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Improving Ambulance Compartment Insulation, Energy and Lighting Design

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by

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Abstract

The engine of the ambulance is left running for a majority of the day in order to be prepared for medical emergencies. Ambulance idling leads to the emission of pollution and is a waste energy. Energy is also lost through heat flux and electrical systems which is due to poor insulation and inefficient lighting systems. The goal of this project is to improve the ambulance compartment design in the areas of insulation, lighting and energy efficiency while abiding by the standards specified by the Federal Specification for the Star-of-Life Ambulance (KKK-A-1882E), National Fire Protection Association (NFPA), the Ambulance Manufacturers Division (AMD), and the Federal Motor Vehicle Safety Standard (FMVSS). Modern ambulances are beginning to implement light emitting diodes (LEDs) that are known to be more power efficient than traditional lighting systems such as incandescent lamps. However, the quality of the light is not appropriate for the application of emergency healthcare due to low color rendering index (CRI) and high correlative color temperature (CCT). Hybrid lighting systems (LED-Incandescent) are suggested in order to reduce overall power consumption while maintaining the light quality that is necessary for optimal EMT working performance. The outcome of this research in regards to efficient insulation material suggests that implementing closed-cell polyurethane foam insulation greatly improves sound attenuation and energy efficiency. In order to achieve the goal of this project, research in different scholarly sources identified the technologies currently implemented. A sufficient amount of data was compiled and analyzed to recognize the constraints and limitations of the currently implemented systems. Finally, analysis and comparison led to the development of proposals to the existing problems in insulation, lighting design and energy efficiency.

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Acknowledgements

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CHAPTER 1. ANALYSIS OF INSULATION AND ENERGY CONSUMPTION

1. Introduction

With the increased demand for energy, optimization of system power efficiency has become an imperative issue of concern for ambulances. For instance, efficiency in fuel consumption is one of the main key factors that influence the manufacturing and purchase of vehicles. For this reason modern vehicles are designed to have efficient fuel consumption. Systems are usually energy inefficient due to heat loss, inefficient electrical designs and malfunctioning devices. There can be reduction in the energy waste by improving the insulation design, lighting system and by using automated systems that can have control on the power consumption. This is the case for ambulances where the task is to improve the compartment insulation, lighting design, and energy. Currently used insulation materials have high thermal conductivity which yields to heat transfer. Heat transfer occurs when the external and internal temperatures of the ambulance compartment are not in equilibrium. The temperature inside the ambulance compartment must be maintained in the range between 20°C to 26°C (68°F to 78.8°F). Suggesting the correct choice of insulation materials can also lead to effective dampening of sound. The ambulance sirens and engine as well as other vehicles contribute to the noise that patients and emergency medical technicians (EMT) often complain about. These sounds can be unpleasant and in some cases harmful to the patients and EMTs. In relation to lighting, the ambulance internal and external lighting systems are not efficient due to the type of lamps they use. Major ambulance manufacturers indicate in their specifications that the type of lighting system currently used is based on incandescent lamps. Lamp manufacturers have already launched light emitting diode (LED) models that could replace old incandescent lights; however, LEDs cost significantly more.

In order to propose efficient materials and designs, an investigation was conducted to research common materials used in insulation such as fiberglass and spray foam. We analyzed and compared promising insulation materials such aerogel and radiant barriers. This project emphasized on insulations used in other areas such as spacecraft, housing and other vehicles. In accessing an appropriate proposal to the problems posed by insulation, it was important to investigate the most recent regulations stated by the National Fire Protection Association (NFPA), Federal Specifications for Star-of-Life Ambulances (KKK-A-1822F), American Manufacturer Division (AMD), and Federal Motor Vehicle Safety Standards (FMVSS) concerning the subject matter. The KKK-A-1822F clearly states that any material chosen for insulation must be non-toxic, fire resistant, and non-settling. The plan for this project included making a comparison between the amount of energy that LED and incandescent lighting systems consume. Furthermore, this paper contains a long term cost analysis and provides improvements on the lighting systems that reduce power consumption while maintaining internal light quality.

This report begins by reviewing the basic responsibilities of the EMS and explains the EMS organizational structure. In the same section, it explores different types of lighting and insulation technologies currently being implemented and identifies relevant constraints related to them. The next section suggests three solutions that contribute to improving patient care, comfort, safety and energy efficiency. The last portion of this paper is dedicated to the final remarks that constitute the overall analysis of this paper.

CHAPTER 2. MODERN VEHICLE AMBULANCE DESIGN AND TECHNOLOGY

2. Introduction

In order to develop an understanding of how the primary ambulance users operate, the first section of this chapter discusses the organizational structures of Boston and Worcester emergency medical service (EMS). For further understanding of the EMS, the second section is dedicated to examining the EMS hierarchy and their financial statistics. This chapter presents an overview of the background research done to gain an understanding to what relevant technologies are being utilized to optimize the design of the ambulance compartment. The third section of this chapter focuses on insulation. This portion provides statistical overview of the insulation materials used. It also presents the characteristics and properties of these materials and an in-depth analysis of the limitations that the federal regulatory documents state. Lastly, this chapter presents the types of lighting systems along with their advantages and disadvantages, power consumption and mode of operation. It also contains information about current lighting systems that major ambulance manufacturers implement.

2.1 EMS Organizational Structure

Boston is the capital city of Commonwealth of Massachusetts. It is the largest city for its population located in eastern Mass. In Boston live more than 600,000 residents. Boston EMS is the oldest service provider in the nation and rated one of the best in the country. They provide sophisticated medical care on the streets of the city. Also, they are recognized nationally as the leader in innovation for emergency medicine. Boston EMS is one the busiest EMS in the country because of the fact that they respond to an average of 300 emergencies per day and 100,000 emergencies per year. They obtain the latest technology and the best medicine available. Boston EMS department has over 350 highly skilled and trained EMTs who are always ready to take care of medical emergencies. To ensure best medical care in any circumstance, Boston EMS collaborates with other departments like public safety, healthcare, private care providers etc., to be prepared for any disaster that may occur. The Department of Boston EMS prepares the public for large scale emergencies by educating the Boston community to stay healthy and utilize appropriate safety measures through many specific designed programs [1].

2.1.1 Boston EMS Organizational Structure

Like any well-structured organization, the Boston EMS has a well-defined operational and organizational structure. Figure 1 shows the organizational structure of the Boston EMS. This structure contains an overview of the various personnel in charge and who to contact for any specific question or concern. On the top of the chart is the Boston public health commission executive director. There are five departments under supervision of the Boston EMS superintendent in chief. At the end of the chart are the EMTs/ Paramedics; they are on the ground receiving 911 calls and doing the job that makes the Boston EMS the best in the nation [1].

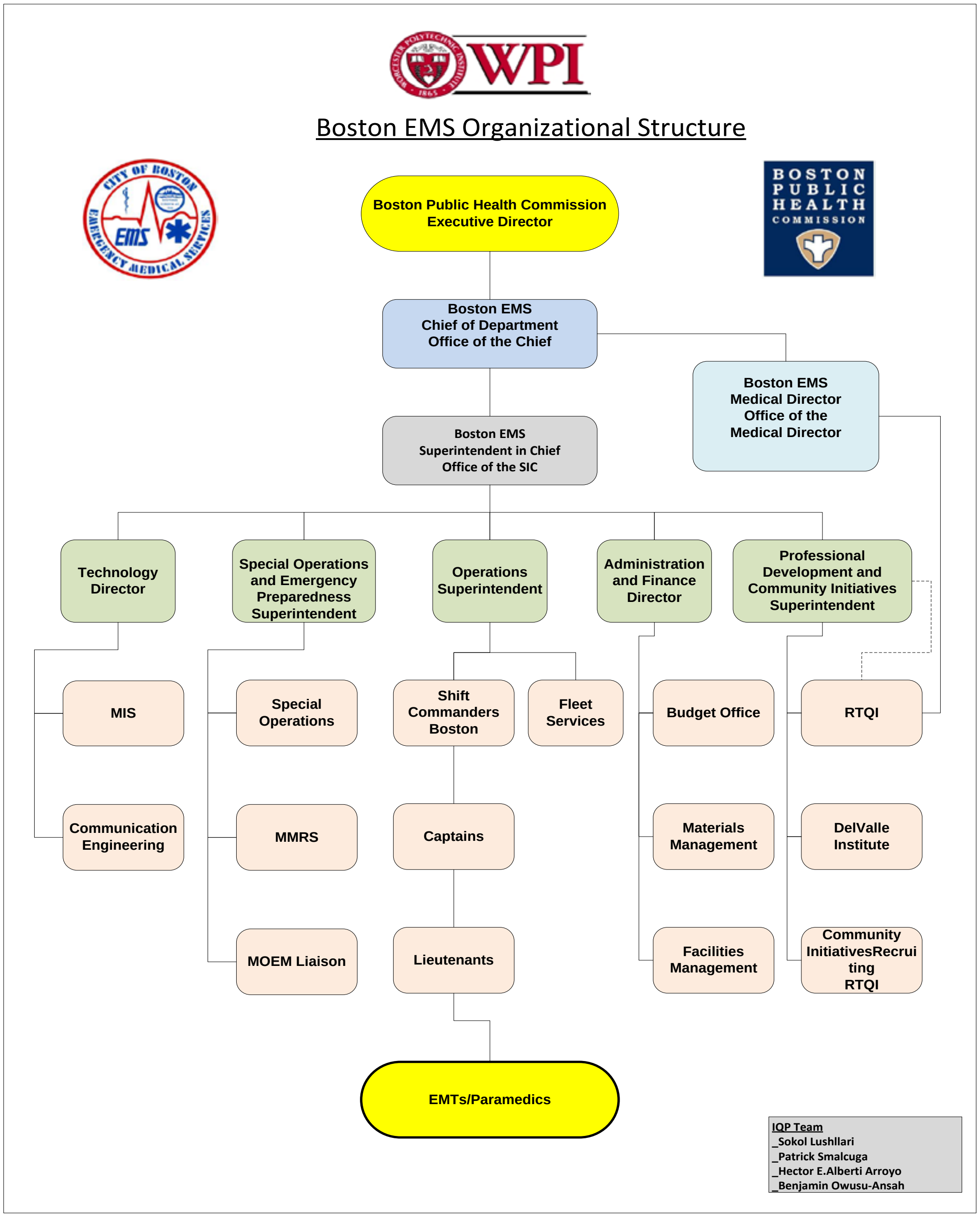


Figure 1: Boston EMS Organizational structure

Boston Public Health Commission (BPHC) is a public department that protects the health of the Boston citizens by promoting a healthy community. This department has seven members in the board. The executive director of the BPHC is Dr. Barbara Ferrer. Under the Technology Director is Management Information System (MIS). MIS manages all the information of different departments. Metropolitan Medical Response System (MMRS) responds to mass casualties. It prepares the city for any big emergencies through special training. Fleet services are responsible for checking the ambulances to ensure safety. They are very well trained and certified by Automotive Service Excellence.

2.1.2 Boston EMS Payment Records

Every year Boston EMS publishes an annual report. In each annual report is the description of the job of the paramedics and their achievements. Furthermore, the annual reports contain analyzed data like patient satisfaction survey, response times, and numbers of emergencies. There are records of the incident priorities of the Boston EMS describing the types and intensity of incidents. Table 1 shows the records of incidents involving human health collected by Boston EMS based on their priorities.

Table 1. Number and percentage of incidents by priority

Incident by Priority	Number of Incidents	Percentage (%)
Priority-1	30441	28
Priority-2	52732	49
Priority-3	23214	21
Priority-4	1956	2

Each priority describes the type of incidents from small injuries to life threating conditions. Figure 2 illustrates the data shown number and percentage if incidents by priority.

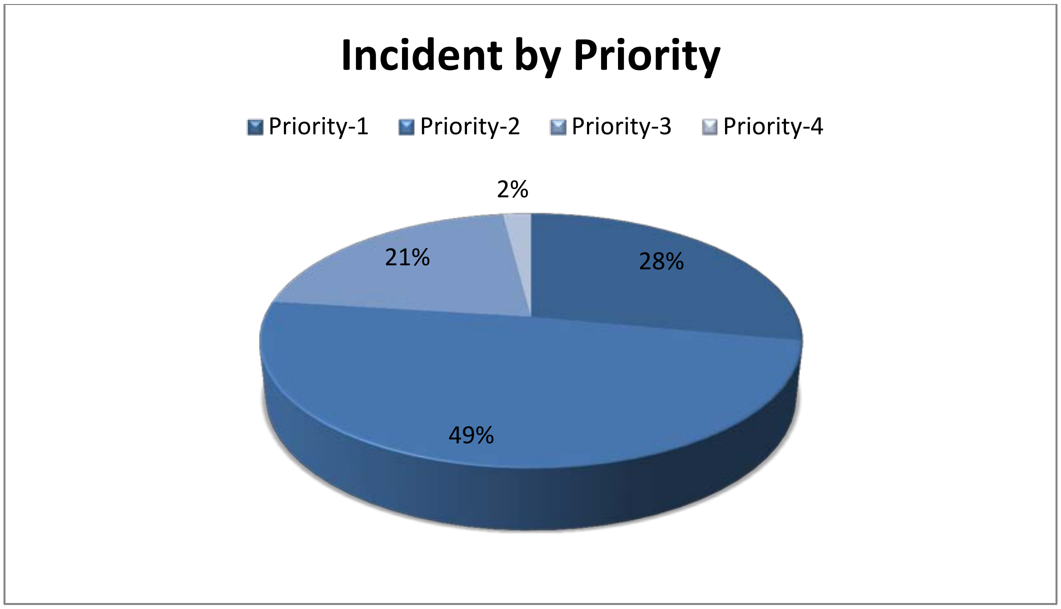


Figure 2: Percentage of incidents by priority

Priority-1 incidents are life threating emergencies which constitute 28 percent of the chart; these emergencies include cardiac arrest and unconsciousness. Priority-2 incidents are potentially life threatening incidents. They make up half of the emergencies. They include lacerations with controlled bleeding and orthopedic injury. Common orthopedic injuries are joint disease, fracture, and sprain. Priority-3 incidents are nonlife threating injuries. As seen from the pie chart Priority-4 emergencies compose just 2% of the total forms of emergencies all combined. In these types of emergencies there are no EMS responses until the police or any other agency confirms the need for EMS intervention. The primary reason for not responding immediately is to save time and resources for other emergencies [1].

Besides records of incidents collected by Boston EMS based on their priorities, there are also records collected by the Boston EMS describing the number of transportation by age of people injured. The data in Table 2 shows the number of transportations of people injured in 2011. These accidents are categorized by patient’s age.

Table 2: Percentage of people by age that needed medical emergency

Transportations by Age	Number of People Injured	Percentage (%)
< 15	5047	6
15-24	11213	14
24-44	21071	27
45-64	25344	32
65-75	6438	8
>75	9579	12

The first column shows the intervals of each age category. The second column has the total number of injuries for each specific category and the third column represents the percentages of each category [1]. Figure 3 is a graphic representation of the information provided in Table 2 showing the transportation of injuries by the Boston EMS across age distribution.

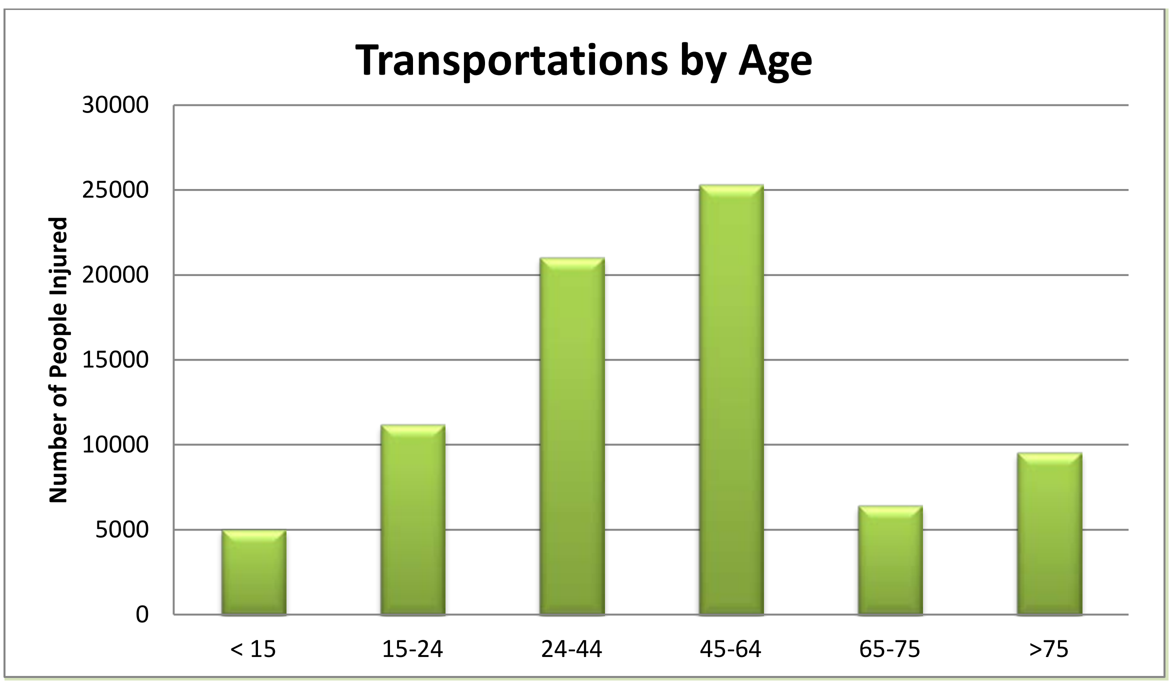


Figure 3: A bar chart of the people by age transported to hospital

Figure 3 shows ages between 45 and 64 are the most critical ages of life. This is because most of the transportation carried out by Boston EMS due to injuries is in these age range. It is interesting that the ages between 24 and 44 are the second on the list. This suggests that people who are 24 years of age should be careful. Having looked into the operations of the Boston EMS, it is imperative that we spend some amount of time looking into the local EMS system, hence, Worcester EMS.

2.1.2 Background for the Worcester EMS

Worcester city is located in the central Massachusetts. It is the second largest city in Massachusetts based on its population.EMS was started by the Worcester City Hospital around 1977. They provide emergency ambulance services to the City of Worcester and the Town of Shrewsbury. Worcester EMS is part of the UMass Memorial Medical Center. Worcester EMS center was visited by IQP and MQP teams at the beginning of the academic year 2012-2013. All the teams had the chance and the privilege to meet with Chief of EMS Stephen Haynes, EMTP [2].

Figure 4 shows the organizational structure of the Worcester EMS it is designed in Microsoft Visio by IQP team. This hierarchy is based on the Worcester EMS website

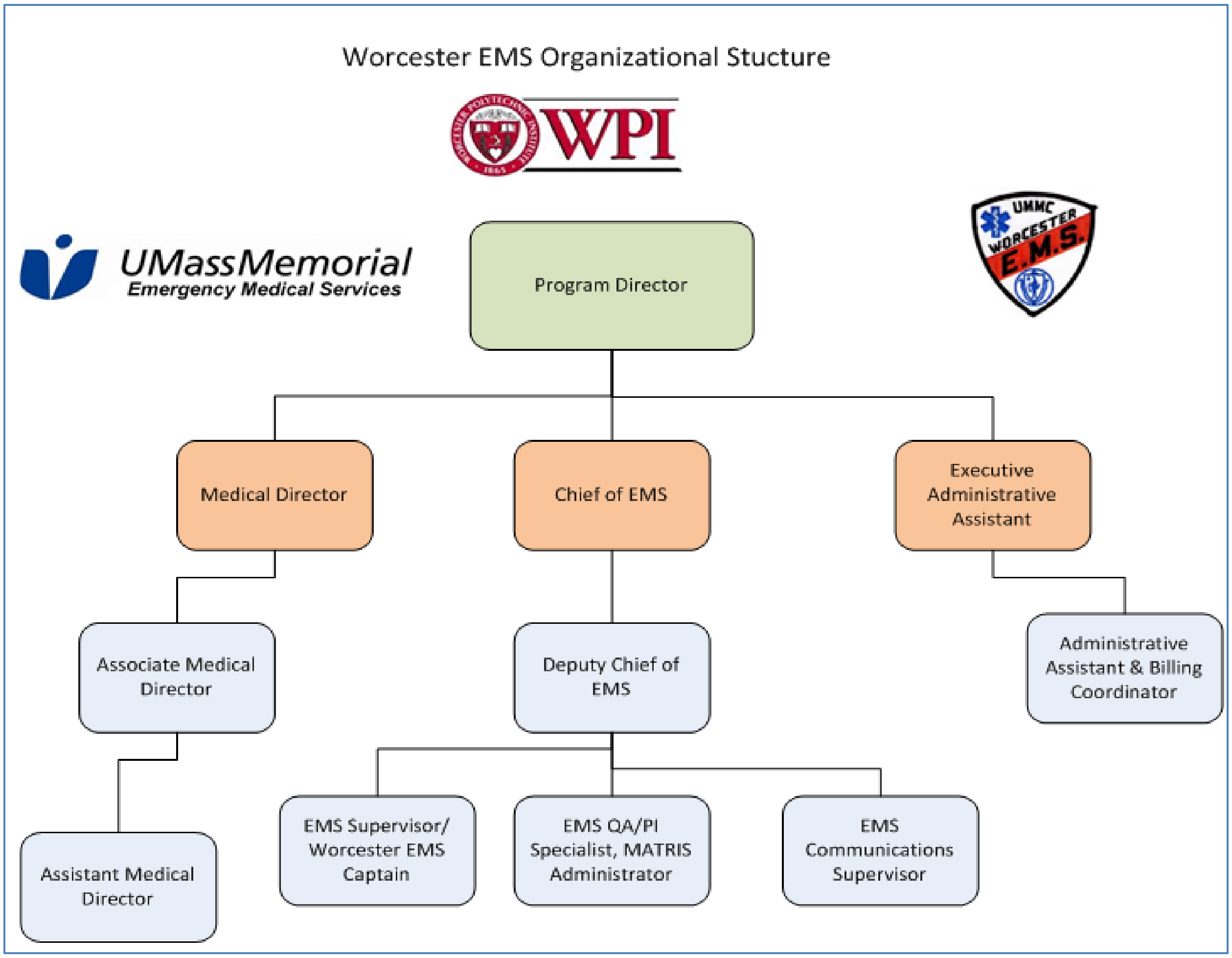


Figure 4: Worcester EMS Organizational Structure

The program director of Worcester EMS is Daniel Meisels, MPA, EMTP, CMTE. He holds a public administration master's degree and is a certified medical transport executive. Marc Restuccia is the Medical Director with over 20 years of experience in the field. Stephen Haynes, Chief of EMS and one of Worcester's first EMS has over 30 years of experience. He is responsible for all 911 emergency response team.

To ensure proficiency and efficiency in the EMS, there are designed education and specialized training organized within specific periods of time to keep the EMS personnel up to date as far as the effectiveness of their duties are concerned.

2.1.3 EMS Levels and Education

Table 3 describes all the levels of Emergency Medical Services (EMS) and the amount of hours trained for specific skills and education.

Table 3: EMS Levels and their responsibilities

EMS Levels	Hours of Training	Trained for:	Education
First Responder	40-60	*Automatic External Defibrillator (AED) *Bandaging *Oxygen *CPR *Administration *Splinting * Emergency Child Birth	EMT approved course
EMT-B (Basic)	150	* All the above *Epinephrine with an Epi-Pen *Administration of nitroglycerine *Aspirin and Activated charcoal *Nonvisual Airways	EMT approved course
EMT-I (Intermediate)	250	*All the above *Cardiac monitoring *Intravenous access (IV)	EMT approved course and Advance EMT course
EMT-P (Paramedics)	1500 (18-24 months)	* All the above * Advance airway management *Pharmacology *Pleural decompression (inflate lungs)	College Degree

First Responders, for instance police officers, receive training to do some basic medical services [3]. They go through training to give CPR and Bandaging. The training and the course has to be EMT approved. People in the category of the EMT-basics are capable of the same skills as First Responders in addition to dealing with trauma and administration of nitroglycerine. EMT paramedics primarily respond to 911 calls and possess training to give a variety of medical treatments such as IV administration and stitching wounds. They must attend college, complete an associate's degree and attend 1,500 hours of training [4].

EMS training provides education in the usage of health related emergency equipment and specialized health related areas. Automatic External Defibrillator (AED), one of the essential devices used in health related emergencies, is an electronic device which diagnoses patients with cardiac arrest. The cardiac arrest results in many deaths in U.S.A. The AED device regulates the rhythm of the heart and it is easy to use for basic service level EMTs [5]. Intravenous access (IV) is to have access and proper training in infusing liquid substances into the veins of patients. This liquid substance is a medication inserted directly into the blood stream. Pharmacology is a branch that manages drugs; in this case, paramedics obtain training to manage all the drugs available to them. Also, paramedics are capable of doing pleural decompression procedures for different types of traumas. Though EMS in general provides similar services, there are two basic types of EMS which are being discussed in the next section.

2.1.4 Public and Private EMS

The two main types of EMS are public EMS and private EMS. The EMS system is mainly founded by tax money or user fees. Private EMS provides a better service because of competition. Private EMS combines the latest technology to make a better system. They compete with other EMS services to provide the quickest response time. They are very committed to the innovation of new technology to increase their service performance. For instance, Boston EMS is one of the best in the country for the technology and performance. Boston EMS receives 23% of its funding from the city of Boston, 76% comes from the user fee and 1% from grants as shown in Figure 5.

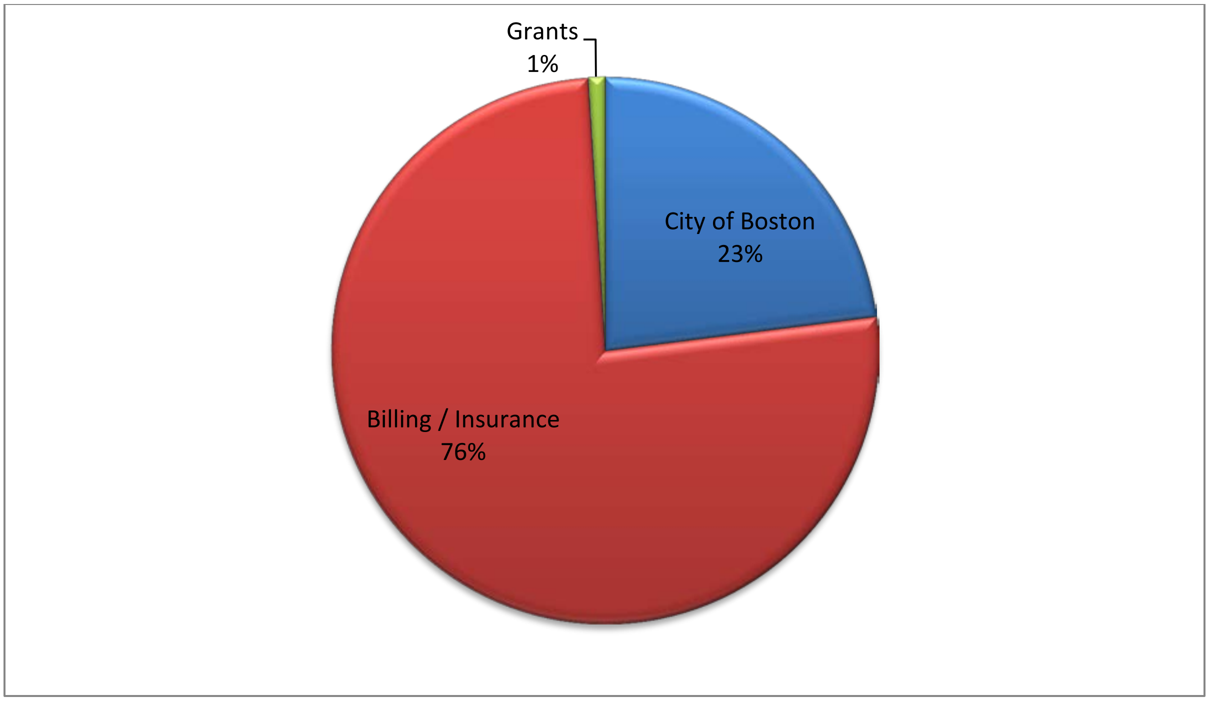


Figure 5: Boston EMS Funding

Boston EMS receives a bulk of its funds from those who receive its services. The insurance companies that cover the bills of the EMS service are Medicare, Medicaid, private insurance companies and from the pockets of the patients. Medicare is government for the elderly and people with disabilities. Similarly, Medicaid is a federal program for people with low income who cannot afford private insurance.

