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MODIFICATION OF LUAS HEATING AND VENTILATION SYSTEMS TO REDUCE ENERGY CONSUMPTION

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Abstract

Luas is a state of the art light rail system operating in Dublin Ireland. Being electrically powered, energy is a major operating cost for Luas. One component of rolling stock identified by this research that consumes a disproportional amount of energy is that of the heating and ventilation systems. The heating and ventilation systems fitted to Luas vehicles consume as much as 60% of total vehicle power, and under certain conditions can consume more than that of the traction motors. This paper explores solutions to reducing the energy consumption of Luas heating and ventilation systems. The identified software modifications and hardware installations proposed by this research have been estimated to save over 1,400,000 kWh, 7% of total Luas energy consumption. Based on the current average industry price of €0.12 per kWh, this saving equates to almost €170,000 per year.

Transport systems are not immune to the economic downturn seen throughout the Europe Union. With decreasing passenger numbers, operators are faced with reduced revenue streams, which could lead to reduced services or possible job losses. To avoid such action, operators must reduce their operating costs adequately. Heating and ventilation systems provide passengers with a controlled, fresh, temperature-regulated air supply to ensure maximum comfort. Light rail systems are arguably one of the most difficult transport modes in which to regulate air temperature and quality, due to their short trip distances with a high number of stops.

Each Luas vehicle has three heating and ventilation units. The total rated power of the three systems is 60 kW, power is supplied by way of 750 V DC direct from the overhead catenary supply. Each unit is controlled by a self-contained control unit where in all eventualities, the system endeavours to achieve a variable interior set point between 14 °C and 20 °C. The system is set up to automatically start once the vehicle is prepared (switched on) and will remain on (temperature depending) until the vehicle is de-prepped (switched off).

Testing of the system, recorded a maximum consumption of 60 kWh at an operating temperature of 2 °C. Contrastingly a test conducted at 19 °C the consumption was 3 kWh. Detailed analysis of Luas operations indicates that on average 30% of the time Luas trams are in operation, is not actual passenger service. However the heating and ventilation systems are operational during these periods. Automatically disabling the systems during these non-passenger periods would reduce energy consumption significantly, while not adversely affecting passenger comfort.

To achieve this objective, three modifications have been identified. The first two will automatically disable the heating and ventilation system while operating in periods of non-passenger service when the vehicle is in traction and while the vehicle is stable in the shunt (end of line). The third modification will reduce the set point profile, the system endeavours to reach. The paper describes in detail the software modifications and hardware installations required to roll out these modifications across the Luas fleet.

I. Introduction

Energy is a significant cost for operators of electrically powered rail systems. One component of rolling stock energy consumption is that of climate control systems. Heating, ventilation and air conditioning systems may consume as much as 60% of the total power of light rail vehicles [1]. Heating, ventilation and air conditioning systems provide passengers with a controlled air supply to ensure maximum comfort. These systems deliver a temperature-regulated air supply to the passenger compartments of the light rail vehicles. Such systems should also provide a fresh airflow, which must comply with the European Standards EN 14750-1 of 2006 for rolling stock [2].

With a recent fall in passenger numbers across the European rail industry, operators are striving to increase passenger satisfaction and comfort to make rail transport a viable alternative to the passenger car [3]. One aspect of passenger satisfaction is thermal comfort within light rail vehicles, determined by the air quality. Haller [4] describes thermal comfort as a perception by passengers that the surrounding air is of ideal temperature, humidity and pressure. Heating ventilation and air conditioning systems are installed to achieve optimal thermal comfort, but come at a cost to transport operators.

