

DEVELOPMENT OF AN ADVANCED COMPUTER TOOL, AUSSSM TOOL, FOR A COUPLING SIMULATION WITH BUILDING THERMAL SYSTEM AND URBAN CLIMATOLOGY

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ABSTRACT

The computer software AUSSSM TOOL, originating from the methodology of the revised-Architectural-Urban-Soil-Simultaneous Simulation Model (revised-AUSSSM), was developed by adopting the Graphical User Interface (GUI) features to support users, who can use the interactive computer display for parameter settings, simulating, visualizing, and reporting the numerical calculation results instead of complicated programming. The purpose of the AUSSSM TOOL is to determine quantitative parameters such as air temperature, exhaustive heat from air conditioning systems, energy heat balance, etc. within the Urban Canopy structure, which data enables the evaluation of effects of Urban Heat Island (UHI) in concrete terms useful to urban planners, architects, engineers, and so forth in the field of urban climatology involving building scale.

INTRODUCTION

Recently, using a computer to handle a numerical simulation has become a significant solution to solve complex calculating schemes in the field of Urban Thermal Environments studies. We found that many researchers have adopted programming features that allow the computer to perform their numerical calculations. Increasingly, computer simulation has become quite useful for urban planning specialists and urban climate researchers. Generally, most researchers self-generate computer programming to simulate a selected subject and subsequently present the simulated results in many papers (Kusaka et al., 2001). Consequently, from a viewpoint of practical business such as urban planners and architects, it is very difficult to comprehend at once the algorithm and the concept of the programs and the research content itself, so it is really hard to adopt these programs as their application. However, this gap between research and practical application might be closed if the computer-programming development process is expanded to support various levels of users of simplified computer simulation.

Therefore, to resolve the above difficulties, we used our knowledge of computer-programming techniques to develop various types of intelligent computer

software, including ET_AEE (Tanimoto, 2000) and Angle Factor, which were designed for educational use. These programs can be downloaded from our web-site at <http://ktlabo.cm.kyushu-u.ac.jp/>. Additionally, MCDM-23 (Chimklai, 2002), developed as a computer tool and embedded within IEA SH&C Task23 Activity, was designed to aid urban planners in decision-making during the primarily design process of sustainability buildings. These programs have been devised to provide a simpler and more intuitive interface between the user and the computer by providing GUI ability.

To this end, we recently developed computer software called the AUSSSM TOOL, which was based on the revised-AUSSSM method. This software quantitatively estimates and evaluates the main causes of UHI. This paper describes the AUSSSM TOOL, the original method of the revised-AUSSSM, and the developing environment in detail.

THE METHODOLOGY OF THE REVISED-AUSSSM

The schematic diagram of the revised-AUSSSM is illustrated in Fig.1. Similar buildings are assumed to be in a rectangular lattice space, arranged homogeneously and infinitely in a supposed urban area. This premise means that only the vertical atmospheric diffusion is considered. In an overview, the revised-AUSSSM consists of three main sub-models related to the urban atmosphere, the land surface, and the buildings, respectively.

The first model is the *urban atmospheric sub-model*, which involves the equations of momentum, heat, and vapor contained in the Urban Canopy Model (UCM) to clarify the diffusing potentials of air temperature, wind velocity, and specific humidity, respectively. The second model is the *soil sub-model*. In this sub-model, three types of land surfaces, including bared soil, lawn (on both ground and rooftop), and pavement, are assumed and estimated by using the one-dimensional heat conductive equation. In addition, to clarify the relation between UHI and alternation in land usage, it is crucially important to estimate water balance, which affects heat balance, at the urban surface. Hence, the investigation of evaporation from those respective

Table 1
Factors and Levels in a certain numerical experiment
based on the Taguchi Design of Experiment Theory using the revised-AUSSSM.