The pie chart in Figure 6 shows the coverage of the patients who have taken treatments by Boston EMS [1].

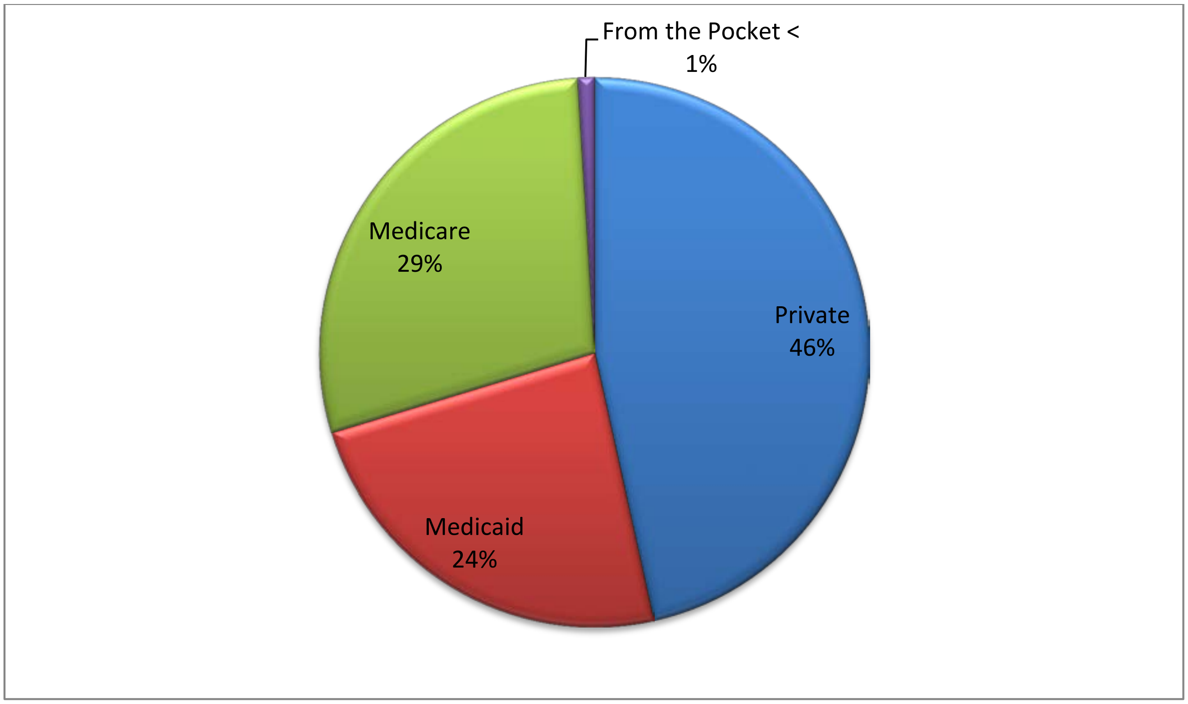


Figure 6: EMS Billing Coverage

From the chart in Figure 6, patients having private insurance have the greatest coverage. Private insurance covers majority of Boston population because the composition of work force is greater than the population receiving Medicaid and Medicare.

2.2 Background for Insulation Materials

Insulation is a material or a combination of materials, with air spaces, which function together to prevent the transfer of heat with appropriate temperature under ordinary conditions. [6].Modern ambulance insulation has the problem of not being effective in keeping the compartment at temperatures specified by KKK regulation (20°C to 26°C or 68°F to 78.8°F). . Failure to meet these temperature specifications could potentially cause the patient anxiety and could worsen the condition of patients in critical conditions. Commonly used Ambulances face the problem of not having an insulation that reduces the sound intensity which could lead to sound-induced headaches and patient discomfort. An improvement to the weight of the insulation materials along with the consideration for cost and effectiveness are the major aspects this project works on to enhance. Ambulances have payloads that must be taken into consideration and by reducing the weight of the insulating materials the possibility of indirectly improving the ambulance by allowing more equipment and features to be implemented could be achieved.

However, it is imperative that thorough investigation is made in an attempt to look into all the specifications and standards outlined in the Federal Specifications for Star-of Life Ambulances (KKK-A-1882E), the National Fire Protection Association (NFPA), Ambulance Manufacturing Division (AMD), Federal motor vehicle safety standards (FMVSS) and the Society of Automotive Engineering (SAE) in relation to insulation, lighting design and energy. Having a keen insight of the required information, these specifications and standards outlined will go a long way to provide the yard stick in measuring what could be done, limitations and restrictions as far as the desire for improvement of insulation of ambulance compartment is concerned. The first to be looked into is the KKK-A-1882F and NFPA specifications on insulation.

2.2.1 Regulatory Standards for Ambulance Insulation

Emphasis will be placed on the specifications stated in the June 1st 2002 Federal Specifications for Ambulances; [7] and the National Fire Protection Association – 1917, 2013 Edition [8] as far as the insulation of the ambulance patient compartment is concerned. According to the specifications listed in 3.10.16 of the KKK-A-1822F, the entire components of the ambulance patient compartment consisting of the roof, ends, sides and body must be thoroughly insulated. The insulation must be a non-settling type. This means that the material used for the insulation must possess the appropriate properties and capacities that enable it to maintain its thermal resistivity (R-Value) without settling over time. Again, the insulation material must be fire retardant, non-hygroscopic, non-toxic, and resistant to rust, mildew and the collection of small insects like lice, fleas, and bedbugs (vermin). By non-hygroscopic, the properties of the material used for insulation must be such that it doesn't absorb moisture from the air. Not only must the insulation material align with the specifications listed above, it must also have the properties that will make it a great barrier between the ambulance compartment and external world; thus, preventing the permeability of noise outside the compartment of the ambulance from entering inside the compartment as much as possible; which if underestimated can create issues for both the patients and paramedics.

The insulation of the ambulance compartment must improve the capability of the environmental systems as stated in sections 3.4.2 and 3.13 of the KKK. As far as temperature is concerned, the insulation of the ambulance compartment must be able to accommodate for ambient temperatures between -34°C to 52°C in order to make possible the appropriate storage of temperature sensitive medications (section 3.4.2 of KKK). When being operated between the temperatures of -18°C to 35°C outside ambient temperature, there should be a constant temperature range of 20°C to 26°C in the patient compartment of the ambulance (section 3.13.1 of KKK).

After cabinet insulation, the width of the aisle between the cot and base of the squad bench of the compartment must be 46 cm +/- 15 cm, while from the floor to the ceiling shall measure 152 cm (section 3.10.4 of KKK). Below the ambulance, body skirts shall not exceed 8 cm (section 3.10.6 of KKK). It is imperative to remember that the overall width of the ambulance bodies having a single pair of rear wheels shall be between 200 cm and 213 cm (section 3.4.11.2 of KKK). Including all roof mounted equipment, but excluding the radio antennas, the total height of the ambulance must not exceed 279 cm (section 3.4.11.3 of KKK). For sound deadening and the prevention of corrosion and stone damage, the material used for the body of the ambulance should be undercoated with sandless petroleum base undercoating (or other equivalent highly efficient undercoating materials) of thickness ranging from 1.6 mm to 3.2 mm. However, it is specified by the manufacturer the general overall weight of the Type IAD and Type IIIAD ambulance is approximately 14,000 Lbs. (section 3.5.2 of KKK).

The body of the ambulance must be made of either welded aluminum or other lightweight materials which are equivalent or greater than aluminum in respect to their useful and appropriate properties, and must all have high resistance to corrosion. To a greater extent, the material used must be capable of resisting external impacts from penetrating into the patient compartment, and must be strong enough to carry the required weight of the mounted equipment and all other accessories. Wood-wood materials must not be used unless laminated with plastic. It is important that the body material meets that Static Load Test for Ambulance Body Structure, AMD Standard No. 001 (3.10.5). For Type I and III ambulance, each of the two doors must have the height of 117 cm and width of 112 cm coupled with a minimum of 1613 sq. cm per door (3.10.8). The side walk-through doors must have the height of 117 cm and width of 43 cm. From the interior of the Type I and III ambulance, the dimension must be as shown in Table 4.

Table 4: The Interior Dimension of the Type I and Type III Ambulance

Dimension	centimeters	inches
Width	76	30
Diameter	46	18
Height	102	40

From Table 4, the interior dimension of the Type I and Type III ambulance are 76 cm, 46 cm and 102 cm for the width, diameter, and height respectively. It is imperative; therefore, that any material used for insulation meets all the required specifications and dimensions listed above.

As far as materials for insulation are concerned, aluminum is the standard for modular ambulances. Nevertheless, other appropriate materials such as fiberglass can be used. Fiberglass, however, shall not be exposed to water (3.10.16). The next standard to investigate is from the National Fire Protection Association (NFPA) in light of insulation.

The National Fire Protection Association (NFPA) of 1917, 2013 Edition does not give a lot of specifications as far as insulation is concerned. Just as it is stated in the KKK-A-1822E, the materials used for insulation must be non-settling type, non-toxic, non-hygroscopic, and resistant to mildew, vermin (NFPA 6.15.1). It also emphasizes that if the insulation material is made up of fiberglass, it should not be exposed to water (NFPA 6.15.2).

After looking at the specifications outlined in the NFPA, the next to look at are the specifications and standards given by the Ambulance Manufacturing Division (AMD).

The AMD is a division of a much greater organization known as the National Truck Equipment Association (NTEA). The purpose for this standard is to improve the ambulance body in order to reduce injuries and fatalities due to the failure of the structure of the ambulance body. To do so the AMD standards state performance requirements. The AMD standards provide methods that test for the credibility of the vehicles. The AMD works with other regulatory organizations such as the KKK-A-1822E in improving these standards. The KKK-A-1822E requires that all ambulances conform to the specifications of the AMD and Federal Motor Vehicle Safety Standards (FMVSS). The AMD is designed to reinforce the regulations and standards specified by the KKK-A-1822E by providing standards and procedures in verifying the reliability and safety of the ambulance body design [2]. In this report we will take into confederation some of these regulations and discuss their relevance to the project. The following are some of the standards of the AMD relevant to this project.

Although acoustics and vibration analysis are not quite within the scope of this project, when searching for the optimal insulation material sound dampening is an important factor. Insulation contributes to shielding harmful sounds, especially sounds created by the siren which rings on average of about 120 decibels. According to the standards given by the KKK-A-1822 E the sounds within the patient compartment cannot exceed a sound intensity of 80 decibels. This means that all the materials that incorporate the ambulance patient compartment must dampen the sound intensity of approximately 40 decibels. This dampening approximation does not consider sounds created by the ambulances engine or any external sound that the environment may provide.

According to the AMD standard 006 this measurement is made with a microphone which is suspended vertically 6 inches above the normal position of the patients head on the primary cot. This test is done with no large reflective surfaces around the ambulance for at least 50 feet and all of doors, windows, and vents are closed. In addition, all the heat blowers/air conditioners, sirens, and engine will be turned on such that the greatest sound intensity that the ambulance environment can create would be in play.

The AMD requires that the heating system should be sufficient enough to raise the thermocouple temperature to a minimum of 68 degrees Fahrenheit (24 degrees Celsius) within 30 minutes assuming the original temperature is 0 degrees Fahrenheit(-18 degrees Celsius).

This test is performed with all of the compartment doors, cabinet doors, hood, and exterior compartment doors opened throughout. 9 thermocouples are placed along the centerline of the patient compartment and are equally spaced. 3 thermocouples are to be 7 inches above the floor, another 3 thermocouples should be 7 inches from the ceiling and finally the other 3 thermo couples should be placed midway between the ceiling and floor but not directly under the dome light.

As far as great insulation materials are concerned, most of the standards including the KKK-A-1882F make mention of aluminum. However, it is stated in the specifications that materials of equal or greater quality could be used. At this point, different insulation materials are going to be investigated to study their respective properties such as thermo conductivity, cost, efficiency, and weight. Among the materials and forms of insulation being studied are fiberglass, spray foam, aerogel, loose-fill and batt insulation, reflective insulation and multi-layer insulation.

2.2.2 Types of Insulation Materials

In the market are different types of insulation. They are rated by their R-values which depend on the type of material, thickness, density etc. Some insulations require professional installation because it is important to underline that if they are compressed, R-value changes. The R-value of any insulator is stated on its label because it is a rule set forth by the Federal Trade Commission (FTC) in order to protect the buyers. Label also contains information about safety, health and fire-hazard [9].

Fiberglass

The most common insulator used today especially in walls of houses is fiberglass which comes in a variety of different forms. The most used is fiberglass blankets which come in the form of bats or rolls as shown in Figure 7. They come in one standard size and can be cut easily to any size [9].

Figure 7: Fiberglass bats

Fiberglass batts are very easy to deal with however they lack the ability to conform to tight spaces that can lead to portions of the wall not being properly insulated. However, fiberglass can be very inexpensive and provide quality insulation for certain insulating applications.

Another form of fiberglass is loose-fill . This type of insulation requires profesional installation and the right equipment to blow the insulation. Loose-fill fiberglass is ideal for filling cavities in walls [9]. Poplyicynene insulation is put on by a professional with special equipment which mixes and sprays the foam. This insulator is an open-celled foam. The foam lets the water vapor to penetrate the material easily, but they have a smaller R-value than clossed cell foams with the same thickness [9].

Next is the study of reflective insulation and its potency is controling heat flow as a result of radiation.

Reflective Insulation and Heat Flow

Figure 8 shows the three main factors affecting heat flow from hot temperature to cold temperature.

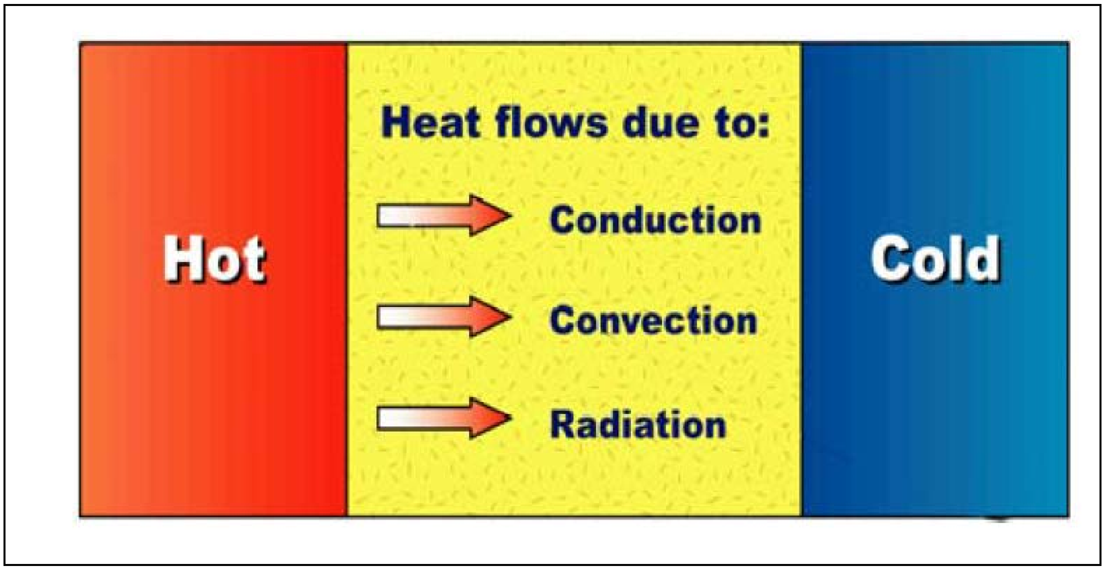


Figure 8: The heat flow diagram

As shown in the Figure 8 heat flows from hot enviroment to cold due to conduction, convection and radiation. The last factor, radiaion is prevented in houses by reflective insulation system. This system is efficient in derceasing downward heat flow. The radiant barriers have less than 0.1 emittance and 0.9 and more reflectance [9].

Aerogel

Aerogels are a state of the art material currently known as the lightest material known to man. Aerogels are derived from gel which is a two phase material of liquid and solid. If the liquid component of a gel is removed and replaced with a gas then what is left is an incredibly light substance with outstanding physical properties further discussed. Aerogels consist of a cross-linked skeletal structure that can be made by different types of materials. Silica aerogel is perhaps one of the most common aerogels and is derived from silicon dioxide. All aerogels are extremely porous with holes having average diameters of 10nm to about 100nm. Aerogels are typically anywhere from 85% to 99.8% of the original gels volume [10]. Though it has very low mechanical strength it is has very low density which can be as low 3 kg/m^3 [10]. Aerogel's low density combined with its extremely low thermal conductivity makes it one of the most promising materials used for insulation. Making sure the payload of an ambulance is as low as possible is ideal in order to allow for the addition of new medical equipment or other applications that many be useful for the EMTs and patient satisfaction.

One of the many reasons why aerogels have low thermal conductivity is because it is resist to all sorts of heat flow. Aerogel has extremely low density which results from having a very low solid presence. Since there is nearly no surface area on aerogel, thermal conduction has little to no ability to transfer heat by contact. In addition, many of the links within the aerogel itself are broken which leads to further reduction in conduction. In general most aerogels are non-flammable and non-toxic making them safe for ambulance use. Figure 9 displays the internal structure of a carbon nanotube aerogel. This tunnel-like skeletal structure is produced by having gas being trapped within its tunnels. The characteristic pore size along with the air pressure explains why aerogels are so effective in low gaseous conductivities.

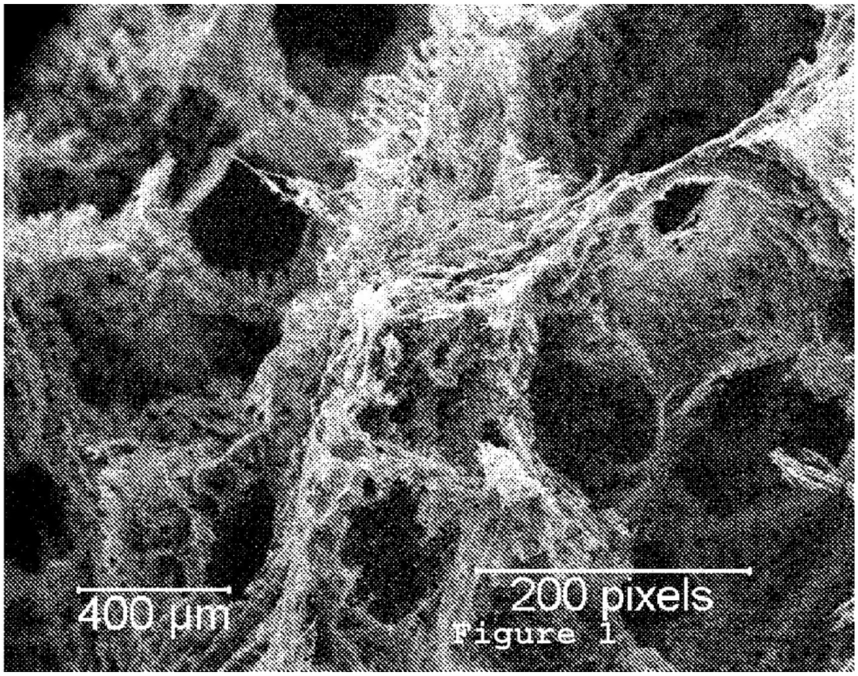


Figure 9: Carbon Nanotube Aerogel

The Knudsen effect defines why aerogels have such low gaseous conductive properties and is described with eq. (1) and eq. (2). This equation will also give some incite as to how to develop aerogels as an insulation material. For the following equation K_n is the Knudsen number which is described by the ratio between the $l_{mean,}$ the mean free path of air molecules, and δ, the pore diameter. K_b is the Boltzmann constant, T is the temperature, P_g is the gas pressure, and β is the efficiency of energy transfer when gas molecules hit the solid structure.

$$\lambda_g = \frac{\lambda_{g,}0}{1+2\beta K_n} \quad (1)$$

$$K_n = \frac{l_{mean}}{\delta} \; and \; i_{mean} = \frac{K_B T}{\sqrt{2}\pi d_g^2 P_g} \quad (2)$$

According to Knudsen effect described by eq. (1) and eq. (2), in order to reduce gaseous conductivity there must be a consideration for β and K_n because of their significant impact on the gaseous conductivity. Since aerogels have very small pores δ is very small which results in K_n

being large leading to an indirect decrease in gaseous conductivity. During the drying process, if a lower conductive gas would replace the liquid, it would result in β being much larger and ultimately result in a lower gaseous conductivity [11].

When considering the most effective insulation for an ambulance it is important to note that sound dampening is significant in choosing the correct material. Aerogels are known for having very strong acoustic dampening properties. Granular aerogels attenuate sound as much as 60 decibels with a thickness of 7cm [10]. Ambulance sirens ring on average of 120 decibels right outside the ambulance compartment. By nearly all of the ambulance standards, the maximum limit within the patient compartment must be at 60 decibels. Aerogels insulation would successfully be able to negate the sound with only 7 cm of thickness not including the aluminum body to shield the compartment as well.

Aerogel Applications

Currently, the costs of aerogels are too high for them to be considered for commercial insulation use. Aerogels are starting to be applied to building insulation, and companies such as Aspen Aerogels are beginning to develop commercially used insulation. Although, all the properties are very promising for improving the ambulance compartment design, the drying process in creating the aerogels make it far too expensive to be conceivable for commercial ambulance use. Though, there is on-going research on the topic of aerogels (mainly silica aerogels) that developing process that will make aerogel an economical choice.

Loose-fill and Batt Insulation

One of the most popular and economic choices for insulating houses is fiber glass. As seen in Table 5 fibrous insulation such as mineral, rock-wool, and fiber glass are comparatively cheaper and cost-effective. According to Table 5 many of these fibrous insulations can be less than 5 cents per square foot making fibrous insulations the cheapest amongst all commonly used insulations. In order to analyze fiberglass insulation it is important to know the price range for fiber glass in batt form with varying thicknesses. Below is Table 5 which provides values for fiber glass specifically [12].

Table 5: Fiberglass Batt Insulation Characteristics

Thickness (inches)	R-value	Cost ($/sq ft)
3 ½	11	0.28 – 0.35
3 ½	13	0.34 – 0.37
3 ½	15	0.64 – 0.67
6 to 6 ¼	19	0.43 – 0.55
8	30	0.64 – 0.91
9 ½ to 9 ¾	30	0.61 – 0.81
12	38	0.78 – 0.83

In an ambulance the walls in which insulation can be installed are only limited to about 3-4 inches in thickness. For this case it is only necessary to consider the values that are 3 ½ inches thick. When installing fiber glass insulation it is important not to compact the insulation because fiber glass insulation owes much of its low conductive properties to the air pockets. Fiber glass insulation as batts is fibers that are woven together. These fibers are woven in a way that allows small air pockets to form. These air pockets are what prevent convective air flow from getting through by trapping the air within these pockets. If these pockets were to be compromised by compaction due to over stuffing though the insulation would be thicker ultimately, the fiber glass insulation loses much of its effectiveness because the air pockets will be deflated.

Spray foam insulation

Like many insulations spray foam insulation behavior varies depending on the temperature. If spray foam is in contact with a low temperature surface it can potentially induce Cyro pumping within the foam. This creates low pressure within the cells of the spray foam and causes air and moisture to accumulate and condense within the spray foam. This process adds a significant amount of weight to the insulation and can even comprise the effectiveness of the insulation [12]. Because weight is one of the major factors when optimizing the insulation, this poses a problem to what is becoming a mainstream insulation for ambulances.

Polyurethanes are made from a chemical reaction of a diisocyante with a polyol. The substance produced by this reaction is liquid foam that contains a low-conductivity gas within its cells. This property allows polyurethane to be effective in reducing convective heat flow as opposed to just being resistant to conductive heat flow like much loose-fill insulation such as fiber glass relies on. In addition polyurethane is a fast expanding liquid that solidifies as rigid foam. This allows for quick and easy installation as well as making awkward shaped cavities easy to insulate. In doing so polyurethane also serves as an air sealant which improves R-value ratings significantly. Polyurethane is a substance that is safe and inert. This is especially important because according the KKK-A-1822F standards any insulation material used must be safe to use and handle. In addition, the material must be non-settling which is aided by the fact that polyurethane is inert. This non-reactive property makes oxidation and other reactions that deter a material more difficult to occur. Its durability makes for a more cost effective choice above other insulation materials. This is evident in industry as ambulance manufacturing companies are beginning to adopt polyurethane as the primary insulation material. Braun Ambulances, a prominent ambulance manufacturing company, has taken upon themselves to develop ambulance by only utilizing polyurethane insulation in their vehicles. Figure 10 shown below shows polyurethane foam's thermal conductivity versus time [13].

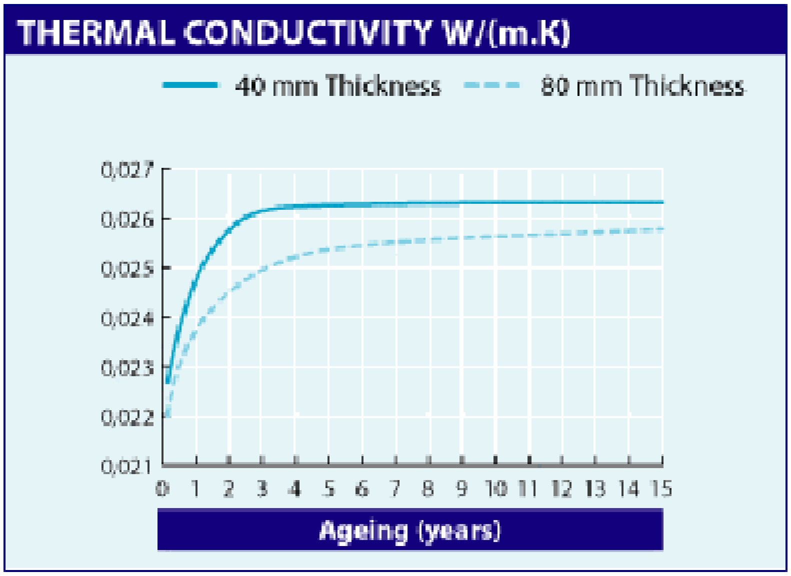


Figure 10: Thermal conductivity of rigid Polyurethane foams

Within the first two years is where most of the materials ability to prevent heat transfer occurs. This is caused by a process known as thermal drifting, the low-conductive gas which is trapped within the cells of the polyurethane foam escapes and is replaced with air. However, this process is most significant for the first two years and polyurethane retains a constant R-value for the remaining 13 years. This shows that despite its initial regression of R-value polyurethane holds a constant R-value after the thermal drifting plateaus. This makes the material reliable for many years before the insulation needs to be replaced and provides effectiveness till the next ambulance model. In addition, there are methods in which can be embraced in order to slow thermal drifting such as reinforcing the foam with a plastic covering. Though this may add to the cost of the overall implementation is could prove cost-effective since bracing the polyurethane will improve its thermal resistance by adding another layer of insulation.

Perhaps one of the most appealing reasons why polyurethane spray foam is so attractive is because it is light in weight in comparison to it competition. In an ambulance the KKK-A-1822 specifies certain gross vehicle weight rating (GVWR) which grants type III ambulances a weight limit of 10,001 to 14,000 pounds. Weight plays a significant role in considering the premium material because they can use that weight in order to implement medical equipment and features that improve the EMTs working experience.

Multi-Layer insulation

Multi-layer insulation (MLI) is primarily used for thermal protection system for spacecraft atmospheric re-entry. It is a high-performance insulation technology that is used to prevent thermal radiation primarily. It finds its applicability in most spacecraft and space-related situations such as insulating a satellite. The reason being is that in space there is a vacuum so heat transfer with respect to convection or conduction isn't of consideration in space. Though, the insulation is very effective in space it would have very few applications for ambulances since conduction and convection are two very important thermal aspects that must be embraced when on earth. Figure 11 shows the commonly used materials for multi-layer insulation [14].

