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Improvements in Lighting, Insulation and Ventilation in an Ambulance

An Interactive Qualifying Project

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Abstract

The Project's potential can be realized by first understanding the Lighting, Insulation, Ventilation systems Efficiency (LIVE) process in ambulance design. This process includes the understanding of present methods and materials used in ambulance design, the evaluation of these current methods and materials, and the examination of results to determine where improvements can be made. The LIVE analysis is completed with focusing on important parameters that affect everyone involved from the manufacturers to the medical personal, and finally patients. The process includes the literature review of regulations and standards for better understanding of the importance of LIVE in ambulance design.

Table of Contents

List of Figures

List of Tables

Acknowledgements

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CHAPTER 1: EMS LIFE SAVING PRACTICES

An Emergency Medical Technician (EMT) is the most important line of defense in case of a medical emergency, and while their training is substantial, the real conduit to their effectiveness is an ambulance. When a patient is under the care of an EMT inside an ambulance, the interior surroundings are very important to the quality of the care provided. The present lighting inside the ambulance is an irritant, and contributes to a more stressful working environment. In the United States, especially in and around New England, the vehicles consume a large amount of energy to keep the compartment air at a stable temperature. An investigation into materials that have lower heat transfer rates has been done to see if we can help reduce the consumption of power that the air conditioner consumes. The ventilation of the compartment is a field of study investigated as well, since the fumes that get in the compartment can be a severe irritant to both EMTs and patients. The success of the project starts with a thorough investigation of the existing insulation, ventilation, and lighting systems to determine what aspects should be improved uponto increase the quality of the EMTs' work space. The results have the potential to increase performance of treatment from EMTs' to the patients.

This project focuses on the: understanding of present methods and materials, evaluating the implementation of these methods and materials, and studying alternatives to these in an ambulance. The present lighting system is examined; inside and outside, of the ambulance compartment. The analysis is in efforts to reduce the amount of added stress the harsh internal lighting adds to the EMT working inside the ambulance. The exterior lighting has been investigated in the hopes of being able to find a lighting system that will increase the visibility of the ambulance. There was also a focus on checking the quality of the insulation implemented in the walls of the compartment, and what material the insulation is made out of. Multiple analyses were performed on the different materials and methods used for both lighting and insulation. These analyses indicated which material and method is the most efficient. The analysis of efficiency focuses on both cost efficiency and energy efficiency. The ventilation system of the ambulance is also considered. Analysis has been done for the challenges present inside the ambulance that may hinder the ventilation systems abilities. Evaluation on other systems already in use to has provided a basis of comparison. The purpose of this is to attempt to reduce the risk of tainted air to the EMTs while they are aiding patients. The completion of this project- our understanding, evaluation and study of the various methods of ventilation and materials used for lighting and insulation-has aided us in determining what improvements we can make to these vehicles.

With these project goals in mind, many ideas were proposed to expand on the presently used technology inside ambulances. As a possible alternative to the fluorescent lighting, implementation of LED lighting is considered. Observation of the heat transfer rate of the present insulation has been done to see what advantages reducing that rate could present, and what disadvantages it also may give rise to as well. Investigation into advances for reducing exhaust fumes toxins of the ambulance has also been done. As an additional investigation, research includes the different means of cycling air inside the compartment to keep the ambulance clean of contaminated air. A major idea involved in our solution to the limitations of the existing technology is an easily adjustable curtain with reflective material facing the inside of the compartment to both aid in heat retention and increase overall lighting. This sort of material has not been investigated in the project, due to time constraints, however. The following report consists of three more chapters. The second chapter consists of homage to the history of EMT care and ambulance design. It is important to understand the trend of advancements over time to better anticipate the future challenges that may be encounter in the project. The third chapter will include the results of our research, an in depth discussion into the materials that have been investigated and their efficiencies, and the methods involved in ventilation. This chapter is critical in providing the necessary details to derive solutions to the previously set goals. The fourth and final chapter provides a summary of the work and the key takeaways of the research.

CHAPTER 2: EMS AND PATIENT-CENTRIC QUALITY CARE

2. Introduction

The medical ambulance is an engineered vehicle that provides medical attention where needed. The ambulance is designed to be safe, functional, efficient, and even comfortable. The safety ambulance design is for the protection of both patient and medical care provider. The ambulance is a moving vehicle and the design and layout of the ambulance is important in terms of safety. The mission of every ambulance is to transport patients while provide medical attention. Functionality of the ambulance design is critical to the success of this mission. The combination of both safety and functionality of the ambulance design creates the efficiency of the ambulance design. Another important factor in ambulance design is dedicated to the comfort of the patient in transit. This design focuses on the overall atmosphere of the interior involving the placement of lights and air vents. These important parameters are responsible to the guidance of the ambulance design. This chapter will contain the research of the different ambulance manufacturer's models, interview notes, polls, and the standards and regulations regarding the medical ambulance's lighting, ventilation, insulation, and energy systems (LIVE), as outlined in Chapter 1. There will also be a brief history regarding the evolution of each of these features as they relate to the construction of the ambulance.

2.1 Standards and Regulations

In the design of the Medical Ambulance, there are many factors that need to be considered in order to manufacture and maintain an effective emergency transport vehicle. Due to the focus of this project on Lighting, Insulation, and Ventilation in the ambulance compartment, only looking at the individual subsections of such standard revisions as the Ambulance Manufacturers Division, Triple-K, and the National Fire Protection Association suffices. These specific standards will be discussed more in depth in the following subsections, but before getting into the details, the history of ambulance standard production is reported.

2.1.1 Early Standards

The first ambulance to ever contain the bulk of the essential elements considered in an ambulance you would find today was sold in 1937 in Cincinnati, Ohio. This ambulance contained roof-lighting, medical storage, was motor run, and was insulated and ventilated. These ambulances may be considered primitive to the ambulances we have today. However, standardized ambulance manufacturing was not implemented until well after the Harrow and Wealdstone train crash of 1952. This event is mentioned again later in the report; however, it is important to mention that this incident is the reason why ambulances are considered more of a hospital on wheels than just a hearse. The train crash happened in Britain, where 112 people were killed and 340 others were injured; most of the casualties happened during transport from the wreckage. This placed a very cumbersome burden on the government of Britain to enforce strict standards and regulations on the manufacturing of medical ambulances as well as standards and regulations on the paramedics (who at the time were and still are army veterans).

Not all Ambulances that were manufactured prior to 1952 were vans. In fact, most of them were structured and shaped like ordinary automobiles readily available at the time; so, in a sense there was no distinction apart from the sheer length of the vehicle. The height of the patient compartment was not considered an important aspect of design until these standards were beginning to be enforced. Needless to say, when the government began to instill these standards and regulations on medical ambulance manufacturers, absolutely none of the units produced were able to come close to the standards necessary for care. This forced striving manufacturers to begin their design from the very beginning to try and match the set standards. A quick realization that the successful ambulance manufacturers were able to make was an increase in the compartment height to create more room for the patient and tools. The EMTs did not yet ride along the patient delivering medical care to the extent they do today until this increased height feature was implemented. This realistically did not take effect until the late 1960s to the early 1970s. The first American standards for EMS and ambulance design came into effect in 1973, under the federal The Emergency Medical Service Systems Act of 1973. Most of the details of this document are not readily available for the public, and disclosure of any information about the specifics of which could potentially have unwanted repercussions.

Needless to say, a few leaps and bounds in patient medical care were necessary before the EMTs finally called the ambulance compartment a workplace; such as mouth-to-mouth resuscitation and the invention and implementation of the defibrillator. When these tools were finally used in practice, the EMTs added to their arsenal, thus starting the beginning of a continuing amount of medical practices readily available to patients who are using the ambulance. This fusion of EMT and ambulance led to an astounding increase in the number of standards necessary for the ambulance, but at the same time opened the doors for nearly limitless medical practices capable on the go. [2]

2.1.2Evolution of Standards

The first standards that were required of the ventilation system had as requirements that the air circulation system and/or the HVAC would have separate functions from the cabin of the ambulance and the patient compartment. This meant that the vehicle's ventilation system would have to have separate dials and controls for the air or that a secondary system is installed onto the ambulance in order to provide adequate air. The patient compartment required an input or air that would either provide heat, air conditioning, or surrounding air being filtered into the compartment. The surrounding air being filtered into the compartment was mostly to provide for the maintenance of temperature and the freshness of air quality. The standards have not evolved much from the main points: provide heat in the winter, coolness in the summer, and renewal of air. The biggest changes were mostly in the vehicles that were being used rather than the actual standards changing. At first, the standards were completed by the states rather than the unified federal system present known as the KKK-A-1882F along with the "Star of Life" certification. Not much more specific information of the evolution of the standards can be provided based upon the strict measures that control the intellectual properties of the standards and regulations.

Figure 1:

This Figure shows the image of the star of life. Each ambulance receives a star of life when it is certified

2.1.3Modern Standards

Modern Standard providers for medical ambulance construction come from the Triple-K and the National Fire Protection Association (NFPA). These standard enforcers are branches of emergency response teams (the medical industry and the fire protection industry). The head enforcer of all of these standards is the manufacturers really, but the regulations are enforced by the federal government via the EMS enforcement acts that have been taking place since the early ‘70s. The people that enforce the standards presently have a lot to gain from making the standards the way they want, however we will get into that in a different section. We would now, for the benefit of the reader disclose the standards used today when constructing or designing the lighting, insulation, and ventilation systems of the type I and II medical ambulances on the road, however by law we cannot document any sort of data directly from the standards. If the reader wishes to learn more about the standards that manufacturers comply to then we recommend you purchase the 1917-13 NFPA standards, and review subsections 6.15 and 6.24, 6.23.3, and 7.11.1through 7.11.8. For the scope of this report, the 2007 Triple-K standards for lighting, insulation, and ventilation are similar enough that you need only refer to the most recent updated NFPA standards for the most relevant standards in ambulance design.

2.2 Lighting

2.2.1Introduction to Interior Lighting and its History

In the compartment of a medical ambulance, proper lighting is required for quality patient medical care (PMC). The history of American ambulances as it relates to their use in medical care first started in 1865 in Cincinnati, Ohio, during the time of the Civil War [13]. These ambulances were dominantly used to treat the injured in battle, where the typical arrangement of equipment inside these horse-drawn vehicles included splints, stomach pumps, vogue, and brandy.

It should be noted that, obviously, lighting within these ambulances was likely limited to flame-lit lanterns, as the conventional use of electrical lighting was not practical or safe until 1879 when Thomas Edison invented the light bulb. Even after this, the use of light bulbs did not actually make it into the horse-drawn carriages until auto-mobiles became the new convention for travel, and this did not happen in the medical industry until 1899 when the first electric ambulance was purchased in Chicago, Illinois. In 1900, a similar ambulance was purchased likewise in New York City. An image of the model of this ambulance can be seen below.

Fig. 30 Mark XI Electric Delivery Wagon of 1899.

Figure 2:

This image portrays a general image that we could associate with an 'ambulance' that would be available to only the wealthy during the years 1899 to 1900. It is purely electric.

The first automotive (that is, motor powered) ambulance was used in Canada for military purposes, and was heavily armored with a single steering wheel and tracks. This ambulance was unconventional, and for all purposes, not practical for common-place medical treatment. The design was altered to be mass-produced, and in 1909, James Cunningham, So and Company of Rochester, NY began manufacturing these machines. These ambulances contained electric lighting (you guessed it, in the form of Edison's light bulb), which was very unconventional for its time. James Cunningham, So and Company is mentioned as the manufacturer who popularized the use of these light bulbs in ambulances. The truth is that there were other manufacturers of medical ambulances who had already been using these light bulbs in their ambulances, but due to the cost of these vehicles and inefficiency of the lighting, this report will not go very far into detail when describing the history of the lighting fixtures.

An important issue not yet discussed is the practicality of the ambulances for their time. The truth is that the ambulance was predominantly used as a hearse; a vehicle to transport the dead. In this way, the medical ambulance did not serve the same function as we commonly associate with ambulances today. The more modern conventional use of ambulances began to appear during the First World War, when hospitals began dispatching ambulances to bring the sick or wounded to hospitals for treatment. We will not go very far into detail here about the structure of the hospitals dispatching system, nor how the communication link between the dispatchers and the ambulance was formed, but the changing in lighting over this period of time did not see very much change. The need for ambulances to become more than just transportation automobiles became more and more apparent as the years went by, culminating in the defining moment in 1952 when the Harrow and Wealdstone train crash happened; where 112 people were killed and 340 others were injured.

Figure 3:

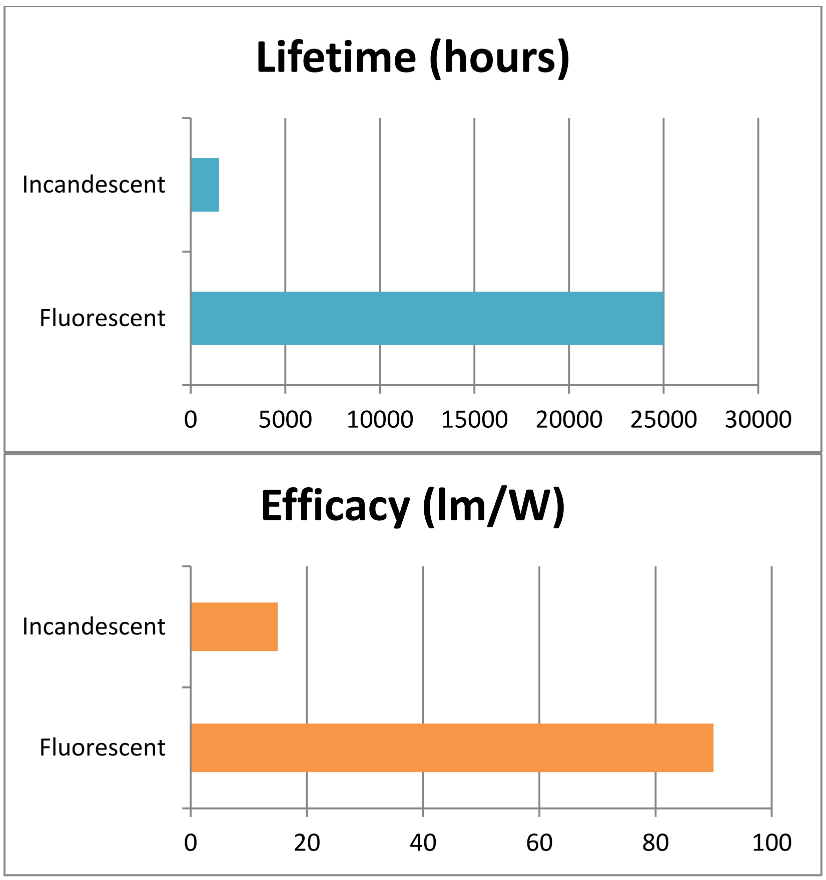
This image gives the reader a glimpse of the disaster that occurred in the Harrow and Wealdstone train crash of 1952. [28]

Most of the people that died due to that incident were not killed on impact- it was the lack of immediate treatment that caused the bulk of the fatalities. This spark ignited the fire that is the ever expanding emergency medical ambulance that we see on the streets today. This is the point where the innovations on lighting began to become more apparent.

For a long time, the standard incandescent light-bulb was used as the dominant source of lighting in medical ambulances. Once the need for a more advanced ambulance came about, the need for medical professionals to be working with patients during the drive to the hospitals also arrived. This change is what caused the lighting previously acceptable in ambulances to no longer be enough to do the job that society demanded the ambulance and its teams do. With the expansion of treatment options available inside the ambulance compartment, a need for brighter, more focused lighting became a very important issue in the world of ambulance manufacturing.

Incandescent lighting was very popular for its time. Many bright minds in engineering developed ways to increase the power consumption efficiency of this bulb so that it could remain commonly used; as the incandescent bulb was used (and is still used in many places) by just about everyone all over the United States, Europe, and just about all other developed nations.

However, in 1938 [4], GE began producing fluorescent light fixtures that were able to realize much greater efficiencies than incandescent bulbs, and with the need for a more efficient bright light to put in the compartment, these fluorescent fixtures began either being used in conjunction with or even replacing incandescent bulbs due to their sheer level of luminosity at equivalent or lesser amounts of power consumption. The Figure on the following page highlights the differences between the Incandescent and Fluorescent bulbs.



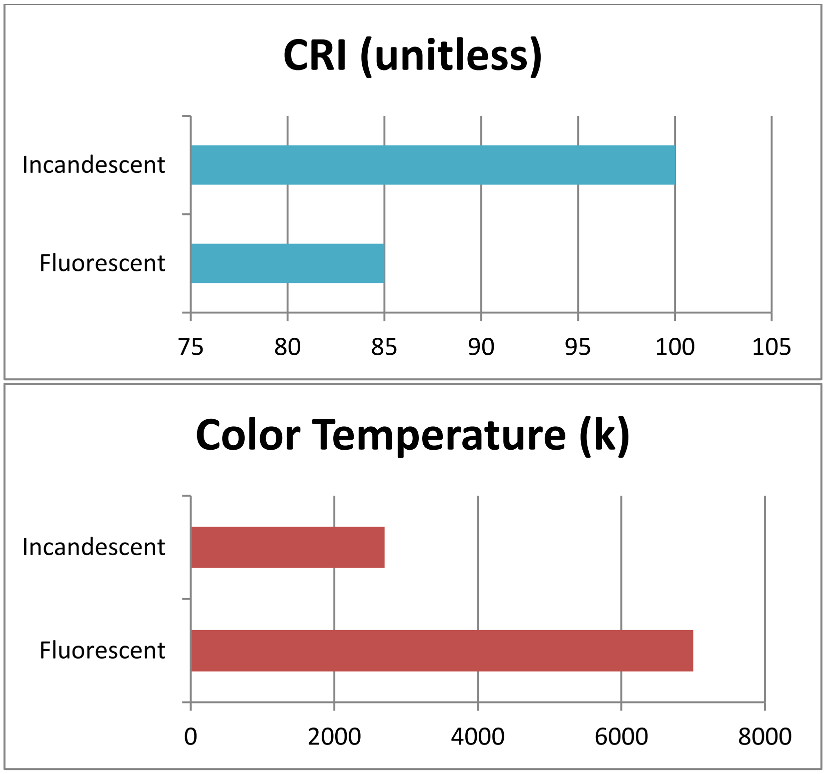


Figure 4:

This Figure illustrates the differences between Incandescent and Fluorescent bulbs.

They both are relatively inexpensive, but fluorescents are about 5 times more efficient, last about 17 times longer, and are able to produce a large variety of color intensities. They fall behind incandescent light bulbs in CRI, or Color Rendering Index. Light sources with a higher CRI tend to better replicate the color of natural lighting, which is generally considered a desirable quality of lighting in all applications.

The trouble with these fluorescent fixtures (which is still seen even in today's fluorescent lights) is their delay before reaching maximum brightness, and to a similar extent, the sheer intensity of light produced by these fixtures can be too brutal for the EMT and patient psyche.

Standards and regulations have come a long way in 60 years, and the level of lighting that is necessary to achieve the desired effect for PMC is rather strictly monitored by standards like the Triple-K and the NFPA (the latter of which takes most of its lighting standards from the former). Nevertheless, these two limitations with fluorescent bulbs were enough to merit a look into different forms of lighting. Two such results of this need that make their mark on the world of Emergency Ambulance lighting are Halogen light bulbs and LED bulbs. These two methods have been compared in a similar way as the incandescent and Fluorescent bulbs were.

