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BIM2BEM for room heating-cooling time estimation after turning on the HVAC systems

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Abstract. The complexity of real constructions, with irregular geometry, inhomogeneous materials, variable morphology, alterations and damages, poses numerous challenges in digital modeling and simulation of structural performances under different types of actions. Recent developments in Building Information Modeling (BIM) have introduced advanced modeling capabilities. This paper presents a new methodology using BIM2BEM for the estimation of heating and cooling time after we turn on the HVAC systems. The generation of the BIM is carried out with information of a case study model in Autodesk REVIT software. Then, BIM is turned into a Finite Element Model (FEM) in COMSOL Multiphysics software and Building Energy Modelling (BEM) is obtained in winter and summer which preserves irregularities and anomalies, such as verticality deviation and variable thickness. Afterwards, the cooling and heating time of the whole room after turning on the cooling and heating appliances was calculated and compared with reality results.

1. Introduction

Architectural firms are moving from CAD to BIM and today relationship between BIM and BEM is a solution to develop HVAC systems, because BIM is an advantageous method to produce efficiency solutions for energy and reduce cost and time during the design of the building [1, 2, 3], so BIM and BEM are able to work efficiently and improve sustainability [3, 4, 5, 6, 7], but researchers have shown that a few papers have utilized BIM as an accurate database for BEM [8]. Studies have shown that in winter, cities have greater temperature than rural areas and this phenomenon causes the air conditioners to work higher and release carbon dioxide into the air which is harmful to the climate and environment [9]. Some studies have proposed methods for avoiding overheating as well as decrease the loss [10, 11]. Another study on heating time have shown when the heating time is shorter, the heat transfer is better. Also, researchers believe that decrease of cooling time is more important and has a great impact on its system performance [12, 13]. But this issue is different in heating systems such as radiators. In radiators, the surface is very important in heating. If the radiator surface is small, the heating temperature is very low. Also, the heating is very high when the radiator surface is too large. So, the size of radiator is a necessary component for suppliers and customers [14]. Generally, one of the important things in studies is data accuracy specifically in simulation studies to know how much these simulations are near to reality. In this paper, according to before studies that we have done for BEM simulation for HVAC systems in COMSOL Multiphysics, we want to calculate and estimate the cooling and heating time after turning on the systems. So, we followed BIM2BEM with: 1) BIM definition in Autodesk REVIT software, 2) BEM definition in COMSOL software, and 3) Conducting tests to depict and validate BIM2BEM approach. This paper has three section. After introduction, it is begun with BIM2BEM analysis in section 2. Then, in section 3, experiments are performed and the results are shown. Finally, conclusion and future work are presented.

2. BIM2BEM analysis

In this research, we use the case study model in Mashhad, Iran, as known Toos Arman Star Apartment Hotel. So, at first, the Computer-Aided Design (CAD) layout is introduced into the Autodesk REVIT software, and the unit geometry (unit 502) is manually drawn in REVIT (Figure 1) [3, 6].

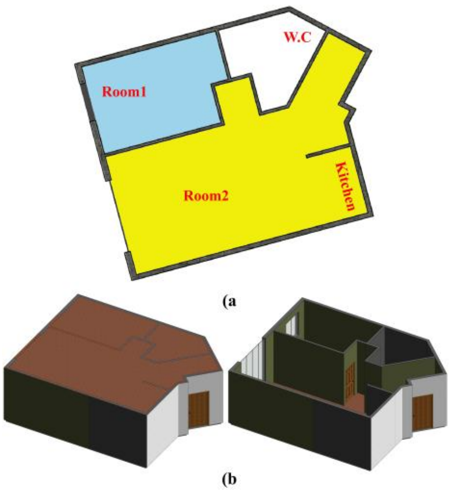

Figure 1. (a) a view of room 1 and room 2 and (b) a view of the building geometry of unit 502 drawn in REVIT [3, 6].

Then, the REVIT model is created in COMSOL Multiphysics. The unit has two rooms and for cooling and heating the unit, it is used a fan-coil and a radiator for room 1 and a fan-coil and two radiators for room 2. Thus laminar and turbulent processes are done (Figures 2, 3)
[3, 6].

The total process of BIM2BEM has been shown in Figure 4 [3, 8, 15].

