Methods for the Efficient Operation of Ceiling-Mounted Fluorescent Residential Luminaires

April 2004

1.0 Introduction

During the past few years, there has been increasing concern about the premature failure of residential fluorescent lamp luminaires, including those with the ENERGY STAR® label. Lighting manufacturers agree that excessive heat inside the luminaire may be the main cause of their failure. In the round table conference held as a part of the durability testing project, with Energy Star partner manufacturers in October 2001, the participants accepted that the premature failures could be reduced by reducing the heat within the luminaires. The hypothesis was that excessive heat reduces the life of the capacitor inside the ballast, resulting in shorter ballast life due to degradation of the capacitor itself or failure of other components inside the ballast that interact with the capacitor.

Following the round table, the LRC measured the ballast case operating temperature inside various ceiling-mounted and recessed downlight luminaires. The results showed that the majority of the luminaires tested had ballast case operating temperature below the Underwriters laboratory (UL) limit of 90°C, but was above the limits established by ballast manufacturers (65°C - 70°C) [1]. Ballast manufacturers claim a certain life for the ballast. Ideally, none of the components of the ballast should have rated life lower than the rated life of the ballast. Hence it was important to understand the effects of a higher ballast case temperature on its components and device simple methods to reduce the high temperature.

The objectives of this phase of the project are to:

- Investigate, through literature review on ballast components, if capacitor failure is linked to ballast failure and potentially to luminaire failure
- Investigate the relationship between ballast case temperature and ambient temperature.
- Investigate effective ways to reduce ballast case temperature in ceiling-mounted luminaires and
- Propose guidelines that will help reduce the ballast case temperature

2.0 Ballast basics and components

Ballast in fluorescent lighting systems performs two basic tasks:
1. Provides the proper voltage to establish an arc between the two electrodes in the lamp
2. Regulates the electric current flowing through the lamp to stabilize light output.
In many systems the ballast also provides a controlled amount of electrical energy to heat lamp electrodes.

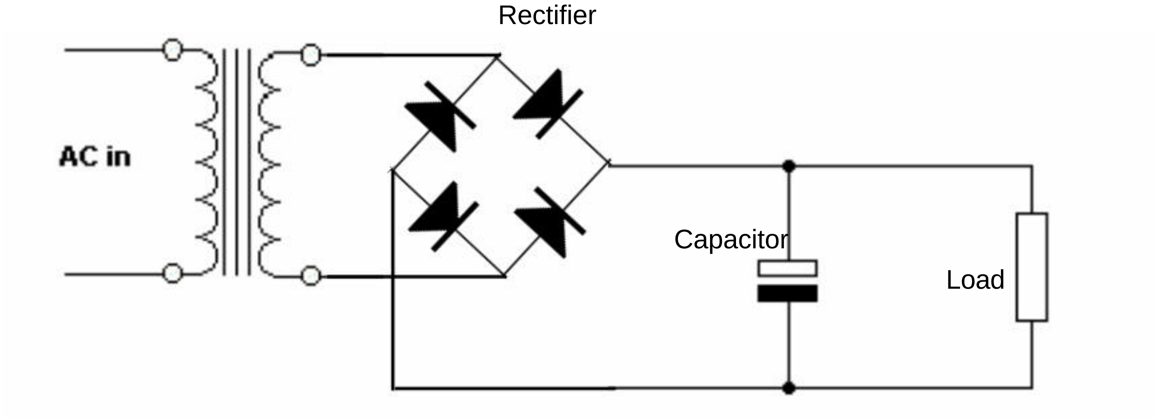


Figure2.1: Components of a typical electronic ballast [2]

The main components of a typical electronic ballast is shown in Figure 2.1. Ballast life depends on a number of variables such as supply voltage, ambient temperature, and the operating temperature. For electronic ballasts, life is also dependent upon the quality of the electronic components including the capacitor and the degree to which the ballast is protected from line voltage surges, electrical transients and excessive temperature. The electrolytic capacitor is generally accepted to be the "weakest" component inside the ballast and degradation of the electrolytic capacitor may lead to ballast failure directly or through failure of other components.

2.1 Electrolytic capacitor

A capacitor is an electric circuit component used to store charge temporarily, consisting in general of two metallic plates separated and insulated from each other by a dielectric[3] as shown in Figure 2.2.

The capacitance is directly proportional to the surface area of the electrodes and inversely proportional to the thickness of the dielectric.

When one of the conducting surfaces or the metallic plates is replaced with a chemical compound or an electrolyte, it is an electrolytic capacitor. An electrolytic capacitor has a high capacity per unit volume compared to most other capacitor types [3].

Most commonly used anode is aluminum and a thin film of its oxide forms the dielectric.

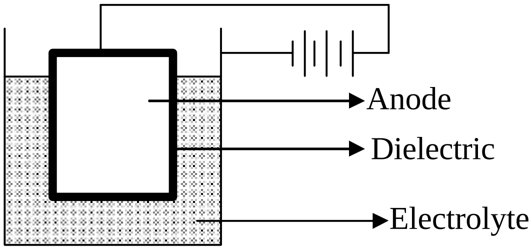


Figure 2.2: Schematic of an Aluminum electrolytic capacitor

The function of a capacitor in a ballast is to smoothen the ripple voltage after it comes from the rectifier before it goes to the other components as shown in Figure 2.3.

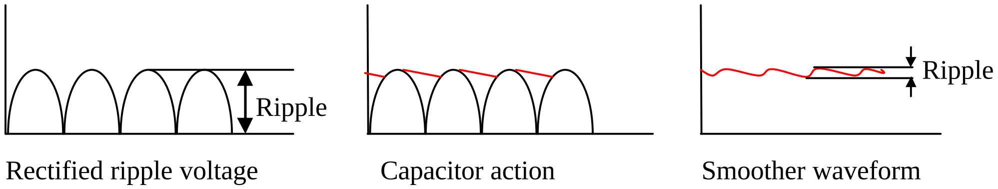


Figure 2.3: Function of a capacitor

2.1.1 Failure mechanisms

Several factors can cause electrolytic capacitors to degrade and fail, such as severe cold temperatures, heat (soldering, ambient, AC-ripple), high voltages, transients, extreme frequencies or reverse bias. [4, 5] Heat is, however, considered one of factors that have the strongest influence on the operational life of electrolytic capacitors. [5]

The hot spot located inside the capacitor is where the highest temperature will be found. This temperature is dependent on several factors such as the luminaire ambient temperature, thermal resistance from hot spot to luminaire ambient temperature, and energy loss caused by the ac current. Excessive heating will accelerate the evaporation of the electrolyte causing degradation in the electrical parameters such as capacitance, leakage current and the equivalent series resistance (ESR) of the capacitor. When the amount of electrolyte is reduced to a critical amount, the end of life of the capacitor is reached causing the ballast to fail. Though this kind of catastrophic failure is less common in a capacitor, the degradation of the capacitor affects the life of the other components in the ballast causing the ballast to fail eventually.

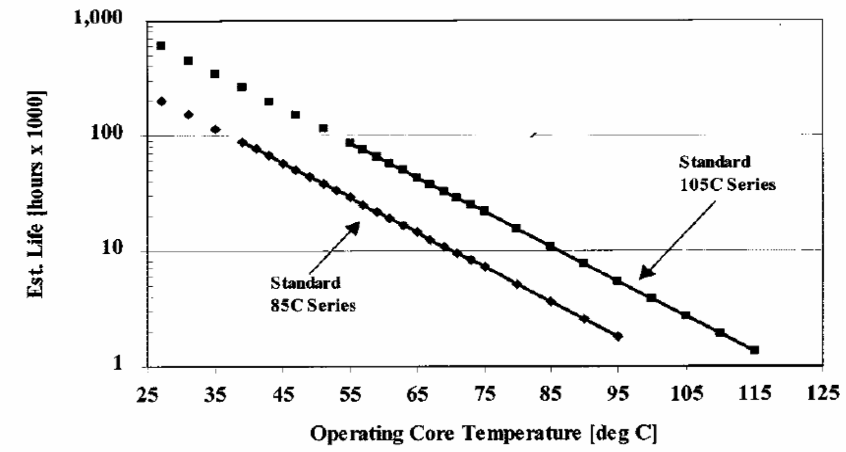


Figure 2.4: Estimated life as a function of capacitor operating temperature [6]

In general, the rated operating temperature of the capacitor and the life at that temperature are specified by the manufacturers. A capacitor rated at 105°C could have a rated life of 1000, 2000 or 5000 hours. As a rule of thumb, for each 10°C decrease in operating temperature, the life of the capacitor is doubled; similarly, for each 10°C increase in operating temperature, the life of the capacitor is halved as shown in Figure 2.4 [1]. For example, if the rated life of a capacitor is 1000 hours at 105°C, it can be predicted to have a life of 2000 hours at 95°C, and 4000 hours at 85°C and similarly 500 hours at 115°C, 250 hours at 125°C, etc. Hence even a 10 increase in temperature could halve the life of a capacitor and eventually the ballast and vice versa.