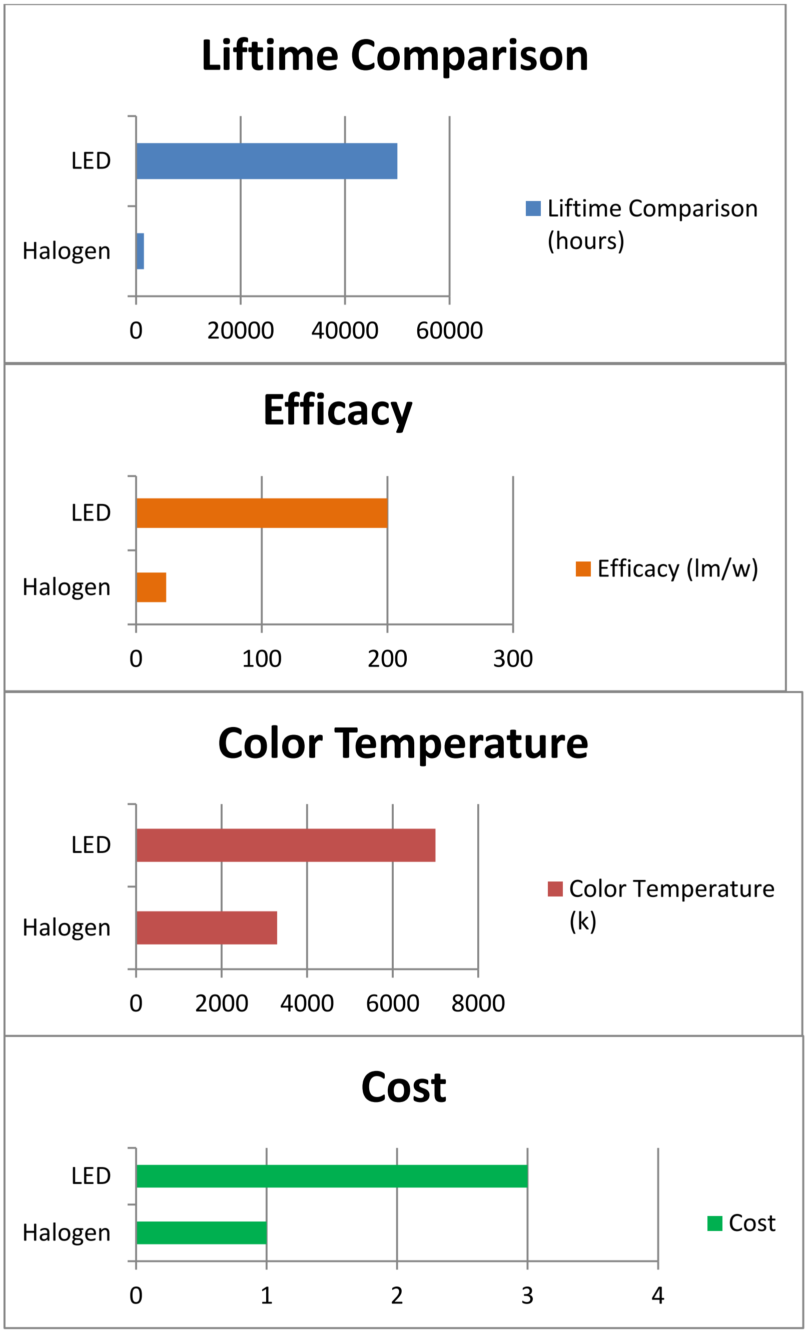


Figure 5:

This Figure shows a similar comparison between Halogen and LED lighting to Figure 4.

A point of clarity of the Cost graph: 1 corresponds to low cost, 2 correspond to medium cost, and 3 correspond to high cost. Where LEDs clearly operate much better than halogen lamps, they are still not used in many applications due to their high cost.

The first of these two methods of lighting is the Halogen light bulb. These light bulbs are very similar in performance and in nature to Edison's Incandescent light bulb, but they use halogen gas instead of the tungsten filament to illuminate the glass container and refract light. These bulbs were a convenient substitute to the incandescent light bulbs of old, but they did not make their official debut until 1959 – long after the release of fluorescent lighting. The nice thing about these halogen bulbs is that they were able to fit in the conventional fluorescent light sockets that were implemented in many people's homes when the incandescent light bulb was first popularized nearly 70 years earlier. While this addition to the market was a welcome sight to most, its initial cost upon release was higher than its extensively engineered counterpart; however, despite having about 30% better power efficiency than its older relative, it was not popularized in the world of ambulance lighting until a few years later. Unlike its counterpart, and unlike fluorescent bulbs, halogen lights were capable of producing a softer light.

The latter of the two methods that came about from this need for other methods of lighting is newer. In fact, the transition between conventional forms of lighting and LED lighting is still taking place as this piece is written. The technology is not new, per se, however its price is still much, much higher than the other forms of lighting the industry has seen over the course of its lifetime. That being said, it is roughly 90% more efficient in power consumption than incandescent bulbs, making it extremely desirable for just about everything that requires lighting. LEDs come in all shapes, sizes and colors, but the specific white variety of LED makes them much more desirable for commercial applications. With the ability to produce either soft lighting or bright harsh lighting, white LEDs have seen widespread use in many applications, but specifically in this case in the compartment of Emergency Ambulances. Each manufacturer of ambulance has a different array of lighting, but in the ambulances we see today, these white LED lights are replacing the halogen dome lights and the fluorescent bank lights that you can see in Figure 6 below in some instances.

Figure 6

This Figure shows the fluorescent banks and halogen lights (which are presently off in this image) of one of the Worcester Fleet's Ford Ambulances (left), vs. the interior Fluorescent lighting in Braun's Liberty line ambulances (right).

Clearly the difference between fluorescent lighting and fluorescent banks with halogen dome lights can be noticed. With this introduction into the world of medical lighting, consider the challenges and opinions the designers, Emergency Medical Technicians (EMTs), and patients have when dealing with the lighting inside the compartment of the modern ambulance.

2.2.3Relevance to Patient Medical Care

The lighting in the ambulance compartment is generally considered a rather important aspect of ambulance design from a power consumption point of view, but how does it affect the quality of patient medical care provided by the EMTs? In order to accurately answer this question, the first step is to do a bit of searching to find some psychological aspects generated by the colors in the ambulance.

2.2.4 Psychological Aspects of the Color Spectrum used in the Ambulance Compartment

The information gathered in this subsection has been gathered from Colour Affects, based in Dolphin Square, London.

As can be appreciated in some of the Figures that are displayed, the interior of the ambulance compartment is white in color, with gray cabinets mostly. The lighting fixtures are also (supposed to be) white. In medical hospitals, the dominant color is also white. So with this dominant emphasis on white in the medical community as a whole, there must be a reason for it.

White is total reflection of all colors in the visible spectrum. The resulting effect of the color white is a reflection of the full force of the color spectrum into our eyes. The effect of this can lead white to be a strain to look at directly, and it can create barriers accordingly. White can be associated mentally with purity, sophistication, cleanliness, hygiene and sterility. This association with sterility can also have a negative connotation, but in the case of medical practice this is not the case. White also gives a heightened perception of space, allowing white rooms to appear larger than they actually are. White can also have a visibly negative effect on warm colors that are used in conjunction with white, making them look garish. [48]

So just to review what white is all about, listed below are the positive and negative qualities of the color white, as seen in reference [48]
Positive: Hygiene, sterility, clarity, purity, cleanness, simplicity, sophistication, efficiency.
Negative: Sterility, coldness, barriers, unfriendliness, elitism.

The color of the cabinets is gray, requiring the search of said color from Colour Affects.

Gray is a color that really has no direct psychological properties, but it is a really suppressive color; meaning that it detracts from the positive nature of other colors used in conjunction with it with only a few exceptions. The precise tone of gray has a lot to do with the psychological interpretation of the color. For a darker gray, there may be a link to dampness, or hibernation. A heavy use of the color may indicate lack of confidence and fear of exposure. [48]

Again, here are the positive and negative features of Gray: Positive: Psychological neutrality.
Negative: Lack of confidence, dampness, depression, hibernation, lack of energy.

So taking a look at the overall appearance of the ambulance's compartment, it looks like there is a bit of a clash of wills. The purity and sterility aspects of the white color make it particularly appealing, but the lack of confidence and depression that can be taken from the negative aspects of the color gray seem to place a bit more strain on the psyche than the positives. The plus side of the gray is that it is seemingly psychologically neutral, so if one were to ignore the negative sides of abundance of gray, the color is pretty much a safe color. White with gray is one of the exceptions to the rule of gray suppressing another color. This is dominantly due to the fact that white is the reflection of all colors, and as such cannot really be detracted from in any meaningful way by the color gray. To the patient, however, the colors of the cabinets may be a bit disheartening.

2.2.5 The Effect of Lighting Intensity on the patients or EMTs

Originally, the analysis considered the effects of the magnitude lighting to be very central to defining how effective an EMT would be at delivering the best possible medical care to a patient. Without access to a team of EMTs to thoroughly test this hypothesis, the ability to conduct this experiment for the benefit of the project could not be conducted. However, in another study comparing the effects of exposure to dim light vs. bright light at different times of day to detect levels of melatonin and cortical, we were able to find a general result that disproved our theory immediately. These results are shown in Figure 7 seen below.

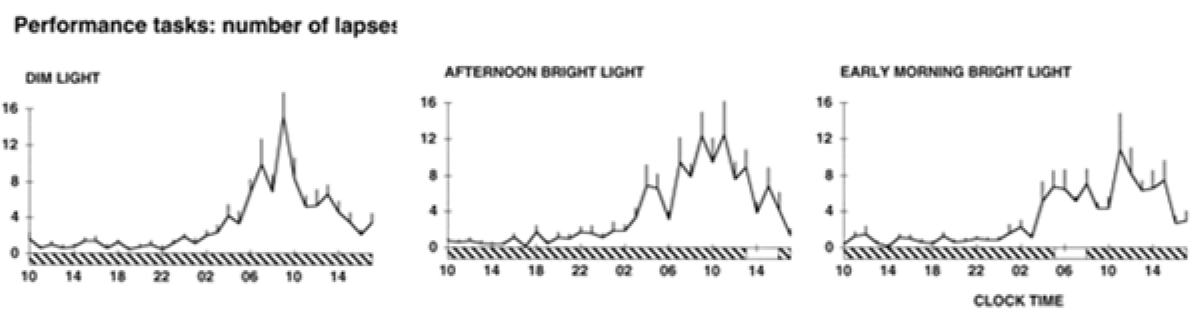


Figure 7

This figure shows statistical data regarding the performance level of young men who were tested under different lighting conditions.

In the three images you can see above in Figure 7, it is pretty conclusive that the effects of dim light and bright light do not really have a noticeable effect on the performance of the average healthy young male. However, with the extensive training of EMTs, the effect of lighting would be even less on their performance, and we have since concluded that there is no noticeable effect outside of sleepiness due to the sleep schedule of an average EMT. [24]

With this conclusion drawn, all heads turn to the patient who is in need of medical care, and to this we were not able to draw any statistical evidence in support of the claim that bright lights provide excessive irritation; however, instances of patients who have light sensitivity who have had problems with the intensity of the light provided in ambulances were found. The overall luminosity above the stretcher cot, by the NFPA 1917 standards, has to be about 19 foot-candles across 90% the entire cot in the compartment. This amount of lighting is incredibly bright, and can easily bother the patient; making them more prone to increased levels of adrenaline or blood pressure which could easily result in a misdiagnosis.

2.2.6 Concluding remarks about relevance to Patient Medical Care

The information we found to be most relevant to the quality of patient medical care seems to be the actual color of the lighting and the color of the ambulance's gear and compartment space. The intensity of brightness has a range of effects on the patients depending on whether or not they have any sort of light sensitivity issues. In these cases, the lower setting of light can be used to assist in this scenario, but the true effects of this change has yet to be seen or documented. For the scope of this section of the paper being more of an introduction to the challenges lighting design faces in ambulances, inclusion of an analysis of the effect of different levels of lighting on patient response is not included; though this concept would be a good one to look at for a more specialized IQP.

In today's world of medical ambulances, a lot has changed since their first widespread applications in the medical field for the lighting. The importance of running a more power-efficient ambulance has become more visible in the field considering the implementation of LED lighting has become more prevalent despite its higher initial cost. In this subsection, lighting specifications of a few different types of ambulances are presented below: Wheeled Coach, Braun Industries Inc., and McCoy Miller Corporation.

The information readily available to the public for these manufacturers can be found on their websites which will be listed at the end of this subsection and for the benefit of the interested reader. [6, 26, 43]

The first ambulance manufacturer we will look at is Wheeled Coach, based out of Ohio, whose standard ambulance line is coined the 'Medic Series', as Wheeled Coach makes many other types of ambulances – some non-transport like their Strikeforce Series. For a more streamlined documentation of the lighting types in these ambulances, see table 1 below.

Table 1: Wheeled Coach Medic Series		
Ambulance Name	Ambulance Lighting Technique	Optional Ambulance Lighting Options /Features
Citimedic Plus	Halogen Dome Lights over cot	LED
Crusader Plus	Halogen Dome Lights over cot	LED
Custom	• 7 Weldon Model 8045 Halogen Dome Lights mounted in recessed headliner, 4 over Cot, 3 over S/B	LED

Table 1: *This table shows the different models of ambulance interior lighting used in the Wheeled Coach Medic Series.*

The next Manufacturer we will look at is the Braun Industries Inc., based out of Ohio, and all their ambulances in table 2.

Table 2: Braun Industries Inc.		
Ambulance Name	Ambulance Lighting Technique	Additional Ambulance Lighting Options/ Features
Signature Series	VitalMax Lighting	Dimmable
Patriot	VitalMax Lighting	Dimmable
Super Chief	Angled Fluorescent	Dimmable
Chief XL	VitalMax Lighting	Dimmable
Liberty	Angled Fluorescent	Dimmable
Express	VitalMax Lighting	Dimmable

Table 2: *This table shows the different models of ambulance interior lighting used in the various Braun Ambulance Inc .ambulance lines.*

It should be noted what is meant by VitalMax, as the Angled Fluorescents can be seen in the right side of Figure 6. The VitalMax lighting technique is exclusive to Braun ambulances, and claims to have the highest luminosity in the industry, while still granting the EMTs control over the magnitude of the lighting. The VitalMax technique is combining halogen or LED dome lights with the angled fluorescent banks to create a shadow-less compartment. The information regarding how much luminosity the VitalMax lighting technique provides is not presently made available to the public.

The next manufacturer we will look at is McCoy Miller Corporation, based out of Massachusetts, whose ambulances can be seen in table 3 below.

Table 3: McCoy Miller Corporation		
Ambulance Name	Ambulance Lighting Technique	Additional Ambulance Lighting Options/ Features
Resqmedic	8 dual-element Halogen Dome lights	Dimmable and controllable from separate switches

Type II Guardian	6 dual-element Halogen Dome Lights	Dimmable and controllable from separate switches
Medic 146, Type I	8 dual-element Halogen Dome lights	Dimmable and controllable from separate switches
Mini Rescue, Type IV	custom	Halogen, LED, Strobe / dimmable

Table 3: *This table shows the different models of ambulance interior lighting used in the McCoy Miller Co. ambulance lines.*

Clearly there is quite a bit of variety from the different manufacturers in the industry, but these are just a few of the American models of ambulance lighting. It would be an interesting comparison to see what sorts of ambulance lighting techniques are done overseas. However, the information regarding European ambulance manufacturers is limited to the degree that finding any specific lighting information is a rather difficult task, and while not irrelevant to our project, may be specified in a more in-depth comparison between automotive manufacturers in a later project.

2.2.7 Exterior Lighting

The exterior lighting of a medical ambulance has also experienced a long history, but with similar outcomes as the interior lighting. The push to have a 'hospital on wheels' after the Harrow and Wealdstone train crash incident also brought with it the necessity of improving the exterior lights on the ambulance, but for different reasons. At first, ambulances were little more than long automobiles. There are many sources the reader can find easily in any search engine that claim ambulances were dominantly used as hearses, and many ambulance manufacturers produced automobiles that were low to the ground in frame, much like a modern day hearse. These ambulances had interior lights, but limited their exterior lights to just the standard headlamps and brake lights typically. Any sort of exterior lighting was largely ignored in the preliminary models. This design concept began to change rapidly as more and more automobiles were hitting the road, and the need to alert people that there was an emergency became more pressing. The end result of this period of evolution is what is seen in current ambulances in most countries.

Figure 8:

The headlamps and the brake lights are still used, but now there are many more flashing lights used on the ambulance that are, in general, much more powerful than the standard headlamps and the interior lights of the compartment.

Ambulance exterior lighting is divided into a few categories. There are the lights in the front of the ambulance, the lights on the side and top of the ambulance, and the lights on the back of the ambulance. Before getting into the specific types of lighting, one could expect to see on any of these sections, not every ambulance is the same. There are a bunch of different street models of ambulances that are used in different applications, and the exterior lighting is different for all of them. There are a few common threads that keep them all relatively consistent with one another and truly define the ambulance as is known by many.

The first key feature of an ambulance is a light bar. This device was originally just a metal rod already on the vehicle which manufacturers would just mount two rotating beacons to. However, over time the people making the beacons began making light bar units containing the same components and selling those instead. These light bars were pretty popular in police cars and ambulances, and the units were simple enough at their time of manufacture that they were inexpensive. Today, ambulances still bolster light bars, but not in the same way that can be imagined when we look at the light bars on police cars. Instead, the light bars are now effectively built in when the unit is produced.

The front of the ambulance can sport a variety of other lights as well, including patterned lighting that also flash in a pattern to enhance visibility during both day and night to alert drivers quicker to the ambulance’s presence. There are also grill lights that flash in an alternating pattern on the grill of the vehicle, and dash lights that are installed on the interior of the ambulance cockpit that provide a piercingly sharp light to allow the driver slightly better visibility in low visibility conditions. The front may also support a system that flashes the high beams as an alternative to the extraneous lights in the front of the vehicle that flash in a certain pattern.

Figure 9:

This image shows a pretty good indication of the lighting you could expect to see on an ambulance today.

The reader may also notice lighting on the side of the passenger door as well as on the side. That is presented next.

Body mounted lighting is a pretty crucial element for medical ambulances that are at the scene during dark hours where the patient is on the ground, in such a location as to make getting him or her into the compartment a difficult task due to low vision. There are several types of body mounted lighting for commercial use today, but LED lighting is usually preferred due to its immensely low profile and sharp light quality potential. The square light patches that are pretty visible from the image above can be used as a reference to what these mounted ‘body lights’ tend to look like. These are NOT the only option available for use for body mounted lighting, and in fact, there are some vehicles equipped with side bar lighting that illuminate a large area- up to 20 feet from the side of the ambulance- for just such an occasion. These devices are, generally speaking, much more expensive than flush mount side mounted lights like in the picture, but they do provide the best level of light for use when the ambulance has to remain stationary for a long period of time.

The trouble with side mounted lighting, aside from their cost, is that they consume power profusely. If the devices are not LEDs, this power draw commonly exceeds 50 watts, which is fairly substantial considering how much power is available for use with exterior lighting. There are a few other “exterior” lighting types for use on the side of an ambulance that append to the list already; however, the reason exterior is in quotations is because technically this light is on the interior of the ambulance, but is accessible from the outside of the ambulance. This light is used predominantly to see the materials inside of this storage department, but it is certainly bright enough to emit a useful amount of light to the surrounding area, which by no means is an amount necessary to illuminate a workspace for a long period of time, but can be useful when locating a patient and transporting them into the compartment for treatment faster.

