Development of a single-zone RC model for predicting hourly load calculation

B.K. Jeon[1], S.H. Park[1] and E-.J. Kim[2*]

[1]Department of Architectural Engineering, Graduate school, Inha University, Inchon, Korea
[2]Department of Architectural Engineering, Inha University, Inchon, Korea

ABSTRACT

Single-zone modeling has advantages over multi-zone modeling, particularly in simplicity of parameterization and model construction. To account for some multi-zone characteristics such as balcony effects of acting as a buffer and reducing more solar transmitted radiation, modifications are proposed in the single-zone model. The U-value for the balcony window is increased, and the calculation of double-transmitted solar radiation is externalized. In addition, internal walls are also added to the single-zone model. With such modifications, the single-zone model becomes a linear systems, and an RC(Resistance-Capacitance) model can be applied for such a single-zone model. This RC model is more useful as the number of parameters to define is fewer and the calculation is fast. Results show that the proposed single-zone model can predict similar annual loads as the reference multi-zone model. Only 5% of error is shown in annual loads. The RC model is also similar to the TRNSYS model in hourly dynamics, but deviations are important in annual heating loads since the internal walls cannot be included in the proposed RC model. However, it is the most accurate model for cooling load prediction in the presented test case. **KEYWORDS**

RC model, Multi zone modeling, Simulation, Annual hourly load

INTRODUCTION

According to the international standard ISO13790 (2008), building simulation methods are sub-grouped into single-zone modeling and multi-zone modeling. Typically, multi-zone models describe more directly the building plan but require setting more parameters. The results may be more accurate compared to single-zone models. However, the design process is labor intensive (Rick and Jos van et al. 2012) and a probability to cause human errors tends to be increased. Use of a single-zone model is limited to a simplified case. For instance, attached space such as a balcony cannot be taken into account. In this paper, we proposed a method to improve the errors of the single-zone model simplified from a multi-zone model, particularly in

* Corresponding author email: ejkim@inha.ac.kr

TRNSYS. Then, a RC (Resistance-Capacitance) models deduced from the single-zone model is proposed and compared with other TRNSYS models.

MODEL DESCRIPTION

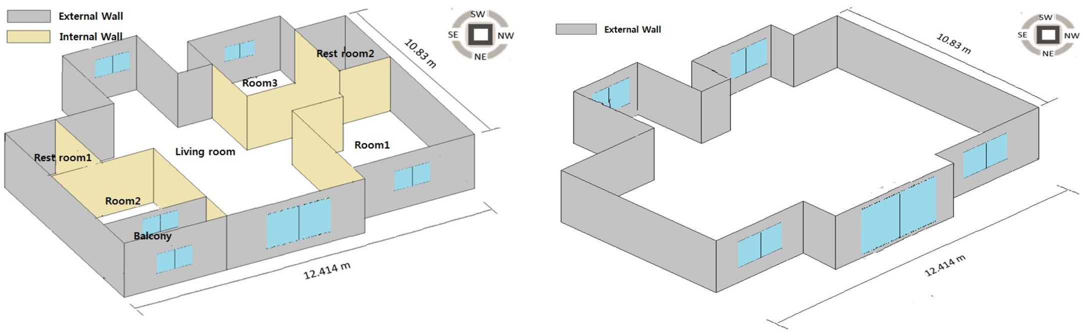

***Figure 1**. Differences between multi-zone(left) and single-zone(right)*

To test differences between multi-zone and single-zone modeling, a typical flat in Korea is selected as shown in Figure 1. The right side figure shows a single-zone configuration simplified from the multi-zone model (left). A distinct difference is of the exclusion of the internal walls and balcony. Simulations of each model run in TRNSYS, and wall thermal properties are set similar ones of recently built domestic apartments. Window properties was set from the Trnsys library that is based on the ASHRAE (1997) standard values. Detailed simulation input data are given in Table 1-2

***Table 1.** Simulation conditions*

Weather data	Seoul.Try	
Ventilation rate [1/h]	0.5 ACH	
Set temperature [C]	Heating : 22	Cooling : 26

