

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

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Summary

The actual energy performance of buildings depends on not only the design criteria but also on the construction quality of buildings. Many design assumptions can be invalidated by unexpected construction quality issues, and lead to large variations between the designed performance and the constructed performance. Though important, very limited research, especially quantitative study, is found on evaluating the impact of construction quality issues on building energy performance. In this paper the construction quality issues of residential buildings in the United States is discussed, along with reviews of building envelope related research. A case study on residential attic construction is presented to illustrate how construction quality affects the energy performance of attics. The case study utilized 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]. When air leakage leads to excessively energy consumption burden for a building, it can cause the heating or cooling

load surpassing the ability of HVAC system in a building so as to affect the thermal comfort in the building [2, 3]. In addition, Leaking airflow may contribute to moisture problem which can “impact the long-term performance of the building material and the building’s structural integrity” [2, 6, 7, 8]. The unintended air leakage issues exist in both new and existing buildings. 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.

In the majority of states in the US attic are required to be vented to reduce moisture problems. Insulations are commonly used to cover the whole ceiling area from the attic side. One problematic air leakage area is from indoor space to attic space through the canister vents of the recess lighting fixtures, even when the lighting trim is properly sealed. When recess 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 [9, 10].

There are two types of recessed lighting fixtures, IC-rated and non-IC rated (Fig 1). IC-rated fixtures are allowed to be in contact with insulation, thus are very common in residential buildings; non-IC rated housing fixtures should keep a certain distance, at least 3 inches, away insulation over the ceilings or be installed in non-insulated ceilings, therefore, are more often in commercial buildings. For security, bulb installed in the recessed lighting had better not exceed 75 watts, especially for the IC-rated recessed lighting which often directly contact with insulation [9]. IC-rated and non-IC rated recessed lighting are often designed to have perforated canister to dissipate heat generated from the light bulb [10]. And thus air leakage is quite common through canister’s openings.

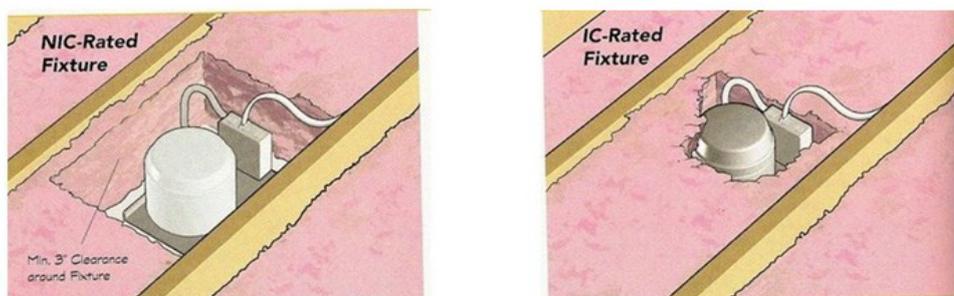


Fig. 1 Non IC Rated Fixture and IC-Rated Fixture

(Source: <http://www.single-family-home-remodeling.com/recessed-lighting.html>)

Using infrared camera, leaking areas in the existing residential buildings can be easily detected. However, it is difficult to measure and quantify the air leakage using infrared camera. 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 recess 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 stability 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. 2. 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.

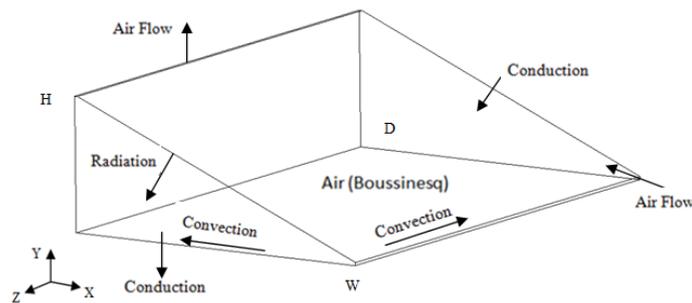


Fig. 2 Schematic of heat transfer mechanisms in ventilated attic

The detailed schematic diagram of recess light is shown in the Fig. 3. 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.

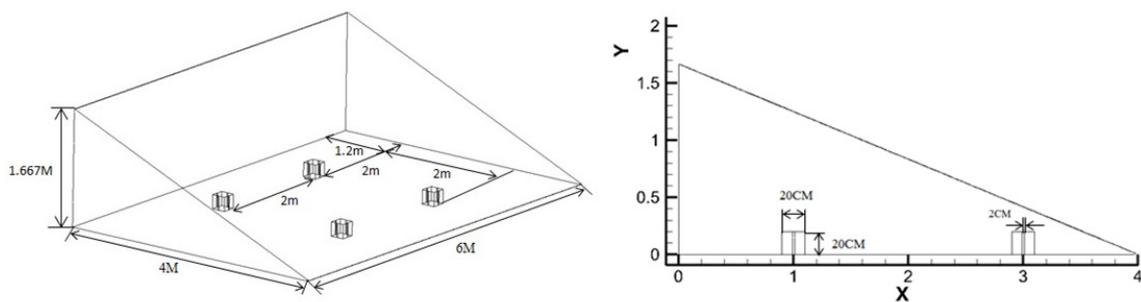


Fig. 3 Geometry of attic with recess lighting

Natural ventilation 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 [11]. In this case, the ventilation ratio is supposed to be 1/200. 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	258 K (-15 °C)	R-1.2 (4.733 W/m ² K)	/
Vertical Wall	263 K (-10 °C)	R-1.2 (4.733 W/m ² K)	/
Ceiling (indoor)	293 K (20 °C)	R-20 (0.284 W/ m ² K)	/