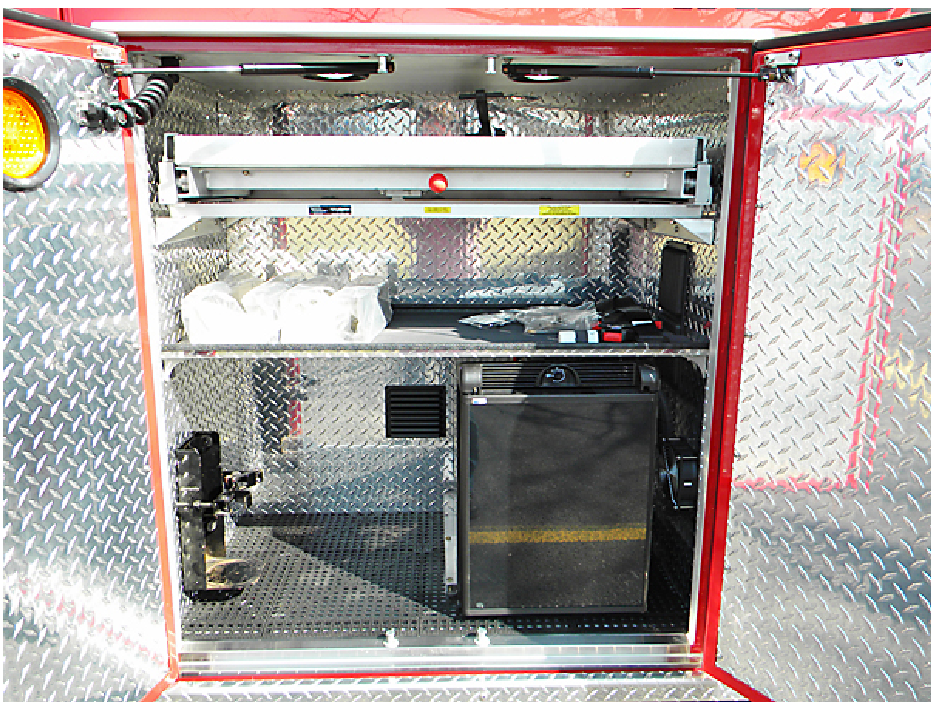


Figure 10

The reader can see a light source on the top of this compartment as well as a yellow reflector light on the left hand side of the image. This is just one example of the many different types of ambulance exterior compartments.

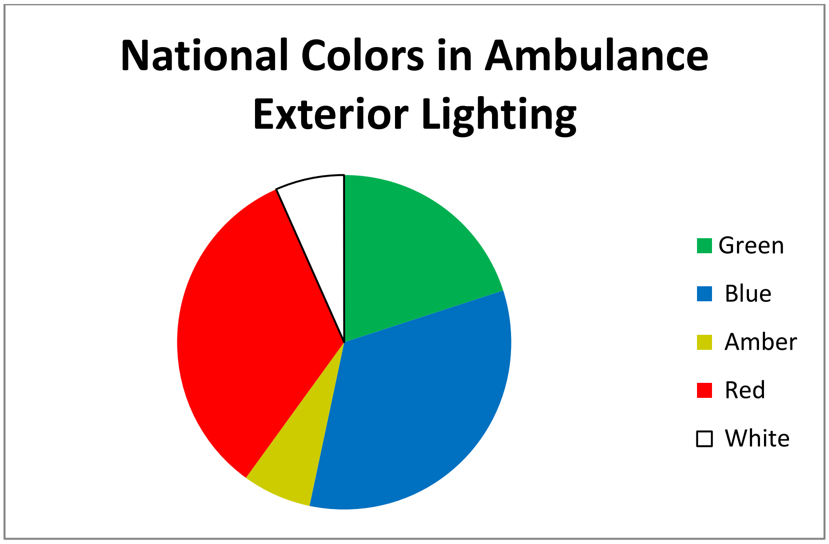
The back side of an ambulance probably has the most lighting on the entire body of the vehicle. While the standard brake lights and directional lights are clearly visible on the back, there are also many pattern lights that flash back and forth to promote visibility. There, also, tends to be extraordinarily bright lights above the doors to the compartment as well in order to provide the best visibility when trying to get a patient into the ambulance compartment. These lights change per manufacturer, and their intensity depends largely upon the type of ambulance. The doors themselves even have lighting on the inside of them.

Figure 11:

This image displays the exterior lighting aside from any beacon that may sit on the top of the ambulance.

The brake lights and directional lights can be seen on the steel plate closer to the bottom of the ambulance by the wheels; the long skinny yellow bar centered above the door is the ultra-bright light mentioned briefly; the other lights are patterned flashers that usually flash red and amber here in the stated to alert people to stay back. Next is described the different methods of lighting in different cultures.

The developed world depends on ambulances to arrive at a fast time to reach a patient to bring them to the nearest hospital and deliver PMC. However, in the United States, the medical ambulance also gets special roadway privileges that force the drivers of common automobiles to pull over and yield the right of way to the ambulance driver. There is a color code in most developed countries that denote what sort of privileges are granted to specialty vehicles based on the color of light they have flashing. Below is a pie chart showing a percentage of color use.



Area/Country	Ambulance Lighting Color
USA	Blue and Red
South Korea	Green
New Zealand	Red
Japan	Red
Hong Kong	Blue
United Kingdom	Blue
Spain	Amber
Germany	Blue
Netherlands	Blue
Canada	Red and White
Australia	Red and Green
Argentina	Green

Figure 12:

The most common colors used for ambulance exterior flashing lights are clearly the colors red or blue. In some instances there are green lights, but for the most part those are used when the ambulance is stationary like in the example of Australia. [44]

2.3 Insulation

2.3.1 Introduction to Insulation

For the purposes of insulation, the patient compartment of an ambulance can be treated as a double walled aluminum box. Aluminum provides many useful mechanical and thermal properties. It is strong, light, and an excellent thermal conductor. During operation, the patient compartment of an ambulance has to be kept at a minimum temperature. The outside air temperature is not always in the acceptable range. Having insulation helps maintain the compartment at a comfortable working temperature. Insulation has the added bonus of helping to keep noises form the environment from penetrating the compartment. Insulation is mainly a matter of material selection. As the field of material science advances, the effectiveness of insulation will improve while costs will go down.

2.3.1The Impact of Insulation on the Quality of Patient Medical Care

Insulation improves Patient Medical Care by providing an environment that reduces stress on the patient and helps the emergency personnel diagnose and treat his/her injuries and/or illnesses. Insulation does this in two ways. First, it helps maintain the recommended temperature while decreasing the power consumed by, the size, and the weight of the HVAC; therefore, allowing more power, space, and weight to be used by medical equipment. Second, insulation keeps outside noise from entering the patient compartment allowing work do get done.

Current regulations only specify that the insulation not be hazardous and require a level of performance that is only just useful. This leads to some ambulance users to add additional requirements to get improved qualities while others get by with the current standard to maximize bidders and cut costs. Some improvements in insulation are not expensive and if they were standard requirements all entities would benefit from these improvements without much additional cost. Other improvements in the factors impacted by insulation might be expensive. For these improvements, there could be modifications to the standards and emergency services evaluations to measure optional improvements and incentivize increased benefits from insulation.

2.3.2 Requirements for Insulation Materials

Regulations regarding thermal insulation are found in three places: NFPA 1917 Standards for Automotive Ambulances 2013 edition, Federal Specification for the Star-of-Life Ambulance

KKK-A1822F, and FVMSS 302 Flammability of Interior Materials. These are produced by the National Fire Protection Agency, Government Services Agency, and the Department of Transportation respectively. NFPA 1917 deals with thermal insulation in sections 6.15.1 and 6.15.2. KKK-A1822F refers to thermal insulation in sections 3.4.2.2 and 3.10.15. The FVMSS 302 does not directly deal with insulation, but is mentioned here because it is sighted in section 6.15.1 of NFPA 1917. Both the NFPA 1917 and KKK-A1822F specifications state that the insulation material used must have the following properties:

- Non-settling: meaning, that the insulation does not compact to the bottom of the cavity under its own weight even after its continuous vibration from its use in motor vehicle.
- Vermin proof: meaning, that the insulation resists tunneling by vermin and cannot be made into nesting material
- Mildew proof: The insulation material must resist the growth of mold and mildew in any climate.
- Nontoxic: means that the insulation material is not toxic to humans
- non-hydroscopic: means that the insulation material does not readily absorb water or moister from the environment

[31, 40, 38]

The NFPA also requires that the insulation material meet the requirements of FMVSS 302. FMVSS 302 requires

> "Material shall not burn, nor transmit a flame front across its surface, at a rate of more than 4 inches per minute. However, the requirement concerning transmission of a flame front shall not apply to a surface created by the cutting of a test specimen for purposes of testing. If a material stops burning before it has burned for 1 minute from the start of timing, and has not burned more than 2 inches from the point where timing was started, it shall be considered to meet the burn-rate requirement of the standard."
>
> [40]

2.3.3 Thermal Performance Requirements for Insulation

Unlike the NFPA document, the KKK-A1822F stipulates that

> “The entire body, sides, ends, and roof of the patient's compartment shall be completely insulated to enhance the performance of the environmental system.” In section 3.4.2.2 KKK-1822F also requires that “the interior of the ambulance patient compartment must be maintained at a minimum temperature of 50oF when the ambulance is prepared for immediate response.”

[40]

Moreover, KKK-A1822F references the NATIONAL TRUCK EQUIPMENT ASSOCIATION / AMD (Ambulance Manufacturers Division) Standards 001 through 025. Standard 012: INTERIOR CLIMATE CONTROL TEST impacts the insulation requirements indirectly. Standard 012 specifies that the climate control system must be able to restore a suitable temperature in the patient compartment within 30 minutes:

- for the heating system to a minimum of 68^o F from 32^o F
- for the cooling system to a maximum of 78^o F from 95^o F

[1, 38]

However, it should be noted that effect of improving insulation on meeting these requirements is negligible. The requirements are met by providing high capacity heating and cooling equipment provide a major benefit to patient care when an idle ambulance is rushed into service, or when an open ambulance door causes the ambulance to get too hot or too cold. In addition, the cooling system is required to remove the heat generated by equipment, including lighting, and personnel.

Energy efficiency is not included in the standards for Ambulances. The energy savings and return on investment for drastically improved insulation is much less than the return from a similarly sized investment into improved lighting and/or ventilation technologies, and more efficient heating and cooling equipment. Therefore, it is appropriate that energy efficiency, such as the R factors, used for building insulation not be part of the specification for thermal insulation for ambulances.

2.3.4 Acoustic Performance Requirements for Insulation

This insulation must keep the noise level in the compartment below 80dBA at all-time concurrent with section 3.13.6 of the KKK-A1822F. The procedure of testing sound level in the patient compartment is specified in AMD STANDARD 006: PATIENT COMPARTMENT SOUND LEVEL TEST.

[1]

80 dBA is ten times as loud as 70 dBA, the EPA identified maximum to protect against hearing loss and other disruptive effects from noise, such as sleep disturbance, stress, learning detriment, etc. Most significantly, 80 dBA is also quite loud for emergency personnel who are responsible for providing the preliminary diagnosis of the patient and measuring the response of the patient to their interventions and reporting this to the hospital emergency doctors.

[40, 1, 14]

The insulation of the patient compartment can only do so much to reduce the noise level in the patient compartment. Noise reduction requires a systems approach including an efficient combination of the following:

1. reducing noise at its source
2. installing specific insulation at the major noise source
3. insulating the patient compartment
4. active noise cancelling

With recent developments in technology, all of the above approaches should be able to contribute to lowering the noise level in the patient compartment; however, it may be too early to lower the minimum standard. It is proposed that instead that a standard noise measurement be required so that customers can consider noise performance in the same way that they consider fuel economy.

To provide the most useful data, the noise testing should include optional tests with the siren in operation and the vehicle moving on a paved road. The purpose of these tests would be to measure siren noise and tire noise and other noises from the vehicle in motion.

2.3.5 Recommendations for Improving Insulation Standards

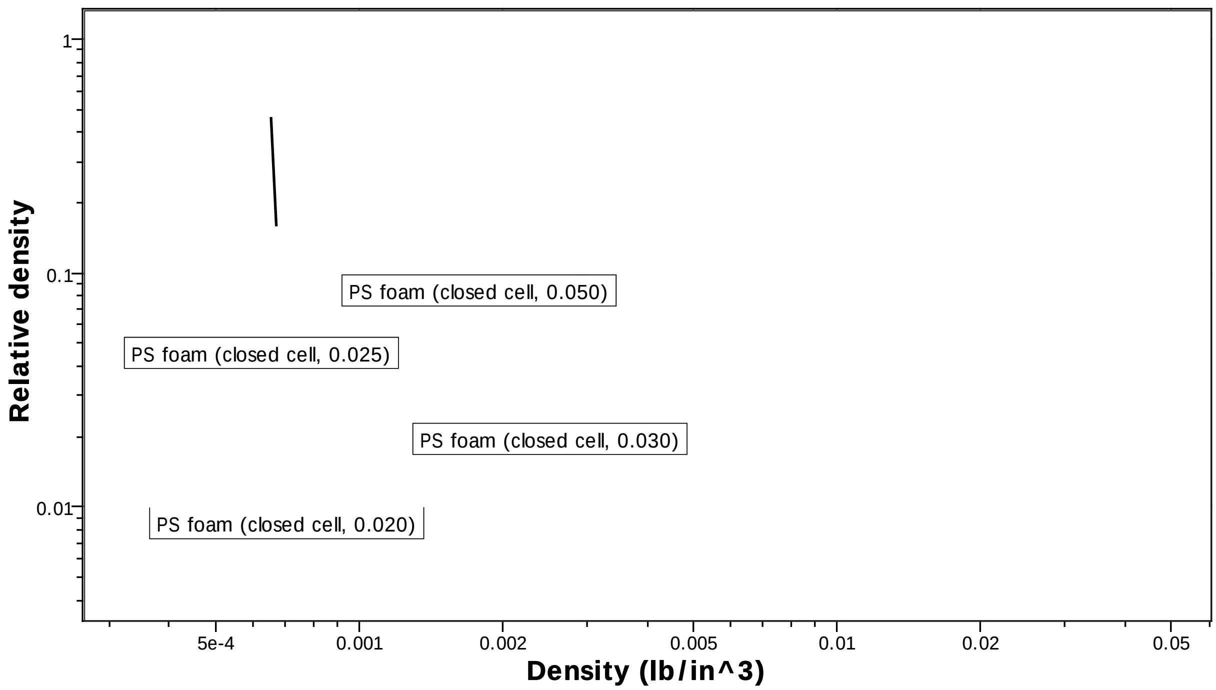
The material and thermal requirements for insulation are good and do not need to be changed. The acoustic performance requirements are adequate, but because of the significant benefits from improved acoustic technologies, optional standard tests should be instituted: to enable customers to compare noise control performance, to incentivize and reward manufacturers who use new technologies, and improve design and construction to improve the Quality of Patient Medical Care.

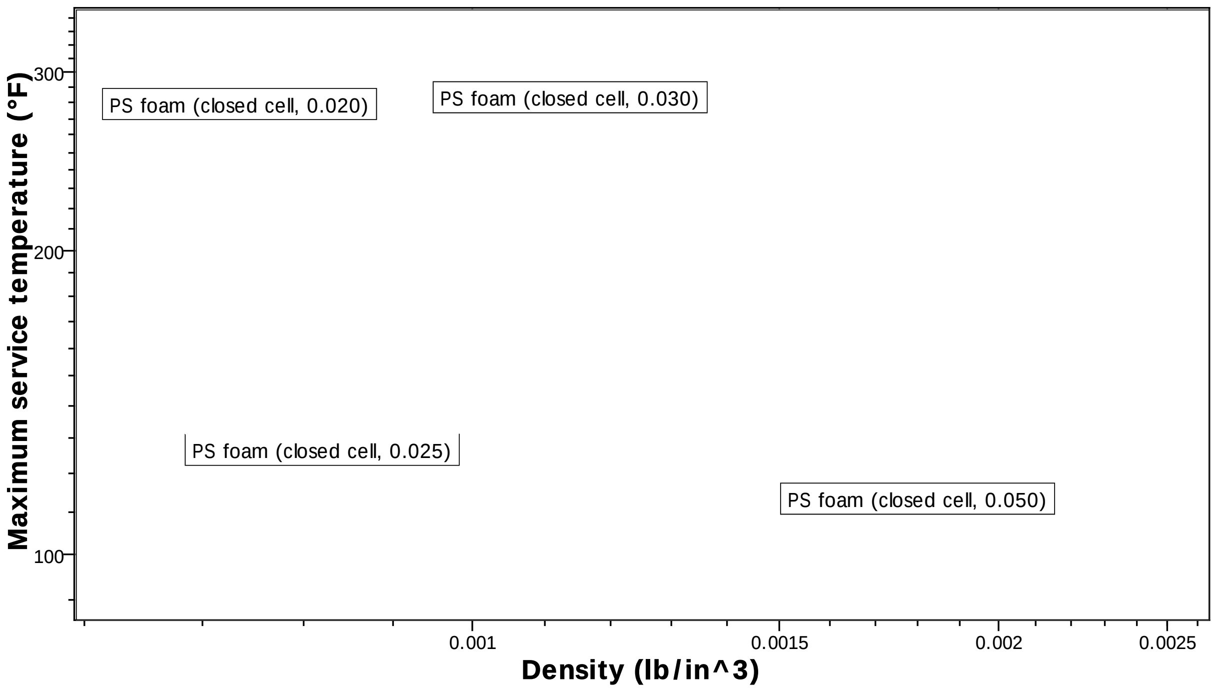
2.3.6 Various Types of Insulation used in Ambulance Patient Compartments

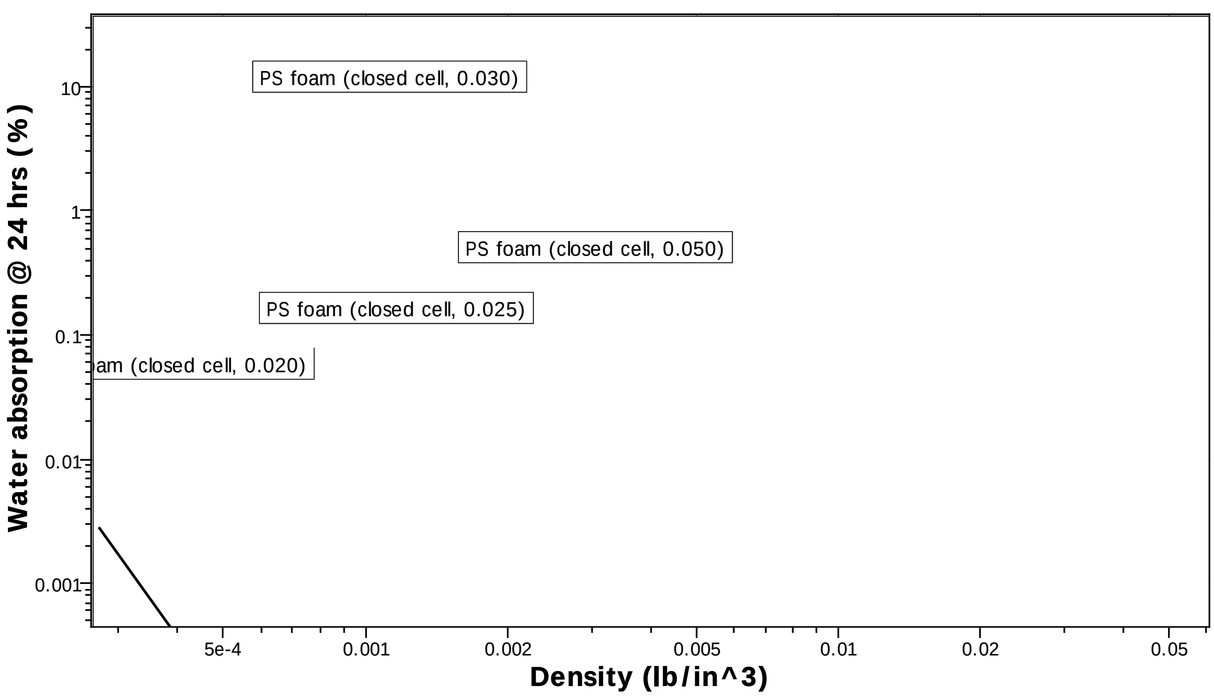
Note: There are a great many different types that can be used as insulation. The following are some of the more interesting examples. Thermal properties are focused on because they will be the most relevant to the subject of Chapter 3.