***Table 2.** Floor areas and window area by orientation*

Multi zone				Single zone		
Floor area (m^2)		Window (m^2)		Floor area (m^2)	Window (m^2)	
		area	Orientation			
Room1	19.47	3.6	North-East	105.76	3.6	North-East
Room2	11.69	3.6	North-East		3.6	North-East
Room3	12.43	2.5	South-West		2.5	South-West
Bath1	4		-			
Bath2	4.78		-		-	
Living Room	53.39	7.2 2.2	North-East South-West		7.2 2.2	North-East South-West
Balcony	5.3	3.5	North-East	-		

TRNSYS MULTI-ZONE MODELING

In TRNSYS, energy balance is achieved by iterative calculations of energy gains and losses in a zone and across thermal zones. However, some complex energy gain mechanism is not well accounted for. One case is that the solar transmitted energy gain is well calculated to a first thermal zone, but the secondary transmitted energy to an adjacent zone via internal windows cannot be considered. To take into account such a drawback, the secondary transmitted energy is added to the adjacent zone by an externalized calculator in TRNSYS. The externalized calculator considers the variable transmittance rate for beam radiation, and the double transmitted energy passed through first the balcony outside window and then the inside window is calculated. This modified model is set as the reference model in the paper.

TRNSYS SINGLE-ZONE MODELING

Predictably, a common single-zone model shows a significant difference compare to a multi-zone model (as shown below in the result section). However, no particular method has been proposed up to now. In this study, we propose modifications of a TRNSYS single-zone model to improve the model accuracy. The proposed methods are given as follows:

i) Adding an internal wall mass

In the multi-zone model as shown in Figure 1, the internal walls partition the indoor space. The internal walls are capable of storing heat and affecting the annual loads. A correction is done by inserting an equivalent internal wall mass into the single-zone model.

ii) Accounting for the balcony effect

In Figure 1, the single-zone model doesn't include a balcony. By such an exclusion, windows placed near the balcony is directly receiving solar radiation. Thus, more solar radiation can be transmitted to inside, and it may affect simulation results. In addition, the balcony plays a role to buffer outside thermal impact. The multi-zone modeling can describe such an effect as it models the space. To account for both effects, we propose to use an opaque wall instead of the window behind the balcony. An increased thermal resistance as much as the balcony has. A corrected U-value is used for a new single-zone model. Similar to the multi-zone reference model, a double transmitted solar energy is directly given to the indoor zone.

SINGLE-ZONE RC MODEL

In this paper, the proposed single-zone model is defined into an RC model. Coincidently, the proposed TRNSYS single-zone model becomes a linear system as non-linear characteristics such as the variable solar transmittance are separated from the model. Figure 3 shows a schematic of the 3R2C model used for depicting the single-zone model. Since only two states are calculation nodes and related coefficients are few, the parameterization and calculation using the 3R2C model are fast. All the main elements of the RC model are given in Table 3. (Jerome and Darren 2006)

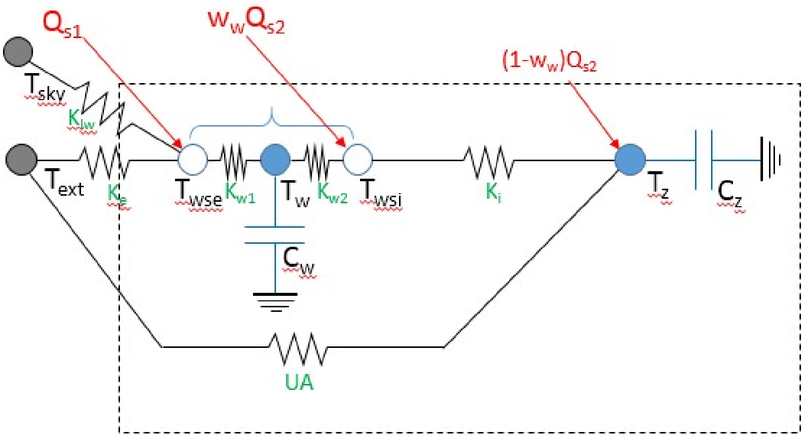

***Figure 3**. Schematic of the RC model (analogy to a 3R2C electric circuit)*

***Table 3.** Main elements of the 3R2C model*

symbols	*elements*
C_w, C_z	Wall & air thermal capacity of the zone
$_{w1}$, K_{w2}	Conductance of the external & internal wall
K_i, K_e	Heat exchange coefficients at the internal & external wall surfaces
UA	Heat exchange coefficients through windows and ventilation
T_{ext}	Outdoor air temperature
Q_{S1}	Energy flux from the sun to the external wall surface
Q_{S2}	Energy flux from the sun into the room (transmitted irradiance)
W_w	Fraction of Q_{S2} that is absorbed on the wall surface

