IMPACT OF AIR LEAKAGE THROUGH RECESSED LIGHTING FIXTURES ON THE ENERGY PERFORMANCE OF RESIDENTIAL BUILDINGS – A CASE STUDY

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Summary

Actual energy performance of buildings depends on not only the design criteria but also on the construction quality of buildings. Design assumptions can be invalidated by construction quality issues, and lead to large variations between the designed performance and the actual performance. But very limited quantitative study is found on evaluating the impact of construction quality issues on building energy performance. In this paper a case study is presented utilizing 3D computational fluid dynamics to simulate air leakage issues in recessed lighting using different boundary conditions. The results of the case study suggest that some seemingly insignificant construction quality issue can cause significant increase in energy consumption of residential buildings. The paper provides scientific evidence to help residential construction industry to improve the construction quality of residential buildings in the United States.

Keywords: construction quality, energy performance, residential building envelope, attic, recessed lighting, CFD

1 Introduction

Unintended air leakage through buildings' envelopes is a common issue in the design and construction of single-family residential buildings in the US. In many cases, unintended air leakage can lead to significant extra energy consumption [1, 2]. This paper will discuss particular leakage cases associated with recessed lighting fixtures installed in the ceiling area, which is next to the vented attic space. The boundary condition settings used in the case studies are very typical in the US.

When recessed lighting fixtures installed between indoor space and attic space, under the stack effect, the perforated recessed light fixtures may become small "chimneys" and

contributes to great heat loss. In one case, a large house located in Harrisburg, Pennsylvania suffered ice dams and unusual high fuel pay. After investigation, air leakage of the recessed lights was identified to be the main reason [3, 4].

In this paper we employed a numerical approach, 3D computational fluid dynamics (CFD) method, to simulate air leakage in the recessed lighting to quantitatively investigate recessed lighting fixtures' impact on energy performance of residential building. Please note the authors only study the leakage phenomenon through perforated canisters when the light bulbs are not on. The light-bulb-on cases can be further studied in the future.

2 Numerical Model

An attic with sixteen square shaped recessed lights is simulated in this case. Due to the buoyancy stableness of the attic ventilation as well as the symmetry in both geometry and boundary conditions, a quarter of attic is used in the computational domain to achieve computational efficiency. The schematic of heat transfer mechanisms in ventilation attic is shown in the Fig. 1. Both the convection and radiation are considered in the simulation. In order to simplify the simulation, 3D shapes of roof and ceiling trusses, as well as the thickness of the insulation are not considered, the computational domain is only occupied by air, which is assumed to be a Boussinesq fluid.

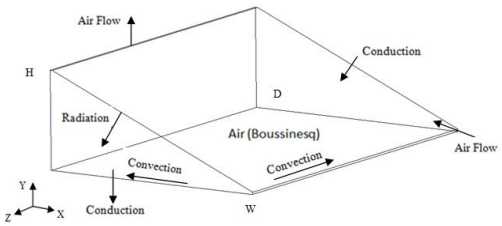

Fig. 1 *Schematic of heat transfer mechanisms in ventilated attic*

The detailed schematic diagram of recessed light is shown in the Fig. 2. The length, width, and height of the attic simulated in the model are 6 meters, 4 meters, and 1.677 meters respectively, corresponding to a roof pitch value of 5/12. Each recessed light is supposed to be non-IC rated, and have four 2 cm x 20 cm openings of air leak surround each side of the recessed canisters.

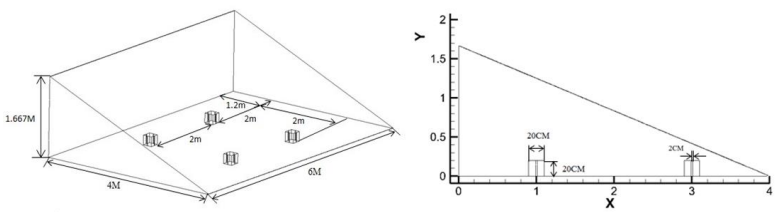

Fig. 2 *Geometry of attic with recessed lighting*

Natural ventilation ratio 1/200 through the attic is considered in this case. Ventilation ratio refers to the net free area, such as soffit and ridge vent regions, divided by the deck area of the attic [5]. The insulation level represented by R-value is also considered at different locations of the attic in this model. As shown in Tab. 1 and Tab. 2, different ambient air temperatures in winter and summer conditions, as well as R-values are assumed in

different regions. The emissivity of a material is the relative ability of its surface to emit energy by radiation. Since the impact of radiation in winter is insignificant, emissivity is only considered in summer condition.

