LONG WAVE RADIATION EXCHANGE FOR URBAN SCALE MODELING WITHIN A CO-SIMULATION ENVIRONMENT

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ABSTRACT

This paper describes the implementation of long wave radiation (LWR) exchange as part of a co-simulation process of an urban scale simulation program, CitySim, and a building scale program, EnergyPlus. This coupling process was achieved through the use of functional mockup units (FMU) to exchange various weather, load, and environmental information between the two simulation engines. LWR is an important factor to exchange between the programs as CitySim has more advanced capabilities for radiation exchange calculations from a set of urban buildings and EnergyPlus has a more advanced building heating and cooling load calculation engine. The LWR exchange between surfaces is computed in CitySim by a linearization of the longwave energy balance at each surface around an average between the surface and its environmental temperatures. The environmental temperature for each surface is determined using the simplified radiation algorithm neglecting inter-reflections and is aggregated into a single, global environmental radiant temperature (T_{env}). The LWR exchange process is implemented in EnergyPlus by CitySim sharing the variables T_{env} and h_{env} that are then used to calculate radiation gain or loss through the envelope as well as influence on the conductances of the surfaces. This approach overrides the conventional EnergyPlus ground, sky and air radiation calculations. Solo and coupled simulations are performed on a set of four scenarios and result in up to a 36% discrepancy in heating and 11% in cooling load calculations amongst solo and coupled simulations.

Keywords: Urban-scale simulation, Co-simulation, Long Wave Radiation Exchange

INTRODUCTION

Today about 50% of the worlds population lives in urban areas and is expected to grow to 66% by 2050 [1]. Collectivities, urban planners and stakeholders will therefore have to face major energetic issues during the next decades. Urban energy simulation tools are becoming more common in order to simulate these environments for planning purposes. However, when simulating only one building within an urban district (for a retrofit action for example), actual detailed building simulation engines have the drawback of not taking into account the adjacent buildings in their calculations (obstructions and energy exchange). One way to address this issue is to establish a co-simulation environment between urban and building energy simulation engines to benefit from both advantages - the urban environment and a detailed output for one considered building.

One effort in coupling and co-simulation pairs the widely used building simulation engine, EnergyPlus, with the urban-scale simulation engine, CitySim [2]. This approach establishes a link between the two programs using a functional mockup interface (FMI) and a work-flow automation process. The co-simulation process enables the exchange of outdoor conditions between CitySim and EnergyPlus. This feature enhances EnergyPlus simulations due to CitySim's ability to calculate urban scale conditions in a more detailed means than the conventional typical weather file method. This exchange sends the outdoor air drybulb and wetbulb temperatures, relative humidity, diffuse and direct solar radiation, and wind speed and direction to EnergyPlus at each simulation time-step in exchange for surface outside face temperatures and heating and cooling loads. The last missing step in this effort is to couple environmental long wave radition (LWR) between the engines, a variable that has been shown to have a non-trivial impact on heating and cooling loads [3].

This paper outlines the addition of LWR exchange to the list of variables coupled between the two simulation engines. Coupling this variable enhances the building-scale simulation within EnergyPlus by allowing for radiant heat gain or loss to adjacent surfaces. As is, EnergyPlus does not take these characteristics of adjacent buildings and surfaces into consideration. LWR exchange has been implemented in EnergyPlus previously by implementing new input variables into the engine that specify the radiant heat transfer coefficients of nearby obstruction surfaces [3]. This approach used flat-file schedules and hard-coded variables containing the necessary radiation input data at each time step of the simulation in order to emulate radiation exchange with these surfaces. The novelty in our implementation is the coupling of EnergyPlus with the CitySim program that will provide a comprehensive LWR calculation automatically and in a reusable manner.