2.1. *Parametric study and synthetic data*

Engineers usually integrate the local heat flux density over total heat transfer area to calculate the overall heat transfer rate. Thus the total transferred heat rate is as below (Eq. 1) [14]:

$$Q = \int_0^A k \cdot (\vartheta_2 - \vartheta_1) dA \tag{1}$$

Where, ϑ is the heat-transfer coefficient, A is cross-sectional area, and k is the thermal conductivity coefficient. Also, energy balance equations 2 and 3 are employed to determine the temperature difference in the surface area dA [14]:

$$\delta Q = m_1 \cdot d\vartheta_1 = m_1 \cdot C_{p1} \cdot d\vartheta_1 \tag{2}$$

$$\delta Q = -m_2 \cdot d\vartheta_2 = -m_2 \cdot C_{p2} \cdot d\vartheta_2 \tag{3}$$

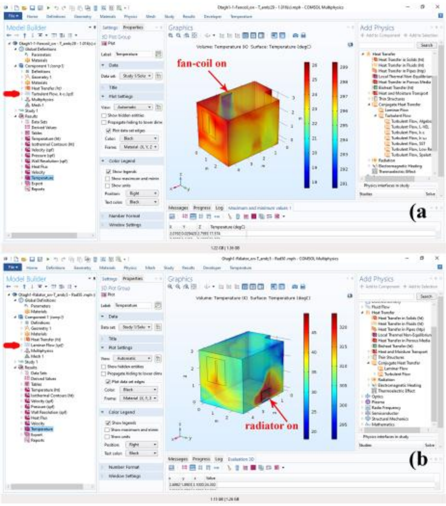

Figure 2. (a) turbulent flow (for fan-coil); and (b) laminar flow (for radiator) (room 1) [3, 6].

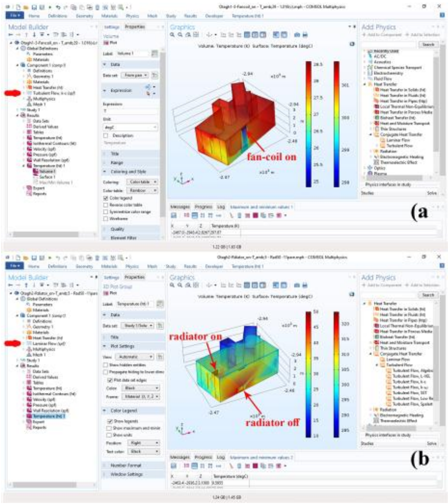

Figure 3. (a) turbulent flow (for fan-coil); and (b) laminar flow (for radiator) (room 2) [3, 6].

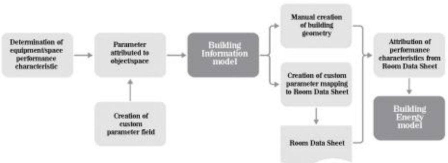

Figure 4. Bringing information to BIM, definition, collection and documenting information for BEM [3, 8, 15].

Where m is mass, ϑ is overall heat-transfer coefficient, and C_p is the specific heat at constant pressure. The temperature change, $\vartheta_2 - \vartheta_1$ is replaced with $\Delta\vartheta$. Thus, this variation can be determined by the change of the fluid temperatures (Eq. 4).

$$d\Delta\vartheta = d\vartheta_2 - d\vartheta_1 = -\delta Q \cdot [\frac{1}{m_1 \cdot C_{p1}} + \frac{1}{m_2 \cdot C_{p2}}] \quad (4)$$

From equations 2, 3 and 4, we have (Eq. 5),

$$Q = m \cdot C_p \cdot \Delta\vartheta = \rho \cdot V \cdot C_p \cdot \Delta\vartheta \quad (5)$$

Where V is the volume of the rooms. Here, the space of the rooms has been filled by air, so ρ and C_p is equal to 1.2 and 1003.5, respectively. All the information of room 1 and room 2 for calculation of the Q have been given in Table 1.

Table 1. The information of room 1 and room 2.

Room information	$\rho(kg/m^3)$	$V(m^3)$	$C_p(J/(kg°K))$	$m \cdot C_p(J°K)$
Room 1	1.2	39.92	1003.5	48071.664
Room 2	1.2	114.7	1003.5	138121.74

For calculation of the power of P for fan-coil and radiators, it obtained from tables [16]. The characteristic of powers is given in Table 2.

Table 2. Characteristic of radiator and fan-coil powers [16].