3.0 Capacitor temperature and ambient temperature

While the capacitor temperature is known to increase with an increase in the temperature within the ballast [5], a direct measurement of the case temperature of the electrolytic capacitor is required to determine whether the capacitor is really working within or outside its rated range.

An experiment was designed to measure the temperature on the capacitor case while operating a typical residential luminaire at different ambient temperatures. The setup, procedure and the results are explained below.

3.1 Experimental Setup

Four indoor ceiling mounted luminaires from four different manufacturers were used for the experiment. They were operated at different ambient temperatures and the temperature measurements were taken by positioning thermocouples in specific locations (Figure 3.1).

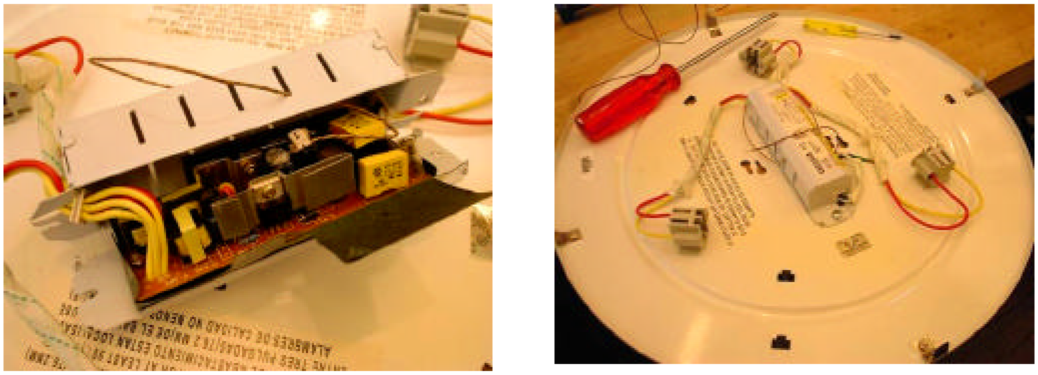


Figure 3.1: Position of thermocouples with in the test setup

The thermocouple leads followed the same routes as the electrical supply wires, to avoid making any extra holes in the luminaire through which air might circulate and thus change the internal temperature distribution. In one ballast, which was ‘potted’(filled with a black grease to help thermal distribution), holes had to be drilled to get the thermocouple to the capacitor. The capacitor in all the luminaires had a rated temperature of 105°C.

The luminaires were mounted to a thick plywood backboard similar in thickness to a single layer of ceiling plasterboard. The plywood had a 1.5” hole drilled to allow access for the supply cables; a similar sized hole would be required to allow installation of the luminaires in a domestic ceiling, so the experimental setup closely resembles the intended operating environment of the luminaires. The plywood backboard was suspended in the middle of a temperature-controlled oven on a small metal scaffold.

3.2 Experimental procedure

Three temperatures were recorded during the experiment: the ambient air temperature inside the oven; the air temperature inside the luminaire, and the capacitor case temperature. Ambient air temperature was used as the independent variable, and was varied by setting a target temperature on the oven controller. Targets of 35, 45 and 55°C were used, and one reading was taken with the luminaire in free air sitting on a table in the laboratory, since the laboratory air was close to 25°C.

After being switched on, each luminaire took between 30 and 90 minutes to achieve a stable operating temperature in 25°C ambient air. The luminaire was then placed in the oven, and the oven target temperature set to 35 ° C, 45°C, or 55°C. All luminaires achieved a new stable operating temperature within 30 minutes.

3.3 Results

A summary of the temperature readings at the electrolytic capacitor for each luminaire at ambient temperatures of 35°C, 45°C, and 55°C are shown below. (Complete data – Appendix A)

Ambient temperature	55°C	45°C	35°C
Manufacturer 1	103.4	91.6	83.9
Manufacturer 2	107.9	101.8	93.8
Manufacturer 3	108.5	101.8	85.4
Manufacturer 4	124.3	112	102.8

Table 3.1. Capacitor temperature at different ambient temperatures

These results confirm that the case temperatures of the electrolytic capacitors in the 3 out of 4 luminaires tested do exceed the maximum rated temperature when the ambient is 55°C. Even when the ambient temperature is 45°C, the capacitor case temperature is close to the rated temperature, which implies that the expected life of the capacitor would be 1000 hours, much lower than the expected life of the ballast (30,000 to 50,000 hours). At 35°C ambient temperature, 3 out of 4 luminaires had the capacitor case temperature roughly between 85°C and 95°C, which is just 20°C less than the rated temperature. This implies that, as a rule of thumb, the life of the capacitor would be approximately 4000 hours if rated life is 1000 hours. This could be a possible mechanism causing early failure of luminaires.

3.4 Investigation into failed luminaires

One of the ways of finding out if the capacitor failure is the real cause of the luminaire failure is to analyze luminaires that have failed during use. Twelve luminaires that were purchased and returned because of premature failure were obtained from a lighting distributor. The distributor did not have enough information regarding the number of hours these luminaires were operated before failure.

All the luminaires were first visually evaluated for signs of external damage. Some of the luminaires had broken lamps and some did not have any lamp in them. New replacement lamps were bought for all the luminaires, upon which two luminaires seemed to work and the rest of them did not work. This confirmed that the luminaire failure was related to the ballast.

Out of the remaining ten, three of the luminaires had a ‘potted’ ballast, rendering them useless for investigation because of the solidified thick black grease over the components. Visual inspection was done on the remaining luminaires to try to determine whether the capacitor had failed or degraded. Out of the remaining seven luminaires, three had a visible capacitor failure, one had possible transistor failure, one had possible fuse failure and one had possible inductor failure. It is important to note, however, that capacitor degradation may lead to failure of other components and, thus, the ballast, even though capacitor failure is not clearly visible through visual inspection. The table below summarizes the result of the investigation.

Luminaire Type	Manufacturer	Observations in the ballast
Outdoor Flood	A	Water marks on board, transformer shows signs of corrosion, possible over heating
Ceiling Mount	B	Potted – not discernable
Ceiling Mount	B	Potted – not discernable
Wall Sconce	B	Potted – not discernable
Ceiling Mount	A	Possible over heating of transistor
Outdoor Lantern	C	Possible over heating, inductor bulged due to excess current.
Ceiling Mount	C	Signs of inductor over heating, acidic odor of the electrolytic capacitor
Ceiling Mount	C	Fuse is discolored, may be blown
Ceiling Mount	D	Capacitor blackened- possibly failed, Inductor bulging
Ceiling Mount	D	Capacitor blackened- possibly failed, Inductor bulging

Table 3.2: Observations on the failed luminaires

3.5 Conclusion

This experiment shows that the temperature on the electrolytic capacitor case increases with an increase in ambient temperature and, in some extreme cases (55ºC ambient), will achieve higher temperatures than the ones rated by the manufacturer. Even at a nominal ambient temperature of 35ºC, the temperature at the capacitor does not reduce more than 20ºC from the rated temperature and hence the life of the capacitor may not exceed 4 times its rated life (probably 4000 hours). This again shows that heat can directly affect the life of the ballast by reducing the life of the capacitor.

Investigations into failed luminaires suggest that failed or degraded capacitors may be one of the reasons for the luminaire failure, either directly or through the failure of other components inside the ballast.

If we can redesign the luminaire with simple modifications that would improve the heat dissipation from the ballast, that would improve the life of the luminaire. Even a 10 degree reduction in the temperature could potentially double the life of the luminaire.

