Annual environmental performance evaluation of light and heat in daylight harvesting systems using Radiance and NewHASP

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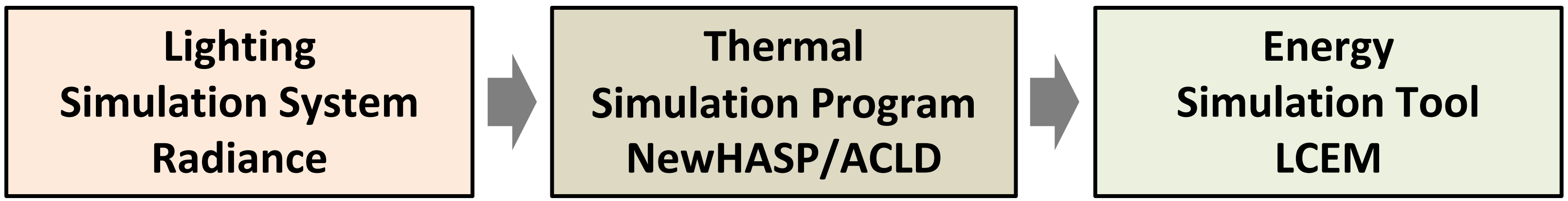
Background

- A thermal load simulation program, **NewHASP/ACLD** (the society of Heating, Air conditioning and Sanitary engineers Program /Air Conditioning LoaD), was developed by SHASE (the Society of Heating, Air Conditioning, and Sanitary Engineers, Japan) in 2004, and is now widely used in academic research and design practice in Japan.
- The program has original functions to estimate the effect of daylight harvesting, but its algorithm is simple and cannot take into consideration complex daylight control systems.
- We developed a new "**Meta-simulation platform**" to calculate energy savings from daylight harvesting by combining **Radiance** , **NewHASP/ACLD** , and **LCEM** (Life Cycle Energy Management: an energy simulation program developed by Japan's Ministry of Land, Infrastructure, and Transport).

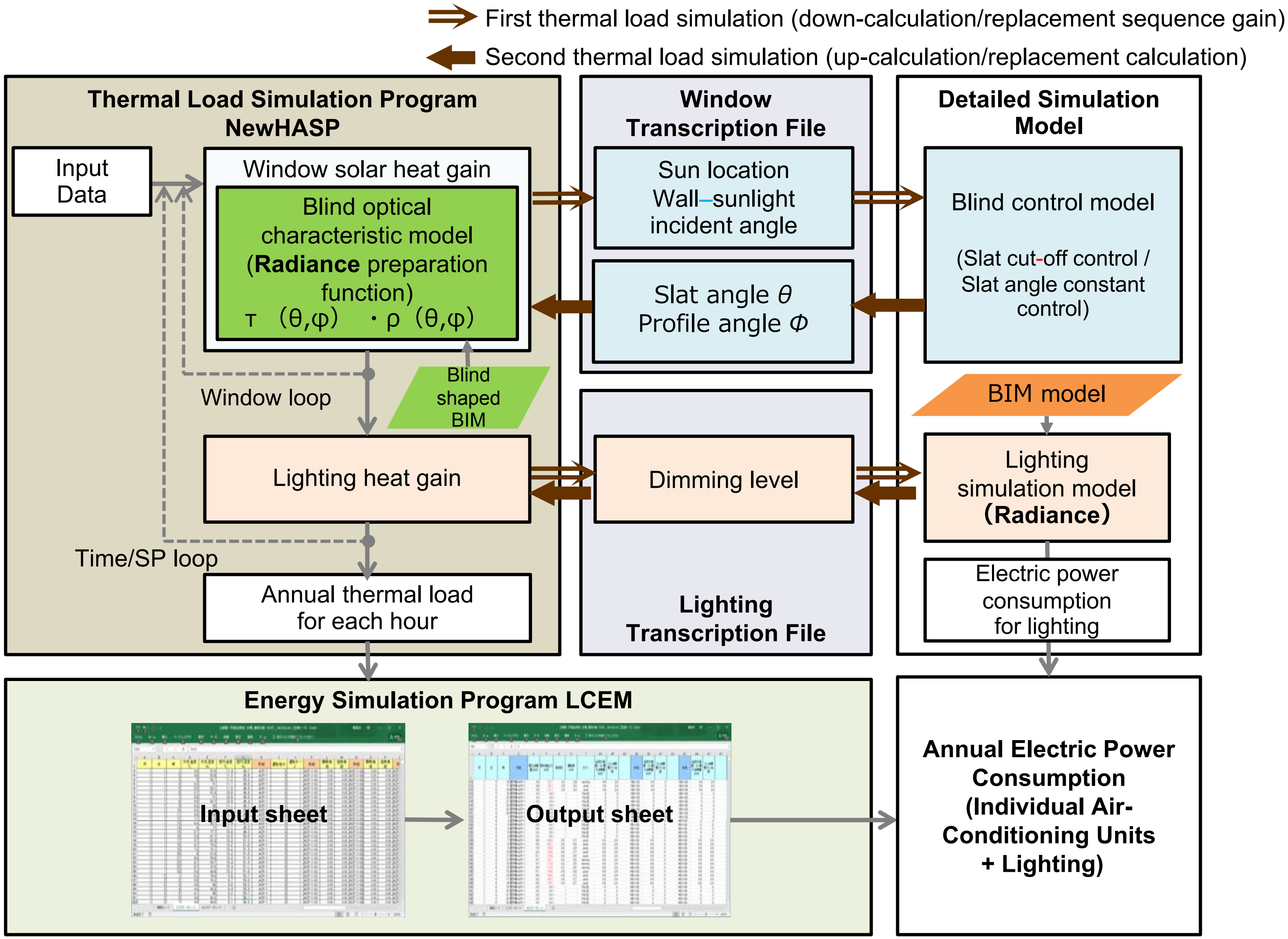
Radiance/NewHASP/LCEM Meta-simulation

A simulation method that combines the results of three simulations to produce better results

- Light simulations – **RADIANCE**
- Thermal simulations – **NewHASP**
- Energy simulations – **LCEM**



Integrated Meta-simulation Flowchart



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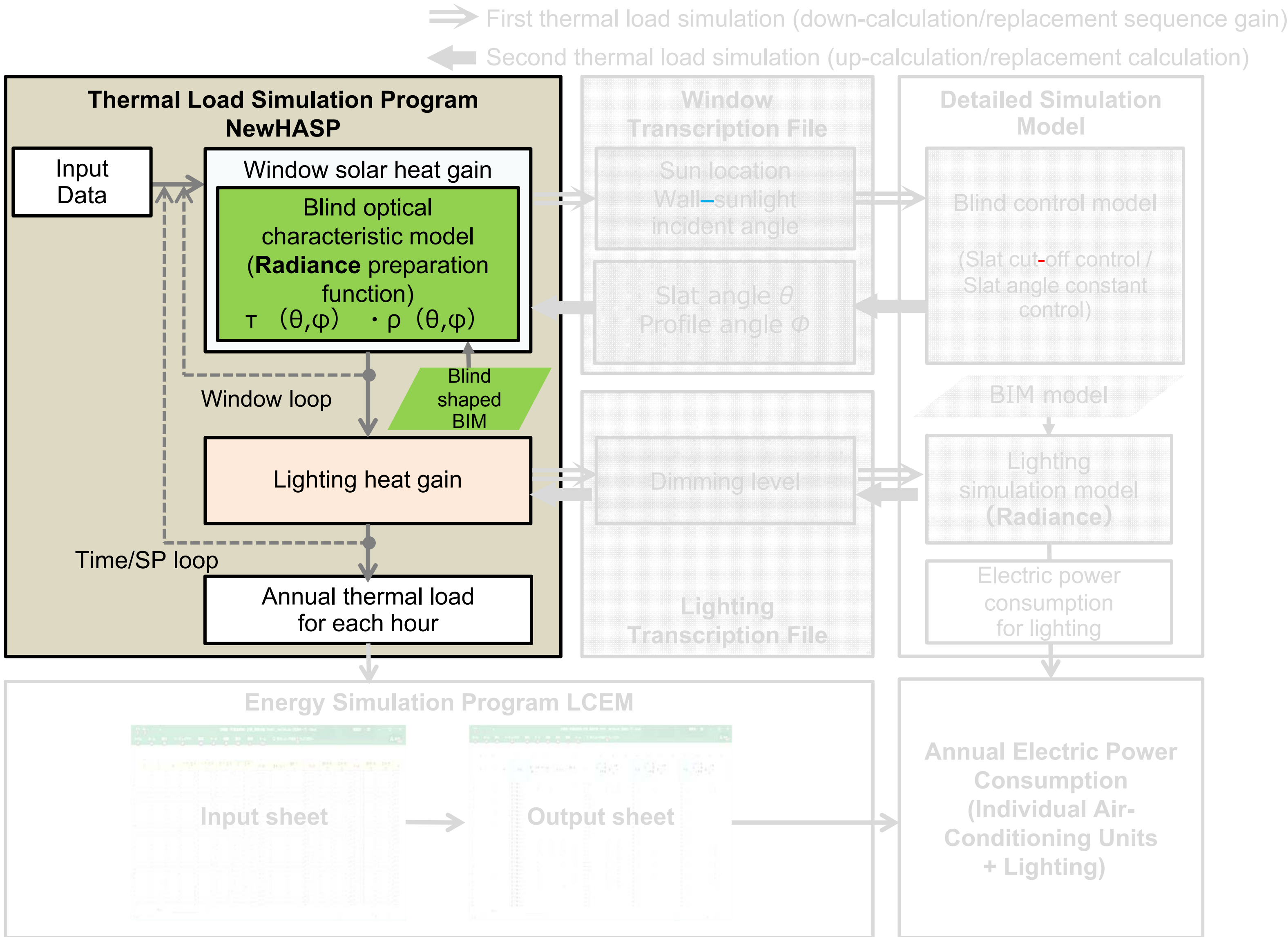
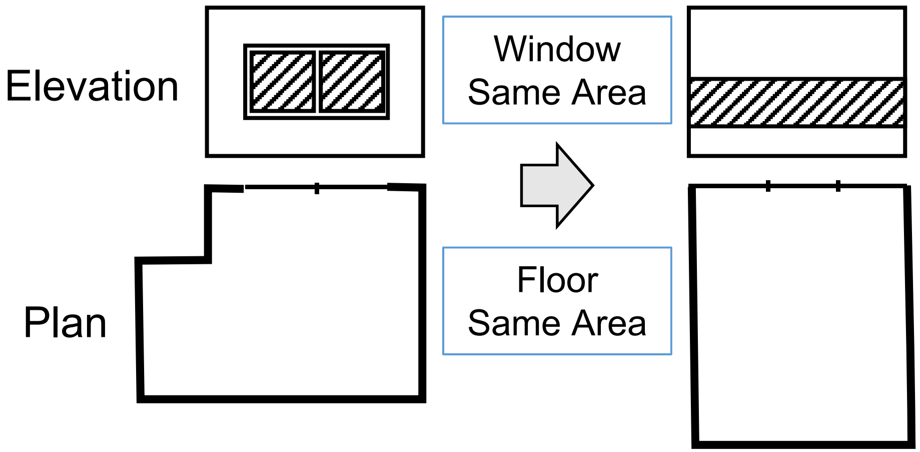
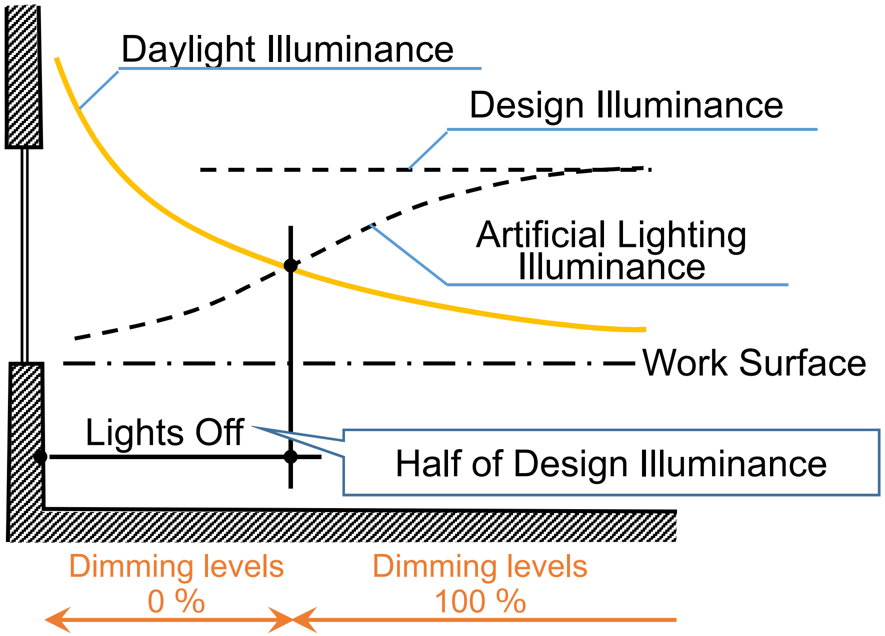