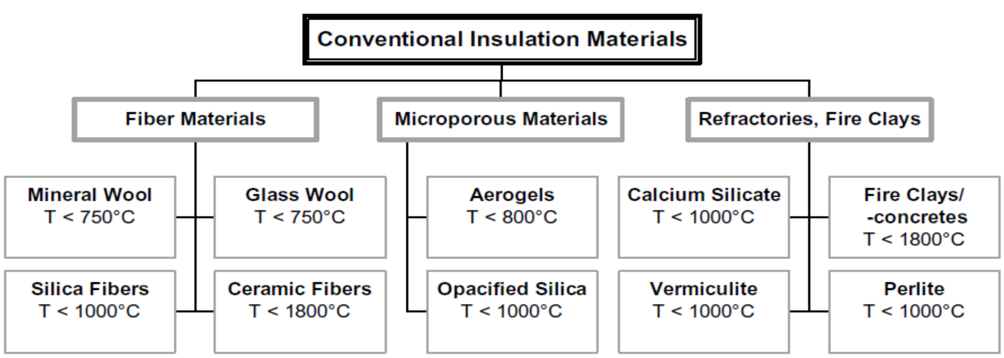


Figure 11: Commonly used materials for multi-layer insulation

Because of the high pricing (approximately $100-$200 a roll) and its limited effectiveness against preventing thermal conduction and thermal convection MLIs will not be considered as an optimal choice for ambulance commercial use. However, ongoing research at NASA and commercial industries are making the technology increasingly more feasible for commercial insulation use.

2.2.3 Comparison of Commonly Used Insulation

In improving the insulation of ambulance it is wise to look towards applications and materials used for building insulation. Though the information is not exactly tied to research done specifically for ambulance it will aid in developing an understanding of where insulation is in contemporary society. Among the most commonly used insulations used in housing and buildings are fiber insulation and foam insulation. Both of which are the most popular choices due to their effectiveness in insulation and cost efficiency. According the KKK-A-1822f insulation in an ambulance must be safe to handle. Any irritants caused by the insulation could lead to injuries or fatal events. It is important to consider not only the EMT's and the patients who ride in the ambulance but also those who install the insulation in the first place.

Perhaps the most important aspect of the insulation of choice is its R-value. A higher R-value will generally lead to more effective insulation. The most commonly used insulations being fiber insulation and foam insulation have very high R-values for their price and their weight which are shown in Table 6 [15].

Table 6: Comparison of insulation materials

	Types of Insulation	Installation Methods	R-Value per inch	Indoor Air Quality
Fiber Insulation	Cellulose	Loose-fill, wet- spray dense pack, stabilized	3.0 – 3.7	Fibers and chemicals can be irritants, should be isolated from interior space
	Fiberglass	Batts, loose- fill, stabilized, rigid board	2.2 – 4.0	Fibers and chemicals can be irritants, should be isolated from interior space
	Mineral Wool	Loose-fill, batts	2.8 – 3.7	See fiberglass
Foam Insulation	Open-cell Expanded Polystyrene	Rigid boards	3.6 – 4.2	Concern only for those with chemical
	Closed-cell Extruded Polystyrene	Rigid boards	5	Concern only for those with chemical
	Closed-cell Polyisocyanurate	Foil-faced rigid boards	5.6 – 7.7	Concern only for those with chemical
	Closed-cell Phenolic Foam	Foil-faced rigid board	8	Concern only for those with chemical
	Open-cell Polyicynene	Sprayed-in	3.6	
	Open-cell Soy-based Foam	Sprayed-in	3.6	
	Closed-cell Polyurethane	Sprayed-in	5.6 – 6.8	Concern only for those with chemical
	Open-cell Polyurethane	Sprayed-in	4.3	Unknown, appears to be very safe

Foam insulation materials have superior R-values in comparison to the fiberglass insulation. With R-values being 2-3 higher than of fiber insulation, polyurethane is much more effective in preventing heat flow. However, in synthesizing polyurethane the cost can go up much higher than that of the fiber glass counterpart. Installation methods are also shown in Table 6 because of its importance to the effectiveness of the insulation itself. Batts and loose-fill insulation can be very difficult to work because they do not conform to shapes of the walls very easily. In addition, supplemental conditions are needed for batts in order to create an air tight seal for a potent insulation. Batts must pre-emptively in order to have a well installed loose-fill batt. This can prove difficult because an air-tight and well-fitted shape is needed for the batts to work as intentioned. Tight corners and awkward captivities make this process nearly impossible which is a great down fall for fiber insulation. With spray-in insulation the process of pre-emptively cutting the batts are no longer necessary which makes installing much less difficult to deal with. Polyurethane and other spray foam insulation begin as foam and expand to fit cavities and ill-shaped sections of the wall. This accomplishes both a well-fitted insulation fill and provides as an air sealant. This in combination with makes spray foam insulations superior to its fiber insulation counterparts.

Polyurethane can become quite expensive and dense especially if closed-cell polyurethane method is implemented. In order to achieve higher R-values a low conducting gas must be inserted during the synthesizing process. Though spray foam insulations much higher R-values and generally prove easier to install and maintain, fiber and loose-fill insulations still are much more economical as far as costs go. This leads to the idea of method of using both insulations in conjunction in order to have a high quality and effective insulation as well as a cost-friendly option as well. Well insulating an ambulance it is not always important to achieve the maximum R-value possible if it means trading off price and weight.

Table 7 shows the most commonly used insulations used in housings with their respective R-values and pricing per square feet [15].

Table 7: Cost comparison of Insulating Materials

Type	Material	Typical R-Value (per inch)	Typical Cost ($/sq ft per R-value)
Batts, blankets and loose-fills insulation, mineral wool, fiberglass, rock wool	Batts or blankets	2.9 - 3.8	0.020 - 0.032
	Loose-fills	2.2 - 2.9	0.015 - 0.020
	Cellulose (loose-fills)	3.1 - 3.7	0.009 - 0.036
	Cotton insulation	3.0 - 3.7	0.048 - 0.055
Foam insulation and sheathing	Polyisocyanurate and polyurethane	5.0 - 5.7	0.172
	Extruded polystyrene	5	0.075 - 0.091
	Expanded polystyrene	4	0.063 - 0.084
	Fiberboard sheathing (blackboard)	2.6	0.082 - 0.136
	Isocyanate Foam	3.6 - 4.3	N/A

On average this table shows that almost all spray foam insulation yields an R-value 2-3 times greater that of the loose-fill insulations. Although, the table also reveals the price is much cheaper for utilizing loose-fill insulation. In comparing the cheapest loose-fill insulation with the most expensive spray foam insulation the table shows reveals that the most quality insulation is 6.6 times more expensive than that off the most cheap loose-fill insulation. Though this may be the case an ambulance is required to be capable of heating the compartment from 0 degrees Fahrenheit to 68 degrees Fahrenheit within 30 minutes. Thus, it is important that we not only consider the price but also the effectiveness of the insulation especially since there is a quality that must be met specified by the AMD, NFPA, and the KKK-A-1822F.

Table 8: Insulation used in Modern Ambulances

Ambulance Model	Ambulance Manufacturer	Insulation Type
Signature Series 2013 Ford E-350	Braun Industries	POLYURETHANE SPRAY FOAM
Signature Series 2013 Chevy G-3500	Braun Industries	POLYURETHANE SPRAY FOAM
Super Chief 2013 4300LP	Braun Industries	POLYURETHANE SPRAY FOAM
Super Chief Ford-650	Braun Industries	POLYURETHANE SPRAY FOAM
Super Chief Freightliner M2	Braun Industries	POLYURETHANE SPRAY FOAM
Super Chief MetroStar	Braun Industries	POLYURETHANE SPRAY FOAM
Commando	Marque Ambulances	Fiberglass batts in ceiling and walls, block foam in doors
Recruit	Marque Ambulances	Fiberglass batts in ceiling and walls, block foam in doors
Brigadier	Marque Ambulances	Spray foam in ceiling, walls, doors and floors
CitiMedic plus	Wheeled Coach	Fiberglass in module and ceiling, solid block foam in doors
Crusader plus	Wheeled Coach	Fiberglass in module and ceiling, solid block foam in doors
Resqmedic	McCoy Miller	Fiberglass side wall & roof insulation and foam insulation in compartment
Medic 163 & 170 Ford E-450	McCoy Miller	R-11 Fiberglass batts
Medic 146 Ford F-350/F-450	McCoy Miller	R-11 Fiberglass batts
Medic 142 Ford F-350	McCoy Miller	R-11 Fiberglass batts
Type II Guardian	McCoy Miller	R-11 Fiberglass batts
Medallion 170 Ford E450	PL Custom Emergency Vehicles	Thinsulate® & Sound Stop insulation
Medallion 80 Ford E350	PL Custom Emergency Vehicles	Thinsulate® & Sound Stop insulation
Titan Medium Duty International 4300	PL Custom Emergency Vehicles	Thinsulate® & Sound Stop insulation

To get an idea as to what technologies are being embraced the project collected data from multiple different ambulance manufacturers. This was to see what different companies had in common and what they had in contrast to each other.

From inspection of Table 8 it is evident that the most commonly used insulation materials are various spray foams and fiberglass. Table 8 also reveals that commercial ambulances don't have the luxury of being able to have the most state of the art insulation. Insulation must be cost-effective and must be proven to be safe. Fiberglass and spray foam have been used commercially for a very long time in buildings and other applications. Fiberglass is a low cost, reliable and prominent insulation that the building industry often incorporates into their designs. Spray foams provide very high R-values per inch and also function as an air sealant making it a cost-effective choice of insulation. Analyzing these materials will aid in determining their dominance in the insulation market and provide insight in selecting an optimal insulating material.

2.2.4 Insulation Recommendation for Houses in USA

Figure 12 is shown the insulation recommendation from the Department of Energy (DOE) for houses all over United States.

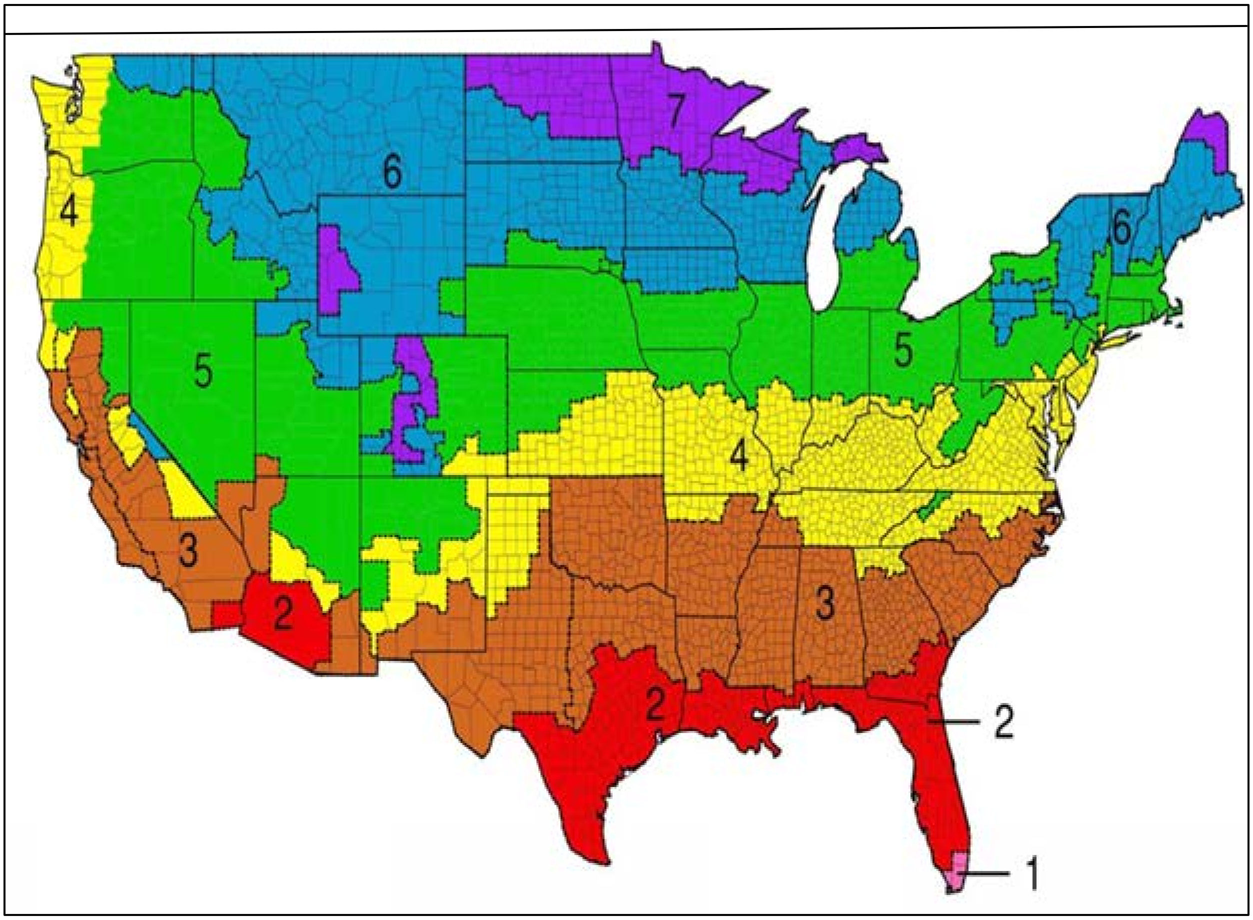


Figure 12: Insulation Recommendation by DOE for houses in USA

This data can be used and applied into ambulance across the country or a similar study should be made for ambulance manufactures in order to know what kind of R-value insulator to use and how can they improve the insulation of the ambulance. The study is based on the climate changes, types of houses, and energy cost [9].

In Table 9 is the insulation recommendation by Department of Energy. In the first column there are the 8 zones that match on the map shown in Figure 12. The second column shows the heating system of the house in America by zone. For instance, Massachusetts house owners belong in zone 5 and they are recommended to insulate the attic of the house with insulation rated R-value R38 to R60. For the cavities of the wall, they are recommended to use insulation with R-value R13 to R21. As was mentioned before, the same type of recommendation can be developed for ambulance manufactures.

Table 9: Insulation recommendation by DOE for houses in USA by zone

Zone	Heating System	Attic	Cathedral Ceiling	Wall		Floor
				Cavity	Insulation Sheathing	
1	All	R30 to R49	R22 to R38	R13 to R15	None	R13
2	Gas, Oil, heat pump	R30 to R60	R22 to R38	R13 to R15	None	R13
	Electric Furnace					R19 to R25
3	Gas, Oil, heat pump	R30 TO R60	R22 to R38	R13 to R15	None	R25
	Electric Furnace				R2.5 to R5	
4	Gas, Oil, heat pump	R38 to R60	R30 to R38	R13 to R15	R2.5 to R6	R25 to R30
	Electric Furnace				R5 to R6	
5	Gas, Oil, heat pump	R38 to R60	R30 to R38	R13 to R15	R2.5 to R6	R25 to R30
	Electric Furnace		R30 to R60	R13 to R21	R5 to R6	
6	All	R49 to R60	R30 to R60	R13 to R21	R5 to R6	R25 to R30
7	All	R49 to R60	R30 to R60	R13 to R21	R5 to R6	R25 to R30
8	All	R49 to R60	R30 to R60	R13 to R21	R5 to R6	R25 to R30

To prevent the heat rushing out of ambulance compartment it is important to seal any openings like outlets, gaps on doors and windows as recommended in Table 4. This air leaks carry energy and moisture for instance in summer they carry humid inside the ambulance which might have significant temperature changes and in winter they do the opposite [9].

In case the insulation improvement are needed in an existing ambulance table 10 can help to calculate the R-value. Table 5 shows how to identify the insulation and how to calculate the R-value. After this is done an extra layer of insulation can be added to improve it. This has to be done within the federal and manufacture regulations.

Table 10: How to calculate the R-value of insulators

Types	Appearance	Material	Total R-value
Loose fibers	Light-weight yellow, pink or white	Fiberglass	2.5xDepth
	Dense gray or near-white, may have black specks	Rock wool	2.8xDepth
	Small gray flat pieces or fibers (from newsprint)	Cellulose	3.7xDepth
Granules	Light-weight	Vermiculite or perlite	2.7xDepth
Batts	Light-weight yellow, pink or white	Fiberglass	3.2xDepth

2.3 Background for Lighting Design

Before it is possible to suggest a particular lighting design for the ambulance compartment design it is important to have a strong background in prior research and implementations. In particular, it is important to know the standards and regulations that govern what can be modified within the compartment design. This section consist the regulations with respect to lighting and a review of the prior art that has been implemented in industry for lighting systems.

2.3.1 Regulatory Standards for Ambulance Lighting

The following sections will give an overview of the different regulations such as the KKK-A-1822E, NFPA, AMD and the FMVSS. These regulations dictate what types of designs can be implemented at standards that these designs must meet in order to be implemented in the compartment design.

2.3.1.1 FMVSS Specification for Ambulance Lighting

Lighting is an integral part of the electric system of ambulances. The exterior lighting of the ambulance must correspond with the specifications found in the Federal Motor Vehicle Safety Standards (FMVSS) No. 108 and in the Federal Specifications for Star-Of-Life Ambulance KKK-A-1882E. The FMVSS No. 108 provides thorough standards for original and replacement lambs, reflective devices and associated equipment for vehicles of all sorts (passenger cars, multi-purpose passenger vehicles, trucks, buses, trailers, and motorcycles). The primary purpose of the FMVSS No. 108 is to diminish traffic accidents, injuries and deaths that occur due to traffic crashes, through the act of improving visibility on the public roads and ensuring the improvement of conspicuity of all sorts of vehicles in order to make them more visible and their signals comprehended and apprehended in daylight, darkness and all weathers that tend to hinder visibility [4].

Table **11** shows the required motor vehicle lighting equipment (apart from the headlamps) indicating their respective colors and numbers as seen in No. 108 of the FMVSS [16].

Table 11: Required Motor Vehicle Lighting Equipment

Items	Multi-Purpose Vehicles, Trucks, and Buses	Trailers	Applicable SAE Standards
Tail lamps	2 Red	2 Red	J585e, Sep. 1977
Stop lamps	2 Red	2 Red	J1398, May 1985
License Plate Lamps	1 White	1 White	J587 October 1981
Reflex Reflectors	4 Red, 2 Amber	4 Red, 2 Amber	J594f, Jan. 1977.
Side Marker Lamps	2 Red, 2 Amber	2 Red, 2 Amber	J592e, July 1972
Backup Lamps	1 White	None	J593c, Feb. 1968.
Turn Signal Lamps	2 Red or Amber, 2 Amber	2 Amber	J1395, April 1985.
Turn Signal Operating Unit	1	None	J589, April 1964
Turn Signal Flasher	1	None	J590b, Oct. 1965.
Vehicular Hazard Warning Signal Operation Unit	1	None	J910, Jan. 1966.
Vehicular Hazard Warning Signal Flasher	1	None	J945, Feb. 1966.
Identification Lamps	3 Amber; 3 Red	3 Red	J592e, July 1972
Clearance Lamps	2 Amber, 2 Red	2 Amber, 2 Red	J592e, July 1972
Intermediate Side Marker Lamps	2 Amber	2 Amber	J592e, July 1972
Intermediate Side Reflex Reflectors	2 Amber	2 Amber	J594f, Jan. 1977
Conspicuity	S 5.7	S 5.7	S 5.7

Table **11** shows the required motor vehicle lighting equipment other than headlamps of multipurpose passenger vehicles, trucks, trailers, and buses, of 80 or more inches overall width. The first column of the table shows the list of different required lights. The second and third columns show the quantity of each respective light listed in the first column of multi-purpose vehicles, trucks and buses in comparison to trailers respectively. The fourth column shows specific references as stated in the Society of Automotive Engineers (SAE) in relation to each of the respective lights, their quantity and colors shown in columns 1, 2 and 3 respectively. The last row of

Table **11** shows the conspicuity of the vehicles listed in the headings of columns 2 and 3 in section S 5.7 of the FMVSS. In regards to the conspicuity systems, all vehicles under the categories of the vehicles listed in the headings of columns 2 and 3 in

Table **11** has to be equipped with retro-reflective sheeting which must be composed of smooth, flat, transparent exterior film with retro-reflective properties and elements embedded or suspended beneath the film so that in effect, a non-exposed retro-respective optical system could be formed (FMVSS-S 5.7.1.1). In addition Table 12 shows the required location and measurements in height above the surface of the road as measured from the center of the item (light) on the exterior part of the vehicle at curb weight.

Table 12: Equipment for Multipurpose Passenger Vehicles

Items	Location on –		Height above road surface
	Multi-Purpose Vehicles	**Trailers**	
Head lamps	On the front, 1 on each side of the vertical centerline	Not required	Not less than 22 inches (55.9 cm) nor more than 54 inches.
Tail lamps	On the rear, 1 on each side of the vertical centerline	On the rear, 1 on each side of the vertical centerline	Not less than 15 inches, not more than 72 inches.
Stop lamps	Same as above	Same as above	Same as above
License Plate Lamps	At rear top side of the license plate	At rear top side of the license plate	No requirement
Backup Lamps	On the rear	Not required	Do
Turn Signal Lamps	At or near the front—1 amber on each side On the rear—1 red or amber on each side of the vertical	At or near the front—1 amber on each side of the vertical centerline	Not less than 15 inches, nor more than 83 inches.
Identification Lamps	On the front and rear—3 lamps, amber in front, red in rear with lamp centers spaced not less than 6 inches or more than 12 inches apart.	On the rear—3 lamps to the vertical centerline, with lamp centers spaced not less than 6 inches or more than 12 inches	No requirement
Clearance Lamps	On the front and rear—2 amber lamps on front, 2 red lamps on rear	On the front and rear—2 amber lamps on front, 2 red lamps on rear	Do
Intermediate Side Marker Lamps	On each side—1 amber lamp located at or near the midpoint between the front and rear side marker lamps	On each side—1 amber lamp located at or near the midpoint between the front and rear side marker lamps	Not less than 5 inches
Intermediate Side Reflex Reflectors	On each side—1 amber located at or near the midpoint between the front and rear side reflex reflectors	On each side—1 amber located at or near the midpoint between the front and rear side reflex reflectors	Not less than 15 inches nor more than 60 inches.
Conspicuity	See S5.7	See S5.7	See S5.7
Reflex reflectors	On the rear—1 red on each side. On each side—1 red far to the rear and 1 amber far to the front	On the rear—1 red on each side. On each side—1 red far to the rear and 1 amber far to the front	Same
Side marker lamps	Same as above	Same as above	Not less than 15 inches, and on the rear of trailers not more than 60 inches.

Table 12 shows the various exterior lights in the first column. The second column in

Table **11** shows the required location and colors of each respective exterior light on multi-purpose vehicles, trucks and buses in comparison with that of trailers in the third column. The fourth column indicates the required measurement in and measurements in height above the surface of the road measured from the center of the item (light) on the exterior part of the vehicle at curb weight. "Same" in some of the boxes simply means the requirement for that specific light or item in question is the same as the requirement stated in the box right above the "Same" box. The conspicuity system as seen in section S 5.7 in the FMVSS is exactly as explained for that of

Table **11**.

KKK-A-1882E Specification for exterior lighting

In regards to the exterior lighting of the ambulance, the Federal Specification for the Star-of-Life Ambulance (KKK-A-1822E) makes reference to the specifications outlined in the Federal Motor Vehicles Safety Standards (FMVSS) No. 108 as discussed above (KKK-A-1822E, 3.8.1). However, it also goes on to state that the furnished light assemblies must be made up of stainless steel, plastic, and other materials that are weather resistant. The method of insulating the lights should be such that the electrolysis of light housings of the body of the vehicle will not occur. The standard emergency light of the ambulance must be composed of twelve fixed red lights, one fixed clear light and one or two fixed amber or SAE recommended yellow light or lights. Figure 13 shows the general spotlight pattern of the ambulance.

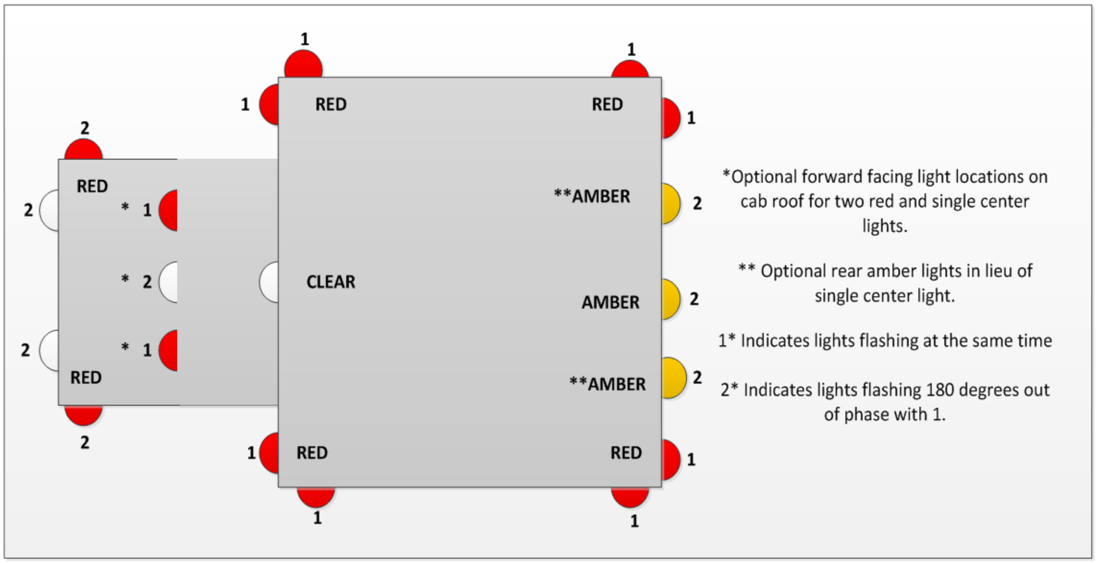


Figure 13: General Flash Pattern on the Top of Ambulance

Table **13** shows the general spotlight pattern of ambulance. The upper body warning lights are positioned at the extreme top corners of the body of the ambulance, just beneath the roofline. The only one clear light is mounted in the middle of the two facing and upper corner red lights. The warning lights are not supposed to be blocked by anything on the body of the ambulance including the doors. The amber lights are located asymmetrically between the two facing red lights in the rear of the ambulance. The “grill” red lights are 76 cm above the ground and 46 cm apart from each other (3.8.2.1). Table 4 shows the information outlined in figure 1 and the mode of operation of the lights.

Table 13: Model Emergency Lighting Systems

Color	Red	Clear	Amber	Red
Location	Front and rear corners	Front and upper center	Rear Center	Grille and Fender
Mode of operation				
Primary "Clear the right of the way"	ON	ON	ON	ON
Secondary "Hazard Vehicle stopped on right of way"	ON	OFF	ON	OFF

Table **13** shows the model emergency lighting system and their mode of operation. The red spotlight in the front rare corners and the amber spotlights in the rare center of the ambulance are turned on during both primary and secondary mode of operation. The clear spotlight located at the upper front center and the red spot lights on the grill and fenders are turned on during the primary and off during the secondary mode of operations respectively.

The KKK-A-1822F provides specifications for Type I, Type II and Type III ambulance in relation to exterior lighting. There are a couple of deferent factors distinguishing a Type 1 ambulance from a Type II ambulance, which also differs from Type III ambulance. Type I ambulance according to the KKK-A-1882F is a conventional, cab-chassis with modular ambulance body. Table 5 shows the exterior lighting system of Type I ambulance as specified in the Federal Specification for Ambulances (KKK-A-1882F) in accordance with the specifications outlined in the FVMSS No. 108 standards.

Table 14: Exterior Lighting Design of Type I Ambulance

NUMBER	ITEM	QUANTITY AND COLOR
1	Headlamp	(2) white (4 white optional)
2	Front side marker lamp	(2) amber
3	Front side reflector	(2) amber
4	Front turn signal (includes vehicular hazard warning signal flasher)	(2) amber,
5	Front identification lamps	(3) amber
6	Front clearance lamp	(2) amber
7	Rear side marker lamp	(2) red
8	Rear side reflector	(2) red
9	Rear identification lamps	(3) red
10	Rear clearance lamp	(2) red
11	Rear reflector	(2) red
12	Rear, stop, tail, lamp	(2) red
12a	Rear turn signal (Includes vehicular hazard warning signal flasher (optional location)	(2) amber
13	Rear backup lamp	(1) white
14	Rear license plate lamp	(1) white
15	Front warning light	(2) red
15a	Front warning light	(1) white
16	Rear warning light	(2) red
16a	Rear warning light	(1) amber
17	Side warning light	(2) red per side
18	Grille light	(2) red
19	Intersection lights	(1) red per side
20	Side floodlight	(2) white
20a	Rear floodlight	(1) white
21	Spotlight)	(white hand held)
21a	Sport light	(white, optional location)

The first column of Table 14 shows the respective numbers that correspond to the numerical labeling of the Type I ambulance in figure 2. The second column shows what type of light corresponds with the respective numbers. Finally, column three shows the color and quantity of the respective lights (KKK-A-1882F, pp 88). There are approximately 46 exterior lights on the

Type I ambulance; 22 are red, 14 amber, and 10 white. Table 14 shows the respective numerical labeling of the exterior of the ambulance showing where each light is located in relation to Table 14.