Tab. 1 *Winter boundary conditions*

	Temperature	**Thermal Conductivity**	**Emissivity**
Roof	258K(-15°C)	R-1.2 (4.733W/m^{2}K)	/
Vertical Wall	263K(-10°C)	R-1.2 (4.733W/m^{2}K)	/
Ceiling (indoor)	293K(20°C)	R-20 (0.284W/ m^{2}K)	/

Tab. 2 *Summer boundary conditions*

	Temperature	**Thermal Conductivity**	**Emissivity**
Roof	345.15K(72.15°C)	R-1.2 (4.733W/m^{2}K)	0.85
Vertical Wall	315.15K(42.15°C)	R-1.2 (4.733W/m^{2}K)	0.85
Ceiling (indoor)	297K(24°C)	R-20 (0.284W/m^{2}K)	/

3 Results and Discussion

3.1 Winter Condition

The contour of temperature and streamlines of the recess lights in winter condition are shown in the Fig. 3. As shown clearly from streamlines, there are four areas with high temperature on the roof which are caused by the hot leakage air from the openings around recessed lights. The air enters through the bottom of the canister has a higher temperature which means a lower density and results in rising up easily.

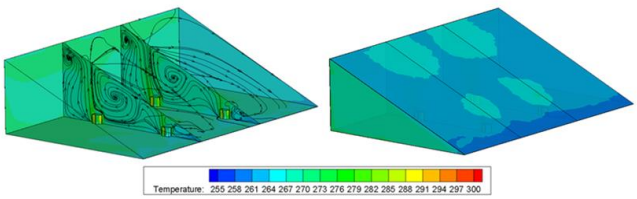

Fig. 3 *Streamlines and Contour of Temperature in winter*

3.2 Summer Condition

In summer, the temperature of the roof in summer is relatively uniform as shown in temperature contour of Fig.4. As shown from the streamlines, the air entering through the leakage at the recessed lighting has a lower temperature which means a higher density. After mixing with the hot air entering through the soffit, the temperature of the air goes up and air rises to leave the attic at ridge.

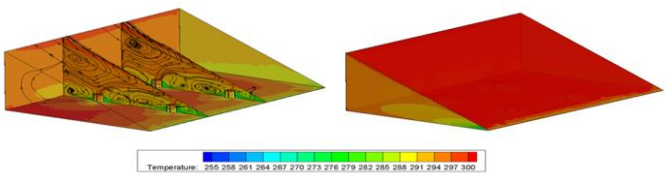

Fig. 4 *Streamlines and Contour of Temperature in summer*

3.3 Results and Conclusion

The results of air leakage in the recessed lighting fixtures in winter and summer condition are listed in the Tab. 3. The positive value of the heat transfer rate means the heat transfer from the indoor to the attic. The negative value means the heat transfer from the attic to the indoor space. High heat transfer rate at recessed lighting leakage is found both in winter and summer conditions, which indicates significant energy loss despite of good ceiling insulation R value.

The ceiling heat transfer rate is larger in summer than that in winter due to the higher temperature gradient in summer. However, in winter the heat transfer rate of the leakage area in recessed lighting tends to be greater, thus the effects caused by the air leakage in recessed lighting is more significant in winter.

Tab. 3 *Comparison of winter and summer condition*

	Winter	**Summer**
Heat transfer rate through ceiling (W)	161.12	-218.4
Heat transfer rate through recessed lighting leakage (W)	105.72	-55.8

4 Conclusions

In the simulated simple case, 16 recessed lighting fixtures on a 12x8 square meters R-20 ceiling, the ratio of winter heating loss of 105.72 / 161.12 is very significant considering the total recessed-lighting fixture area only accounts less than 1% of the total ceiling area. Although, in summer, the ratio of cooling loss of 55.8 / 218.4 indicates cooling loss is less compared to heating loss in winter, it is still significant considering the relatively small area of the lighting fixtures. Based on the case study of recessed lighting discussed above, we can conclude that some seemingly insignificant air leakage issues can cause significant increase in energy consumption of residential buildings.

Acknowledgement

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