Heat Reduction Treatments for Electrical Cabinets

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Abstract

Main Roads WA has many electrical cabinets and enclosures in the field across the state that are exposed to intense heat and high temperatures. This project investigates and models different solutions to reduce the heat loads on the cabinets and electronics housed inside. A trial with empty cabinets was setup to test experimental heat reduction treatments and data was collected on active traffic signal cabinets in the field to gain a basis for analysis. Models of the heat transfer between the cabinets and the environment were constructed using first principles and accepted methods to predict equilibrium temperatures. By combining real world trials and applying modelling to a variety of locations where cabinets are installed, an informed recommendation can be made on requirement and efficacy of solutions such as sunshades or heat reflecting paint.

1. Introduction

Main Roads Western Australia is investigating various options to reduce high temperatures in electrical cabinets. Excessively high temperatures in desert and remote areas adversely affect the operations of electronics, with potential drawbacks of loss of operational capabilities through shutdowns, expensive unscheduled maintenance and call outs, and possible degradation of operational lifespan. Main Roads' current approach of using high temperature equipment and monitoring is common in industry, however due to the range of different areas in which they operate more suitable solutions for high heat loads may exist.

Current academic literature around reducing or rejecting heat generally follows two areas: active solutions for heat dissipation in electronics, and passive solutions applicable to building and large structures. Examples of active solutions are airtight heat exchangers (Kobayashi & al., 2001) and phase change materials (Zhao, & al., 2016), while an example for large structure systems is underground air pumping and heat sinking (Hong, & al., 2008).

Neither of these dominant areas are applicable to a 1.3 m tall outdoor electrical cabinet; active solutions can compromise the IP ratings, or are power inefficient, and introduce another system to monitor. Most large structure passive solutions aren't applicable to cabinets due to relatively small budgets and tiny thermal mass. Industry solutions such as metal sunshades spaced away from the cabinet do exist (Delvalle, 2019), however academic research is limited.

2. Process

2.1 Experimental treatment trial

The experimental trial consisted of taking 4 decommissioned cabinets that had their electronic components removed and applying experimental heat reduction treatments. One cabinet was painted with Solacoat (heat reflecting paint); a second was clad with Rockwool insulation; a third had galvanized steel panels spaced 40 mm away and bolted to the cabinet as sunshades; and the fourth was left unchanged as a control cabinet.

The cabinets were placed near each other at Main Roads' Jandakot depot. Inside each cabinet a temperature data logger was installed on the centre of a tray two thirds the height of the cabinet. The loggers recorded their temperature every 30 minutes with an uncertainty of ±1 °C.

Due to the ad hoc nature of the trial, some aspects could be improved to better reflect high temperature cabinets in the field. The cabinets had no internal heat generation, they were free standing rather than bolted onto a plinth which fed cables into the ground, the cabinets were closely spaced and interfered with radiative heat to an extent, and there were buildings near by which would unpredictably change the wind and radiation environment.

2.2 Active cabinet data collection

Cabinets in the field that housed operational hardware for traffic signal intersections had high accuracy (±0.2 °C) data loggers installed, logging every 30 minutes. Similarly to the trial, the loggers were installed on a tray and avoided contacting hot surfaces and heat sources. A total of 9 cabinets in batches of 3 have been monitored to date.

In addition to monitoring a single temperature inside active cabinets, a cabinet with a vertical "top hat" extension had three temperature loggers installed concurrently at different heights to measure vertical variations in heat inside a cabinet. One was installed in the extension, another on the tray as before (now at half the height) and the third just above the floor. The method was repeated on a regular cabinet without the extension.

A contact temperature probe (±1 °C) was used to measure the outer surface temperature of the cabinets on each panel and several points inside. The time of day was kept between 1:30-3:00 PM to keep near the maximum cabinet temperature period. 9 measurements on the exterior of the cabinets and then 3 measurements inside the cabinet were taken at each sampling.

