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Effect of ground boundary and initial conditions on the thermal performance of buildings

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ABSTRACT

The adiabatic boundary condition and the surface heat flux continuum boundary condition for the ground layer beneath a building are examined by comparing the numerical predictions with the corresponding measurements. The effect of the ground depth on the validity of the deep ground boundary conditions is also addressed. Comparison of room air temperature predictions under free floating conditions for different boundary conditions is made for cavity brick and brick veneer housing test modules located on the campus of the University of Newcastle. The sensitivity of the different ground boundary conditions to the heating and cooling loads under air conditioned scenarios is also studied. Finally the effect of the initial condition on the solution is discussed. A new treatment of weather data is proposed to mitigate the effect of the initial condition.

1. Introdction

Crawley et al. [1] comprehensively summarized the characteristics of various building energy performance simulation programs and indicated that there existed several hundred building energy performance simulation programs with various functions and focuses. In these simulation programs, several sub-models are used. These include a building wall thermal conduction model, a weather model, a window model, an infiltration/ventilation model, and an HVAC model.

The modelling of the thermal performance of a building is difficult due to the varying building geometry, complex environmental factors such as wind and solar radiation effects, the lack of the accurate measurements of the thermal properties of the construction materials, and the inaccuracy of the correlation of the surface heat transfer coefficients with the environmental parameters. The accuracy of software predictions of zonal air temperatures under free floating conditions and zonal energy consumption for air conditioned buildings is therefore influenced by these effects.

Under steady or harmonically varying ground surface temperature, there exists an analytical solution for the ground surface heat flux. Delsante et al. [2] presented the analytical solution for heat flow into the ground under a building using the complex Fourier transformation. Delsante [3] also verified this solution by comparison with other measurements. These results can be used for a building simulation using the complex Fourier transformation. However, it is unsuitable for use in the definition of the ground surface heat flux which can be coupled with other wall thermal conductivity discretised equations.

To consider the horizontal heat transfer between the ground beneath the room and the outer ground, several research groups carried out two-dimensional or three-dimensional numerical simulations for the temperature distribution in and under a slab-on-ground floor. Adjali et al. [4] used the finite volume method to discretise the energy balance equation and compared two-dimensional and three-dimensional numerical simulation results with measurements, concluding that for a large ground floor 3D results did not differ significantly from the 2D results. Rees et al. [5] used the finite element method to discretise the ground heat conduction equation, studied the effect of the thermal properties of soils on the earth-contact heat transfer, and compared the numerical results with measurements, showing that the overall comparison is reasonable and the significant disparity occurs during the coldest part of the year. Adjali et al. [4] and Zhong and Braun [6] used adiabatic boundary conditions and Rees et al. [5] used constant temperature at the bottom of the ground. Zhong and Braun [6] assumed two major heat transfer paths: (1) the quasi-steady heat transfer between the perimeter of the slab and the ambient, and (2) thermal conductivity along the depth of the ground.

No publications can be found in the open literature on the effects of the different ground thermal boundary conditions on the final room air temperature predictions. In this paper, we propose

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a new boundary condition for the thermal boundary condition at the bottom of the ground and compare the performance of three different boundary conditions. At the same time, the effect of the initial conditions at the computational nodes on the predictions of the zone air temperature is also addressed.

Nomenclature

C_p	thermal capacity (J/kg K)
h	convective heat transfer coefficient (W/m^2 K)
k	thermal conductivity (W/m K)
L_t	thickness of a material layer (m)
q''	heat flux (W/m^2)
t	time (s)
T	temperature (K or °C)
x	coordinate system with the origin locating at the middle of the layer (m)
Greek symbols	
Δt	time step (s)
Δx	spatial step (m)
ε	the thermal radiation absorptivity (−)
ρ	density (kg/m^3)
σ	Stefan–Boltzman constant
Subscripts	
1	inner nodes within a construction layer
2	inner nodes within a construction layer
s0	outer surface of a construction layer
s1	inner surface of a construction layer

2. Experimental measurements

Four thermal housing test modules as shown in Fig. 1 using different wall systems were built on the campus of the University of Newcastle for the purpose of monitoring the thermal response of various construction walls to various climate effects (Sugo et al. [7]). Temperatures of all surfaces, surface heat fluxes, wall air-gap air temperatures, indoor air temperatures, and ground surface temperatures/heat fluxes were recorded. From January 2003 the cavity brick and brick veneer modules without windows were monitored. From 2004 to 2005 the study was expanded with the addition and monitoring of a further two modules with insulated walls and a major window opening in the northern wall. The solar radiation data was collected using Davies solar radiation sensors installed on the four walls and horizontally on the roof of each module. The wind speed and direction were monitored by a Davies anemometer at a height of 3 m above the roof, and the humidity by a Honeywell HIH-3610 humidity sensor. At different periods of the study, the interior of each module was allowed to either "free float" or was controlled by air conditioning within a temperature range of 18–24 °C, with the heating/cooling energy consumption measured.

The heat flux and temperature sensors in the investigation were used on the surfaces considered crucial. For each module, temperature and heat flux profiles through the walls, slab and ceiling were recorded in conjunction with the internal air temperature and relative humidity. In total, approximately 104 data channels were scanned and logged every 10 min for each of the modules all year round. The data was recorded using a Datataker DT600 data logger located in each building. All temperatures were read using Type T thermocouples connected to three, 30 channel expansion modules. To minimise any cold junction compensation errors, all the thermocouple inputs were maintained at uniform temperature through the use of a thick wall aluminium box. The temperature recording system (thermocouple wire characteristics, cold junction compensation, etc.) has been cross-referenced using a Prema Precision Thermometer and the corresponding temperature offsets are adjusted automatically in the logging process.

Heat flux profiles across the wall were measured using 100 × 100 mm ultra-thin sensors with typical sensitivities in the order of 25 μV/W/m^2. The heat flux sensors were placed on the wall in such a manner that the proportion of masonry unit/mortar ratio being measured was representative of that in the masonry wall. An attempt was made to match the absorbance and emissivity of the heat flux sensors to that of the masonry units by painting the exterior sensors a similar colour to that of the bricks. The interior

Fig. 1. Four thermal housing test modules using different wall systems on the Campus of The University of Newcastle, Australia.