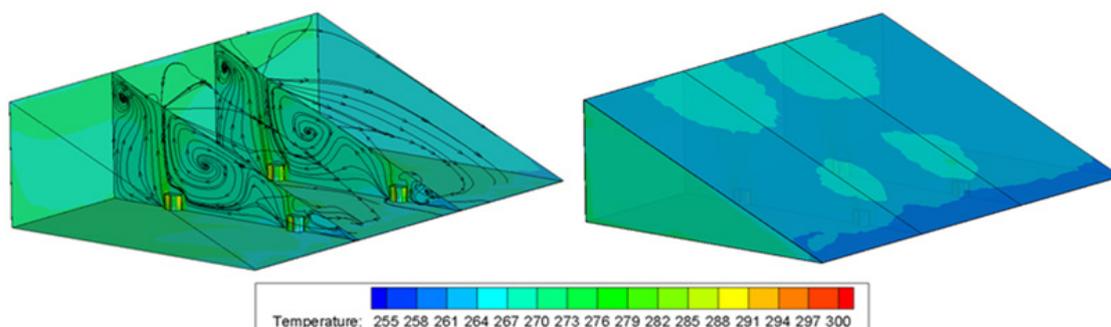
Tab. 2 Summer boundary conditions

	Temperature	Thermal Conductivity	Emissivity
Roof	345.15 K (72.15 °C)	R-1.2 (4.733 W/m ² K)	0.85
Vertical Wall	315.15 K (42.15 °C)	R-1.2 (4.733 W/m ² K)	0.85
Ceiling (indoor)	297 K (24 °C)	R-20 (0.284 W/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. 4. 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. This phenomenon is also found in the real observation as shown in the Fig. 5.

**Fig. 4** Streamlines and Contour of Temperature in winter**Fig. 5** Excessive Humidity Damages Attic
(Source: <http://www.hankeyandbrown.com/icedams>)

3.2 Summer Condition

In summer, the temperature of the roof in summer is relatively uniform as shown in temperature contour of Fig. 6. As shown from the streamlines, the air entering through the leakage at the recess 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.

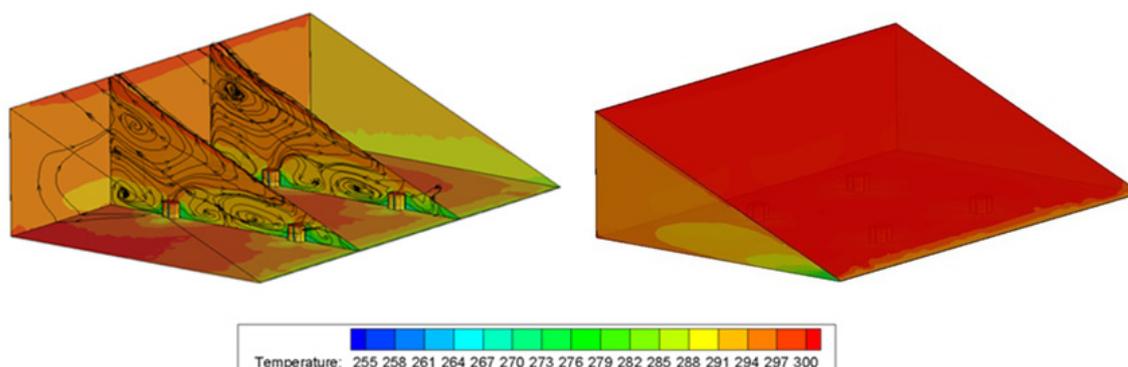


Fig. 6 Streamlines and Contour of Temperature in summer

3.3 Results

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. High heat transfer rate at recess 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 owing to the higher temperature gradient in summer. However, in winter the heat transfer rate of the leakage area in recess lighting tends to be greater, thus the effects caused by the air leakage in recess lighting is more significant in winter. Since the “stack effect” is more intensive in summer, the mass flow rate of air leakage in recess lighting and soffit in summer is larger than that 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 recess lighting leakage (W)	105.72	-55.8
Mass flow rate at recess lighting leakage (Kg/s)	0.0209	0.0355
Mass flow rate at soffit (Kg/s)	0.024	0.048

4 Conclusions

We use a simple ratio of heating or cooling loss between lighting fixture leakage and through ceiling heat transfer to measure the significance of lighting fixture leakage. In the simulated simple case, 16 recess lighting fixtures on a 12 x 8 square meter R-20 ceiling, the ratio of winter heating loss of 106:161 is very significant. Although, in summer, the ratio of cooling loss of 56:218 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 recess lighting discussed above, we can conclude that some seemingly insignificant air leakage issues can cause significant increase in energy consumption of residential buildings. These air leakage issues may come from design or construction in either new or old buildings. More studies are needed to improve the scientific knowledge base of design and construction quality of residential buildings in the US in order to increase the energy efficiency.

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