Types of Polystyrene

There are four main type of Polystyrene foam that is used for insulation the difference between them is their relative density. Relative density is the density of the foam divided by that of the solid from with the foam is made [alpha 1].




Maximum service temperature (°F)
300
200
100
PS foam (closed cell, 0.020)
PS foam (closed cell, 0.030)
PS foam (closed cell, 0.025)
PS foam (closed cell, 0.050)
0.001
0.0015
0.002
0.0025
Density (lb/in^3)


Water absorption @ 24 hrs (%)
10
1
0.1
0.01
0.001
PS foam (closed cell, 0.030)
PS foam (closed cell, 0.050)
PS foam (closed cell, 0.025)
am (closed cell, 0.020)
5e-4
0.001
0.002
0.005
0.01
0.02
0.05
Density (lb/in^3)

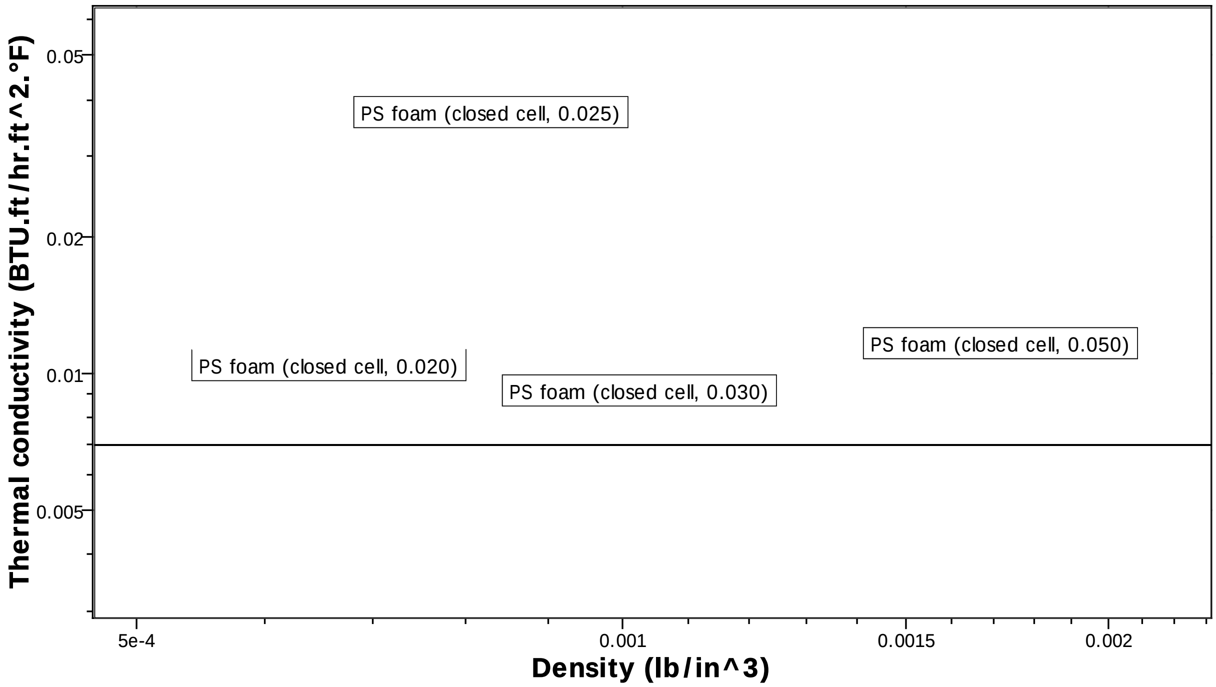


Figure 13:

These graphs display the various important properties of insulation materials that would be used in an ambulance. These particular types of insulation are polystyrene foam.

The crew installing 1 1/2" EPS sheets under the steel roof deck as cavity fill insulation. [Alpha 1]

Expanded polystyrene is made of pre expanded beads of polystyrene that form tough closed cell foam. These rigid sheets are often used as cavity fill insulation in building construction as well as ambulance construction. The sheets are often used in conjunction with spray foam insulation.

 [Alpha 2]

Extruded Polystyrene is similar to expanded polystyrene in that is also produced in rigid sheets.

> "Extruded polystyrene foam begins with solid polystyrene crystals. The crystals, along with special additives and a blowing agent, are fed into an extruder. Within the extruder the mixture is combined and melted, under controlled conditions of high temperature and pressure, into a viscous plastic fluid. The hot, thick liquid is then forced in a continuous process through a die. As it emerges from the die it expands to foam, is shaped, cooled, and trimmed to dimension."
>
> "This continuous extrusion process results in a unique foam product with a uniform closed-cell structure, a smooth continuous skin, and consistent product qualities."

[Alpha 3] http://www.diversifoam.com/xeps.htm

This production process gives Extruded Polystyrene a lower thermal conductivity than expanded polystyrene.

Right [alpha 4] http://energyefficiencyandretrofits.blogspot.com/2010/11/fiberglass-batts.html

Left [alpha 5] http://www.deckerhomeservices.com/fiberglass_insulation_problems.htm

Figure 14:

Alpha 1-5 display the various kinds of extruded polystyrene foams.

Fiberglass batts come in two forms, backed and un-backed. The main problems using fiberglass batts for insulation have to do with its installation. It is very easy to improperly install and the small glass fibers can cause skin iteration. One of the more serious problems with fiber glass batt is that their R-value 11-28 % lower than the labeled after installation. Another drawback is that it must be protected from exposure to water.

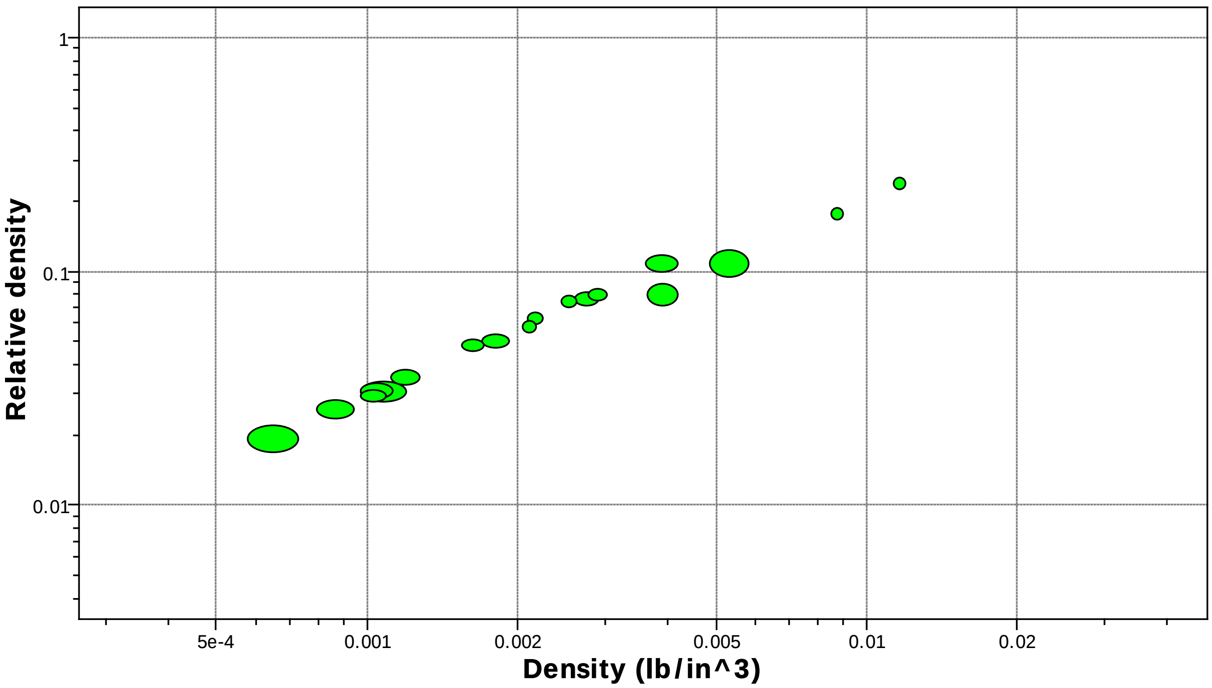
Types of Polyethylene foams

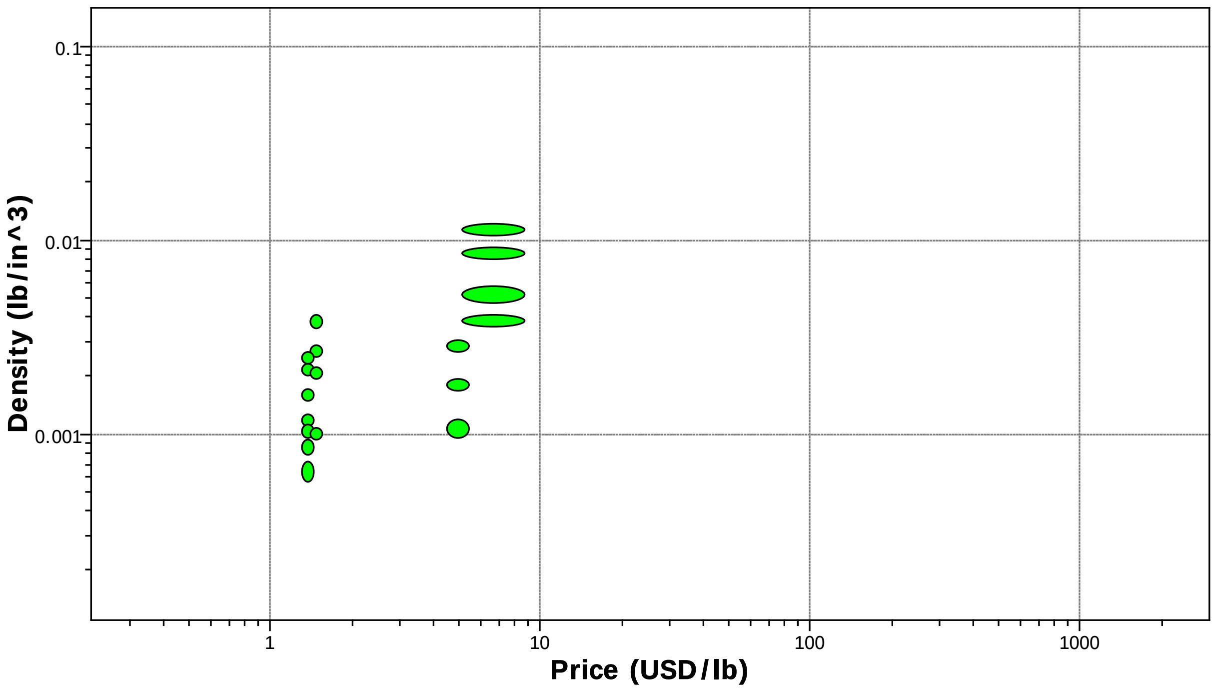
Labeling of the different types of polyethylene foams on the graphs was impractical their names are

Name	Thermal conductivity
PE foam (cross-linked, closed cell, 0.030)	.022-.0243 BTU*ft/hr ft^2 ^{o}F
PE foam (cross-linked, closed cell, 0.050)	.0248-.0272 BTU*ft/hr ft^2 ^{o}F
PE foam (cross-linked, closed cell, 0.080)	.0277-.03 BTU*ft/hr ft^2 ^{o}F
PE-HD foam (cross linked, closed cell, 0.080)	.0352-.0376 BTU*ft/hr ft^2 ^{o}F
PE-HD foam (cross-linked, closed cell, 0.030)	.0266-.0277 BTU*ft/hr ft^2 ^{o}F
PE-HD foam (cross-linked, closed cell, 0.060)	.0318-.0341 BTU*ft/hr ft^2 ^{o}F
PE-HD foam (cross-linked, closed cell, 0.115)	.0416-.0451 BTU*ft/hr ft^2 ^{o}F
PE-LD foam (cross-linked, closed cell, 0.018)	.0208-.022 BTU*ft/hr ft^2 ^{o}F
PE-LD foam (cross-linked, closed cell, 0.024)	.0208-.022 BTU*ft/hr ft^2 ^{o}F
PE-LD foam (cross-linked, closed cell, 0.033)	.0225-.0237 BTU*ft/hr ft^2 ^{o}F
PE-LD foam (cross-linked, closed cell, 0.045)	.0243-.0245 BTU*ft/hr ft^2 ^{o}F
PE-LD foam (cross-linked, closed cell, 0.060)	.0272-.0283 BTU*ft/hr ft^2 ^{o}F
PE-LD foam (cross-linked, closed cell, 0.070)	.0289-.03 BTU*ft/hr ft^2 ^{o}F
PE-LD foam (cross-linked, closed cell, 0.029)	.022-.0231 BTU*ft/hr ft^2 ^{o}F
Polyethylene terephthalate foam (closed cell, 0.108)	.016-.0177 BTU*ft/hr ft^2 ^{o}F

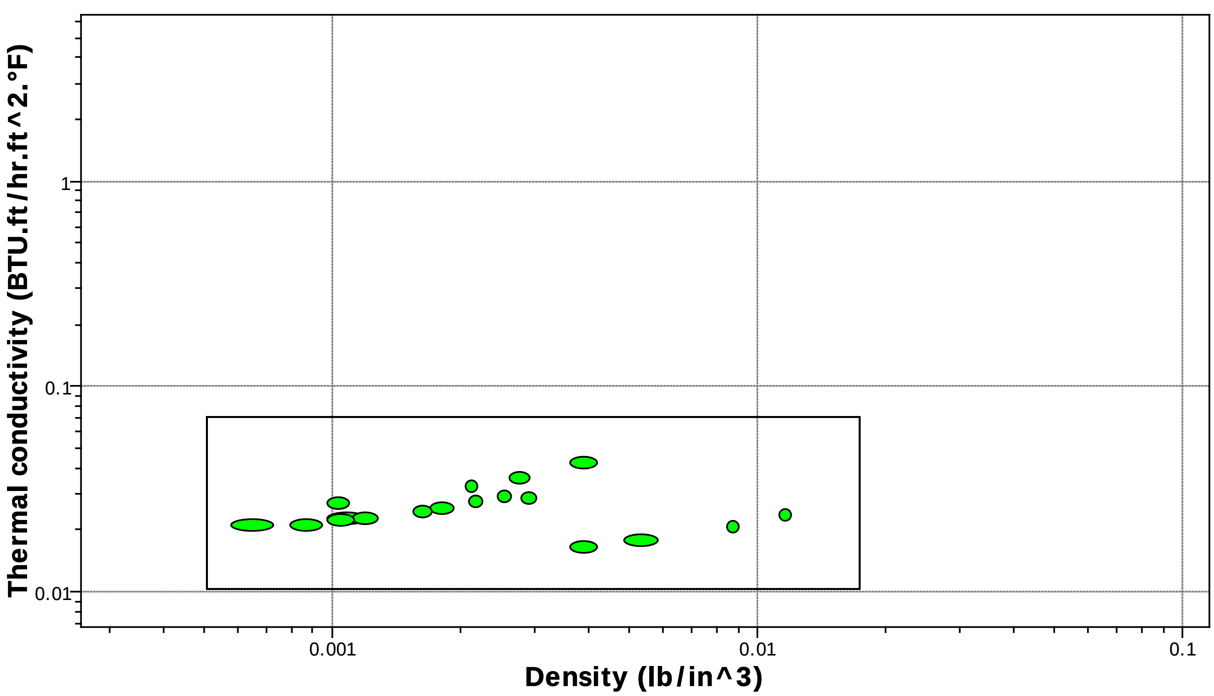
Polyethylene terephthalate foam (closed cell, 0.15)	.0171-.0189 BTU*ft/hr ft^2 ºF
Polyethylene terephthalate foam (closed cell, 0.24)	.02-.0221 BTU*ft/hr ft^2 ºF
Polyethylene terephthalate foam (closed cell, 0.32)	.0229-.0253 BTU*ft/hr ft^2 ºF

Table 4: *This table shows the Thermal Conductivity of each of the Polyethylene foams observed.*

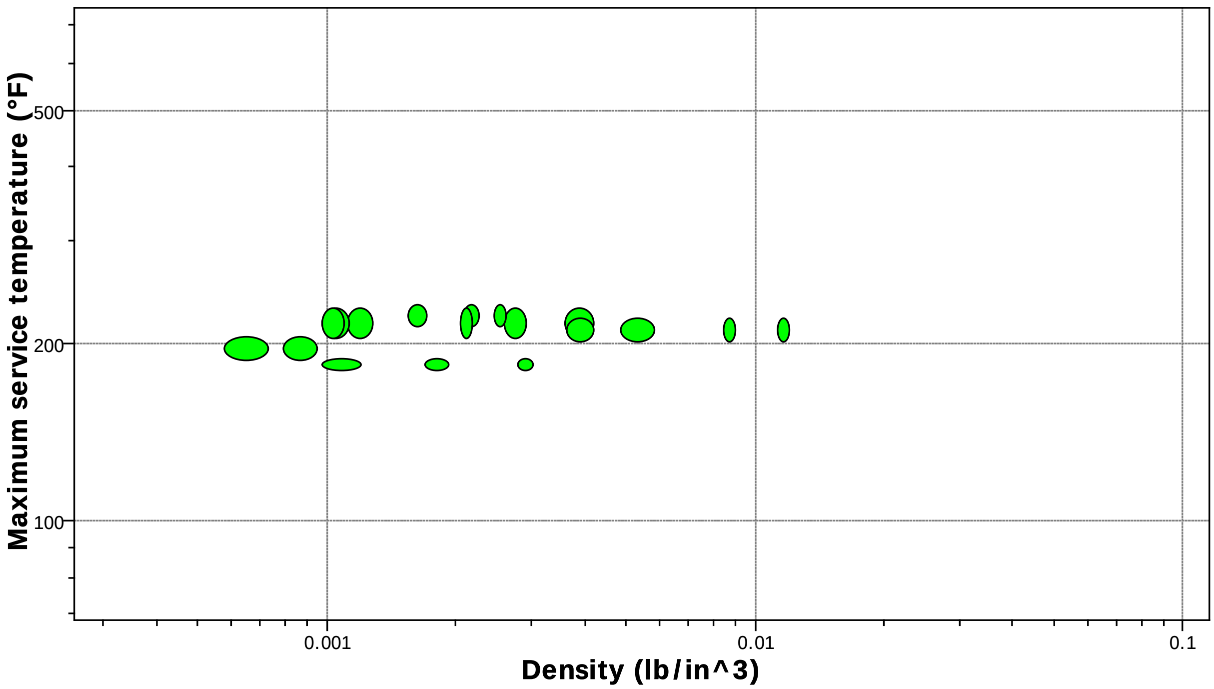




Density (lb/in^3)
0.1
0.01
0.001
1
10
100
1000
Price (USD/lb)