II. Modeling

Light rail vehicles are arguably one of the most difficult transport modes in which to regulate air temperature and quality. These systems are characterized by their short trip distances with a high number of stops. As a consequence, vehicle doors are constantly opening resulting in the passenger compartment air being recycled at regular intervals. Luas operations show the heating and ventilation system, energy consumption being four times its design allowance [5]. The Luas Red Line is a 16.5 km track section. There are 26 stops along the line from Tallaght to the Point stop. Alstom Citadis 401 style vehicles are operated on the Luas Red Line. The vehicles are 40 meters in length and have an occupancy rating of 6 people per meter squared (ppm²) [6]. Each vehicle consists of five passenger compartments M1, NM, CC, NP and M2 as described in figure 1 below.

The passenger compartment has a total area of 81.3 m³ and a total volume of 179 m³ [6]. According to research by Neu [7] the estimated air leakage area of Luas passenger compartments is 2144 cm². The average U value (overall heat transfer coefficient) of the glass doors and windows within the passenger compartment is 155.68 (W/m²-K). The average R value (thermal resistance) of the surrounding structure is 7.28 (W/m²-K). Comparing these U and R values and the overall insulation envelope of Luas to the values seen in Chow [8], a study of a Hong Kong passenger rail system, the thermal insulation of Luas vehicles is significantly lower. In addition, Luas vehicles stop on average, less than every 3 minutes where the saloon air is almost completely recycled with outside air [9]. As a direct result of this, maintaining the desired interior set point temperature by way of a heating and ventilation system can consume significant amounts of energy and prove inefficient.

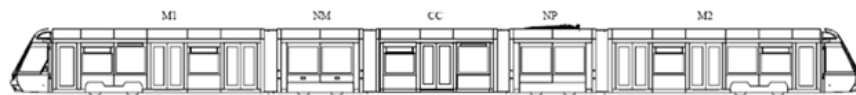


Figure 1: Citadis 401 Style Tram Vehicle Layout

With an average temperature range not exceeding 20 °C in Ireland [10], there is no requirement for an air conditioning module on Luas vehicles. Each vehicle has three heating and ventilation systems installed. The units are located on the roof sections of M1, CC and M2 cars. Each heating and ventilation system consist of a self contained unit which houses a fresh air inlet of 1.32 m², a resistor heater element, a ventilation fan, temperature sensing probes and a control unit, shown in figure 2. The electric resistor heater elements have a rated power of 18 kW, power is supplied by way of 750 V DC direct from the overhead catenary supply. The heater elements are controlled by a proportional integral derivative

regulator connected to the internal control unit [11].

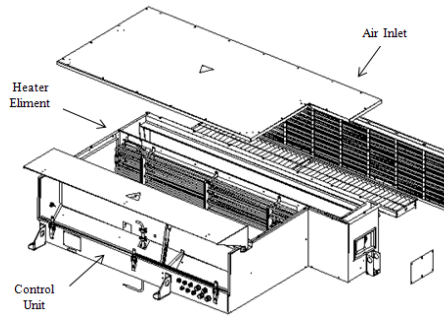


Figure 2: Luas Heating and Ventilation Unit

A fan located within the base of the unit provides ventilation. The fan is powered by an asynchronous motor, which has a power output of 510 W at a Rated speed 1400 r/min allowing for a max Airflow of 3600 m³/h. Both the fresh and recirculated air inlets are controlled by a damper, which has a torque value of 4 Nm and a max opening/closing time of 35 seconds. This damper regulates the flow of both fresh and re-circulated air, and can rotate the ratios between both. Thermostatic temperature probes located, inside the passenger saloon and externally relay temperature signals to the control unit [11]. The heating and ventilation system is controlled by a self-contained control unit. In all eventualities, the system endeavors to achieve a variable interior temperature set point. This set point is determined by a set point formula, which is influenced by the exterior temperature. The set point formula is $20\text{ }^{\circ}\text{C} + 0.25 \times (\text{STN} - 17^{\circ}\text{C})$ where STN is the temperature of the fresh air at the inlet [12]. Figure 3 describes the set point profile. The heated air supplied by the system is fed into a main duct located on the roof of the interior passenger compartment [11].