METHODOLOGY

Long Wave Radiation Exchange Calculation

In EnergyPlus, LWR exchange for a surface is calculated through the summation of radiation gain from the ground, sky, and air as seen in Equation 1 and Figure 1a [4]. The radiant heat transfer coefficient for each of these environmental variables is calculated according to Equation 2 with σ as the Stefan-Boltzmann constant and ϵ as the emissivity. A major assumption of this approach is that the modeled building's surfaces and those of adjacent buildings are at a uniform temperature and the LWR radiation exchange is negligible; a situation that is an oversimplification in an urban scale domain [3].

$$Q_{LWR,EnergyPlus} = h_{r,grd}(T_{surf} - T_{grd}) + h_{r,sky}(T_{surf} - T_{sky}) + h_{r,air}(T_{surf} - T_{air}) \quad (1)$$

$$h_{r,variable} = \frac{\epsilon\sigma(T_{surf}^4 - T_{variable}^4)}{T_{surf}^4 - T_{variable}^4} \quad (2)$$

In comparison, CitySim calculates LWR exchange by calculating an aggregated equivalent temperature, T_{env}, and radiative heat transfer coefficient, $h_{r,env}$, from surrounding urban surfaces in addition to ground, sky, and air [5]. The calculation for T_{env} is expressed in Equation 3 with the F values being view factors of the surrounding environment including adjacent surfaces $i = 1..n$. $h_{r,env}$ is based on a first order Talyor development of Equation 2 around $(T_{surf} + T_{variable})/2$. $Q_{LWR,CitySim}$ is calculated using Equation 4.

$$\sigma T_{env}^4 = \sigma F_{sky} T_{sky}^4 + \sigma F_{grd} T_{grd}^4 + \sum_{i=1}^{n} \epsilon_i \sigma F_i T_i^4 \quad (3)$$

$$Q_{LWR,CitySim} = h_{r,env}(T_{surf} - T_{env}) \quad (4)$$

In the proposed coupled simulation, EnergyPlus uses the CitySim supplied equivalent $h_{r,env}$ and T_{env} to calculate weighted $h_{r,sky}$, $h_{r,grd}$, and $h_{r,air}$ values using the view factors and the sky-to-air split ratio. Figure 1 illustrates the schematic differences between the solo and coupled simulations on a theoretical example of a target building with two adjacent buildings with surfaces available for radiation exchange.

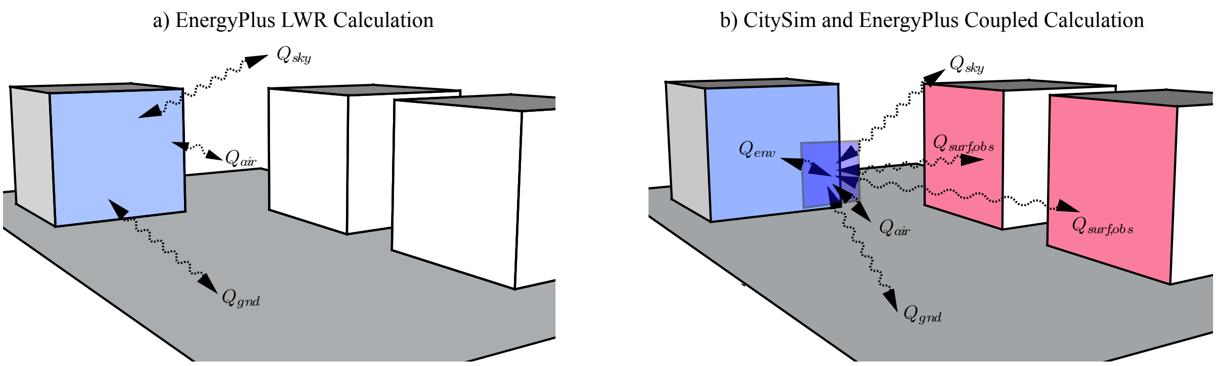

Figure 1: Comparison of the LWR components between a) Solo EnergyPlus and b) Coupled CitySim/EnergyPlus configuration)

Simulation Coupling and Co-Simulation

Simulation engine coupling is accomplished through a work-flow automation process that extracts geometry from a building information model, converts the geometry to EnergyPlus and CitySim simulation models and simulates two solo simulations and two coupled simulations. Figure 2 illustrates the adapted single-zone, theoretical coupling scenario and work flow configuration from previous research that is adapted for the experiments in this methodology [2].

