Interpretation of the Matlab Programs

1 Introduction

A typical 3-occupant residential apartment is taken as the studied object for building dynamic thermophysical process simulation and Matlab programs are developed based on the State-Space Method (SSM) to implement the simulation. For the plain layout of the flat and more information in relation to building envelope, parameter settings and calculating conditions, etc., please refer to the document entitled ‘Building apartment information and parameter settings’.

For the SSM, please find further information in the following references:

[1] Tsinghua University DeST Development Group, Simulation analysis methods of built environment systems: DeST, China Architecture & Building Press, 2006.

[2] D. Yan, J. Xia, W. Tang, F. Song, X. Zhang, Y. Jiang, DeST – an integrated building simulation toolkit. Part I: Fundamentals, Building Simulation 2 (2008) 95–110.

[3] X. Zhang, J. Xia, Z. Jiang, DeST – an integrated building simulation toolkit. Part II: Applications, Building Simulation 3 (2008) 193–209.

There are three types of objectives in the present building performance simulations. Namely, a) room free temperature calculation (no heating &cooling loads for all rooms);

b) building heating & cooling loads calculations of three functional rooms (bedrooms R1, R3 and sitting room R5) in the ideal condition (fixed room target temperature 18 °C for heating and 26 °C for cooling as the default settings);

c) building heating & cooling loads calculations of three functional rooms from the perspective of system control with fixed supply powers and room temperature control bands (18±1 °C for heating and 26±1 °C for cooling as the default settings)

Thus, three versions of Matlab programming codes are needed to implement the simulations. The fundamentals of the three types of objectives are similar to each other. The present interpretation document will mainly focus on the type b) - ideal building heating & cooling loads calculations with fixed room target temperatures.

In the program, there is a unique main program for running and a series of subroutines are embedded in the main program. In the following, the main program is underlined with interpretations throughout the code. The subroutines (invoked functions) are briefly explained. The exporting report file of the program is mentioned in the last.

2. Interpretation of the main program in Matlab

File name: Main\_program.m

As interpreted in the beginning of the source code, the main debugging programming code is used for calculating ideal heating &cooling loads of 3 functional rooms in a typical 5-room flat.

NUMBER ROOMS: 1- MAIN BEDCHAMBER; 2- TOILET (NEGLECT HEAT & COLD SUPPLY); 3- SECONDARY BEDCHAMBER; 4- STORAGE ROOM & KITCHEN (NEGLECT HEAT&COLD SUPPLY); 5 SITTING ROOM

NUMBER BUILDING ENVELOPE COMPONENTS (WALLS, CEILING & FLOOR): 1- EAST WALL; 2- WEST WALL; 3- SOUTH WALL; 4- NORTH WALL; 5- CEILING; 6 - FLOOR; 7- WINDOW

OPTIONS:

EXT - EXTERNAL; INT- INTERNAL

WALL THERMAL MASS: 1-CLAY BRICK WALL; 2-REINFORCED CONCRETE; 3- AERATED CONCRETE BLOCK

Lines 31-54: define global variables - matrix dimensions and model matrices A, B, C for five rooms, successfully.

Line 58: assign specific location ‘place’.

 LOCATION OPTION: 1-CHONGQING/2-SHANGHAI/3-CHANGSHA

Line 59: assign heating & cooling mode ‘HC\_mode’.

HEATING AND COOLING MODE: 1 - 24 h FULL TIME H&C; 2 - PART TIME HEAT AND COLD SUPPLY AS PER SPECIFIED OCCUPANT BEHAVIOUR PROFILE

Line 60: assign insulation order of the external walls ‘INS\_OPT’.

INSULATION OPTIONS: 1-EXTERNAL INSULATION; 2-INTERNAL INSULATION

Line 61: assign thermal mass scenario of the external walls ‘WALL\_MASS’.

1-CLAY BRICK WALL (HEAVY WEIGHT); 2-REINFORCED CONCRETE(HEAVY WEIGHT); 3- AERATED CONCRETE BLOCK

Lines 63-65: assign window-to-wall ratios in different directions (south, north, east).

Lines 66-116: assign area information for the 5-room flat.

Line 124: set Air Exchange Rate per hour of each room:

 The default setting is n\_air = 1 (ACH= 1 h-1)

Line 125: set window heat transmittance coefficient

 k\_window = 2.8 for DOUBLE LAYER GLAZING

Lines 137: set thermal insulation thickness of external walls (in the case of heavy-weight walls). The thickness should be assigned according to target U-value and the composition of external walls. Here, the setting of 38.7 mm EPS insulation is intended to obtain a U-value of 0.83 W/(m2 K).

Line 151: set iterative time interval dt. Usually, the time interval is chosen as 3600 s (1 hour), but a time interval of 900-1800s (15-30 min) is preferable for high-resolution solution.

Lines 153-154: set room target temperatures for heating and cooling, respectively.