Factor	Level	L1	L2	L3
A	Building Volume Proportion	700%	1000%	1300%
B	Gross Building Volume Proportion	150%	250%	350%
C	Ground Surface Covering	Asphalt 1 : Lawn 0	Asphalt 1 : Lawn 1	Asphalt 0 : Lawn 1
D	Glazing Area Proportion on Building Walls	35%	60%	85%
E	Reflectance of Solar Radiation for Building Walls	0.8 (high-albedo painting finish)	0.5	0.2
F	Heat Generation in Building Space	General Present Status	1.5 times	2 times
G	Set Room Air Temperature for HVAC Control	24°C	26°C	28°C
H	HVAC Systems	Private System HPair:30% TR:31% AR:39%	Private System + HST HST+HPair:30% HST+TR:31% AR:39%	DHC + HST DHC+HST+HPair:27% DHC+HST+HPwater:41% DHC+HST+TR:9% DHC+AR:23%
I	Rooftop finishing	None	50% Vegetation	100% Vegetation
J	HVAC Systems Operating Time	8:00am-21:00pm	20:00pm-8:00am	12:00pm-1:00am
K	Reflectance of Solar Radiation for Rooftop	0.8	0.5	0.3
L	Reflectance of Solar Radiation for Asphalt	0.8	0.5	0.1

Considered Interactions : AxB, AxC, AxD, AxE, BxC, BxE, BxF, BxH, BxI, BxK, BxL, CxL, DxE, DxF, ExF, ExI, FxG, FxH, FxJ, GxH, GxI, HxI, HxJ, HxK, IxK
DHC : District Heating and Cooling System, HST : Heat Storage System, HPair : Air Source Heat Pump, TR : Turbo Refrigerator, AR : Gas Fueled Absorption Refrigerator

THE METHODOLOGY OF THE REVISED-AUSSSM

AUSSSM TOOL Structure

The AUSSSM TOOL has three offshoot programs: *Simulator*, *PostGraph*, and *Viewer*, as shown in Fig. 2. *Simulator* works as a preprocessor for data input, and as a solver based on the revised-AUSSSM. *PostGraph* provides a wide variety of schematic expressions for the simulation results. Those two programs work together to run the simulation solver, whereas *Viewer* functions alone, providing stages to see a set of results of characteristic values coming from a compact database to confirm various factorial effects on UHI. The results are solved previously based on the Taguchi’s Design of Experiment (DOE) theory.

Applications of *Simulator*

Simulator carries out the numerical simulation process based on the revised-AUSSSM executed file to calculate the groups of data used to estimate UHI effect depending on the input conditions such as urban & building design data, meteorological data, and HVAC systems data. Fig. 3 illustrates the dialog for input data related to urban and building design, and Fig. 4 shows the dialog for input data related to HVAC systems. Regarding HVAC systems data,

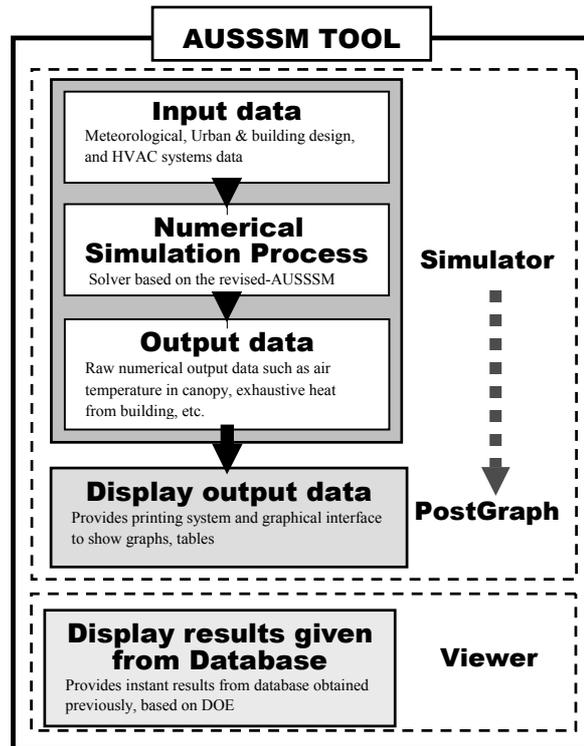


Figure 2 The holistic structure of the AUSSSM TOOL.

although there are 14 systems to provide the default data, the user can add and define up to 10 new systems. The meteorological data is the group of data on air temperature, humidity, wind velocity at Surface Boundary Layer (SBL), solar radiation or

geographical information, all of which were obtained from the statistical record of a hot day during the summer season in Tokyo.