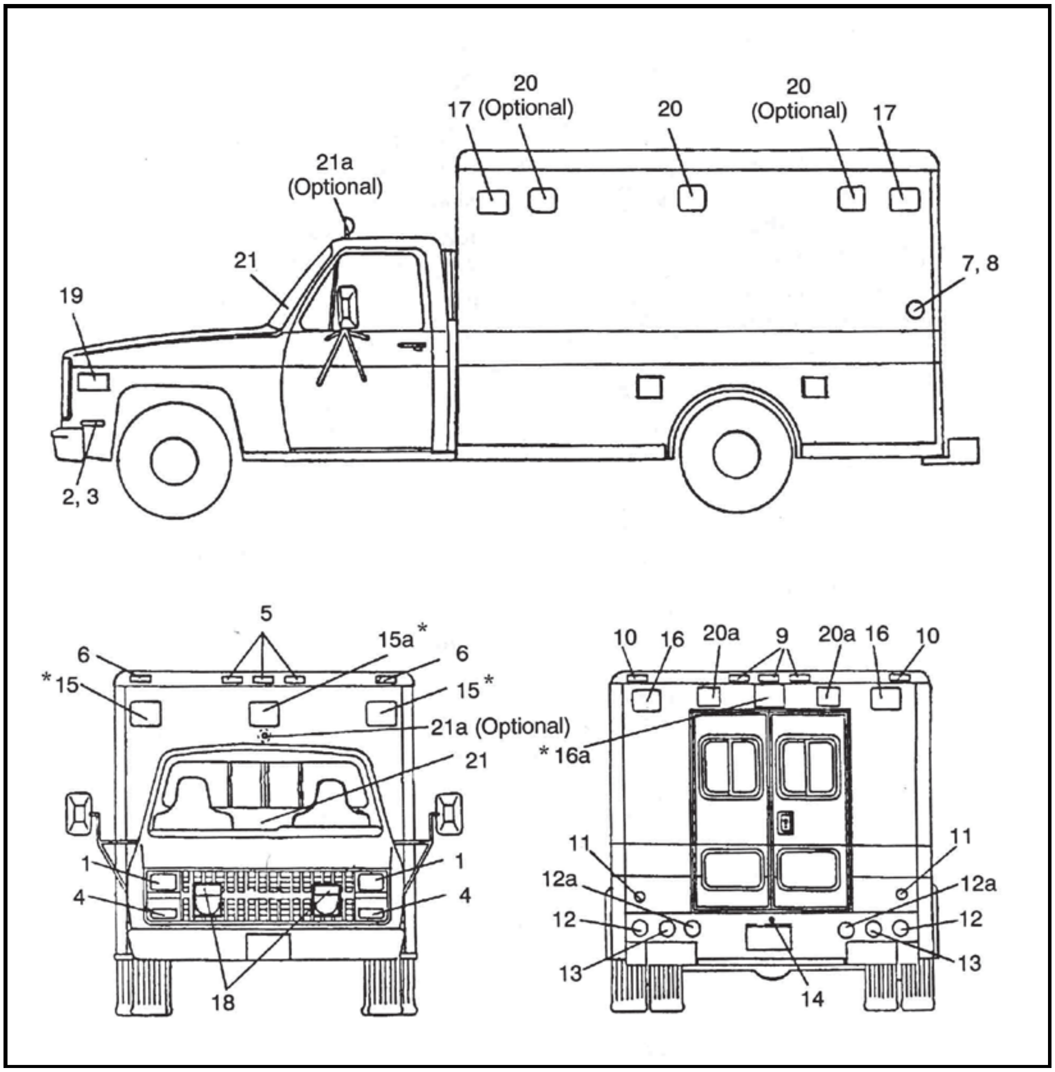


Figure 14: Exterior Lighting Design of Type I Ambulance

Figure 14 shows the exterior lighting design for Type I Ambulance as specified in page 89 of the KKK-A-1882E. Each numbered light or lights correspond with the numbers in the first column of Exterior Lighting Design of Ambulance in the KKK-A-1882F corresponding to FVMSS No. 108 Standards. The respective name for each light according to its matching number is given in the second column of Exterior Lighting Design of Type I Ambulance. Type II is a standard van, integral cab-body ambulance. Table 15 shows the exterior lighting system for Type II ambulance as specified in the Federal Specification for Ambulances (KKK-A-1882E) in accordance with the specifications outlined in the FVMSS No. 108 standards (KKK, pp 90).

Table 15: Exterior Lighting Design of Type II Ambulance

NUMBER	ITEM	QUANTITY AND COLOR
1	Headlamp	(2) white (4 white optional)
2	Front side marker lamp	(2) amber
3	Front side reflector	(2) amber
4	Front turn signal (includes vehicular hazard warning signal flasher)	(2) amber,
5	Rear side marker lamp	(2) red
6	Rear side reflector	(2) red
7	Rear Reflector	(2) red
8	Rear Stop, tail and turn signal light	(2) red
9	Rear backup lamp	(1) white
10	Rear license plate lamp	(1) white
11	Front warning light	(2) red
11a	Front warning light	(1) white
12	Rear warning light	(2) red
12a	Rear warning light	(1) amber
13	Side warning light	(2) red per side
14	Grille light	(2) red
15	Intersection lights	(1) red per side
16	Side floodlight	(2) white
16a	Rear floodlight	(1) white
17	Spotlight)	(white hand held)
18	Sport light	(white, optional location)

The first column of Table 15 shows the respective numbers that correspond to the numerical labeling of the Type II ambulance in figure 3. The second column shows what type of light corresponds with the respective numbers. Column three shows the color and quantity of the respective lights (KKK, pp 90). Unlike Type I ambulance which has approximately 46 exterior lights, Type II ambulance has approximately 34 exterior lights; 17 are red, 7 amber, and 10 white. Figure 3 shows the respective numerical labeling of the exterior of the ambulance showing where each light is located in relation to Table 15.

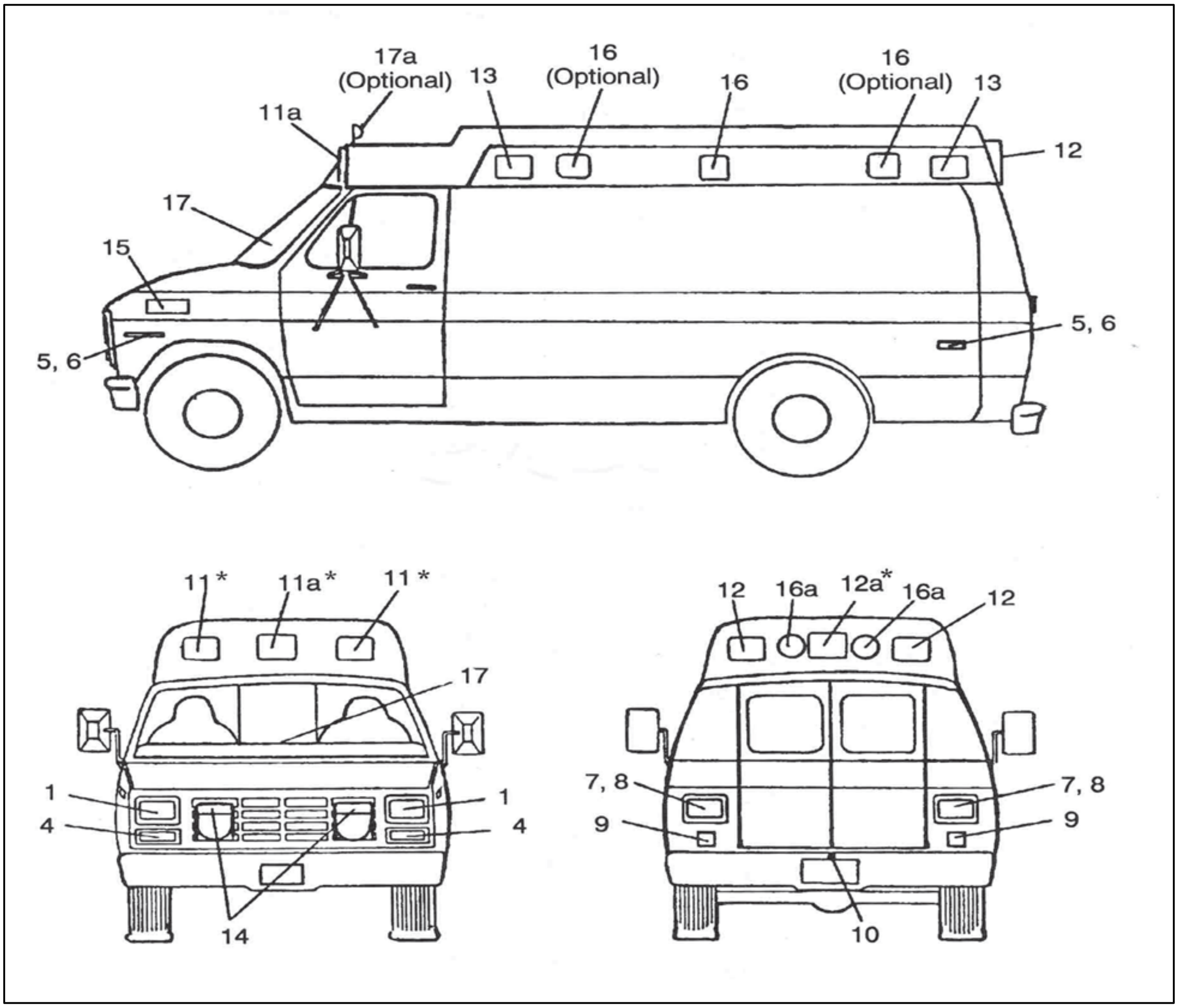


Figure 15**:** Exterior Lighting Design of Type II Ambulance

Table 16 shows the exterior lighting design of Type II Ambulance as specified in page 91 of the KKK-A-1882F. Each numbered light or lights correspond with the numbers in the first column of table 6. The respective name for each light according to its matching number is given in the second column of table 6.Type III ambulance is a cut-away van, cub-chassis with integrated modular ambulance body. Table 16 shows the exterior lighting system for Type III ambulance as specified in the Federal Specification for Ambulances (KKK-A-1882F) in accordance with the specifications outlined in the FVMSS No. 108 standards (KKK, pp 92).

Table 16: Exterior Lighting Design for an Ambulance

NUMBER	ITEM	QUANTITY AND COLOR
1	Headlamp	(2) white (4 white optional)
2	Front side marker lamp	(2) amber
3	Front side reflector	(2) amber
4	Front turn signal (includes vehicular hazard warning signal flasher)	(2) amber,
5	Front identification lamps	(3) amber
6	Front clearance lamp	(2) amber
7	Rear side marker lamp	(2) red
8	Rear side reflector	(2) red
9	Rear identification lamps	(3) red
10	Rear clearance lamp	(2) red
11	Rear reflector	(2) red
12	Rear, stop, tail, lamp	(2) red
12a	Rear turn signal (Includes vehicular hazard warning signal flasher (optional location)	(2) amber
13	Rear backup lamp	(1) white
14	Rear license plate lamp	(1) white
15	Front warning light	(2) red
15a	Front warning light	(1) white
16	Rear warning light	(2) red
16a	Rear warning light	(1) amber
17	Side warning light	(2) red per side
18	Grille light	(2) red
19	Intersection lights	(1) red per side
20	Side floodlight	(2) white
20a	Rear floodlight	(1) white
21	Spotlight)	(white hand held)
21a	Sport light	(white, optional location)

Table 16 for Type III ambulance has the same information and description as shown and discussed for Type 1 ambulance in table 5. The respective light numbering in accordance to their names, quantity and colors are seen in columns 1, 2 and 3 respectively. Type I and Type III have the same number of lights and color distributions of exterior light design; 46 in total, 22 red, 14 amber, and 10 white. Figure 16 shows the respective numerical labeling of the exterior of the ambulance showing where each light is located in relation to Table 16.

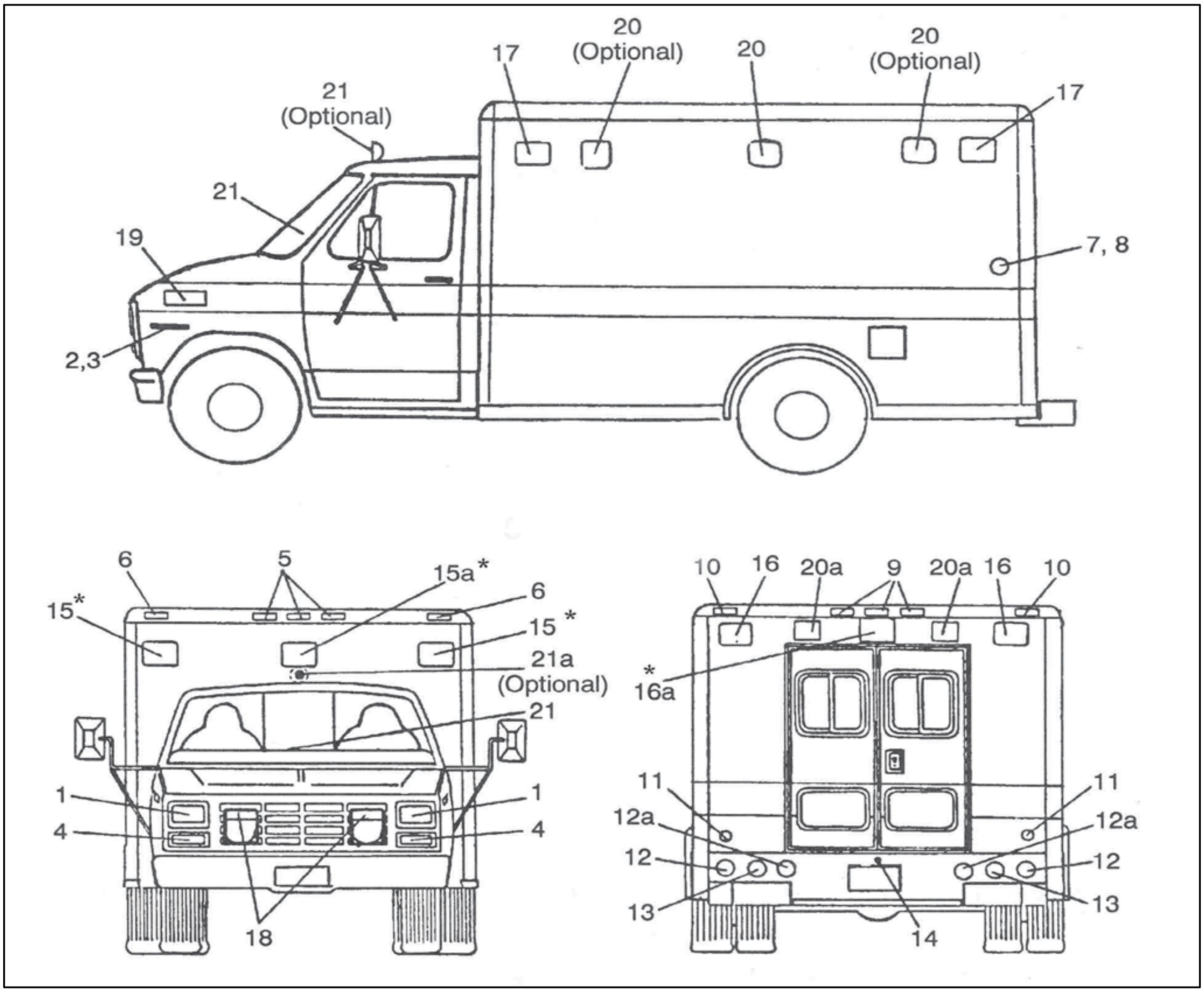


Figure 16: Exterior Lighting Design Type III ambulance

Figure 16 shows the exterior lighting design of Type III Ambulance as specified in page 93 of the KKK-A-1882E. Each numbered light or lights correspond with the numbers in the first column of Table 17. The respective name for each light according to its matching number is given in the second column of Table 17.

Beside the different make ups of the three types of ambulances discussed above, one important phenomenon that distinguishes Types I and III from Type II ambulance is the number of exterior light design and the distribution of colors respectively. Table 8 shows a summary of the difference between the Types I, II and III ambulances as far as exterior light design is concerned.

Table 17: Exterior lighting for type I, II, and III ambulances

AMBULANCE TYPE	TOTAL # OF EXTERIOR LIGHTS	RED	AMBER	WHITE
I	46	22	14	10
II	34	17	7	10
III	46	22	14	10

Both Types I and III ambulances have the same total amount of exterior lights; 46. They have 22 each of red exterior lights, 14 each of amber, and 10 each of white. Type II ambulance on the other hand has 34 total exterior lights; 17 red, 7 amber (half the amount of Types I and III) and 10 whites. All the three have the same amount of white exterior light – 10.

In the KKK-A-1882E Specification, Light Emitting Diodes (LED) is recommended due its long life durability and reduced current draw to be used in the patient's compartment (KKK pp 82 fff). There are some ambulances that do use dome LED lights and others use regular bulbs. The advantages and disadvantages of these different lights shall be discussed later in the chapter.

KKK Specification for Interior Lighting

The general interior ambulance lighting design aims at minimizing electrical loads. The various areas of lighting designs include the driver's compartment dome light, master switch panel, instrument panel light, console light or lights, and the lights for the patient's compartments (KKK, 3.8.5). In the patient's compartment, which is the subject of interest, there must not be less than 15 foot candle intensity of normal white illumination. The measurement should be along the centerline of the clear floor with no external ambient light. The main cot has to have at least 35 foot candles of illumination measured on a minimum of 90% of the cot's total surface area. Blue lights and lenses are not to be used, but fluorescent lighting or fixtures (with removable covers that can be appropriately locked in place) operating on 12 colts DC can be used. The lights in the patient's compartment are not supposed to be powered by the ambulance's 115 volt AC system, and must be activated automatically when the doors of the patient's compartment are opened. The interior dome lights and the checkout lights (6 candle power lamps) have to be near the flush mounted and shall not exceed 3.8 cm (1.5 in) in length from the base of where they are mounted. One of the light fixtures has to be mounted towards the front of the patient's compartment and another towards the rear. Having two separately secured and controlled circuits, the dome lighting must not use over 15 amps of power in the bright setting (KKK, 3.8.5.1).

This section explores a variety of lighting systems that are currently being used in homes, roads, cars and other applications. We also compare different lighting systems that are implemented in ambulances by different manufacturers. These lighting systems include incandescent light bulbs and LED mainly.

Different companies around the world are implementing new lighting systems based on Light Emitting Diode (LED). LEDs are commonly used because of their low power consumption they are used in cars, homes, theaters, roads and other applications. Figure 13 shows a LED lighting system from the UNESCO World Heritage Site Golden Hall at Chuson-ji, Japan [17].

Figure 17: LED lighting system from the Golden Hall in Japan.

However, there are other factors that have to be considered in order to design an efficient and effective lighting system. Advantages and disadvantages regarding LED lighting systems are discussed as well as different approaches that have been developed in order to produce "white light" using LEDs.

2.3.2 Types of Lighting Systems.

There are four main types of lighting systems that are based on the following technologies: Incandescent Bulbs, Fluorescent Lamps, Metal Halide Lamps, and the White LED [18]. From those mentioned, the one that offers higher efficiency is the LED technology however it also offers disadvantages that will be discussed in this section.

Incandescent Light Bulbs.

The light of incandescent bulb is produced by a filament wire. When this filament wire is heated by electric current passing through it illuminates a bright light. Incandescent bulbs do not need an external driver circuit which is the reason why they are simpler to manipulate and implement. The cost is much less than fluorescent lamps, Metal Halide lamps and LED lamps. Figure 18 shows the main parts of a typical incandescent bulb used in homes.

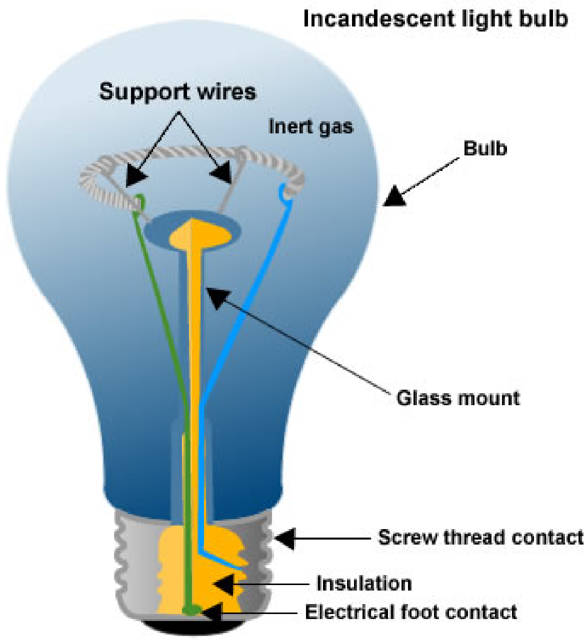


Figure 18: Main parts that compose an incandescent bulb.

The following circuit illustrates how simple it is to be implemented in a lighting system. Note that in the circuit the light bulb is directly connected to a power supply in series with a switch that controls the flow of current which is shown in Figure 15.

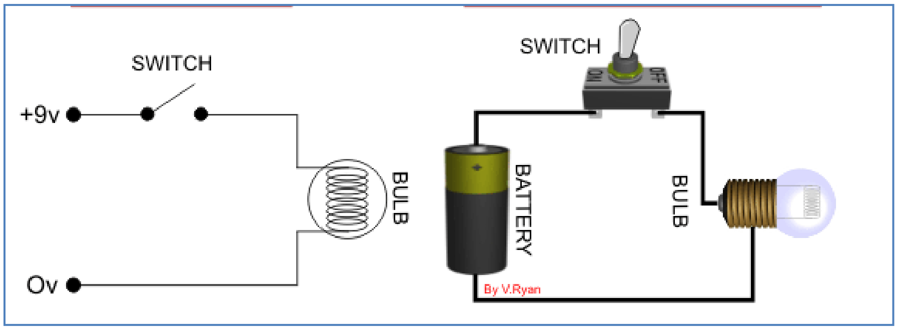


Figure 19: Circuit to Energize an Incandescent Light Bulb.

The only issue with the circuit shown in Figure 15 is the fact that when the voltage across the battery drops due to the discharge of the battery which can cause the light intensity to fluctuate. This problem can be easily solved by using a voltage regulator to maintain the voltage approximately constant. However, this is not a problem for light bulbs operated by car batteries at 12VDC or utility at 120VAC. For those operated with 120VAC, voltage fluctuations under utility normal operation will not represent considerable light intensity changes.

Fluorescent Lamps.

Fluorescent lamp technology uses electric current to excite mercury vapor along a glass tube. Figure 20 shows the main components of this type of lamp.

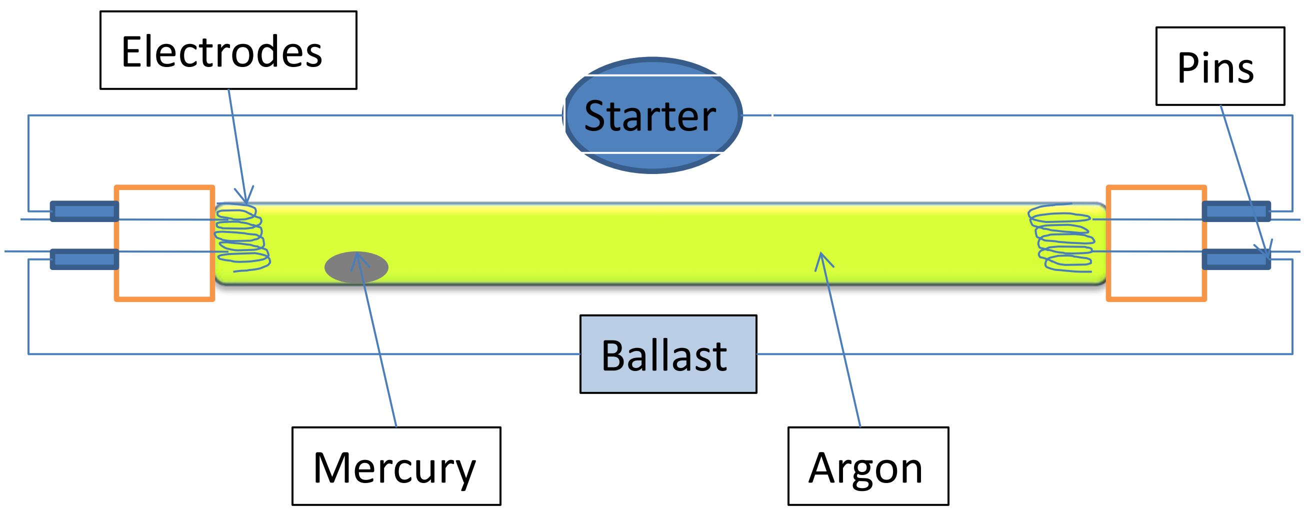


Figure 20: Main components of a common Fluorescent lamp.

These excited mercury atoms produce a short wave of ultraviolet light that causes a phosphor to illuminate in order to produce visible light. Fluorescent lamps have a lower energy cost compared to incandescent bulbs though their unit cost is higher due to the fact that they need a special circuit that regulates the current that flows through the tube.

Metal Halide Lamps

Metal halide lamps produce light by an electric arc that excites a mixture of vaporized mercury and a composition of metals that consist of Brimine or Jodine (metal halides). Metal Halide lamps are more energy efficient than incandescent bulbs and fluorescent lamps and also has a better color rendition of the light. This type of lighting systems is often used to illuminate wide areas such as stadiums. Figure 21 shows the main parts than compound metal halide lamps.

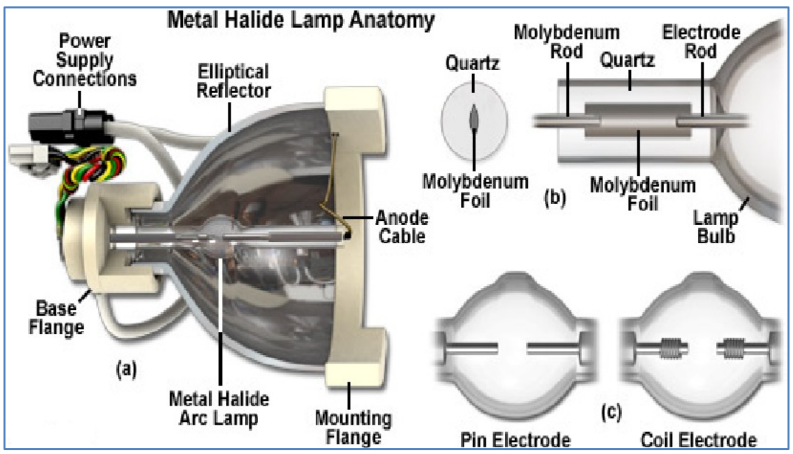


Figure 21: Main parts in a metal halide lamp.

One of the main disadvantages that this type of technology presents is the fact that their installation and maintenance is more complex and cumbersome than most common types of lighting systems such as incandescent light bulbs. Metal halide lamps operate under relatively high internal pressure compared to other lighting technologies. If a failure in the installation occurs it could ends up rupturing the bulb, which causes hot particles that could cause a fire in the surrounding space [19].

A high internal temperature has to be reached in order to have a full operation metal halide lamp. This also causes a relatively long period of time required in order for the lamp to reach its proper operating point. This time may range from a few seconds up to a few minutes depending on the driver circuit and type of metal halide lamp. This excludes this type of lighting systems from being used in emergency vehicles such as ambulances. Since safety is an immense issue in emergency vehicles metal halide lamps will not be considered in the lighting system selection.

This type of lamp also requires a special circuit to operate properly due to its high initial voltage that is required to start. Figure 22 contains a circuit designed by Unitrode Corporation to power up a 30W metal halide lamp [20].