4.0 Methods to reduce Ballast case temperature

The goal of identifying methods to reduce ballast case temperature is to come up with simple practical changes that manufacturers can incorporate into the design of the luminaries.
The three methods of transferring heat from a surface are conduction, convection and radiation.
Conduction is a process in which heat moves through a substance or from one substance to another by the direct contact of molecules. The conductive properties of the material play a major role in the efficiency of this process. Within the luminaire, the ballast case temperature can be reduced by improving the contact between the ballast case and a good thermally conductive material (heat sinking). In cases where the luminaire has metal housing, the housing can be used for heat sinking.

When the heat from a surface transfers to air around it, the warm air rises up. This process of cooling hot surfaces is called convection. The amount of surface exposed to the air and the amount of air flow determines the efficiency of this process. Ventilating the luminaire is a way of cooling the ballast case through convection.

Radiation is the transfer of heat energy through space. It does not require any medium to transfer the heat. The efficiency of this process depends on how hot the material is and the emissivity of the material.

While it is important to consider all three methods to reduce ballast case temperature, the goal is to suggest simple practical modifications to the luminaire. Hence pilot tests were required to understand the effectiveness of some of these methods.

Previous literature indicates that ventilation is a good way to improve the operation of a luminaire [7]. Hence initial pilot tests were conducted to determine the best way to ventilate the luminaire to get the maximum reduction in ballast case temperature.

4.1 Pilot test to determine the best venting method

The purpose of this experiment was to evaluate different configuration of venting of the luminaire to enhance convective cooling and thereby reduce the temperature within the luminaire and the ballast case temperature.

4.1.1 Apparatus:

For the purposes of this experiment, the apparatus was designed to simulate a typical 2-lamp residential ceiling-mounted luminaire as shown in Figure 4.1, instead of the actual luminaire.

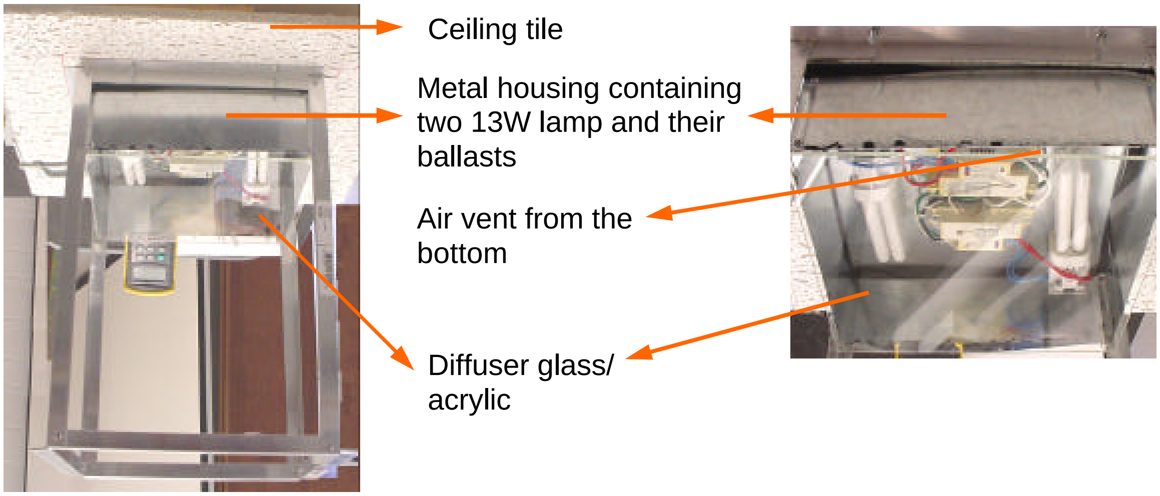


Figure 4.1: Apparatus simulating a typical ceiling-mounted luminaire for the experiment

A metal plate was mounted on an 18” square acoustic ceiling tile made of plaster and had a hole of one inch diameter drilled in the center. A rectangular metal box (11” X 10.75” X 3”) simulating the housing of the luminaire was mounted on the ceiling tile. This housing contained the lamp and the ballast.

Two 13W compact fluorescent lamps (CFL) from OSRAM SYLVANIA were placed inside the box along with ballasts from Advance transformers. The ballasts were mounted on the metal plate and lamp sockets were mounted symmetrically on L-brackets beside the ballasts.

Since ceiling mounted luminaires had both glass and plastic diffusers, both glass and acrylic sheets was used to simulate the diffuser in the experiment.
A standard metal junction box (j-box) was mounted on the back of the ceiling tile and electric power was fed through this j-box to the ballasts. Thermocouples fed through the j-box, were placed at the hot spots of the ballast to measure the ballast case temperature and between the lamps to measure the temperature within the luminaire. The luminaire was powered through a watt meter to measure the energy consumption. The experimental setup closely resembled the operating environment of the typically installed luminaires.

Venting of the luminaires was done by giving a gap between the diffuser and the housing and/or between the housing and the top plate, using quarter or half inch spacers.
The frame was 18” high was built around the housing. The frame was mounted on an 18” square acoustic ceiling tile made of plaster.

4.1.2 Experimental procedure

The experiment was done to understand how the ballast case temperature varies with different configurations of venting.
Three temperatures were recorded during the experiment: the ambient air temperature, the air temperature inside the housing, and the ballast case temperature. Thermocouples shielded from direct radiation from the lamps were place at two different locations inside

the housing to measure air temperature. Ballast case temperatures of both ballasts were measured by placing thermocouples at the hot spot point specified by the manufacturer. Ambient air temperature was approximately 22.5°C.

The independent variables were the area of the opening (opening size) for venting, its position (no opening, top, bottom, or top and bottom), and the material of the diffuser (glass or acrylic) (See Figure 4.2).

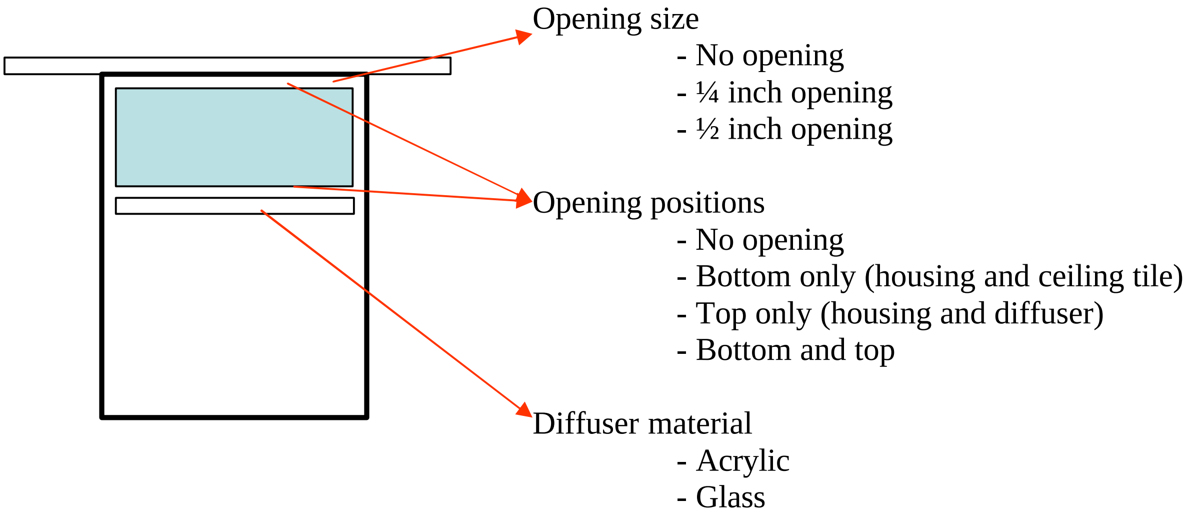


Figure 4.2: Schematic design of housing.

Prior to conducting the measurements, the lamps were turned on for a period of 100 hours until they reached light output stabilization. Once stabilized, the measurements were taken for the all the opening sizes (no opening, ¼ inch opening, and ½ inch opening) and opening positions (no opening, bottom only, top only, and bottom and top) described in Figure 4.2.