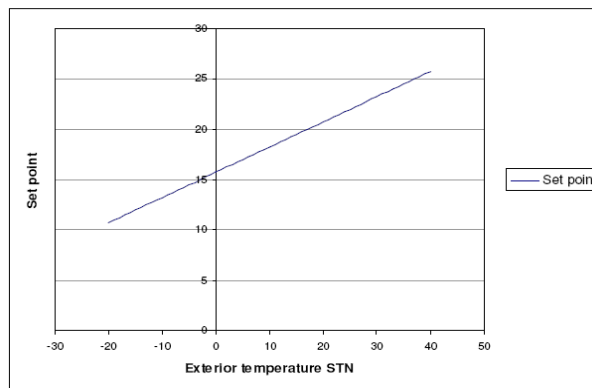


Figure 3: Set Point Profile

There are 3 functional settings to which the system will operate as described in table 1 (STI refers to the interior set point).

Operation	Temperature	Flap Position	Air Flow Rate (m ³ /h)	Fresh Air Rate (ms/h)	Recirculated Air Rate (ms/h)
Heating	When STI < Set point - 3 °C	Closed	3600	0	3600
Heating	When Set point - 3 °C < STI < Set point + 3 °C	Partially Open	3600	900	2700
Ventilation	The heating resistor is switched off and the air fresh inlet is at maximum.	Fully Open	3600	3200	400

Table 1: Heating and Ventilation Operation

III. Consumption Analysis

Based on the power ratings of the Luas heating and ventilation system components, the maximum consumption per vehicle is 60 kW. However it would be assumed that the

actual consumption would be much less than this, especially during summer operations. Tests were performed on the Luas Red Line where, on average an in-service round passenger trip along this route takes 120 minutes [9]. Testing took place during winter and summer months with the temperatures and energy consumption recorded. Table 2 outline some of the results acquired [12].

Test	Day	Time of day	Duration of test (Mins)	Km travelled (Km)	Heater Consumption	Auxiliary Consumption	Temperature (oC)	Heater Consumption (kWh/hr)
Test 1	Sunday	07:14	108	32.4	83	2.8	6	46.1
Test 2	Monday	09:07	121	32.4	96	2.8	9	47.5
Test 3	Tuesday	11:17	106	32.4	45	2	11	25
Test 4	Wednesday	13:10	113	32.4	39	1.9	12	21.7
Test 5	Monday	14:30	120	32.4	46	2	13	23
Test 6	Thursday	01:56	92	32.4	105	2.8	2	68.1
Test 7	Thursday	03:30	93	32.4	102	2.8	2	65.8
Test 8	Friday	11:12	115	32.4	23	1.5	12	12.1
Test 9	Saturday	17:20	121	32.4	3	1	19	1.5

Table 2: Testing Results

From the testing results above, it is clear to see the wide range of energy consumption relative to the external temperatures of operation. With a maximum consumption of 60 kW per tram, test number 6 recorded a max consumption at an operating temperature of 2°C. Contrastingly, test number 9 returned results of 3 kWh where the external temperature was 19°C. From these tests, it is clear that seasons and operating conditions have a great effect on the energy consumption of these systems. The percentage of time the heating and ventilation systems are activated on heating mode can be determined from these tests. [12]. Table 3 indicates these percentages relevant to external temperatures.

External Temperature (°C)	Heating Time (%)
<3	100
4-7	70-90
8-11	50-70
11-15	20-50
15>	0-10

Table 3: Heating Consumption Temperatures

IV. Luas Operations Analysis

An analysis of fleet operations indicates the hours of service operated by Luas. Table 4 indicates the hours of service currently provided by Luas [9].