Thermal conductivity (BTU.ft/hr.ft^2.°F)
1
0.1
0.01
0.001
0.01
0.1
Density (lb/in^3)



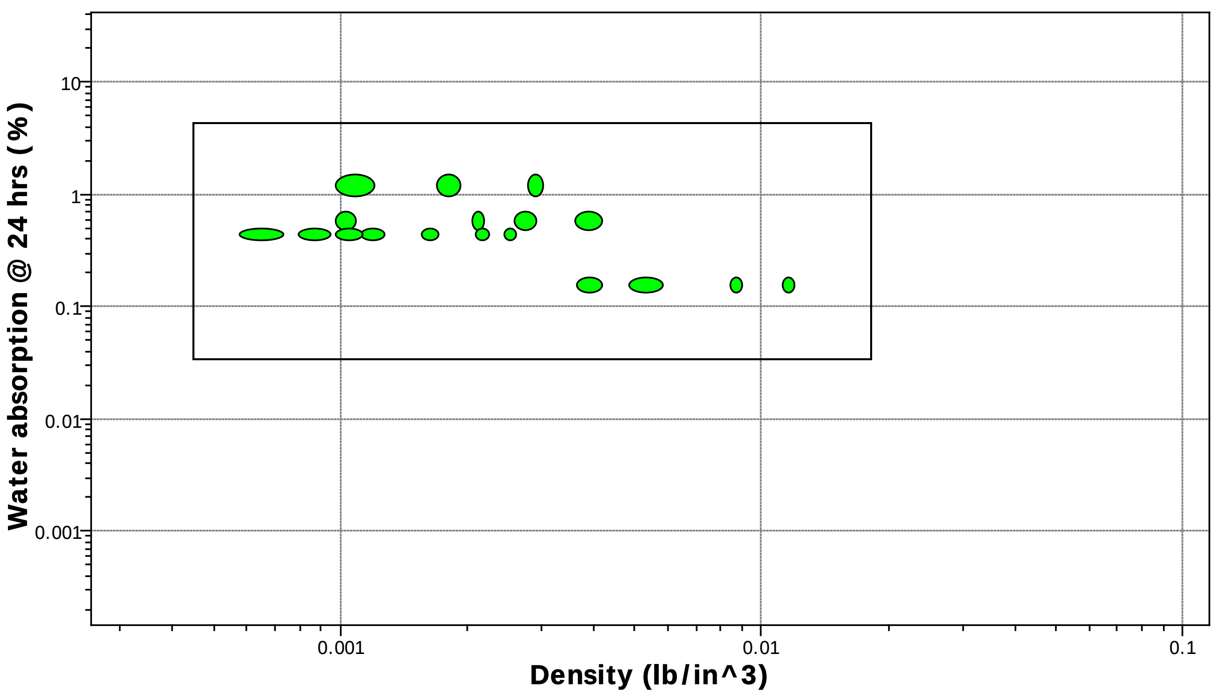


Figure 15:

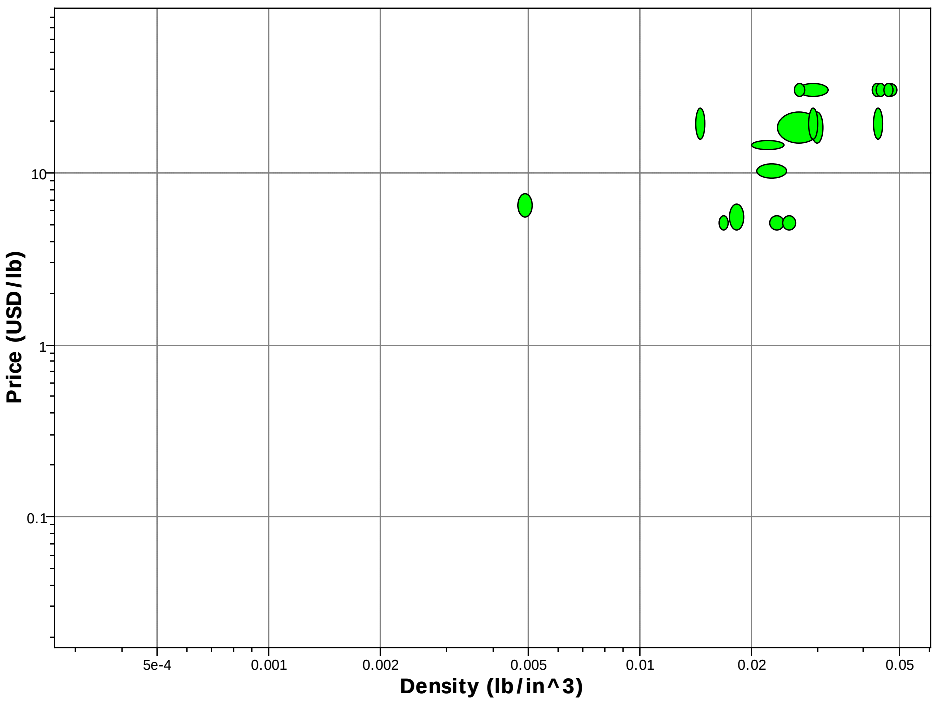
These graphs are the same as the polystyrene graphs only for polyethylene.

Oxide based foams

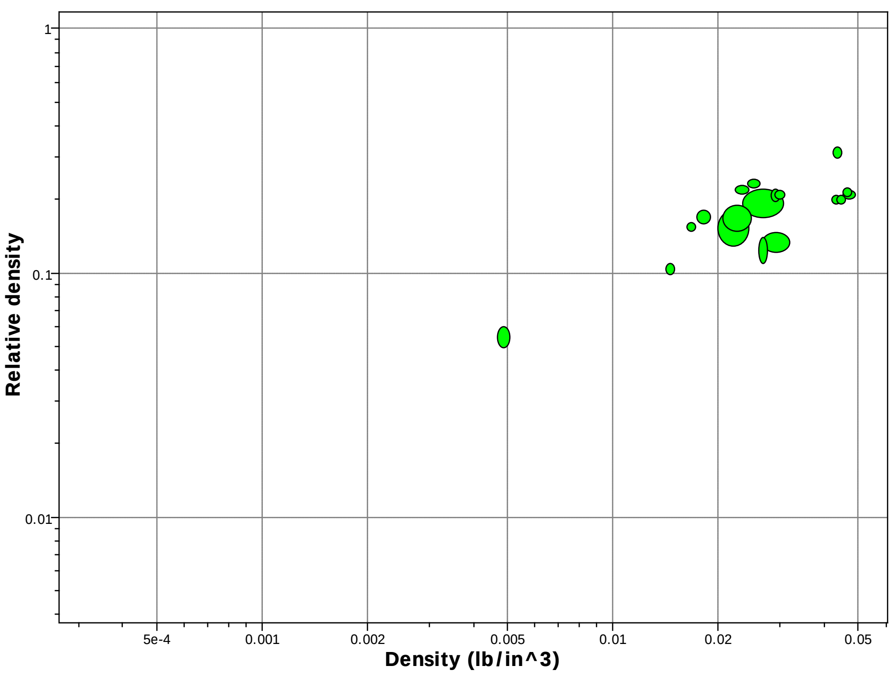
Note: naming foams on the graphs was not practical

Name	Thermal conductivity in BTU*ft/hr ft^2 °F
Alumina foam (92%)(0.61)	.289 - .385
Alumina foam (99%)(0.825)	.328 - .414
Alumina foam (99.5%)(0.745)	.289 -.385
Alumina foam (99.8%)(0.4)	.2950 - .416
Alumina foam (99.8%)(0.8)	1.04 – 1.27
Alumina foam (99.8%)(1.2)	1.79 - 2.25
Cordierite foam (0.5)	.144 - .241
Glass Foam (0.013)	0.0248-0.0266
Mullite foam (0.65)	.0965 - .192
Mullite foam (0.70)	.0965 - .192
Mullite foam (NCL)(0.46)	.0867 - .183
Yttria zirconia alumina foam (1.20)	.144 - .159
Zirconia foam (partly stabilized)(1.23)	.149 - .169
Zirconia foam (partly stabilized)(1.27)	.154 - .173
Zirconia foam (partly stabilized)(1.28)	.149 - .169
Zirconia mullite alumina foam (0.63)	.192 - .289
Zirconia with calcia foam (fully stabilized)(0.74)	.14 - .164
Zirconia with magnesia foam (partly stabilized)(0.81)	.14 - .145

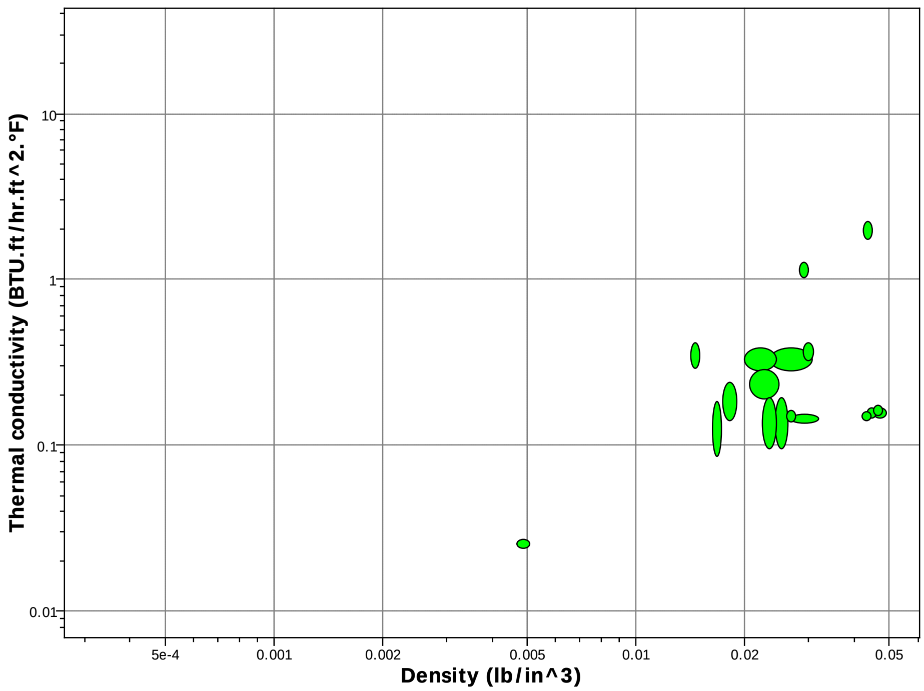
Table 5: *This table shows the Thermal Conductivity of each of the Oxide-based foams observed.*

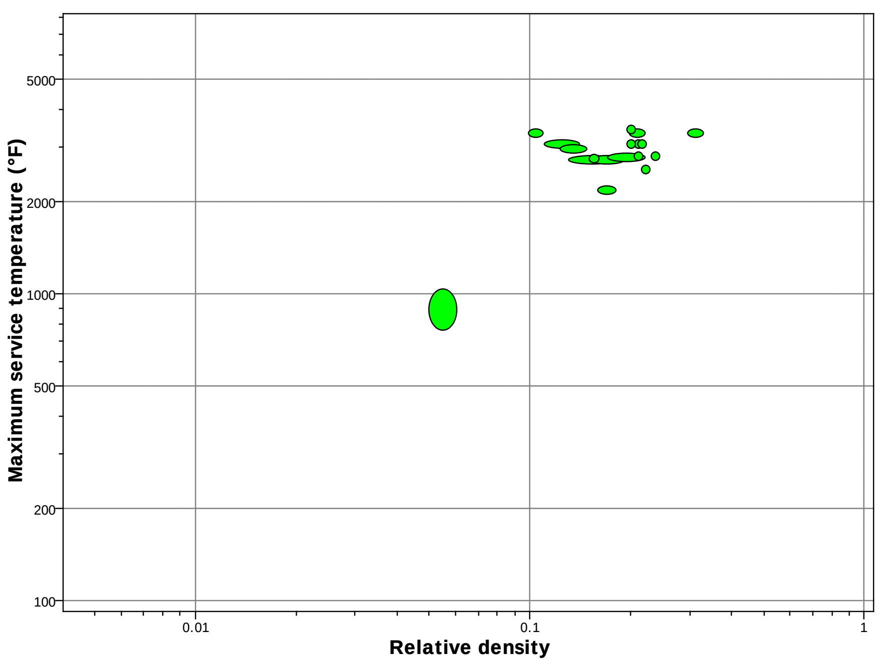


Price (USD/lb)
10
1
0.1
5e-4
0.001
0.002
0.005
0.01
0.02
0.05
Density (lb/in^3)



Relative density
1
0.1
0.01
5e-4
0.001
0.002
0.005
0.01
0.02
0.05
Density (lb/in^3)


Thermal conductivity (BTU.ft/hr.ft^2.°F)
10
1
0.1
0.01
5e-4
0.001
0.002
0.005
0.01
0.02
0.05
Density (lb/in^3)


Maximum service temperature (°F)
5000
2000
1000
500
200
100
0.01
0.1
1
Relative density

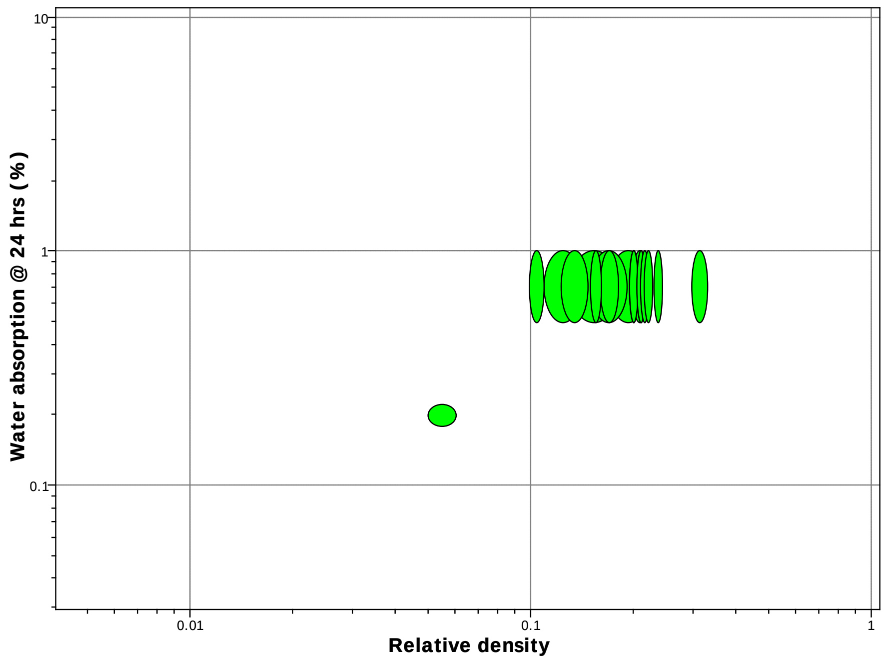


Figure 16:

This Figure shows the same graphs as the other two types of foams shown in this document for Oxide based Foams.

2.4 Ventilation

2.4.1 Introduction to Ventilation

The constant evolution of the ambulance contributes to the creation of ever efficient systems to be implemented, providing the best possible environment to treat and transport patients. The interior ventilation system is no different. The first systems that were introduced to maintain the climate in the patient compartment was provided by the vehicles standard ventilation system. At first, the ambulances did not have any interior climate control mechanism nor did they have any care for it. The ambulances were only meant to transfer an individual to a hospital where they could be better maintained. The ambulances transforming from a vehicle with some form of additional carry space transformed into a hearse-type vehicle, which was also used for funeral homes. The ventilation system was as sophisticated as the vents that the hearse had to offer. However, as the ambulances became standardized, the ventilation system began to separate itself from that of the vehicles. This was the start of a specialized patient compartment ventilation system. The objective was at first simple; provide fresh air for both patient and the care provider. The outstanding objective still stands today, but with greater importance to maintenance of air quality, temperature, humidity, and circulation. [27, 29, 40]

2.4.2 Interview Notes

One of the many methods of properly researching and investigating any subject is to make contact with those whose livelihoods are invested in the subject. The project includes interviews of the men and women who work with ambulances or make their money trying to provide the most efficient ambulance that they can provide. These interviews were conducted on October 16, 2012. The responses were informative and helpful to our project.

The inquisition includes the standards and regulations that guided their work and efforts the interviews stated that the KKK-A-1882F is the standard that dominates with the NFPA 1917 as a supporting role. The NFPA is based off of the Triple-K, thus creating the priority for the Triple-K. The Triple-K is also supported by the AMD testing regulations. When providing the limits and testing scenarios, the AMD provides the work behind testing and presents the resultant numbers used to create benchmarks that are considered to be reasonable. This is why when building, buying, or certifying an ambulance the Triple-K is used as the utmost authority.

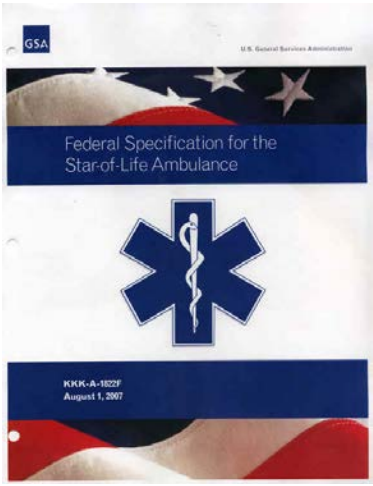


Figure 17:

This Figure shows the different labels that you would find on the documents regarding ambulance standards and regulations.

The interviewees were asked about the ventilation system in particular and all speaking from distinctive perspectives: buyers, sellers, and co-workers of the ambulances. They replied that the risk of exhaust fumes being present in the ambulance is a real risk creating undesirable effects and more difficulties for those working inside the ambulance. Even so, the modern ambulances have a reduced issue with fumes being present within the ambulance compartment due to many advances in door and window seals, rerouting of exhaust fumes, and attachment hoses that are locked unto the exhaust when inside an enclosed area. The ambulances are also being equipped with CO sensors that inform the paramedics and EMTs working inside the ambulance of elevated levels of toxins present. One of the most influential causes of exhaust fumes presenting itself in the ambulance compartment is faulty door and window seals. The door seals usually fail before window seals, mostly due to the loads and cyclic work that they endure with the constant opening and closing of the doors. The weather and climatic elements also add further wear on seals causing a decrease in effectiveness of the seals. The other factors, as indicated by the interviewees, is the number of openings the ambulance. The ambulances have large doors in the back, side doors, and windows. These are direct openings between the ambulance compartment and the external environment. Ambulances, also, have outside compartment for storage purposes that are separated from the ambulance compartment, using either a solid wall or a window that can be opened from the ambulance compartment. Even with these difficulties, ambulances are generally well ventilated and have few cases of fumes creating issues.