2.3 Heat and temperature modelling

2.3.1 Approach

The heat transfer and temperature modelling of the cabinets assumes that the cabinet is at its daily maximum temperature; this maximum was at or close an equilibrium; and no rapidly changing heat transfer was occurring. Following these assumptions, a steady state heat energy equation can be constructed where the incoming heat can be balanced to the outgoing heat by finding the cabinet temperature where the net heat transfer balanced. Each component of the equation is then considered individually. The overall equation and components can be written as Eq. 1. This approach is based on advice and a paper from Prof H.T. Chua (Chua, 2019).

$$\dot{Q} = 0 = Q_{solar} + Q_{internal} - Q_{rad} - Q_{ground} - Q_{conv} \quad (1)$$

The modelling was constructed in Excel and validated using the active cabinet data. The model assumes an average temperature across the entire cabinet and ignores variations across panels and internal temperature. Simplifications were also applied to the environment.

2.3.2 Heat transfer equation components

$$Q_{solar} = \alpha_{surface} \cdot (A_{beam}E_{beam} + A_{diff}E_{diff}) \cdot C_{cloud} \quad (2)$$

Q_{solar} – Represents solar irradiation, both beam and diffuse. The beam and diffuse components have relevant areas and emissive powers with a cloud cover factor applied if necessary. Data is retrieved from the Bureau of Meteorology (BOM).

$Q_{internal}$ – Represents heat generated by internal components by electric power consumption.

$$Q_{rad} = \frac{\sigma \varepsilon_{surface} A_{sky}(T_{cab}^4 - T_{sky}^4)(1 - F_{w,ground})}{(1-\varepsilon_{surface})(1-F_{w,ground}) + \varepsilon_{surface}} \quad (3)$$

Q_{rad} – Represents radiation emitted to the sky from the cabinet. It considers the local sky view factor and sky temperature. Sky temperature is determined from the dew point and cloud cover.

$$Q_{ground} = \alpha \cdot F_{w,ground} \cdot Albedo_{ground} \cdot (E_{beam} + E_{diff}) \quad (4)$$

Q_{ground} – Represents the diffusely reflected solar energy coming from the ground surrounding the cabinet. Although not necessary for the required level of accuracy, the albedo and view factor can be adjusted for each panel of the cabinet. Radiation exchange between the cabinet and ground is not considered since their similar temperatures would have negligible heat flow.

$$Q_{conv} = hA(T_1 - T_2) \quad (5)$$

Q_{conv} – Represents heat dissipated from the cabinet to the atmosphere through convection. It is determined by using semi-empirical methods from academic literature to calculate a Nusselt number for each panel, giving an accurate heat transfer coefficient, h. Forced, natural and mixed convection are use ground wind speed.

3. Results and Discussion

3.1 Experimental treatment trial

The experimental trial showed that a consistent trend between the different treatments. The control cabinet consistently had the highest temperature as expected, followed by the insulation cladding, heat reflecting paint, and (the lowest temperature): the sheet metal sunshades. The temperatures are plotted below in Figure 1 and tabulated in summary in Table 1.

While the drawbacks with the setup outlined in the Process couldn't be mitigated in the circumstances, the trial provided useful practical information early in the study to guide further investigation and decisions. This trial demonstrated that the sheet metal sunshade was effective at eliminating almost all the incoming radiant heat from the sky and ground, while the paint and insulation split the difference between the sunshade and control cabinets. The insulation's weather resistance was poor, so further consideration was discontinued as long-term durability is a key consideration for Main Roads.