Green Line Operational Hours									
	In Service	Lay Over	Pull In / Out	Preparation	Total	Total OOS	% OOS to In-Service	Total No of Vehicles	Average Hours OOS per Vehicle
Weekday	189:21:00	34:13:00	06:14:00	07:20:00	237:08:00	47:47:00	25.2	19	2:30:54
Saturday	137:10:00	32:16:00	04:46:00	03:40:00	177:52:00	40:42:00	29.7	11	3:42:00
Sunday	101:02:00	22:46:00	04:38:00	02:40:00	131:06:00	30:04:00	29.8	8	3:45:30
Red Line Operational Hours									
	In Service	Lay Over	Pull In / Out	Preparation	Total	Total OOS	% OOS to In-Service	Total No of Vehicles	Average Hours OOS per Vehicle
Weekday	329:57:00	60:22:00	12:27:00	11:12:00	413:58:00	84:01:00	25.5	27	3:06:42
Saturday	137:10:00	32:16:00	04:46:00	03:40:00	177:52:00	40:42:00	29.7	21	1:56:17
Sunday	185:09:00	52:41:00	08:28:00	06:49:00	253:07:00	67:58:00	36.7	17	3:59:53

Table 4: Luas Operational Hours

- i. "In service" represents the actual hours the Luas fleet is in passenger service.
- ii. "Lay Over" represents the total hours Luas vehicles spend idle at the end of line (shunt area), waiting to depart on the next service.
- iii. "Pull In/Out" represents the time taken to exit the depot before going into passenger service and return to the depot after passenger service.
- iv. "Preparation" represents the time taken by the Luas fleet to prepare tram vehicles, and complete pre departure checks before departing into passenger service.

On weekday operations over both lines, 25% of the time Luas trams are in operation is in fact not actual passenger service. As mentioned above, during this time tram vehicles are fully prepped and functional and as a result the heating and ventilation systems are automatically activated (consumption will be temperature depending). On Saturday and Sunday operations, this non-passenger service time increases to 30% on both lines.

V. Climate Analysis

Ireland's maritime climate is influenced by the Atlantic Ocean and a Polar front that exists around the country during winter months. Winters are cool and generally windy and summer months are mostly mild. According to the Irish Met office, the number of days with an air temperature below 0 °C in Dublin is 10 per year and the average temperature is 10 °C. Table 6 indicates the month average temperatures for the Phoenix Park weather station, the closes weather station to the Luas Red Line [10].

Average Temperature for Previous 12 Months Dublin											
Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
13.5	14	11.8	9.7	5.8	6.1	6.6	8	6.6	9.8	12.7	14

Table 5: Dublin Average Temperatures

VI. Proposed heating and ventilation system modification

There are a number of potential modifications, which will result in reduction of energy consumption associated with the Luas heating and ventilation system. Because of the above mentioned results, the decision was taken to propose modifications that would automatically disable the system in periods of non-passenger operations. These modifications would result in vast energy savings, while not adversely affecting the operation of the heating and ventilation system while passengers are on board. Three modifications have been identified, these include;

- Disabling the heating and ventilation system while operating in periods of non-passenger service (When in traction).
- Disabling the heating and ventilation system while stable in the shunt.
- Reduce the set point temperature profile of the heating and ventilation system.

Depending on external temperature conditions, the consumption of Luas heating and ventilation systems can differ greatly, from a minimum of 1 kWh to a maximum of 60 kWh. Table 6 details the energy consumption savings that could potentially be achieved across both Red and Green lines with the above mentioned modifications.

LUAS RED LINE	Total out of service Consumption 2012 (kWh)	Potential Total Saving (kWh)	Potential saving (€ (@0.12))	Potential Total Saving (€)	GREEN LINE	Total out of service Consumption 2012 (kWh)	Potential Total Saving (kWh)	Potential saving (€ (@0.12))	Potential Total Saving (€)	Potential Fleet Saving
	106367	910,126	€12,764	€109,215		59005	509,227	€7,081	€1,107	€170,322
99587	€11,950		55639		€6,677					
78790	€9,455		44602		€5,352					
102468	€12,296		56942		€6,833					
80555	€9,667		44817		€5,378					
75869	€9,104		43055		€5,167					
46674	€5,601		25886		€3,106					
47121	€5,655		26219		€3,146					
43930	€5,272		24855		€2,983					
47121	€5,655		26219		€3,146					
77630	€9,316		43270		€5,192					
104014	€12,482		58718		€7,046					