An issue that persists and creates a challenge for designers and engineers to solve is the maintenance of the temperature within the ambulance compartment. In the winter, the ambulance needs to have the air heated, but not dried. In the spring, the ambulance requires a comfortable air without being too humid in any form. In the summer, the air needs to be cool without getting too humid and muggy. The fall requires some heat, but not as much as the winter. This wide array creates problems as manufacturers, EMTs, and paramedics all know very well. If not solved, the ambulance compartment is uncomfortable and adds more stress onto the patients, EMTs, and paramedics. Although trained to maintain concentration at all times through any issue, the reduction of additional stress to the medical providers inside the ambulance is ideal. The issue with the maintenance of the temperature is the constant opening and closing of the ambulance doors. When the paramedics and EMTs have to load and unload patients, the back doors open causing the air to be in contact with the environment losing its comfort. The manufacturers understand this and have been addressing this issue with better ventilation systems. The interviewees stated that they have seen a multitude of different ambulances that each have tried to make the best system possible, abiding by restrictions such as size, real estate, weight, and cost. These factors are the ones responsible for limiting the manufacturers to provide the best ventilation system. They have even used different methods of delivering the air, such as multiple location fans, ceiling ducts, and other air circulation systems.

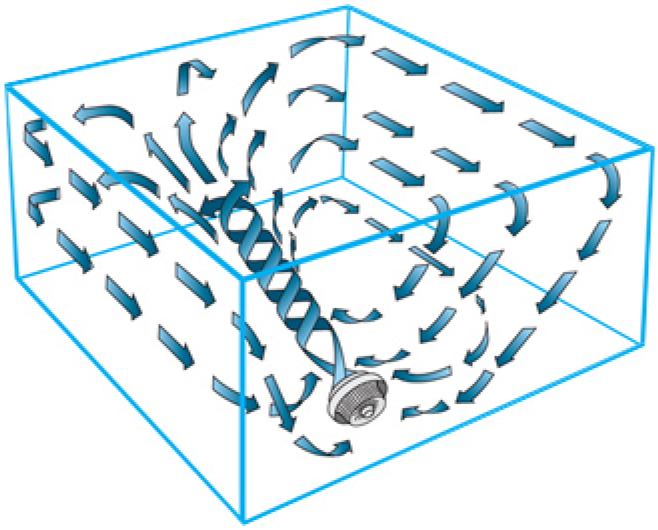


Figure 18:

This Figure shows the air flow pattern of an air circulation system in a simulated enclosed area.

Each of these solutions has their advantages, but they also have limits as well. The ducting has the issue of maintaining air pressure throughout the duct and the amount of space it occupies. Those who have to maintain the ambulances, indicate that the location of the filters to clean is hard to reach, making it difficult to clean and/or replace. This added difficulty creates a filter that is not changed as often adding contaminates in the air. Other air recirculation methods require taking up valuable wall space to function properly. An additional heating/cooling unit on the outside of the ambulance may provide excellent results, but its cost, size, and weight makes it undesirable. In the end, it is accepted that the ideal system would have the source of the air flow being near the ceiling closest to the driver, pushing the air towards the back of the ambulance. This flow creates circulation preventing the sensation of stalled air. Even with all these advances, the liability created by the opening of the back doors is truly the most difficult to solve.

Figure 19:

This Figure shows the open back end of an ambulance. Fumes from the exhaust system can enter the compartment and cause a hazard.

The ventilation systems are also now becoming adjustable with temperature settings and multiple fan settings. The fan settings are for air conditioning, heating, and exhaust vents. The fans, as stated by both the interviewees and the standards, have at least three speed settings: Low, Medium, and High. The manufactures all have these settings and some even have more to provide a versatile system. The interviewees informed us that the primary function of the exhaust vents are to vent away any unwanted odor or uncomfortable air. The exhaust vents were not directly created for the ventilation of fumes, but mainly odors that the patients may have for various reasons. These exhaust vents are located in the ceiling. These exhaust vents do not take up much space since they are a simple design.

The ventilation systems are becoming more advanced to provide efficiency and comfort. As indicated by the interviewees, the fan blades of changed to reduce any additional vibrations and unwanted sounds. The air conditioning is advancing to become more efficient than required by the standards. The standards require the air to be cooled from 95°F to 72° in less than 30 minutes, but the advance air conditioning provides the same effect in less than 15 minutes. The air conditioning has to provide the sensation of air circulation for those inside. As indicated before, the sensation of stalled air creates discomfort. To address this discomfort, the occupants such as paramedics or EMTs would open windows. These open windows negatively affect the climate control, making it appear inefficient. The main outcome of ventilation is to provide an internal environment that is comfortable to the patient. The paramedics and EMTs benefit from a comfortable environment, but their training and professionalism minimizes the side effects of unpleasant environment.

The internal environment of the ambulance compartment is the main work place for the first responders that are trying to provide the best medical attention to victims. The interviewees all indicated that the comfort that they provide is for the patient. To provide a comfort zone is the least that they could do to help increase the survival chances for patients. Advances are being made as indicated by the manufacturers. Ventilation is vital in this sense.

2.4.3 Patient Medical Care

The ventilation system is to provide the most comfort for the patients in the ambulance. In a few words, the ventilation is made specifically for patients' medical care. With that being said, a study of paramedics shows the amount of interest that the ventilation system has on the internal compartment of the ambulance. The study had the participants who were EMS to rank the importance of the ventilation system in the ambulance patient compartment.

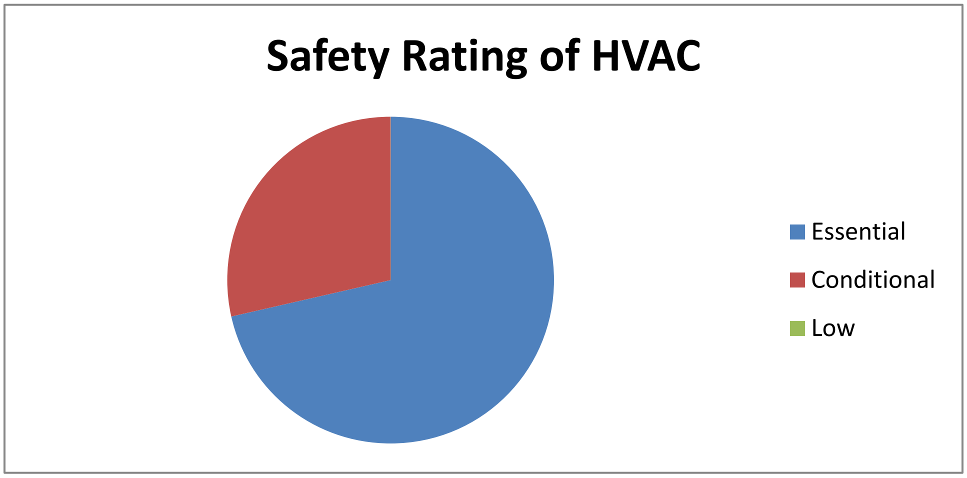


Figure 20:

The results when asked of the safety rating of HVAC system that maintains a comfortable and appropriate environment.

The results graphed in Figure 20 indicate the safety implications that the HVAC system has on the patient. The majority answering that the HVAC is essential to provide the safety for the patient goes further to the proof that the HVAC is ideally made for the patient and is recognized by the EMS that were participating in this survey. In Figure 21, the results are indicative to not only the safety rating, but the functionality rating of the HVAC system has on the patient compartment. [16]

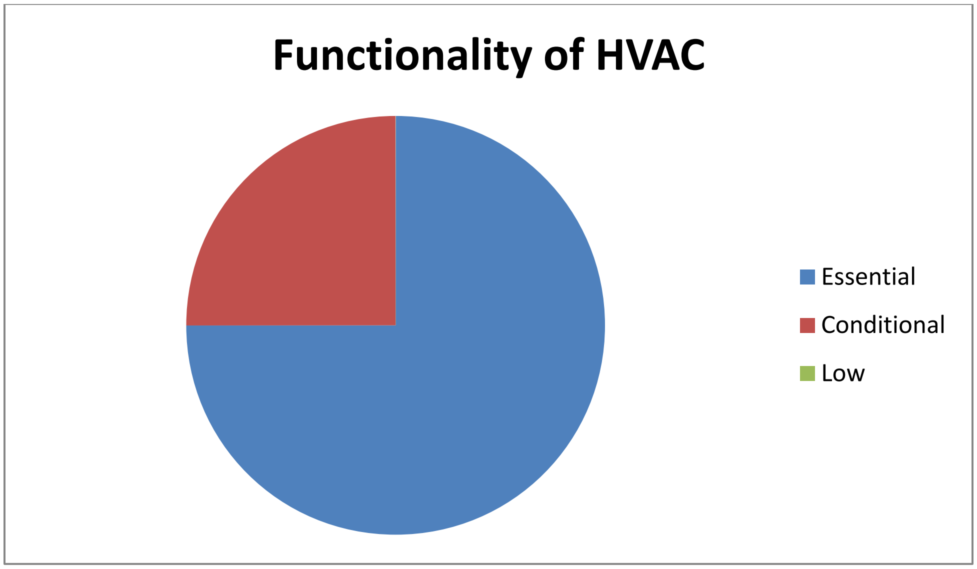


Figure25:

The functionality rating of HVAC system providing a comfortable and appropriate work environment.

The other perspective that one could gather from these charts is that no one answering the survey found the HVAC is of low safety and functionality factor. The HVAC must provide a comfortable environment because it increases the chances of stabilizing the patient in such a manner that the EMS can focus better on the dominant issue. [16]

The maintenance of air quality is very important in all aspects of life. The quality of air includes temperature, humidity, and particulates that are present in the air. In a living area, it is know that a poor air quality contributes to negative side effects including asthma, lung cancer, cardiovascular problems, etc. These issues are more so for those who have prolonged exposure to such environments. These issues may not affect the patients who are in the ambulances usually for a few minutes, but it can be appreciated that these issues can cause side effects to the EMS working inside the ambulances. A poor air quality may trigger symptoms in a patient that have a preexisting condition making the task of providing medical assistance that much more difficult.

Although a possibility, this risk is dramatically reduced by the efficient systems that are in ambulances today. [15, 16, 17]

The air quality is not only compromised by static air and the surrounding air outside the ambulance compartment, but the exhaust fumes that leak into the patient compartment. A study published in 1984 and conducted in New Jersey indicated that 27% of ambulance tested had 10ppm (parts per million) or more carbon monoxide (CO) greater inside the ambulance compartment than that of the air outside the ambulance. The greater threat was that 29 of the ambulances tested had levels of at least 35ppm greater than the surrounding air. These numbers were higher than the regulation and are health threats to both the patient and the EMS. The Figure below represents the result of the study. [20, 40]

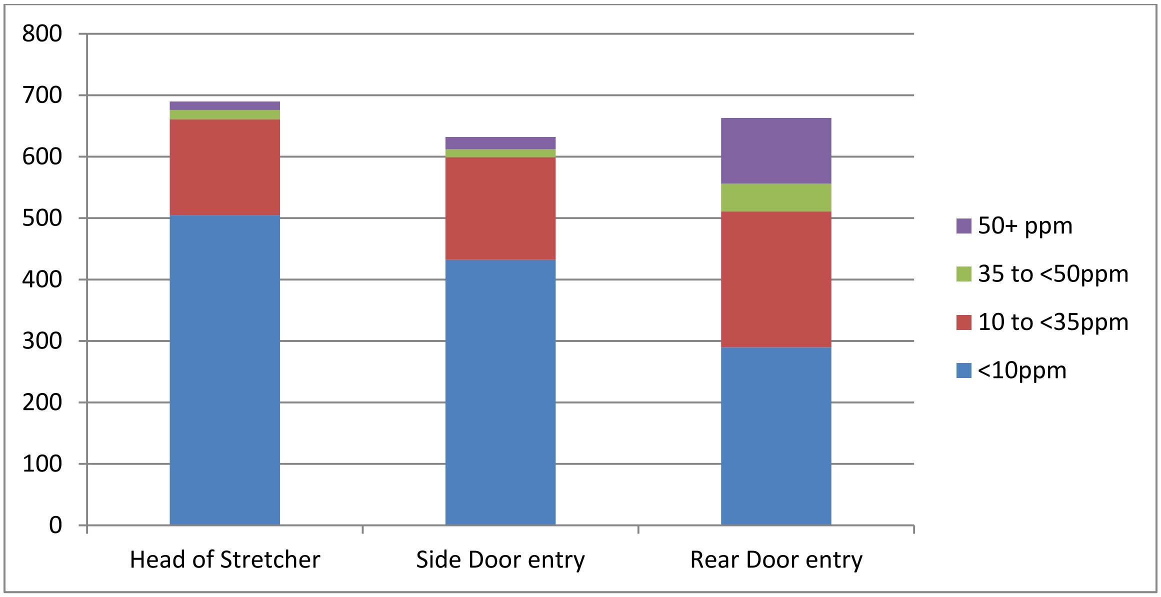


Figure 22:

The results of the CO levels tested in the study.

The fear of having contaminants in the ambulance is real and present. These number, although old, prove that the levels of CO present can and will affect everyone exposed. For that reason, the improvements of the ventilation system to recycle the air and the door and window seals provide the best defenses for the ambulance compartment from external contaminants. [20]

CHAPTER 3: A CLOSER LOOK INTO VENTILATION

3. Introduction

The ambulance is a mobile medical provider that must navigate through neighborhoods, towns, cities, terrains, and weather conditions. The ambulance must navigate through different environments each with their own set of demands and parameters. A visible and critical issue is atmospheric conditions including the weather. In Massachusetts alone, the temperature varies from low teens to high 80s. This wide range of thermal conditions creates demands that the ambulance patient compartment must adapt in order to provide the comfortable conditions. The ambulance must also maintain a level of internal purity for the safety and comfort of those inside. This includes the proper circulation of purified air, free of most contaminates. Such conditions are addressed by the ambulance's ventilation system on the inside and even the control of contaminates of the vehicles exhaust. This chapter is a closer look and analysis of the ventilation system of ambulances. The ventilation system has evolved to adapt itself to environmental, work load, and changing standard demands. The government and buyers of ambulances require that the HVAC within ambulances are up to par to provide the best environment possible. The analysis also includes the challenges and limitations to the ventilation system, the relevance of insulation to the HVAC system, and the HVAC applications in other industries. The understanding of all these fields will provide an overview of the importance of the efficiency of ventilation systems in the patient medical care environments.

3.1 Domestic Ambulances

The domestic ambulances are evolving in sync with the changing regulations and standards created for ambulances. Due to these changes, the manufacturers of the ambulance chassis are adjusting as such, usually resulting in either a delay in new releases and/or an increase in price based upon the adjustments needed. The document, Pinnacle Session Updates Agencies on Ambulance Chassis Delays and Changes, summarizes the changes in 2009 to the standards of the chassis affected the new ambulances that were to be produced after December 2009. These changes came as a result of the government deciding to make more stringent standards in terms of engine emissions. Even though the changes to the standards were already made, the manufacturers were not producing at full functionality due to the unstable and weak economy of the time. [18]

This uncertain atmosphere of the economy did not allow for the manufacturers to adjust accordingly. For instance, Ford was only running at two-thirds production speed, General Motors (GM) was only at half speed, and Dodge was still recovering from extended shutdowns. Either way, the government issued changes to the emission for the diesel trucks in order to improve on the air quality. This change includes the implementation of the selective catalytic reduction (SCR) system. This system would allow the diesel engine truck burn on nitrogen oxide in efforts to improve air quality. [18]

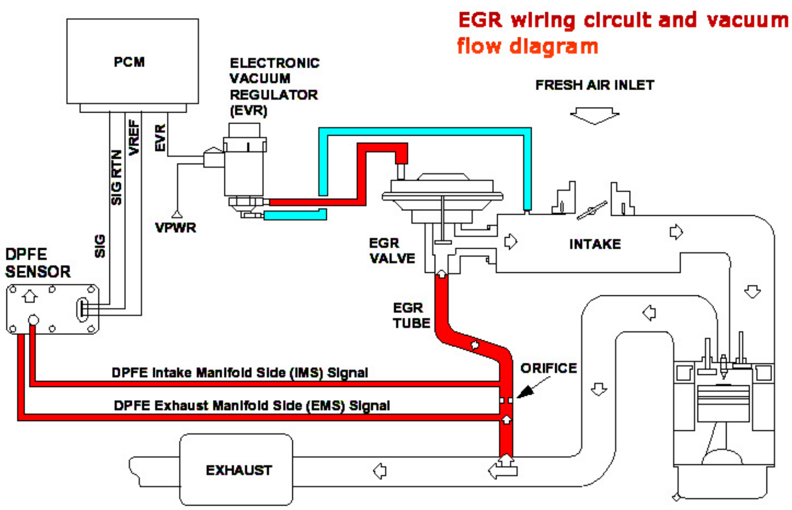


Figure 23:

This Figure shows the EGR wiring circuit and vacuum flow diagram of a diesel engine.

For a further change in the fumes and exhaust of the diesel engines, the government also implemented a higher level of emission benchmarks that include the diesel exhaust fluid system. These changes mentioned thus far are a universal across the board changes that are for all the manufacturers to comply in any manner that they find possible. For instance, some of the diesel engines would have the new diesel oxidation catalyst (DOC) that redirects the diesel exhaust fluid (DEF). This new implementation would affect the newer ambulances after the Dec. 31, 2009. As mentioned before, this would be a universal implementation that would affect all the brands equally with the exception of the International Truck which has its own exhaust system that differs with the DOC. [18]

The International Truck uses a newer exhaust gas recirculation (EGR) system. This system is mostly new to diesel engines since most gasoline operated vehicles of the last decade already have and EGR system that improves the exhaust system that is being improved upon. [18]

The Dec. 31, 2009 deadline also had as a regulation that all the diesel engines will need to burn off the nitrogen oxide. This again is part of a better air quality goal. The new diesel ambulances would have to use a six- to eight-gallon DEF tank. The purpose of these tanks would have to inject the DEF into the exhaust system in order to burn off the nitrogen oxide. [18]

Figure 24:

This image displays a typical Ford ambulance model, likely diesel.

Even with all these regulations and changes in efforts to improve the air quality of the ambulances, Ford did not produce a diesel engine ambulance of the Econoline van and cutaway chassis that satisfactorily complied with the regulations. This was an issue mostly due to the popularity of the ambulance. In response to this inability to have the Econoline compliant, Ford did provide a V-10 gasoline engine for those chassis and this avoided the conflict of the diesel engines. This solution was the best idea at the time, but it undid the previous ideology of the 70s and 80s. Ford had determined in those times that the V-8 engines were no longer suitable for ambulance operations. They in turn decide that the ambulances would have diesel engines instead of gasoline engines. The addition of the DEF additive created the new issue of become attentive of the DEF additive tank level. Taken from the document previously cited, the description of the DEF system functionality. [18]

“1. The driver will an initial warning indicator on their instrument panel when the DEF tank gets down to 1.5 gallons;

2. The driver will get a second warning (visual and audible) and a digital indication of the number of remaining "engine starts" they have (counting down from 20) when their tank hits 0.8 gallons;

3. If the operator ignores both warnings and continues to drive the unit until it runs out of the DEF (urea) additive, they'll experience a "final engine start" and not be able to start their ambulance the next time they attempt to do so. Because this can result in a delayed or failed response, this could result in a serious patient care delay/failure and present a liability to an ambulance agency.” [18]

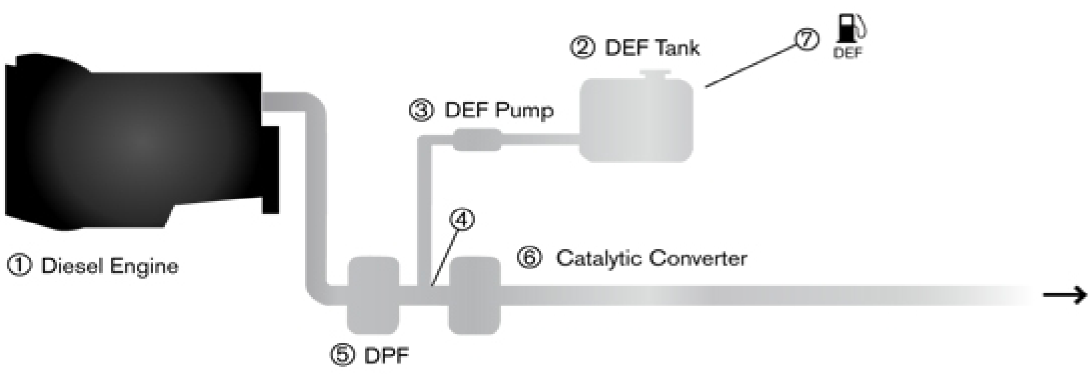


Figure 25:

This image displays another sort of schematic view of the diesel engine with a focus on the DEF system.