Ta\_targ\_min=18; % ROOM TARGET TEMPERATURE FOR SPACE HEATING

Ta\_targ\_max=26; % ROOM TARGET TEMPERATURE FOR SPACE COOLING

Lines 158-200: set thermoproperties of each type of thermal mass composition for external walls, including thickness, density, conductivity and specific capacity.

Lines 202-227: set thermoproperties for internal walls, floor, ceiling and windows.

Lines 230-232: set emittance and absorptance of wall surfaces for calculating radiative heat transfer processes.

Lines 243-248: set long-wave radiative heat transfer coefficients of room inner wall surfaces by simplification.

Lines 250-259: assign external comprehensive heat transfer coefficient of external walls in different cities according to the TMY weather data.

Lines 261-264: set internal convective heat transfer coefficients of walls, floors, ceilings, windows.

Lines 266-269: diffusivity settings for building envelope components.

Lines 271-274: calculate the spatial step of each component by assuming Fourier number equals 1.

Lines 276-279: determine numbers of elements for each components in terms of the spatial step estimated. The numbers are forced to be integers.

Lines 281-284: re-calculate the spatial step of each components as the numbers of dividing elements are forced to integers.

Lines 286-290: set the thermal capacitance matrices C for building envelop components (walls, floors, ceilings, windows) by invoking functions. For different types of building components, corresponding subroutines should be chosen.

setC\_wall: External walls;

setC\_INTwall: Internal walls, ceilings, floors;

setC\_window: Windows

Lines 293-336: Construct the whole thermal capacitance matrices C for 5 rooms separately, taking into account all the temperature calculating nodes (temperature nodes of building component elements and indoor air node)

 C\_main, C\_main2, C\_main3, C\_main4, C\_main5 represent C matrices for Rooms 1-5 successively.

Lines 338-438: Construct heat flux flow relationship matrix A\_main for room 1. Specifically, diagonal elements of matrix A\_wall\_1\_R1 (east wall), A\_wall\_2\_R1(west wall), A\_wall\_3\_R1(south wall), A\_wall\_4\_R1(north wall), A\_ceil\_R1 (ceiling), A\_floor\_R1 (floor), A\_window\_R1 (window) are set in lines 339-357;

Radiative heat transfer relations of walls, ceiling, floor, window are set in lines 358-403;

Convective heat transfer relations between indoor air and i-th building envelope components are set in lines 406-411;

The whole heat flux flow relationship matrix A\_main for room 1 is constructed in lines 432-438. The indoor air temperature node of room 1 is excluded from matrix A\_main because it should be judged in terms of thermal comfort in building heating/cooling load calculation.

Lines 441-841: Similar to lines 338-438 where the heat flux flow relationship matrix A\_main is constructed for room 1, these statements are used to construct heat flux flow relationship matrices A\_main2, A\_main3, A\_main4, A\_main5 for room 2,3,4,5, successively.

The difference is that the cases of rooms 2 and 4 are different. For rooms 2&4, there is no heat or cool supply and room temperature notes should be directly solved. Thus, the indoor air temperature nodes are included in the construction of A\_main2 and A\_main4.

Lines 845-905: input TMY weather data for the option ‘Chongqing’ (place=1);

The hourly meteorological conditions are interpolated to arbitrary time interval. Moreover, it should be emphasized that 6 more days is added in the beginning for removing initial thermal inertia of the calculation. The same treatment is used for the other two cities.

Lines 806-964: input TMY weather data for the option ‘Shanghai’ (place=2);

Lines 966-1025: input TMY weather data for the option ‘Changsha’ (place=3);

Lines 1027-1028: calculate the date order in a year for further calculating solar incidence angles on windows and solar irradiances penetrating glazing windows.

Lines 1030-1103: initialisation for calculations

Specifically, lines 1031-1035 define the dimensions of model matrices C and A for five rooms; lines 1037-1042 assign the initial temperature values for temperature variables; lines 1044-1055 assign initial values of building heating/cooling loads for 3 functional rooms; lines 1057-1063 define humidity ratio and occupants’ heat and humidity emission rates; lines 1080-1088 initialise the occupied state (indicator 1 stands for ‘occupied’) of occupants and internal heat source states of equipment and lighting; lines 1090-1103 initialise the internal heat gains through convection and radiation.

Lines 1105-1533: iterative cycle process from the 2nd time step to the end time step T= nhour\*3600/dt.

For each time step, lines 1109-1126 assign the occupied state of occupants in bedrooms and sitting room as well as the internal heat source states of equipment and lighting according to part time occupancy schedule.