NewHASP's Standard Calculation Method

NewHASP's Calculation Method with Daylight Using

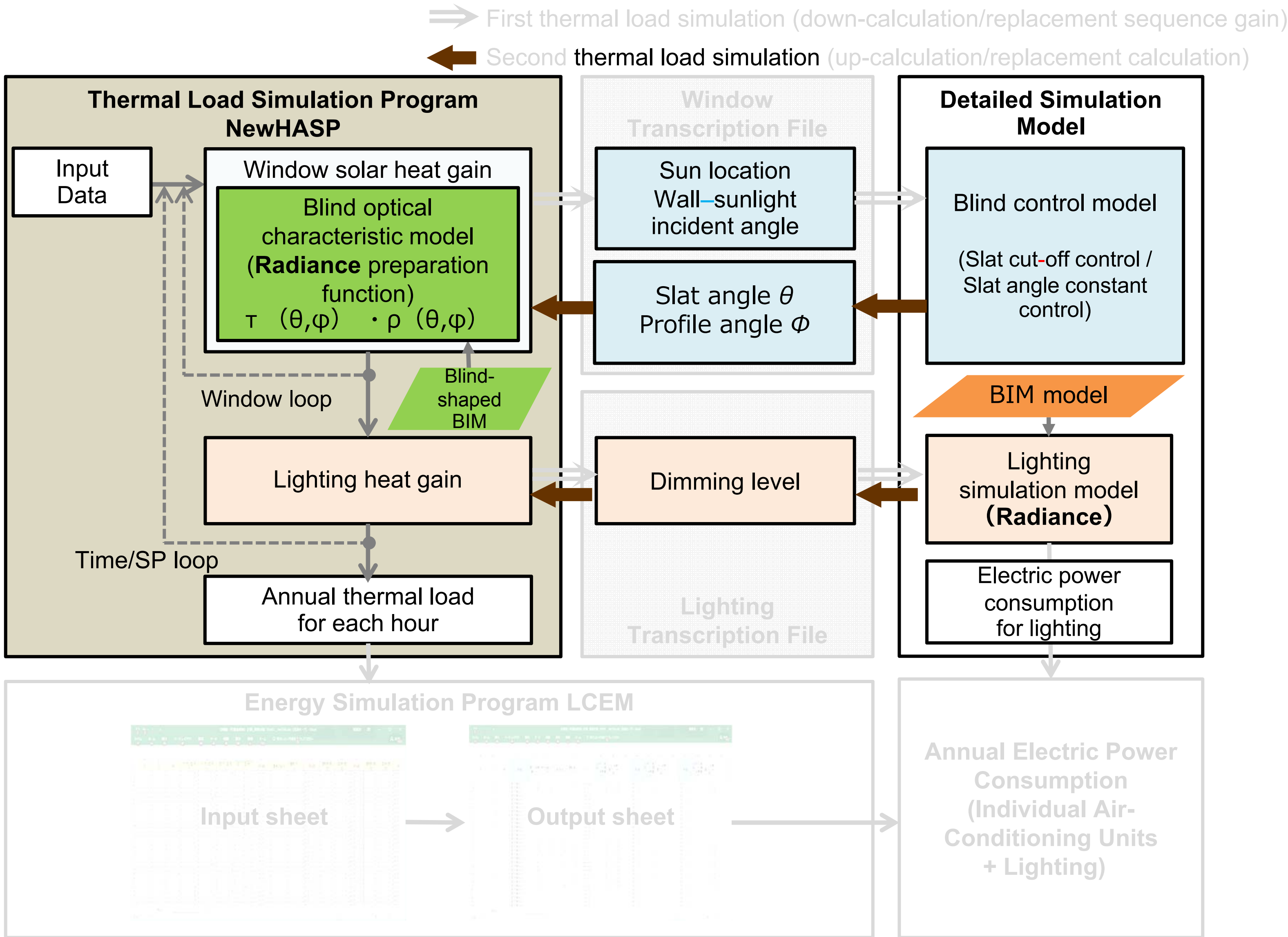


Simplification of Window / Floor Shape



Range to Turn Off

Integrated Meta-simulation Flowchart



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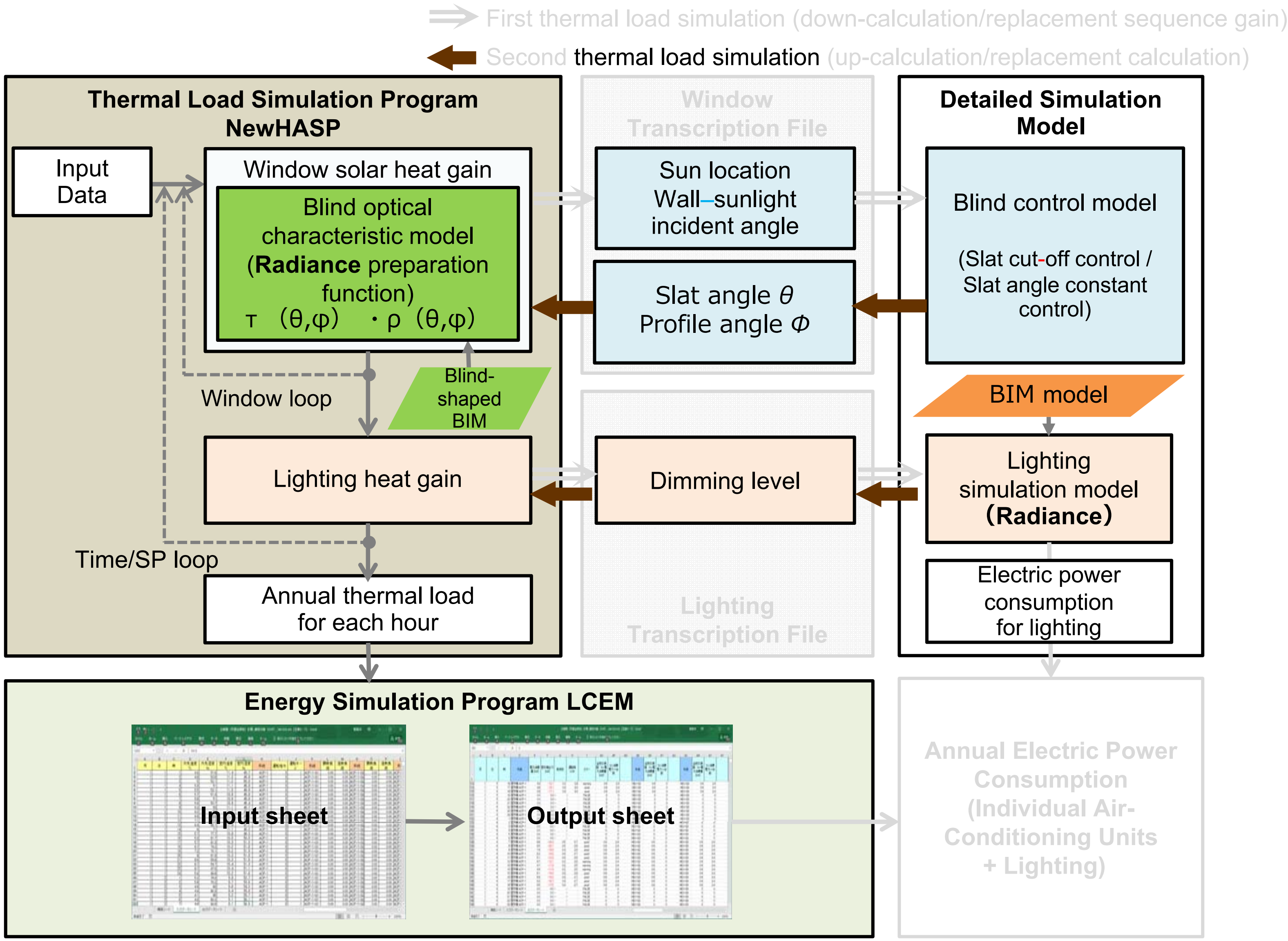
Meta-simulation Flowchart



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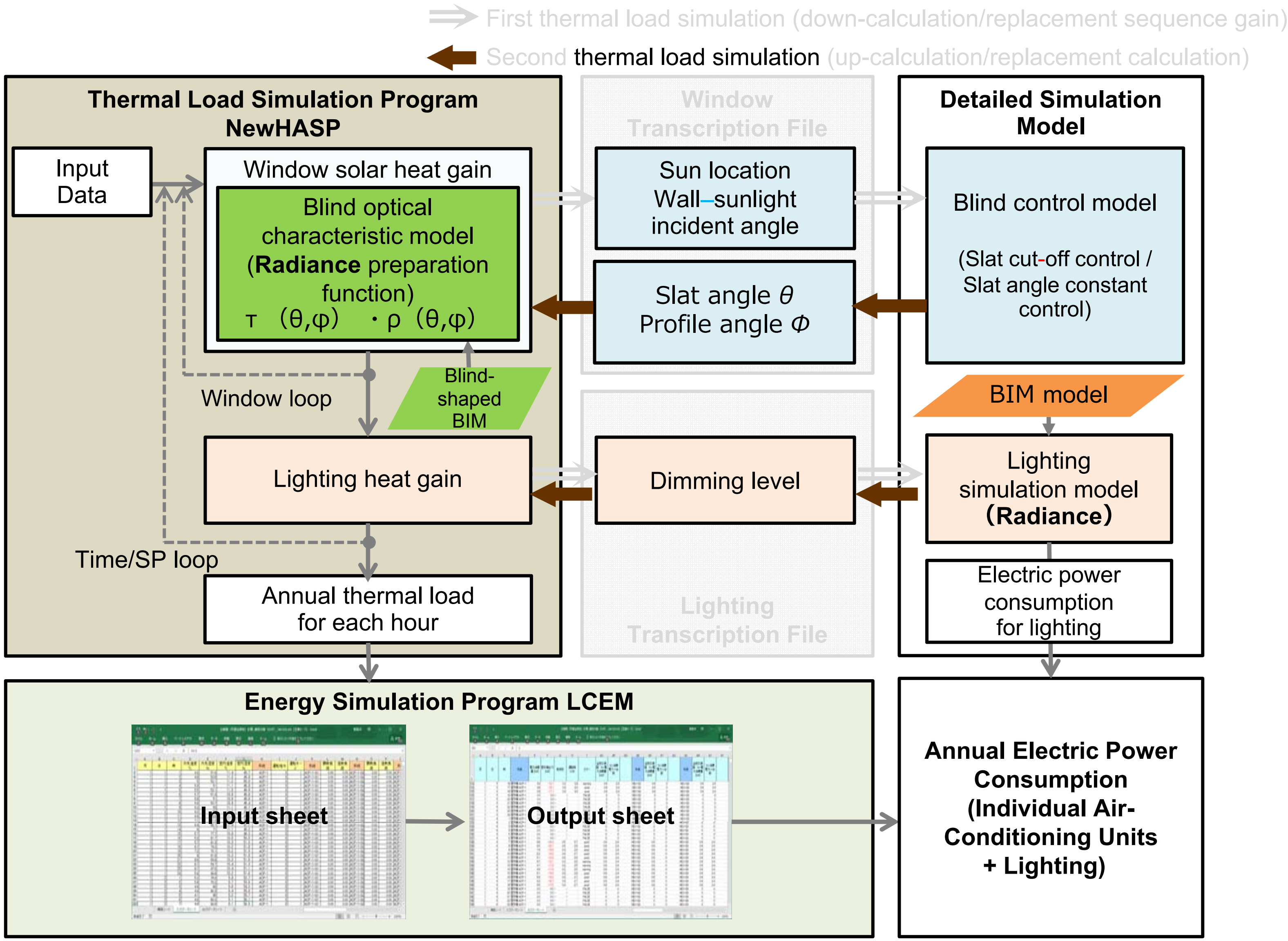
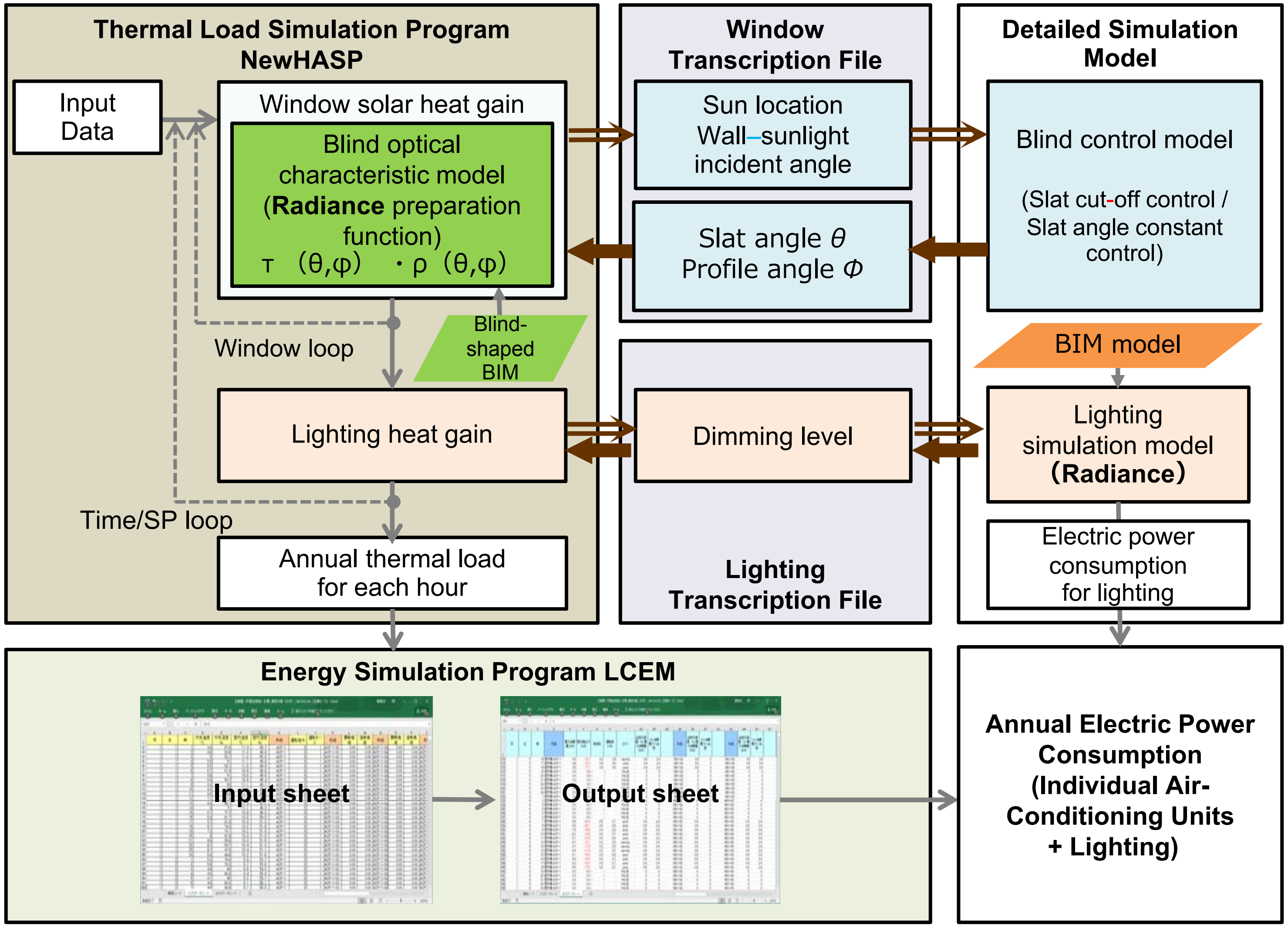


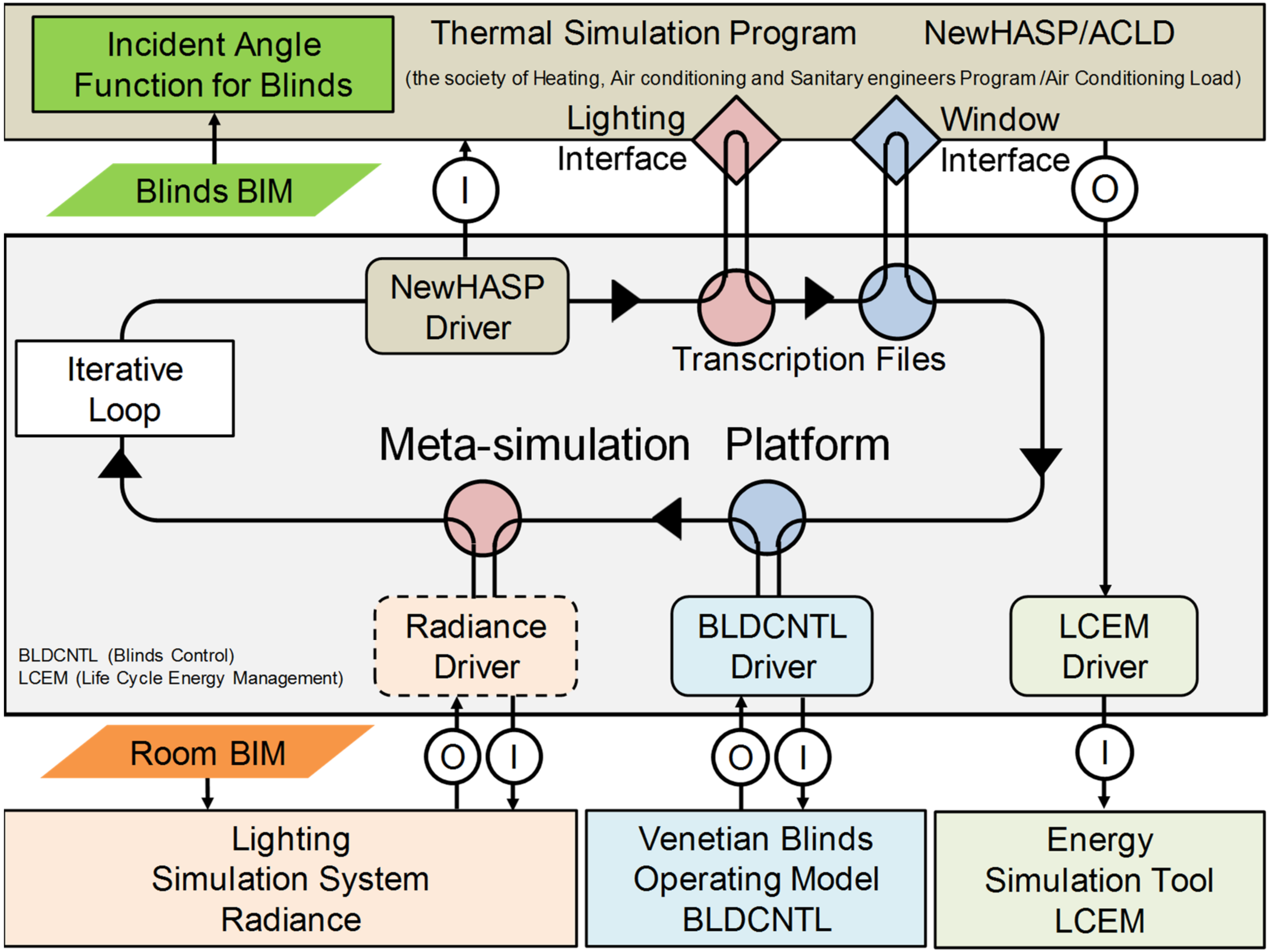
Integrated Meta-simulation Flowchart

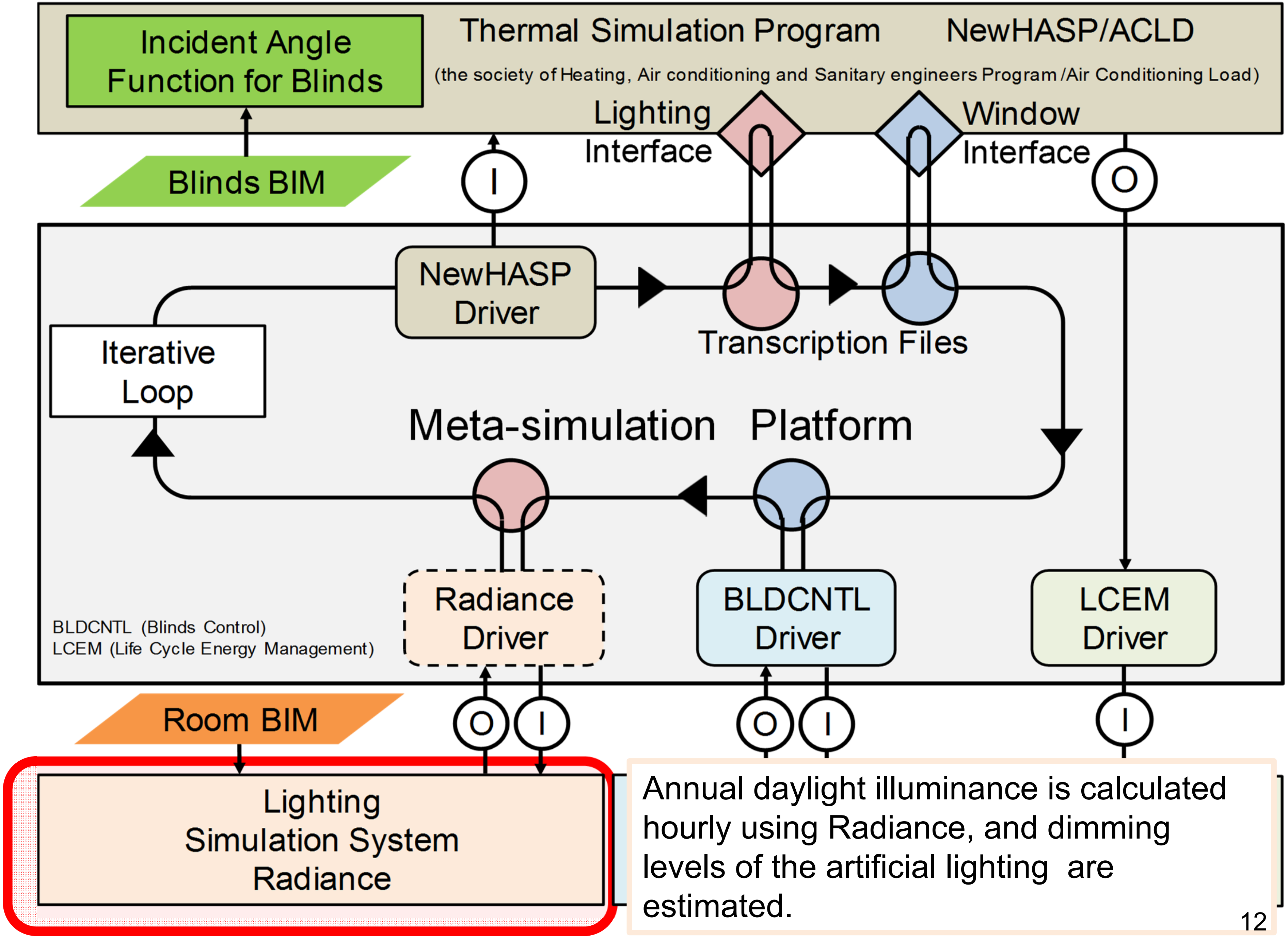
⇒ First thermal load simulation (down-calculation/replacement sequence gain)