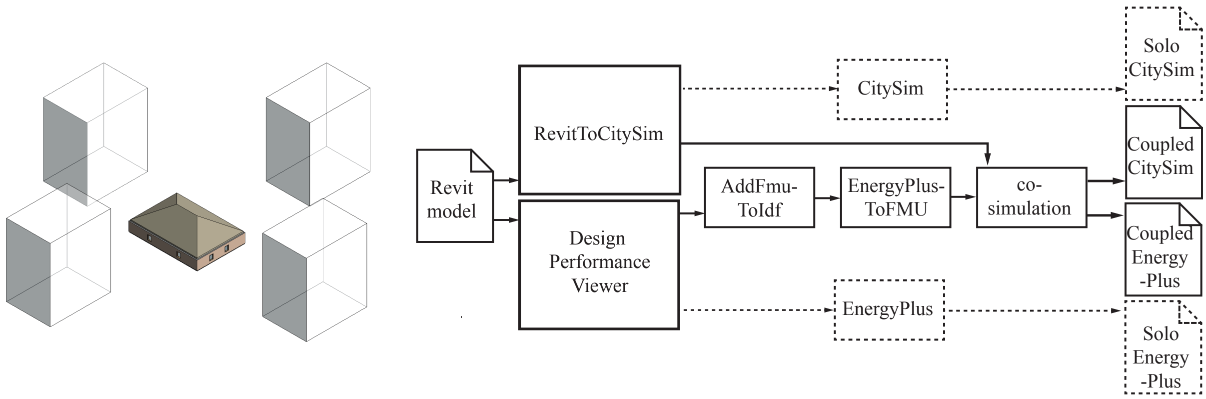

Figure 2: (left) Theoretical, single-zone test model surrounded by four buildings, and (right) overview diagram of the coupling process (adapted from [2])

Experimental Scenarios

Four scenarios, seen in Table 1, are designed in order to illustrate the LWR exchange impact. These experimental scenarios simulate EnergyPlus in four combinations of solo versus coupled and non-surrounded versus surrounded. Scenarios 1 and 2 include the solo and coupled simulations in the absence of surrounding buildings, while 3 and 4 are the same with the surrounding buildings included. The scenarios all have constant base internal loads and use weather data for Zürich, Switzerland. Infiltration and ventilation loads are not included in any of the scenarios.

Scenario	Label	Description
1_S_NS	Solo No Surrounding	EnergyPlus without neighboring buildings
2_C_NS	Coupled No Surrounding	Co-simulation without neighboring buildings
1_S_WS	Solo With Surrounding	EnergyPlus with all neighboring buildings
4_C_WS	Coupled With Surrounding	Co-Simulation with all neighboring buildings

Table 1: Experimental scenarios for demonstrating co-simulation and LWR exchange

RESULTS AND DISCUSSION

After executing the automated work flow process for the four experimental scenarios, an analysis is presented of the LWR calculation input variables and heating and cooling load impact. Figure 3 illustrates a comparison of the average outside surface temperatures of the target buildings to the sky, ground, and air temperature and the T_{env} variables from the coupled scenarios. The target building surface temperatures are, in general, higher than the T_{sky}, T_{gnd}, T_{air} and T_{env} in the outlined scenarios. This situation results in LWR loss to the environmental surroundings, a phenomenon that could be the opposite in many other practical scenarios when the adjacent building surfaces have high enough surface temperatures or emissivity to produce a T_{env} value that is above the target building's surface temperatures.

