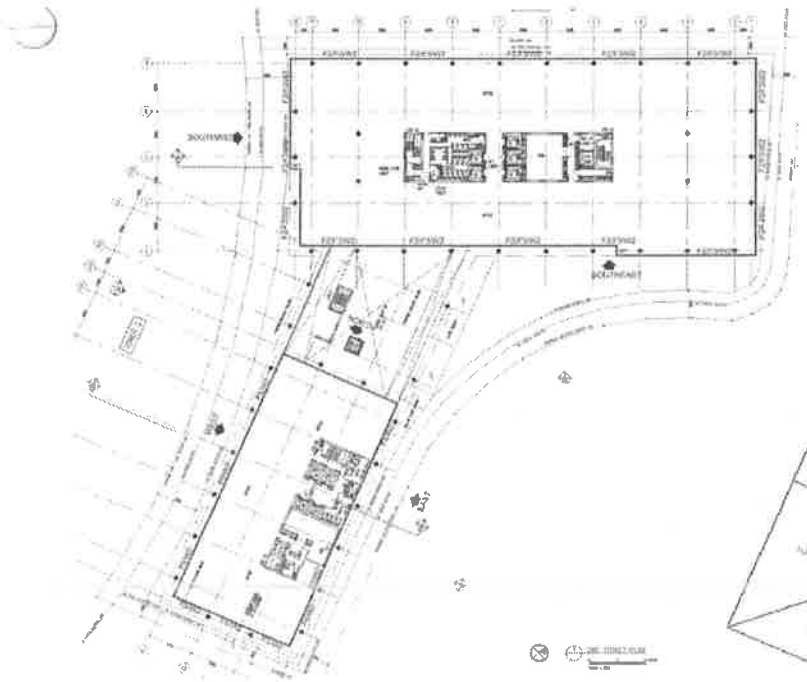
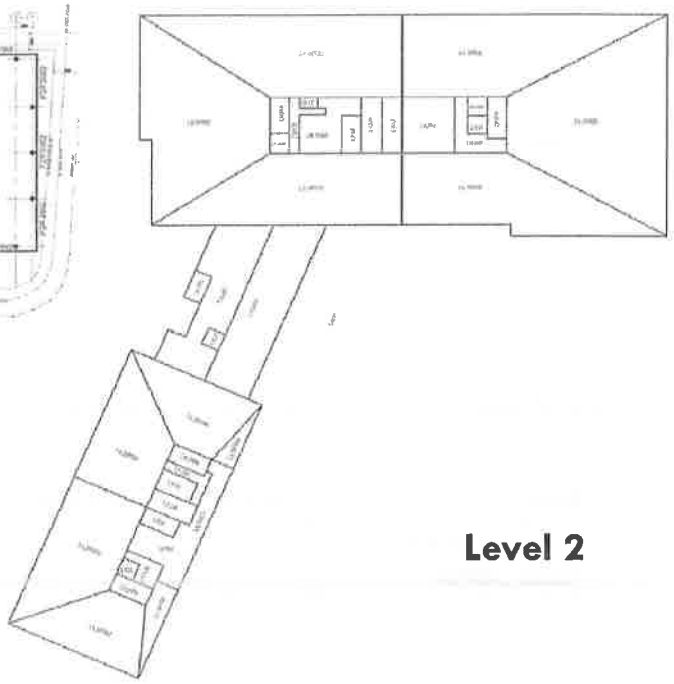
METHODOLOGY

Simplified Floor Plans

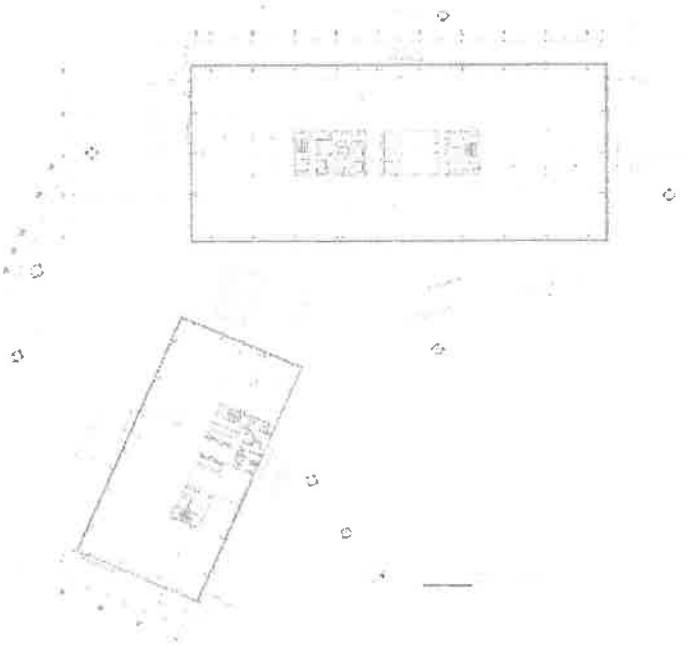




Level 2

METHODOLOGY

Simplified Floor Plans







Typical Floor
L3-L8

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

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

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SIMULATION INPUTS

HVAC System (example)

BUILDING ELEMENTS	REFERENCE MODEL	PROPOSED MODEL
AHU Fan Properties	AHU VAV Fan with 0.74 W/cmh	AHU Fan with average 0.36W/cmh
Central Plant Efficiency	2 x 600 Rton Cent Chillers, COP = 6.1 2 x 300 Rton Screw Chillers, COP = 5.5 CHW pump = 0.117 kW/ton CW pump = 0.088 kW/ton Cooling Tower = 0.06 kW/ton	2 x 600 Rton Cent Chillers, COP = 7.25 2 x 300 Rton Screw Chillers, COP = 6.94 CHW pump = 0.05 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: 35 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: 35 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

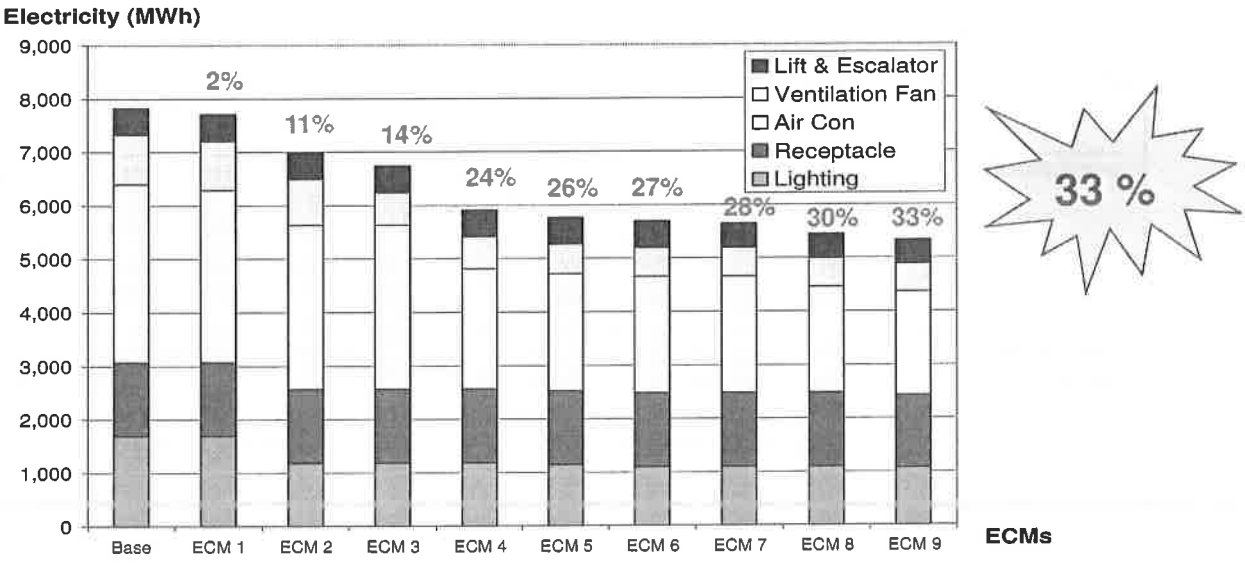
Energy Conservation Measures

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.

Annual Energy Consumptions

Annual Energy Consumption Comparison for ECMs



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, Kim DongKyun
Environmentally Sustainable Development (ESD) Consultant,
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GMP : Energy Modeling Theories (Cooling load)
How should we understand process of cooling load calculation?

01 02 03 04 05

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, Kim DongKyun
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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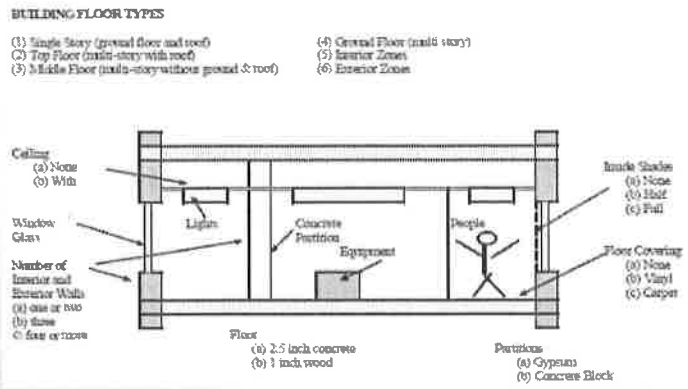
1. Introduction of cooling load calculation in EM

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.

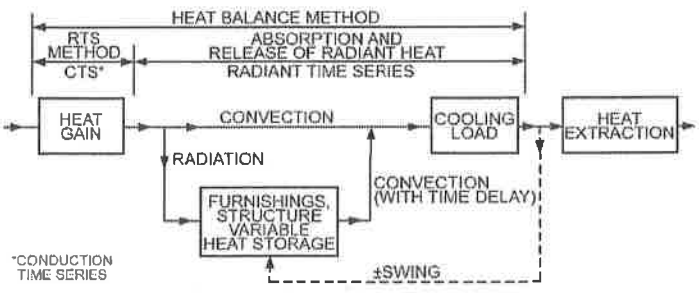


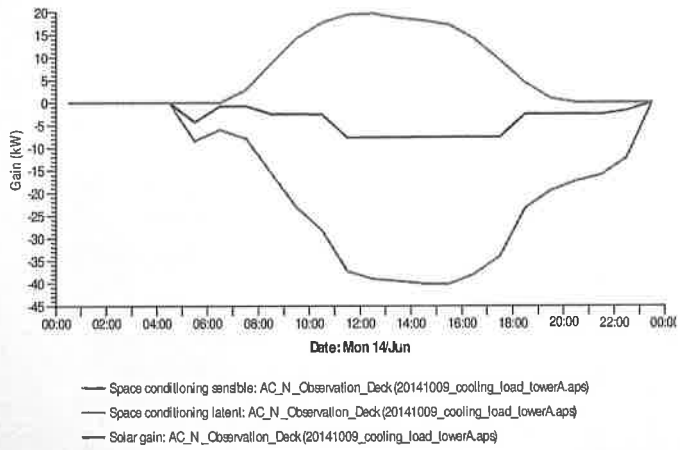
Fig. 1 Origin of Difference Between Magnitude of Instantaneous Heat Gain and Instantaneous Cooling Load

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.

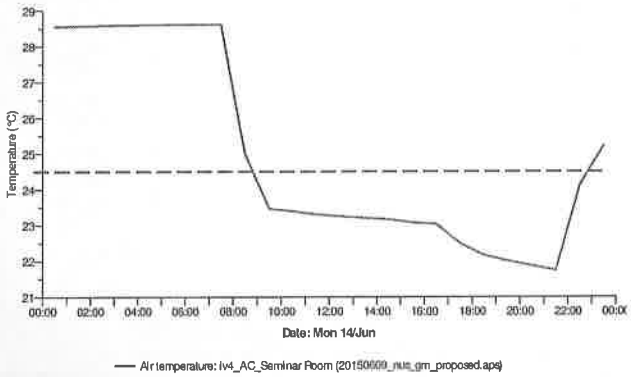
The space cooling load is what cooling system have to remove from zone to maintain design temperature.

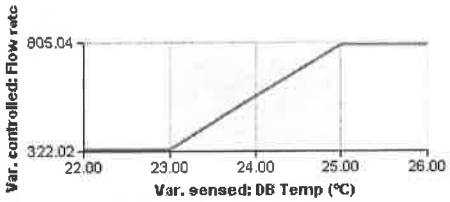
1. Introduction of cooling load calculation in EM

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.

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.

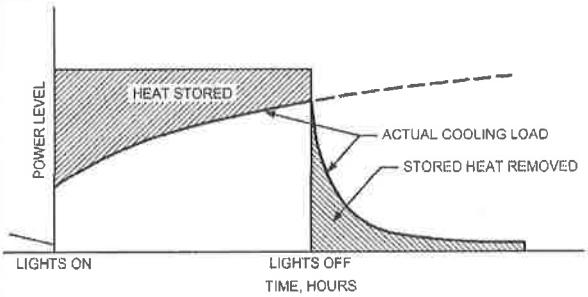


Fig. 2 Thermal Storage Effect in Cooling Load from Lights

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.

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.

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

		Total Heat, W		Sensible Heat, W	Latent Heat, W
Degree of Activity		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*	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	26
	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	106	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: Homi 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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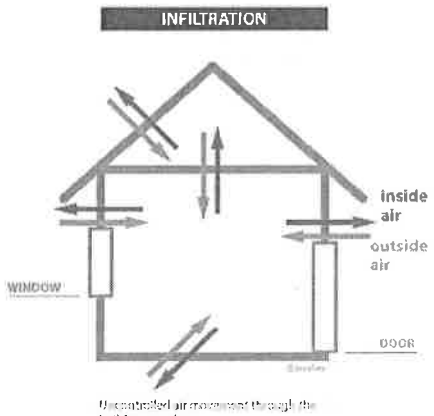
3. Infiltration Heat Gains

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.

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.

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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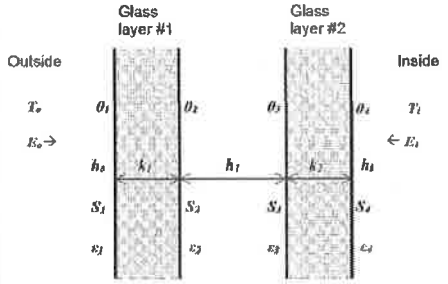
4. Fenestration Heat Gain

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.