Characteristic	$P(kCal/h)$	$P(W)$
Fan-coil (Model 400)	2730	3166.8
Radiator with 11 blades	1430	1658.8
Radiator with 12 blades	1560	1809.6

3. Experiments and results

After turning on the cooling and heating appliances, i.e. fan-coil and radiator, the cooling and heating time of the whole room 1 and room 2 is as follow (Eq. 6):

$$t = Q/P \tag{6}$$

In this study, two methods are considered for calculation of the temperature difference, which obtains as follow (Eqs. 7,8):

$$\Delta\vartheta = \vartheta_{amb} - ((\vartheta_{Max} + \vartheta_{min})/2) \tag{7}$$

$$\Delta\vartheta = \vartheta_{amb} - \sum_{i=1}^{n} \frac{\vartheta_i}{n} \tag{8}$$

Where, ϑ_{amb} is ambient temperature, ϑ_{Mx} and ϑ_{min} is the maximum and minimum of temperature which obtain after turning on the fan-coil and radiators from COMSOL Multiphysics, and n is the number of temperature points. Thermal comfort is 25°C. This study is tested and evaluated for two days in the year (the warmest day in summer and the coldest day in winter) [6]. In summer we turn on the fan-coil when the ambient temperature is 27, 28 and 29°C. The fan-coil is tuned in desired temperature, 23°C, and the velocity of fan-coil wind is 1.016 m/s. The cooling time is calculated for each of the rooms, and the time is calculated with both equations 7 and 8 (Table 3).

The chart of fan-coil $t - \vartheta_{amb}$ of room 1 for two equations are given as Figure 5.

In winter we turn on the radiators when the ambient temperature is 5°C. The radiators is tuned in temperatures 50, 55, 60 and 65°C. The room 1 has one radiator and room 2 has two radiators with 11 and 12 blades. The radiator in room 1 is tuned in temperatures 50, 55, and 60°C, because this room is smaller than room 2 and for room 2, the radiator temperature 65°C is also added. The heating time is calculated for each of the rooms, and the time calculated from both equations 7 and 8 (Table 4).

Table 3. Room cooling time estimation after turning on the fan-coil.

Characteristic	The fan-coil has been tuned in desired temperature, 23°C with velocity of 1.016 m/s						
Room1	ϑ_{amb}(°C)	Eq. 9			Eq. 10		
		$\Delta\vartheta(°K)$	$Q(J)$	$t(minute)$	$\Delta\vartheta(°K)$	$Q(J)$	$t(minute)$
	27	2.501	120227.232	0.63	1.969	94689.675	0.50
	28	3.158	151810.315	0.80	2.537	121966.900	0.64
	29	6.953	334242.280	1.76	5.643	271285.026	1.43
Room2	27	1.989	274655.08	1.45	0.972	134243.557	0.71
	28	2.689	371340.298	1.95	1.247	172296.551	0.91
	29	6.061	837086.805	4.41	2.819	389371.074	2.05

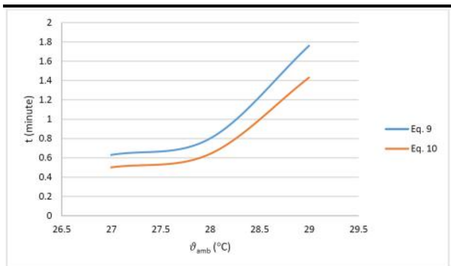

Figure 5. The chart of fan-coil $t-\vartheta_{amb}$ for room 1.

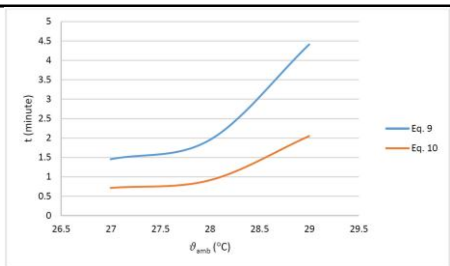

Figure 6. The chart of fan-coil $t-\vartheta_{amb}$ for room 2.

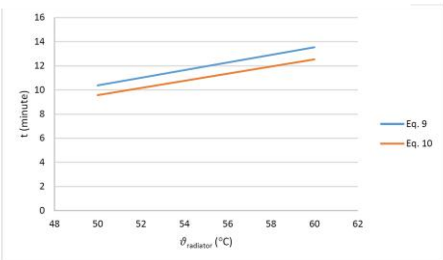

Figure 7. The chart of 11 blades radiator $t-\vartheta_{radiator}$ for room 1.

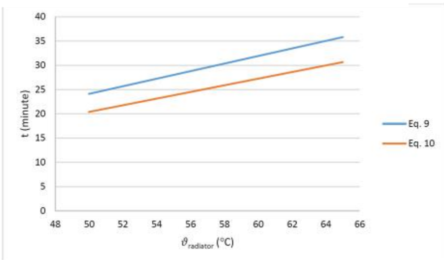

Figure 8. The chart of 11 blades radiator $t-\vartheta_{radiator}$ for room 2.

The charts of 11 blades radiator $t-\vartheta_{radiator}$ of room 1 and room 2 for two equations 7 and 8 are given as Figures 7 and 8.