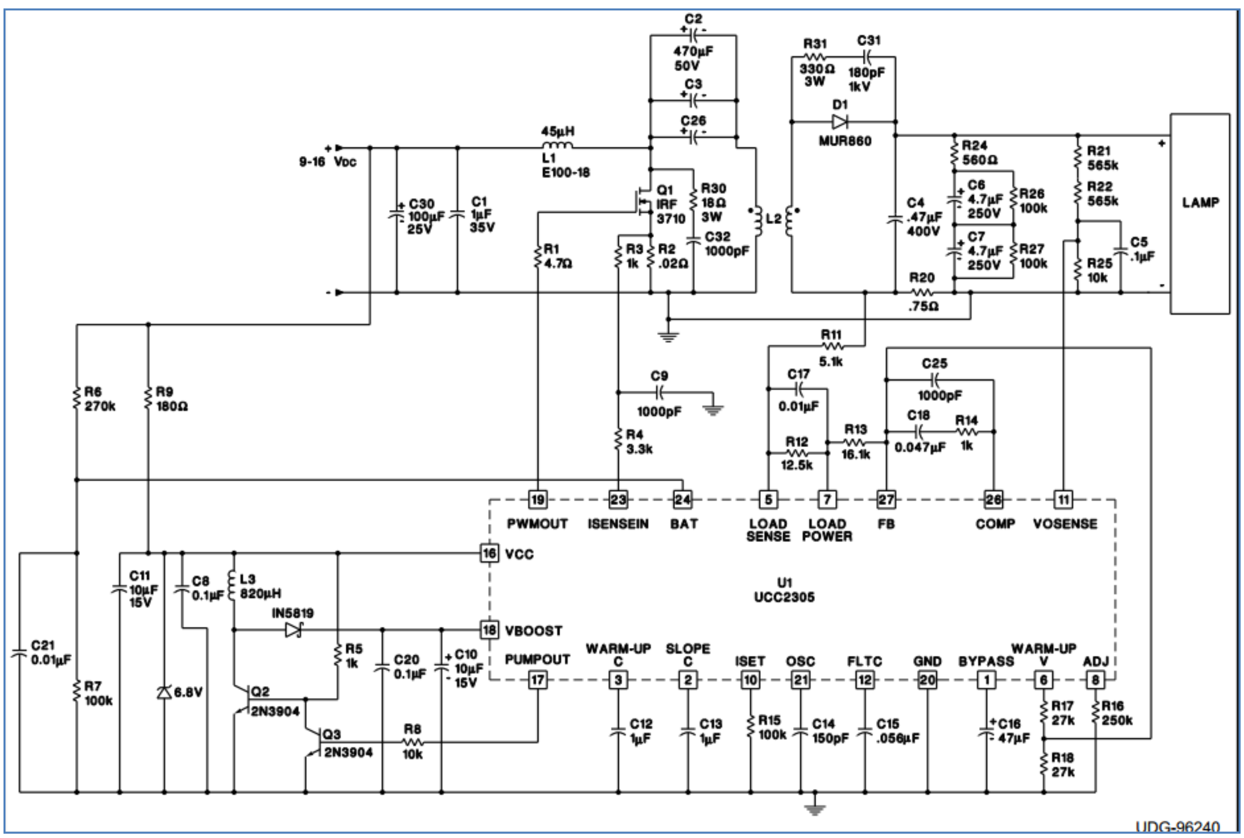


Figure 22: Metal Halide lamp driver circuit by Unitrode Corporation.

This circuit is much more complex than the ones needed to operate incandescent lights, fluorescent lights and LED lamps. This increases the initial cost of the lighting design because of all the diodes, transistors, capacitors, resistors and other electrical components that are essential to operating metal halide lamps properly.

White LEDs

Light-Emitting Diodes (LED) are semiconductors than produce light as a result of the release of energy when electrons combine with positive ions. Because their operation, it is well known that LED have a longer life time compared to incandescent light bulbs, fluorescent lights and metal halide lamps. Figure 23: Main parts that compound a LED**.** shows a basic LED and its basic parts.

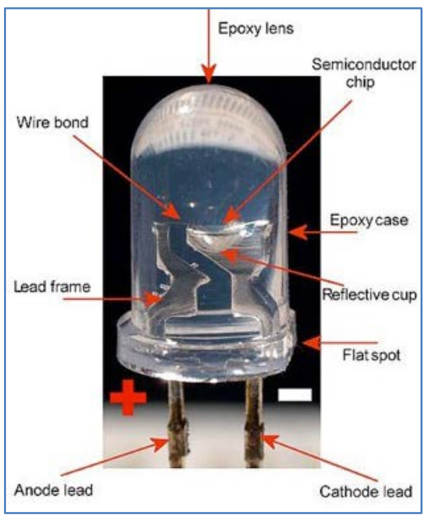


Figure 23: Main parts that compound a LED.

LEDs are known to have very low power consumption and work under relatively low input voltages that range from 1.2V (typical from a red LED) to 5.2 V (maximum voltage drop for a VLWW9900 white LED). Their current requirements range from 10mA to 50 mA for small LEDs and up to 150mA for 8mm LEDs as the P804TW4D manufactured by Asiaopto Industrial LTD. However, due to their relatively low operational voltages and currents, special driver circuits are necessary in order to provide with this power requirements. The following circuit shows a basic driver circuit that provides to a white LED with 3.2V at 20mA.

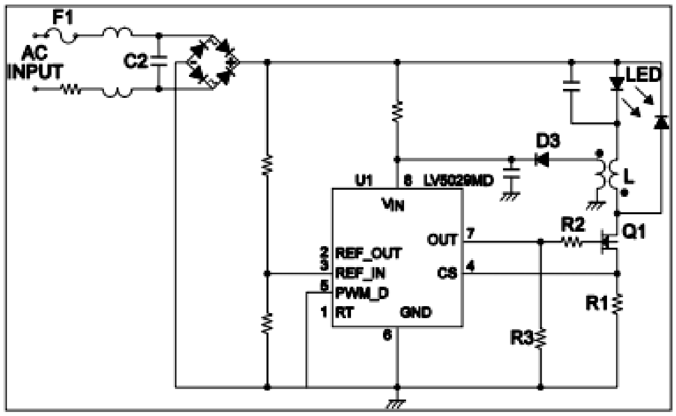


Figure 24: LED lamp driver based on an integrated circuit.

There are currently many LED lamps suppliers in the market and circuits as the one in Figure 24 are already packed inside the lamp. This is the reason why the difference in cost between an incandescent light bulbs and LED lamps is relatively high. Table 18 shows different LED lamps that are being currently commercialized along with their application, power requirements and cost.

Table 18: Commercial LED lamps

Part Number	Operating Voltage (V)	Power Comsumtion	Eficacy (lm/W)	Max. Candela	CRI	Color Temperature (K)	Price ($)	Application	Source
BSD-1890-SIW 	28 VDC	1.3 W–1.8 W	58.5	146	n/a	2800K to 3200K	**$26.46**	Reading Light for Aircraft, Trains, Buses	LEDtronics, Inc.
LED48T8SM-288-XPW-24/42VWA  	24 - 42VDC	16W	102	536	75	4500K to 5000K		Interior light for Buses, rails, cars	LEDtronics, Inc.
LED48T8SM-276-XIW-001W  	90-290	13.3	64	48cd	79	3000K to 3400K		Housing	LEDtronics, Inc.
DEC-A19F-8W-XIW-120AWD 	100–120	7.7	90	179	85	3000K to 3200K		Housing	LEDtronics, Inc.
SLL002P-3D60W-XPW-004 	100-277VAC	82 W	58	3236	76	5500K to 6350K		Street and Road lighting systems	LEDtronics, Inc.

As it can be seen from the table, LED lighting systems are being used in several applications that range from a small flashlight to big lamps. They already include the circuitry needed for them to be able to operate under common voltages as the utility or a car battery. The table shows a important factor that is to be taken into consideration: the color temperature.

Main Constraints with LED Lighting Systems

Because of the way how LEDs operate, white LED's are achieved by two main approaches that are listed and briefly explained below. This is the main reason why color rendering, and color temperature are now two of the most important issues that keep LED researchers busy.

Red-Green-Blue LED approach uses a combination of these three colors mixing their wavelength so that a "white" color can be seen by the human eye. In reality, the light produced is not pure white. In fact, mostly all lighting systems have this characteristic. Light is not achieved by only one length wave but instead a combination of them that produce a light that appears to be white for the human eye.

Blue LED and Phosphor approach According to the US Department of Energy, this type of white LED is commonly based on a blue LED covered by phosphor. This caused a modification in the wavelength of the light emitted in a way that can produce white light as the combination of different light colors.

Though the second approach is the most developed, there are still many disadvantages with LED white light. Figure 12 compares both methods and the advantages and disadvantages for each method [18].

Table 19: Advantages and disadvantages of white LED.

Technology	Advantages	Disadvantages
Phosphor Conversion	Most mature technology	
	High-volume manufacturing processes	High Correlative Color Temperature (CCT) that produces a cool or blue appearance
	Relatively high luminous flux	Warmer CCT LEDs are more expensive
	Relatively high efficacy	May have color variability in beam
	Comparatively lower cost	
Red-Blue-Green	Color flexibility, both in multicolor displays and different shades of white	More difficult to control and drive. Each color needs different conditions: power requirements, light quality, dimming, and operating temperature.
		Need more control over lamp power source.
		Often have low Color Rendering Index

Table 19 contains a very important fact that is one of the main reasons why manufacturers do not make use of LED-based lighting systems inside the ambulance. All lights, except the warning lights, in an ambulance have to be white. This includes interior lights. Therefore the use of white LEDs is a must if the lighting system is aimed to be based on LED technology. However, as mentioned in the table, white LEDs usually have a very high Color Cool Appearance (CCT) [21]. This can generate considerable problems when a paramedic observes a patient. Since this color can be observed on the surfaces where the LED light hits, patients can be wrongly diagnosed with illnesses that produce that color in a person's skin.

However, LED based lighting systems might be implemented in exterior lighting without having the problem described above.

2.3.3 Comparison Between Lighting Systems.

Ambulances are vehicles that are modified such that they can operate as rescue trucks that include many systems needed to assist a patient when an accident or incident occurs. Ambulance manufacturers buy those vehicles and design interiors and exteriors such that they meet the regulations established by the KKK and NFPA. Lighting systems used by Ambulances manufactured by McCoy Miller, MARQUE Ambulances and HORTON ambulances are analyzed in the following table that contains information extracted from the specification sheets available at the websites of those companies.

Table 20: Lighting Systems by Ambulance Manufacturers

		Ambulance Manufacturer		
		McCoy Miller (Resqmedic)	**Marque Ambulances (Recruit)**	**Horton Ambulances**
Types of light	**Dome Lights**	8 Dual element, halogen	8 dual filament, incandescent	7 Weldom Halogen lights
	Side scene lights	Six Whelen 900 Series Halogen	Whelen 900 Series Â– two per side	(2) 900 Series Whelen Halogen with Chrome Bezels
	Step Well light	Not specified	Not specified	Weldon with Chrome Bezel
	Rear Loading Lights	Two Whelen 900 Series Halogen	Whelen 900 Series Â– two above rear doors	(2) Whelen 900 Series Halogen
	Spot light	One, 400,000 CP hand-held with momentary switch	One 400,000CP hand-held light with momentary switch	(1) Optronics Hand Held in Cab
	Tail Lights	Not specified	Not specified	Whelen 600 Series Halogen
	Compartment lights	Not specified	Not specified	Full Height LED Strips
	Warning Lights	Ten Whelen 900 Series Halogen	Whelen perimeter lighting	8 Whelen 900 Series Halogen (red) and 2 Whelen 700 SeriesHalogen(Clear)
	Grille and Intersection Lights	Whelen LED	Not specified	(2) Whelen 700 Series LED (red) and (2) Whelen 400 Series Halogen (red)

From Table 20, it can be seen that the following types of lights are often used by manufacturers:

Table 21: Power Consumption per lamp model

Current model	Operating Voltage	Operating Current	Power consumption	Cost	Dimensions
Dual Element Halogen	12	2.916667	35		181mm (H) *232 mm (W)
Whelen 900 Series halogen	12	5	60		181mm (H) *232 mm (W)
400,000 CP hand-held	12	14.16667	170		
Whelen 700 Series Halogen	12	5	60		78 mm (H) * 184mm (W)
Whelen 600 Series Halogen.	12	5	60		105 mm (H) * 165mm (W)
Whelen 400 Series LED	12	0.75	9		77mm (H) * 124mm (W)
Whelen 700 Series LED	12	0.75	9		78 mm (H) * 184mm (W)

From here it can be concluded that the vast majority of ambulance manufacturers do not implement lighting systems based on LED on their designs. Most of the designs are based on incandescent lights.

CHAPTER 3. INSULATION, LIGHTING AND ENERGY EFFICIENCY

3. Introduction

The ambulance is constantly on in order to be ready for emergencies which results in a large amount of energy being wasted. This project seeks to reduce any waste of energy by developing solutions that reduce power consumption, heat loss and causalities. This section seeks to take advantage of the data collected in the previous chapters in order to develop a solution to improve the ambulance compartment design. This chapter discusses three solution approaches: Closed-Cell Polyurethane, Hybrid Lighting System (LED-incandescent lamps).

3.1 Insulation

After considering all the commonly used materials this projects goal was to solve and discuss the solution to what the optimal insulation would be for the ambulance compartment design. The conclusion research led to polyurethane spray foam being the best choice as far choosing the insulation that had to satisfy all the requirements of the ambulance. Polyurethane in comparison can be thought of being directly in the middle. Polyurethane is more on the expensive side of insulation materials but it is cost effective and does an excellent job in delivering the R-value needed to keep patients comfortable. In addition, compared to fiber glass which would perhaps be the second choice in the money versus value evaluation, polyurethane is very effective in providing an acoustic barrier for external noises that could be harmful to the patient. Polyurethane may not be the lightest of materials but it provides a low thermal conductivity at an average density of 30 kg/m^3 making the perfect balance between weight and quality.

3.1.1 Design Objectives for Insulation

Developing a solution to selecting the most proper insulation for the ambulance compartment design requires a list of objectives to fulfill. Figure 25 shows the list of objectives that are taken into consideration in order to optimize the insulation design.

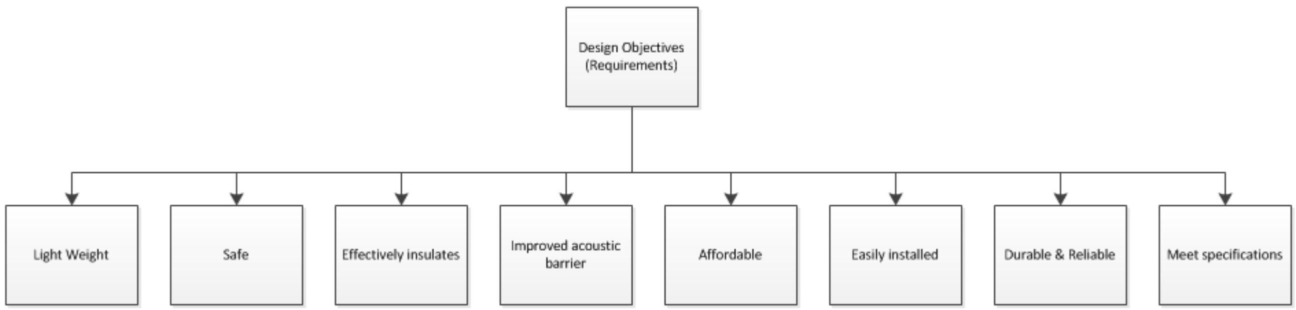


Figure 25: Design Objectives for Insulation

Light Weight

The insulation material must be light weight. The KKK-A-1822F specifies that type III ambulances must have a gross vehicle weight rating between 10,001 to 14,000 kilograms. Utilizing this objective permits the possibility of adding additional equipment and accessories to improve the EMTs working performance. Reduction in weight optimizes fuel efficiency which makes ambulances more environmentally friendly. Additionally, it minimizes stress and strain on engine components of the ambulance. This results in a more reliable and long lasting investment by reducing maintenance cost.

Safe

According to the KKK-A-1822F, insulation must be non-toxic and fire retardant. These conditions are more a necessity than they are an objective, however, it is important to note that the insulation chosen can also be treated chemically to improve its resistance to fire spread. In addition, the objective is not only to find an insulation that is safe for personal but also for the environment. The manufacturing of insulation materials leads to the production of greenhouse gases which are environmentally harm. The selection of insulation will consider the reduction and optimally omit the production of greenhouse gases or other environmentally threatening by products.

Effective Insulation

This objective is to improve the insulating quality of the insulation selected specifically during the winter season in regions of the U.S. where temperatures are relatively low. The insulation will optimally prevent as much conduction heat transfer as possible. However, what is more important is that the insulation is effective in reducing convective heat flow. Many different types of insulation give a false sense of insulating capability because although the R-value may be “high” the insulation may still fail to insulate effectively. During temperature extreme season like the winter and summer it is important to have insulation that effectively protects against convection heat flow. In temperature extremes the difference in temperature between the outside of the ambulance compartment and the inside is much greater. This difference in temperature increases the amount of convection heat transfer that occurs and renders insulations that fail to protect against convection much less effective.

Improved Acoustic Barrier

One of the major issues with the ambulance compartment design is the amount of noise the sirens make in order to alert local traffic of an emergency. According to the KKK-A-1822f standards the interior of the compartment must but exceed 60 decibels. According to the National Institute on Deafness and Other Communication Disorders an ambulance siren rings at 120 decibels. Research by the institute also suggests that regular exposure to 85 decibel noises or higher risks permanent hearing loss [23]. This objective seeks to improve the acoustic barrier in order to prevent the risk of EMTs developing hearing problems. Since EMTs are regularly stationed within the compartment it is much more likely for EMTs to develop hearing problems due to constant exposure. This is also to include the safety and comfort of the patients who are being serviced in medical emergencies

Affordable

Among all of the criteria cost is one of the most important aspects in improving the development of the ambulance compartment design. Developing a cost effective solution is important in order to provide a more flexible budget for the overall design. Ultimately, an improved budget can be invested into advancing ambulance technologies or providing higher quality medical care.

Easily installed & durable

Ideally the insulating material will maintainable, reliable and durable. Some materials are capable of maintaining thermal resistivity for long periods of time. This is an attractive quality that this project seeks because of less maintenance and being more cost- effective. Being easily installed and removed is another attribute that will be considered in making the final decision.

3.1.2 Design Constraints for Insulation Design

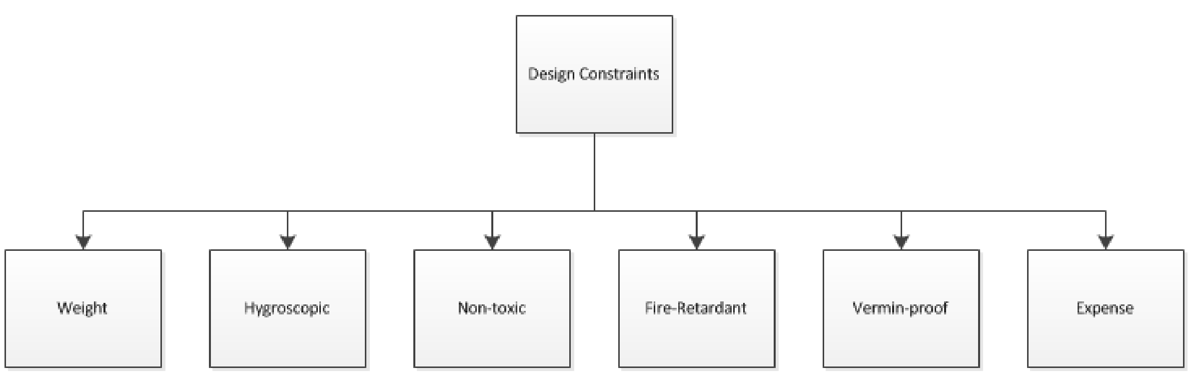


Figure 26: Design Constraints for Insulation

In addition, to objectives it is important to address the limitations of what types of insulating are acceptable in the ambulance compartment design. As mention in chapter 2 our selected insulation must be non-toxic, hygroscopic, fire-retardant, and vermin proof which is displayed in Figure 26.

3.1.3 Final Design of Insulation

After considering all the commonly used materials this projects goal was to solve and discuss the solution to what the optimal insulation would be for the ambulance compartment design. The conclusion research led to polyurethane spray foam being the best choice as far choosing the insulation that had to satisfy all the requirements of the ambulance. Polyurethane in comparison can be thought of being directly in the middle. Polyurethane is more on the expensive side of insulation materials but it is cost effective and does an excellent job in delivering the R-value needed to keep patients comfortable. In addition, compared to fiber glass which would perhaps be the second choice in the money versus value evaluation, polyurethane is very effective in providing an acoustic barrier for external noises that could be harmful to the patient. Polyurethane may not be the lightest of materials but it provides a low thermal conductivity at an average density of 30 kg/m^3 making the perfect balance between weight and quality.

3.1.4 Advantages of Polyurethane

Friendswood Volunteer Fire Department Annual Report for 2007 reports that ambulances are suggested to be replaced every 5 years. This vehicle replacement structure provides the department optimal and reliable ambulances and avoids maintenance downtime. These results are summarized in Table 22 [24].

Table 22: Vehicle Replacement Schedule

Vehicle Type	Expected Life (years)	Expected Life with Rehabilitation (years)
Fire Pumper, Class A	15	20
Fire Ladder Truck	20	25
Brush Truck (truck only)	8	N/A
Brush Truck (Fire Pump Skid Unit and Tank)	10	20
Support Vehicles (fire)	8	N/A
Special Vehicles	TBD	N/A
Duty officers Vehicles	7	N/A
Chief's Vehicles	8	N/A
Ambulance Chassis - Heavy Duty	7	N/A
Ambulance Chassis	5	N/A
Ambulance Module	5	5
EMS Response Vehicles	7	N/A

Closed-cell polyurethane insulation is the optimal choice for the standard type III ambulance because most ambulance provides 5 years of service before they are replaced. Polyurethane will provide optimal R-values for the compartment despite the thermal drifting which is summarized in figure 10. Though, polyurethane will still give a higher R-value than that of all the most commonly used insulation materials. Figure 27 compares the effectiveness of different conventional insulating materials used in buildings.

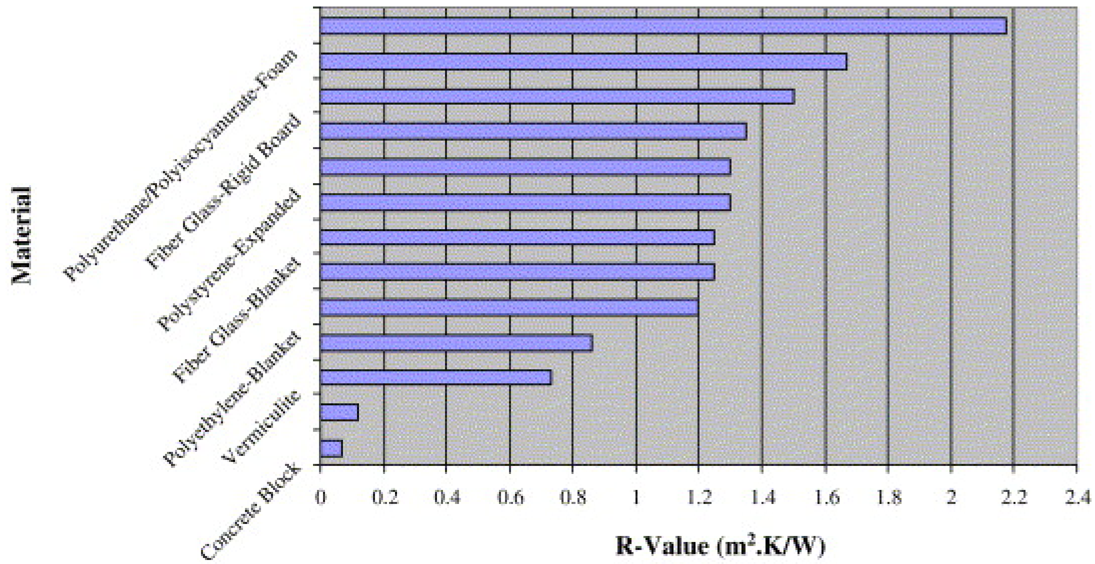


Figure 27: Thermal resistance of common insulation materials

For the maximum energy efficiency in a 5 year period polyurethane foam can be utilized to reduce energy costs by reduced heat loss significantly. Since polyurethane intrinsically provides a nearly air tight seal when it expands. This provides an extremely effective means in preventing convective heat loss. This is especially accounted for when the interior and exterior temperatures of the ambulances differ drastically. The difference in temperatures results in the stimulation of convective heat flow. This cannot be done with many of the other commonly used insulations because at certain temperatures insulations such as fiberglass do keep a consistent R-value in varying temperatures.

Appendix B demonstrates the basic characteristics and guidelines for the different characteristics and properties of conventional insulation materials [26]. Appendix B reveals that foamed-in-place polyurethane provides excellent barrier against infiltration, a proficient water vapor barrier, high sound absorption capabilities, and a large R-value. With a good resistance to water vapor polyurethane insulation is not as susceptible to having its properties diminished from water infiltration which can cause mold and retard the materials ability to insulate. As mentioned in the desired criteria the optimal insulation prevents the sounds from reaching 60 decibels within the compartment. A study done at the University of Adelaide has shown that sirens posted in different locations on a 2005 Mitsubishi Magna station wagon resulted in sound pressure within the cabin lingering around 70 decibels. These results are shown in figure 30 [27].

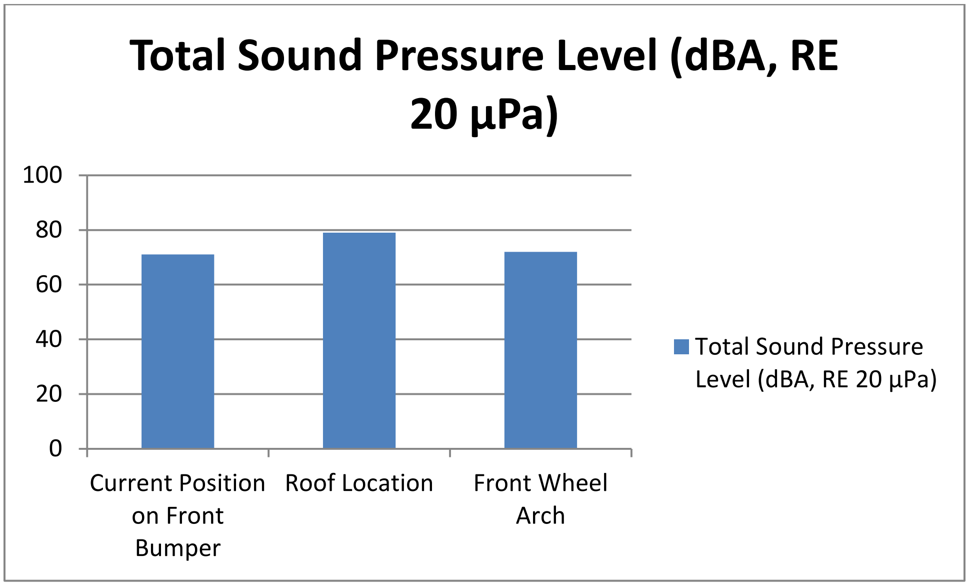


Figure 28: Total A-weighted siren sound pressure

Common standard issue insulation is fiberglass because of its pricing which yields low acoustic attenuation. Thus, it is important to consider materials such as polyurethane in the ambulance compartment design.

A primary concern in the consideration of selecting polyurethane was that it was safe. This mandatory standard specified by the KKK-A-1822f and the NFPA are retains great weight in choosing the proper insulation material. An insulation material cannot be implemented it is potentially hazardous to anyone who isexposed to the material. Thus, it is important that we analyze the impact of the insulation on human health. Table 23 summarizes the different environmental and health impacts characteristics of the conventional insulation materials

Table 23: Comparison of Envelope Insulation Materials

Type of Insulation	Installation Method(s)	R-Value per Inch	Raw Materials	Pollution from Production	Indoor Air Quality Impacts	Comments
Fibrous Insulation						
Cellulose	loose fill, wet spray, dense pack, stabilized	3.0 - 3.7	newspaper, borates, ammonium sulfate	Negligible	Fibers and chemicals can be irritants, should be isolated from interior space	High recycled content, very low embodied energy
Fiberglass	batts, loose fill, stabilized, rigid board	3.0 - 4.3	silica, sand, limestone, boron, resin, cullet, some types contain trace amounts of phenol formaldehyde in the binder	Air pollution from energy use	Fibers and chemicals can be irritants, should be isolated from interior space	some loose-fill products have no binder.
Mineral Wool	loose fill (no binder), batts, wet spray	2.3 – 4.0	steel slag or rock , phenol formaldehyde,	Air pollution from energy use	Fibers and chemicals can be irritants, should be isolated from interior space	Sound deading capacity
Perlite	loose fill	2.5 - 3.3	volcanic rock	Negligible	Some nuisance dust	
Rigid Insulation and Sheathing						
Expanded Polystyrene	rigid boards	3.85 - 5.0	fossil fuels, pentane	Pentane emissions contribute to smog	Concern only for those with chemical sensitivities	Primary non-HCFC foam board
Extruded Polystyrene	rigid boards	3.1 - 5.0	fossil fuels, HCFC-142b	Ozone depletion	Concern only for those with chemical sensitivities	At one time, a recycled product was available
Polyiso-cyanurate	foil-faced rigid boards	3.6 – 5.6	fossil fuels, HCFC-141b	Ozone depletion	Concern only for those with chemical sensitivities	One non-HCFC-based product is available
Closed-cell Polyurethane	sprayed-in	3.4 – 6.2	fossil fuels, HCFC-141b	Ozone depletion	Concern only for those with chemical sensitivities	
Open-cell Polyurethane	sprayed-in	3.5	fossil fuels, soy oil	Negligible	Unknown, appears to be very safe	Doesn't harden; good air sealing
Fiberboard Sheathing	rigid boards	2.6	sawmill waste, organic by-products, asphalt, wax	Dryer emissions	n/a	

It can be seen that polyurethane only has problems with chemical sensitivities; however, not isn't much concern to the objectives of this project. It is shown that the indoor air quality is not impacted by polyurethane which is makes polyurethane a safe material to use as insulation [15].