The changes in requirements and standards resulted in the increase of pricing of the vehicle chassis. The increases ranged from $3,500 to $10,000 increase of the vehicle, which would unfortunately be passed onto the purchaser. These costs cover the adjustments in the engine for the requirements of the new emission regulations, the DEF tanks and heaters of the tanks for cold environments. [18]

Although costly and almost an unwarranted additional challenge, these improvements are in an effort for the reduction of environmental side effects and air quality around the ambulance. The air surrounding the ambulance can filtrate into the ambulance compartment making it saturated with pollutants that are unneeded and harmful. This portion is an emphasis to the needed improvements for the exhaust system to reduce the exposure of contaminants to the patient in treatment. This is a universal overview, but below is the comparison as how each manufacturer planned to become compliant to the new emission regulations of 2010.

Response to the changes

Ford

- Concluded that the Ford Econoline with the diesel engine Type II ambulance after Dec. 31, 2009.

- The Econoline ambulance featuring the 6.8L, V-10 gasoline engine started in production in October 2009.

-Due to the new emission system the F Series chassis, with a new Ford 6.7 Liter diesel with SCR, will still be available, but with the increase of cost in response to the new emission system.

- For future Type I ambulances, the Ford F-350/F-450 diesel chassis and cab will have the SCR system.

- For future Type II, Ford E350 cutaway chassis with a V-10 gasoline engine with additional costs.

- For future Type III, Ford E350/E450 cutaway with V-10 engine.

- For future Medium Duty, Ford F650/F750 diesel engine with SCR ambulance package.

GM

-G3500 Cargo Van is no longer useable as an ambulance chassis effective with the

2010 models due to inadequate UVW weight rating.

-The G series 3500 and 4500 cutaways will be available with an SCR diesel for Type III

ambulances.

- For future Type I, GM C-3500 has an inadequate GVW capacity for ambulance applications.

- For future Type III, The GM G3500/G4500 Diesel Cutaway Chassis with a 6.6 Duramax diesel and SCR system will be available and is expected to be a popular model.

Dodge

- For future Type I, Dodge RAM 4500 Diesel cab/chassis will have the SCR system.

- For future Type II, Sprinter will offer the 2500 SRW diesel with SCR.

- For future Type III, Dodge will offer the D4500/5500 Cab Chassis (with SCR system), but no production is planned to start until mid-2010.

- For future Type III, Sprinter 3500 (with SCR system) will be available. The future of the Sprinter as a

Dodge product is unknown based on the new FIAT alliance and the fact that FIAT is a

competitor to Daimler.

Figure 26:

This Figure shows the Type III G4500 AEV series ambulance 3d model.

3.2 Challenges faced by Ambulance ventilation systems

Ventilation systems in buildings and ambulances face the same challenges, but on different scales.

The most obvious challenge is temperature management and the second is filtration. Temperature management is deceptively simple. The system has to know two things to function. First, what the current room temperature is, and second, what the desired temperature is. The latter is set by the occupant on the thermostat. When the environment temperature differs from the set value by more than a certain amount the thermostat energizes either the heating or cooling circuit. All heating and cooling circuits work in similar fashions. Air from the room is blown past a heat exchanger which either raises or lowers its temperature. How quickly the system can change the rooms temperature is a function of the surface area of the heat exchanger and how much air the system can move past the exchanger's coils in a given amount of time. The amount of air that can be moved by the systems circulation fan and the systems filters are two main limitations in this area. The size of the fan and heat exchanger are limited in ambulances by the amount of available space and power. Thus the efficiency of the system's air filter is very important.

The design of air filter varies widely, but their task is the same. Their task is to remove contaminants from the air stream while providing the least amount of resistance to the air streams movement. Another challenge is to design the filter in such a way that the build-up of trapped contaminants does not impede the air flow through them. Below is a common high-performance automotive air filter that is designed for long life and to provide the minimum resistance to the engines intake of air.

Picture [Charlie 1]

The filtration set up for ambulance ventilation systems is much more involved. They usually use multiple filters. Following the direction of the air flow, there is the primary filter that is designed to trap large particulate. This filter is there to extend the operation lifetime of the subsequent filters. The number and design of subsequent filters is determined by what is needed to be removed from the air stream.

Primary filter for large particles [Charlie 2]

Secondary filter [Charlie 3]

Final filter [Charlie 4]

Figure 27

Charlie's 1-4 were taken of filters inside Edmund's car and inside of the ambulance MIRAD Laboratories has granted us work with.

3.3 Relevance of insulation.

Insulation decreases the thermal flux of the patient compartment. This decreases the amount of work that the HVAC system. The following equation explains the effect of insulation. The situation described is extremely simplified.

$Y = L+T+V$

$T_H = ((x/I)-V_T-L_T)*E_H$
$T_C = ((X/I)+V_T+L_T)*E_C$
$L = W_L*E_L$
$V = W_V*E_V$
Note: The "V" in the equation is not the same as the "V" in LIVE.

Y= energy required to maintain patient compartment as a comfortable work environment.

L= requirement of the lighting system, L_T= heat give off by the lighting system. W_L= lighting output required E_L=Lighting efficiency
T_H= thermal energy added during heating, E_H= efficiency of heating system. X= thermal flux of patient compartment, I= effect of insulation. T_C= thermal energy removed during cooling. The situation determines whether $T_H$orTc is entered into the equation.
V= ventilation input required, W_V= power required by ventilation system, E_V= efficiency of ventilation equipment

3.4 Ventilation in Other Applications

Ventilation is a staple among many industries that have a need for proper air filtration, heating, and cooling. It is critical that an in depth look into some of these industries may provide a greater insight into how we could improve or modify the ventilation in a medical ambulance to promote a higher level of PMC.

There are countless applications where ventilation is considered to be an important consideration. The two we will look at that we look at are the Agriculture and Chemical Processing Industry because they contain important, yet different, aspects of ventilation design that could be made relevant in ambulance design and engineering.

3.4.1 Agriculture Industry

The Agricultural Industry has a need to provide a stable temperature range of operation for all of the plants and wildlife that the industry concerns itself with. The industry uses two main types of ventilation systems for its environments: natural and mechanical. The mechanical ventilation systems typically consist of electrically driven fans that are used to modify the air flow into the area directly. The result of this implementation is higher control over interior conditions. However, the problem with this method of ventilation is its heavy dependence on energy, which has sparked a new movement to natural ventilation.

The driving forces behind natural ventilation can be seen in the image on the page below.

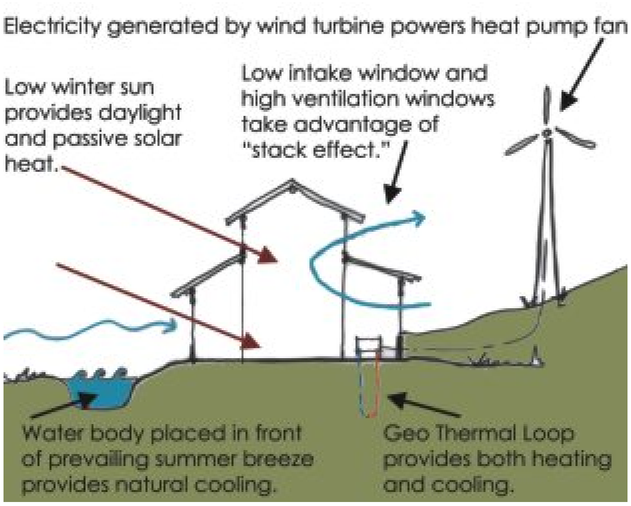


Figure 28:

This simple image provides a good visual as to how some natural ventilation systems interface with houses.

Natural ventilation is driven by two distinct mechanisms. The first driving mechanism is caused by thermal buoyancy, called the "stack effect", which is dependent on the heating caused by incoming convective and radiative fluxes or by other means.

To get a little bit more involved with the understanding of how and why the stack effect is utilized in ventilation design, a bit more data was found about the phenomena. The stack effect is the scientific term given to a quality of air that we are all familiar with already – hot air moves in all directions, depending on the pressure surrounding it, and cold air rushes in to take its place. This is not rocket science, but the implications of this feature have made a real splash in the agriculture industry. Buildings have been specifically constructed or modified to include economizers which keep track of the indoor and outdoor temperatures and open and close vents to keep a consistent air flow throughout the structure. The buildings utilizing natural ventilation may also be oriented in a way to utilize wind to flush warm air out.

An economizer is- at its most basic level – a mechanical device used to reduce energy consumption or preheat fluids. In HVAC designs, typically a network of Air-side economizers are used which can be used to regulate the indoor temperature of a facility by circulating in the cool air outside, and shutting off the flow when the temperature gets too low. Clearly this device would not work well when the outside temperature is high; however there are many other kinds of economizers which all perform, in such a way, to regulate indoor temperatures that can be used in conjunction with one another to control building air flow.

The second mechanism, wind driven ventilation, is caused by the wind exerting pressure changes over the building frame, and thus forcing airflow across ventilation openings. This mechanism can be understood fairly simply by looking at the second law of thermodynamics, where a fluid at a high density will always move toward a low density area if given the chance. Since, the indoor air pressure and density tends to vary within a structure, varying with the different shape and pitch of house roofing, and tending to be on average lower than the air outside, selectively passing outdoor air over the contour of the structure can provide a means of air circulation based solely on wind pressure. Those are the basics of natural ventilation- which is a feature that could potentially be used in ambulance design to increase efficiency and reduce costs for proper ventilation.

3.4.2 Chemical Processing (chemistry Lab)

In industrial chemical processing plants and chemistry labs, the vapors resulting from chemical reactions may produce (and commonly do produce) fumes toxic to humans when exposure is prolonged. For this reason, adequate ventilation is required in order to provide enough exhaust so as to not harm workers. Industrial chemical processing plants are rather large in size and scale, requiring very large and powerful fans to run the exhaust systems at an appropriate level. This is dependent on the building size and the standards and regulations, but a better idea of how these larger structures ventilation systems are designed and what factors influence the design by looking at smaller chemistry labs. The standard method of ventilation in chemistry labs is the hood vent, of which an image is shown below.

Figure 29

This is a typical set up of a hood vent in a chemistry lab. The interior air flow design can be seen in Figure 30 on the next page.

These hood vents are designed in a few distinct ways that we will briefly discuss. The internal layout of each hood vent, regardless of method of exhaust follows the image on the next page.

There are numerous methods of exhaust control in these hood vents, but the three we will focus on are the single hood/single fan, central, and collection and dilution systems. The first of these systems, the single hood/single fan is easily the most flexible in design for chemistry labs', considering each hood has an exhaust fan that feeds into the duct work. The advantage of single hood/single fan production is that it makes the integration of multiple hoods modular in design. This allows for easy installation, free control over each hood per operator, and easy maintenance. The disadvantages of this system reside primarily in initial cost, since each hood has a fan then each hood unit will cost more money, making modularized systems more expensive than, say, a central system controlled hood infrastructure.

The Central system utilizes only one fan in order to control fume exhaust in multi-hood infrastructures in chemistry labs. This approach to ventilation design is attractive due to its low cost. It does, however, pose a serious risk of failure, and when failure does occur there is a much higher risk (if unavoidable at that) of backflow of toxic chemicals. This puts every station in the network out of commission, whereas the single hood/single fan approach would only take one hood out of commission on a per-fan-failure basis.

The last system is the collection and dilution system which has gained some popularity in Europe. This system function similarly to the single hood/single fan approach, except instead of dispersing the exhaust directly into the air it collects each hoods exhaust in a centralized container called a 'plenum' and from there a high flow, low static fan disperses the contaminants prior to releasing them into the air. This system is comparatively newer than the other two discussed. [8]

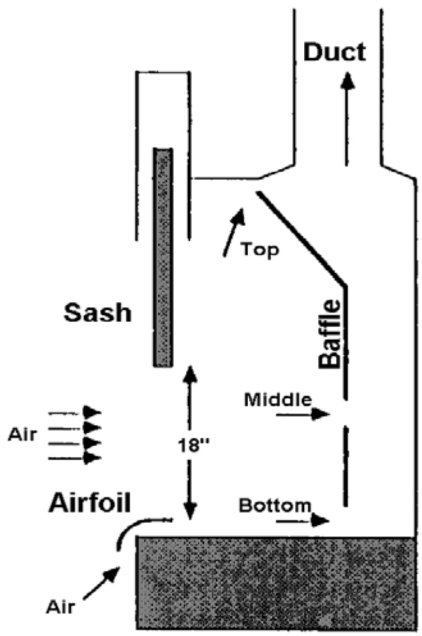


Figure 30:

This is the interior of a typical hood in a chemistry lab like one would expect out of Figure 29 on the previous page. The air comes in through the air foil, flows over the gaps in the top middle and bottom of the baffle creating pressurized streams of air the jettison out of the hood through the duct.

As mentioned before, so long as air flow is necessary in any way – be it for safety or for comfort – proper ventilation will always be a need that cannot go overlooked. Two industries are studied in the briefest of ways to get an idea as to how they do ventilation, as information was readily available for use. Other industries use different methods of ventilation depending largely on the requirements of that particular industry. For example, though the chemical processing industry uses hoods with fan exhaust control, a welding shop may use hoods with different fans that have different power ratings to dissipate the smoke. Each application will be different, but one thing remains pretty constant: good ventilation will always be needed in industrial settings, and the method of ambulance construction is no exception to this rule. With that said, let's talk a little about the future of the ventilation industry.

3.5 The future of Ventilation

Ventilation will always have a critical role to play in industrial settings and in applications where high quality air flow contributes to productivity or comfort. For this reason, engineers who work with ventilation systems will always be needed. The future of ventilation is sure to be an interesting one, but one thing that will remain a constant concern in the industry is energy consumption. One company is doing a lot of work in household ventilation in the UK, where they have come up with a system used in chimney stacks to increase air quality in homes with a product that requires absolutely no power to operate and has minimum maintenance. This company is called Ventive™, founded by Tom Lipinski, and this product – also called Ventive™ – is where we think the future of some ventilation engineering may be going. Their Ventive™ S is shown below in the following picture.

Figure 31:

This is an image of someone installing a Ventive™ system over a pre-existing chimney vent.

The use of Ventive™ is restricted to buildings for now, but what it actually does is this: the install replaces the chimney pot inside a standard house chimney with a cowl and cassette that features a patented incredibly efficient heat exchanger. Ventive™ uses a combination of air buoyancy and wind to create a flow of air within the interior of the building, ensuring high standards of air quality are achieved and maintained.

The biggest challenge in ventilation design right now that will likely remain in the future of ventilation is going to be using natural ventilation in air conditioning designs. There is a lot of untapped potential in what's already around us, and the future of effective ventilation engineering will rest on the ability to look at what is already available for use and creating systems that utilize the natural abundance of air flow in areas already. These systems are already in use in the agricultural industry. The trouble with those systems, however, is their high cost. Over time, as most technologies get older, this method will become more and more affordable to the point where a major overhaul in ventilation systems in construction is possible.

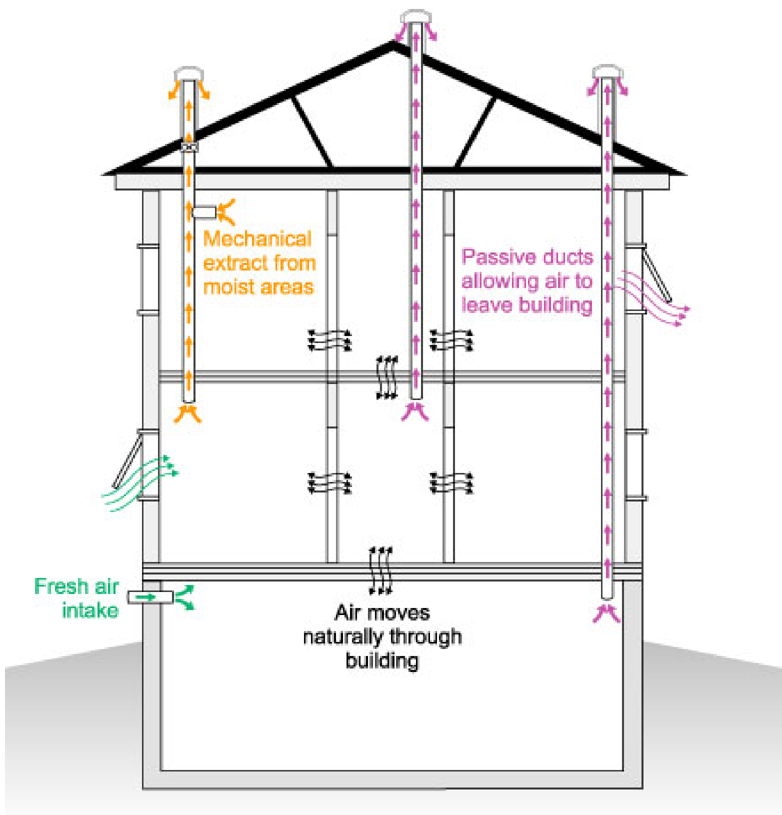


Figure 32:

This Figure shows the natural ventilation cycle in a typical building.

A good question to ask is how this relates to medical ambulance design, to which can be said with some certainty that it is difficult to predict the flow of technology transfer from one industry to the next. Without any sourcing, it is difficult to say how the future of medical ambulance ventilation will shape up. The design of ambulances will always reflect the needs of the public that relies on their operation. If the need for more efficient ventilation becomes apparent in social doctrine, then we will see it in the ambulance manufacturer designs. The idea of natural ventilation in ambulances is an interesting one at the very least, and more time and more effort *should* be given to discovering a method of which that increases energy efficiency overall in the vehicle while still maintaining a quality medical environment.

CHAPTER 4: CONCLUSION

The research has yielded excellent insight into the procedures that engineers and designers presently use to produce the systems central to our focus in this IQP. The central goals of the project have been accomplished, to some point, since a better understanding of how challenges are faced within each of these systems based on their limitations, and how much effort is required to reformulate the standards to produce a medical ambulance that operates with greater efficacy than the last is achieved. Over the course of the study, however, a few key features that have hindered the ability to work with the medical ambulances and get a better idea of the limitations so that can be included as part of prospective solutions to any of the challenges these systems face. For various reasons, including EMT certification training requirements, and limited access to operational medical ambulances, sufficient measureable data to make any sound recommendations for improvements to materials presently used inside medical ambulances in some cases were unattainable.