The charts of 12 blades radiator and 11&12 blades $t-\vartheta_{radiator}$ of room 2 for two equations 7 and 8 are given as Figures 9 and 10.

According to the cooling experiments, the size of the room is larger, the temperature difference is smaller and the cooling time is higher. Also, with equation 10, the cooling time is lower than the equation 9, and fan-coil requires more time for cooling the rooms when the ambient temperature is high. According to the heating experiments, the temperature difference and heating time of the rooms are higher when the radiator temperature is being more and more. Also, the temperature difference with equation 10 is lower than the equation 9. The temperature difference is lower when the size of the room is larger, but the heating time is higher. The radiator type, i.e. 11 blades or 12 blades, does not have an effect on time heating, and the location of the radiator at room is important accordance with Table 4 and

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Table 4. Room heating time estimation after turning on the radiators.

Characteristic			The radiator has been tuned in temperatures, 50, 55, 60 and 65°C					
Room1		$\vartheta_{radiator}$(°C)	Eq. 9			Eq. 10		
			$\Delta\vartheta(°K)$	$Q(J)$	$t(minute)$	$\Delta\vartheta(°K)$	$Q(J)$	$t(minute)$
		50	21.48	1032555.307	10.37	19.79	951395.619	9.56
		55	24.75	1189557.362	11.95	22.87	1099367.997	11.05
		60	28.01	1346439.237	13.53	25.94	1247142.122	12.53
Room2	11	50	17.36	2398345.893	24.10	14.67	2026735.699	20.36
	blades	55	20.18	2787020.470	28.002	17.15	2368701.092	23.80
	radiator	60	22.99	3175487.863	31.91	19.62	2709929.674	27.23
	on	65	25.80	3563817.135	35.81	22.09	3050429.021	30.65
Room2	12	50	18.11	2501591.894	23.04	17.69	2443973.331	22.51
	blades	55	21.01	2901730.575	26.73	20.51	2832508.598	26.09
	radiator	60	23.91	3301869.256	30.41	23.32	3220378.953	29.66
	on	65	26.80	3701938.875	34.10	26.12	3607572.773	33.23
Room2	11&12	50	17.29	2388677.372	11.48	16.37	2260791.241	10.86
	blades	55	20.08	2773415.478	13.33	19.02	2626685.549	12.62
	radiators	60	22.86	3158084.524	15.18	21.66	2991868.041	14.38
	on	65	25.65	3542684.509	17.02	24.30	3356350	16.13

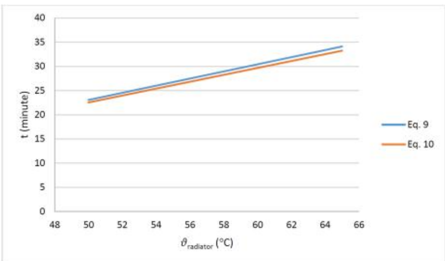

Figure 9. The chart of 12 blades radiator $t-\vartheta_{radiator}$ for room 2.

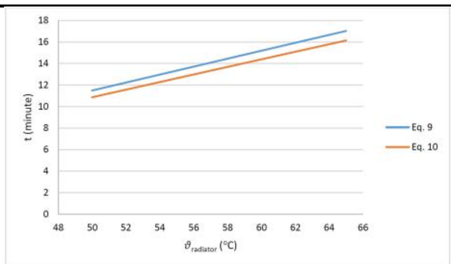

Figure 10. The chart of $t-\vartheta_{radiator}$ for room 2 when both radiators are on.

Figures 8 and 9. It is considered that the heating time of room 2 with 11 blades radiator is lower than the heating time of that with 12 blades radiator. At last, according to the Table 4, when both radiators are on in room, the heating time is lower. Therefore, it is concluded when the number of radiators is more, the heating time will be lower.

3.1. Evaluation

For evaluation of this study to see these results are near to reality or not, we collected data for cooling and heating time from the unit. For cooling time, we turn on the fan-coil in room 1. The fan-coil was tuned in desired temperature, 23°C, and the ambient temperature was 29°C. For heating time, we turn on the radiator in room 1. The radiator was tuned in 60°C, and the ambient temperature was 5°C. All the results are shown in Table 5.

Table 5. Room heating time estimation after turning on the radiators.

Characteristic	Time from Eq. 9 (minute)	Time from Eq. 10 (minute)	Time from Reality (minute)
Fan-coil cooling time	1.76	1.43	2
Radiator heating time	13.53	12.53	14

According to the Table 5, the estimation results are very near to the reality results.