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

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

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

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

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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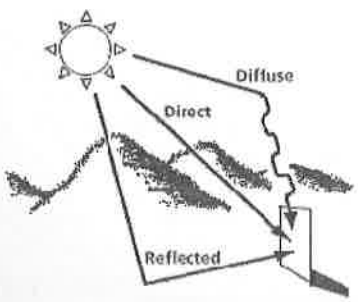
4. Fenestration Heat Gain

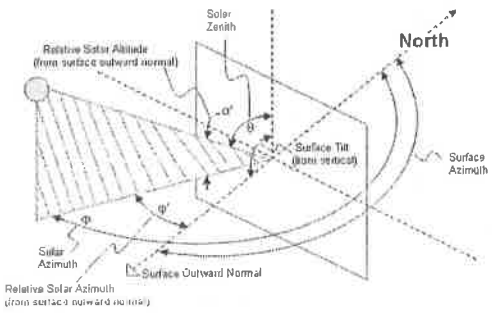
Fenestration heat gain in Cooling load calculation

(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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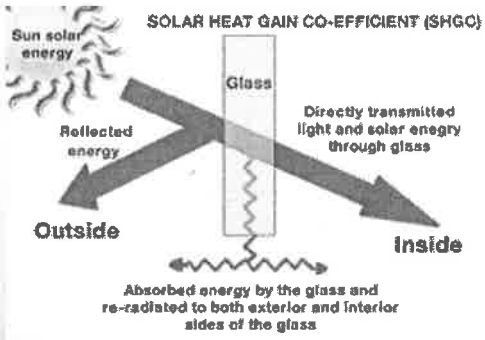
4. Fenestration Heat Gain

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.

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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).

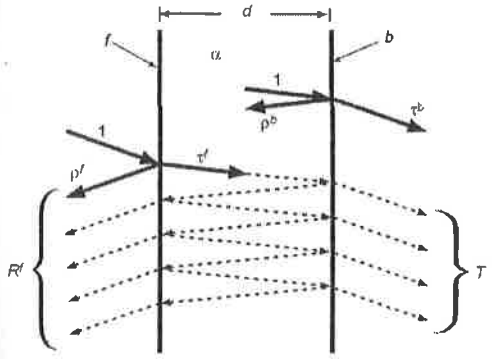

Fig. 6 Optical Properties of a Single Glazing Layer

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).

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

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.

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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.

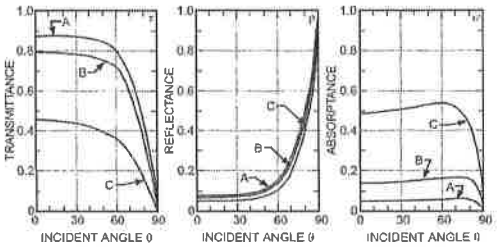
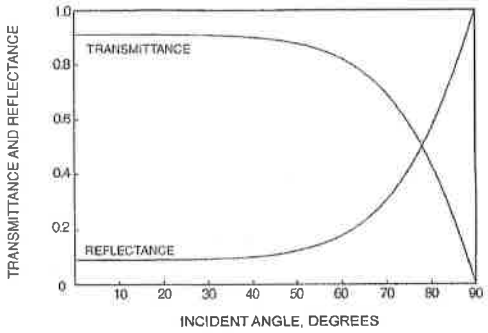


Fig. 8 Variations with Incident Angle of Solar-Optical Properties for (A) Double-Strength Sheet Glass, (B) Clear Plate Glass, and (C) Heat-Absorbing Plate Glass



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 $\mathfrak{A}$ 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

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

where

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

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

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

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

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

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

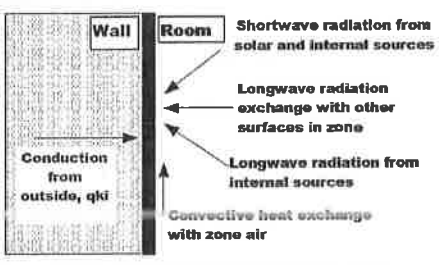

Figure 18. Inside Heat Balance Control Volume Diagram

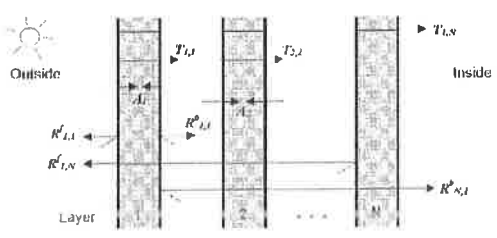

Figure 73. Schematic of transmission, reflection and absorption of solar radiation within a multi-layer

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5. Heat Balance Method

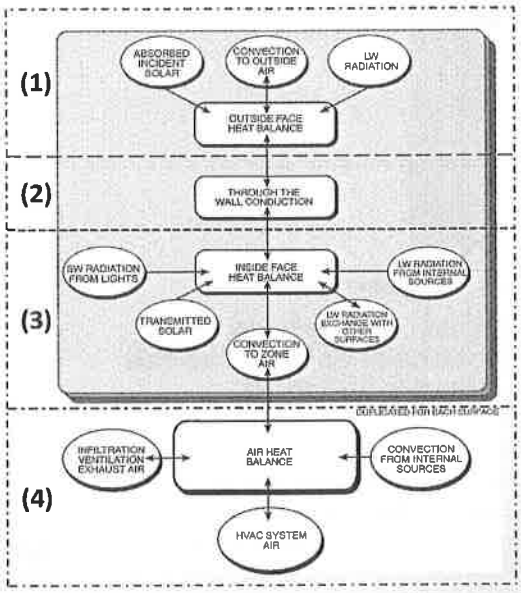
Heat Balance Method in Cooling load calculation

(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.

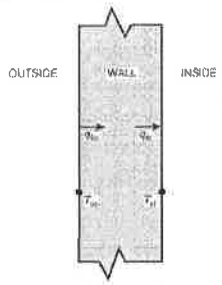

Fig. 6 Schematic of Wall Conduction Process

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

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

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 .

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

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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SCA GREEN MARK AWARDS IN 2013/14

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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, Kim DongKyun
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, Kim DongKyun
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>

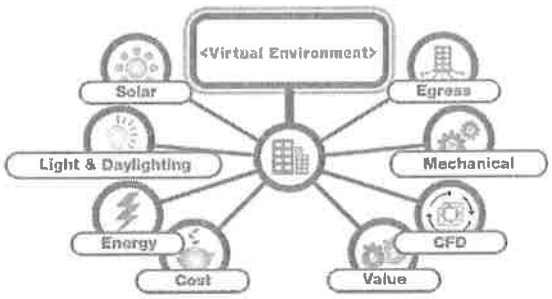
1.Introduction for IES<VE>

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.

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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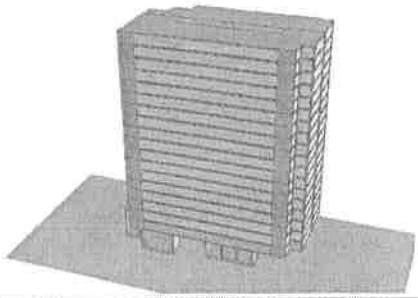
1.Introduction for IES<VE>

Integrated Analysis tool of Dynamic Building Energy Simulation

IES<VE> Modules applicable for energy modeling.

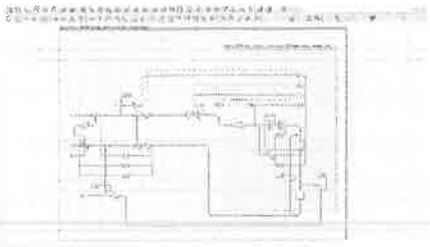
1. Model IT is for Geometry model (plan and elevation).



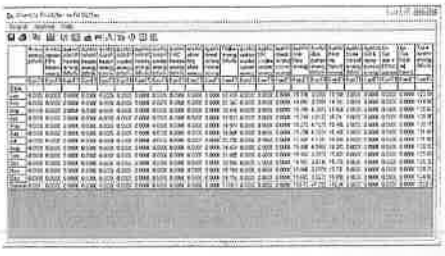
2. Apache-Sim is for physical model (internal condition and facade).



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

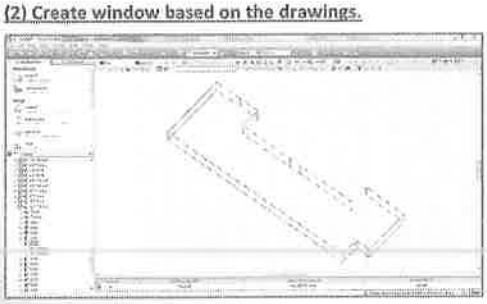
Based on the imported drawings, 3D model can be created in Model IT.

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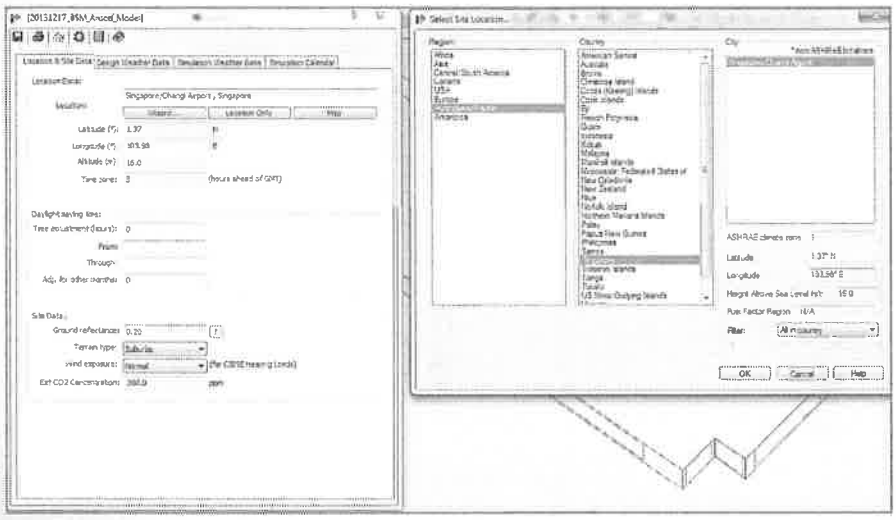
2.General understanding of Model IT in IES<VE>

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).

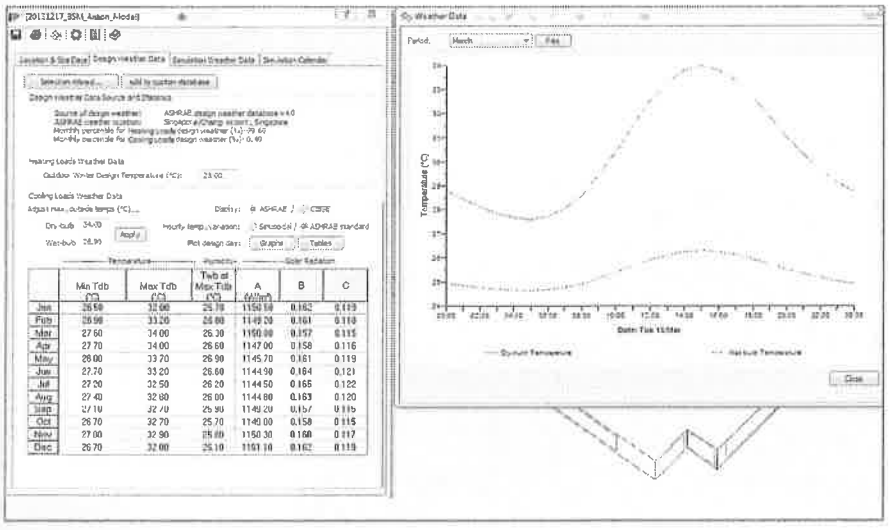
International weather data is available in IES<VE> website. (http://www.iesve.com/support/weatherfiles)

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.

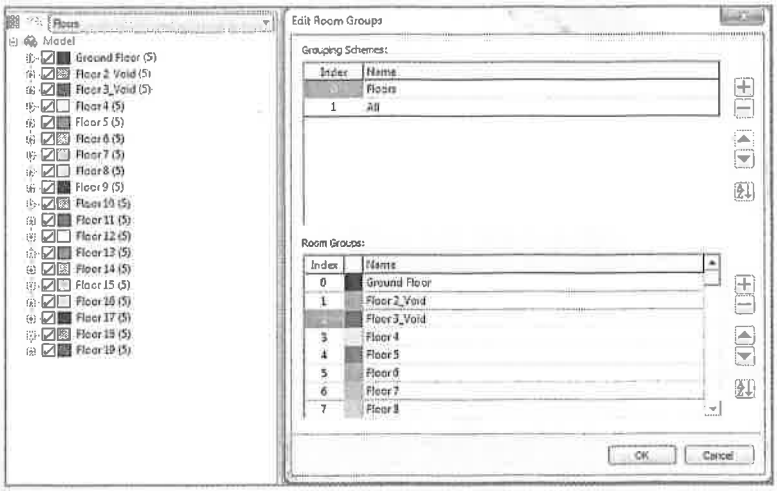
International weather data is available in IES<VE> website. (http://www.iesve.com/support/weatherfiles)

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.

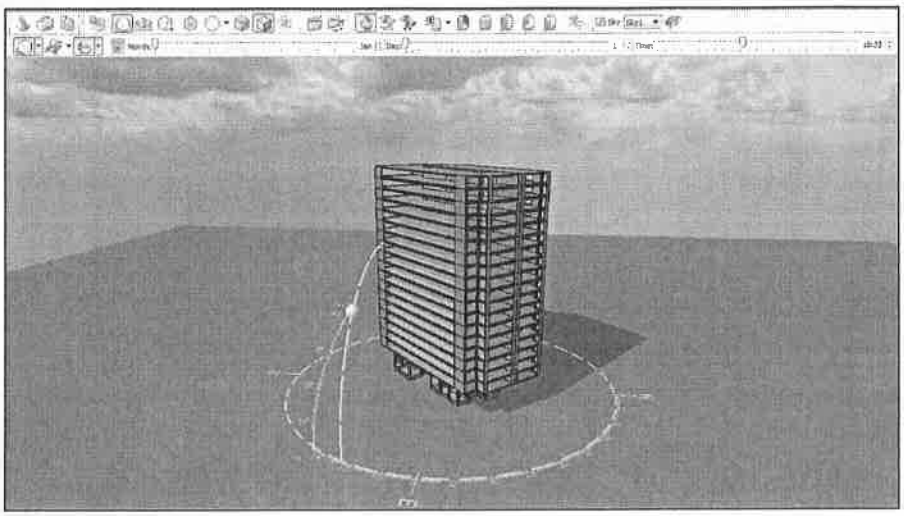
Function of "Edit Room Groups " is useful to check total area of the window and plan according to the different category of the space.

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.