3.1.5 Disadvantages of Polyurethane Insulation

Polyurethane can become quite expensive and dense especially if closed-cell polyurethane method is implemented. In order to achieve higher R-values a low conducting gas must be inserted during the synthesizing process. Though spray foam insulations much higher R-values and generally prove easier to install and maintain, fiber and loose-fill insulations still are much more economical as far as costs go. This leads to the idea of method of using both insulations in conjunction in order to have a high quality and effective insulation as well as a cost-friendly option as well. Well insulating an ambulance it is not always important to achieve the maximum R-value possible if it means trading off price and weight. Table 24 shows the most commonly used insulations used in housings with their respective R-values and pricing per square foot [26].

Table 24: Cost comparison of Insulating Materials

		Typical R-Value (per inch)	Typical Cost ($/sq ft per R-value)
Batts, blankets and loose-fills insulation, mineral wool, fiberglass, rock wool	Batts or blankets	2.9 - 3.8	0.020 - 0.032
	Loose-fills	2.2 - 2.9	0.015 - 0.020
	Cellulose (loose-fills)	3.1 - 3.7	0.009 - 0.036
	Cotton insulation	3.0 - 3.7	0.048 - 0.055
Foam insulation and sheathing	Polyisocyanurate and polyurethane	5.0 - 5.7	0.172
	Extruded polystyrene	5	0.075 - 0.091
	Expanded polystyrene	4	0.063 - 0.084
	Fiberboard sheathing (blackboard)	2.6	0.082 - 0.136
	Isocyanate Foam	3.6 - 4.3	N/A

On average this table shows that almost all spray foam insulation yields an R-value 2-3 times greater that of the loose-fill insulations. Although, the table also reveals the price is much cheaper for utilizing loose-fill insulation. In comparing the cheapest loose-fill insulation with the most expensive spray foam insulation the table shows reveals that the most quality insulation is 6.6 times more expensive than that off the most cheap loose-fill insulation. Though this may be the case an ambulance is required to be capable of heating the compartment from 0 degrees Fahrenheit to 68 degrees Fahrenheit within 30 minutes. Thus, it is important that we not only consider the price but also the effectiveness of the insulation especially since there is a quality that must be met specified by the AMD, NFPA, and the KKK-A-1822F.

Polyurethane spray foam insulation has negative impacts on the environment as shown in Table 23. Chlorofluorocarbon is a byproduct of the polyurethane when it is being manufactured. Chlorofluorocarbons and other greenhouse gases cause the ozone to deplete which is an undesirable characteristic of Polyurethane.

3.2 Lighting Design in Ambulances

This section explores the advantages and disadvantages of a hybrid LED-Incandescent lighting system. It is divided into five subsections containing the design requirements, design constraints, an analysis of the current lighting system, the analysis of LED lighting systems with advantages and disadvantages and finally, the suggested hybrid LED-Incandescent lighting design. A power consumption analysis is performed for the final design.

3.2.1 Design Requirements for Lighting Design

A complete list of requirements for the suggested improvements is presented in this section. These requirements are aimed to guarantee standards and improve power efficiency. This is done while maintaining or improving safety, cost and other aspects that are vital for the ambulances to operate under optimal conditions. Figure 29 shows a diagram containing all these requirements.

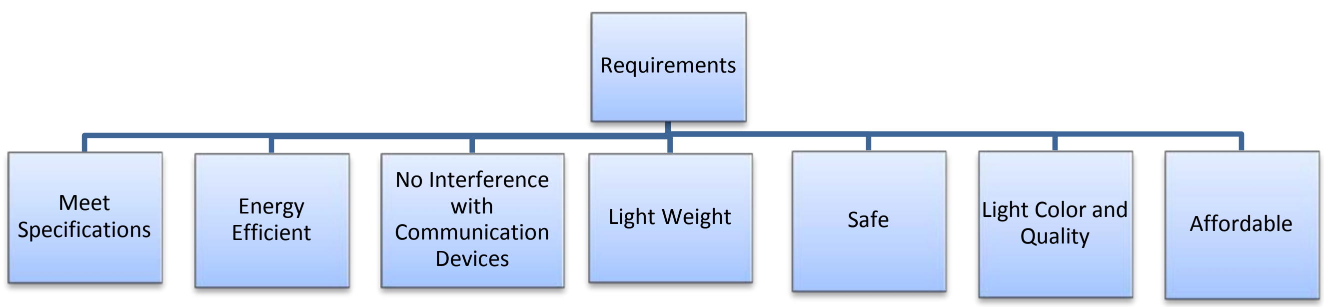


Figure 29: Design objectives for the lighting system

The requirements illustrated in Figure 29 are discussed in further detailed.

Meet the KKK specifications

As stated in the KKK-A-1822F in section 3.8, the current drawn from the interior lighting system has to be less than 25 Amperes, which implies a maximum power consumption of 300W.

The suggested improvement has to fulfill this power requirement so that the total current drawn from the batteries do not exceed the current that is provided by the main alternator (electric energy generator from kinetic energy). Improvements in the exterior lighting system are also suggested as part of this project. These improvements have to be consistent with the standards that regulate health care, ground transportation and especially ambulances.

Energy Efficient.

The suggested changes in the design are aimed to improve not only quality but also energy consumption compared with the current design. High power efficient lamps and circuits to control the power delivered to each lamp are suggested to decrease power consumption of the system.

No Interference with Communication Devices.

Ambulance communication systems are highly important and play a critical role when an emergency takes place. Devices that interfere with the ambulance communication systems have to be avoided to prevent faulty communication such as dropped calls and static. This requirement rules out lighting technologies that produce electromagnetic fields such as the induction fluorescent lamps.

Light weight

Improvements in the lighting system should not considerably increase the weight of the ambulance, and ideally, the final outcome should be lighter.

Safe

Safety is one of the most important aspects to take into consideration when suggesting improvements to the system. The suggested modifications should not represent any type of risk for patients and paramedics. Failure to meet this requirement could end up in tragedies that could have been prevented.

Prevent from Wrong Diagnosis due to Light Color and Quality

The use of lamps containing relatively high components of blue color in its energy spectrum have to be avoided as stated in the KKK-A-1822F regulations. Lamps with poor color rendering must also be avoided in healthcare environments. This will prevent EMTs from misdiagnosing illnesses related to observation of patient's skin color. Concepts as Color Rendering Index (CRI) and Correlative Color Temperature (CCT) are taken into consideration in order to meet this requirement.

Affordable

Changes in the final design should not increase the cost considerably. The suggested design may imply a higher initial cost compared with the current design. However, in long term our final design will be more affordable.

3.2.2 Design Constraints

Weight

The suggested design has to be implemented such that the overall weight of the ambulance does not get altered.

Power Consumption

One of the main objectives of implementing a new design is to make the whole electrical system more power efficient. Low power lamps are suggested as part of the new design.

Color Rendering Index

The Color Rendering Index is a property of a light that refers to how natural the colors of a given body look under certain illumination sources. White light with low values of Color Rendering Index (CRI) imply relatively low quality for general illumination purposes such as interiors where colors have to be shown vivid and natural [27].

For CRI less than 70, the colors are not clear and the skin presents a bluish color; this CRI is present in Standard Warm and Cool White Fluorescent, High Pressure Sodium and Conventional Metal Halide lamps. CRI ranging from 70 to 80 present a more vivid color and these values are found in Thin Coated Tri-Phosphor Fluorescent lamps. White lamp color with CRI ranging between 80 and 90 have a better quality than the ones described before and they are present in Warm Metal Halide, Thick Coat Tri-Phosphor Fluorescent and White High Pressure Sodium lamps. Finally CRI ranging from 90 and 100 have the best color rendering quality and are present in high CRI Fluorescent, Incandescent and Tungsten- Halogen lamps.

Correlative Color Temperature

A white light source has an assigned quantity in Kelvin that corresponds to the temperature at which a black body would emit the same color of light when heated. This quantity is called Correlative Color Temperature (CCT) [28]. The higher this value, the bluer component the light contains. This also implies that the warmth of the light is inversely proportional to the CCT of a given light source. A more comprehensive explanation can be visualized in Figure 30.

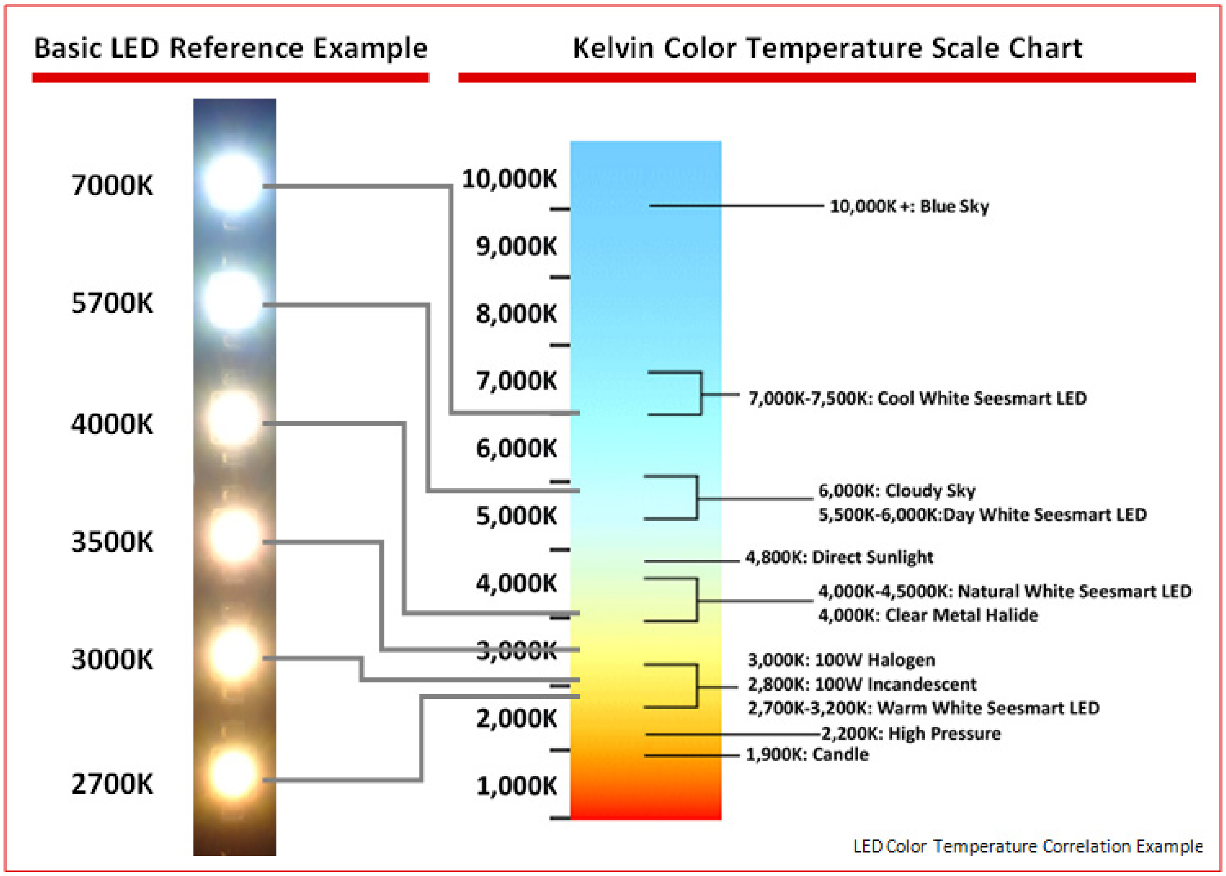


Figure 30: Correlative Color Temperature.

Note that white light sources containing high blue components, are assigned a higher CCT compared with those containing more warm color components. The use of white light in ambulance interiors poses this big constraint, white light sources with relatively high values of CCT have to be avoided. Warm light colors are preferred. Figure 31. Provides with the same picture taken with three different CCT levels; this figure shows the impact that CCT has on the objects hit by the light.

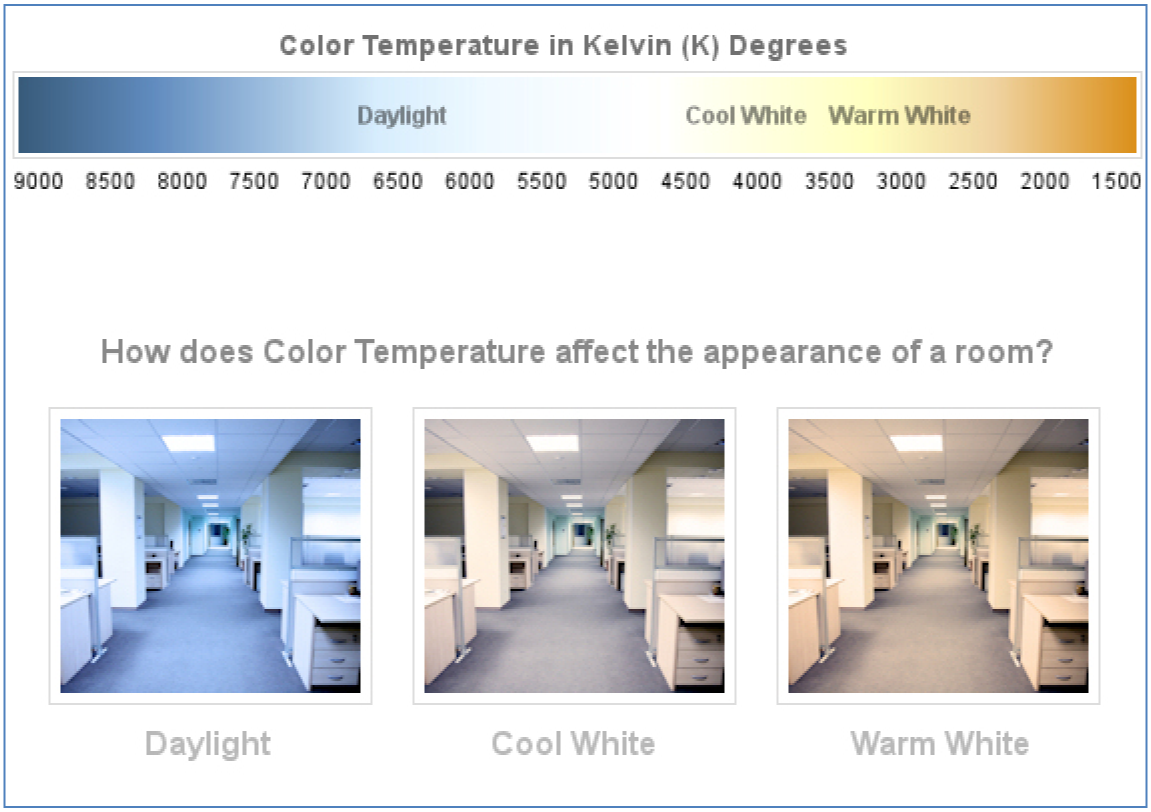


Figure 31: Impact of CCT on an office color.

Objects exposed to white light with high CCT present a bluish appearance to the human eye. While objects exposed to light with relatively low CCT values present a more realistic appearance. Notice how the interior of the office presents a high blue component that is caused by the high CCT value found in daylight. A less-blue environment is encountered in the next image of the same office; this corresponds to a cool white light color and is manifested in white light with CCT values higher that 3500K and below 6500K. Finally the same room is illuminated with a warm white light source that corresponds to CCT values between 2000K and 3500K.

3.2.3 Current Lighting System Design.

As shown chapter two, lighting systems in most ambulances are designed using incandescent lamps. Interiors (dome lights) and exterior lights described by the specification sheets provided by the manufacturers confirm that the vast majority of ambulances use incandescent light bulbs. As dome, emergency and others lights, they use halogen lamps and common two contact incandescent light bulbs. Considering these specifications the total power consumed by the lighting system can be calculated as it is in Table 25.

Table 25: Total power consumed by the lighting system

Type	Model	Location	number of units	Power consumption per unit (W)	Total power (W)	Current drawn (A)
Dome lights	Dual Element Halogen	Ambulance ceiling	8	35	280	21.875
Side scene lights	Whelen 900 Series halogen		6	60	360	28.125
Rear Loading Lights	Whelen 900 Series halogen		2	60	120	9.375
Spot light	400,000 CP hand-held		1	170	170	13.28125
Tail Lights	Whelen 600 Series Halogen		1	60	60	4.6875
Warning Lights	Whelen 900 Series Halogen and or/ 700 series		10	60	600	46.875
Grille and Intersection Lights	Whelen 700 Series LED		2	9	18	1.4
	Whelen 400 Series LED		2	9	18	1.40625
Total					**1626 W**	**127.025 A**

The total amount of power that is being provided by one of the ambulance's battery (probably add citation) is relatively high. It is imperative to mention that this power is consumed only by the emergency and interior lights.

3.2.4 Lighting Design Using LED Lamps.

LED technology allows reducing the power consumption in lighting systems as well as improving white light quality in environments where CCT and CRI are irrelevant. This section explores a variety of products related to LED lamps that could replace the incandescent lighting system that is now being used in the ambulances that were researched. For each type of light described, a similar product is compared and analyzed. The following table shows the list of light that are used and the proposed change.

Table 26: Current lights and their suggested replacements.

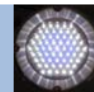
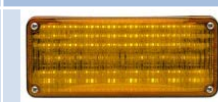
Current model	Picture	Replacement	Picture
Dual Element Halogen		LED dome lights	
Whelen 900 Series halogen		Whelen 900 Series LED 24-48Watt	
400,000 CP hand-held		400,000 CP hand-held	
Whelen 700 Series Halogen		Whelen 600 Series LED	
Whelen 600 Series Halogen.		Whelen 900 Series Halogen and or/ 700 series	
Whelen 400 Series LED		Whelen 400 Series LED	

Table 26 contains the list of lamps that are being used in ambulances along with the suggested replacement product. Notice that Whelen Engineering provides with the LED version of the Whelen 900, 700, 600 and 400 series halogen lights listed above. This facilitates the task of suggesting a lighting system based on LED technology for ambulances. Ambulances that already have been purchased with incandescent lighting systems could be upgraded to LED technology easily. This change of course would cause an increase in the initial cost of an ambulance however, due to the long lamp life and low power consumption LED lighting systems represent substantial savings. Figure 32 contains a life time comparison between different technologies showing how LED lamps have a much longer lifetime compared with other technologies.

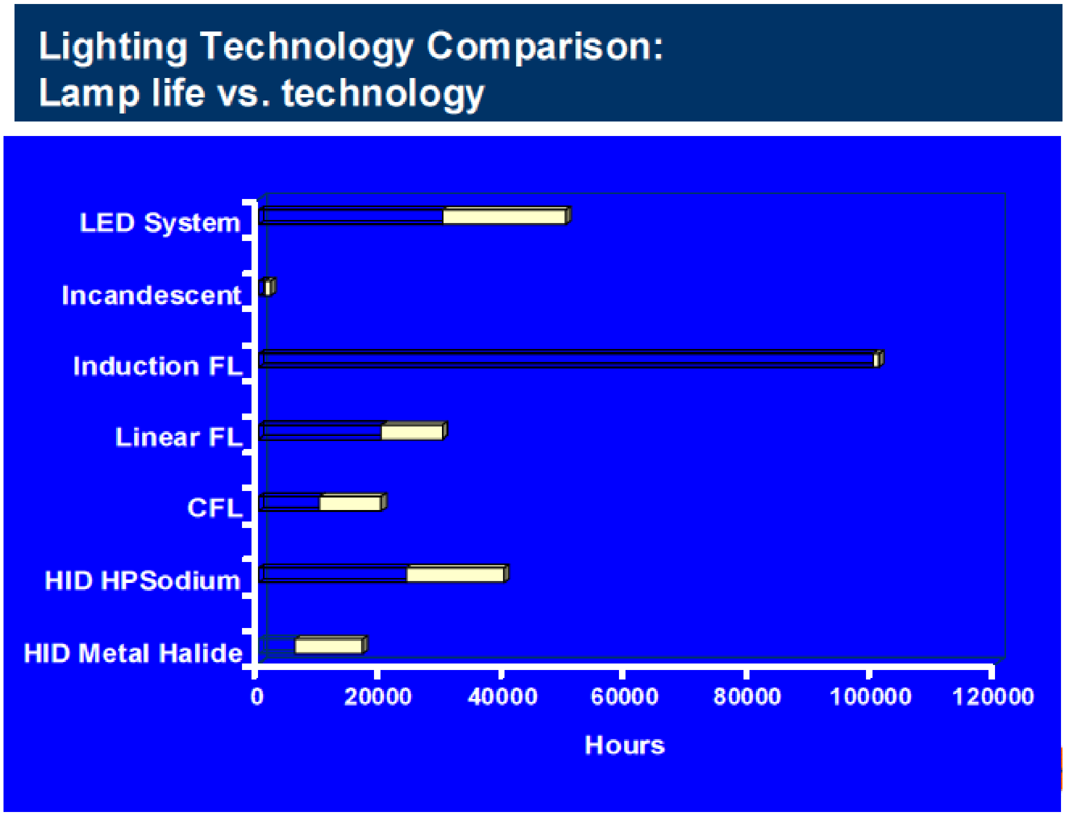


Figure 32: Lamp life comparison in hours.

Notice that the average LED lamp life is above 50000 hours while incandescent lamps life is well below 5000 hours. The graph presented is very descriptive and shows a drastic advantage of LED's over incandescent lamps. As it can be seen from the graph, LED lamps are the second type of light with longer lifetime while Induction Fluorescent is the one with the longest. However, as analyzed before, induction fluorescent lights are not recommendable since they might interfere with the ambulance communication systems.

On the other hand, LED lamps are also high power efficient due to the way how they operate. Their power consumption allows LED lamps to provide with additional savings. Figure 33 shows the comparison between the different types of lamp light sources and their efficiency measured in lumens per Watt (LPW).

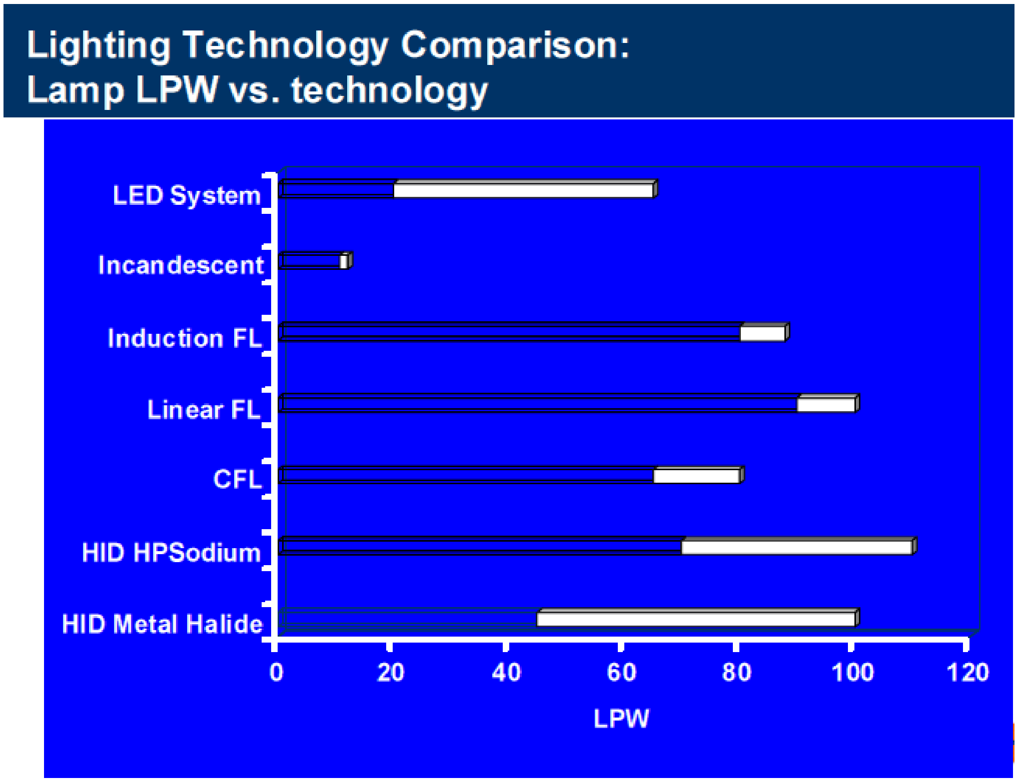


Figure 33: Lamp efficiency comparison in Lumens per Watt

According to the graph in Figure 33, incandescent lamps are the less efficient type of lamp. This is due to the great amount of electric current that is converted into heat when it flows through the filaments that compound the lamp. The graph indicates that for each Watt of power consumed by the lamp, less than 20 lumens are delivered. LED lamps on the other side, are capable of delivering up to 70 lumens per watt consumed. It is also important to mention that according to the graph, the other types of lamps except incandescent, are more efficient than LED lamps; however, they have been discarded due to the complexity of their driver circuit, the time required to reach full illumination and RF noise that can be produced when operating normally.

The difference between the power consumption can be more realistically observed with the actual specifications provided by Whelen Engineering. Table 27 contains the comparison between the halogen (incandescent) and LED lamp versions.

Table 27: Power consumption comparison Incandescent vs. LED

Current model	Number of Units	Power consumption per unit (W)	Total power consumption (W)	Replacement	Power consumption per unit (W)	Total power consumption(W)
Dual Element Halogen	8	35	280	LED dome lamps	10	80
Whelen 900 Series halogen	18	60	1080	Whelen 900 Series LED	24	432
400,000 CP hand-held	1	170	170	400,000 CP hand-held	170	170
Whelen 700 Series Halogen	2	60	120	Whelen 700 Series LED	24	48
Whelen 600 Series Halogen	1	60	60	Whelen 600 Series LED	24	24
Whelen 400 Series LED	2	9	18	Whelen 400 Series LED	9	18
			1728 W			**772 W**

Notice that the power that the actual lighting system is approximately 1730Watts while the power required in order to run the same system with LED lamps would be 772 Watts. This would represent more than 50% of energy savings in the lighting system. Also, since one of the best characteristics of LED lamps is reducing heat production while operating, overheat in undesirable areas can be prevented. This includes wires, plastic parts and other materials that when overheated could cause a fire or simply, the damage of that part.

3.2.5 Disadvantages of Using LEDs

The KKK standard establishes that relatively high blue appearance in the light color has to be avoided in the interiors of the ambulances. This means that the light used in interiors has to be *warm* light. This implies at the same time that the Correlative Color Temperature has to be in a range of 2000K to 3000K.

However, according to the U.S. Department of Energy, LED lamps in a good range of color containing low energy spectrum in blue color and with good values of CRI, could have a relatively low efficiency as depicted in Table 28.

Table 28: Efficiency, CCT and CRI of white LED lamps

	CRI		
CCT	**70-79**	**80-89**	**90+**
2600-3500 K	23-43 lm/W	***	25lm/W
3500-5000K	36-73 lm/W	36-54 lm/W	***
>5000 K	54-87 lm/W	38 lm/W	***

This issue is really important to be considered in the final design. For good values of CCT and CRI, the efficiency is not really good enough compared to that from the incandescent lamps that also have a much lower cost in the market.

Figure 34 shows the energy spectrum of three different light sources: incandescent, fluorescent and LED lamps. Notice that the energy distribution of incandescent lamps is more uniform with a high concentration of colors with wavelengths ranging from 500 to 800 nanometers and do not contain relatively big peaks compared to fluorescent and LED lamps that have notable peaks at their main color components. This is what causes that LED lamps have relatively high CCT since there is a noticeable peak from 450nm to 500nm. Blue colors have wavelengths between 460 and 480 nanometers.