After turning the luminaire on, they took between 30 and 90 minutes to achieve a stable operating temperature at an ambient air temperature of about 22.5°C. The luminaire was considered to have attained stable operating temperature when in three consecutive measurements 15 minutes apart, the difference in the temperature was less than a degree (as per UL 1958 section 16.2.4). The luminaire was allowed to cool down to ambient temperature between measurements.

4.1.3 Results

The results of the experiment for different venting sizes and positions when using glass and acrylic diffusers at an ambient air temperature of 22.5 °C is as shown in Table 4.1.

	Acrylic Diffuser						Glass diffuser					
	NO Vent	0.25" bottom only	0.25" top and bottom	0.25" top only	0.50" top only	0.50" bottom only	NO Vent	0.25" bottom only	0.25" top and bottom	0.25" top only	0.50" top only	0.50" bottom only
Inside ambient temp °C	56.5	53.4	43.6	56.7	52.1	55.6	60.3	56.6	43.9	56.4	53.1	55.7
Ballast case temp °C	61.5	58.9	49.8	58.7	55.4	57.6	61.6	58.4	49.2	58.5	55.8	57.6
Power (W)	21.3	21.7	23.7	21.8	22.5	22.3	21.6	21.5	23.3	22.1	21.9	21.9

Table 4.1: Results from the experiment at an ambient air temperature of 22.5°C

The lowest ballast base case temperature was obtained when there was a gap at the top and bottom of the housing, compared to no gap, or a gap at the top or bottom only. For example, when using the acrylic diffuser, the ballast case temperature was 61.5 °C with no venting and 49.8 °C when vented both top and bottom of about 1/4 inches (see Figure 4.3).

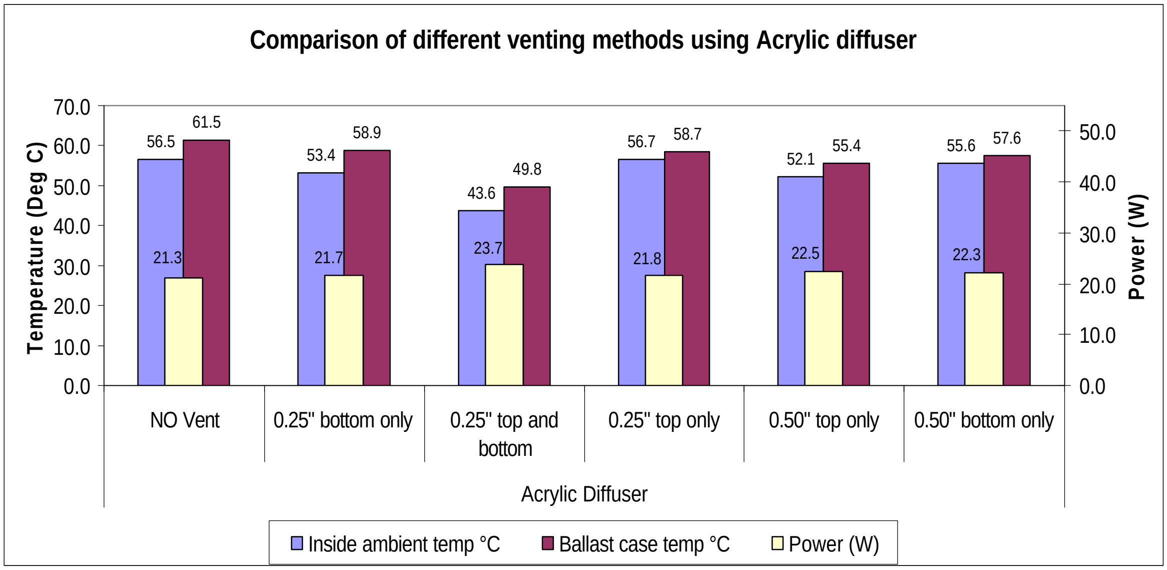


Figure 4.3: Results at an ambient air temperature of 22.5°C using (acrylic diffuser)

Figure 4.4 compares different venting methods using the glass diffuser. The performance with different venting conditions was very similar to the acrylic diffuser.

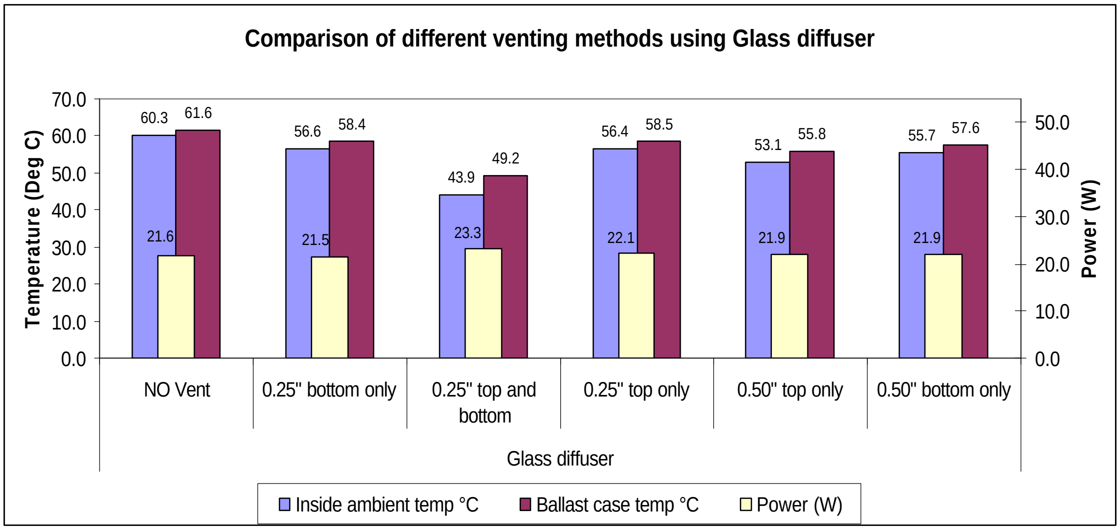


Figure 4.4: Results at an ambient air temperature of 22.5°C (glass diffuser)

Figure 4.5 compares the performance of acrylic and glass diffusers for all the venting conditions. The difference in ballast case temperatures between glass and acrylic diffuser seems to be very little for all the conditions.

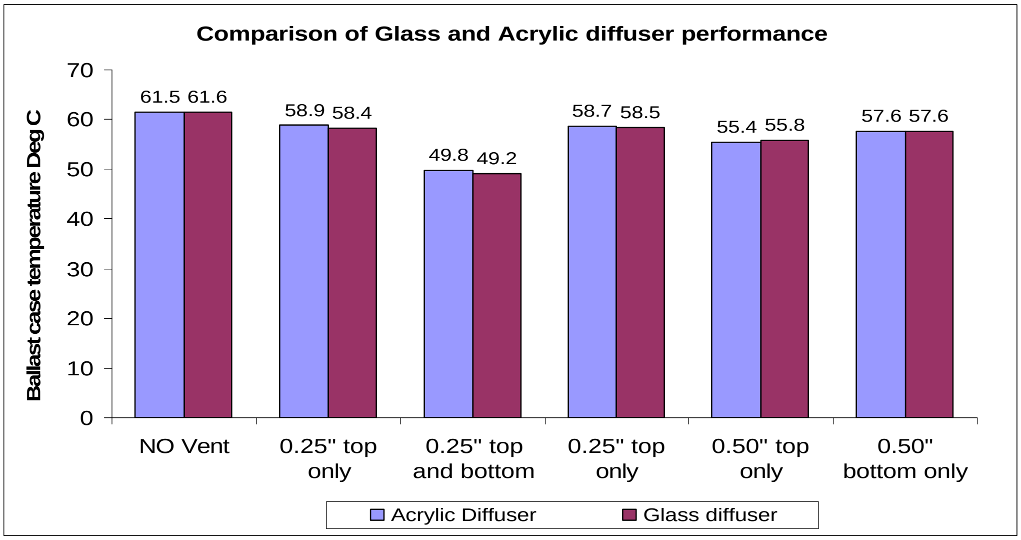


Figure 4.5: Results comparing Acrylic and Glass diffuser

4.1.4 Conclusions

Venting does seem to reduce the ballast case temperature especially when the gaps are located at the top and bottom of the diffuser. There is a reduction of up to 10°C on the ballast case temperature compared to no venting at all. Based on earlier literature a reduction of 10°C on the ballast case temperature can double the life of the capacitor [6]. In other words, by adding a ¼ inch opening on top and bottom of the diffuser, the life of the capacitor can be doubled, which can, in turn, increase the life of these luminaires.