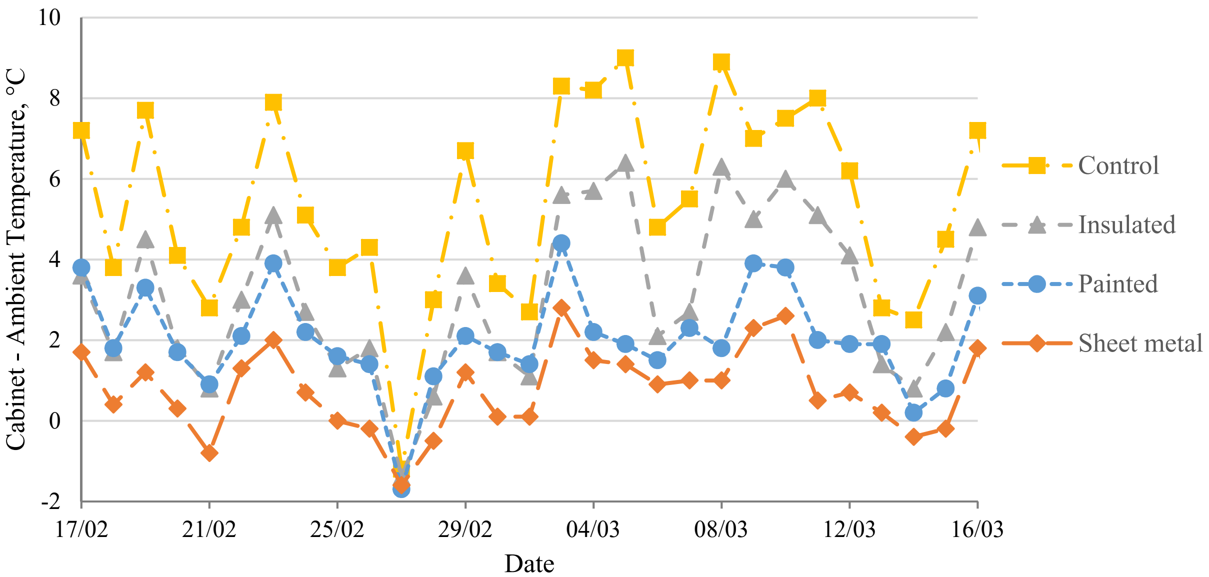

Figure 1 A plot of daily maximum temperature of the 3 experimental trials and a control. Temperatures are shown relative to ambient air temperature.

		vs. Ambient			
Date	**Ambient**	**Control**	**Insulation**	**Paint**	**Sheet**
17/02 - 09/04	30.08	+5.32	+3.15	+1.94	+0.78

Table 1 A table summarising Figure 1 using averages over the date range.

3.2 Active cabinet data collection

The temperature data loggers installed in active cabinets gave several insights into not just the heat from the environment, but also heat distributions inside the cabinet. Figure 2 shows the daily cabinet and ambient maximum temperatures. It is immediately noticeable that the temperature differences between the cabinets and ambient air is much greater than the trial due to internal heat generation in the active cabinets.

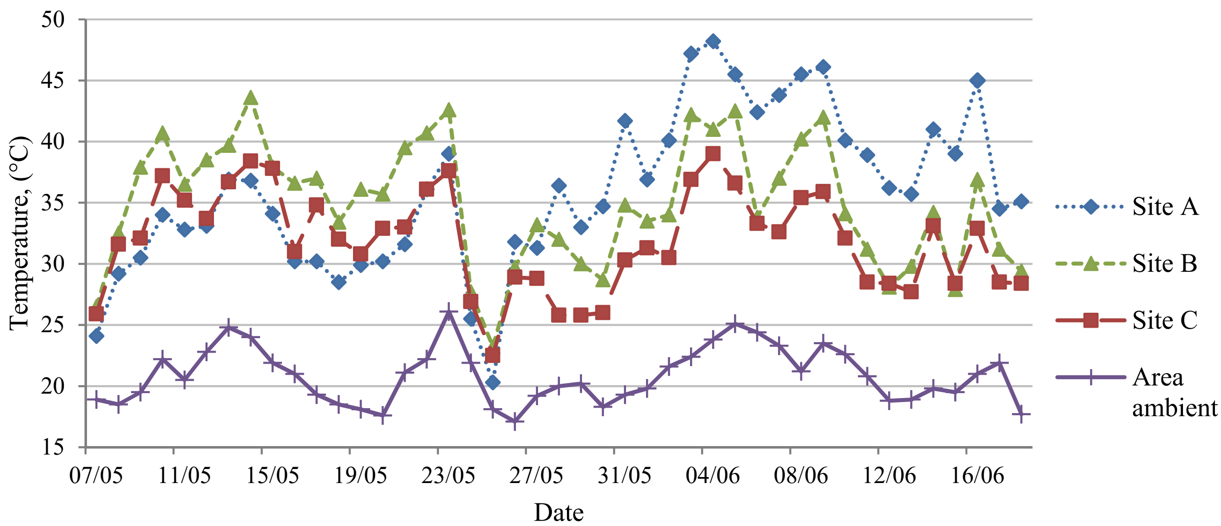

Figure 2 A plot of daily maximum temperature of the 3 active cabinets and ambient air measured in catchment area. The irregular drop on 25/05 was due to a wind and rain. Site A has an irregularity discussed later.

