Validation and modification of modeling thermally activated building systems (TABS) using EnergyPlus

Tao Yu1,2 (✉), Per Heiselberg2, Bo Lei1, Michal Pomianowski2
1. School of Mechanical Engineering, Southwest Jiaotong University, Chengdu 610031, China
2. Department of Civil Engineering, Aalborg University, Aalborg 9000, Denmark

Abstract
EnergyPlus (EP) integrates a low temperature radiant system module to evaluate thermal performance of radiant systems such as thermally activated building systems (TABS), but the assumptions in this module neglect thermal resistance of the pipe and thermal resistance between the pipe exterior surface and the pipe level, which may result in the inaccurate evaluation of TABS in terms of surface temperature and surface heat flow. In this paper, in order to validate this module used in EP, steady and transient heat transfer processes of TABS in buildings were studied by analytical solution, two-dimensional numerical simulation and EP simulation. The comparison shows that the assumptions indeed result in a largely overestimated cooling and heating capacity of TABS. In order to improve this radiant module, a simple solution of introducing a no mass material layer with the neglected thermal resistances to both sides of the pipe level was proposed. With this method, the results of mean surface temperature and mean heat flow show good agreement with that from analytical solution as well as numerical simulation. Furthermore, the results of the simulation coupling the modified module with room systems show very small deviation from the results found in the literature. In addition, the application of the modified module in a hollow core concrete deck structure with TABS was investigated.

Keywords
thermally activated building systems, EnergyPlus, low temperature radiant system module, thermal resistance, modified simulation

Article History
Received: 18 November 2013
Revised: 19 February 2014
Accepted: 17 March 2014
© Tsinghua University Press and Springer-Verlag Berlin Heidelberg 2014

1 Introduction
As one kind of typical high temperature cooling and low temperature heating systems, thermally activated building systems (TABS) have shown a trend of booming growth in Europe since the 1990s when they first appeared in Switzerland. In such systems water is used to transport energy which is a more efficient way compared to traditional air-based systems due to the higher heat capacity of water (Olesen 2008). This kind of system exchanges heat by radiation and convection. In general, radiant heat exchange accounts for more than 50% which is beneficial to improve the occupant thermal comfort (Olesen 2008). Furthermore, as a result of integrating thermal systems with building structures, such systems can utilize building thermal mass effectively and have the potential of saving energy consumption and creating a more comfortable environment in buildings (Feustel and Stetiu 1995; Stetiu 1999). For the application of TABS in buildings, researchers and designers usually pay particular attention to thermal parameters like cooling/heating capacity of the system and surface temperature. However, thermal performance of TABS is largely dependent on building constructions, heat sources, control strategies, and so on, as a consequence a reliable evaluation tool is indispensable.

During the fast development of TABS, there has been a substantial amount of research on the methods of solving the heat transfer process for the slab and evaluating the thermal environment for buildings with TABS, which can be classified as the following:

1) Using analytical solutions to solve the heat transfer process of concrete slab. The early analytical solution of the heat transfer of TABS was developed by Koschenz and Lehmann (2000). Applying the method of separation of variables to the heat conduction partial differential equation, de Monte (2000) analyzed the transient response...
of one-dimensional multilayered composite conducting slabs to sudden variations of the temperature of the surrounding fluid. Sun and Wichman (2004) presented a theoretical solution to a problem of transient heat conduction in a one-dimensional three-layer composite slab. Using analytical expressions handling both conduction and convection phenomena, Simões and Tadeu (2006) studied the transient heat transfer across multilayer floors subjected to multiple heat sources. Laouadi (2004) addressed a two-dimensional semi-analytical model for radiant cooling and heating systems for integration in energy simulation software. Flores Larsen et al. (2010) introduced separation of variables, superposition method and orthogonal expansion techniques to develop the exact 2D transient solution of a slab with an embedded array of parallel circular pipes for heating and cooling, making a faster estimation of thermal variables. Obviously, analytical solutions are insufficient to evaluate the transient operation of TABS coupling with building systems, and are normally combined with building energy simulation tools.

(2) Using numerical simulations to solve the heat transfer process of concrete slab. Different methods are used to discretize the heat conduction equation and boundary conditions. Jin et al. (2010) built a numerical model for the radiant floor cooling system using finite volume method (FVM) with composite grids, and the calculated floor surface temperature and the heat flux were in good agreement with the measured results. Meanwhile, it was concluded that the pipe had a certain effect on the system performance when the thermal conductivity of the pipe was low while the effect of water velocity on the system performance was not great. Holopainen et al. (2007) used an uneven nodal network in floor heating simulation with finite difference method (FDM), it was found that the total number of nodes could be reduced by placing the densest gridding in sections where the curvature of the temperature gradient was steepest. Koschenz and Dorer (1999) developed a model to study the transient two-dimensional heat flow for TABS, and finite element method (FEM) was adopted to validate the simulation results. FVM, FDM and FEM are reliable to evaluate surface temperature and heat flow as long as the boundary conditions are given. Nevertheless, due to the complex interaction between TABS and building systems, numerical methods are time-consuming and it is difficult to use them to predict the dynamic thermal performance of TABS in practical use for long-term evaluation.

(3) Using building energy simulation tools to evaluate the thermal environment in buildings with TABS. To simulate the dynamic heat transfer process combining TABS with building systems, some simplified methods are integrated into the thermal model of energy simulation tools. Through the literature review, it is found that TRNSYS and EnergyPlus (EP) are two currently-prevalent simulation tools for modeling hydronic radiant systems, integrating different hydronic radiant modules respectively. Fort (2001) developed a special module to model the multidimensional heat transfer processes for a floor heating system and coupled it into TRNSYS. Strand and Pedersen (2002) implemented a low temperature radiant heating and cooling system model into the room heat balance in EP by applying the additional term for heat sources/sinks in the standard conduction transfer function. For the development and application of these two tools in buildings with TABS, Henze et al. (2008) investigated the relative energy and comfort merits of ventilation assisted TABS in continental climates compared to conventional all-air systems using a highly modified version of TRNSYS. Rijksen et al. (2010) adopted TRNSYS to calculate the reduced cooling load for TABS, and it was found that reductions up to 50% of the cooling capacity for a chiller