Venting only on one side does not seem to as good an effect as venting from both top and bottom as expected. It seems, however, that changing the diffuser material does not seem to affect ballast case temperature.

The next steps are to first understand how much heat was being radiated by the lamp and how much heat was being internally produced by the ballast. This will give an idea of the effect of lamp radiation on the ballast.

4.2 Pilot test - Effect of lamp radiation on ballast case temperature

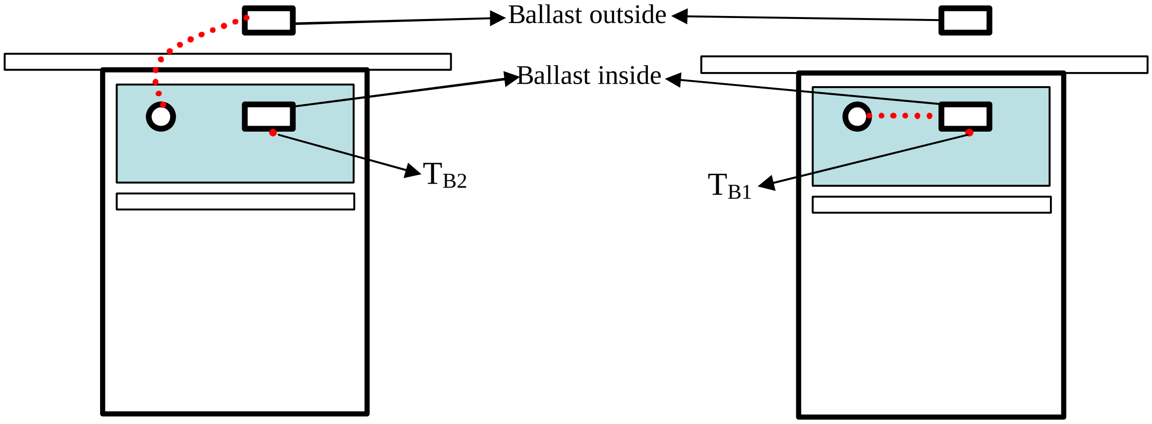
One way to determine the effect of lamp radiation on ballast case temperature is if we power the lamp in the luminaire with a ballast outside the luminaire while measuring the case temperature of the ballast inside the luminaire. This can be compared to the ballast case temperature when the lamp is powered by the ballast inside the luminaire.

4.2.1 Apparatus

For this experiment, the same apparatus as before was used with minor changes (Figure 4.6). Instead of two 13W lamps, only one 26W, 4pin CFL lamp was used. The setup was rewired so that the lamps could be powered by either ballasts (the one inside the housing and the one outside the housing). The measurements were conducted for vented (¼ inch top and bottom) and unvented conditions.

4.2.2 Experiment procedure

Two ballasts were used, one outside the luminaire and one inside the luminaire as shown in Figure 4.6. The ballast located inside the luminaire had thermocouples placed on the hot spot, as determined by the ballast manufacturer. In the first set of measurements, the lamp was powered by the ballast inside the luminaire and its case temperature was measured (T_{B1}). Subsequently, the ballast inside the luminaire was turned off and its case temperature was measured while the lamps were powered by the ballast located outside the luminaire (T_{B2}). The difference in temperature between the ambient temperature and T_{B2} is the temperature increase due to lamp radiation. (? T_{B2})



Lamp powered by ballast outside

Lamp powered by ballast inside

Figure 4.6: Pilot study set up

4.2.3 Results

The results (Table 4.2 and Figure 4.7) show that T_{B2} is 33.4°C while T_{B1} is 51.2 °C in the vented housing, suggesting that there is an increase in ballast case temperature due to lamp radiation; ? T_{B2} is 11.2°C for vented and 22.3°C for unvented housing.

The increase in temperature due to lamp radiation is significant especially in case of an unvented luminaire. Venting seems to not only reduce the ballast case temperature, but also cool down the lamp by reducing the heat radiated from the lamp.

	Acrylic diffuser	
	Vented	Unvented
Ambient (°C)	22.2	21.5
T_{B1} (°C)	51.2	64.9
T_{B2} (°C)	33.4	43.8
? T_{B2} (°C)	11.2	22.3

Table 4.2: Ballast case temperature increase due to lamp radiation for vented and unvented housing

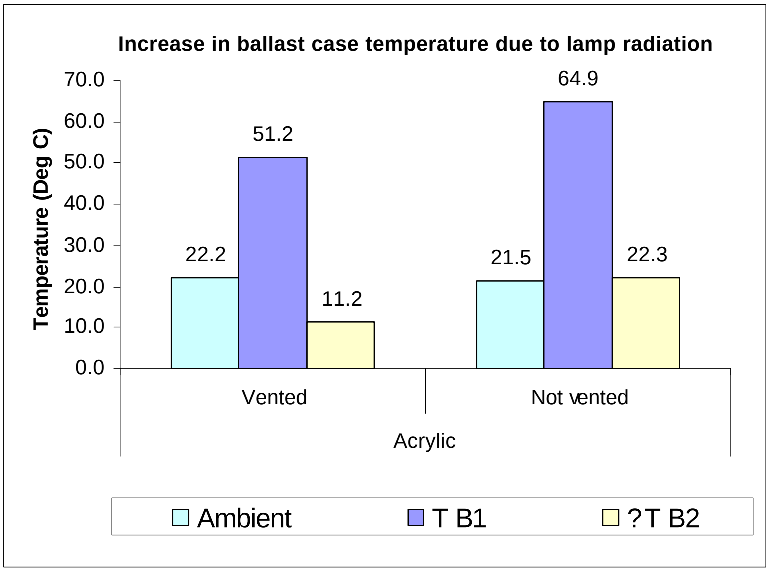


Figure 4.7: Ballast case temperature increase due to lamp radiation for vented and unvented housing

4.2.4 Conclusions

Lamp radiation is a significant cause of increased ballast case temperature either directly or through heating up the air within the luminaire. Removing the ballast completely out of the luminaire can potentially reduce the ballast case temperature by keeping it away from the direct radiation of the lamp and the trapped heat within the luminaire. But that

may not be a practical solution. Shielding the ballast from the direct view of the lamp may be a way to reduce the effect of direct lamp radiation to an extent.
Another factor that could affect the ballast case temperature is the wattage of the lamps (heat source) used. Higher wattages produce more heat and would have higher ballast case temperatures.

Conducting the heat away from the ballast could also be a way of reducing the ballast case temperature. This can be determined by comparing the performance of a metal housing with a thermal plastic housing. Thermal plastics have much less conductivity compared to metals. Hence a good contact between the ballast case and the metal housing can be expected to reduce the ballast case temperature better than thermal plastic housing.

The next step would be to determine which of these three methods, conduction, convection and radiation or interactions between would be the most effective way to reduce ballast case temperature. It would also be important to know if changing the lamp wattage would make a difference in their performance.

5.0 Final experiment

The final experiment was designed with four variables.

i) With and without ventilation (1/4 inch top and bottom) (convection)
ii) With and without shielding between lamp and ballast (radiation)
iii) With thermoplastic and metal housing for the luminaire (conduction)
iv) Two 13W lamps (26Wtotal) and two 18W lamps (36W total) (effect of lamp wattage)

The experiment had a total of 16 (2 X 2 X 2 X 2) conditions from which the best methods and their interactions could be clearly rank ordered. The results would be the basis for creating a guideline document that will aid manufacturers to make simple changes to reduce ballast case temperatures inside luminaires and there by potentially increase the life of the luminaires.

5.1 Apparatus:

The same apparatus as before was used for this experiment with modifications (Figure 5.1).

Venting for the top and bottom was done by using 1/4 inch metal spacers at the four corners. For the condition with no vents, foam gaskets were used to tightly seal off the gaps between the metal housing and the glass diffuser.

White painted 1/16 inch aluminum sheets were used to make shields between lamp and ballast. They were designed to easily, attach to and remove from, the socket of the lamp and totally shield the ballast from the direct view of the lamp when attached.