General process of Apache in IES<VE>

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

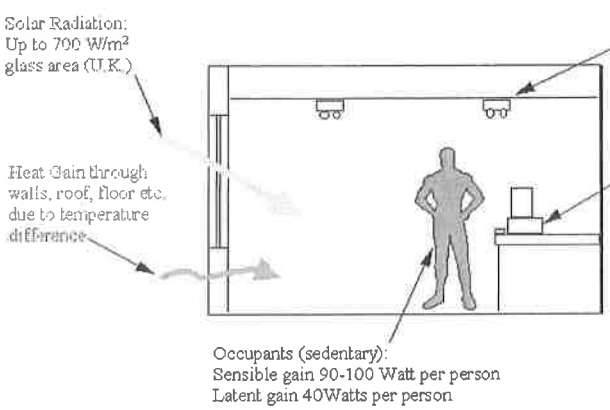
-Internal condition
-Operating schedule of lighting, equipment, people, system etc
-Thermal properties of façade
-Report generator for room level
-Simple HVAC model in early stage of project
-Hot water system and solar hot water system

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.

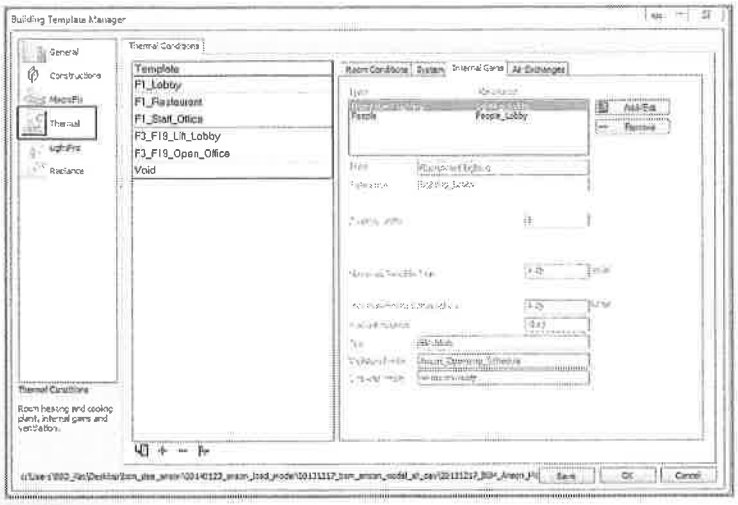
External heat gain : Thermal properties of façade can be defined in 'construction' tap. The IES<VE> will calculate the cooling load from the facade based on the hourly weather data .

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.

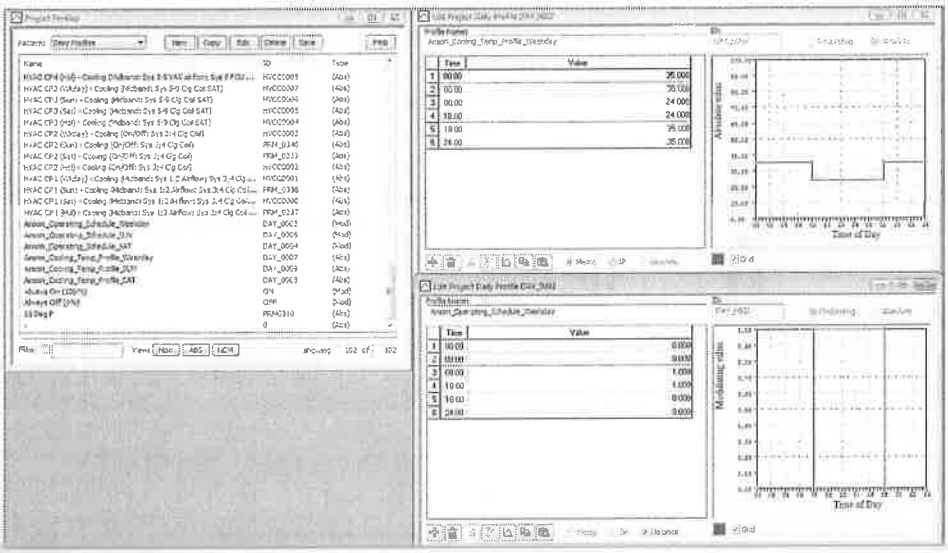
BSD building system & diagnostics

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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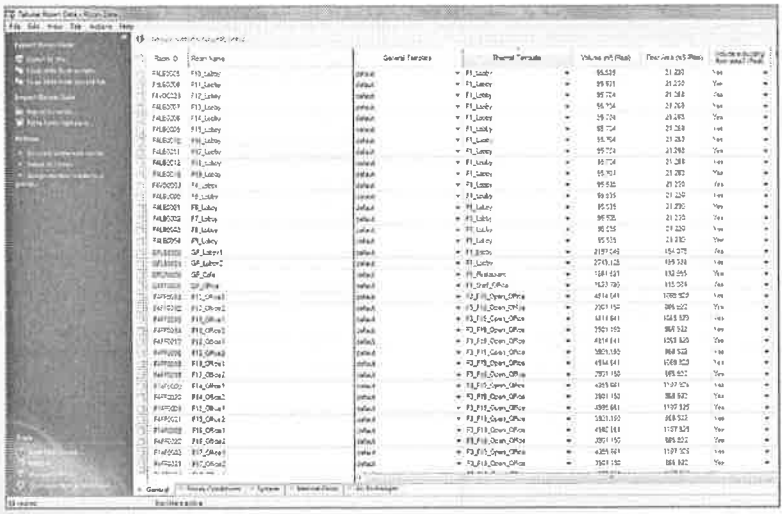
3. General understanding of Apache in IES<VE>

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.

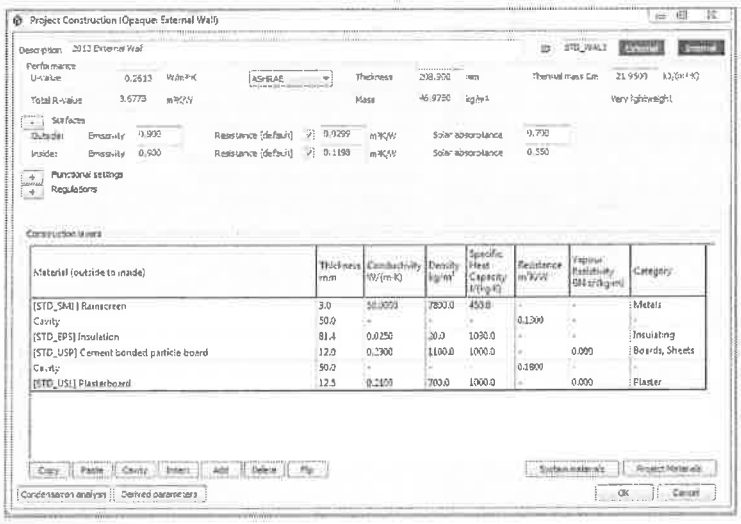
Based on this template, IES<VE> will generate cooling or heating load for internal heat gain components and it will be referred for the calculation of the energy consumption from lighting and equipment as well.

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

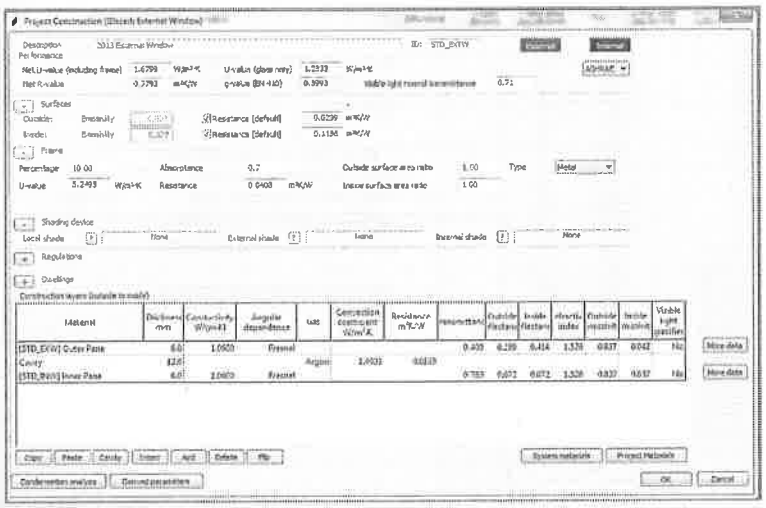
Based on this template, IES<VE> will generate cooling or heating load for external heat gain components based on 8,760hrs weather profile inclusive of the solar profile, solar radiation, wet-bulb temp, dry-bulb temp, wind speed, etc

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

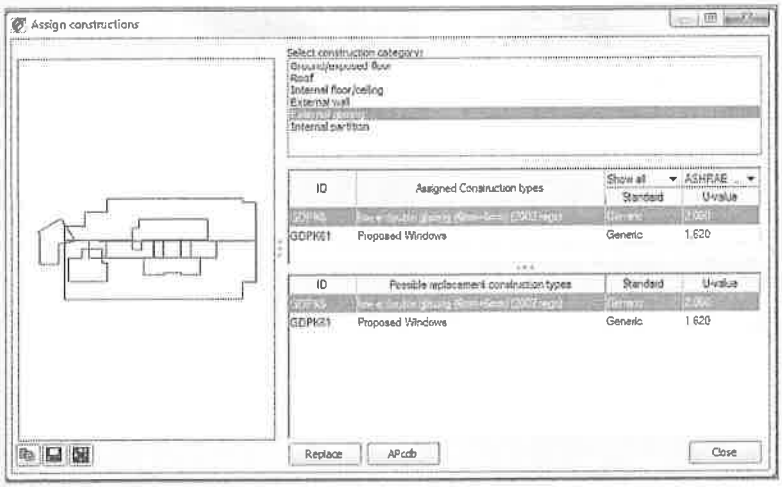
Based on different calculation methodologies from ASHRAE, CIBSE and EN-ISO standard, thermal properties of external window and external wall are generated differently.

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 facade 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

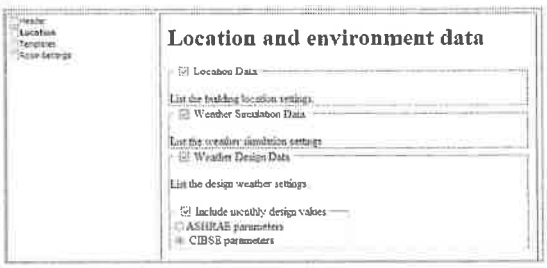
By using "Assign constructions", the project team can define the type of the façade or floor to correspond space.

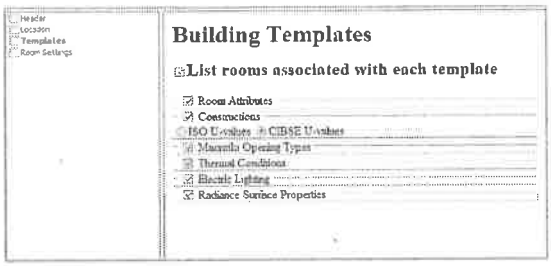
3. General understanding of Apache in IES<VE>

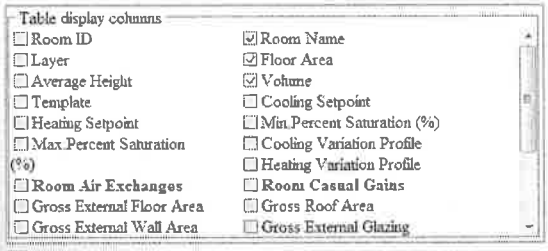
To define the thermal properties of the building (Internal condition and façade).

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.

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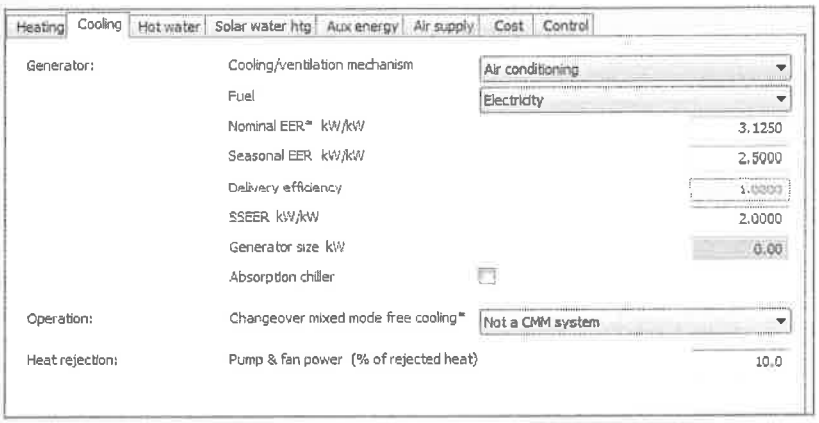
3. General understanding of Apache in IES<VE>

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.

(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.

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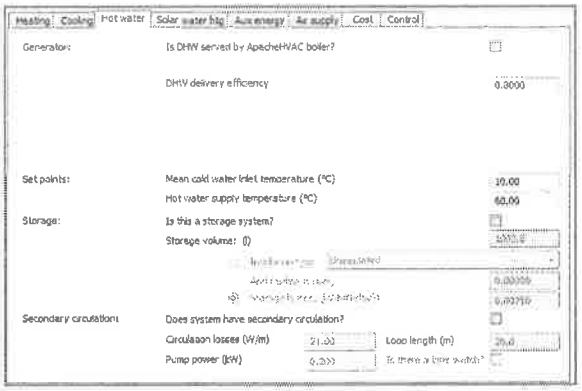
3. General understanding of Apache in IES<VE>

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

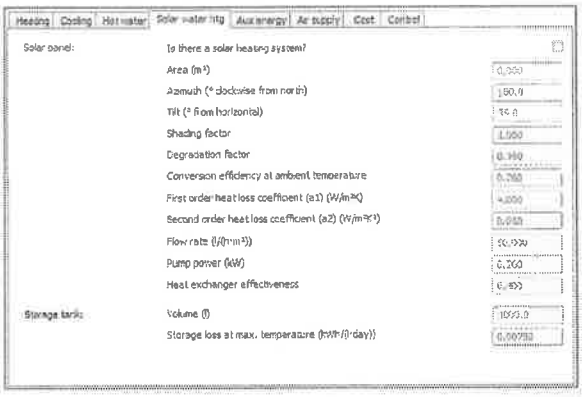
After creating 3D model, we can define thermal properties of building such as the internal condition and façade.