After all of the input conditions have been defined, the numerical simulation process is conducted by taking the revised-AUSSSM executed file as a solver. All of the calculated results are saved into an .opt file and ready to make viewing by using *PostGraph*.

Viewing the calculated results by *PostGraph*

PostGraph allows the user to display, export (data-handling), or print the output data given by performing the numerical simulation process on the *Simulator* with an interactive environment. To bring up the graphical display, the user is first required to

The screenshot shows the 'AUSSSM General Condition' dialog box with several sections:

- Building Related:** Building Width (m) 32.000, Gross Building Volume Proportion (%) 300.000, Floor Height (m) 3.400, Number of Floors (7-15 F) 7.
- Radiation Related:** Solar Absorptance of Building Roof 0.700, Solar Absorptance of Building Wall 0.600, Solar Absorptance of Asphalt Surface 0.900, Solar Absorptance of Soil Surface 0.700, Proportion of Building Windows Area 0.350.
- Ground Covering Proportion:** Asphalt 0.333, Soil 0.333, Lawn/Grass 0.334.
- Heat Generation or HVAC:** Anthropogenic Heat from Vehicles (W/m²) [AHV] 9.700, Indoor Sensible Heat Gain (W/m²) [ISHG] 56.000, Indoor Latent Heat Gain (W/m²) [ILHG] 13.000, Indoor Set Temperature [°C] 26.000, Indoor Set Humidity [%] 50.000, Indoor Heat Transfer Coefficient (W/m².K) 8.000.
- Others:** Building Allocation System Staggered Lattice, Proportion of Roof Vegetation Area 0.000, Irrigation to Roof (Enable/Disable), Irrigation Rate to Roof (mm/hr) 2.000, Evaporation from Asphalt(Road) and Concrete(Roof) (Enable/Disable), Indoor Ventilation (m³/(s.floor area)) 0.00075.
- Wall Materials:** Radio buttons for 'Indoor side is Insulation, and Outdoor side is Concrete' (selected) and 'Indoor side is Concrete, and Outdoor side is Insulation'. A table compares Concrete and Insulation properties: Thickness (m) 0.18 vs 0.025, Heat Conductivity (W/(m.K)) 1.1 vs 0.037, Specific Heat (J/(m².K)) 880 vs 1200, Specific Weight (kg/m³) 2200 vs 28.
- Soil Condition:** Radio buttons for 'No' (selected) and 'Yes'. A table compares Ground and Roof soil properties: Specific Weight (kg/m³) 1297 vs 1297, Saturated Water Content (kg/kg) 0.2301 vs 0.2301, Specific Heat Capacity (J/(m².K)) 2180000 vs 2180000, Heat Conductivity (W/(m.K)) 0.574 vs 0.574.

Figure 3 The input data related to urban and building design (default values).

The screenshot shows the 'COP Sheet' dialog box with a table of HVAC systems and their parameters:

No.	HVAC System	/	Load Sharing Weight	Proportion of Sensitive to Total Heat Exhaustion	Altitude of Exhaustion
1	DHC+HPair	<input type="checkbox"/>	0.00	1.000	From Half height of Bu
2	DHC+HPwater	<input type="checkbox"/>	0.00	0.000	- N/A -
3	DHC+SHPwater	<input type="checkbox"/>	0.00	0.000	- N/A -
4	DHC+TR	<input type="checkbox"/>	0.00	0.125	From Half height of Bu
5	DHC+AR	<input type="checkbox"/>	0.00	0.113	From Half height of Bu
6	DHC+HST+HPair	<input type="checkbox"/>	0.00	1.000	From Half height of Bu
7	DHC+HST+HPwater	<input type="checkbox"/>	0.00	0.000	- N/A -
8	DHC+HST+SHPwater	<input type="checkbox"/>	0.00	0.000	- N/A -
9	DHC+HST+TR	<input type="checkbox"/>	0.00	0.125	From Half height of Bu
10	HPair	<input checked="" type="checkbox"/>	0.30	1.000	From Every floors
11	TR	<input checked="" type="checkbox"/>	0.31	0.125	From Roof top
12	AR	<input checked="" type="checkbox"/>	0.39	0.113	From Roof top
13	HST+HPair	<input type="checkbox"/>	0.00	1.000	From Every floors
14	HST+TR	<input type="checkbox"/>	0.00	0.125	From Roof top
15		<input type="checkbox"/>			
16		<input type="checkbox"/>			- N/A -
17		<input type="checkbox"/>			From Every floors
18		<input type="checkbox"/>			From Roof top
19		<input type="checkbox"/>			From Ground level
20		<input type="checkbox"/>			From Half height of Building
21		<input type="checkbox"/>			
22		<input type="checkbox"/>			
23		<input type="checkbox"/>			
24		<input type="checkbox"/>			