⬅ Second thermal load simulation (up-calculation/replacement calculation)



Meta-simulation Platform



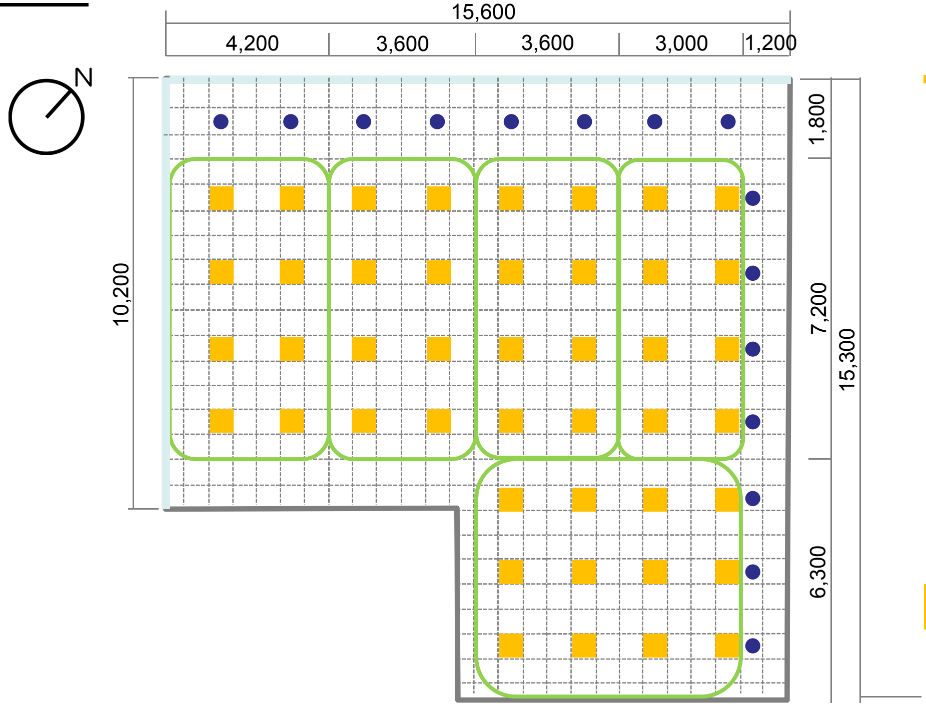


Annual daylight illuminance is calculated hourly using Radiance, and dimming levels of the artificial lighting are estimated.

Lighting Simulation Model

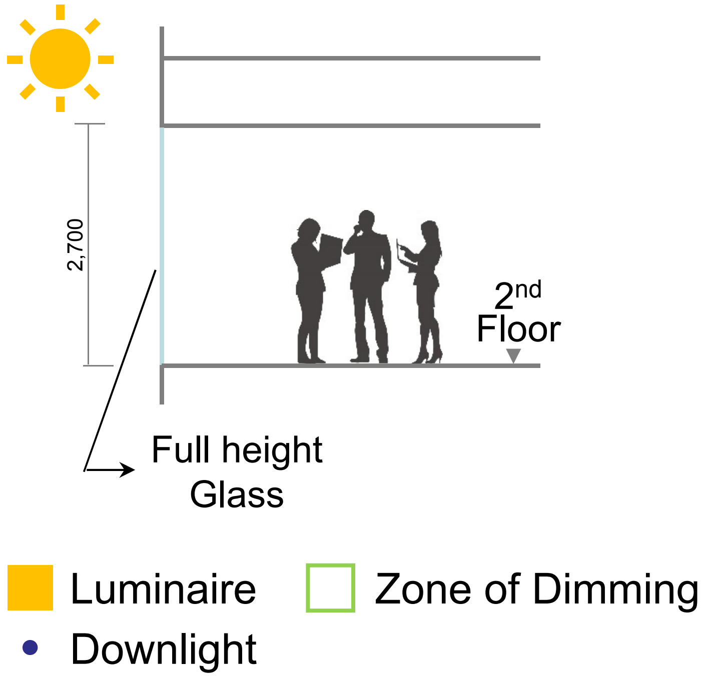
Plan

[mm]



Section

[mm]

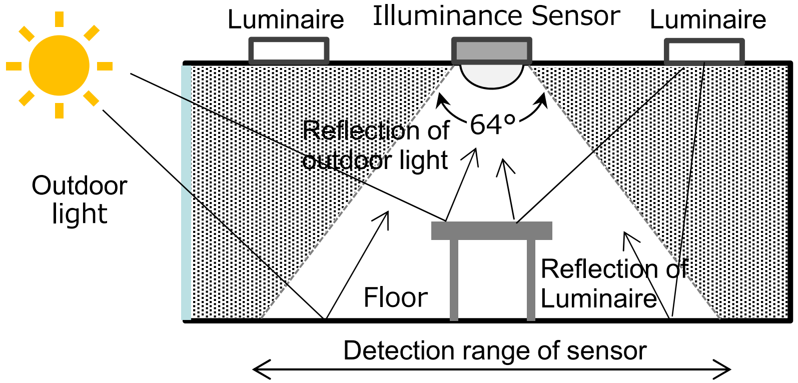


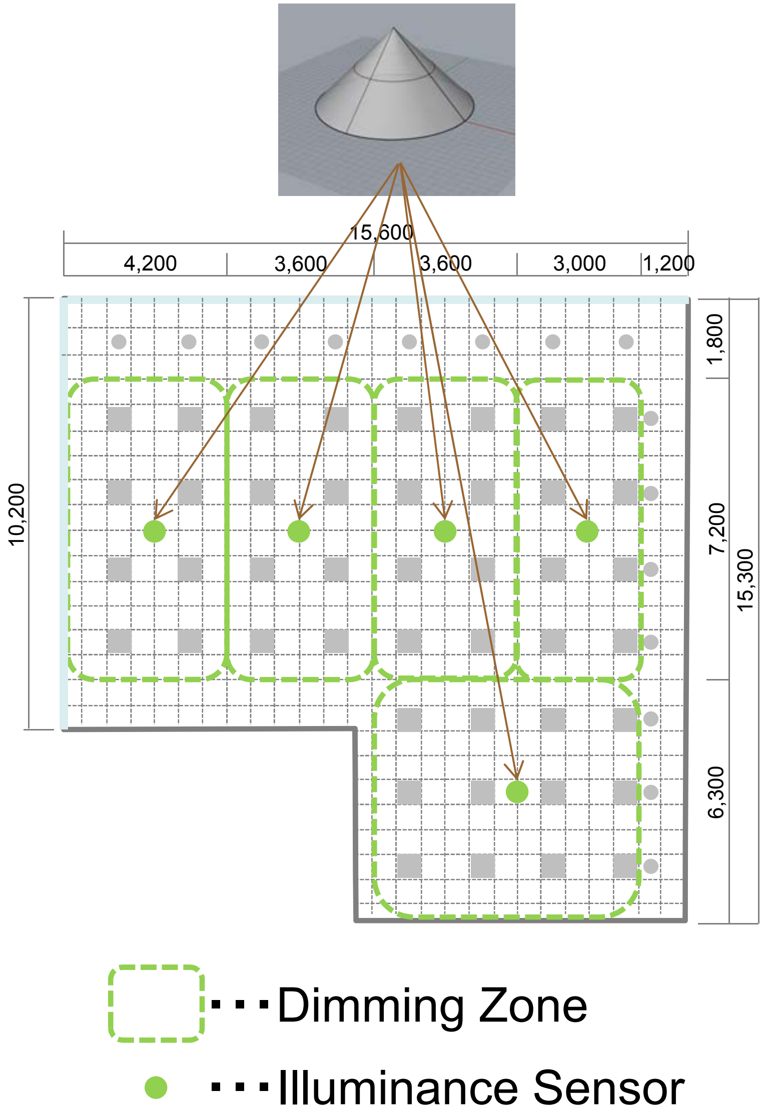
Floor Area	197 m^2	
Luminaire	for grid ceiling : 44 (dimming levels: 5–100%)	
	downlights : 15	
Zone of Dimming	5	
	8–12 luminaire per zone	

Reflection	
Ceiling	85.6 %
Wall	90.2 %
Floor	2.8 %
Transmissivity	
Low-e glass	74.1 %

Dimming Procedure

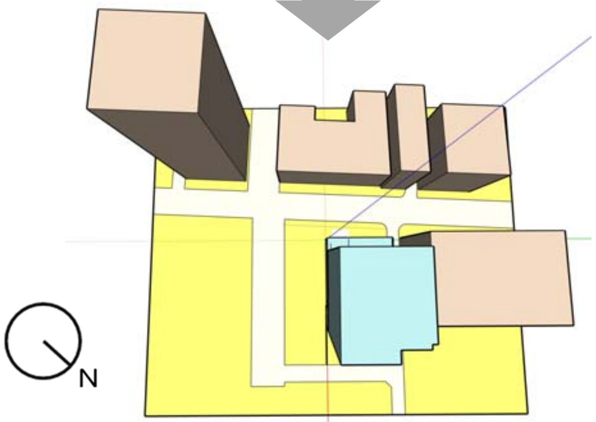
1. Illuminance sensors are placed on the ceiling of each dimming zone
2. The dimming levels of the LEDs in each zone is calculated based on the influence of daylight and LEDs in other zones



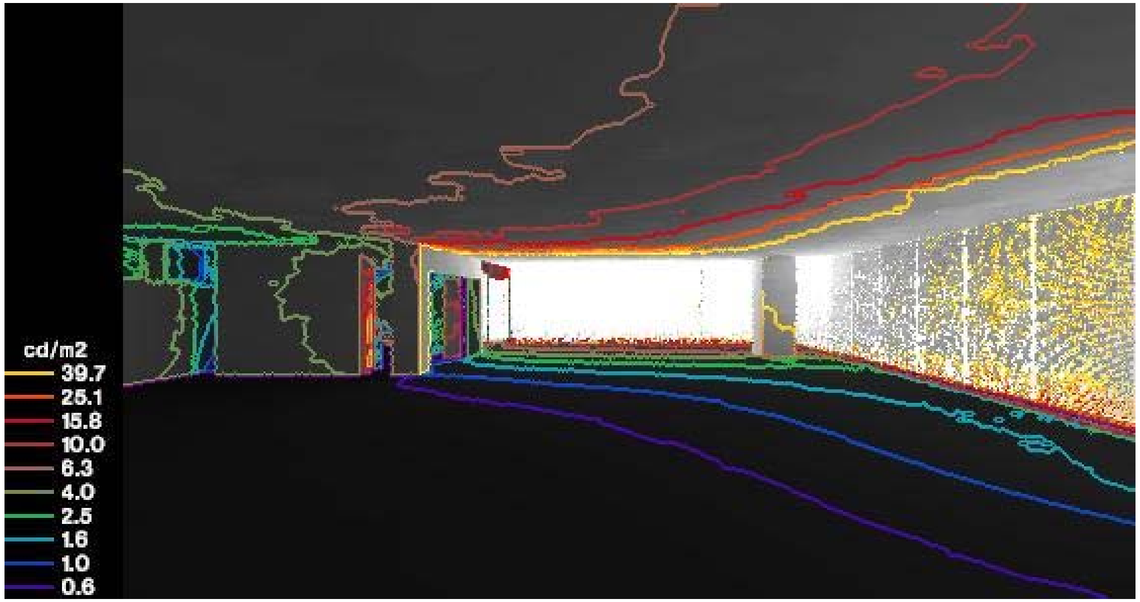


Building Model

BIM (ArchiCAD)

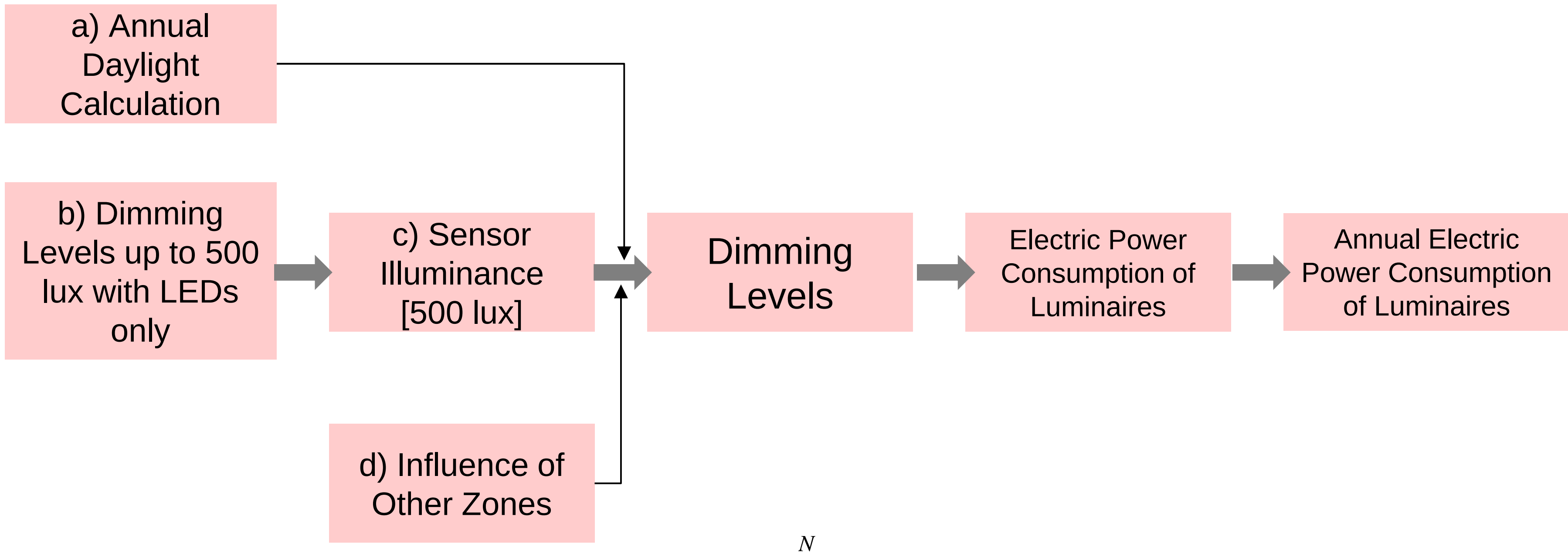


SketchUp



Radiance
Luminance Image

Calculation of Annual Electric Power Consumption of Luminaires



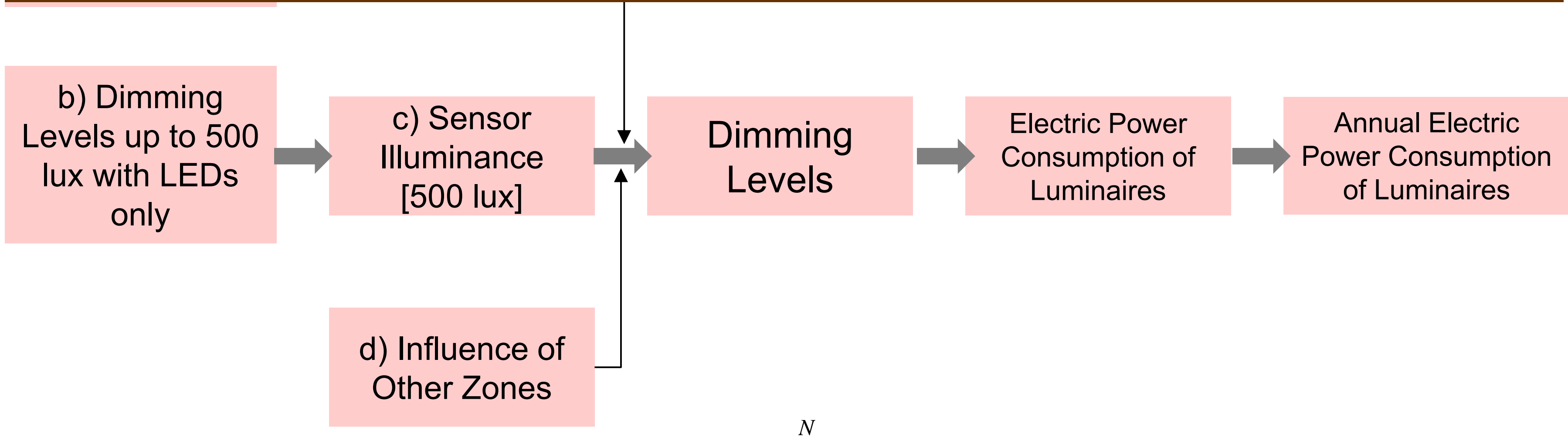
$$E_{(i)} = E_{o(i)} + \sum_{j}^{N} \alpha_j E_{(i,j)} \qquad \text{\_\_\_\_\_\_\_\_(a)}$$

Desktop Illuminance is kept to ≥500 lux with daylight and LEDs

i	:	Sensor zone
j	:	Dimming zone
$E_{(i)}$	:	Sensor illuminance at *i*
$E_{o(i)}$	:	Sensor illuminance at *i* with daylight
α_j	:	Dimming level at *j*
$E_{(i,j)}$	:	Sensor illuminance at *i* with LEDs in zone *j*)