4. Conclusion

This paper tries to estimate the time of heating-cooling after turning on the HVAC systems to see the results are near to reality or not. To estimate the time, all the information was obtained from the BIM, BEM and the fan-coil and radiator catalogs. For this purpose, BEM was used for the acquiring the temperature data from COMSOL Multiphysics software. The experimental results demonstrated the good results in contrast to reality. Another work, BEO for energy saving, is under further development.

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References

[1] G. Spiridigliozzi, L. Pompei, C. Cornaro, L. De Santoli, and F. Bisegna, "BIM-BEM support tools for early stages of zero-energy building design" *IOP Conf. Series: Materials Science and Engineering* 2019; vol 609, 072075, pp. 1-6, https://doi.10.1088/1757-899X/609/7/072075.

[2] Z. Pezeshki, and S.A.S. Ivari, "Applications of BIM: a brief review and future outline" *Archives of Computational Methods in Engineering* 2018; vol 25, no 2, pp. 273-312.

[3] Z. Pezeshki, "Energy Modeling for Estimation of Indoor Temperature of the Building on the BIM Platform", MSc thesis of Faculty of Electrical and Robotics Engineering, Shahrood University of Technology, Shahrud, Iran. 2018; pp. 1166 (http://shahroodut.ac.ir/en/thesis/thesis.php?thid=TK658.) https://doi.org/10. 13140/RG.2.2.21522.09924.

[4] W.S. Jeong, J.B. Kim, M.J. Clayton, J.S. Haberl, and W. Yan, "Translating Building Information Modeling to Building Energy Modeling Using Model View Definition" *The Scientic World Journal* 2014; vol 2014, pp. 1-21.

[5] E. Kamel, and A.M. Memari, "Review of BIM's application in energy simulation: Tools, issues, and solutions" *Automation in Construction* 2019; vol 97, pp. 164-180.

[6] Z. Pezeshki, A. Soleimani, and A. Darabi, "Taguchi method to determine the best location for cooling and heating appliances" *Proceedings of the Institution of Civil Engineers Energy* 2019; pp. 1-69, https://doi.org/10.1680/jener.18.00024.

[7] L.M. Khodeir, and A.A. Nessim, "BIM2BEM integrated approach: Examining status of the adoption of building information modelling and building energy models in Egyptian architectural firms" *Ain Shams Engineering Journal* 2018; vol 9, Issue 4, pp. 1781-1790.

[8] Z. Pezeshki, A. Soleimani, and A. Darabi, ”Application of BEM and using BIM database for BEM: a review” *Journal of Building Engineering* 2019; vol 23, pp. 117, https://doi.org/10.1016/j.jobe.2019.01.021.
[9] S.P. Singh, M. Katiyar, and S. Agarwal, ”An Overview of Passive Cooling Techniques in Buildings Design Concepts” *Journal of Building Construction* 2019; vol 1, no 2, pp. 1-6.
[10] O. Dudina, and A. Dudin, ”Optimization of Queueing Model with Server Heating and Cooling” *Mathematics* 2019; vol 7, no 9, 768, pp. 1-14. https://doi.org/10.3390/math7090768.
[11] P. Puls, C. Lange, and R. chsner, ”Hybrid cooling towers in a free cooling application - modelling and field measurement verification” *Chemical Engineering & Technology* 2019; vol 42, no 9, pp. 1871-1878.
[12] L. Ming, Y. Yanguang, L. Wanqing, and L. Zhi-hui, ”Study of Heating Time of test model and Application in Low Density Wind Tunnel Using Infrared Thermography”, 2014; http://dx.doi.org/10.21611/qirt.2014.048.
[13] M. Xia, X.P. Chen, H.Y. Li, and Z.H. Gan, ”Cool down time optimization of the Stirling cooler” *IOP Conf. Series: Materials Science and Engineering* 2017; vol 278, no 012043, pp. 1-7. http://doi.10.1088/1757899X/278/1/012043.
[14] P. Bckh, and T. Wetzel, *Heat Transfer Basics and Practice* 2012; Springer-Verlag, Berlin, Heidelberg. https://doi.org/10.1007/ 978-3-642-19183-1.
[15] T. Gerrish, K. Ruikar, M. Cook, M. Johnson, and M. Phillip, ”Using BIM capabilities to improve existing building energy modelling practices”, *Eng. Constr. Archit. Manag.* 2017; vol 24, no 2, pp. 190208.
[16] M. Moghiman, *Air Conditioning and Central Heating Engineering* 2016; Ferdowsi University of Mashhad, Mashhad, Iran, 9th edition, pp. 1-535, 9789643860134 (In Persian).