Acrylonitrile Butadiene Styrene (ABS) plastic sheet was used for the thermal plastic housing condition. The plastic was 1/4 inch thick beige tinted conforming to the exact inner dimensions of the metal housing. Galvanized steel 1/16 inch thick, was used for the metal housing of the luminaire

Sylvania lamps (13W Dulux D/E) were used for the 13W lamps and Philips lamps (18W, 4pin PL-C) were used for the 18W lamps and the corresponding ballasts used were universal ballast (C213UNVSE and C218UNVSE) with a metal ballast housing.

The lamps and the ballast were positioned symmetrically to reduce confounds due to asymmetrical thermal distribution.
Thermocouples were soldered to the hotspot of both ballast cases to record the ballast case temperature. The ambient temperature was measured outside the luminaire at the same height as the ballast with a thermocouple dipped in mineral oil (as per UL 1598 section 16.5.3)
The power used by the system was measured by a watt meter.

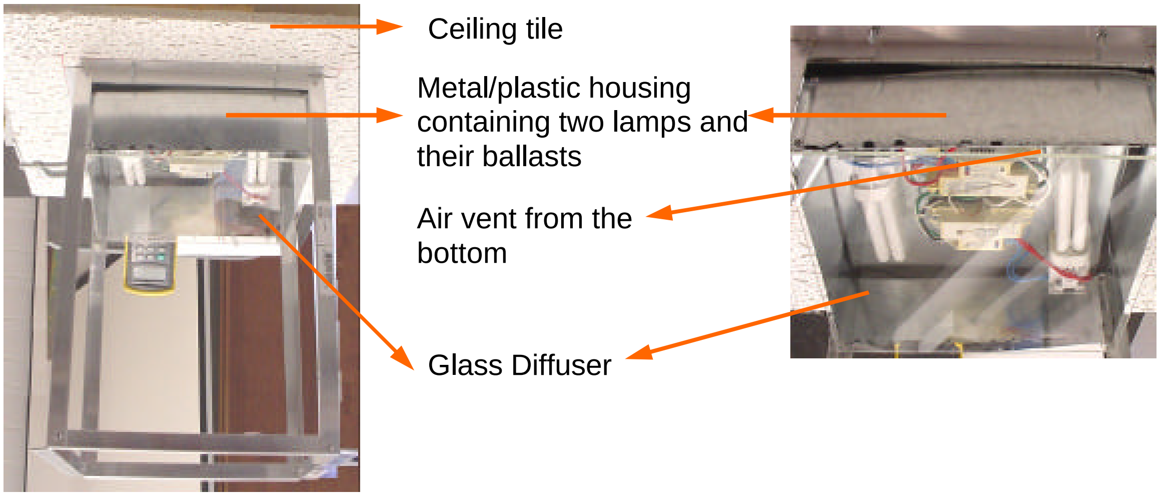


Figure 5.1: Apparatus simulating a typical ceiling-mounted luminaire for the experiment

5.2 Experimental procedure

Prior to conducting the measurements, the lamps were turned on for a period of 100 hours until they reached light output stabilization.
The independent variables are as shown in Figure 5.2.

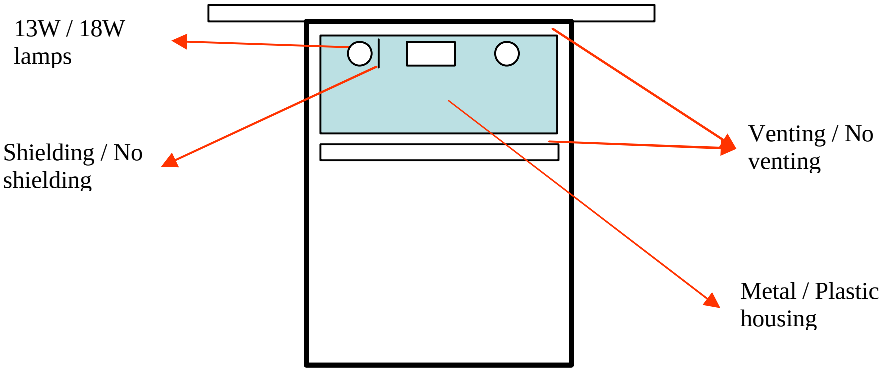


Figure 5.2: Independent variables in the experimental procedure.

The dependent variables were the ballast case temperature and the energy consumed by the system.
Once the lamps were turned on for a given condition, the ballast case temperature, the ambient temperature and the energy consumed by the system were recorded every 15 minutes. The system was considered to have achieved thermal stabilization for that condition, when the difference in ballast case temperature in three successive readings was less than a degree, (as per UL 1958 section 16.2.4). The average of the last three readings was used as the ballast case temperature. Similarly the corresponding measured power and their average was used for energy consumption.

The apparatus was then modified for the next condition and the process was repeated for all the 16 conditions (2X2X2X2 combination of the conditions listed above).

Initially the condition with the metal housing was done with plain unfinished galvanized steel. Since that was not representative of luminaires that had painted housing, the condition was repeated once more with white painted metal housing.
This is because there will be a difference in the emissivity of paint and metal surfaces. Emissivity is the ratio of the thermal radiation of a surface at a particular temperature and wavelength to the black body radiation at that temperature and wavelength. A material with higher emissivity radiates the heat away better than one with lower emissivity. So a difference in performance can be expected because the emissivity of paint is higher than plain metal.

5.3. Results

The results of the experiment for the different conditions are given below. Table 5.1 gives the average ballast case temperature and Table 5.2 the average measured power for the different conditions.

Conditions	Average Ballast case temperature Deg C					
	Metal housing		Plastic housing		Painted metal housing	
Total rated power	26W	36W	26W	36W	26W	36W
No venting with shielding	63.57	68.37	63.07	68.37	59.33	63.30
No venting without shielding	62.63	69.23	62.90	69.10	58.47	64.13
Venting with shielding	51.50	55.30	49.57	56.60	50.47	54.53
Venting without shielding	52.33	55.40	50.67	57.00	51.17	54.93

Table 5.1: average ballast case temperature

Conditions	Average measured power in Watts					
	Metal housing		Plastic housing		Painted metal housing	
Total rated power	26W	36W	26W	36W	26W	36W
No venting with shielding	23.60	28.57	25.03	30.10	24.67	30.07
No venting without shielding	23.77	28.73	24.73	30.13	24.10	29.70
Venting with shielding	27.03	35.07	27.60	35.47	27.23	34.23
Venting without shielding	26.83	34.83	27.83	35.73	27.37	35.03

Table 5.2: Average measured power

Figures 5.3 and 5.4 show the change in the ballast case temperature between the metal (plain and painted) and plastic housing. The painted metal seems to perform better than the plain metal in reducing the ballast case temperature.