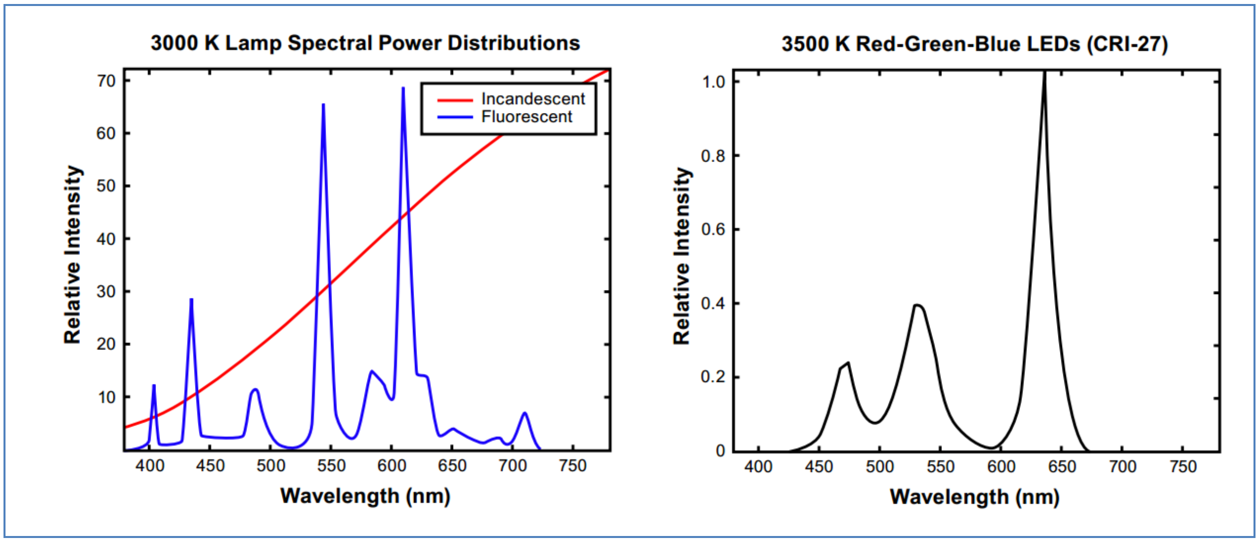


Figure 34: Energy Spectrum of different lamps.

New technologies have been developed in order to obtain warmer colors (lower CCT) from LED lamps however; Table 28 suggests that for warm white color obtained from LED lamps, Color Rendering Index and efficiency are relatively low. In fact Figure 35 shows a more descriptive Color Rendering Index comparison between the lamp types.

Notice that CRI values for LED lamps are in the range from 70 to 90. However, as suggested in Table 28, high values of CRI correspond to higher values of CCT and lower energy efficiency. On the other hand, incandescent lamps have values near 100 (CRI values are categorized from 0 to 100); this means that the quality of image and color rendering under incandescent lamp light conditions are ideal for any environment where light quality plays an important role. This is the case in health care, where paramedics have to be able to recognize skin colors, veins, eye appearance and other aspects in the human body to diagnose the patient.

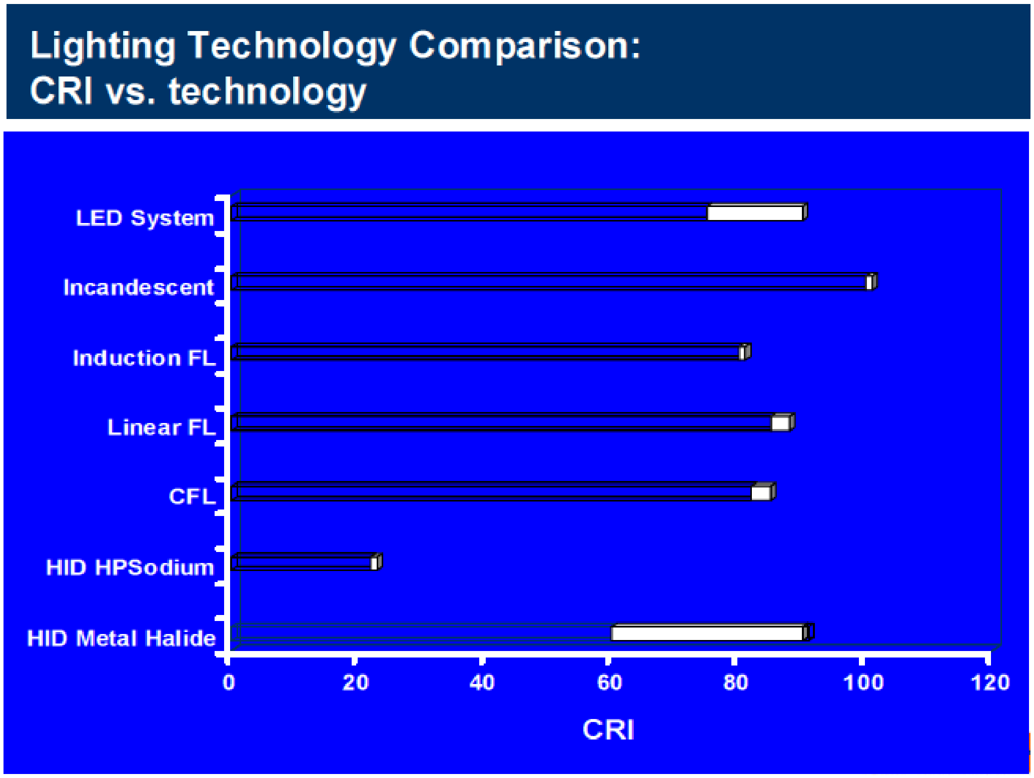


Figure 35: Color Rendering Index comparison.

Using LED lamps as internal lighting in ambulances could compromise the quality of light needed in order for paramedics to do their job effectively and efficiently. Due to this, internal lighting system must not employ LED lamps but incandescent lamps as halogen bulbs. LED lamps might be implemented when new technologies that allow generating warmer white colors at high rendering index and high efficiency are developed. In the meanwhile, incandescent light bulbs should not be replaced by LED lamps.

Based on this observation, Table 29 shows the final power consumption of the modified design. It shows that though the total power consumption increases with respect to the first design using LED lamps only, this increase might not be considerable. This modification will assure to maintain the good Color Rendering Index and Correlative Color Temperature as needed. Lamp life is increased in exterior lighting system and overheating in undesirable zones is avoided.

Table 29: Power comparison of the final design

Current model	Number of Units	Power consumption per unit (W)	Total power consumption (W)	Replacement	Power consumption per unit (W)	Total power consumption(W)
Dual Element Halogen	8	35	280	LED dome lamps	35	280
Whelen 900 Series halogen	18	60	1080	Whelen 900 Series LED	24	432
400,000 CP hand-held	1	170	170	400,000 CP hand-held	170	170
Whelen 700 Series Halogen	2	60	120	Whelen 700 Series LED	24	48
Whelen 600 Series Halogen	1	60	60	Whelen 600 Series LED	24	24
Whelen 400 Series LED	2	9	18	Whelen 400 Series LED	9	18
			1728 W			**972 W**

To visualize in a better way the impact that this modification represents in the design, Figure 36 shows the total power consumption per model. Note that the difference between the current design using incandescent light bulbs and the proposed hybrid design is still relatively big. This can get translated into more than 40% of savings in the lighting system only.

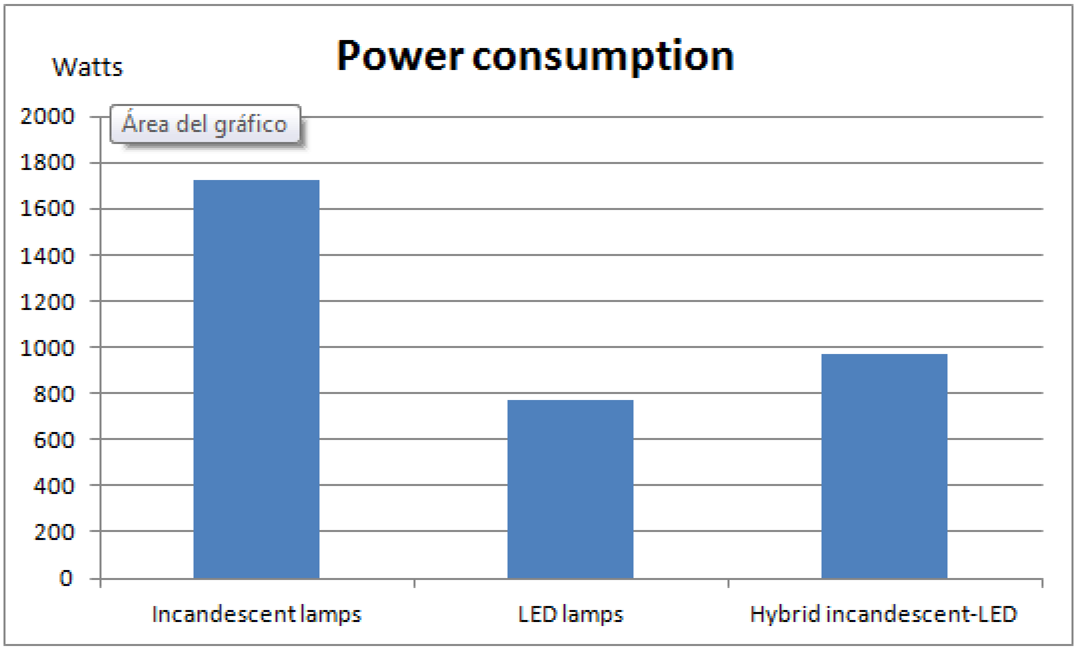


Figure 36: Designs power consumption comparison.

From the graph it can be seen that the hybrid incandescent-LED lighting system would consume less energy compared with the incandescent lighting system. Also, this suggested improvement would increase lamp life on the exterior lighting system as stated in Figure 32.

3.3 Preventing Ambulance Idling

3.3.1 Introduction

To keep engines warm, batteries charged and appropriate interior temperatures; engines of ambulances are left running all day every day to ensure abrupt readiness to emergencies. Also there is the need to keep the electrical equipment used in the ambulance such as GPS, electronic charting components and modems in constant operation. The battery drains out over time if all these equipment are functioning without the engine running, or when the ambulance is not plugged to a shore. It takes a while for the equipment to reset and start to be in the operation mode after they are turned off completely; therefore, the need to leave them on constantly. Studies have shown that at cold start, engines in general need at least 5 minutes to attain full warmth pertaining to coolant water temperature and 10 minutes pertaining to lubricating oil [35]. Within the first 200 seconds is when most of the essential heat losses at exhaust manifold and downpipe happen after cold start. This is because of the thermal inertial of metals; which has an impact on the catalyst light-off time emissions and is responsible for the consumption of about 10% of the fuel [35]. Catalyst light-off time is the total time it takes an exhaust emission-control catalyst to attain its maximum temperature for hydrocarbon oxidation [36]. As temperature decreases, the effects discussed above may tend to increase proportionally [35].

3.3.2 Problems with Starting Cold Engines

Most vehicles being cold started during sub-zero ambient temperatures, have difficulty in attaining appropriate balance between emissions, consumption of fuel, and being drivable [35]. The engine block, accessories and interior of such vehicle attain ambient temperature surrounding the vehicle [37]. There is a decrease in the pumping property of lubricating oil and an increase in its viscosity at low ambient temperatures [38, 39]. This leads to high mechanical losses and increase in the consumption of fuel [40]. Low ambient temperatures can cause the volatility of fuel to degrease leading to poor vaporization of fuel at the inlet port injection location. As the ambient temperature decreases, the richness of the air fuel needed for a startup increases. The rich air mixture leads to the creation of incomplete combustion coupled with excess fuel. This tends to create more carbon monoxide and hydrocarbon emissions, combining to create increase in the consumption of fuel. Catalyst light-off process is crucial for high emissions at cold start; however, low ambient temperature may delay the process [35].

Two important factors that contribute to the determination of the temperature and component of the exhaust gasses are spark timing and fueling. This suggests that the need for appropriate ignition retard and enrichment of fuel are essential to obtaining good drivability for cold start at low ambient temperatures. The disadvantage, however, is that there may be increase in carbon monoxide and hydrogen carbon emissions. However, the advantage is that exhaust temperatures may increase due to the retarded spark timing which may greatly favor the light-off of the catalyst.

3.3.3 Problems Involved in Ambulance Idling

Pollution

Pollution, especially in megacities is one of the reasons why ambulance idling needs to be taken into consideration. The need for a urban air quality has become a great global concern with the increasing population [41]. United Nations (UN) estimates that out of the 8.1 billion people, 4.9 billion will be residing in megacities by the year 2030 [42]. The general pollutants in megacities from emission are total suspended particles (TSP), sulfur oxide ($SO_{2)}$ and nitrogen oxide (NO_2). Table 30 shows the population concentration of TSP, SO_2, and NO_2 from emission pollution in some megacities in the year 2000 [41].

Table 30: Concentration of TSP, SO_2, and NO_2 in various megacities

Megacities in 2000	Population (x1000)	TSP (µg m^{-3})	SO_2 (µg m^{-3})	NO_2 (µg m^{-3})
Tokyo	34,000	40	19	55
Mexico City	18,500	201	97	56
New York	18,000	27	22	63
Soa Paulo	17,500	53	18	47
Bombay	16,000	243	19	43
Calcutta	13,500	312	19	37
shanghai	13,000	246	53	73
Buenos Aires	12,500	185	20	20
Delhi	12,000	403	18	36
Los Angeles	11,500	39	9	66
Osaka-Kobe	11,500	34	19	45
Jakarta	11,000	271	35	120
Beijing	11,000	377	90	122
Rio de Janeiro	11,000	139	15	60
Cairo	10,500	593	37	59
Dhaka	10,000	516	120	83
Moscow	10,000	150	15	170
Karachi	10,000	668	13	30

Table 30 shows that Tokyo has the greatest amount of population of approximately 34 million while Karachi has the smallest amount of population of about 10 million residents. The information in Table 30 is applied in Risk of Mortality or Morbidity resulting from Air Pollution (Ri-MAP) to determine the illnesses and deaths resulting from the emission pollution. Furthermore, the average yearly concentration of the pollutants in the surrounding areas of each respective megacity used in the Ri-MAP is shown in Table 30. According to the results, megacities such as New York, Los Angeles, Tokyo and Sao Paulo have considerably low amount of the total mortality cases resulting from the pollutants. On the other hand Dhaka, Beijing, Cairo and Delhi have high amount of cases. Among other serious cases resulting from emission pollution such as respiratory and pulmonary diseases, Figure 37 shows the cardiovascular mortality cases in the megacities [43].

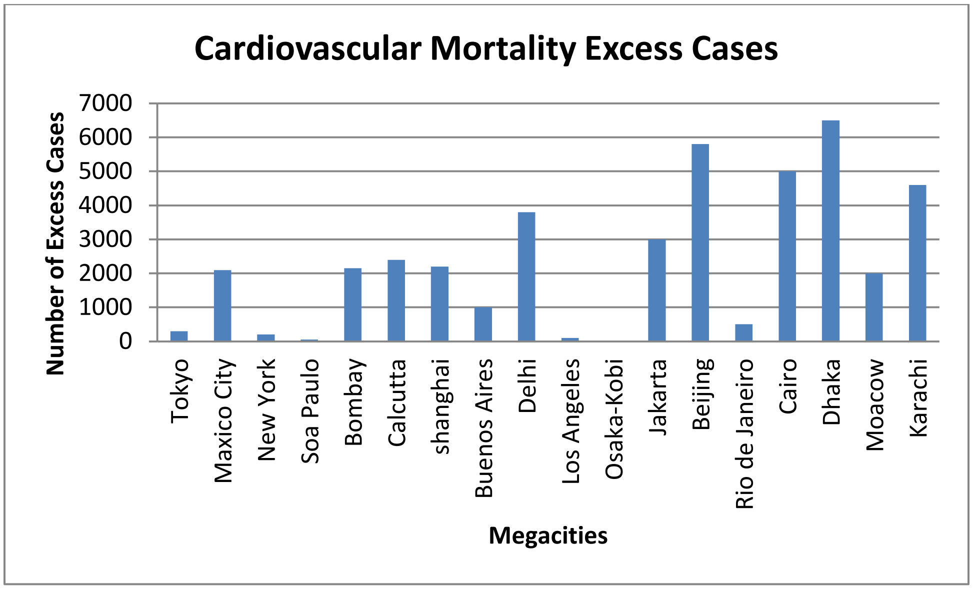


Figure 37: Excess number of cardiovascular mortality cases in 2000

The primary reason for the high excess number of cardiovascular mortality cases in megacities such as Delhi, Beijing, and Dhaka is due to the high level of nitrogen oxide (NO_2) and TSP pollutants in the atmosphere. NO_2 happens to be one of the two major pollutants from diesel emission which the next paragraph discuses in more detail. The average NO_2 concentration recommended by the World Health Organization (WHO) is 40 μg m^{-3} [43]. From Table 30, 14 out of the 18 listed megacities have NO_2 concentration above the recommendation of WHO. Dhaka has an average of 7000 excess cases of cardiovascular diseases a year due to its high concentration of TSP and NO_2. Other megacities like Beijing, Karachi, Cairo and Delhi have averages of 5500, 5200, 5000 and 3500 of excess cardiovascular mortality cases per year respectively as seen in Figure 37.

The two primary pollutants of diesel engines are particulate matter (PM) and nitrogen oxide (NO_x). However other pollutants include carbon monoxide (CO), carbon dioxide (CO_2)

and sulfur oxide (SO_x) [10]. One of the compounds of nitrogen oxide (NO_x), nitrogen dioxide (NO_2) is around 250 times more than CO_2 in posing threat to global warming. This is due to its ability in absorbing infrared rays [45], and staying in the atmosphere for about 150 years. For this reason NO_2 has high level of stability and longevity. Furthermore, NO_x produces photochemical smog when it reacts with sunlight. The reaction causes distortion of the ozone layer creating nitric acid which negatively affects the human eyes, skin and respiratory system [44]. Some components of PM create carcinogenic agents and negatively impact the respiratory system [46].

Studies have shown that fuel is the greatest source of CO_2 pollutant [47]. The study was conducted by collecting energy consumption data from fifteen sampled EMS systems across different regions of North America. The ambulances involved in the study served a population of about 6.3 million. They were engaged in about 554,040 ambulance responses a day. Their mean call volume had a ratio of 77.3 responses to 1,000 people per day. The ambulances involved offered services in the urban, rural and suburban areas. Ten out of the fifteen EMS systems produced 13,890 metric tons of CO_2 within a year [47].

Figure 38 shows the comparison between different sources of the CO_2 from the ten EMS systems [47].

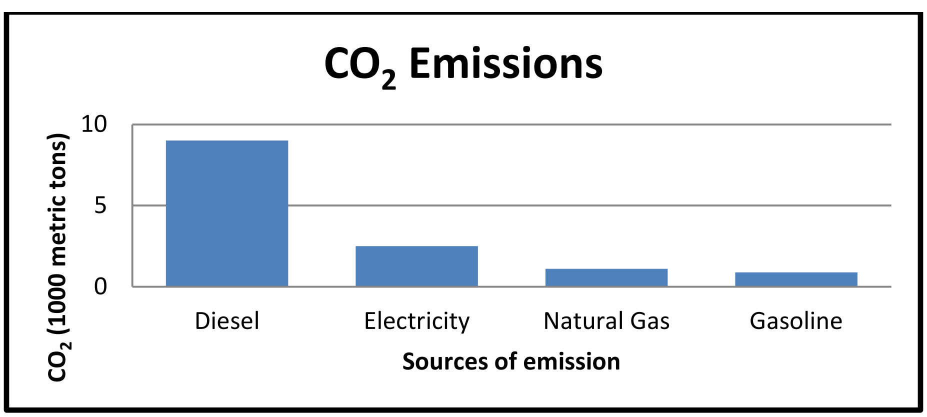


Figure 38: Emissions of CO_2 due to energy consumption

Figure 38 shows that diesel emission produces the most of CO_2 pollutant. Out of the 13,890 metric tons of CO_2 produced, about 9,000 metric tons resulted from diesel. About 900 metric tons of CO_2 resulted from gasoline emission. Figure 39 shows the information in Figure 38 in their respective percentages.

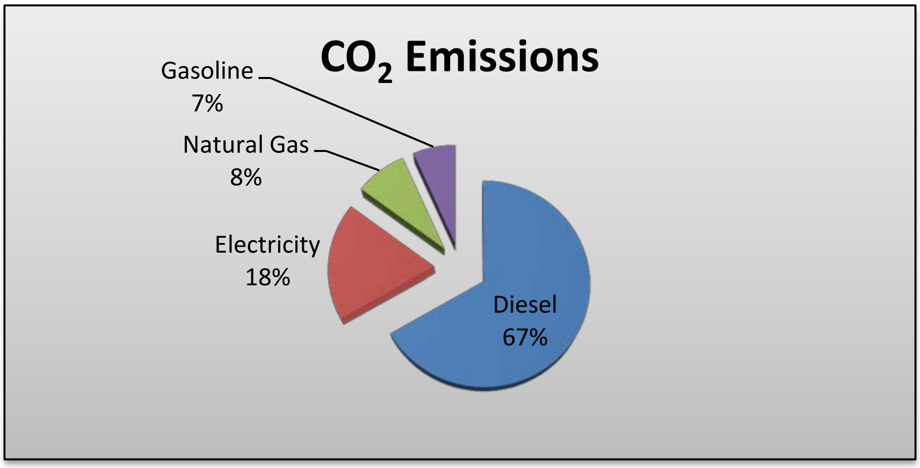


Figure 39: Sources of CO_2 emissions from 10 EMS systems

As shown in Figure 39, diesel fuel is responsible for 67% of CO_2 pollutant or emission. Electricity follows by 18%. The least source of CO_2 emission is gasoline, which constitutes 7% of the total source of CO_2 emission annually [47].

Cost and Energy

The second and third reasons why ambulance idling has to be considered is due to money spent on fuel and the waste of fuel respectively. A study shows that average idling time for an ambulance ranges from 25 minutes to 125 minutes [48]. The study further shows that for an average of 25 times per day, an ambulance idles for over 120 seconds [48]. Within a period of 3 hours, an ambulance burns 1 gallon of fuel on idling [48]. Based on this information, an ambulance consumes an average of 8 gallons of fuel a day and 2,920 gallons a year idling. This is approximately $29.60 a day and $10,804 a year spent on fuel burnt on idling ambulance. The figures do increase with increase idling. In regards to energy, about 173 Ampere per hour (Ah) is needed for total idling of an ambulance per day [48]. Besides emission pollution, saving extra fuel, energy and money could be realized if ambulance idling is stopped.

It is imperative; however, that past attempts made to stop idling be investigated. By so doing, set-backs that were encountered in the past could be avoided as new proposals are suggested in relation to idling.

3.3.4 Past Proposals Addressing the Issue of Idling

In his U.S. Patent No 3,870,855 issued in March 11, 1975 Edlund [49] designs a model involving battery charger, engine block heater and passenger compartment heater all functioning simultaneously while the engine of the vehicle is turned off.

Figure 40 shows the electric heating and battery charging system designed by Edlund for motor vehicles [49].

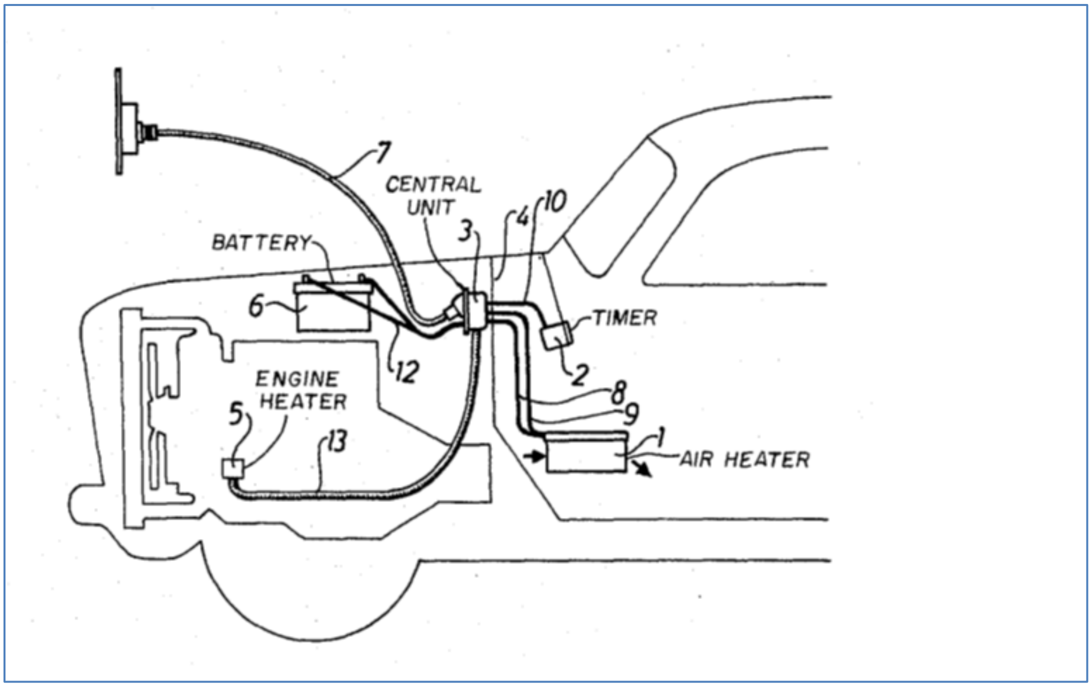


Figure 40: Edlund’s electric heating and battery charging system

The elements in

Figure 40 labeled (1) through (13) are briefly discussed in the subsequent sentences. In the passenger's compartment is the electric heater (1) connected to a central unit (3) through a main cable (8) and a low voltage cable (9). There is also a timer (2) which is manually controlled in the passenger's compartment. To activate the system, the central unit (3) is connected to an external power source through a power cable (7). The electric engine heater (5) and the electric battery (6) are mounted in the motor compartment. The rest of the description of Edlund's system could be found in his paper Electric Heating and Battery Charging System for Motor Vehicle [49]. The problem with Edlund's system is that an entirely different heater and fan unit besides the vehicle's built-in heater and fun unit is required. Secondly, there is the need for a separate engine heater. There is a main voltage cable connecting the control unit and the elements of the additional electric heater. This main voltage cable is located within the interior of the vehicle [37].

There have been series of other proposals in the past attempting to speed up the heating process in vehicles without idling. Some of these proposals suggest the use of auxiliary liquid or gas fuel supplies to power the internal combustion engine. This proposal poses serious fire hazard due to the act of adding another fuel tank and introducing open flames to supply the demanded heat [37]. There have been further proposals suggesting that the heater and the battery charger of the vehicle make use of alternating current resistance heater, which on the other hand is also connected to an external alternating power source. This proposal also demands a separate heater besides the standard hot water heater in the vehicle [37]. It is salient; therefore, to come out with an appropriate proposal that will address the problem in question without encountering set-backs as other proposals do encounter.

The invention Mark H. Moad [37] presents an improved auxiliary stand-by heating and alternating power supply system. Mark H. Moad's system has less components and easy to install in emergency vehicles. The heating/power supply system works in collaboration with the built-in recirculating fluid heating system in the emergency vehicles [37]. There is the connection between the auxiliary electric heater and the pump assembly in series. The auxiliary electric fan control connects to the heater fan of the vehicle. This allows for the independent operation of the heater fan from the conventional fan control in the vehicle. There's also a control unit on the exterior part of the vehicle that facilitates the alternating electric power source [37]. Figure 41 shows the model of Moad's design. The various parts labeled (10) through (20) in Figure 41 are briefly discussed in the subsequent sentences. What powers an emergency vehicle including ambulance is water cooled internal combustion engine (10). In this system, part of the coolant passes through a recirculating front heater coil (11) which can be seen at the front fire wall of the vehicle. There is normally a fun which when the driver turns on, blows the heat that the heater coil (11) generates to warm up the front part of the vehicle. There is also a rear heater coil (12) that is in parallel sequence to the front coil heater (11). The rear fan (13) blows the heat that the back heater coil (12) generates to warm up the patient compartment of the ambulance. The front and rear heaters can either operate together of independent of each other.