Calculation of Annual Electric Power Consumption of Luminaires

Annual Daylight Calculation: annual illuminance, measured by **illuminance sensors** on the ceiling, is calculated per hour



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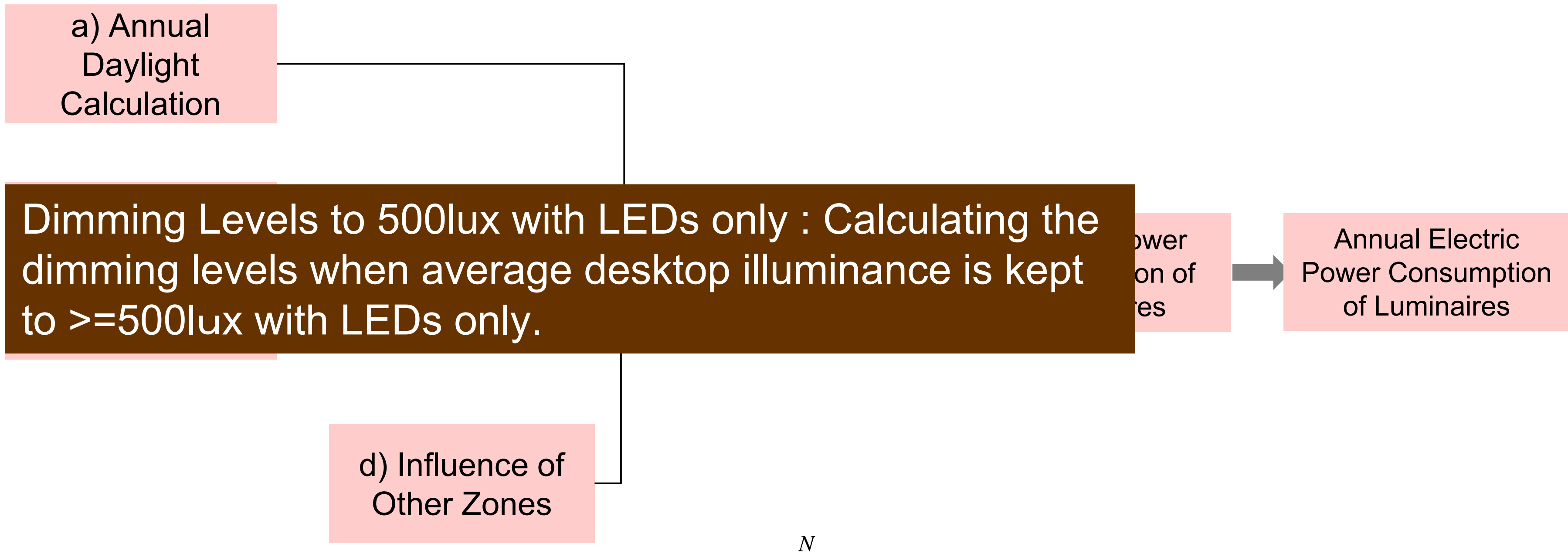

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Calculation of Annual Electric Power Consumption of Luminaires

a) Annual Daylight Calculation

b) Dimming Levels up to 500 lux with LEDs only

Sensor Illuminance [500 lux]: the sensor illuminance is calculated for a desktop illuminance of 500 lux when LEDs are turned on at the calculated dimming levels.

al Electric Consumption uminaires

d) Influence of Other Zones

$$E_{(i)} = E_{o(i)} + \sum_{j}^{N} \alpha_j E_{(i,j)} \qquad \text{\_\_\_\_\_\_\_\_\_\_(a)}$$

Desktop Illuminance is kept to ≥500 lux with daylight and LEDs

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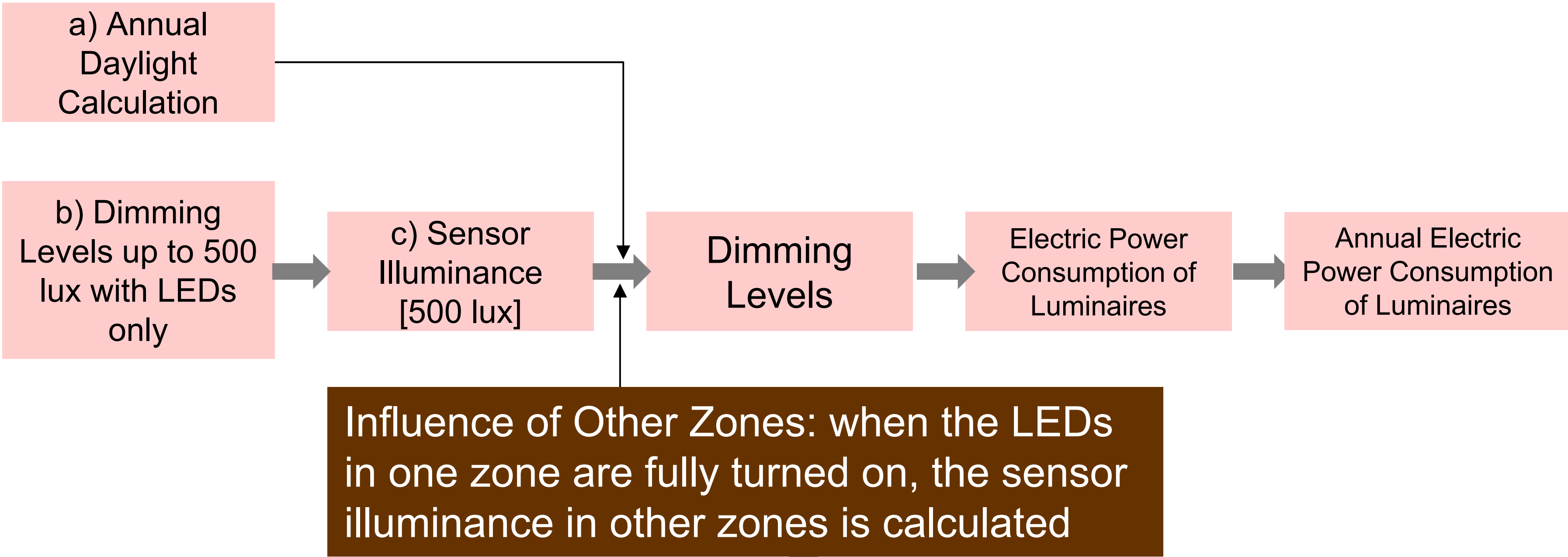

$$E_{(i)} = E_{o(i)} + \sum_j \alpha_j E_{(i,j)} \qquad \text{(a)}$$

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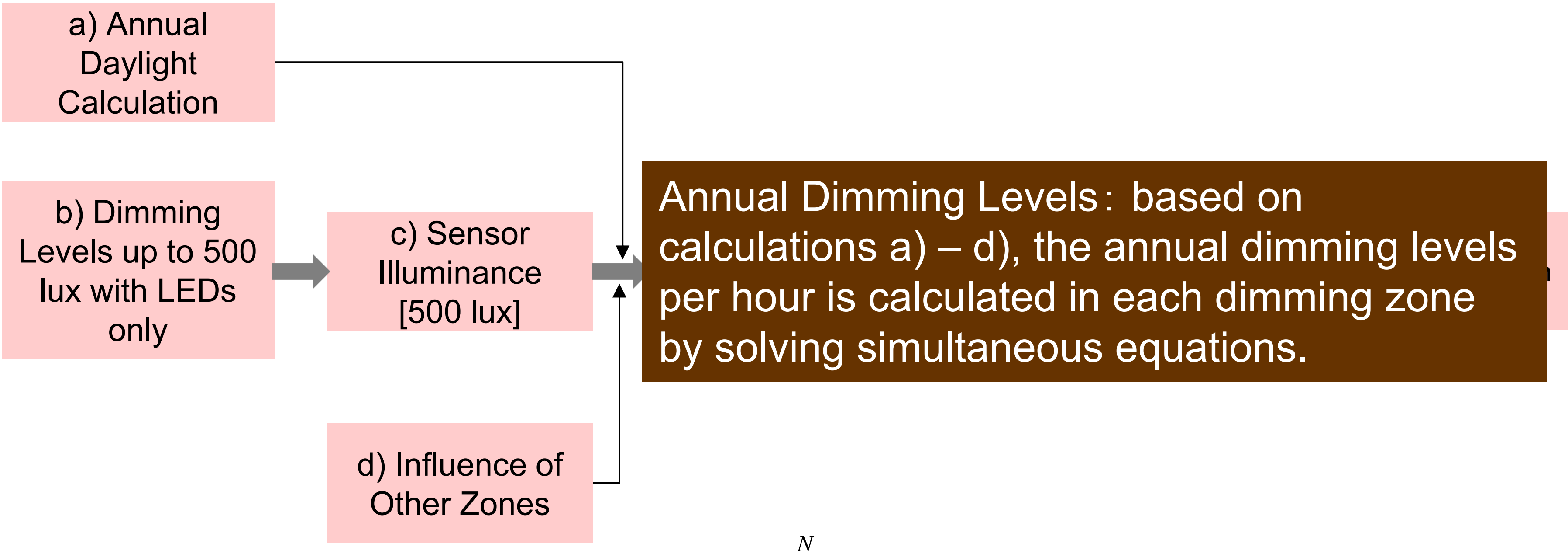

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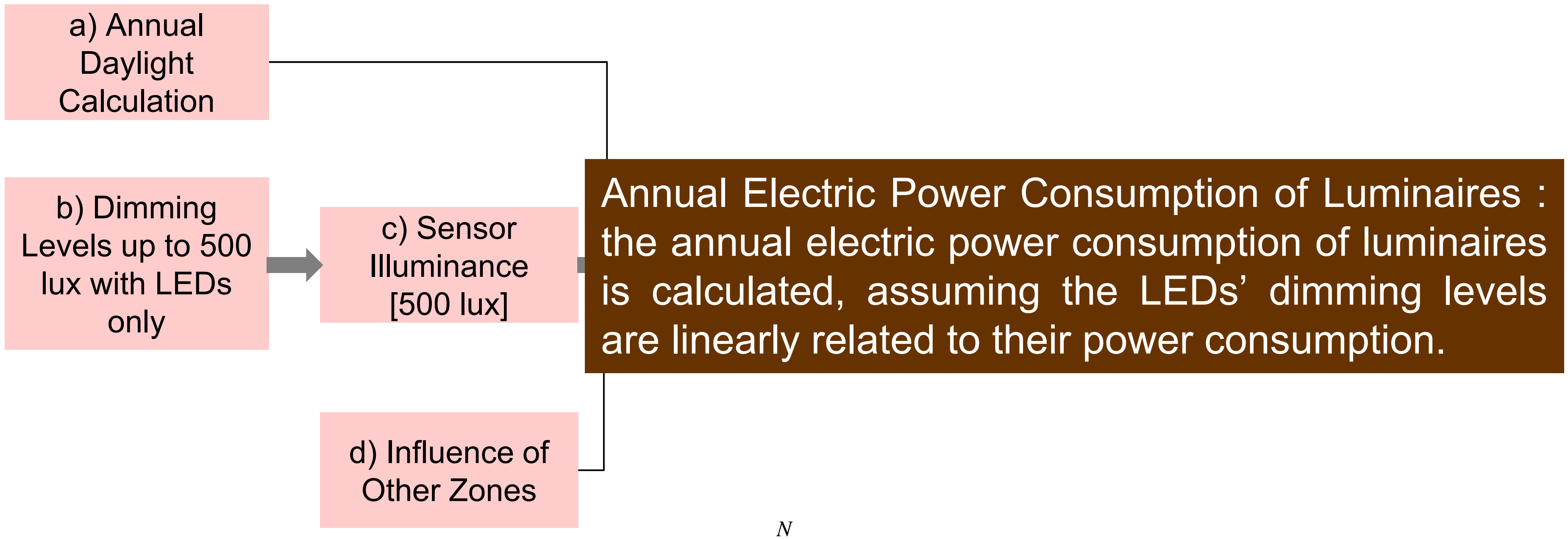

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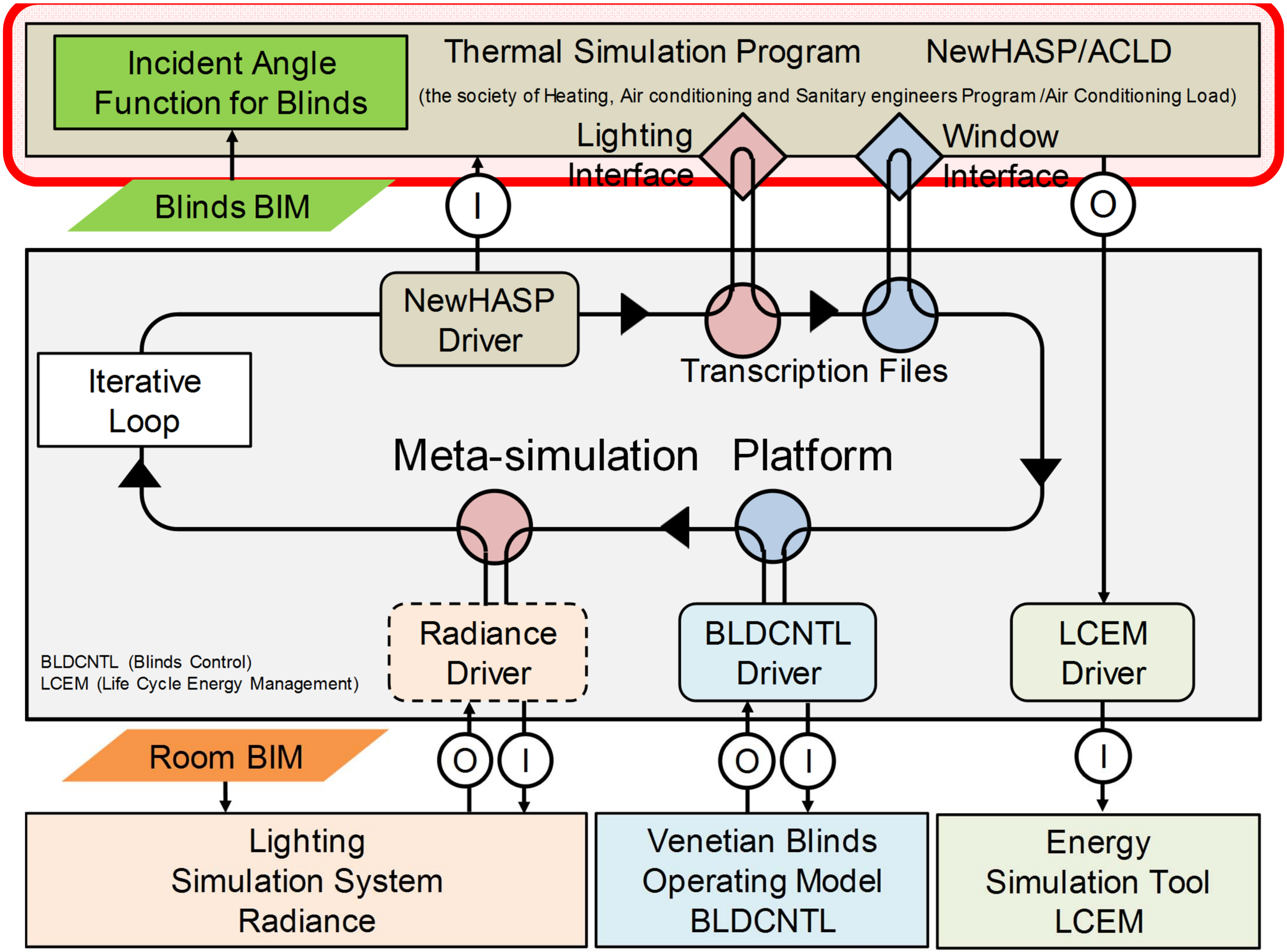

Incident Angle Function for Blinds
Thermal Simulation Program NewHASP/ACLD
(the society of Heating, Air conditioning and Sanitary engineers Program /Air Conditioning Load)
Lighting Interface
Window Interface
Blinds BIM
I
O
NewHASP Driver
Transcription Files
Iterative Loop
Meta-simulation Platform
Radiance Driver
BLDCNTL Driver
LCEM Driver
BLDCNTL (Blinds Control)
LCEM (Life Cycle Energy Management)
Room BIM
O
I
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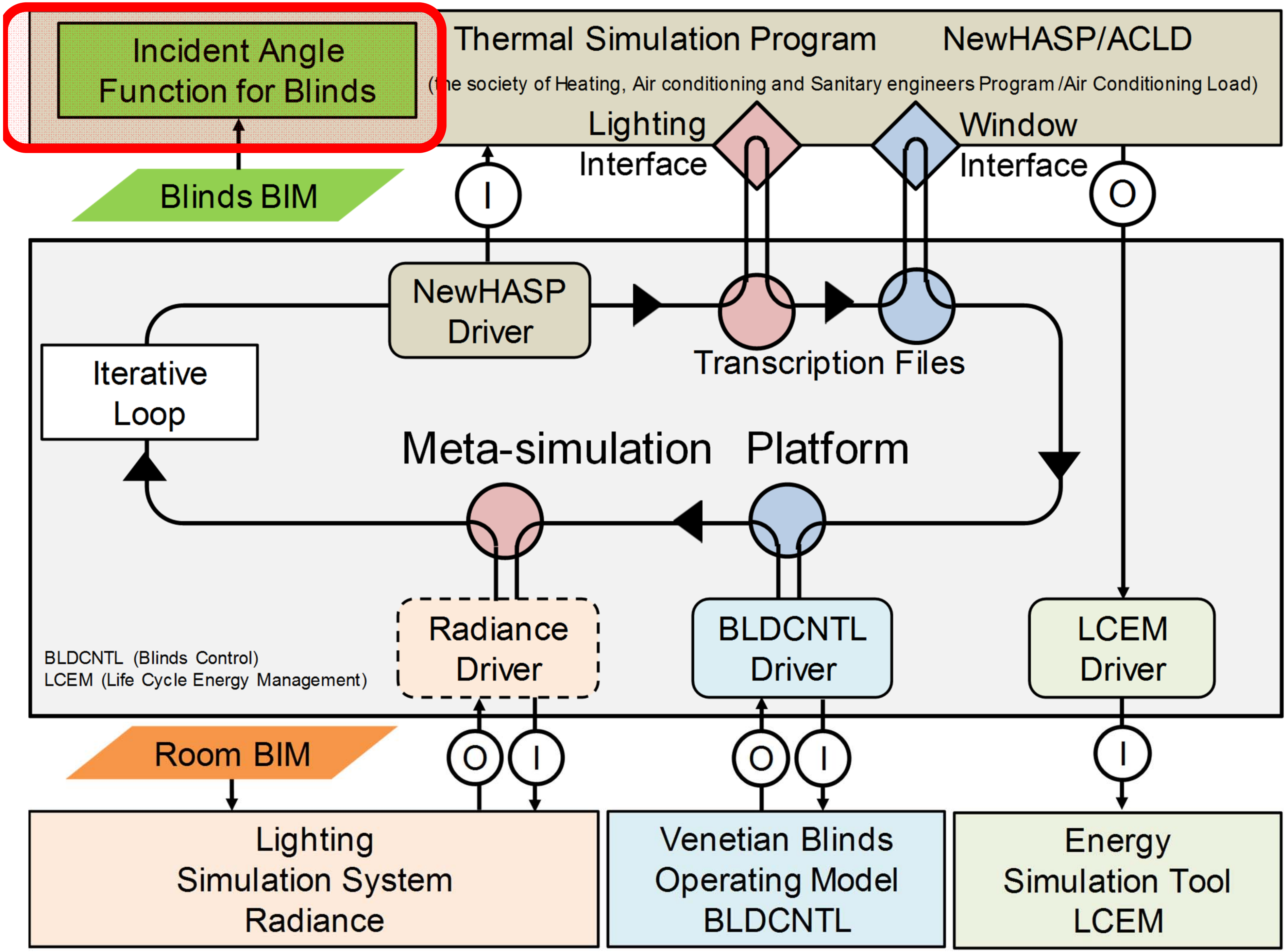
I
I
Lighting Simulation System Radiance
Venetian Blinds Operating Model BLDCNTL
Energy Simulation Tool LCEM

What is NewHASP?