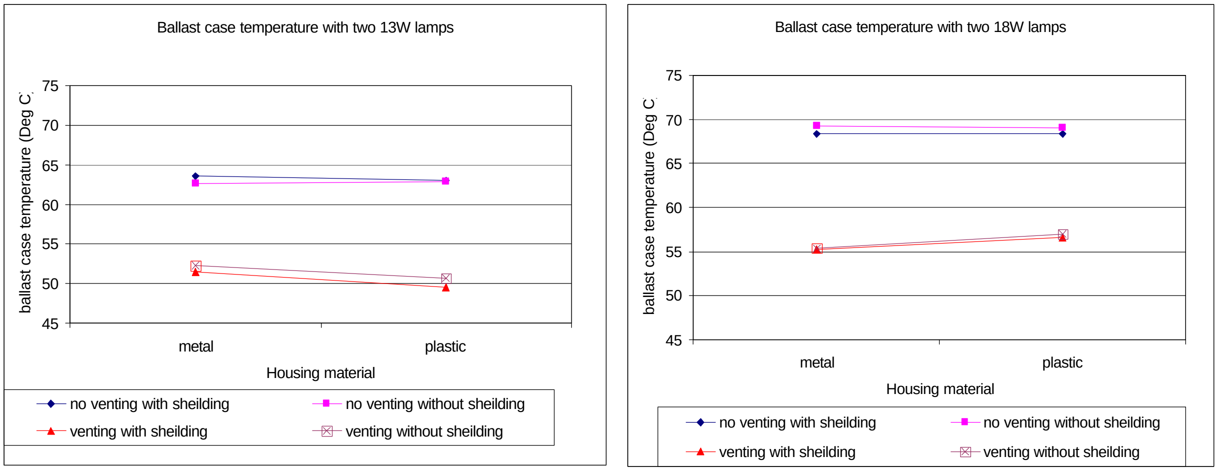


Figure 5.3: Change is ballast case temperature with plain metal housing

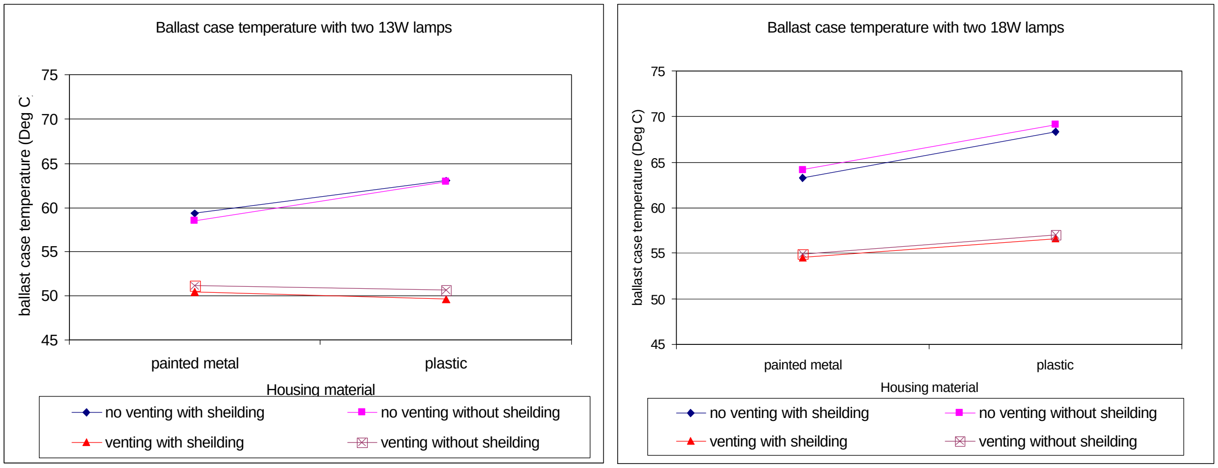


Figure 5.4: Change is ballast case temperature with painted metal housing

5.4 Analysis

The results were analyzed for individual effects and an analysis of variance was done to find the interaction between the variables. The data shown below is only for the set of conditions comparing painted metal housing and plastic housing with the other variables.

Figure 5.5 shows the main effects of the four variables on the ballast case temperature. As seen, ventilation clearly has the highest effect on reducing the ballast case temperature and shielding has very little effect. Increasing the rated power of the luminaire; i.e. using a higher wattage lamp, increases the ballast case temperature and the painted metal housing performs better than plastic housing.
The data from the set of conditions comparing plain metal housing and plastic housing with the other variables (appendix -B) showed significant individual effects with venting and rated power only. Housing and shielding did not have significant effect on the ballast case temperature.

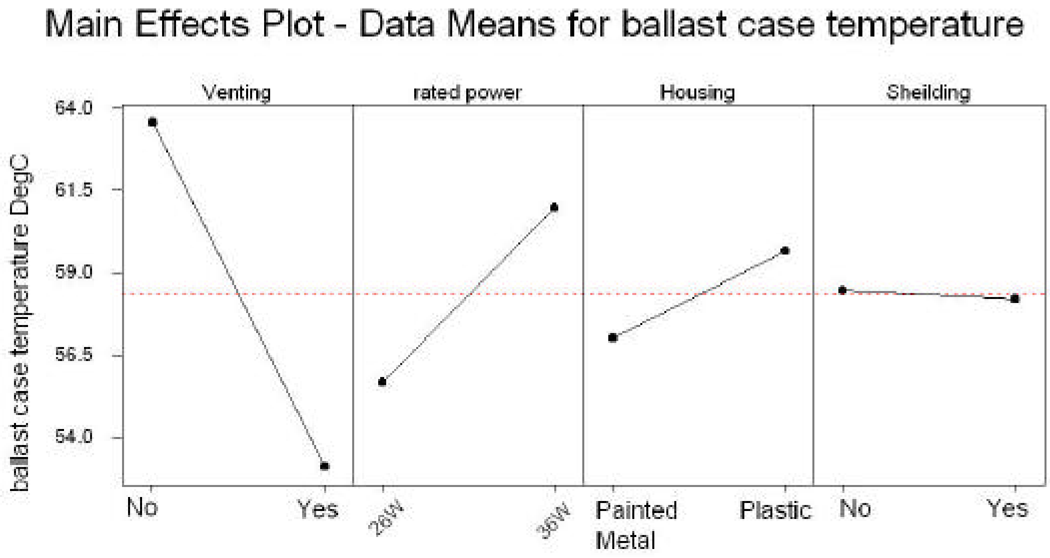


Figure 5.5: Main effects of the four variables on the ballast case temperature

Figure 5.6 shows the interaction between the variables if any. The analysis of variance showed that there is very little or no interaction between the variables. In Figure 5.5, when the two lines are parallel, there is no interaction and when the lines tend to converge, there is a possibility of interaction.

The highest interaction was seen between venting condition and the housing material. When there is no venting, the housing material makes a big difference, where as when there is good venting, the housing material does not seem to make much difference.

There is also some interaction seen between rated power and the housing material. The performance of painted metal housing compared to plastic housing improved when the wattage was increased.

The data from the set of conditions comparing plain metal housing and plastic housing with the other variables (appendix -B) showed no significant interaction at all.

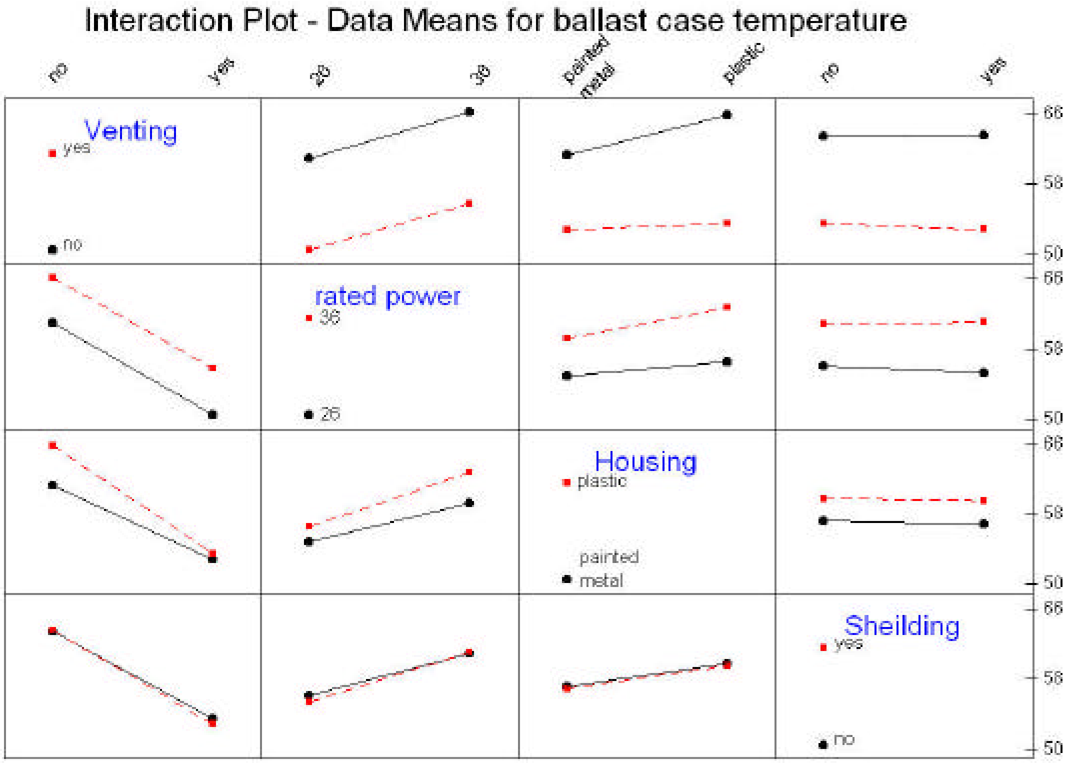


Figure 5.6: Interaction between the four variables on the ballast case temperature

6.0 Conclusions

The pilot tests and the final experiment show that convective cooling by venting the luminaire from top and bottom has the greatest effect in reducing the ballast case temperature.