Another piece of information to notice is that after 28/05, the Site A temperature jumped from being the lowest to the highest of the three. The average temperature above ambient before 28/05 was 10.6 °C versus 19.2 °C after, a change of +9.6 °C; this contrasts with Site B and C which had changes of -1.8 °C between the same date ranges.

This 11.4 °C difference was due to a contractor moving the data logger inside the cabinet from the normal place on the rack to a position on top of electronics at the highest point in the cabinet. The rack position was in air temperature one quarter of the height from the top of the cabinet, while the later position was in air at the very top of the cabinet and in contact with electronic components. This inadvertent repositioning demonstrated how the temperature inside a cabinet can differ greatly from an average internal temperature to temperature of air at the top of the cabinet or of a heat producing component.

3.3 Cabinet heat and temperature modelling

The cabinet modelling allows temperatures to be predicted with reasonable accuracy across environments with high heat loads. The model can be used in two approaches; the first can model and predict the probability of a cabinet exceeding threshold temperatures based on historical weather conditions, thereby creating a basis for treatments in the future. An example for a signalised traffic intersection in the North-West of WA is shown below in Table 2.

Probability rating	Likely		Moderate		Extreme	
Ambient temp °C *(chance)*	35	*(0.6)*	38	*(0.3)*	40	*(0.2)*
Wind speed km/h *(chance)*	30	*(0.6)*	25	*(0.3)*	20	*(0.2)*
Solar flux W/m^2 *(chance)*	850	*(0.6)*	900	*(0.4)*	950	*(0.3)*
Cabinet temp °C	40.8		44.9		48.2	

Table 2 Each **c**olumn contains weather conditions for different probabilities and associated cabinet temperature in the bottom row.

The historical weather for the region was analysed from BOM data and three different heat load probability categories established, Likely, Moderate, and Extreme heat loading. The probability for values listed in Table 2 are the likelihood of the environment meeting or exceeding the value listed independently, not necessarily the chance of them all occurring together. The cabinet temperature associated with the conditions in the columns are listed in the bottom row; this sort of analysis demonstrates how the cabinet modelling can be used as a predictive tool for remote regions that can expect high heat loads.

The second approach is to provide an accurate prediction of the temperature of the cabinet with or without heat reduction treatments. For this example, average weather conditions were selected from distant areas across WA, shown on the left of Table 3, and on the right are listed the cabinet temperatures that would correspond to the weather conditions. The temperatures are listed relative to ambient air to standardise the data. This approach can be used to determine whether the time and cost required to install a heat reduction treatment would be worthwhile given the current situation.

Location	Air temp (°C)	Wind speed (km/h)	Solar heat flux (W/m^2)	Normal cabinet (°C)		Heat reflecting paint (°C)		Sunshade (°C)	
Karratha	37.1	20	900	45.5	*+8.4*	40.8	*+3.7*	38.3	*+1.2*
Kalgoorlie	34.5	18.2	1000	44.3	*+9.8*	38.9	*+4.4*	35.7	*+1.2*
Geraldton	32.2	33.0	1000	39.0	*+6.8*	35.2	*+3.0*	33.4	*+1.2*
Bickley	30.7	18.0	1000	40.5	*+9.8*	35.1	*+4.4*	33.4	*+2.7*

Table 3 Left half: rows contain average weather condition for each location. Right half: corresponding temperature predictions for different treatments at each location.

4. Conclusions and Future Work

The aim of investigating heat reduction treatments and creating a model to predict in which environments treatments may be needed and their efficacy has been achieved. As the project progressed, secondary objectives evolved from active cabinet temperature logging, covering finer topics of temperature variation inside cabinets and on exterior surfaces.

Further work to be completed is gathering a statistically significant number of measurements from cabinets' surfaces and installing the three loggers inside cabinets at different elevations as outlined Section 2.2. Future work beyond this project can focus on how heat and temperature vary inside the cabinets; internal geometries and volumes, closed volume natural convection and how air interacts with heat producing components and wall can form a new investigation.

5. Acknowledgements

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