1. The thermal load simulation program NewHASP/ACLD was developed by SHASE (the Society of Heating, Air Conditioning, and Sanitary Engineers, Japan) in 2004.

2. The open source code was released in 2012.

3. NewHASP/ACLD is now widely used in academic research and design practice in Japan.



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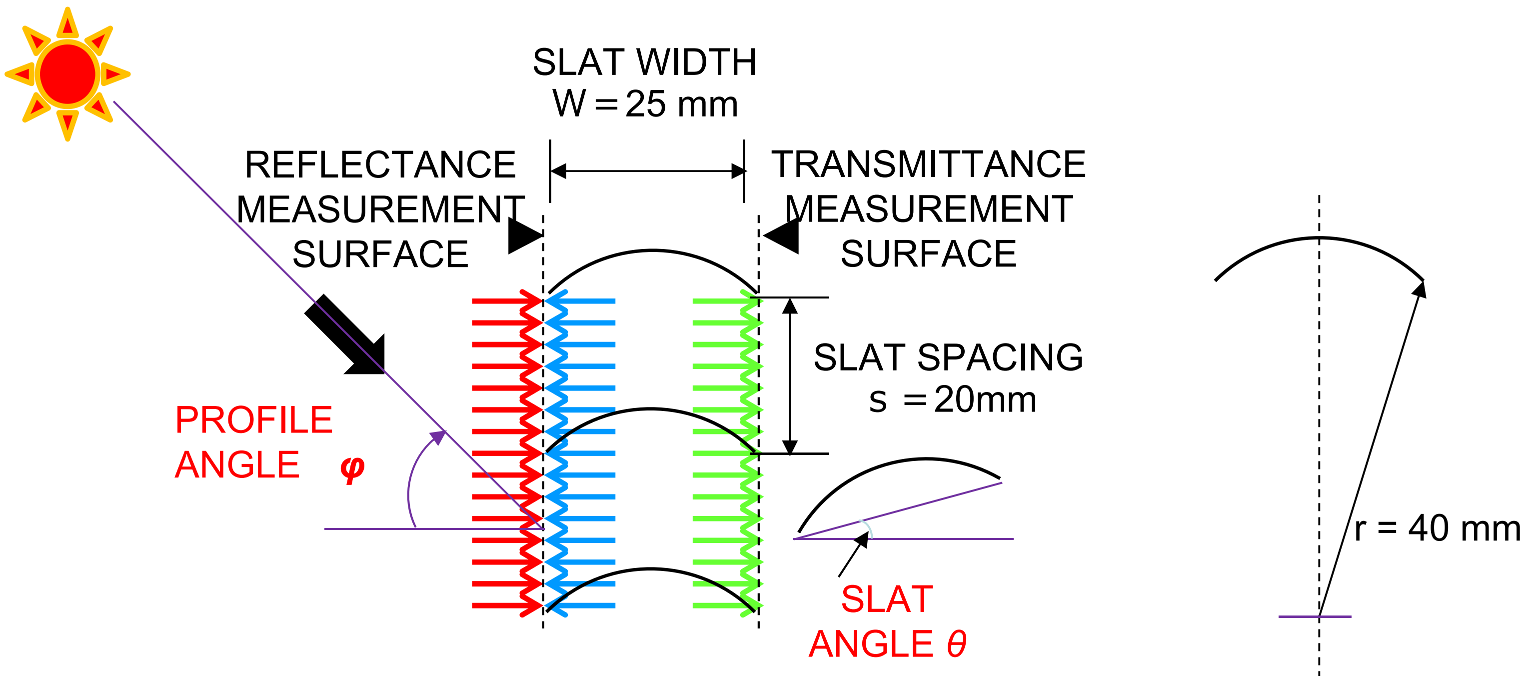
Radiance Simulation

Blind Function: $\tau(\varphi,\theta)$, $\rho(\varphi,\theta)$



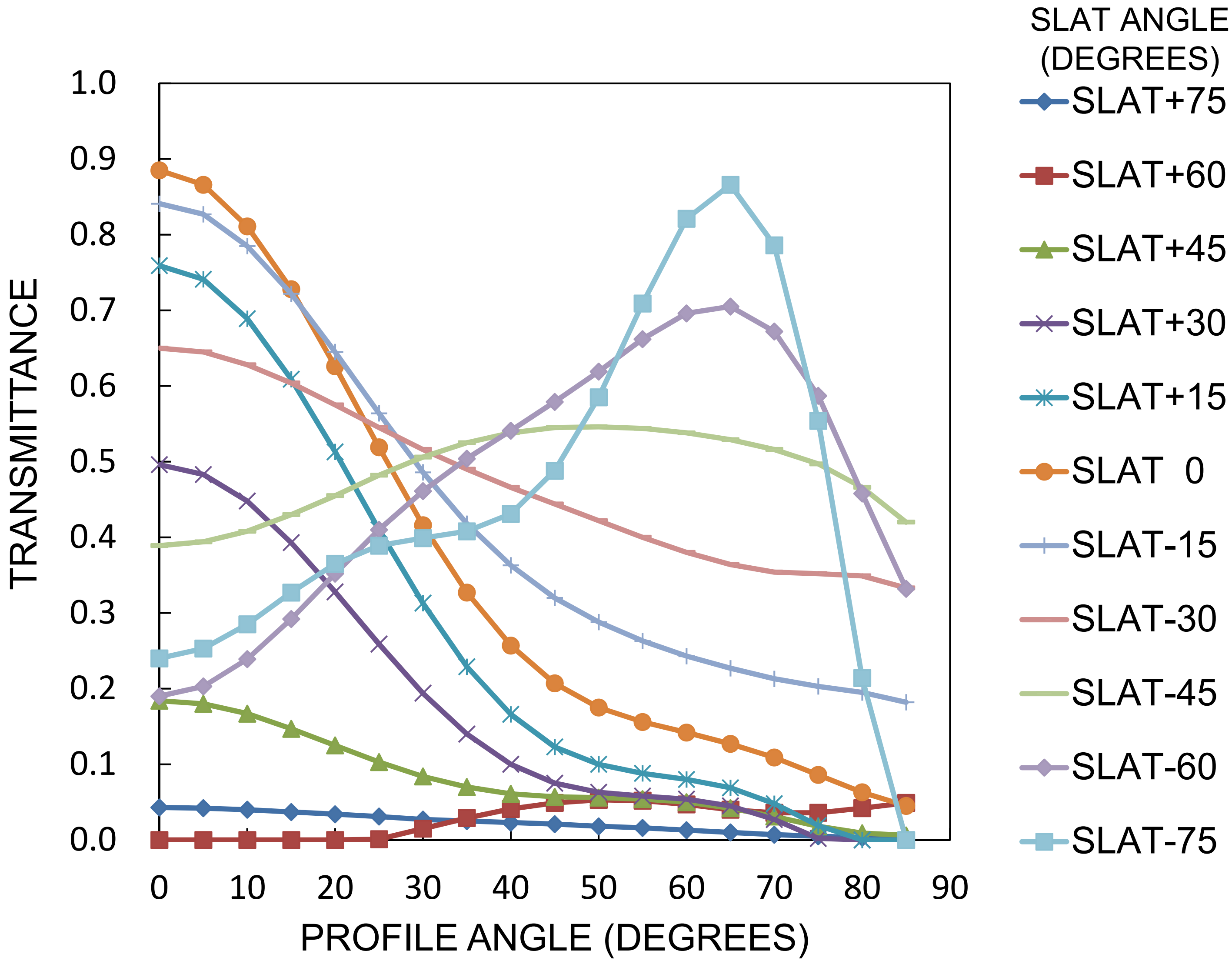
INCIDENT RADIANT FLUX FROM OUTSIDE FOR REFLECTANCE MEASUREMENT SURFACE

INCIDENT RADIANT FLUX FROM INSIDE FOR REFLECTANCE MEASUREMENT SURFACE

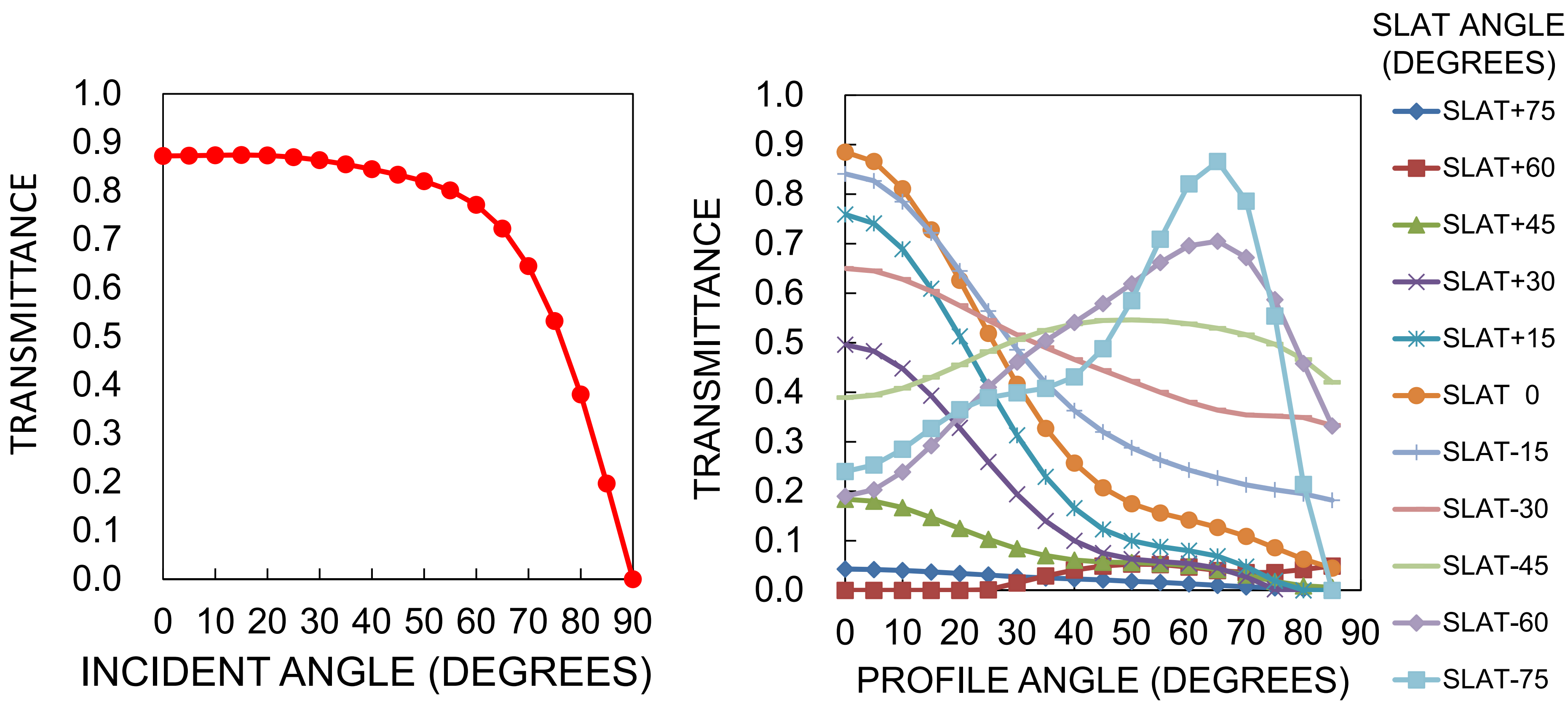
INCIDENT RADIANT FLUX FROM INSIDE FOR TRANSMITTANCE MEASUREMENT SURFACE

DIRECT NORMAL SOLAR IRRADIANCE

Blind Function τ (φ,θ)



Transmittance vs. Incident Angle



(a) Single Sheet of 3-mm Clear Glass

(b) Venetian Blinds

Overall Solar Heat Gain Coefficient

$$SHGC_x$$

$$\tau_x = \frac{\tau_1 \tau_2}{1 - \rho_1 \cdot \rho_2}$$

$$\alpha_{c1} = a_1 \left(1 + \frac{\tau_1 \rho_1}{1 - \rho_1 \rho_2}\right), \qquad \alpha_{c2} = \frac{\tau_1 a_2}{1 - \rho_1 \rho_2}$$

$$N_1 = \frac{R_o}{R_o + R_a + R_i}, \; N_2 = \frac{R_o + R_a}{R_o + R_a + R_i}$$

$$SHGC_x = \tau_x + N_1 \alpha_{c1} + N_2 \alpha_{c2}$$

where

τ = transmittance

ρ = reflectance

a = absorbance

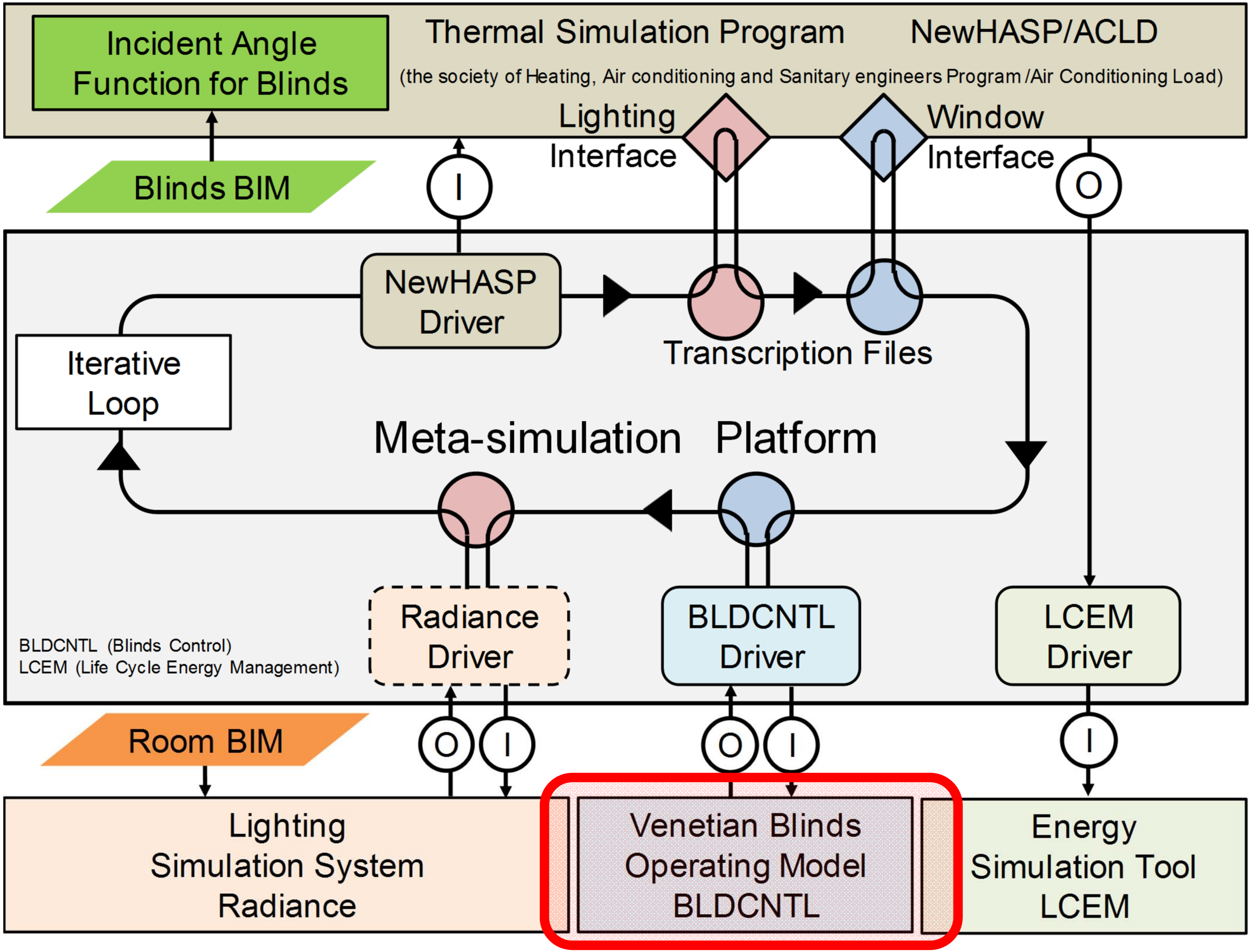
α = firm coefficient, $W \cdot K^{-1} \cdot m^{-2}$