A luminaire with a painted the metal housing will perform better than plain metal housing because the luminaire as a unit is better radiator especially when there is no venting. Just shielding the ballast from the lamp does not help in reducing the ballast case temperature.

In this experiment, the ballast was mounted to the metal top plate which was attached to the ceiling tile. There was no opportunity for the heat conducted away from the ballast to escape. So its performance compared to the plastic top plate was not too different. Conductive cooling will work only if the heatsink is exposed to cooler exterior. At the same time large heatsinks sticking out of the luminaire would not be a practical solution either.

The next step is to pick a sample of luminaires available in the market and see how the above techniques of cooling can be adapted into the luminaire design with out sacrificing its lighting performance and aesthetic design. A guideline document will be made that will help luminaire manufacturers in making simple changes to the luminaire design and potentially increase the life of the luminaires by reducing the ballast case temperature inside the luminaire.

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Appendix -A

Results from the experiment measuring capacitor temperature as a function of ambient temperature for different ceiling mount residential luminaires.

Manufacturer 1

Information:

Diameter	15”
Diffuser material	glass
Notional lamp wattage	30 Circular 1” diameter lamp)
Potted ballast?	Yes
Capacitor	105°C

Temperature measurements:

	Absolute temperatures		
	Ambient	**Air inside luminaire**	**Electrolytic capacitor**
Luminaire #1	24.4	54.4	67.9
	35.5	63.2	72.3
	44.9	72.0	79.4
	54.9	82.6	88.6
Luminaire #2	24.0	51.9	74.9
	35.0	61.7	83.9
	45.7	73.1	91.6
	55.6	85.6	103.4

Manufacturer 2

Information:

Diameter	14”
Diffuser material	acrylic
Notional lamp wattage	30 Circular 1” diameter lamp)
Potted ballast?	No
Capacitor	105°C 33µF

Temperature measurements:

	Absolute temperatures		
	Ambient	**Air inside luminaire**	**Electrolytic capacitor**
Luminaire #1	23.9	52.5	81.9
	35.5	61.9	86.5
	45.9	73.3	101.8
	55.7	76.8	105.6
Luminaire #2	24.3	49.9	84.4
	39.0	63.9	93.8
	45.0	70.3	99.2
	55.6	82.0	107.9

Manufacturer 3

Information:

Diameter	19”
Diffuser material	acrylic
Notional lamp wattage	39 (3x13W 2-pin CFL)
Potted ballast?	No
Capacitor	105°C, 47µF

Temperature measurements:

	Absolute temperatures		
	Ambient	**Air inside luminaire**	**Electrolytic capacitor**
Luminaire #1	24.3	37.8	80.1
	36.1	51.5	85.4
	45.5	60.8	101.8
	55.6	75.2	108.5
Luminaire #2	24.2	39.0	73.1
	39.2	49.5	84.0
	45.7	57.1	89.2
	55.9	71.8	99.7

Manufacturer 4

Information:

Diameter	13”
Diffuser material	glass
Notional lamp wattage	40 (5/8” diameter circular lamp with inner and outer rings
Potted ballast?	No
Capacitor	105°C, 47µF

Temperature measurements:

	Absolute temperatures		
	Ambient	**Air inside luminaire**	**Electrolytic capacitor**
Luminaire #1	25.8	75.8	82.1
	38.5	84.7	90.4
	45.1	94.8	100.9
	55.3	83.8	111.0
Luminaire #2	25.9	74.8	87.7
	36.4	85.1	102.8
	45.7	94.5	112.0
	55.5	89.9	124.3

Appendix -B

The an analysis of variance was done for the data from the set of conditions comparing plain metal housing and plastic housing with the other variables to find the individual effects and interaction between the variables.

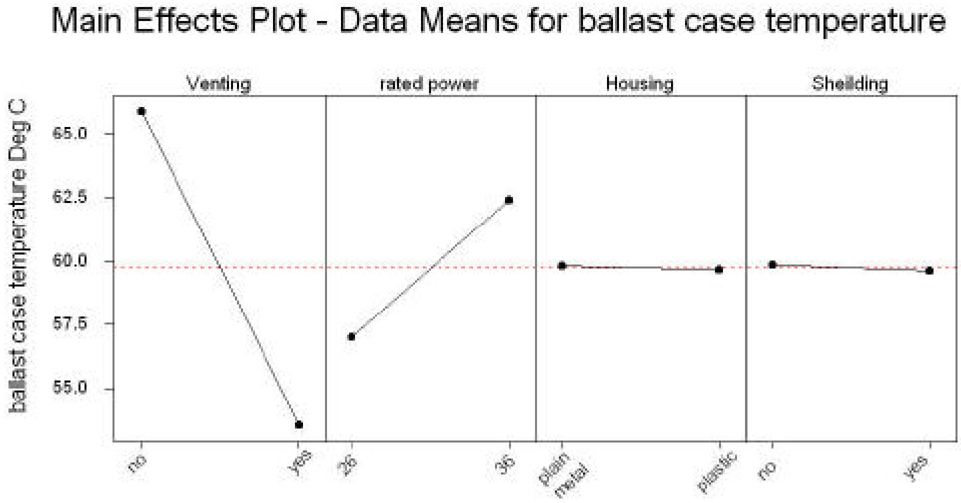

Figure A.1: Main effects of the four variables on the ballast case temperature

Venting showed the maximum reduction in the ballast case temperature followed by the reduction in rated power (figure A.1). The change in housing and shielding had no significant effect on the ballast case temperature.

Figure A.2 shows the interaction between the variables if any. The analysis of variance showed no interaction between the variables.

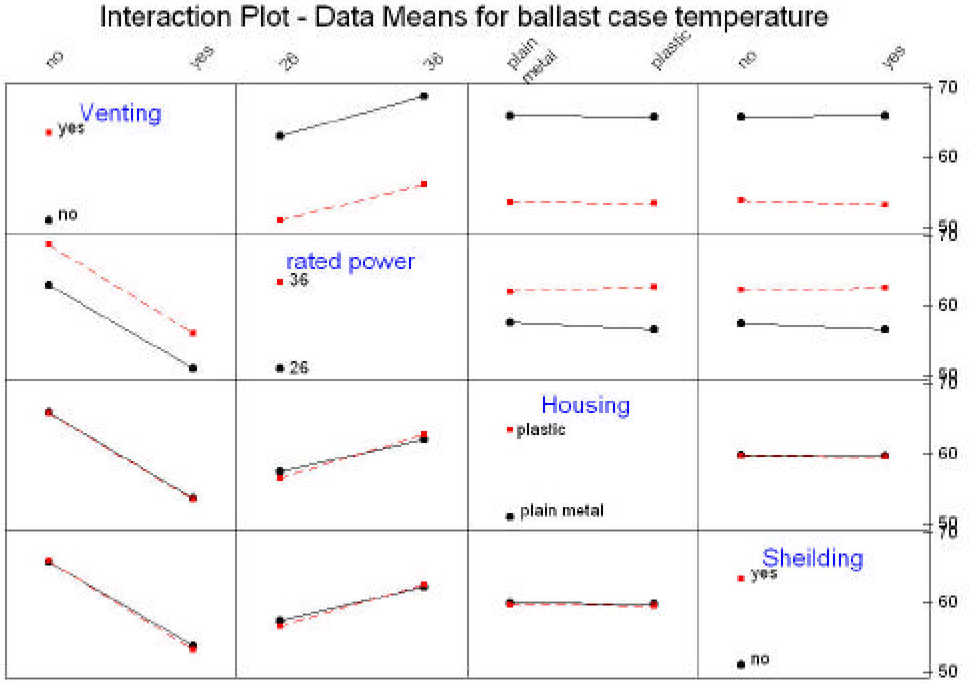

Figure 5.6: Interaction between the four variables on the ballast case temperature