(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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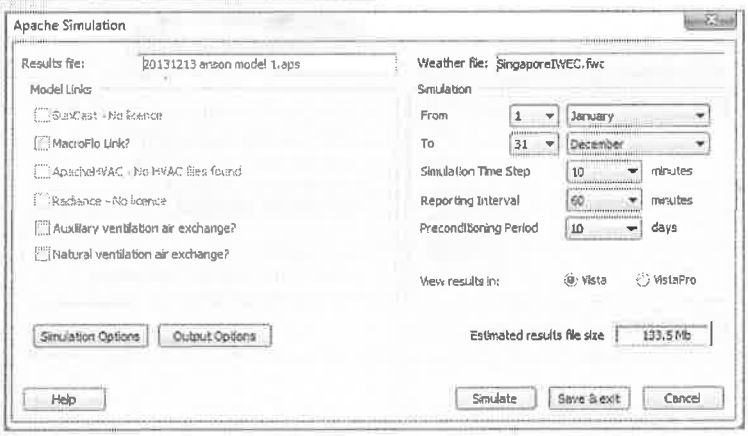
3. General understanding of Apache in IES<VE>

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.

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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

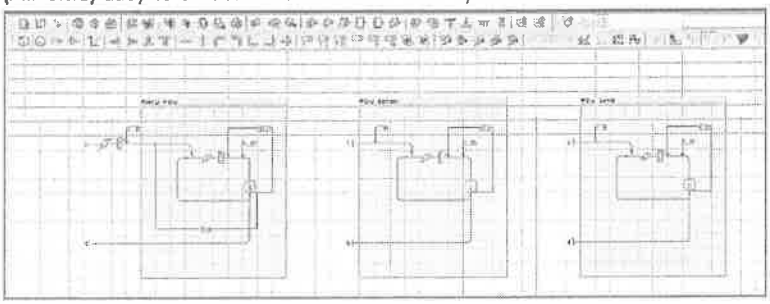
4. General process of Apache HVAC in IES<VE>

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.

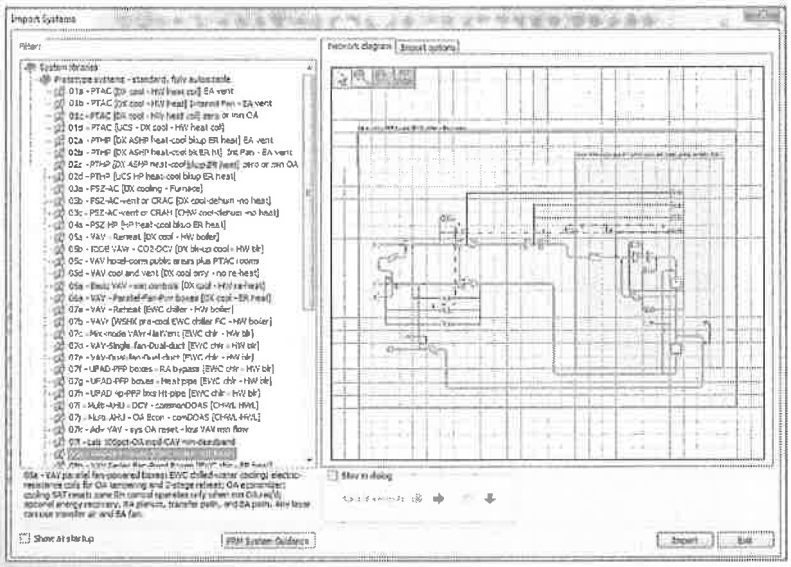
4. General process of Apache HVAC in IES<VE>

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

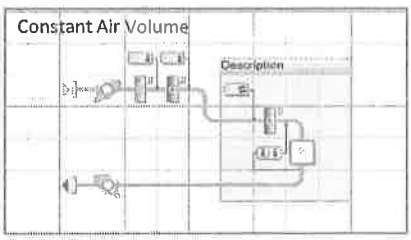
4. General process of Apache HVAC in IES<VE>

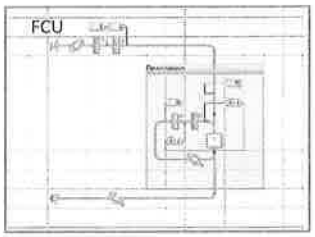
To define detail ACMV system in energy model

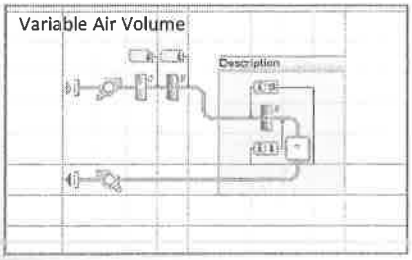
Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

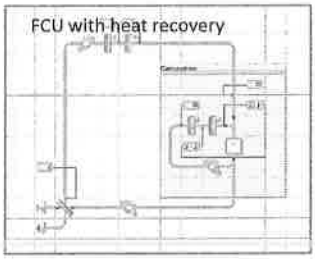
(2-2) Prototype of systems in Apache HVAC

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.

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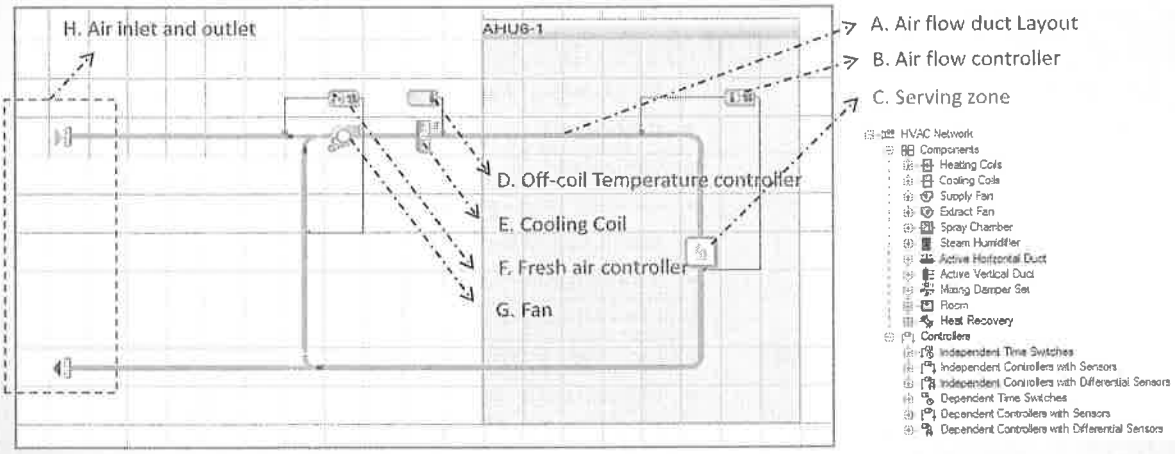
4. General process of Apache HVAC in IES<VE>

To define detail ACMV system in energy model

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

(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).

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.

(3-2) Airside system modeling in Apache HVAC

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

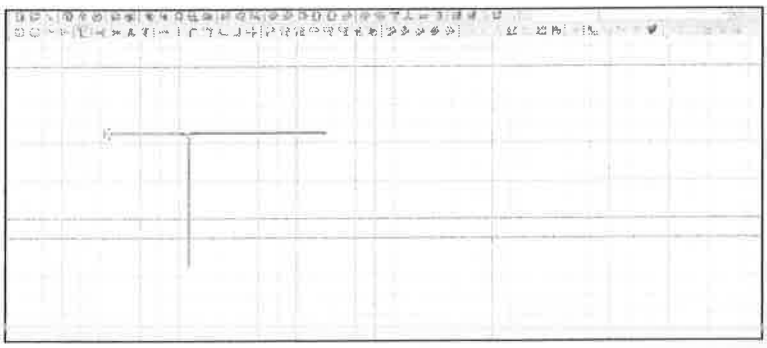


- Room or thermal zone component
- Air inlet
- Air outlet
- Network drawing tool
- Junction / flow splitters (four)
- Straight connectors (two)
- Elbow connectors (four)
- Crossover connector

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





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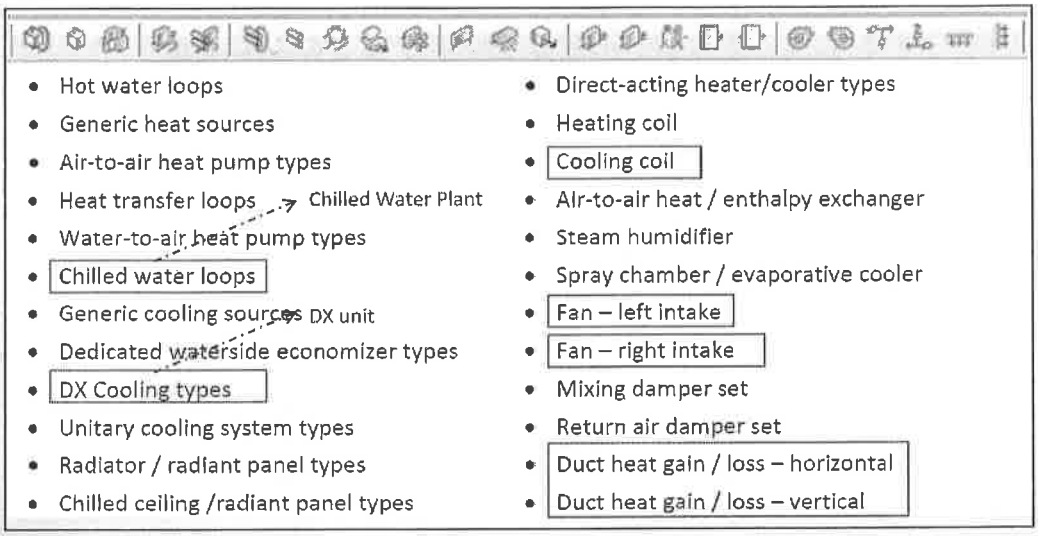
4. General process of Apache HVAC in IES<VE>

To define detail ACMV system in energy model

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

(3-3) Airside system modeling in Apache HVAC

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



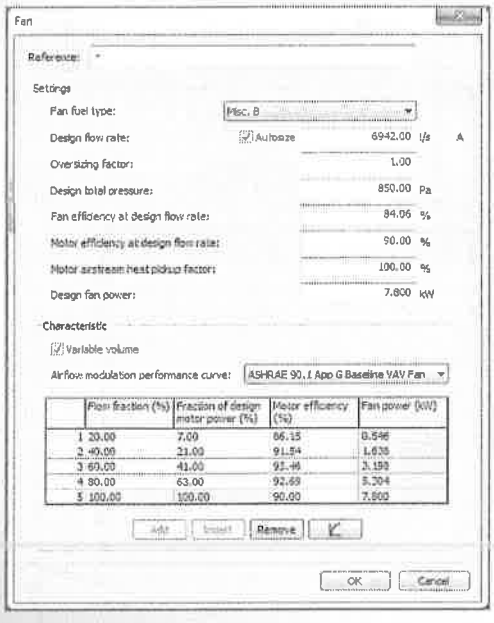
In addition, duct heat gain also can be considered in Apache HVAC module.

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.

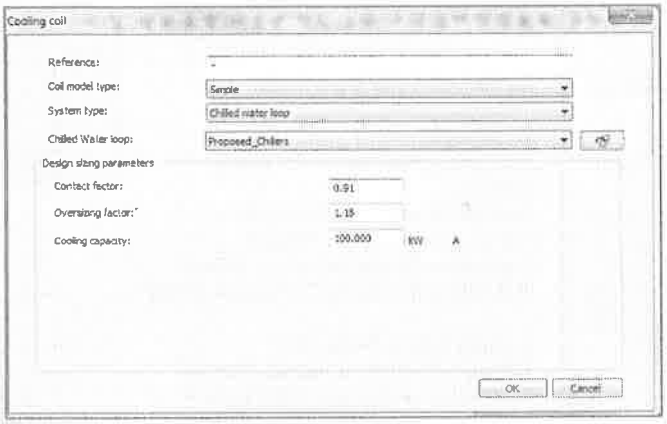
4. General process of Apache HVAC in IES<VE>

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.

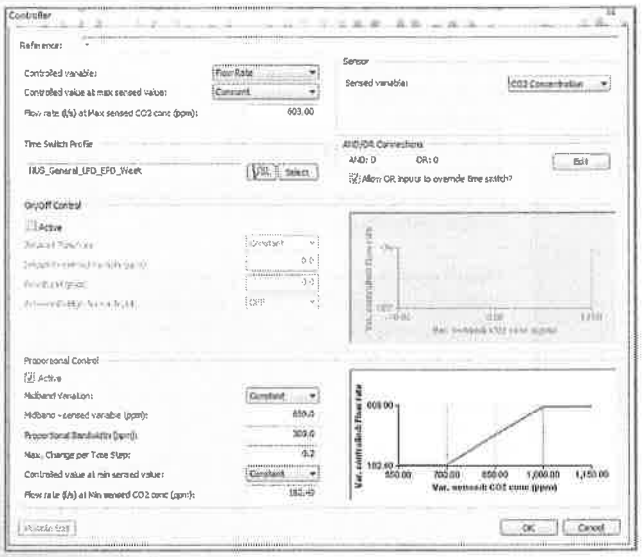
4. General process of Apache HVAC in IES<VE>

To define detail ACMV system in energy model

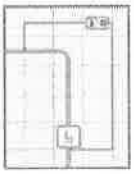
Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

(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

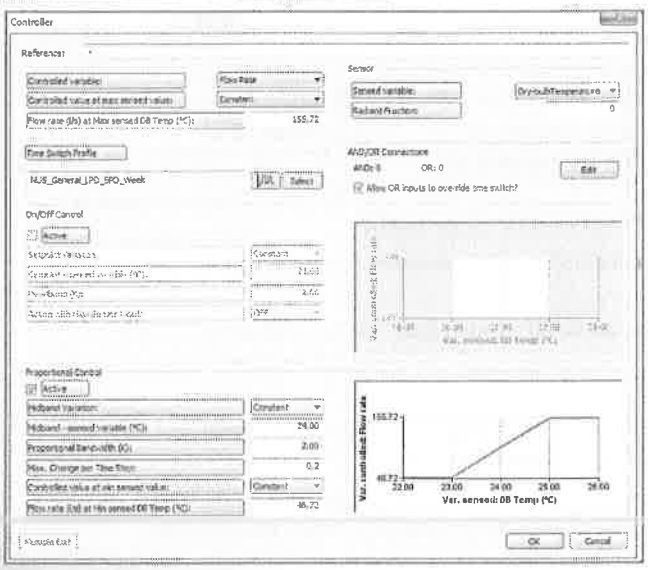
4. General process of Apache HVAC in IES<VE>

To define detail ACMV system in energy model

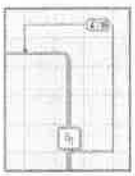
Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

(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

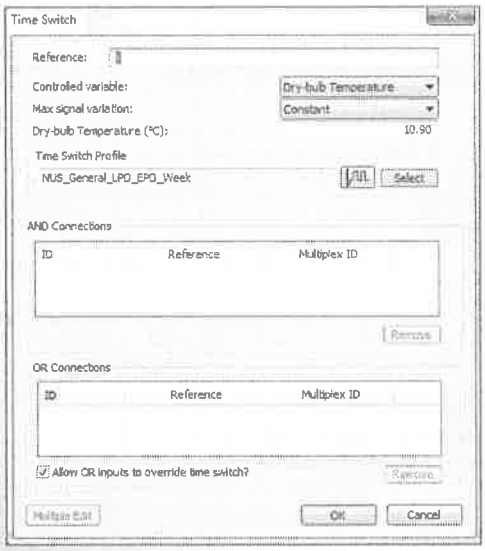
4. General process of Apache HVAC in IES<VE>

To define detail ACMV system in energy model

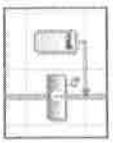
Apache HVAC has advantage compared with other software due to user friendly and visualized interface.