N = inward-flowing fraction of absorbed radiation

R = thermal resistance, $m^2 \cdot K \cdot W^{-1}$

Subscripts x, 1,2 = Overall, Glass, Blind

o, a, i, c = outside, airspace, inside, convection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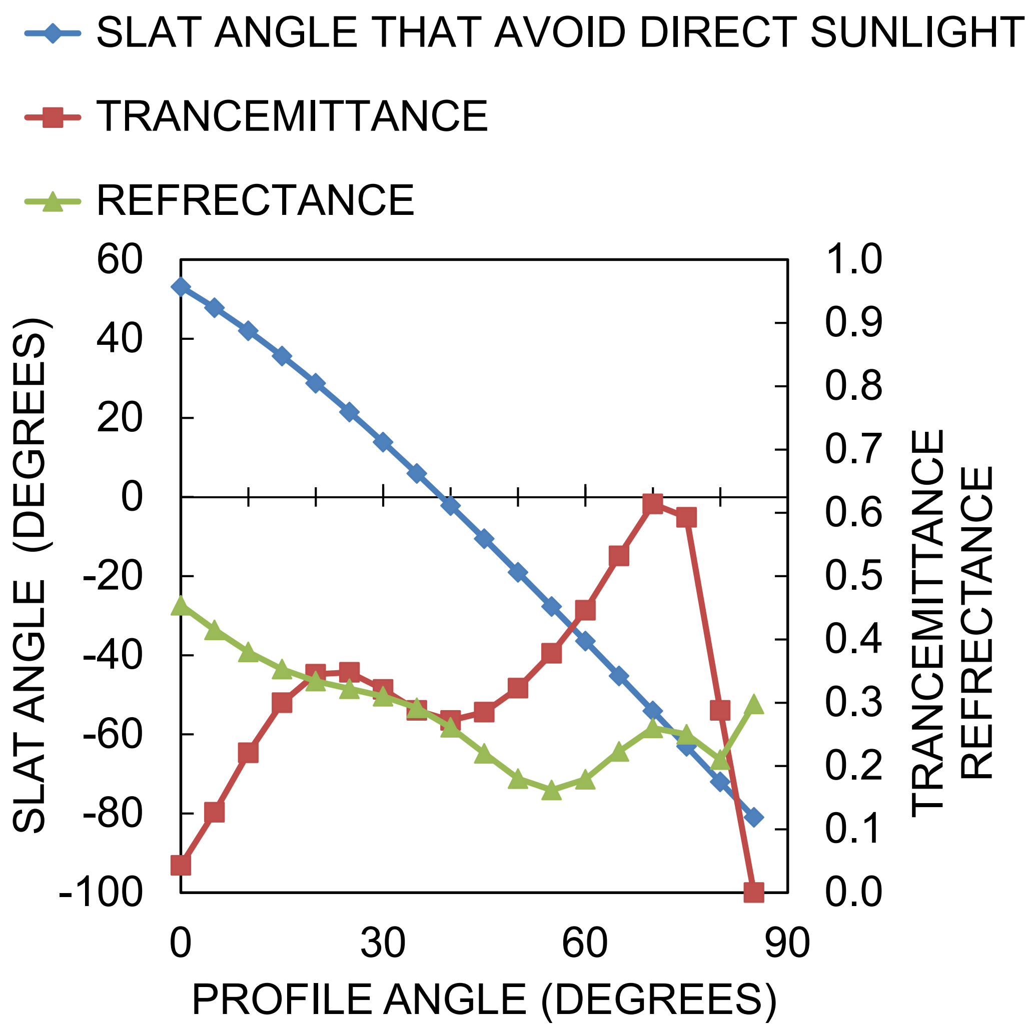
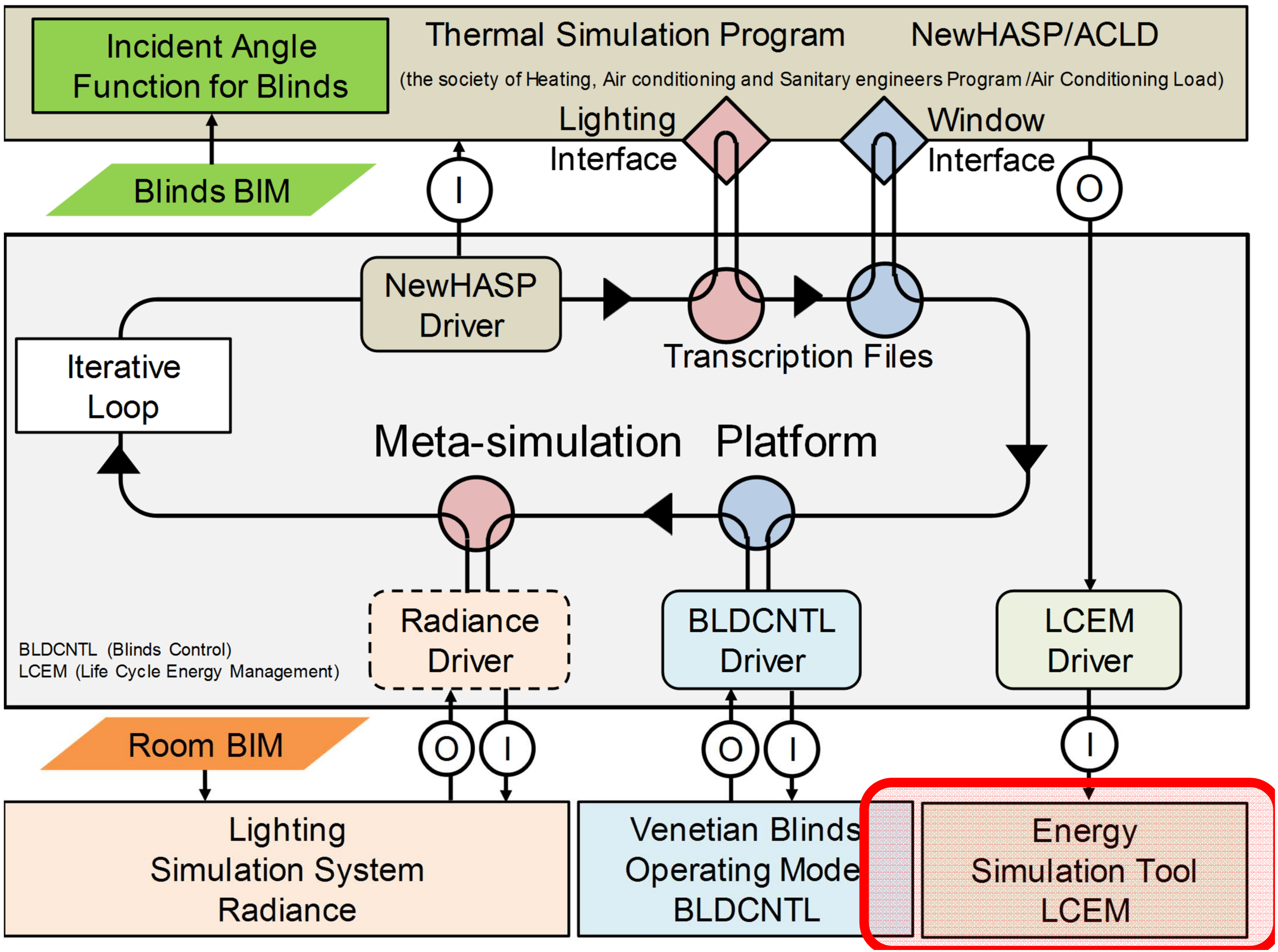
Operating Model for Blinds
BLDCNTL





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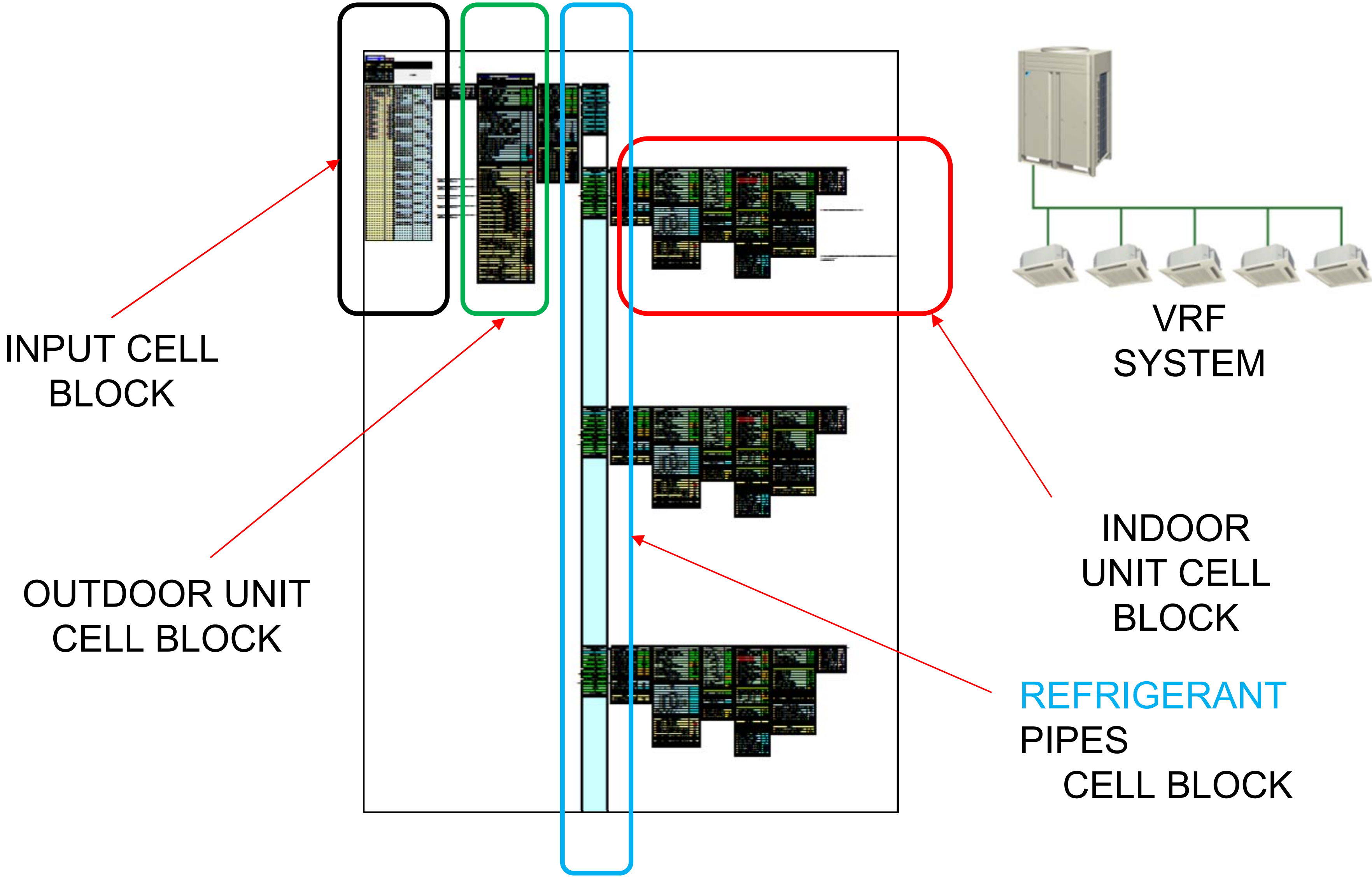
What is LCEM ?

1. LCEM (Life Cycle Energy Management): an energy simulation tool developed by MLIT (Japan's Ministry of Land, Infrastructure and Transport).

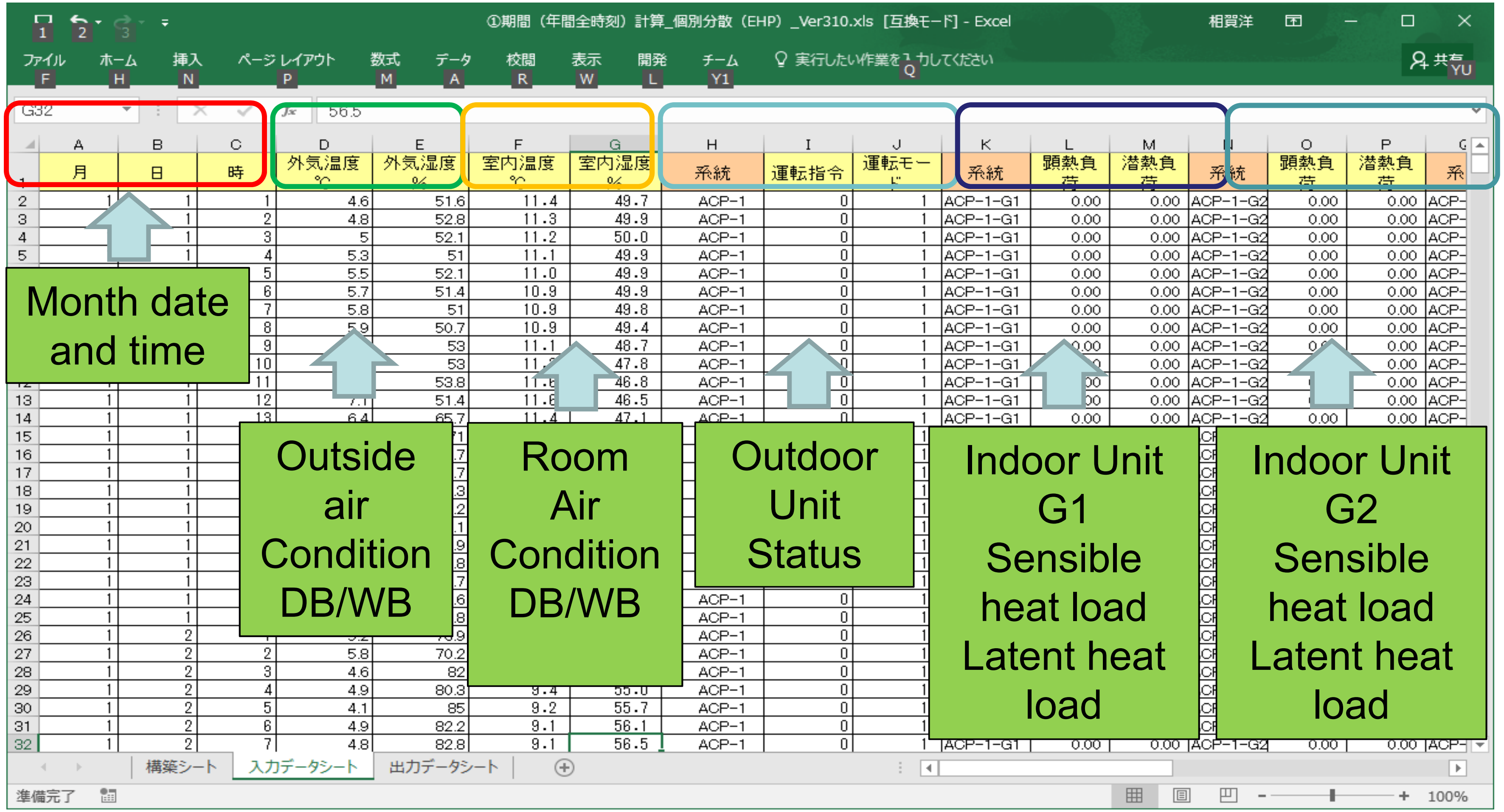
2. The LCEM tool can predict the annual energy usage of an air-conditioning system under various conditions.