Check the HVAC Operation and enter time interval for operating A/C and HST

Non-Operation: Air Conditioning Start: 8, Air Conditioning Finish: 21
 24 Hrs Non-Stop A/C Operation: HST Operation Start: 22, HST Operation Finish: 8

Note = DHC : District Heating and Cooling System, HST : Heat Storage System, HPair : Air Source Heat Pump, TR : Turbo Refrigerator, AR : Gas Fueled Absorption Refrigerator, A/C : Air Condition System

Figure 4 The HVAC systems input data (default values).

load an output file (.opt extension) and browse around to visualize the overall available results. There are wide variety of results provided in *PostGraph* such as vertical profiles, evaporation rates, surface temperatures, exhaustive heat from HVAC system, radiation heat balance or total heat balance at the urban canopy, sensitive and latent heat fluxes at SBL and so forth. Note that the results shown in this section, as examples, reflect input conditions that were defined with the default values shown in Table 2.

Fig. 5 shows that the profiles of air temperature and humidity ratio near the ground surface fluctuate intensively almost up to the top of SBL. Additionally, the humidity ratio in daytime is higher than at nighttime due to evaporation of water from the soil, lawn, or vegetation on rooftop.

Fig.6 illustrates the evaporation from asphalt (pavement), soil, and lawn, respectively. The evaporation from soil and lawn shows attenuating waves that peak at noon and gradually subside day after day. Evaporation from the artificial surface seems to be less significant except on the day after precipitation (the 21st day).

Fig.7 shows the energy balance to urban atmospheric. It may be noted that the effect of rainfall is significant to raise the evaporation flux while it diminishes the convective heat flux in comparison with the 20th and 21st days.

Additional Features

There are a number of advanced features in the AUSSSM TOOL that have not yet been discussed herein. These features serve the user as built-in aids or as a supplementary support frame when using the program. For example, when defining the condition related to building size or geometric proportion within the input data process of the *Simulator*, the user can get help related to this subject from the "Calculator" dialog, as shown in Fig. 8. The obtained data, on building volume proportion, building height, street width, proportion of street width to building height, and plan area density of buildings, which are described in the "Output Elements" frame, are calculated corresponding to the Input Elements that the user has defined.

In addition, a new HVAC system operation can be defined by setting the relation between COP and the heat source temperature in the dialog as shown in Fig. 9. The plotting feature is available in this process for drawing the defined relation.

Within *PostGraph*, the Print and Export features are available in all dialogs of tables and graphs. The Export feature helps the user with data-handling in cases in which individual reporting is required by saving the indicated output data into a ".csv" file.

Viewer

Viewer was developed to support the user's investigation of the primary results (called characteristic values) derived from the numerical experiments (243) previously done. The main concept is that the numerical experiments are based on the DOE theory. Secondly, the entire results obtained from each experiment were saved in one database (DB). Hence, from the DB, the user can instantly catch the results of characteristic values related to the defined initial conditions. In order to illustrate how to work Viewer, we created three hypothetical case studies and the respective conditions for discussion, as shown in Table 3. It can be noted that Case A is assumed to be the relaxation case, whereas Case B is supposed to be an extremely severe case (i.e., it exhibits a severe UHI effect). Case C is defined as having a severity halfway between that of Case A and that of Case B.

In this example, the characteristic values mentioned above are as follows: air temperature at 1.2 m height and in whole canopy, sensitive-latent thermal requirement for building air-conditioning, sensitive-latent exhaustive heat from HVAC systems, sensitive-latent heat flux at the SBL, and energy balance fluxes (net radiation, convection, and evaporation) at the top of the building canopy. These results are available only for the daily maximum,

Table 2
Basic assumptions of the example
for its input data.