Occupancy schedule

|  |  |  |  |
| --- | --- | --- | --- |
| Occupants | Bedrooms R1 & R3 (2 persons for R1 and 1 person for R3) | Weekdays &weekends | 20:00-6:00 |
| Sitting room (3 persons) | Weekdays | 6:00-8:00; 18:00-20:00 |
|  | Weekends | 6:00-20:00 |
| Lighting &Equipment | Bedrooms R1 & R3 | Weekdays &weekends | 6:00-8:00; 20:00-22:00 |
| Sitting room  | Weekdays | 6:00-8:00; 18:00-20:00 |
|  | Weekends | 6:00-20:00 |

Lines 1127-1132: calculate the convective and radiative parts of internal heat gains. The fractions of convection and radiation are referred to the default values in EnergyPlus.

Lines 1135-1141: calculate radiative heat gain of each wall inner surface for room 1.

Line 1142: calculate convective heat gain of indoor air of room 1;

Line 1143: it’s supposed there is not extra HVAC heat or cool supply for room 1.

Lines 1145-1146: No internal heat gain and HVAC for room 2.

Lines 1148-1156: calculate internal heat gains for room 3, similar to lines 1127-1143.

Lines 1158-1159: No internal heat gain and HVAC for room 4.

Lines 1161-1169: calculate internal heat gains for room 5, similar to lines 1127-1143.

Lines 1173-1177: calculate the date order in a year by removing 6 days conditions in the beginning of the weather data which is aimed to remove initial thermal inertia.

Lines 1178-1183: calculate the incident angle in due south and solar internal heat gains through windows for rooms 1 and 5.

Lines 1185-1188: calculate the incident angle in due east and solar internal heat gains through windows for rooms 2 and 3.

Lines 1190-1192: calculate incident angle in due north and solar internal heat gain through window for room 4.

Lines 1194-1209: calculate internal solar heat gains of each building component for rooms 1-5 by simplification.

Lines 1212: humidity ratio calculation throughout the year.

Lines 1216-1241: specify elements of the vector ‘b’ in the matrix form of CdT/dt=AT+b for room 1.

Lines 1241: construct the vector ‘b’ for room 1 excluding the indoor air temperature node by considering the airnode temperature at the previous time step.

Lines 1243: DIRECTLY SOLVE THE MATRIX EQUATIONS CdT/dt=AT+b BY USINING THE MATLAB SOLVER ODE15 (OR ODE45).

Lines 1244-1252: get access to the temperature nodes of inner walls and indoor air. tR1\_wall1\_in – East wall inner surface temperature of room 1;

tR1\_wall2\_in – West wall inner surface temperature of room 1;

tR1\_wall3\_in – South wall inner surface temperature of room 1;

tR1\_wall4\_in – North wall inner surface temperature of room 1;

tR1\_ceil\_in – Ceiling inner surface temperature of room 1;

tR1\_floor\_in – Floor inner surface temperature of room 1;

tR1\_window\_in –Window inner surface temperature of room 1;

tR1\_window\_out –Window outer surface temperature of room 1;

One can get other node temperatures by specifying the variable and matrix element number.

Lines 1255-1261: calculate the indoor air temperature at the present time interval according to thermal balance of the air node. It is necessary to separate the solution of indoor air temperature node from the building envelope components, because it needs to judge the room comfort temperature before calculating building heating and cooling loads. And if the room temperature at a time step is beyond the comfort temperature band, it needs to force the airnode temperature to be the comfort temperature after calculating heating or cooling loads.

Line 1253: calculate humidity ratio at every time step.

Lines 1267-1277: define heating and cooling modes in part time and full time patterns, respectively.

HC\_mode=1: FULL TIME SPACE HEATING AND COOLING - 24 H AVAILABLE IN THE PERIODS STIPULATED IN THE BUILDING STANDARD

HC\_mode=2: PART TIME SPACE HEATING AND COOLING AS PER SPECIFIED OCCUPANTS' BEHAVIOUR PROFILE

Lines 1279-1291: Judging heating conditions for room 1 and calculating latent and sensible heating loads.

Lines 1292-1302: Judging cooling conditions for room 1 and calculating latent and sensible cooling loads.

Lines 1304-1336: calculate temperature nodes of room 2 (no heat or cool supply for room 2);

Lines 1338-1407: similar to the case of room 1, calculate temperature nodes and heating &cooling loads of room 3.

Lines 1409-1444: calculate temperature nodes of room 4 (no heat or cool supply for room 4);

Lines 1446-1521: similar to the case of rooms 1 and 3, calculate temperature nodes and heating &cooling loads of room 5.

Line 1525: calculate building shape factor of the flat.

Line 1526: calculate the U-value of external walls.

Lines 1528-1536: count the total sensible and latent heating loads of the flat.

Lines 1538-1550: summarise the statistical values of heating loads in each month.

Lines 1552-1559: count the total sensible and latent cooling loads of the flat

Lines 1560-1572: summarise the statistical values of cooling loads in each month.

Lines 1574-1677: count different heat sources.

Lines 1680-1681: define the output matrix ‘outcome’;

Line 1682: summarise the heating and cooling loads.

Lines 1684-1692: export the calculating sheets.