3. This tool can be used to evaluate the energy performance of an air-conditioning system at the design stage.

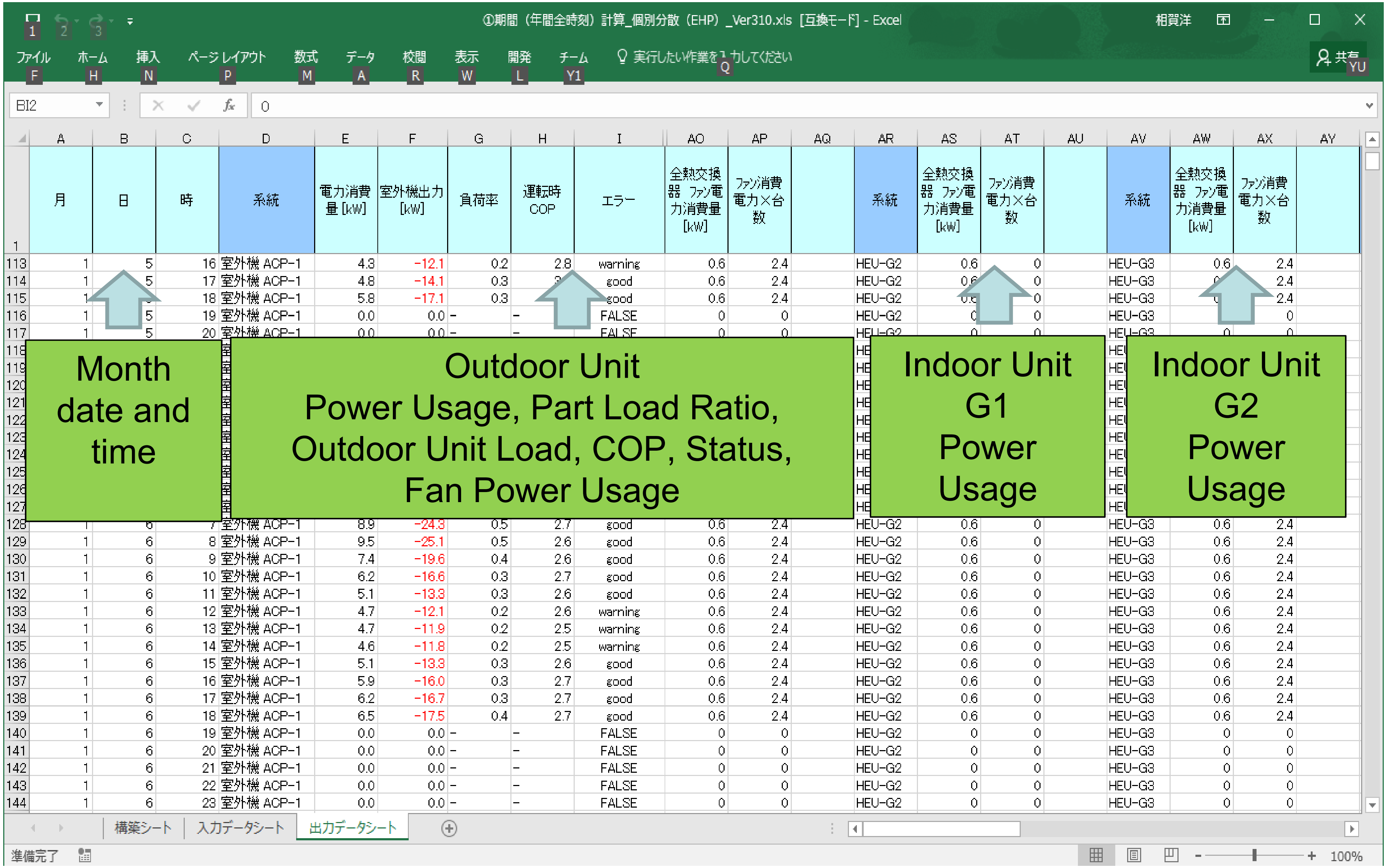
VRF Heat Pump Modeling on Excel Spreadsheet



INPUT Excel Spreadsheet

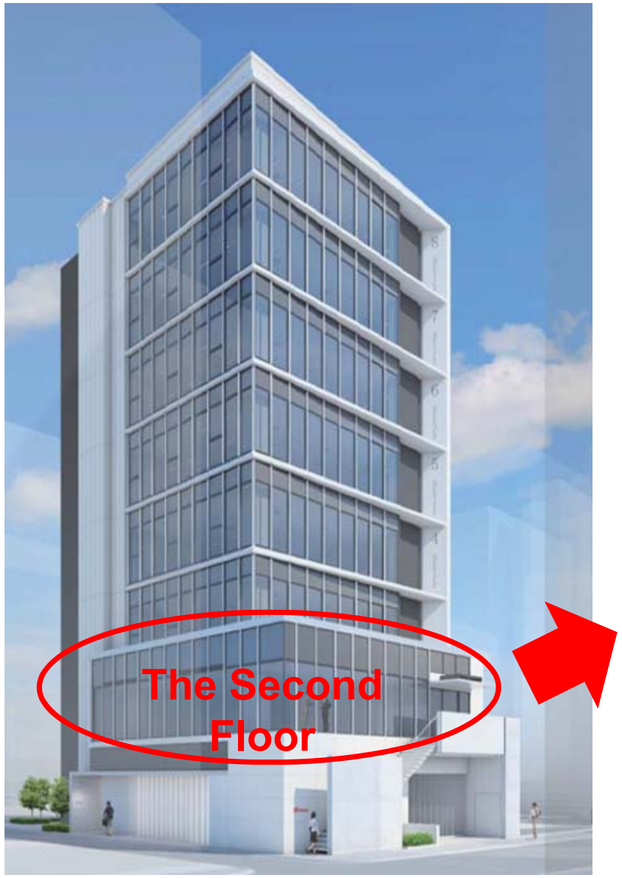


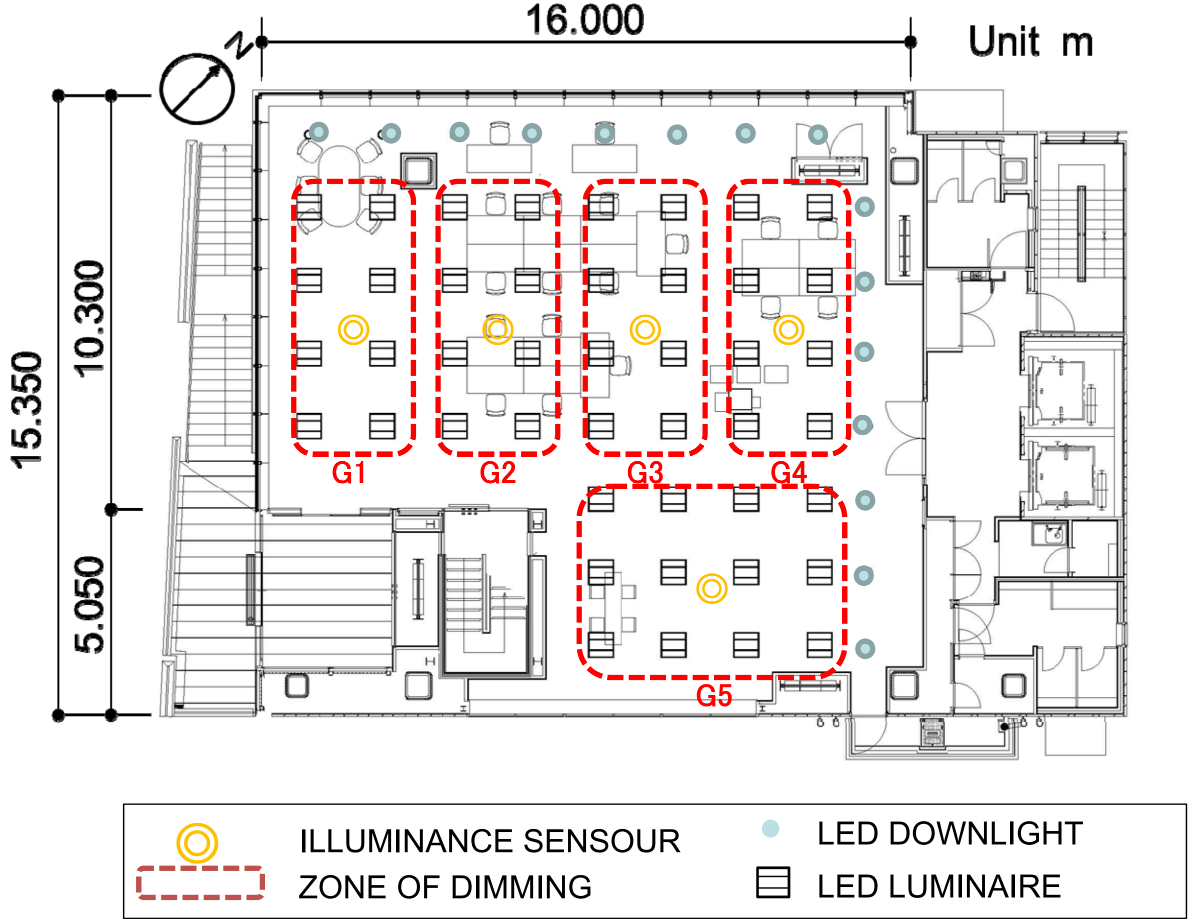
OUTPUT Excel Spreadsheet



1	月	日	時	系統	電力消費量 [kW]	室外機出力 [kW]	負荷率	運転時COP	エラー	全熱交換器 ファン電力消費量 [kW]	ファン消費電力×台数		系統	全熱交換器 ファン電力消費量 [kW]	ファン消費電力×台数		系統	全熱交換器 ファン電力消費量 [kW]	ファン消費電力×台数	
113	1	5	16	室外機 ACP-1	4.3	-12.1	0.2	2.8	warning	0.6	2.4		HEU-G2	0.6	0		HEU-G3	0.6	2.4	
114	1	5	17	室外機 ACP-1	4.8	-14.1	0.3	[illegible]	good	0.6	2.4		HEU-G2	[illegible]	0		HEU-G3	[illegible]	2.4	
115	[illegible]	[illegible]	18	室外機 ACP-1	5.8	-17.1	0.3	[illegible]	good	0.6	2.4		HEU-G2	[illegible]	0		HEU-G3	[illegible]	2.4	
116	1	5	19	室外機 ACP-1	0.0	0.0	-	-	FALSE	0	0		HEU-G2	[illegible]	0		HEU-G3	[illegible]	0	
117	1	5	20	室外機 ACP-1	0.0	0.0	-	-	FALSE	0	0		HEU-G2	0	0		HEU-G3	0	0	
128	[illegible]	[illegible]	7	室外機 ACP-1	8.9	-24.3	0.5	2.7	good	0.6	2.4		HEU-G2	0.6	0		HEU-G3	0.6	2.4	
129	1	6	8	室外機 ACP-1	9.5	-25.1	0.5	2.6	good	0.6	2.4		HEU-G2	0.6	0		HEU-G3	0.6	2.4	
130	1	6	9	室外機 ACP-1	7.4	-19.6	0.4	2.6	good	0.6	2.4		HEU-G2	0.6	0		HEU-G3	0.6	2.4	
131	1	6	10	室外機 ACP-1	6.2	-16.6	0.3	2.7	good	0.6	2.4		HEU-G2	0.6	0		HEU-G3	0.6	2.4	
132	1	6	11	室外機 ACP-1	5.1	-13.3	0.3	2.6	good	0.6	2.4		HEU-G2	0.6	0		HEU-G3	0.6	2.4	
133	1	6	12	室外機 ACP-1	4.7	-12.1	0.2	2.6	warning	0.6	2.4		HEU-G2	0.6	0		HEU-G3	0.6	2.4	
134	1	6	13	室外機 ACP-1	4.7	-11.9	0.2	2.5	warning	0.6	2.4		HEU-G2	0.6	0		HEU-G3	0.6	2.4	
135	1	6	14	室外機 ACP-1	4.6	-11.8	0.2	2.5	warning	0.6	2.4		HEU-G2	0.6	0		HEU-G3	0.6	2.4	
136	1	6	15	室外機 ACP-1	5.1	-13.3	0.3	2.6	good	0.6	2.4		HEU-G2	0.6	0		HEU-G3	0.6	2.4	
137	1	6	16	室外機 ACP-1	5.9	-16.0	0.3	2.7	good	0.6	2.4		HEU-G2	0.6	0		HEU-G3	0.6	2.4	
138	1	6	17	室外機 ACP-1	6.2	-16.7	0.3	2.7	good	0.6	2.4		HEU-G2	0.6	0		HEU-G3	0.6	2.4	
139	1	6	18	室外機 ACP-1	6.5	-17.5	0.4	2.7	good	0.6	2.4		HEU-G2	0.6	0		HEU-G3	0.6	2.4	
140	1	6	19	室外機 ACP-1	0.0	0.0	-	-	FALSE	0	0		HEU-G2	0	0		HEU-G3	0	0	
141	1	6	20	室外機 ACP-1	0.0	0.0	-	-	FALSE	0	0		HEU-G2	0	0		HEU-G3	0	0	
142	1	6	21	室外機 ACP-1	0.0	0.0	-	-	FALSE	0	0		HEU-G2	0	0		HEU-G3	0	0	
143	1	6	22	室外機 ACP-1	0.0	0.0	-	-	FALSE	0	0		HEU-G2	0	0		HEU-G3	0	0	
144	1	6	23	室外機 ACP-1	0.0	0.0	-	-	FALSE	0	0		HEU-G2	0	0		HEU-G3	0	0	

Meta-simulation Model （Actual Building）





Four Simulations

1. Conventional
   Blinds are raised when solar heat gain is below 200W/m^2.
   The U-value of glass and blinds varies.
   Electric lighting is not dimmed.

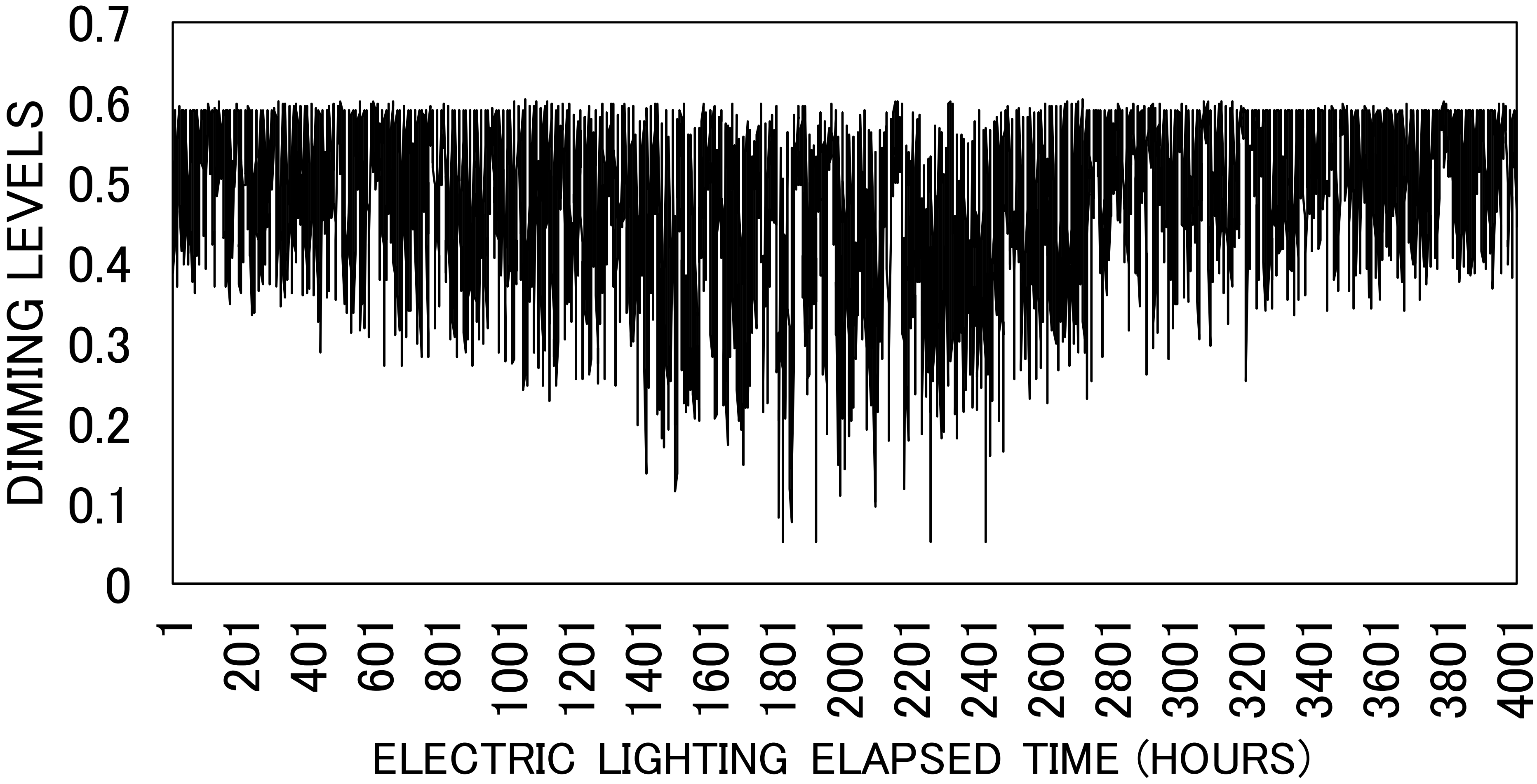
2. Slat 45
   Blinds are lowered, keeping the slat angle 45°.
   The U-value of glass and blinds is constant.
   Electric lighting is dimmed.