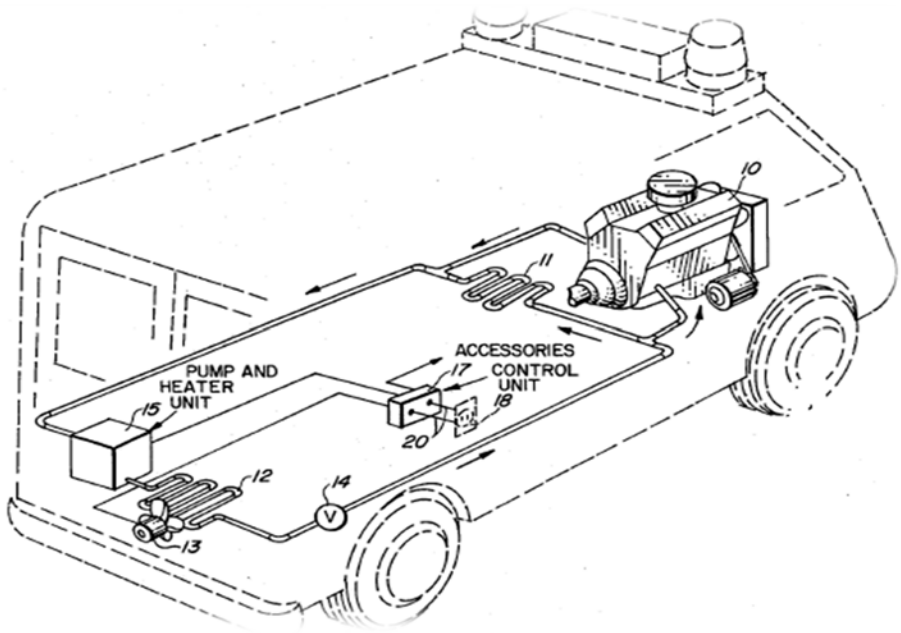


Figure 41: Moad's stand-by heating/power supply system

There is a valve (14) that controls the opening of the passage for warm coolant. The valve system (14) is already used in ambulances [37]. There is a 1500 Watt auxiliary electrical heater and pump combination (15) located on the water line upstream of the heating coil (12). The auxiliary electrical heater and pump combination is responsible for providing a stand-by heating system for the vehicle. The stand-by heating system functions to warm up the fluid located in the coolant line. This in effect heats up the coil (12) so that when the fan (13) is turned on, it blows the warm air to heat up the interior. Due to the nature of its function, the heater located in the unit (15) does not consume much power during operation. A control unit (17) is mounted on the vehicle's interior wall. This control unit (17) is independent of the controls on the dashboard and it controls the power needed to run the pump/heater (15). This system is a modification of the heating system already seen in emergency vehicles and can be easily used in ambulances [37]. After looking at couple of existing ideas and inventions, the next section discusses a proposal based on already existing technology, and a future recommendation is given.

3.3.5 Proposal: Three-in-One Solution Approach

The proposal for the solution to the problem of ambulance idling is termed as the three-in-one solution approach. Using the model set forth by Mark H. Moad [37], this approach aims at using the shore-line charging technology of the ambulance. The aim is to effectively charge the battery, and supply electrical power to create the appropriate internal temperatures. The latter could be achieved through the heating/AC systems of the ambulance or external AC/electric space heaters [37]. By using the electric space heater, the EMTs must unplug the electric space heater and either keep it in the ambulance or out of it before setting off in response to an emergency call [37]. As the ambulance is being charged, an installed power switch interface can alternate between the internal and external power sources respectively. This means that when the ambulance is being charged through an external power source, the interface should be able to deactivate the battery. At the same time, charging of the battery and the heater in the heating unit in as shown in Figure 41 must be activated. There should also be the turning on of the fans to blow the heat into the interior of the ambulance. The moment the external power line is unplugged, the interface should reverse the whole cascade instantly. This functions when the key in the ignition is turned to AC/start mode.

The electric space heater, however, does not take care of the challenge in getting the engine block warm. This leads into the third aspect of the solution approach – engine block heater. The concept of the engine block heater is a future recommendation due to the scarcity of time and resources to actually experiment and test it as part of this project. It is the part that is not used in most ambulances. According to sections 3.6.3.2 and 3.6.3.3 of the KKK-A-18E, engine block heaters are permitted to be furnished in the ambulance. It is also required to be of a single element and easy to disable [50]. Some countries such as Canada, Northern Alaska and those in the frigid zones use engine block heaters during the winter seasons [51] . Most of the time, the oil, water, catalysts and metal surfaces become extremely cold due to the cold temperature and demand thermal energy to heat them up. This means that the main challenge isn’t the air temperature, but the ability to get the engine block heated and appropriate thermal energy to provide the heat [52-56].

CHAPTER 4. CONCLUDING REMARKS

To improve the ambulance compartment design the selection of the proper insulation in order to prevent heat transfer, improve comfort, and increase energy efficiency. Thorough research on typically implemented insulation materials was conducted to understand the basic modern techniques and materials used. Research was directed to finding the insulations used in aircraft, homes and other automobiles to compile data on common materials and the applications of these materials. Research was invested in the understanding of the regulations set by KKK-A-1882F, AMD, NFPA, and the FMVSS. This provided the constraints to the selection process that contributed heavily to final material selection. Since ambulances face the issue of being on throughout the day it is important to reduce energy and heat loss as much as possible.

Closed-cell polyurethane improves the current condition of the ambulance because of its many attractive qualities. Closed-cell polyurethane spray foam has one of the highest R-values of the most commonly used insulation materials. Although it is initially more expensive to implement polyurethane a superior R-value that provides improved comfort, energy efficiency, and sound dampening. Sounding dampening was especially important in choosing polyurethane because the ambulance compartment is consistently exposed to intense sounds of the siren. Finally, polyurethane was chosen because most ambulances average a 5 year life span. This lifespan justified the higher initial cost and made it a cost-effective investment that tailored to the ambulances needs.

This type of insulation is used in homes and by Braun Ambulances. The Closed-Cell Polyurethane is light weight material, safe to use for ambulance compartment, effective to prevent heat transfer and acoustics, affordable, and easy to be implemented. This projects analysis that this type of insulation is very cost-effective for five year period, since the research shows that the ambulances are replaced every five years. For this period of time the R-value of this type insulation is slowly degraded therefore makes this insulation efficient to be implemented in current other ambulances. Also, this insulation will improve the patient care, comfort, and safety.

In addition, the current lighting system in ambulances was investigated and evaluated in order to make improvements. There are four Different type of lighting systems incandescent, florescent, metal halide, white LED that is analyzed. These systems are analyzed in terms of energy efficiency, no interference with communications devices, safety, and light color quality. To design a lighting system three important constrains are taken into consideration power consumption, color rendering index, and correlative color temperature. Also, the system abides the regulations specified by the KKK-A-1882F, AMD, NFPA, and the FMVSS

This project recommends the use of hybrid- LED incandescent into the ambulance exterior and interior lighting system. They improve power efficiency of the lighting system and meet the light quality standards for interior lighting. This type of lighting system is long term cost effective and safe to be implemented emergency medical vehicles.

In regards to ambulance idling, this project proposes the use of external power source to charge the batteries and provide power to create appropriate internal temperatures. An electric space heater could be used during winter to provide heat in the interior of the ambulance when the engine is off. The electric space heater has to be unplugged and taken out of the patient compartment before responding to an emergency. A mobile AC system could be used for the same purpose during the summer. An average of 2,920 gallons of fuel in the amount of $10,804 per ambulance will be saved annually if the issue of ambulance idling is taken care of. Besides cost and fuel, solving ambulance idling will go a long way to reduce emission pollutants such as TSP, NO_2, CO_2, PM, and SO_2 which are very harmful to human health and nature in general.

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APPENDICES

APPENDIX A: TABLE OF AUTHORSHIP

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APPENDIX B: CHARACTERISTICS OF COMMON INSULATION MATERIALS

Form	Material	Density(Kg/m3)	Thermal conductivity (W/m-K)	Fire resistance	Effect as vapor barrier (% water absorption)	Effect as infiltration barrier	Resistance to direct sunlight	Maximum service temperature (C°)	Durability	Sound absorption (%)	Cost per*R*-value	Potential health risks	Typical applications
Blankets: Batts or Rolls	Fiberglass (sand & recycled glass)	12–56	0.04–0.033	Good	Poor fair (*with facing*)	Poor fair (*with facing*)	Excellent	-4–260°	Compression reduces *R* -value	High	Low	Inorganic (organic binders), Irritating dust during installation	Frame wall or ceiling, partitions, prefabricated houses, irregularly shaped surfaces, ducts, and pipes.
	Rockwool (natural rocks)	40–200	0.037	Excellent	Poor	Poor fair (*with facing*)	Excellent	-240–800°	Compression reduces *R* -value	V. high	Low	Inorganic (organic binders), Irritating dust during installation	Frame wall or ceiling, partitions, prefabricated houses, irregularly shaped surfaces, ducts, and pipes.
	Polyethylene	35–40	0.041	Poor	Good	*Good*	Good	-40–90°	*R*-value decreases w/time		Low	Organic. (off-gassing, toxic smoke)	Ceilings, hangers, wrapping, carpet underlay, expansion joints.
Loose-fill blown-in or	Fiberglass (open cell structure)	10–48	0.038–0.030	V. good	Poor (1% of weight)	Poor	Excellent	-4–260°	Comp.& moisture degrade *R* -value	High	Low	Inorganic (organic binders).	Cavities and around obstructio

poured-in												Irritating dust during installation	ns. Added adhesive provides more resistance to air infiltration.
	Rockwool (open cell structure)		0.04	Excellent	Poor (1% of weight)	Poor	Excellent	-240–800°	Comp.& moisture degrade *R* -value	V. high	Low	Inorganic (organic bonds). Irritating dust during installation	Cavities.
	Cellulose (ground-up waste paper)	24–36	0.054–0.046	V. good (added fire resisting chemicals)	Poor (5% to 20% of weight)	Poor	Good	80°	Comp.& moisture degrade *R* -value	Low	Low	Organic. Irritating dust during installation	Blown into small cavities.
	Perlite (natural glassy volcanic rock)	32–176	0.06–0.04	Excellent	Fair	Good	Good	760°	Good	Low	High	Inorganic	Fill or mixed withPortland cement for walls, roofs, and floors, plastering.
	Vermiculite	64–130	0.068–0.063	Excellent	Poor (dries slowly)	Good	Good	1315°	Good	Low	High	Inorganic	Poured into ceilings, cavity walls, and cores of hollow core blocks.
Rigid Board	Fiberglass (open cell structure)	24–112	0.035–0.032	Good	Good 0.2%	Good	Excellent	-4–350°	More rigid than batts	Medium	Medium	Inorganic (organic bonds)	Cavity walls, roofs, and prefabricated structures.
	Expanded Polystyrene	16–35	0.038–0.037	Poor	Good (1.0–	Good	Poor	100°	*R*-value decreases	Low	Lowest of	Organic (uses	Walls, roofs, and

	(closed cell foam)				2.5%)				w/time		rigid board types	pentane gas as the expandi ng agent, toxic)	floors. Must be covered inside for fire and against outside weather.
	Extruded Polystyrene (closed cell foam)	26–45	0.032–0.030	Poor	Excellent (0.2–1.0%)	V. good	Poor	100°	*R*-value decreases w/time	Low	High	Organic (uses HCFC or CFC gases as the expandi ng agent, toxic fumes)	Walls, roofs, floors, perimeter, basement s, and foundation s. Must be covered inside for fire and against outside weather.
	Polyurethane & Polyisocyanu rate (closed cell foam)	40–55	0.023	Poor	Good (0.5–1.5%)	Excellen t	Poor	95°	*R*-value decreases w/time	Low	High	Organic (uses CFC or CO_2gas es as the expandi ng agent, toxic fumes)	Walls and roofs. Must be covered inside for fire and against outside weather.
	Perlite (natural glassy volcanic rock)	32–176	0.06–0.04	Excellen t	Fair	Excellen t	Good	760°	High	Low	High	Inorgani c	Blocks (industrial / commerci al insulation) , light weight insulating concrete.
	Vermiculite (natural mineral)	64–130	0.068–0.063	Excellen t	Good	Excellen t	Good	1315°	V. high	Low	High	Inorgani c	Not in houses (heavy weight).

Sprayed-in-Place	Cellulose (waste paper)	24–36	0.054–0.046	V. good	Poor	V. good (added adhesives)	Good	80°	fire retardant chemical may corrode metals	Low	High	Organic. Requires protection against inhaling fine particles	Attics retrofitting, wood frame sidewalls (experienced help needed). Needs time to dry before enclosing to avoid moisture problems.
Foamed-in-Place	Polyurethane & Polyisocyanurate (closed cell foam)	40–55	0.023	Poor	Good	Excellent	Poor	95°		Low	High	Organic (toxic smoke, off-gassing from aging plastics)	Roofs, cavities, irregular and rough surfaces
Reflective Systems	Aluminized thin sheets (Reflective foil, separated by airspaces)b		Reduces only radiant heat transfer	Good	Excellent	Excellent	Excellent	High	d				Ceilings, walls, and floors. Most effective in reducing downward heat flow.
	Ceramic Coatings (acrylic paint filled with ceramic micro spheres - brush, roller or spray)	1.25	Radiation control	V. good	Excellent (seamless water proofing)	Excellent	Excellent	High	High (Rust proofing)			Requires protective clothing and eye protection when applied	Metal roofs, built-up roofing, walls, storage systems. Ducts and pipes.

APPENDIX C: HORTON AMBULANCE FEATURES

Standard Features

Horton 623 Type I Dodge 4500

Chassis	Dodge 4500
Wheelbase and CA	189" WB, 108" CA
Engine	6.7 L Diesel
GVW	16,500 lbs.
Wheels and Tires	(7) 225/70R19.5
Alternator	(1) 220 Total Amps
Batteries	(2) 730 CCA
Mirrors	Power Trailer Tow Mirrors
Seats	Cloth 40/30/40 Bench
Driver and Passenger Air Bags	Yes
Trim Level	2GGSLT
Radio/CD	AM/FM/CD
Fuel Tank Capacity	52 Gallons
Air Suspension	Monroe

Body	
Length and Width	173" x 96"
Headroom	72"
Number of Compartments	(5) Polished Diamond Plate
Body Skin Thickness	.125"
Body Skin Alloy	5052H34
Body Vertical Structure	2" X 2" Square Tube, .125" Wall
Compartment Thickness	.125" Diamond Plate
Cubic Foot Storage (total)	212.05 Cu. Ft.
Exterior Compartments	102.85 Cu. Ft.
Interior Compartments	109.20 Cu. Ft.
Rear Step	Lift Up Style with Grip Strut Center
Fenders	Polished Stainless
ICC Lights	LED
Rub Rails	Polished Stainless with End Caps
Rear Door Hold Opens	Grabber Style, Chrome
Sound Control	Acoustic/Thermal Spray and Dampening Pad
Door Handles	TriMark Chrome Plated
Lock System	Power Locks on Access Doors
Structural Sub Flooring	2" X 2" Tubing with .250 Wall
Sub Floor Sheet Thickness	.090" Aluminum Plate
Mud Flaps	Front and Rear
Corner Guards	Diamond Plate

Interior Patient Area Cabinets	
Cabinet Construction	Welded .063" Aluminum
Cabinet Configuration	ALS, BLS or Custom
Inside/Outside Storage	Right Front of Body
Cabinet Doors	Plexiglas or Solid
Sliding Cabinet Door Handles	Full Height Extruded Aluminum
Solid Door Handles	Recessed Stainless Southco
Curb Side Cabinetry	Hinged Door Cabinet Above Squad Bench
Sharps/Waste	Yes

Patient Area Accessories	
Sub Floor	.090" Aluminum Plate Plus .5" Composite
Flooring Material	Commercial Grade Loncoin with Antimicrobial Coating
Walls	High Density Aluminum Composite
Headliner	High Density Aluminum Composite
Interior Door Panels	Formica Covered .090" Aluminum
Windows	Extruded Aluminum Frames (All Doors and Over Bench)
Front Bulkhead	Hinged Walkthrough Door on Type 3, Window on Type 1
IV Provisions	(2) Recessed Cast Products with Rubber Stabilizer Arms
Grab Rails	(1) 6' 1.25" Diameter Stainless Steel With Agion Biohazard Coatings
Interior Door Grab Handles	(3) Angled 1.25" Diameter Stainless Steel, (1) On Each Access Door With Agion Biohazard Coatings
Side Door Hold Open	Gas Piston, Double Action Style
Squad Bench Hold Opens	Gas Piston Style
Squad Bench Cushion Latches	Positive Recessed Paddle Handle Style
Work Counters	Stainless Steel
Cot Mount	FW 175-3 for BLS or FW 175-4 for ALS
Fire Protection	(2) 5 Lb. ABC Extinguishers
Attendant Seat	Box Style With Backrest
Seat Belts	All Seating Positions with Enclosed Retractors
Interior Door Reflectors	2"x12" Red Scotchlite
Airbag Protection:	Side Impact Rollover Airbags for Attendant and CPR Seats

Electronic O_2 and Vacuum Systems	
Oxygen System	Horton Electronically Controlled System
Oxygen Regulator	Victor 50 Lb. Preset
Bottle Pressure Indicator	Digital Readout On Patient and Driver Consoles And Analog Gauge in Exterior Oxygen Compartment
Line Pressure Indicator	Digital Readout On Patient and Driver Consoles
Flowmeter	(1) Dial Type 20 LPM with Quick Connect
Oxygen Outlets	(2) NCG Style In Inhalation Area

Vacuum system	Rico RS 4X
Vacuum Outlet	(1) NCG Style with Quick Connect
Pressure Warnings	Audible and Visual Warnings on Driver and Attendant Console for High and Low Pressure
O2 Bracket:	Zico QRM-V with Wrench

Electronic System

System Design	Horton Intelliplex Solid State Multiplexed System
Switch Style	Magnetic Technology, Lighted Outline
Switch Ratings	50 Million Cycles
Switch Panel Style	Flush Mounted
Information Centers	Digital Message Centers on Front and Rear Consoles
Panel Backlighting System	Fiber Optic, Color Coded LED
Decontamination Capability	Sealed Panel, Crevice Free
System Features:	No Load Starting, Load Management, Diagnostics, Timer Circuits, Vehicle System Status, Oxygen Management, Trip Odometer, 24 Hour Clock, Low Voltage Warning, Discreet Door Open Warnings, Patient Status, Digital amperage and Voltage, Automatic Shutdown and Nearly Infinite customization Features

Patient Area Heating and A/C

Unit Style	ProAir 650 CFM
Capacity	32,000 BTU Cool, 65,000 BTU Heat
Static Intake	Roof Mounted
Power Exhaust	Roof Mounted
A/C Compressor	(2), Chassis OEM And Auxiliary
Condensor	Chassis OEM And Auxiliary
Control System	Automatic Climate Control

Interior/Exterior Illumination

Dome Light Style/Quantity	(7) Weldon Halogen Lights
Control System	Horton Infinite Intensity Adjustment
Attendant Area Illumination	3 Position Report Light
Step Well Light	Weldon with Chrome Bezel
Side Scene Lights	(2) 900 Series Whelen Halogen with Chrome Bezels
Rear Loading Lights	(2) Whelen 900 Series Halogen
Spotlight	(1) Optronics Hand Held in Cab
Tail Lights	Whelen 600 Series Halogen
Lower Marker/Turn Light	(2) Whelen 700 Series Halogen with Chrome Bezels
Compartment Lights	Full Height LED Strips
Compartment Light Activation	Automatic Switch When Door Is Opened

Visual and Audible Warning Systems

Front Body Warning Lights	(2) Whelen 900 Series Halogen (Red)
Rear Body Warning Lights	(2) Whelen 900 Series Halogen (Red)
Side Body Warning Lights	(4) Whelen 900 Series Halogen (Red)
Grille Lights	(2) Whelen 700 Series LED (Red)
Intersection Lights	(2) Whelen 400 Series Halogen (Red)
Front KKK Light	(1) Whelen 700 Series Halogen (Clear)
Rear KKK Light	(1) Whelen 700 Series Halogen (Amber)
Siren	(1) SVP SS700 200 Watt
Speakers	(2) Cast SA4320
Reverse Alarm	With Resetting "Disable" Feature
Standby Switching	Automatic with Programmable Priority

Radio Provisions

Antenna Cables	(1) RG58U
Radio Pull Wire	(1)
Console	Custom
Radio Power Feed	(1) Behind Driver Area

Electrical Power

12 Volt Power	3 Cigarette Style Outlets
110 Volt Power	2 Wall Mounted Duplex Receptacles
12 Volt Breaker Style	Mosfet Solid State
110 Volt Breaker Style	20 Amp GFI
Shoreline	20 Amp with Weatherproof Cover
Battery Charger:	45 Amp

Paint

Stripe Style	White With KKK Scotchlite Beltline (Any Color)

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APPENDIX D: MARQUE AMBULANCE FEATURES

MARQUE

Vision Comes to Life

Home
About Marque
Products
Construction Methods
Warranty
Ambulances for Sale
Sales Network
Trade Shows
International Sales
Remount Services
Recent Deliveries
References
Contact Us
Dealer Login

360 Video

Brochure

AVAILABLE ON THE FOLLOWING CHASSIS TYPE I & TYPE III

- Ford
- Chevy
- Dodge
- International

STANDARD FEATURES

BODY

- Modular Body: Fully welded, roll cage design, 1Â"x2Â" tubular structure on 16Â" centers
- Rear Bumper: Entirely hinged to allow tilt in high angle departure

situations

- Crowned roof to inhibit water pooling
- Oxygen Storage: Streetside front compartment with adjustable steel rings for M-size cylinder
- .125 Body Side Skin: Added strength and seamless finish
- Compartments: Aluminum, diamond plate
- Rubrails: Aluminum, diamond plate
- Fender Flares: Black rubber

DOOR

- Latches: TriMark automotive style
- Extruded Door Jams: Fully welded, heavy duty and key locked
- Extruded/Pan Hybrid Doors: Heavy duty, key locked with .125 pan-formed skin
- Integrated Door Seal
- Door Liners: Attached with stainless steel screws into aluminum rivnuts

INTERIOR

- Dome Lights: Eight dual filament, incandescent, two rows of four, switched separately
- Spotlight: One 400,000CP hand-held light with momentary switch
- Cot Mount: Ferno-Washington 175-4
- Flooring: Lon Seat Â"Lon Plate IIÂ"
- IV Holders: Two dual, swing down rubber holders with Velcro retaining straps
- Aspirator: Rico RS-4X disposable
- O2 and Vacuum Outlets: Three oxygen outlets and one vacuum outlet in action area
- Technician Seat: High-back automotive style seat with swivel base
- Laminate: Post Form Grade interior
- ALS Cabinet: Storage for trauma kits
- Upholstery: Seamless cushions

POWER DISTRIBUTION/ELECTRICAL

- Etched-Trace Power Circuits: HD-3 oz.
- Etched-Trace Control Circuits: HD-3 oz.
- Marine Grade High Current Switches: Replaceable, for milliamp

  circuit
- LED Diagnostic Control and Door Open Circuits
- Door Open Circuits: Magnetic/LED diagnostic circuit
- HD Machine Crimped Harness: Pull and load tested to provide a rugged dependable network
- Shoreline: 115-volt 20amp
- Electrical Outlets: Three 125V GFI protected;
- Two 12V outlets in module

ELECTRICAL LIGHTS & SIREN

- ABS Console
- Flasher: Vanner Solid State
- Siren controls in front console
- Siren Speakers: Two 100-watt drivers

- Warning Lights: Whelen perimeter lighting
- Scene Lights: Whelen 900 Series Â– two per side
- Load Lights: Whelen 900 Series Â– two above rear doors
- Back-Up Alarm: 97Db with momentary cutoff

ENVIRONMENTAL

- A/C-Heat System: Ducted system with ceiling vents; 650 CFM blower unit, 35,000 BTU heat and 32,000 BTU cooling
- Thermostat: Fully automatic in action area
- Insulation: Fiberglas batts in ceiling and walls, block foam in doors
- Power Vents: Marine style with three-speed fans

Due to constant product improvements; specifications, component parts and optional equipment are subject to change without notice or obligation. Photos may show optional equipment.

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APPENDIX E: MC COY MILLER AMBULANCE FEATURES

CHASSIS

Chevy GM CG33503

- 12,300 GVWR
- 139" Wheel Base
- 6.6L Diesel (dual alternators) or 6.0L V-8 Gas Engine (single 145 amp alternator)
- 80" CA – Dual Rear Wheel

Ford E-350 Cutaway

- 11,500 GVWR
- 138" Wheel Base
- 6.8L Gas V-10 Gas Engine (single 225 amp alternator)

STANDARD FEATURES

Body

- All aluminum construction
- Fully welded, tubular structure on 16" centers
- Side body crash bar
- Modular Body: 142" L x 90" W x 66" H
- .125 Body Side Skin: 1 piece sidewall
- Crown, rolled roof to inhibit water pooling
- Rear Bumper: Aluminum with flip-up center to facilitate loading
- Front Wall: 9" recess for full driver seat travel
- O2 Storage: Streetside front wall
- Five exterior storage compartments

Warning Lights & Sirens

- Flasher: Vanner 3860 GCPE
- Intersection Lights: Two Whelen 700 Series Super LED
- Grille Lights: Two Whelen 500 Series LED (Ford)
- Grille Lights: Two Whelen 700 Series LED (GM)
- Warning Lights: Ten Whelen 900 Series Halogens
- Load Lights: Two Whelen 900 Series
- Scene Lights: Four Whelen 900 Series
- Siren: Whelen WS-295HFSA7 dual tone
- Speakers: Two CPI with 100w drivers
- Back-Up Alarm: 97 Db with momentary cutoff
- ICC LED marker lights

Environmental

- AC–Heat System: 650 CFM blower, 32,000 BTU heat, 35,000 BTU
- Vent Power: Marine style with 3-speed fan
- Insulation: 3" Fiberglas bats
- O2 Cradle for "M" or "H" tank

Interior

- Height: 66"
- Flooring: Loncoin II Fleckstone with 3" rolled up sidewall and recessed
- Dome Lights: Six dual element, halogen, two rows of three each, switched separately
- Spotlight: One, 400,000CP hand-held light with momentary switch, hard wired to OEM dash
- Cot Mount: Ferno-Washington 175-3
- ALS Cabinet: Storage for two 747 kits, mon./defib., medical cabinet, located at front bulkhead
- Hazardous Waste/Sharps Disposal: Stainless steel A bar at the head of the squad bench
- Aspirator: Rico RS-4X disposable
- IV Holders: Two dual cast, swing down rubber holders with Velcro retaining straps

Door

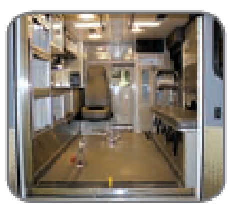
- Improved Design: Reduced welding, heat distortion and body fill to enhance overall appearance
- HD Extruded Door Jams: Key locked and welded
- HD Extruded Door Frames: .125 pan-formed skin
- Integrated Door Seal: Reduces wear on seal and eliminates outer contamination of doors, compartments and modules
- Door Liners: .125 aluminum with durable Multispec finish, attached with 10-24 stainless steel screws into rivnuts
- Magnetic door jam switches
- Latches: TriMark automotive style

Power Distribution/Electrical

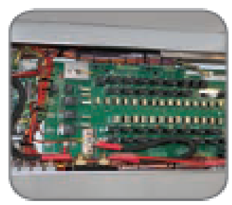
- Commander 357 electronic master switch with timer
- Etched-Trace Power Circuits: HD-3 oz.
- Etched-Trace Control Circuits: HD-3 oz.
- Marine Grade High Current Switches: Replaceable, for milliamp circuit
- Door Open Circuits: Magnetic/LED diagnostic circuit
- HD Machine Crimped Harness: Pull and load tested, prewired for halogen, LED, lighting systems
- Inverter: Prewired for 1000W inverter
- Clock: LED in rear control panel

Warranty

- Body: 4 Year/48,000 mile
- Structure: 15 Year
- Electrical: 6 Year/72,000 mile
- Paint: 7 Year (PPG Delfleet paint product system)



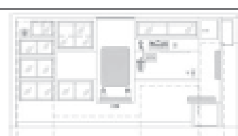
Efficient, Practical Interior



Printed Circuit Board with LED Diagnostic Lights

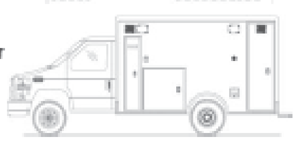
Improved Exterior Door Design

Interior Streetside



Interior Curbside

Exterior



Exterior

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