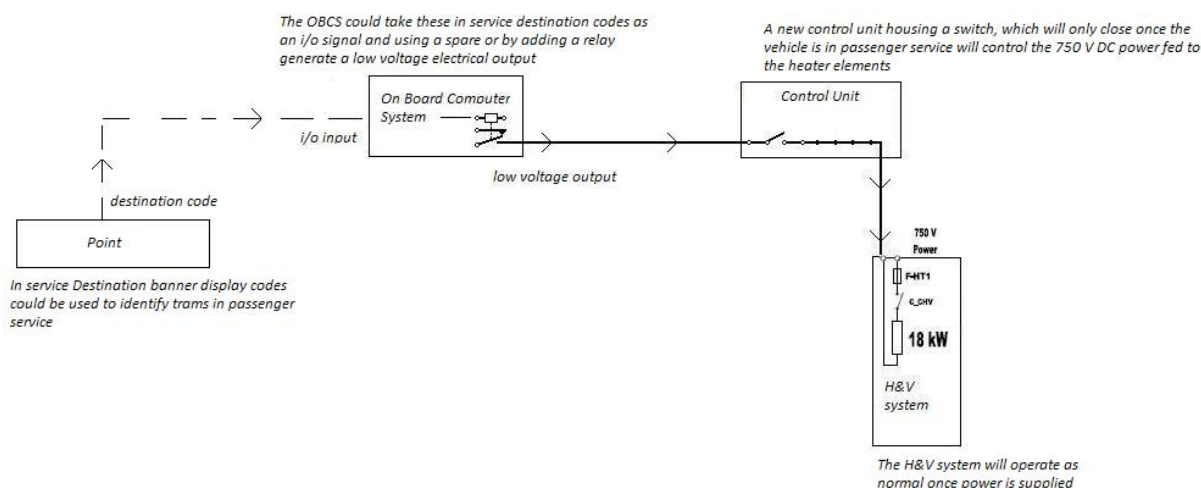
Table 6: Potential Energy Savings of Modification

Modifications to disable the heating and ventilation system have the potential to save in the region of 1,419,353 kWh per year. This is an average figure calculated over a twelve month period. Savings would realistically be greater in winter months and less during summer periods.

The first modification proposed deals with disabling the heating and ventilation system while operating in periods of non-passenger service, but where the tram is in traction. In order to disable the heating and ventilation system during these periods a number of options

were explored. The following modification has been identified as the most simplistic, resulting in the least invasion to Luas vehicles. The modification process is as follows;

Passenger service vehicles automatically display a set destination on the external display banner. This is achieved through the automatic vehicle location system (AVLS), which uses specific service files to determine what service a vehicle is operating and where its destination is. Using ground loops the AVLS can detect when a vehicle is at the designated stop to begin passenger service. Once this loop is detected by the AVLS the external display will automatically display the vehicles destination. Each destination display will have a unique coding within the specific service file. This coding can be used to determine when a vehicle enters passenger service. Each unique coding can be flagged within the service file. Once a flag is identified an input / output signal will be generated and sent to the vehicles on board computer system (OBCS). This connection and communication is already in place on Luas vehicles for other functions and therefore will only have to be modified to accommodate this new process. The OBCS will take this input/output signal once the vehicle enters service and the destinations are displayed, and by adding a new relay generate a low voltage electrical output. This output will then be hard wired to a new control unit. Within this new control unit will be an on/off switch. On command the switch will close sending power to the heating and ventilation system once in passenger service. The system will then work as originally designed. Once the tram finishes service the AVLS will automatically revert back to “not in service”, the switch will then open cutting power to the system. This modification would result in no power being fed to the heating and ventilation system when the tram is not in passenger service. These times equate to 76 hours per week across both lines. Figure 4 describes the modification in schematic form.