Four Simulations

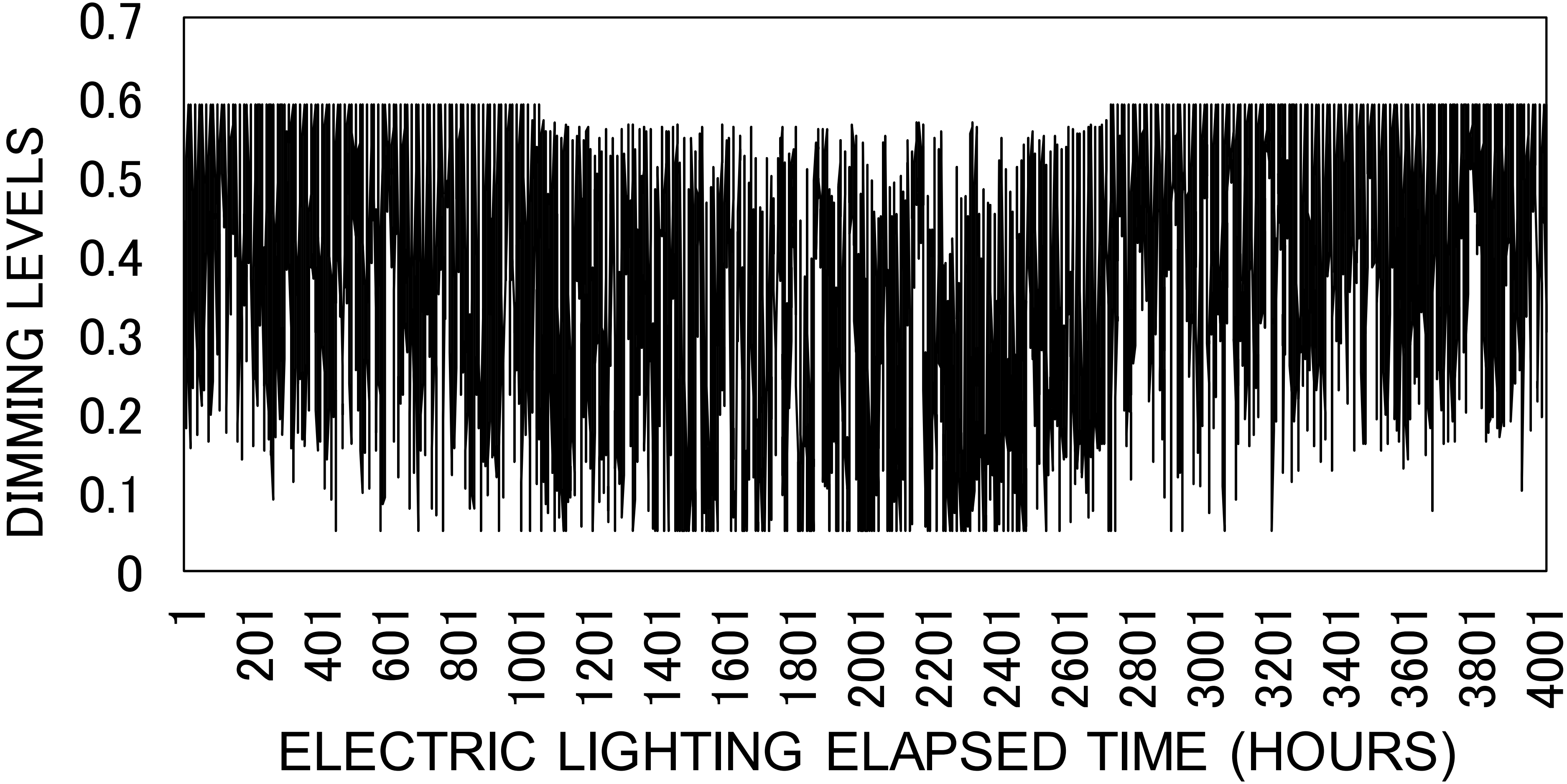
3. Slat 0
   Blinds are lowered, keeping the slat angle at 0°.
   The U-value of glass and blinds is constant.
   Electric lighting is dimmed.

4. Slat Cutoff
   Blinds are lowered and operated to avoid direct sunlight.
   The U-value of glass and blinds is constant.
   Electric lighting is dimmed.

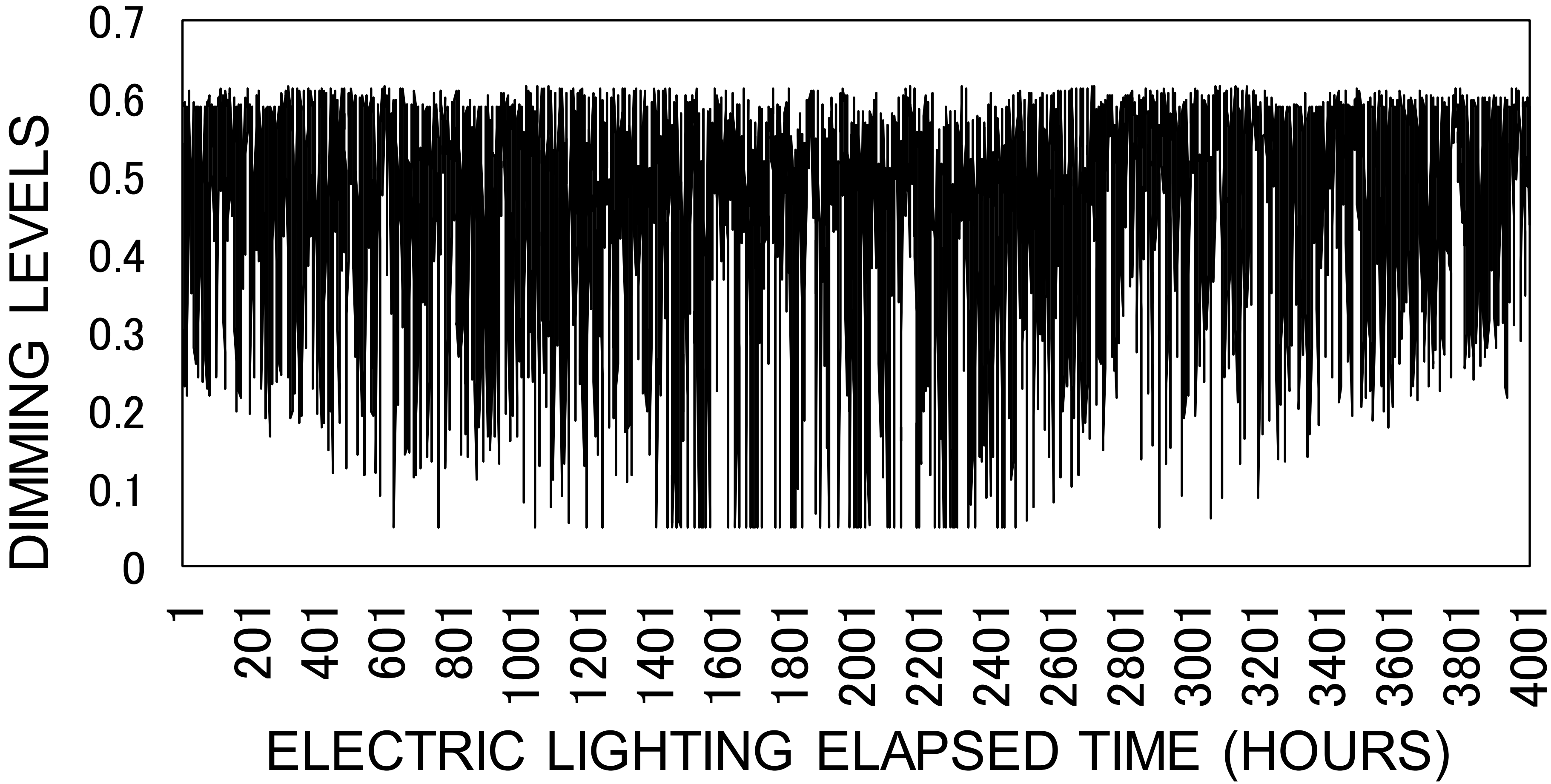
Radiance Simulation Results: Dimming Levels（Slat 45, G1）



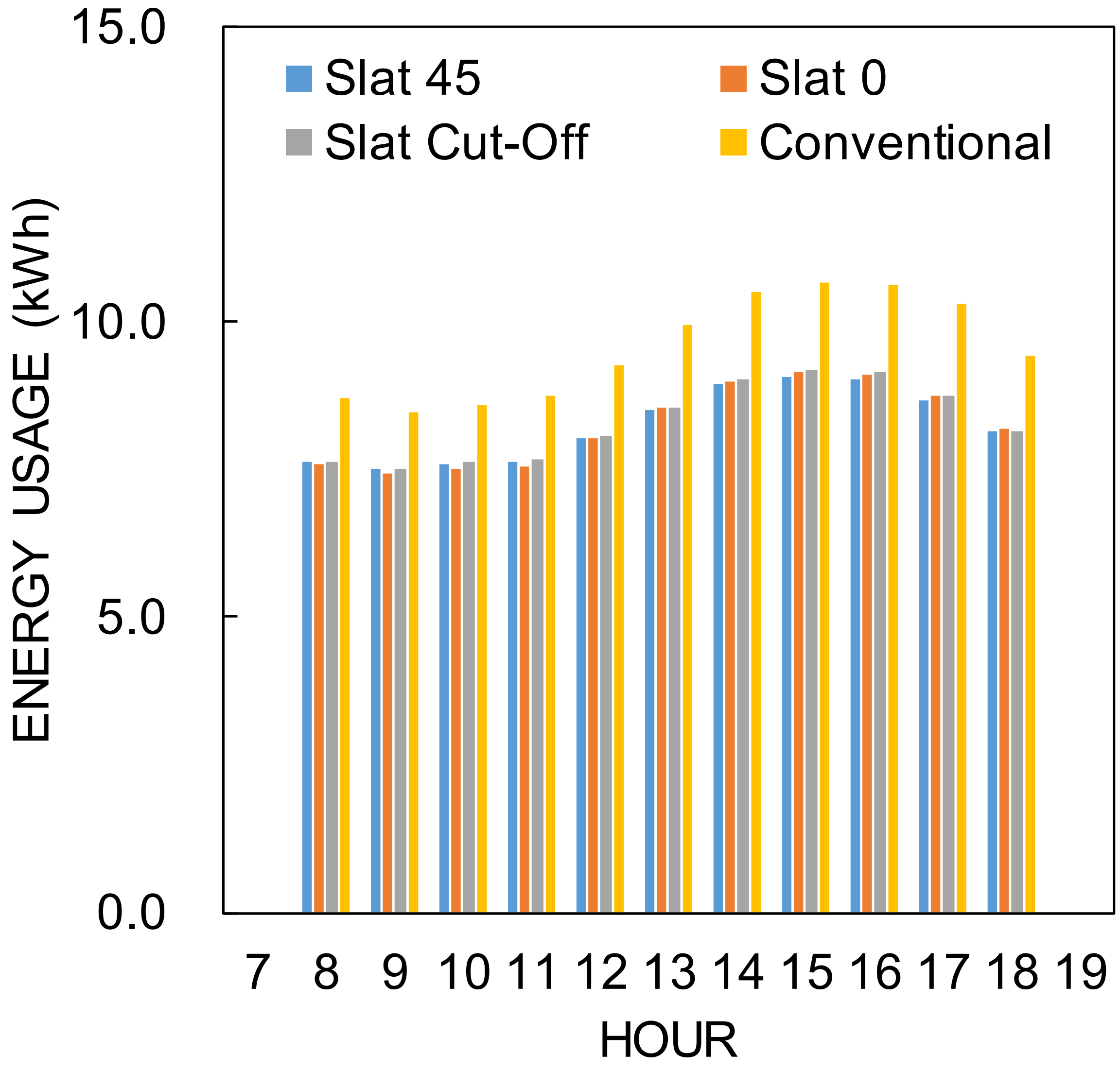
Radiance Simulation Results: Dimming Levels（Slat 0, G1）



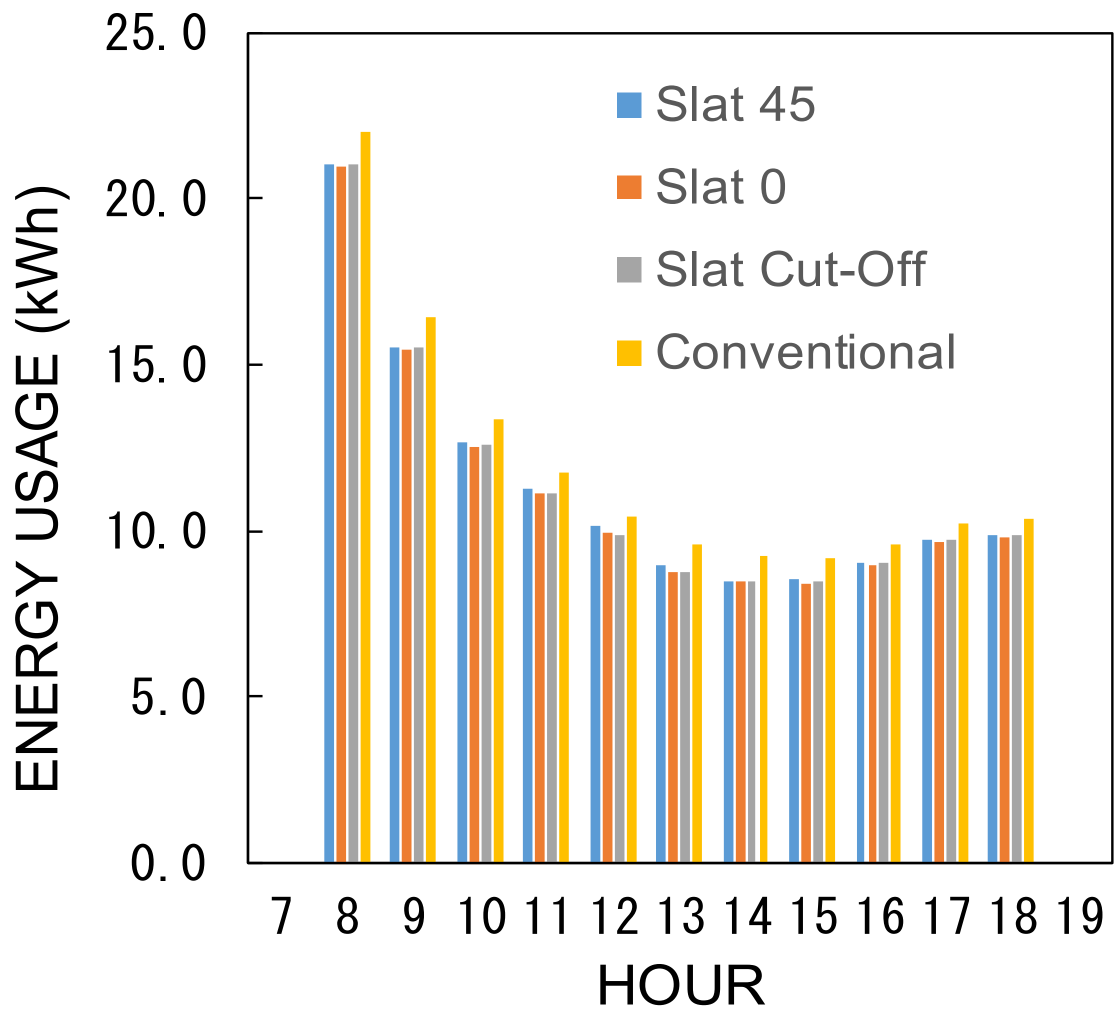
Radiance Simulation Results: Dimming Levels（Slat Cut-off, G1）



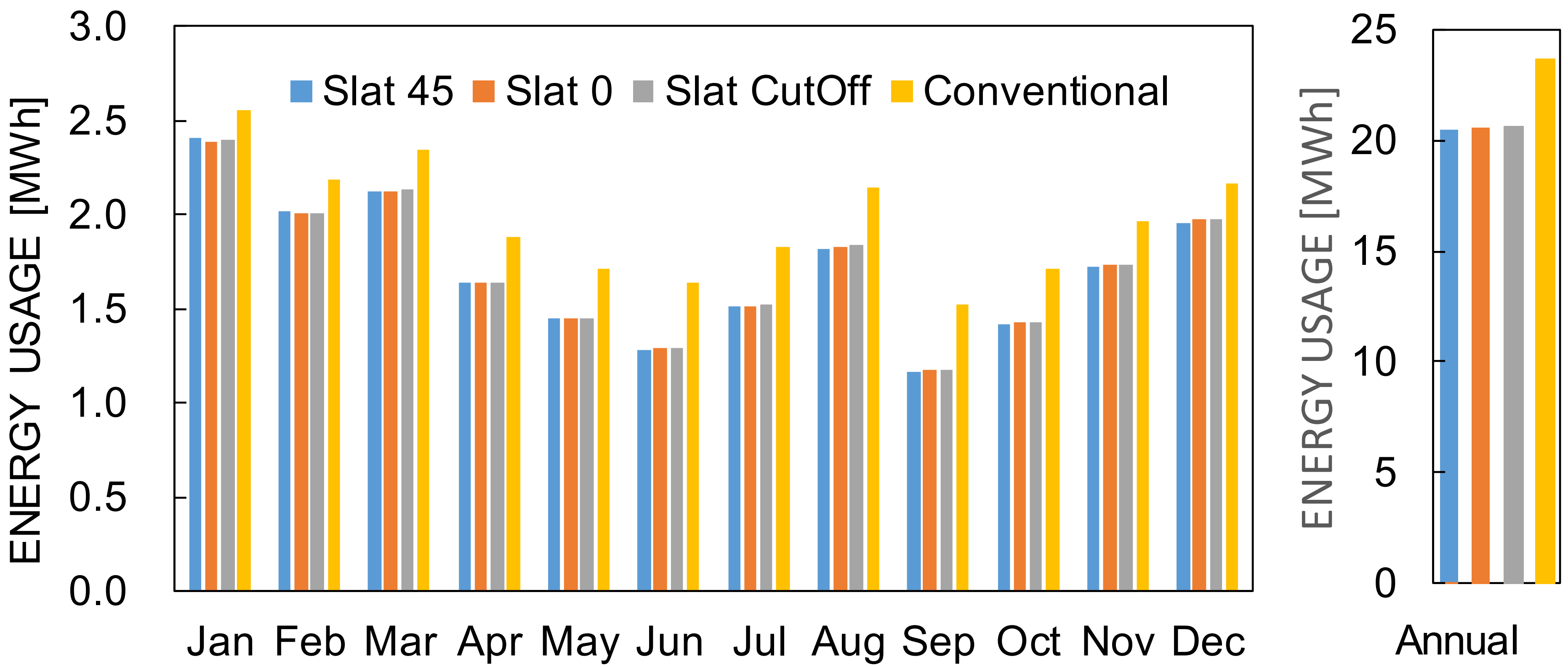
Results for the Maximum Cooling Load（Aug. 10）



Results for the Maximum Heating Load（Jan. 23）



Monthly&Annual Energy Usage
(VRF HEAT PUMP + ELECTRIC LIGHTING)



OBAYASHI