The RC model must be defined using the similar methods proposed for the TRNSYS single-zone model. The balcony effects are similarly taken into account modifying the UA value and the Q_{S2} value. The second problem is the exclusion of internal walls. In the current RC structure (Figure 3), no adequate locations are allocated for the internal walls. Therefore, our RC model is limited to the first modification case.

SIMULATION RESULTS

Figure 4-5 show effects of the proposed methods. At first, Figure 4 shows the proposed single-zone model modified from the initial single-zone model in TRNSYS. The proposed modifications are effective to reduce differences in heating and cooling loads by simplification of multi-zone model. Then, Figure 5 shows the RC model results.The initial RC model show deviations to the initial single-zone model. Although the RC model uses very similar parameters to the single-zone model, the inherent differences in modeling may cause the deviations such as fewer calculation nodes and internal nodes within walls, for example. In addition, the final proposed RC model is far from the proposed single-zone model as the RC model doesn't adopt all the proposed methods. The internal wall also acts as an important buffer.

Table 4 shows comparisons of annual and peak loads. The reference multi-zone model is close to the proposed single-zone model showing about 5% of errors. This implies that a calibrated single-zone model only by correcting physical values as similar to the multi-zone case is sufficient to depict the multi-zone model. The proposed RC model shows similar dynamics with other models, but the annual errors are up to 20% in heating loads. However, the RC model, especially the proposed RC model where double transmitted solar irradiance is taken into account, shows satisfactory results in the cooling season (0.56 and 2.44% error, for annual and peak load). This is because the proposed modifications are related to the solar heat gain. Its effect is more important in the test case. Further improvements in the RC model may be achieved by adding the internal wall capacities.