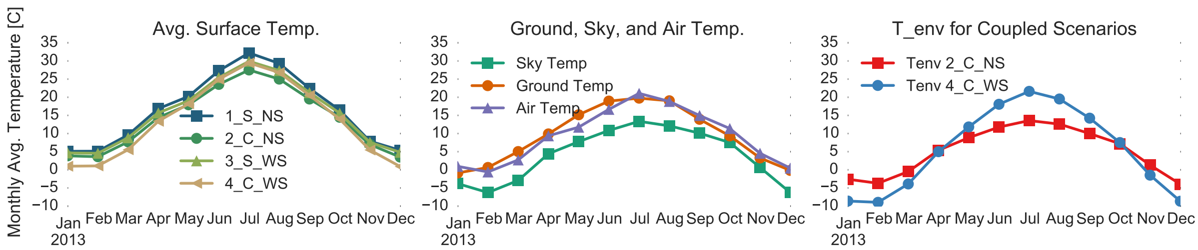

Figure 3: Average annual sky, ground and air temperatures as compared to average outside surface temperatures of targeted building within EnergyPlus

Figure 4 shows a comparison of the radiative heat transfer coefficients. The h_{sky}, h_{gnd}, and h_{air} values for the coupled simulations are calculated within EnergyPlus from the h_{env} value that is passed from CitySim. The coupled simulations result in higher h values due to the surrounding surfaces, resulting in more radiative heat transfer.

Figure 5 illustrates the resultant net thermal radiation summation of all surfaces in the target buildings represented as an average across January, for the heating season, and July, for the cooling season. The higher h values calculated from the CitySim coupling combined with cooler surrounding environmental temperatures results in an increase in LWR exchange in scenarios 2 and 4.

Figure 6 illustrates the impact that coupling has with respect to heating energy consumption. The heating consumption for the coupled simulations is higher by 15 and 36% as

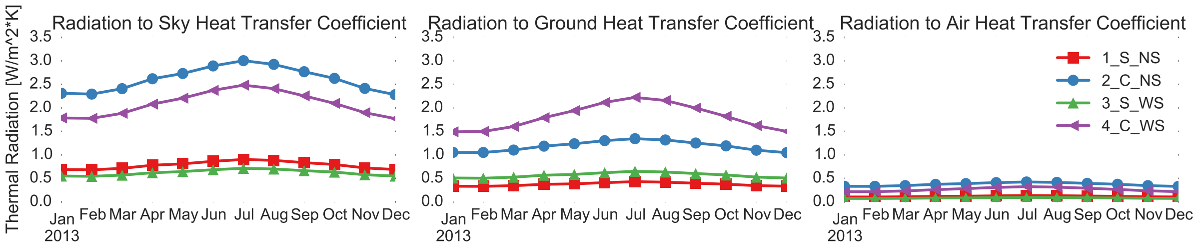

Figure 4: Average annual sky, ground and air radiative heat transfer coefficients within EnergyPlus

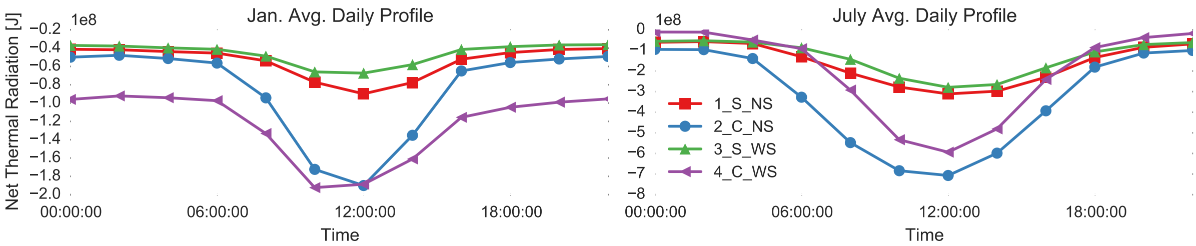

Figure 5: Net thermal radiation summation for all surfaces in target building for January and July

compared to the solo baseline. The emissivities of the surrounding surfaces are 0.9 by default, thus creating cooler radiant temperatures and elevated h values and resulting in net LWR loss to the surroundings, especially at night. These percentages should be interpreted carefully as the scenario developed is envelope dominated and doesn't include ventilation and infiltration loads.