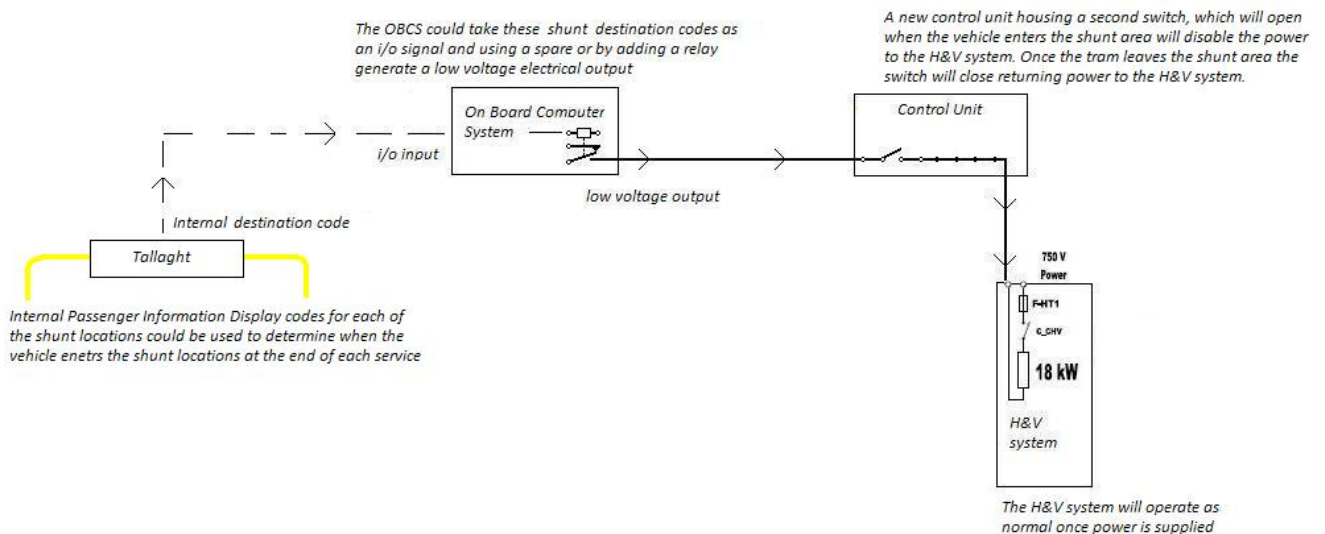
Eoghan Sweeney 25/09/2012

Figure 4: Modification Schematic

To disabling the heating and ventilation system while stable in the shunt a second modification is required. The shunt is the area at the end of each line. Vehicles can spend anywhere from 2-10 minutes in the shunt waiting to depart on their next service as per the timetable. While vehicles are in the shunt, the tram is prepped (switched on) and effectively in service. As a result, the AVLS destination displays are activated and therefore, the above modification will not disable the heating and ventilation system during these periods. A second modification has been proposed for shunt periods. The modification process is as follows;

The automatic vehicle location system (AVLS) communicates with ground loops located around the Luas system. Once a vehicle passes over these loops the AVLS can locate the vehicle anywhere on the line based on loop identifications. Using this system, the destination each vehicle is about to enter is identified by the AVLS and the destination name

is displayed on the internal passenger displays. Each destination display will have a unique coding within the service file. This coding can be used to determine when a vehicle enters the shunt locations. Each unique coding for all the six shunt locations can be flagged within the service file. Once the flag is identified an input/output signal will be generated and sent to the vehicles on board computer system (OBCS) similar to the above modification. This connection and communication is already in place on Luas vehicles and therefore will only have to be modified to accommodate this new process. The OBCS will take this input/output signal once the vehicle enters the shunt locations. By adding a new relay to the OBCS, a low voltage electrical output will be generated. This output will be hard wired to the new control unit as mentioned before. Within this new control unit will be a second switch, located after the first switch, in series. On command the switch will open cutting power to the heating and ventilation system. The system will now not be fed power while in the shunt locations. Once the vehicle leaves the shunt locations the AVLS, through ground loops will recognise the vehicle has left and the switch will close again, sending power back to the heating and ventilation system. This modification would result in no power being fed to the system while stable in the shunt areas awaiting the next departure. These periods equate to 451 hours per week across both lines. Figure 5 describes the modification in schematic form.