Street Configuration	building width =32 m, road width =16.88 m, building height=23.8 m, building volume proportion =700%, gross building volume proportion =300%
Street grid pattern	Staggered array
Reflectance of Solar Radiation	Building wall=0.4, asphalt (pavement) =0.1, soil=0.3, lawn=0.25
Wall materials	Indoor side insulation (25mm) + outdoor side concrete (180mm)
Glazing	Transparent glass thickness = 6mm, ratio of glazing 35%
Rooftop finishing	Soil (10cm) + 0% lawn
Ground covering ratio	Asphalt (pavement) : soil : lawn= 1 : 1 : 1
Anthropogenic heat from vehicles (at the peak)	9.7W per square meter of the area of the block
Indoor heat generation of building (at the peak)	Sensitive heat=56W per square meter of the area of the room, latent heat=13W per square meter of the area of the room
HVAC Systems	Air Source Heat Pump (H_{pair}) = 30%, Turbo Refrigerator (TR) = 31%, Gas Fueled Absorption Refrigerator (AR)=39%
Setting of air-conditioning	26°C, RH=50% constant (8:00 - 21:00), ventilation 2.7m ³ /hr

daily average, and/or daily minimum value on the 20th and 21st days, respectively.

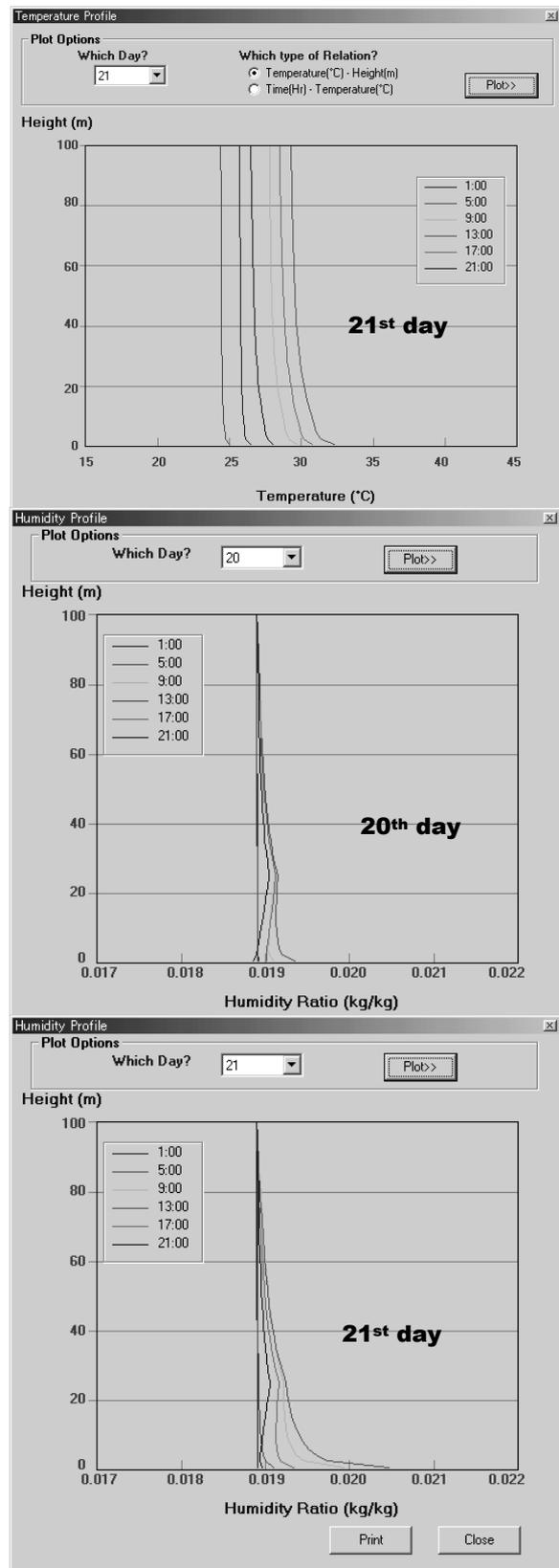


Figure 5 The vertical distributions of air temperature on the 21st day, and the humidity ratio on the 20th and 21st day.