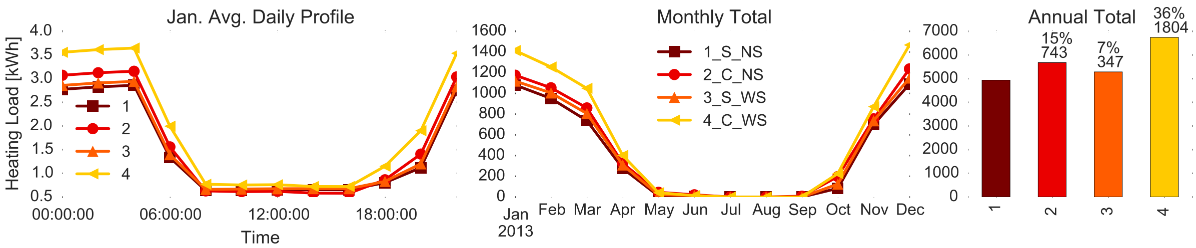

Figure 6: Daily average and monthly and annual total heating load calculation results

Figure 7 reflects the impact that coupling has on cooling energy consumption. The cooling consumption differences show a consistent offset amongst the scenarios across the course of a day and are larger in the summer months. The percentage difference for cooling is lower than heating with a maximum offset of 11%. This decrease in cooling load is also due to the net radiation loss of the target building due to surrounding surfaces emissivities and therefore cooler radiant temperatures and h values. The results of the cooling load calculation should be interpreted only in the context of the scenarios in this study. Scenarios designed with adjacent surfaces that are much warmer than those of the target building could result in a net LWR gain and produce higher cooling loads on hot days.

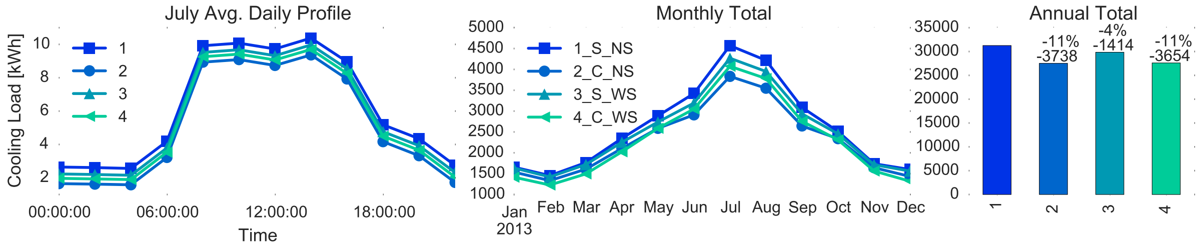

Figure 7: Daily average and monthly and annual total cooling load calculation results

CONCLUSION

This paper describes the addition of LWR exchange within an existing coupling and co-simulation process of two common building performance simulation programs, EnergyPlus at the building level, and CitySim at the urban scale. The exchange of LWR information from CitySim is utilized to overcome the simplification assumptions existent in the EnergyPlus engine, namely that the radiation exchange with surrounding surfaces is negligible. A set of theoretical scenarios illustrates that a coupled EnergyPlus simulation predicts cooling and heating loads that are different from solo simulations by up to 36%. These results are specific only to the scenarios outlined and are not generalizable, however the methodology of LWR exchange in a coupled environment has been validated. The next step within this research effort is to apply the coupled co-simulation environment on a real-world case study project and validate the scenarios using measured data.

ACKNOWLEDGEMENTS

Funding for this project was provided by an ETH Zürich Institute of Technology in Architecture (ITA) Fellowship and the Swiss Competence Center Energy and Mobility (CCEM) through the Urban Multi-scale Energy Modeling (UMEM) project.

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