(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.

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.

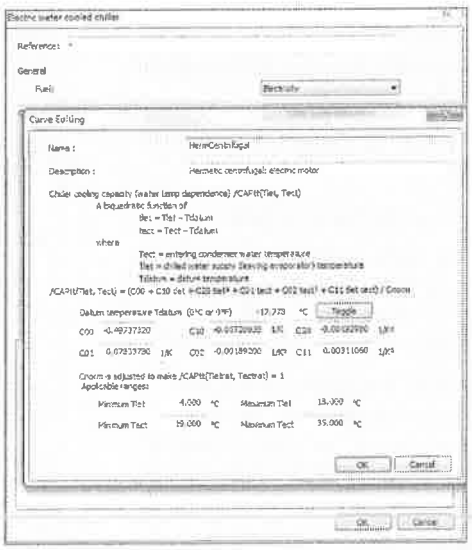
A. Part load curve (by equation and coefficients)

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.



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

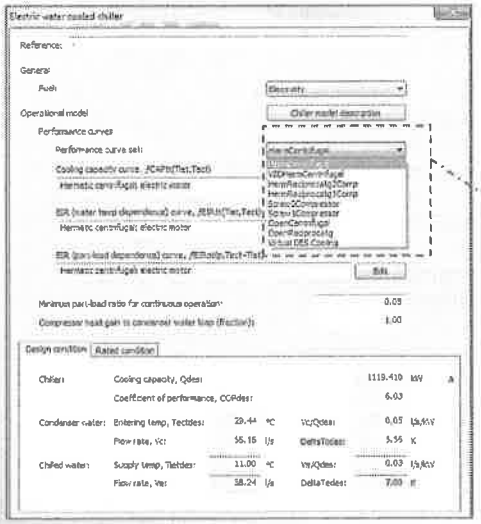
To define detail ACMV system in energy model

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.

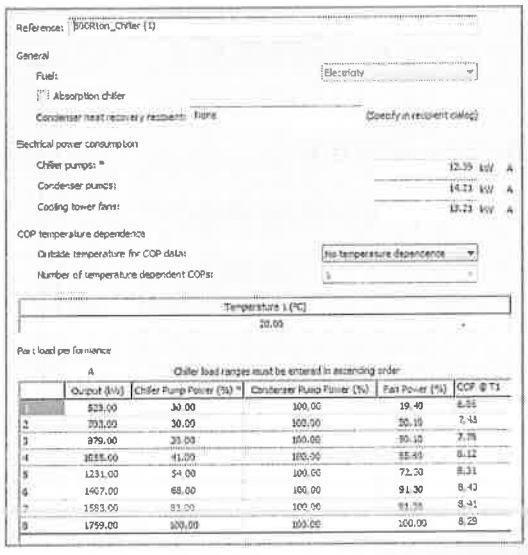
CHWP part load curve : User can input in table

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

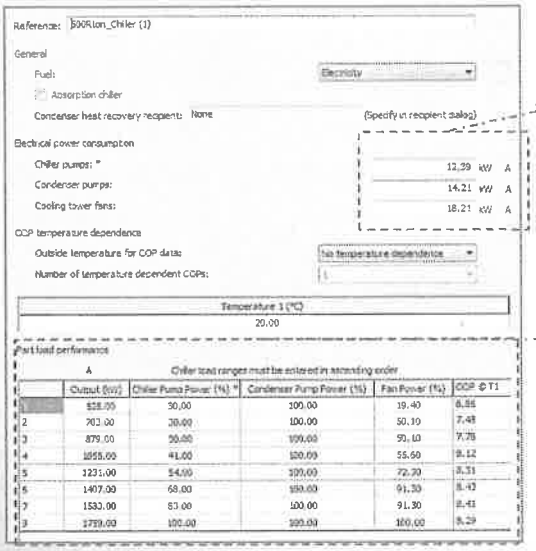
4. General process of Apache HVAC in IES<VE>

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.



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	229.28	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	6.95	14.21	13.16	182.31	0.520
5	60%	1,055	300	0.433	130	8.12	5.08	14.21	10.12	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	93.41	0.696

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	3.29

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)

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.

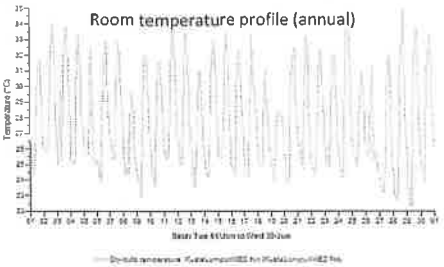
Please note that this module provides cooling and heat load report as well and weather profile can be checked as well.

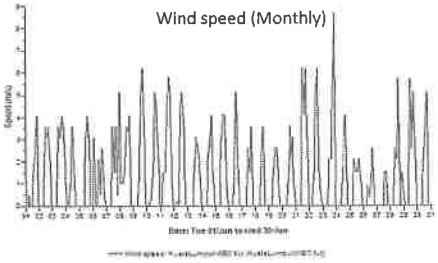
5. General process of Vista and Vista pro in IES<VE>

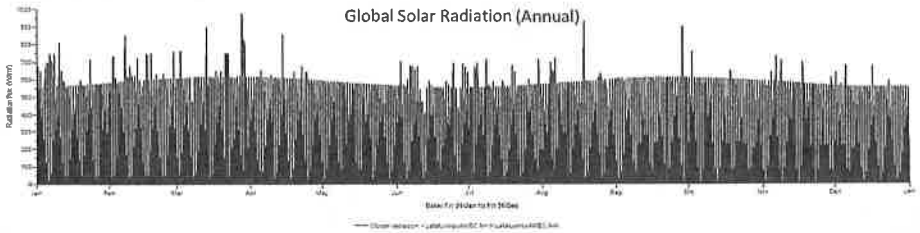
To check result of energy models in detail in terms of building and system components

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.

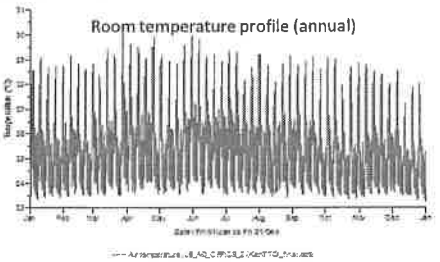
BSD building system & diagnostics

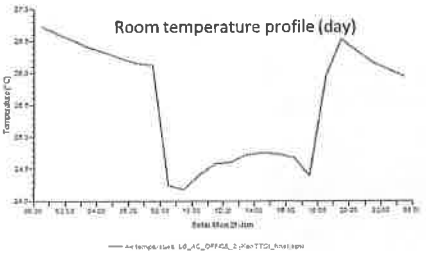
5. General process of Vista and Vista pro in IES<VE>

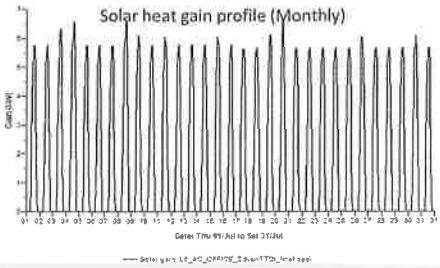
To check result of energy models in detail in terms of building and system components

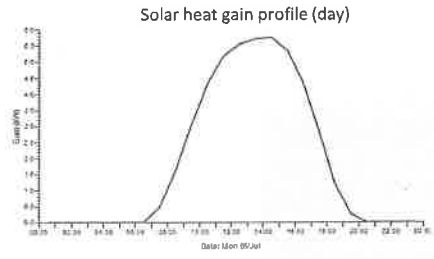
There are two modules to check results for energy model in IES<VE>

(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

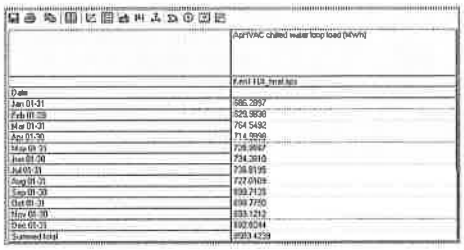
5. General process of Vista and Vista pro in IES<VE>

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)

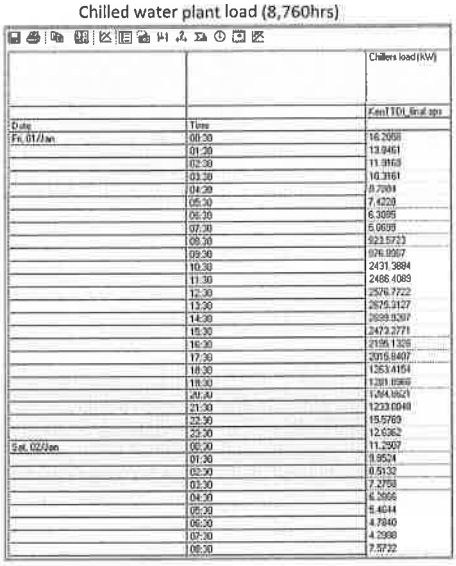


Date	AprHVAC chilled water loop load (MWh)
	KentTDI_final.aps
Jan 01-31	686.3997
Feb 01-28	629.9830
Mar 01-31	764.5492
Apr 01-30	714.9999
May 01-31	728.9967
Jun 01-30	734.3910
Jul 01-31	738.8195
Aug 01-31	727.0109
Sep 01-30	699.7125
Oct 01-31	698.7750
Nov 01-30	693.1212
Dec 01-31	692.8244
Summed total	8583.4239

Chilled water plant load profile



Chilled water plant load (8,760hrs)



Date	Time	Chillers load (kW)
		KentTDI_final.aps
Fri, 01/Jan	00:30	16.2658
	01:30	13.9461
	02:30	11.3958
	03:30	10.3161
	04:30	8.7269
	05:30	7.4220
	06:30	6.3095
	07:30	5.0608
	08:30	923.5723
	09:30	976.9997
	10:30	2431.3884
	11:30	2486.4089
	12:30	2576.7722
	13:30	2675.3127
	14:30	2599.8267
	15:30	2473.2771
	16:30	2195.1326
	17:30	2016.8407
	18:30	1263.4154
	19:30	1281.8966
	20:30	1264.9621
	21:30	1233.0048
	22:30	15.5769
	23:30	12.6362
Sat, 02/Jan	00:30	11.2597
	01:30	9.9524
	02:30	8.5132
	03:30	7.2758
	04:30	6.2066
	05:30	5.4044
	06:30	4.7840
	07:30	4.2988
	08:30	7.5722

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.

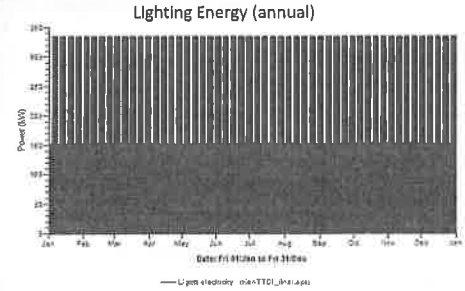
5. General process of Vista and Vista pro in IES<VE>

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

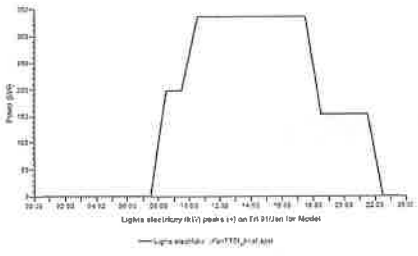
There are two modules to check results for energy model in IES<VE>

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

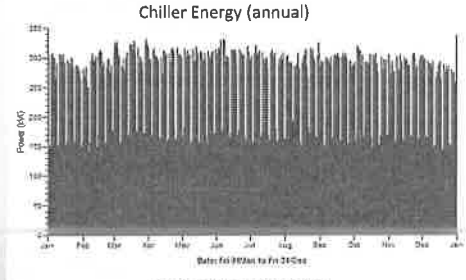
Lighting Energy (annual)



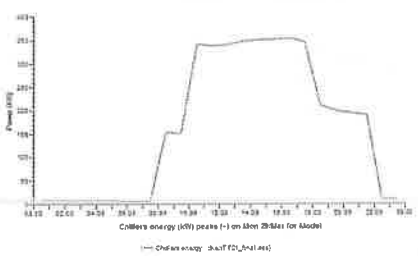
Lighting Energy profile at peak day



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) KenTTDI_final.aps				ApHVAC d ApHVAC h ApHVAC chillers energy (kW) 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	0.000
	1:30	0	0			1:30	0	0	0	0.000
	2:30	0	0			2:30	0	0	0	0.000
	3:30	0	0			3:30	0	0	0	0.000
	4:30	0	0			4:30	0	0	0	0.000
	5:30	0	0			5:30	0	0	0	0.000
	6:30	0	0			6:30	0	0	0	0.000
	7:30	0	0			7:30	0	0	0	0.000
	8:30	901.9218	256.4469			8:30	5.0799	24.3348	105.1191	134.5338	0.525
	9:30	941.9075	267.9156			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	55.1355	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	346.8535			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.

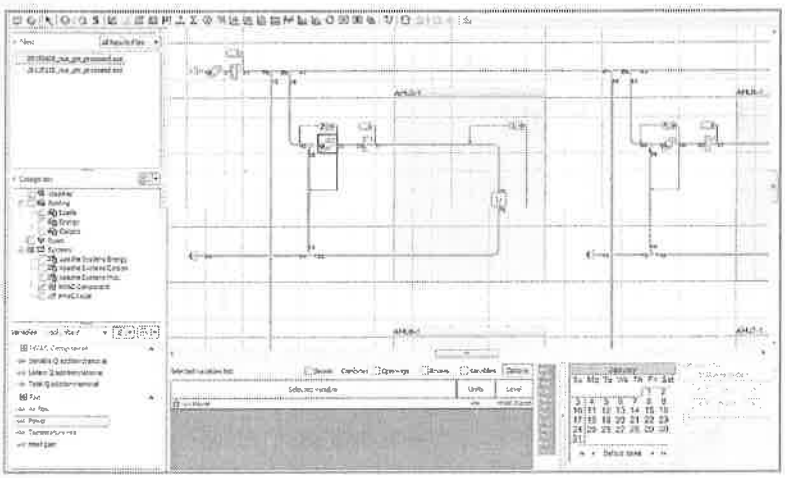
For example,
Hourly operating efficiency of chilled water plant can be generated based on results from Vista module.