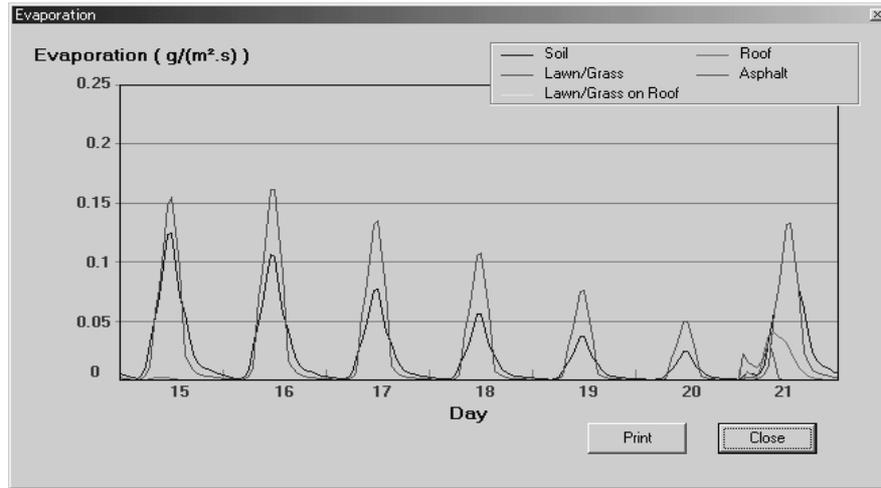


Figure 6 The evaporation from soil, asphalt, and lawn.

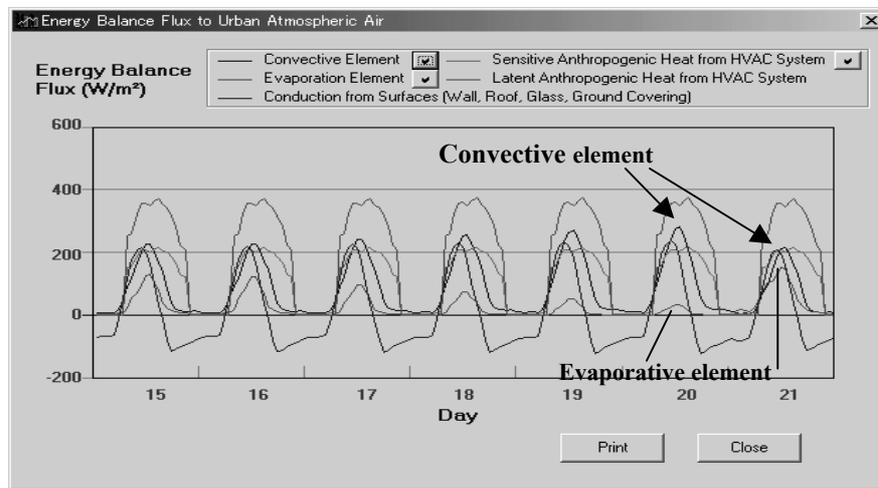


Figure 7 Energy balance to urban atmospheric air.

From the comparison graphs shown in Fig. 10, it was found that both the atmospheric temperature and exhaustive heat in Case B have attracted growing. These results agree with the supposed conditions, which, in this Case, involved a severe effect on the UHI.

Developing Environment

The AUSSSM TOOL was developed as an advanced Windows application by using the powerful features of Visual Basic (VB) programming to offer the user a graphical interface. On the other hand, the revised-AUSSSM executed a file called Solver, the core of performing the numerical simulation process, which was written in and compiled with Fortran. The Solver was utilized like a computing processor together with the AUSSSM TOOL, offering the user an interactive and easy-to-follow environment.