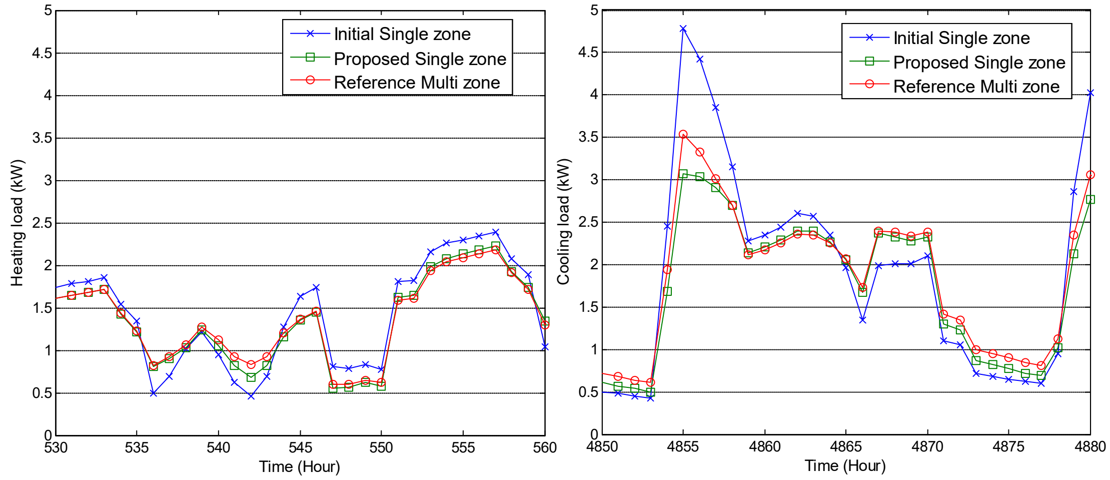

Figure 4. Load comparison: Initial & Proposed single zone, Reference Multi zone

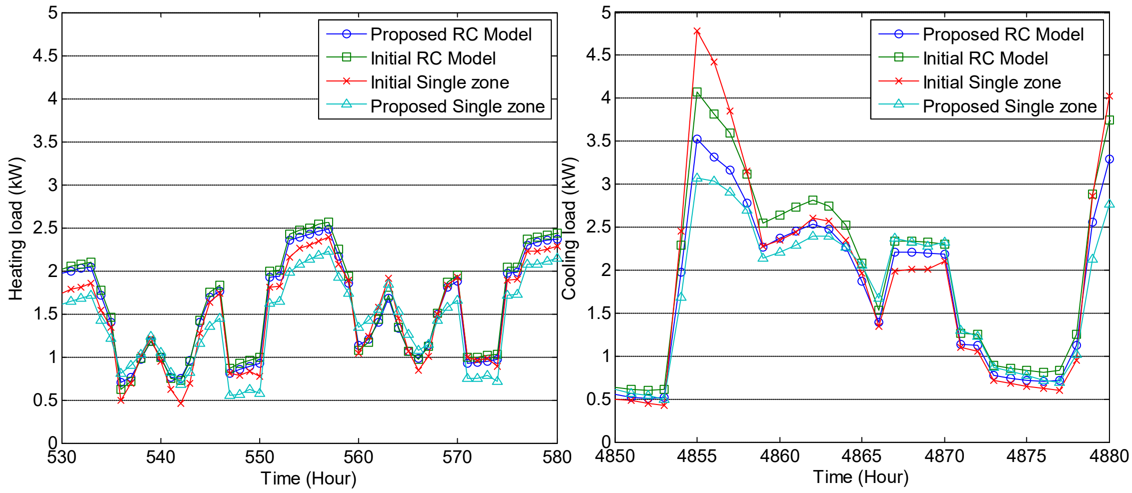

Figure 5. Load comparison: Initial & Proposed RC model and Single zone

Table 4. *Heating and cooling loads comparison*

Models	*Annual Load (kW)* Heating Error (%)	*Annual Load (kW)* Cooling Error (%)	*Peak Load (kW)* Heating Error (%)	*Peak Load (kW)* Cooling Error (%)
Initial Single zone	19.47 (15.82%)	47.83 (8.19%)	2.39 (9.63%)	4.89 (38.14%)
Initial RC Model	20.28 (20.64%)	52.06 (17.76%)	2.56 (17.43%)	4.07 (14.97%)
Modified Tau&U-value	18.11	43.00	2.25	3.99

Single zone	(7.73%)	(2.74%)	(3.21%)	(12.71%)
Modified Tau&U-value Proposed RC model	20.15 (19.86%)	45.29 (2.44%)	2.48 (13.76%)	3.52 (0.56%)
Proposed Single zone	16.15 (3.92%)	41.65 (5.79%)	2.23 (2.29%)	3.14 (11.3%)
Reference Multi zone	16.81	44.21	2.18	3.54

CONCLUSIONS

Multi-zone modeling is compared to various types of single-zone modeling schemes. An initial single-zone model that simply eliminates all the internal and balcony walls shows deviations. The balcony effects such as acting as a buffer and reducing more solar transmitted radiation are accounted for in our proposed single-zone model by correcting the U-value for the balcony window and externalizing the calculation of double-transmitted solar radiation. Internal walls are also added to the single-zone model. In addition, an RC model is developed and compared to this TRNSYS single-zone model. This RC model is useful as the number of parameters to define is fewer and the calculation is fast.

Results show that the proposed single-zone model can predict similar annual loads as the reference multi-zone model. Only 5% of error is shown in annual loads. The RC model is also similar to the TRNSYS model in hourly dynamics.Deviations are up to 20% in annual heating loads while it is the most accurate model for cooling load prediction in our test case.

Further improvements in the RC model are required by accounting for internal walls and by learning-based parameterization.

REFERENCE

ASHRAE. 1997. ASHRAE Handbook of Fundamentals 1997, ASHRAE, USA

ISO 13790. 2008. Energy performance of buildings – calculation of energy use for space heating and cooling. International Organization for Standardization.

TRNSYS User Manual v. 17. Solar energy lab. Univ. of wisconsis-Madison

Jerome H. K. and Darren R. 2006. A simplified thermal model to support analysis of urban resource flows *ScienceDirect Energy and Building 39 (2007) pp.445-453*

Rick K. and Jos van S. and Henk S. 2012. Simplified thermal and hygric buildings models. *ScienceDirect Frontiers of Architectural Research (2012) 1, pp.318-325*