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

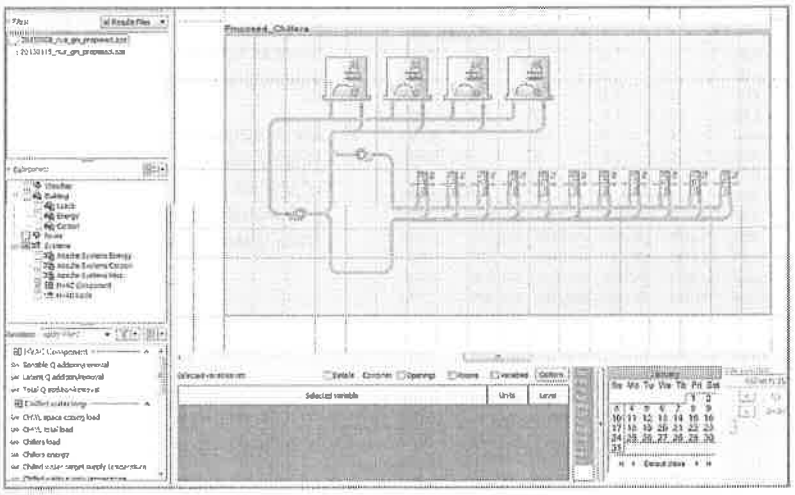
Please note that air flow rate and temperature can be checked in Vista module as well, Vista pro provides more detail information than vista module such as fan power, heat gain etc in system level.

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

BSD
building system & diagnostics

GREEN MARK PROFESSIONAL CORE MODULE :

BUILDING ENERGY MODELING & THERMAL SIMULATION

YONG PING QUEN
(CERTIFIED GMP, LEED AP, GBIF, CEM, BCA-REGISTERED ENERGY AUDITOR)

BUILDING SYSTEM & DIAGNOSTICS PTE LTD



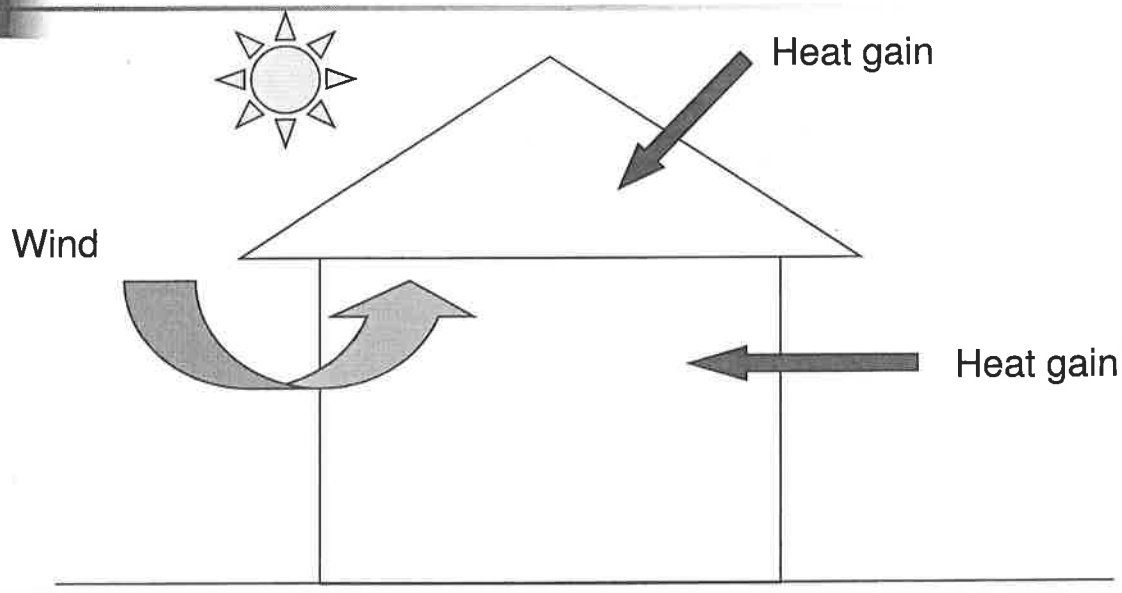
Presented by :
Environmentally Sustainable Development (ESD) Consultant,
Building System and Diagnostics | BSD Pte Ltd. © 2015

Thermal Simulation

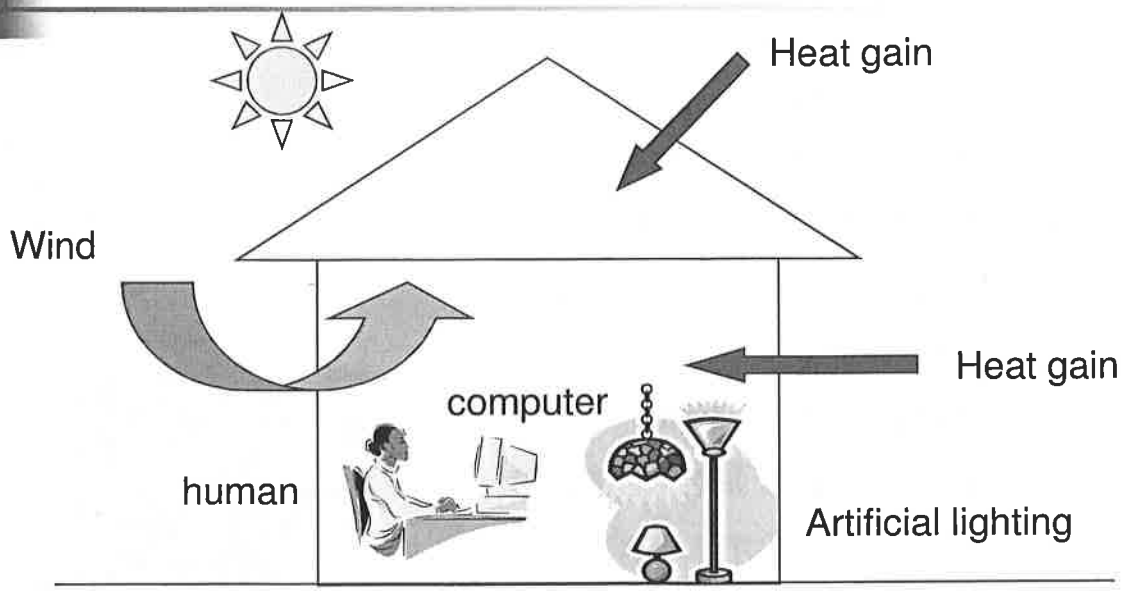
Thermal Simulation Application

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

Heat Gain (External)



Heat Gain (External and Internal)



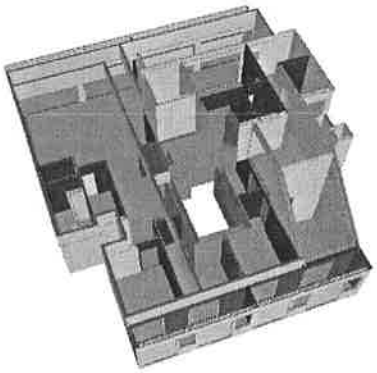
Factors that can be considered

- 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



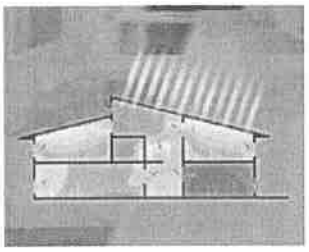


COMMERCIAL SOFTWARES

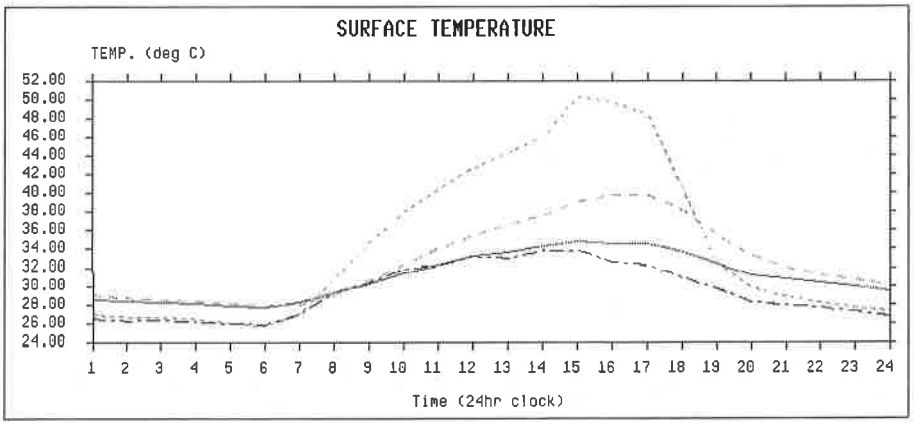
- **Thermal Analysis Software (TAS)**
- **DOE2 (Visual DOE, Power DOE)**
- **eQUEST**
- **TRNSYS**
- **ESP-r**
- **IES<VE>**

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	—·—·—

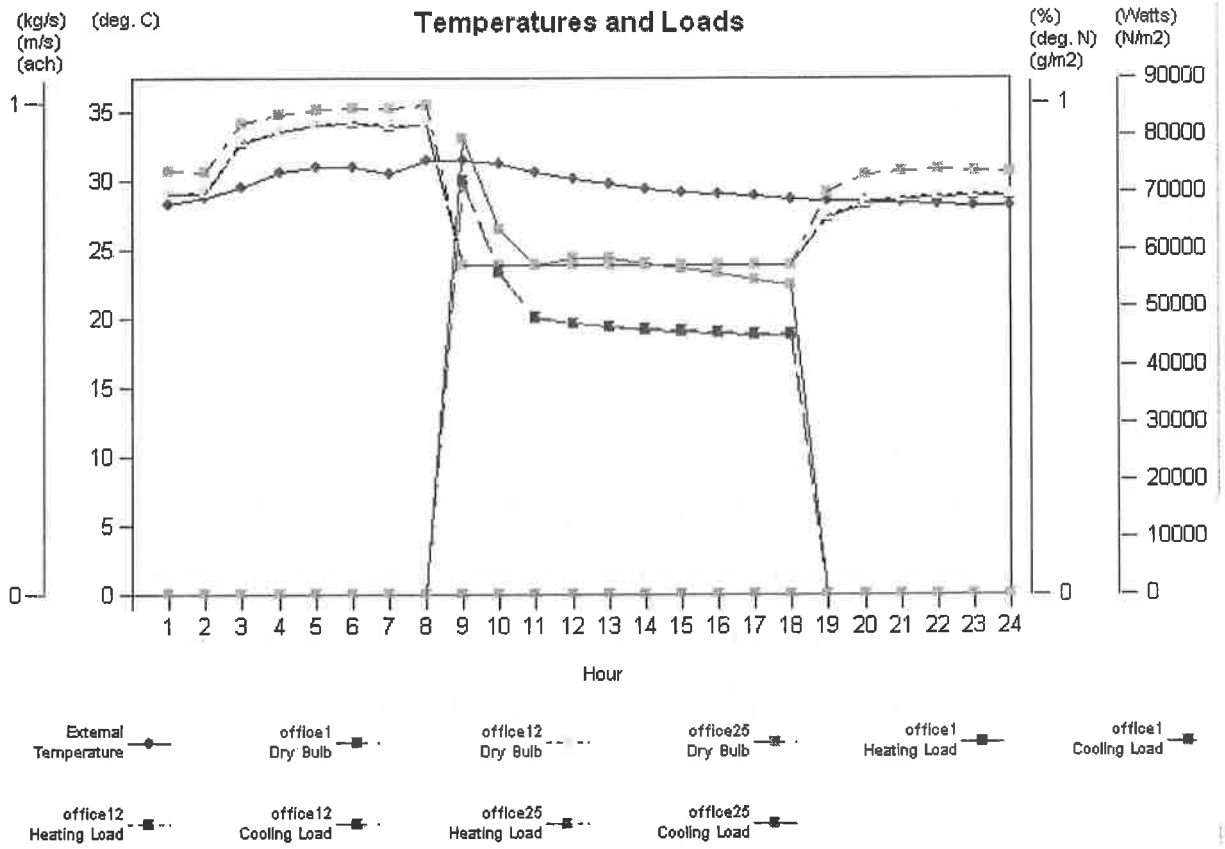
LOCATION

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

Time (24 hr clock)	Internal Surface Temp. (deg C)	External Surface Temp. (deg C)	Time (24 hr clock)	Internal Surface Temp. (deg C)	External Surface Temp. (deg C)
1	29.0	26.9	13	36.6	44.3
2	28.8	26.7	14	37.6	46.0
3	28.6	26.7	15	39.0	50.3
4	28.4	26.5	16	39.7	49.7
5	28.2	26.1	17	39.8	48.4
6	27.9	25.7	18	38.1	40.3
7	28.0	27.0	19	35.5	32.6
8	29.1	30.8	20	33.3	29.8
9	30.6	34.6	21	32.0	28.9
10	32.4	37.9	22	31.2	28.2
11	34.0	40.4	23	30.6	27.7
12	35.4	42.7	24	30.1	27.3



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.

ASHRAE 55 – Thermal comfort

→ Temperature
→ RH
→ Air velocity
→ Mean radiant Temperature
→ Metabolic Rate (MET)
→ Clothing Factor

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

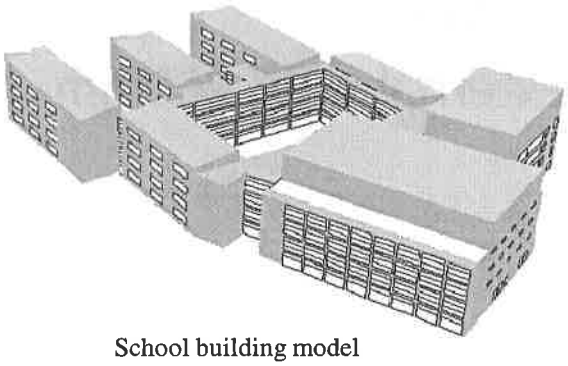
Country	Roofs ($W/K \cdot m^2$)	Walls ($W/K \cdot m^2$)	Windows ($W/K \cdot m^2$)
UK	0.16-0.25	0.35	2.0-2.2
Canada	0.14-0.29	0.37	1.4-2.7
China	0.4	0.52	2

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

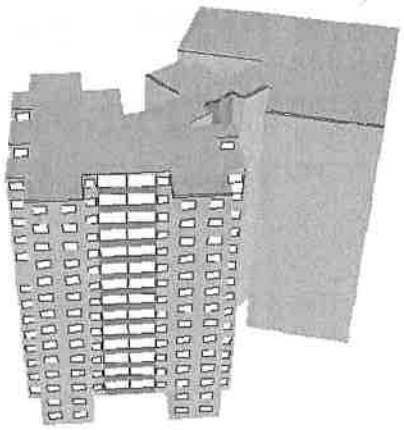
Methodology

- 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.