Although the program seemed clear and simple, a number of help features were included to allow the user to implement and understand it more easily. This comprehensive help function was documented

on RoboHELP Office, and is provided in the Simulator, PostGraph, and Viewer, respectively, to provide the user with a variety of information, including an introduction to the revised-AUSSSM and details of its methodology, how to get started using the program, many useful techniques to

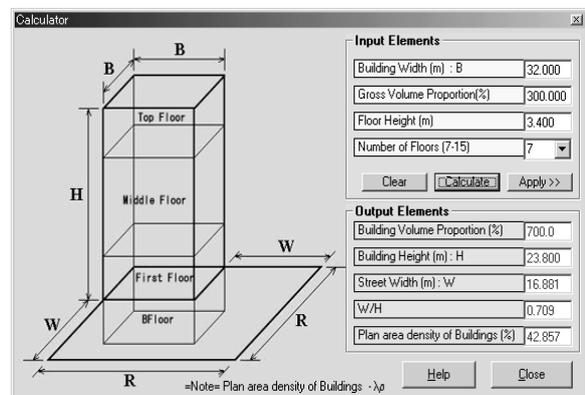


Figure 8 Convenient dialog to define the condition related to building size or geometric proportion.

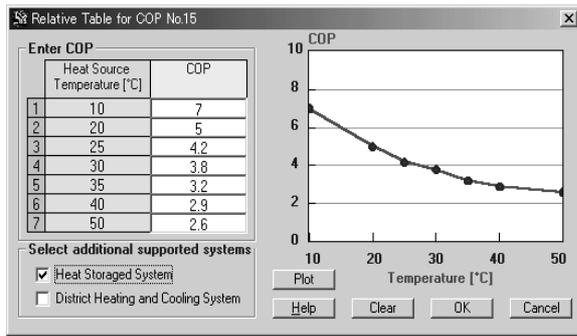


Figure 9 COP-Heat source temperature relation setting dialog.

facilitate effective using, and so on. Fig. 11 demonstrates a help dialog available in Viewer.

Finally, the program install package is prepared with InstallShield Express. This package includes many files devoted to the software itself and the entire source codes in both VB and Fortran.

CONCLUSIONS

The revised-AUSSSM, relevant methodologies, and development of the AUSSSM TOOL for coupling simulation with a building thermal system and urban climatology to estimate Urban Heat Island effects in quantitative terms are described in detail. We have outlined the three parts of the AUSSSM TOOL: the *Simulator*, the *PostGraph*, and the *Viewer*, which offer the user different respective features. *Simulator* provides a wide range of condition settings and full numerical simulation results corresponding to the

Table 3
The supposed conditions for Case A, B and C

	Case A	Case B	Case C
Building Volume proportion	1300%	700%	1000%
Gross building volume proportion	150%	350%	250%
Ground covering proportion	0:1	1:0	1:1
Proportion of Glazing area	85%	35%	60%
Reflectance of Solar Radiation for building wall	0.8	0.2	0.5
Indoor sensitive and latent heat generation	Default	x2 times	x1.5 times
Indoor set temperature	28°C	24°C	26°C
HVAC system	DHC	Stand-alone	Stand-alone +HST
Proportion of roof top vegetation area	100%	0%	50%
HVAC system operating time interval	8am-21pm	20pm-8am	12pm-1am
Reflectance of Solar radiation for roof top	0.8	0.3	0.5
Reflectance of Solar radiation for asphalt	0.8	0.1	0.5

defined initial conditions, which will no doubt make it useful for climatological researchers or experts in urban thermal study who require detailed results for particular situations. *Viewer* works independently to provide the user with results of characteristic values without waiting for the simulation to be completed; the set of results is derived from numerical experiment results compacted into the DB. This database provides results that are adequate for the