Eoghan Sweeney 25/09/2012

Figure 5: Modification Schematic

The original set point profile for the Luas heating and ventilation systems resulted in the system endeavoring to reach an internal temperature of at least 12 °C. From testing it has been found that during winter operations the heating and ventilation system fails to reach the set point as a result of poor insulation and regular door openings. As a consequence the system is in heating mode 100% of the time once the external temperature drops below ~4 °C. Therefore the set point profile is inefficient for Luas operations. In order to reduce the energy consumption associated with the system, the set point formula can be modified to reduce the period of time the system is activated and heating. The modification process is as follows;

The set point profile for Luas heating and ventilation system is determined by a fluid formula, which incorporates the external temperature. The formula is $20\text{ °C} + 0.25 \times (\text{STN} - 17\text{ °C})$, where STN is the temperature of the air at the inlet. This produces a set point profile as displayed in figure 3 above. This formula is set within the control unit of the heating and ventilation system and can be simply modified by connecting into the control unit at source. By modifying this formula to $20\text{ °C} + 0.25 \times (\text{STN} - 50\text{ °C})$ a more realistic and efficient set point profile is achieved. The energy consumption associated with the system will be reduced, as the period of time the system is activated in full heating mode will be reduced. Note that the 3 functional settings to which the system operates will remain as designed and indicated in table 1 above. Prior to installation, it is difficult to quantify or estimate the saving such a modification will make. As Luas vehicles operate at different times of the day with

different passenger loads and at variable temperatures the savings will differ from vehicle to vehicle and from day to day. However, this modification will almost certainly reduce the amount of time the system is on full heating mode, as the internal temperature will be achieved in a shorter time span. Exact energy consumption savings will only be known after the trial period has taken place.

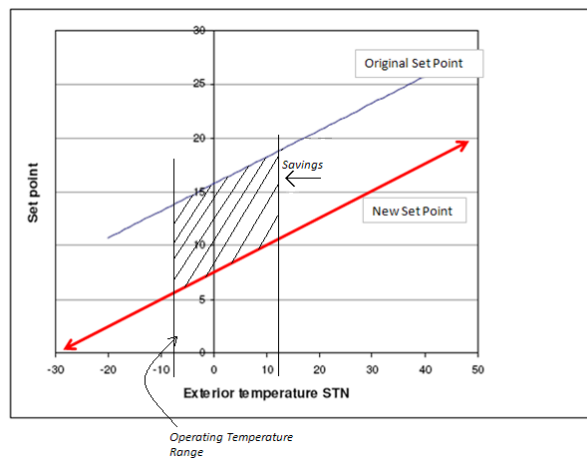


Figure 6: Schematic of set point formula modification

VII. Conclusion

Luas heating and ventilation systems can consume in excess of 60% of vehicle power during winter months, this is 4 times its designed power allowance. In some tests during this research, the consumption of the heating and ventilation system was in fact greater than that of traction motor power. Further analysis the system revealed the inefficient operation of the heating and ventilation system as installed. A conservative estimation found that some 1,419,353 kWh of energy could potentially be saved by modifying the system. To achieve this 3 modifications have been proposed, to disable the system while vehicles are not operating in passenger service and also to modify the set point formula resulting in a more efficient system. The next step in this research is to trial these modifications on a Luas tram. Energy consumption values will be recorded and analyzed for a period of at least six months, incorporating the winter seasons. Future papers will detail the trial period results and include a cost benefit analysis, and return on investment for the project.

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