Computer simulation --- finding acceptable Façade U-value

- Measurement position:

  Height: occupant level

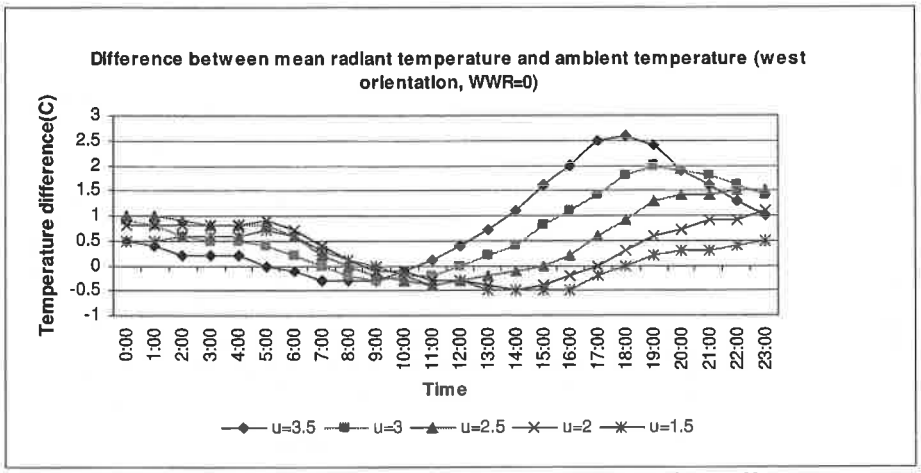
  Distance to the external wall: 200mm

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

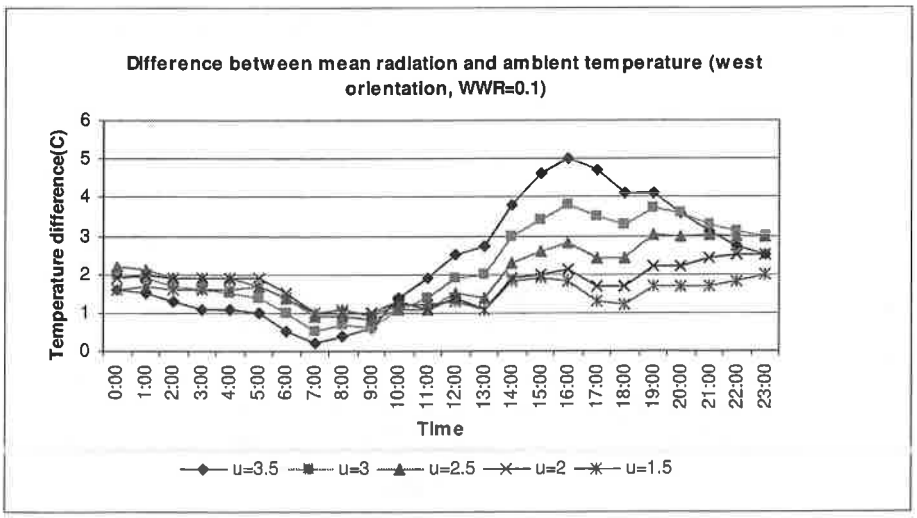
- West orientation
  - Window to wall ratio=0 (Condition I: Without window)



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

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

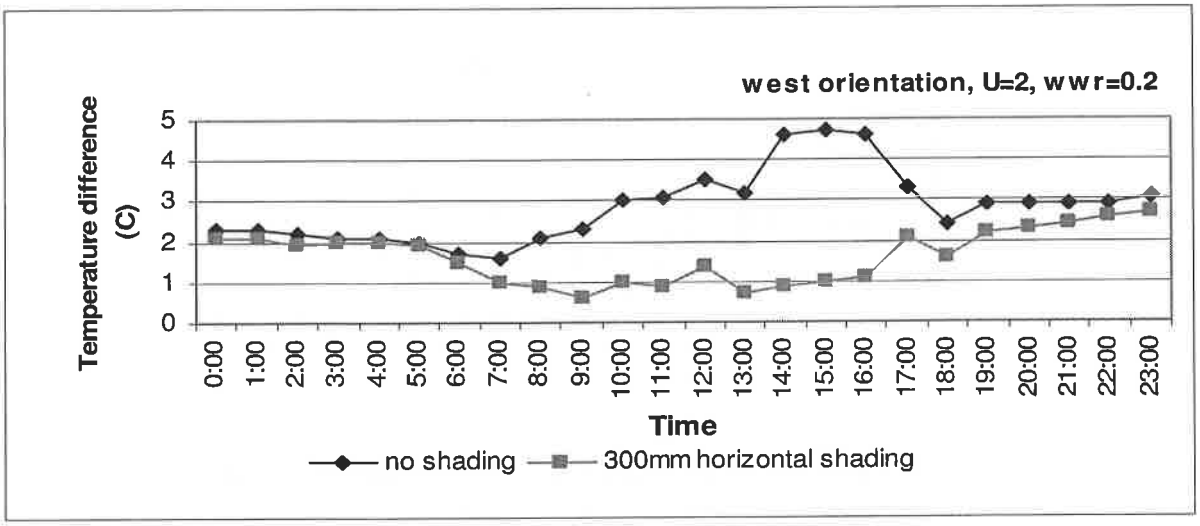
- West orientation
  - Window to wall ratio=0.1 (Condition II: With window)



Acceptable U-value is 2W/K·m^2 .

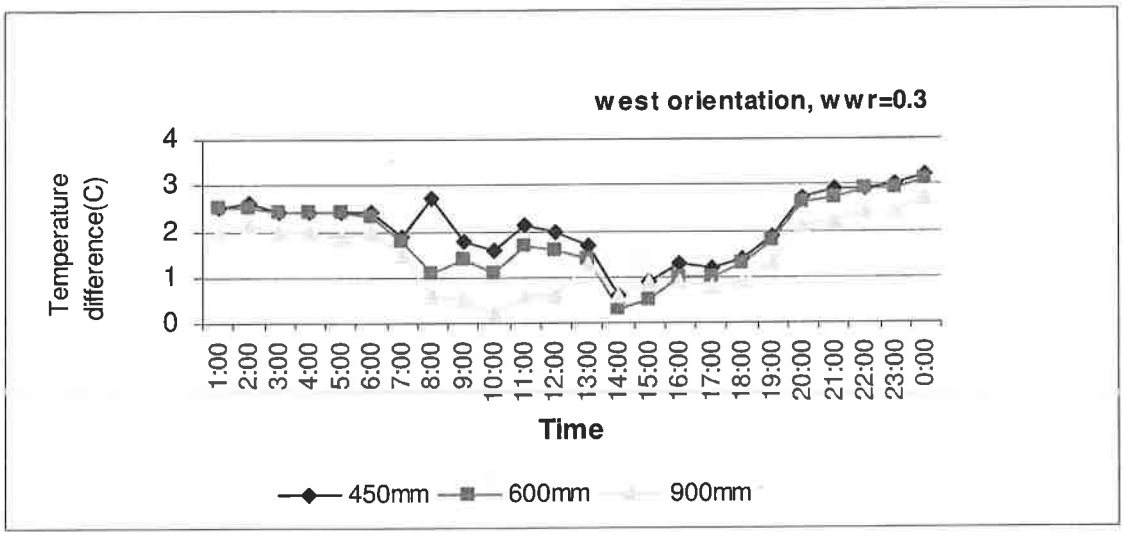
Computer simulation --- finding acceptable external wall U-value

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



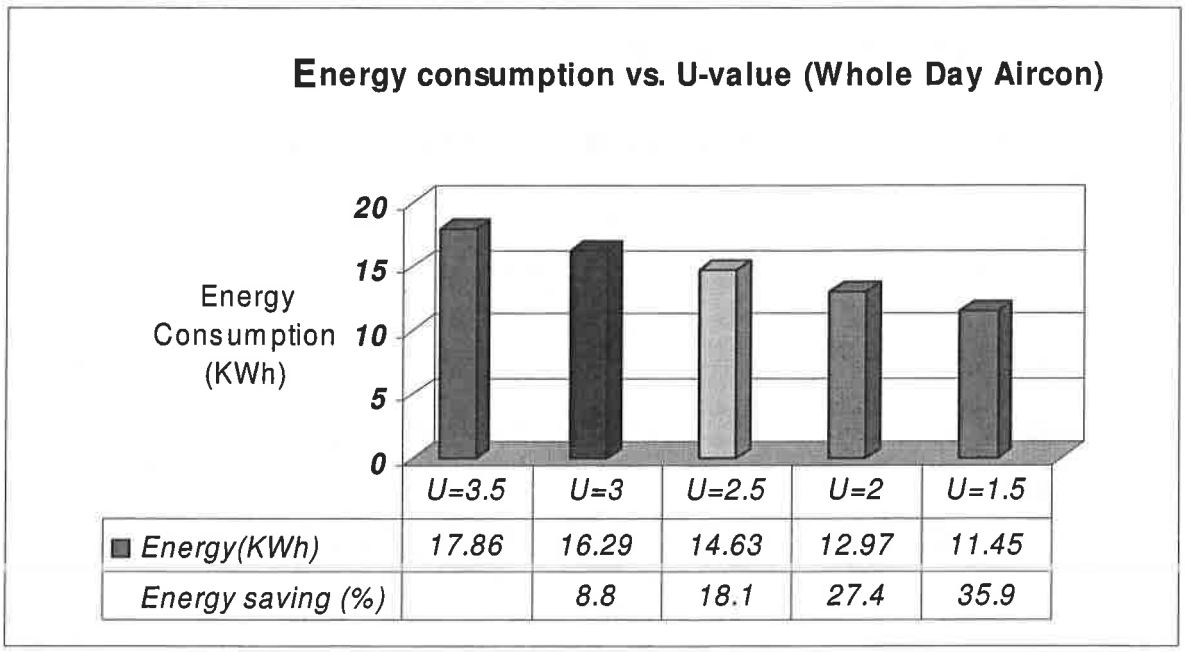
Computer simulation --- finding acceptable external wall U-value

- 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

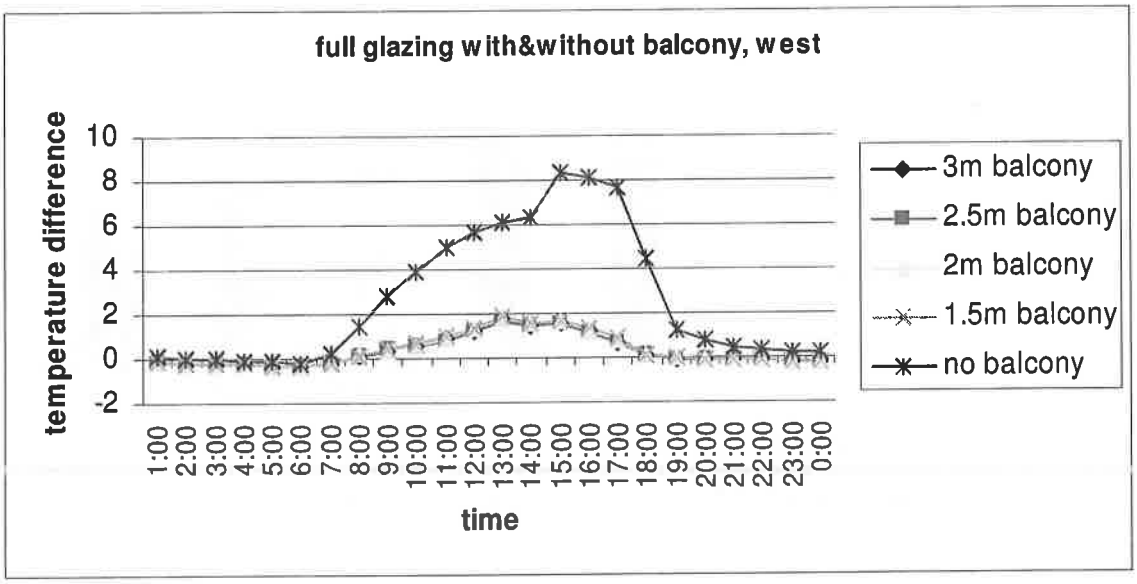


Full glazing wall

- 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?