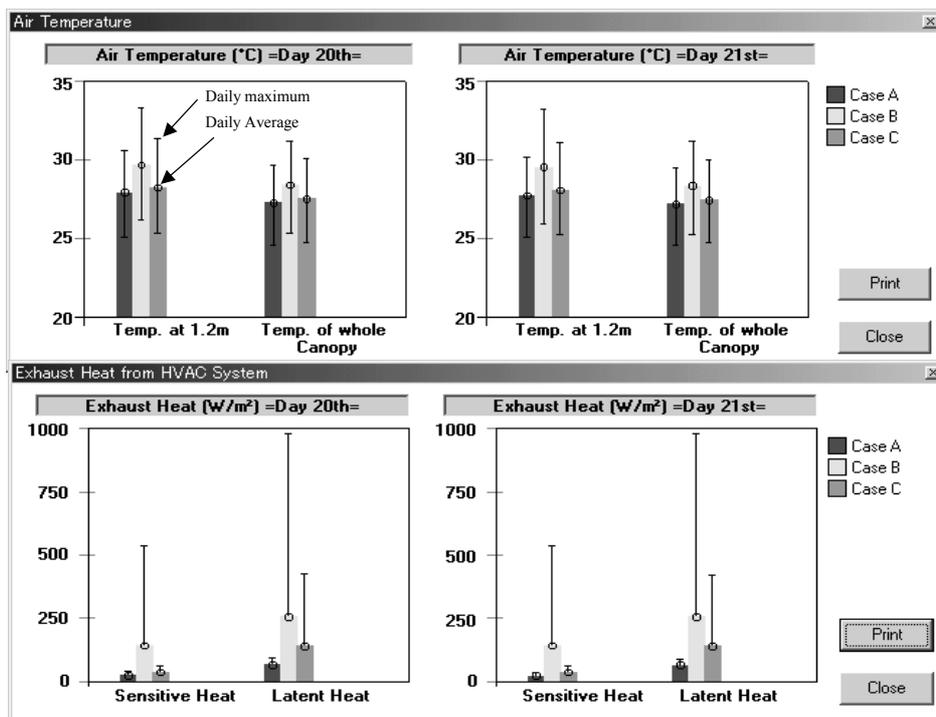


Figure 10 Comparison between Case A, Case B, and Case C provided by Viewer.

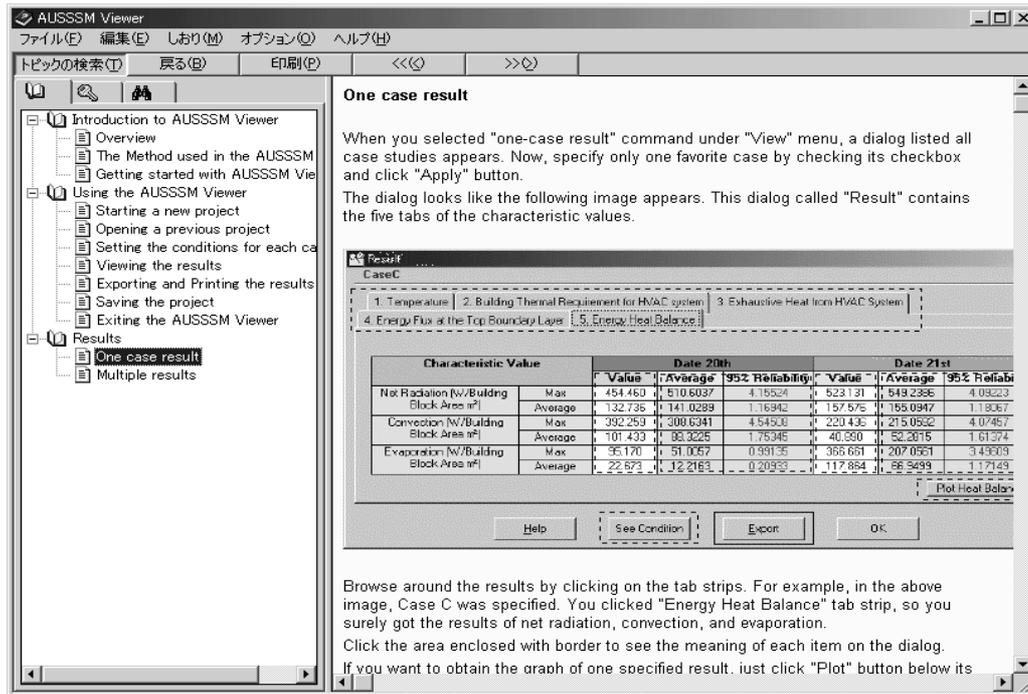


Figure 11 HELP screen provided in Viewer.

user who requires only characteristic values indicated for the day before and after precipitation (the 20th and 21st day), and in the case of result related to many conditions have to be compared each other. *Viewer* is probably most useful for the inexperienced user or users who have a general interest in studying UHI effect, because the input conditions are already fixed. That is, the user simply makes the required choices and proceeds to obtain results.

The AUSSSM TOOL is accessible on our web site (<http://ktlabo.cm.kyushu-u.ac.jp/>). It can be downloaded not only as an executable package but also with the source codes for the revised-AUSSSM written in Fortran and the interface portion in Visual Basic.

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