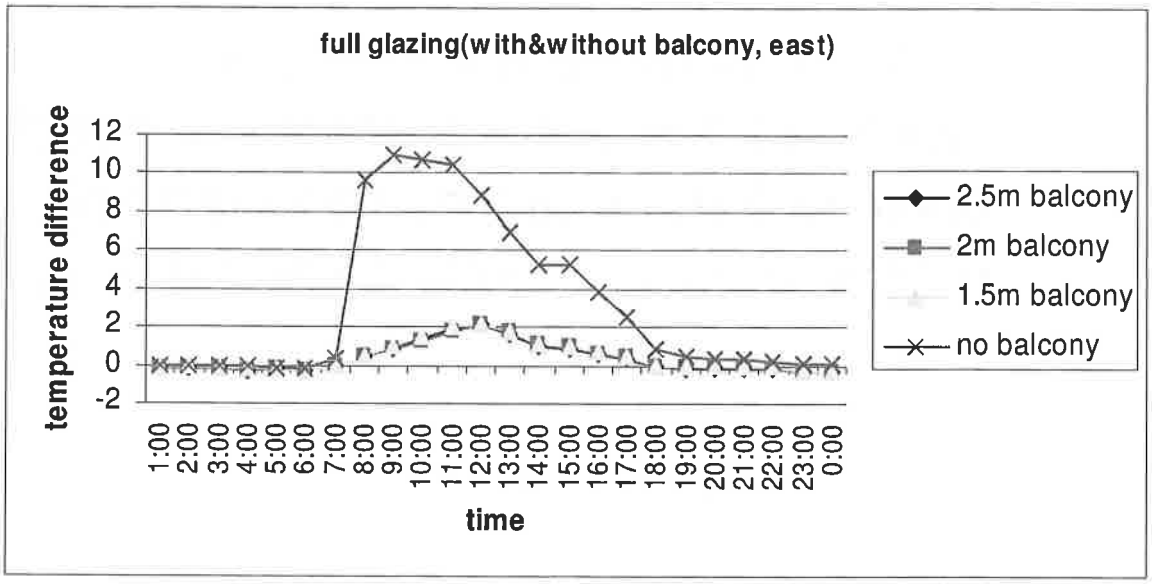
Full glazing wall

- West orientation



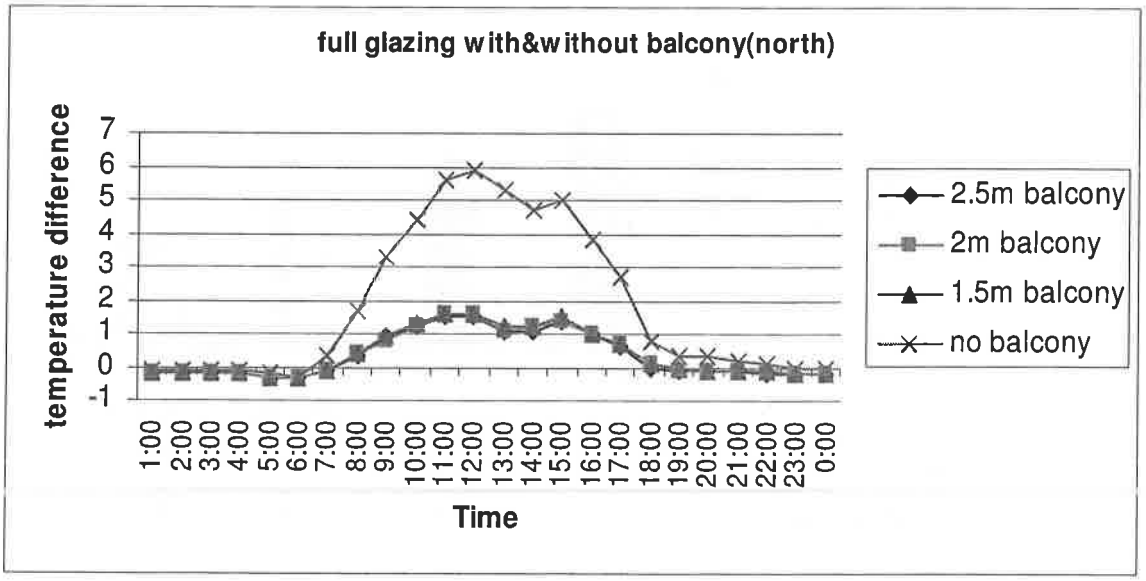
Full glazing wall

- East orientation



Full glazing wall

- North and South orientation

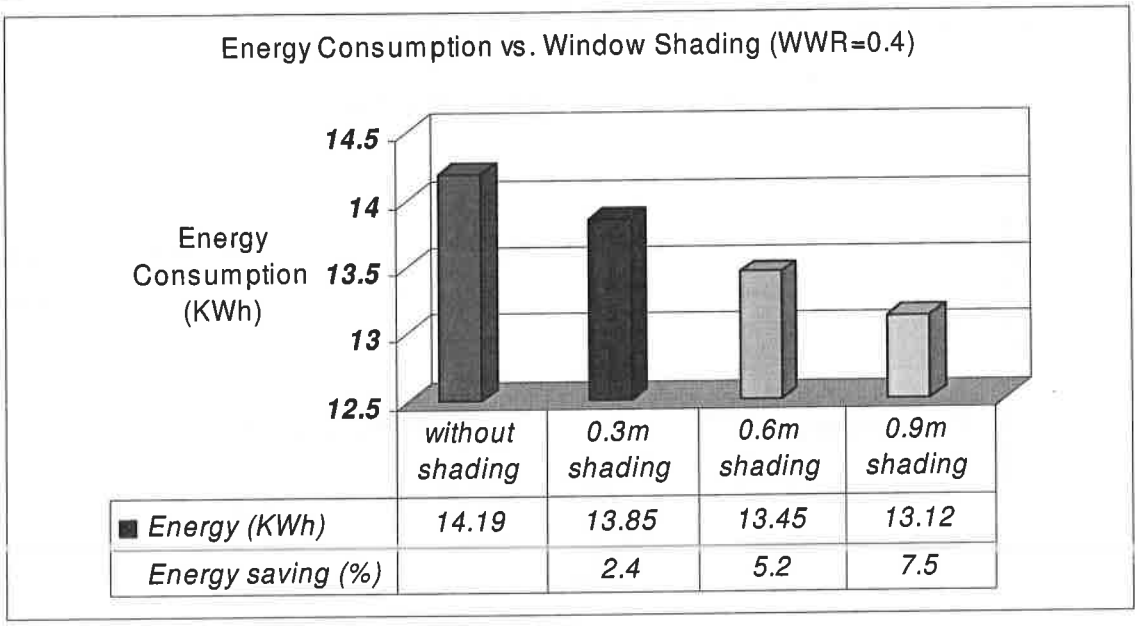


Full glazing wall

- 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.

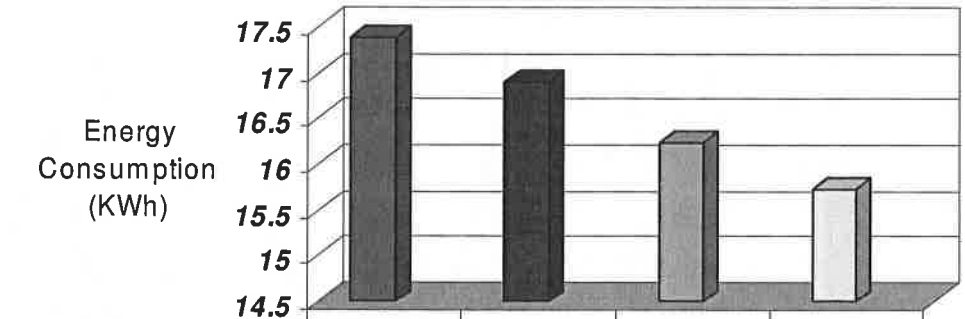
The Impact of Window Shading on cooling energy consumptions



	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

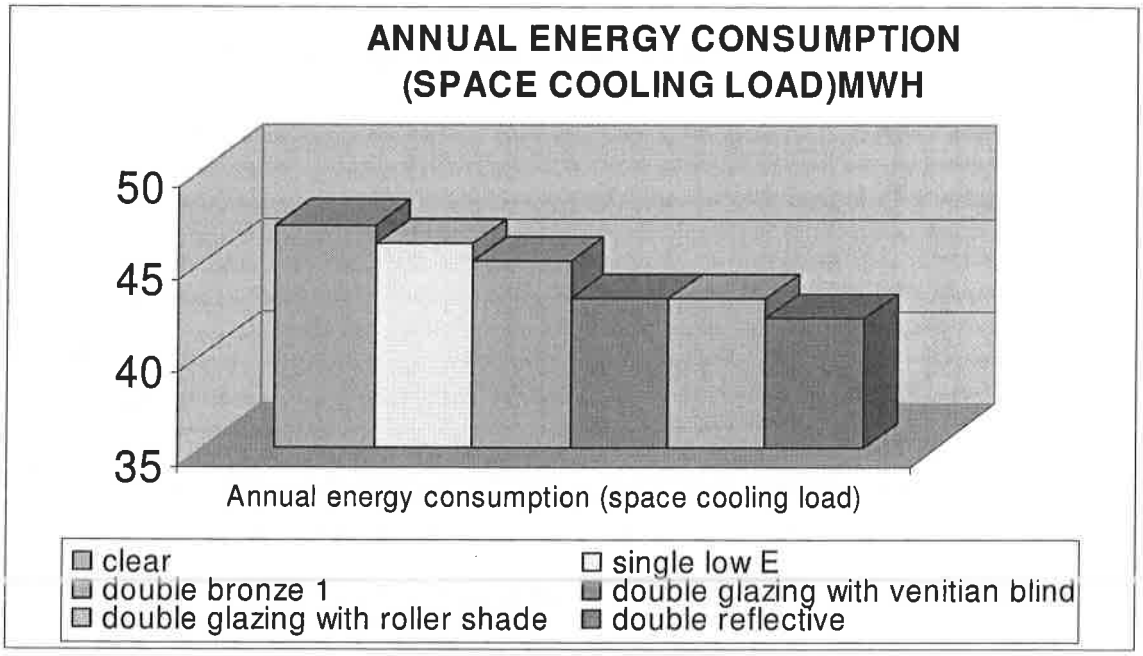
The Impact of Window Shading on cooling energy consumptions

Energy Consumption vs. Window shading (Full height glass wall)

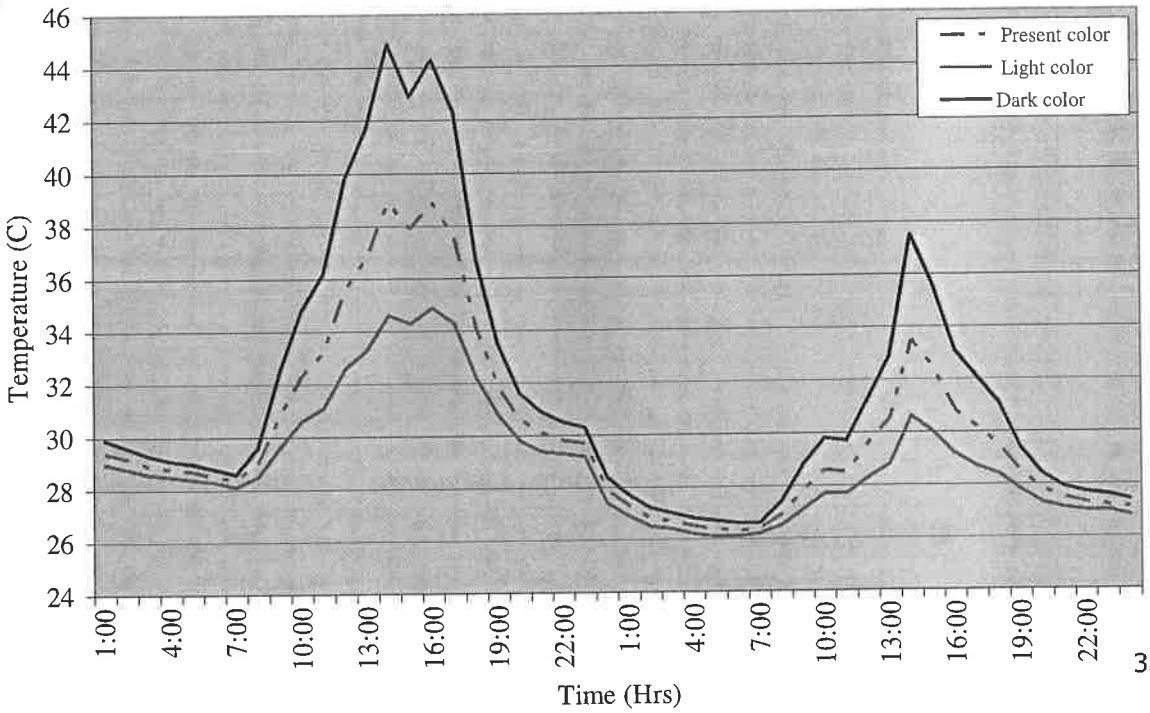


	without shading	0.3m shading	0.6m shading	0.9m shading
Energy (KWh)	17.38	16.9	16.25	15.73
Energy Saving (%)		2.8	6.5	9.5

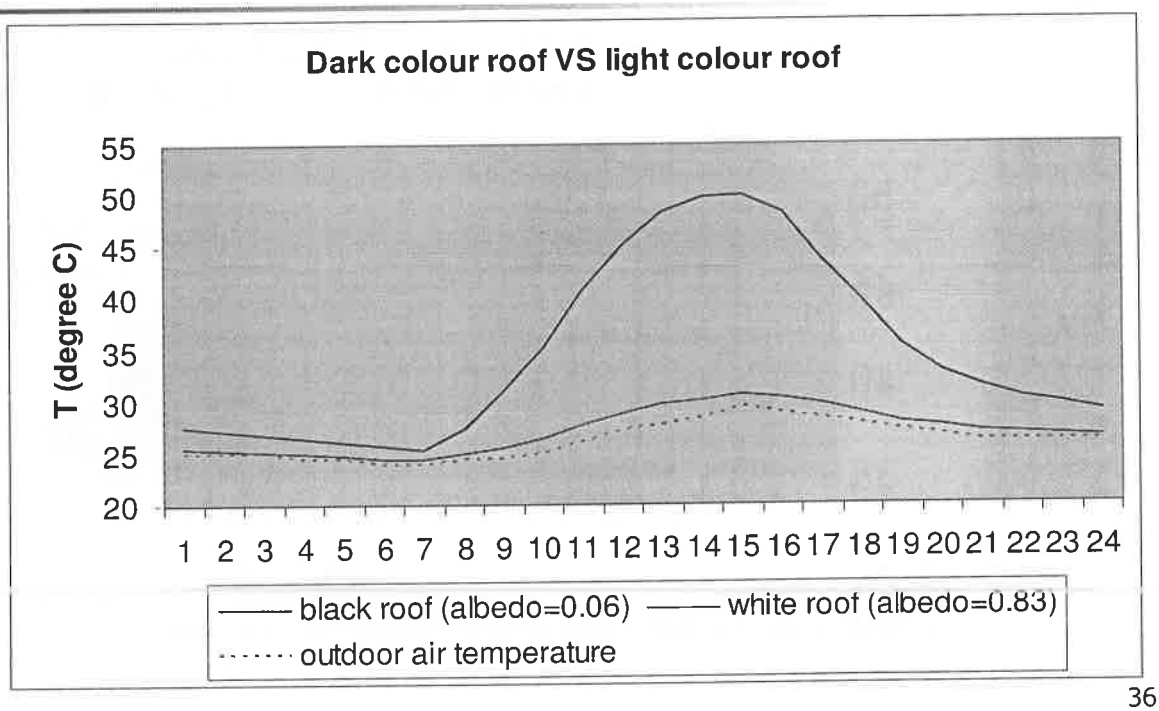
Types of Glazings

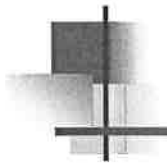


Computer simulation --- effects of façade colour



Effect of facade colour (Roof)





Thank you

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

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	Pumping system design criteria 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. *Propeller or axial fan cooling towers* Cooling Tower performance shall not be less than 3.23 L/s/kW. *Centrifugal fan cooling towers* 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. Fan System design criteria (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. Part load fan power limitation (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			
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 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