Many thanks to MIRAD Laboratories for partnering with the group and assisting by providing access to a medical ambulance, however, with all due respect to the care providers of this machine; it was not operational for the entire duration of the year and was, as a result, rather unfortunately useless as a resource. As a request, for the future of the ambulance design IQPs, machines should either be replaced by a newer, more relevant model, or get properly repaired for sufficient operation and measurement.

The fault of improper lighting measurement analysis falls on no one. The industry has, over the course of the past couple of years, begun to rapidly swap the old lighting interfaces of ambulance models with newer LED lighting, both inside and out. Braun Ambulances, as stated in this report, still use fluorescent bank lights, and most ambulances will still do that for a while longer; nonetheless, there exists much greater transition to interior dome LED lights, as well as exterior LED lights for a crisper, more visible light over the same time period. EMTs and field operatives otherwise have found these replacements suitable, and while further research analysis on lighting in the beginning of this project was wanted, a lack of effectively finding a technology worth replacing the newer LED lighting with was experienced. For this reason, among time limitations, technology has been the limiting factor on the lighting analysis, and the result is a lack of lighting section in our documented research in Chapter 3. This report still includes lighting in regards to the history of ambulance design due to the power consumption of the electrical systems and its effect to the overall ambulance efficiency; however, there is little recommendation beyond replacing the fluorescent bank lights with LED lights that can be done. Considering the extra cost of LED lighting compared to fluorescent bank lights with nearly equivalent color temperature possibilities, the idea of moving towards LED lighting for the complete ambulance design is still a concept that is out of reach for most manufacturers. LED lighting technology is becoming less expensive over time, which bodes well for the prospect of reduced power consumption in ambulances, but the time it will take for full scale LED lighting implementation for all ambulances is difficult to predict accurately.

The systems that were analyzed in depth were the insulation and ventilation systems. The primary system that was further studied was the ventilation system. Even so, the property of thermal insulation made it impossible to separate the importance of one from the other considering the thermal reduction granted by the insulation material. Much of this information is covered within the confines of Chapters 2 and 3.

The future of ventilation design in ambulances will strongly depend on whether or not a system producing an effective use of natural ventilation can be implemented into the ambulance compartment and cockpit. The challenges facing this feat are numerous, but if one were to completely replace the power-hungry ventilation system presently in the ambulance with a system of natural ventilation, the electrical systems would be much less demanding on the batteries; the overall efficiency of ambulance compartments would increase by a noticeable amount.

The beauty of this IQP is that it sets the ground for many other IQPs or MQPs to follow it and continue on any of the three sub areas of interest. The unfortunate truth behind the redesign and recommendation of new materials for ambulance use is that it is not actually a topic that is good for an IQP. The purpose of the IQP is to promote a system that can help somebody, or some group of people in some way that shows that, as future engineers, understanding that the driving force behind the project is the people that depend on the results, and the understanding and evaluation of these ambulance systems do not immediately present themselves as something that is designed for the assistance of other people. It can be argued that this is true is because no one will immediately benefit from any of this information except for maybe the manufacturers of insulation and ventilation with the data received from WPI's materials database. The future of this IQP will probably continue so long as the technology keeps changing and new methods continue to emerge from the scientific community. Nonetheless, during times where the technology is not changing drastically and new tech is difficult to come by, it is suggested that these areas and systems are explored as an MQP, such that individual groups of specialized-background students can evaluate performance of materials and methods, along with a more centralized focus with an emphasis on doing something creative with the materials to demonstrate a mastery of the understanding of the particular area. This project lays the foundation of the understanding of good engineering by following the procedure of understanding, evaluation, and study of the existing technology, not the developments on the understanding of the principles of the engineering itself.

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APPENDIX A Material Data Sheets

1.

PS foam (closed cell, 0.020)

Identification

Designation

Expanded polystyrene (EPS) closed cell foam, 0.020 specific gravity (based on Styropor 20)

Tradenames

Styrofoam, Styrodur C (XPS), Styropor, Peripor, Neopor, Extir, Styrocell, Dytherm, Gedexcel, Koplen, Pentfoam, Jackocell

General Properties

Density		6.5e-4	-	7.95e-4	lb/in^3
Price	*	1.13	-	1.32	USD/lb

Composition overview

Composition (summary)

(CH2-CH(C6H5))n

Base	Polymer
Polymer class	Thermoplastic : amorphous
Polymer type	PS
Polymer type full name	Polystyrene
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer		100			%

Foam & honeycomb properties

Anisotropy ratio	*	1	-	1.5	
Cells/volume		1.64e5	-	8.19e5	/in^3
Relative density		0.017	-	0.021	

Mechanical properties

Young's modulus		4.93e-4	-	0.00102	10^6 psi
Compressive modulus	*	0.00189	-	0.00277	10^6 psi
Flexural modulus		4.93e-4	-	0.00102	10^6 psi
Shear modulus	*	2.9e-4	-	4.35e-4	10^6 psi
Bulk modulus	*	5.8e-4	-	0.00102	10^6 psi
Poisson's ratio	*	0.25	-	0.3	
Shape factor		2.2			
Yield strength (elastic limit)		0.016	-	0.0232	ksi
Tensile strength		0.0247	-	0.0508	ksi
Compressive strength	*	0.0145	-	0.0232	ksi
Compressive stress @ 25% strain		0.0218	-	0.0247	ksi
Compressive stress @ 50% strain		0.0305	-	0.0334	ksi
Flexural strength (modulus of rupture)		0.0218	-	0.0566	ksi
Shear strength		0.00798	-	0.0116	ksi
Elongation		3	-	5	% strain
Hardness - Vickers	*	0.01	-	0.016	HV
Fatigue strength at 10^7 cycles	*	0.029	-	0.0363	ksi
Fracture toughness	*	0.00182	-	0.00273	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	0.1	-	0.3	
Densification strain	*	0.94	-	0.96	

Thermal properties

Glass temperature		180	-	198	°F
Heat deflection temperature 0.45MPa		171	-	180	°F
Heat deflection temperature 1.8MPa		171	-	180	°F
Maximum service temperature		180	-	189	°F
Minimum service temperature	*	-112	-	-76	°F

Thermal conductivity	0.0191	-	0.0208	BTU.ft/hr.ft^2.°F
Specific heat capacity	0.287	-	0.291	BTU/lb.°F
Thermal expansion coefficient	27.8	-	38.9	µstrain/°F

Electrical properties

Electrical resistivity	* 1e20	-	1e21	µohm.cm
Dielectric constant (relative permittivity)	1.02	-	1.04	
Dissipation factor (dielectric loss tangent)	3e-5	-	5e-5	
Dielectric strength (dielectric breakdown)	45.7	-	50.8	V/mil

Optical properties

Transparency	Opaque

Absorption, permeability

Water absorption @ 24 hrs	1	-	3	%

Durability: flammability

Flammability	Highly flammable

Durability: fluids and sunlight

Water (fresh)	Excellent
Water (salt)	Excellent
Weak acids	Excellent
Strong acids	Limited use
Weak alkalis	Excellent
Strong alkalis	Acceptable
Organic solvents	Unacceptable
UV radiation (sunlight)	Fair
Oxidation at 500C	Unacceptable

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 4.56e4	-	5.03e4	BTU/lb
CO2 footprint, primary production	* 4.04	-	4.46	lb/lb
Water usage	* 1.2e4	-	1.33e4	in^3/lb

Material processing: energy

Polymer extrusion energy	* 3.32e3	-	3.66e3	BTU/lb
Polymer molding energy	* 8.57e3	-	9.44e3	BTU/lb
Coarse machining energy (per unit wt removed)	* 230	-	254	BTU/lb
Fine machining energy (per unit wt removed)	* 464	-	513	BTU/lb
Grinding energy (per unit wt removed)	* 723	-	800	BTU/lb

Material processing: CO2 footprint

Polymer extrusion CO2	* 0.618	-	0.681	lb/lb
Polymer molding CO2	* 1.59	-	1.76	lb/lb
Coarse machining CO2 (per unit wt removed)	* 0.0402	-	0.0444	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.0809	-	0.0894	lb/lb
Grinding CO2 (per unit wt removed)	* 0.126	-	0.139	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Embodied energy, recycling	1.19e4			BTU/lb
CO2 footprint, recycling	* 1.05	-	1.17	lb/lb
Recycle fraction in current supply	0.95	-	1.05	%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	* 1.72e4	-	1.8e4	BTU/lb
Combustion CO2	* 3.3	-	3.47	lb/lb
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Packaging: electronics, household goods, food, tools. Structural reinforcement: sandwich structures. Cushioning, Thermal Insulation, Acoustic Insulation, floatation and buoyancy, Energy Absorption.

Other notes

Closed cell, expanded, polystyrene molded foam blocks

Links

- ProcessUniverse
- Producers
- Reference
- Shape
- Values marked * are estimates.
- Granta Design provides no warranty for the accuracy of this data

2.

PS foam (closed cell, 0.020)

Identification

Designation

Expanded polystyrene (EPS) closed cell foam, 0.020 specific gravity (based on Styropor 20)

Tradenames

Styrofoam, Styrodur C (XPS), Styropor, Peripor, Neopor, Extir, Styrocell, Dytherm, Gedexcel, Koplen, Pentfoam, Jackocell

General Properties

Density		6.5e-4	-	7.95e-4	lb/in^3
Price	*	1.13	-	1.32	USD/lb

Composition overview

Composition (summary)

(CH2-CH(C6H5))n

Base	Polymer
Polymer class	Thermoplastic : amorphous
Polymer type	PS
Polymer type full name	Polystyrene
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer	100	%

Foam & honeycomb properties

Anisotropy ratio	*	1	-	1.5	
Cells/volume		1.64e5	-	8.19e5	/in^3
Relative density		0.017	-	0.021	

Mechanical properties

Young's modulus		4.93e-4	-	0.00102	10^6 psi
Compressive modulus	*	0.00189	-	0.00277	10^6 psi
Flexural modulus		4.93e-4	-	0.00102	10^6 psi
Shear modulus	*	2.9e-4	-	4.35e-4	10^6 psi
Bulk modulus	*	5.8e-4	-	0.00102	10^6 psi
Poisson's ratio	*	0.25	-	0.3	
Shape factor		2.2			
Yield strength (elastic limit)		0.016	-	0.0232	ksi
Tensile strength		0.0247	-	0.0508	ksi
Compressive strength	*	0.0145	-	0.0232	ksi
Compressive stress @ 25% strain		0.0218	-	0.0247	ksi
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Elongation		3	-	5	% strain
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Mechanical loss coefficient (tan delta)	*	0.1	-	0.3	
Densification strain	*	0.94	-	0.96	
Thermal properties					
Glass temperature		180	-	198	°F
Heat deflection temperature 0.45MPa		171	-	180	°F
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Minimum service temperature	*	-112	-	-76	°F
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Dielectric constant (relative permittivity)		1.02	-	1.04	
Dissipation factor (dielectric loss tangent)		3e-5	-	5e-5	
Dielectric strength (dielectric breakdown)		45.7	-	50.8	V/mil
Optical properties					
Transparency		Opaque			
Absorption, permeability					
Water absorption @ 24 hrs		1	-	3	%
Durability: flammability					
Flammability		Highly flammable			
Durability: fluids and sunlight					
Water (fresh)		Excellent			
Water (salt)		Excellent			
Weak acids		Excellent			
Strong acids		Limited use			
Weak alkalis		Excellent			
Strong alkalis		Acceptable			
Organic solvents		Unacceptable			
UV radiation (sunlight)		Fair			
Oxidation at 500C		Unacceptable			
Primary material production: energy, CO2 and water					
Embodied energy, primary production	*	4.56e4	-	5.03e4	BTU/lb
CO2 footprint, primary production	*	4.04	-	4.46	lb/lb
Water usage	*	1.2e4	-	1.33e4	in^3/lb
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Landfill		True		
Biodegrade		False		
A renewable resource?		False		

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Typical uses

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Other notes

Closed cell, expanded, polystyrene molded foam blocks

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ProcessUniverse
Producers
Reference
Shape
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3.

PS foam (closed cell, 0.030)

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Tradenames

Styrofoam, Styrodur C (XPS), Styropor, Peripor, Neopor, Extir, Styrocell, Dytherm, Gedexcel, Koplen, Pentfoam, Jackocell

General Properties

Density		0.00101	- 0.00116	lb/in^3
Price	*	1.13	- 1.32	USD/lb

Composition overview

Composition (summary)

(CH2-CH(C6H5))n

Base	Polymer
Polymer class	Thermoplastic : amorphous
Polymer type	PS
Polymer type full name	Polystyrene
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer	100	%

Foam & honeycomb properties

Anisotropy ratio	*	1	- 1.5

Cells/volume		1.64e5	-	8.19e5	/in^3
Relative density		0.027	-	0.031	

Mechanical properties

Young's modulus		0.00112	-	0.00164	10^6 psi
Compressive modulus	*	0.00287	-	0.00443	10^6 psi
Flexural modulus		0.00112	-	0.00164	10^6 psi
Shear modulus	*	5.08e-4	-	7.25e-4	10^6 psi
Bulk modulus	*	0.00116	-	0.0016	10^6 psi
Poisson's ratio	*	0.25	-	0.3	
Shape factor		2.3			
Yield strength (elastic limit)		0.029	-	0.0363	ksi
Tensile strength		0.0435	-	0.0696	ksi
Compressive strength	*	0.029	-	0.0363	ksi
Compressive stress @ 25% strain		0.0305	-	0.0334	ksi
Compressive stress @ 50% strain		0.0377	-	0.0406	ksi
Flexural strength (modulus of rupture)		0.0479	-	0.0827	ksi
Shear strength		0.0145	-	0.0181	ksi
Elongation		3	-	4	% strain
Hardness - Vickers	*	0.02	-	0.025	HV
Fatigue strength at 10^7 cycles	*	0.0435	-	0.058	ksi
Fracture toughness	*	0.00364	-	0.00455	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	0.1	-	0.3	
Densification strain	*	0.89	-	0.93	

Thermal properties

Glass temperature		180	-	198	°F
Heat deflection temperature 0.45MPa		171	-	180	°F
Heat deflection temperature 1.8MPa		171	-	180	°F
Maximum service temperature		180	-	189	°F
Minimum service temperature	*	-112	-	-76	°F
Thermal conductivity		0.0179	-	0.0202	BTU.ft/hr.ft^2.°F
Specific heat capacity		0.287	-	0.291	BTU/lb.°F
Thermal expansion coefficient		27.8	-	38.9	µstrain/°F

Electrical properties

Electrical resistivity	*	1e20	-	1e21	µohm.cm
Dielectric constant (relative permittivity)		1.02	-	1.04	
Dissipation factor (dielectric loss tangent)		3e-5	-	5e-5	
Dielectric strength (dielectric breakdown)		45.7	-	50.8	V/mil

Optical properties

Transparency	Opaque

Absorption, permeability

Water absorption @ 24 hrs		1	-	3	%

Durability: flammability

Flammability	Highly flammable

Durability: fluids and sunlight

Water (fresh)	Excellent
Water (salt)	Excellent
Weak acids	Excellent
Strong acids	Limited use
Weak alkalis	Excellent
Strong alkalis	Acceptable
Organic solvents	Unacceptable
UV radiation (sunlight)	Fair
Oxidation at 500C	Unacceptable

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 4.56e4	-	5.03e4	BTU/lb
CO2 footprint, primary production	* 4.04	-	4.46	lb/lb
Water usage	* 1.2e4	-	1.33e4	in^3/lb

Material processing: energy

Polymer extrusion energy	* 3.32e3	-	3.66e3	BTU/lb
Polymer molding energy	* 8.57e3	-	9.44e3	BTU/lb
Coarse machining energy (per unit wt removed)	* 235	-	259	BTU/lb
Fine machining energy (per unit wt removed)	* 509	-	563	BTU/lb
Grinding energy (per unit wt removed)	* 814	-	900	BTU/lb

Material processing: CO2 footprint

Polymer extrusion CO2	* 0.618	-	0.681	lb/lb
Polymer molding CO2	* 1.59	-	1.76	lb/lb
Coarse machining CO2 (per unit wt removed)	* 0.0409	-	0.0453	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.0889	-	0.0982	lb/lb
Grinding CO2 (per unit wt removed)	* 0.142	-	0.157	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Embodied energy, recycling	1.19e4			BTU/lb
CO2 footprint, recycling	* 1.05	-	1.17	lb/lb
Recycle fraction in current supply	0.95	-	1.05	%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	* 1.72e4	-	1.8e4	BTU/lb
Combustion CO2	* 3.3	-	3.47	lb/lb
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Packaging: electronics, household goods, food, tools. Structural reinforcement: sandwich structures. Cushioning, Thermal Insulation, Acoustic Insulation, floatation and buoyancy, Energy Absorption.

Other notes

Closed cell, expanded, polystyrene molded foam blocks

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

4.

PS foam (closed cell, 0.050)

Identification

Designation

Expanded polystyrene (EPS) closed cell foam, 0.020 specific gravity (based on Styropor 20)

Tradenames

Styrofoam, Styrodur C (XPS), Styropor, Peripor, Neopor, Extir, Styrocell, Dytherm, Gedexcel, Koplen, Pentfoam, Jackocell

General Properties

Density	0.0017	-	0.00191	lb/in^3
Price	* 1.13	-	1.32	USD/lb

Composition overview

Composition (summary)

(CH2-CH-C6H5)n

Base	Polymer
Polymer class	Thermoplastic : amorphous
Polymer type	PS
Polymer type full name	Polystyrene
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer	100			%

Foam & honeycomb properties

Anisotropy ratio	* 1	-	1.5	
Cells/volume	* 1.64e5	-	8.19e5	/in^3
Relative density	0.046	-	0.052	

Mechanical properties

Young's modulus	0.00363	-	0.00435	10^6 psi
Compressive modulus	* 0.00511	-	0.00768	10^6 psi
Flexural modulus	0.00363	-	0.00435	10^6 psi
Shear modulus	* 0.00116	-	0.00145	10^6 psi
Bulk modulus	* 0.00363	-	0.00435	10^6 psi
Poisson's ratio	* 0.25	-	0.3	
Shape factor	2.1			
Yield strength (elastic limit)	0.116	-	0.145	ksi
Tensile strength	0.145	-	0.174	ksi
Compressive strength	* 0.116	-	0.145	ksi
Compressive stress @ 25% strain	* 0.102	-	0.131	ksi
Compressive stress @ 50% strain	* 0.0363	-	0.0508	ksi
Flexural strength (modulus of rupture)	* 0.145	-	0.174	ksi
Shear strength	0.058	-	0.0725	ksi
Elongation	4	-	5	% strain
Hardness - Vickers	* 0.08	-	0.1	HV
Fatigue strength at 10^7 cycles	* 0.0696	-	0.087	ksi
Fracture toughness	* 0.0091	-	0.0182	ksi.in^0.5
Mechanical loss coefficient (tan delta)	* 0.1	-	0.3	
Densification strain	* 0.85	-	0.9	

Thermal properties

Glass temperature	180	-	198	°F
Heat deflection temperature 0.45MPa	171	-	180	°F
Heat deflection temperature 1.8MPa	162	-	171	°F
Maximum service temperature	180	-	189	°F
Minimum service temperature	* -112	-	-76	°F
Thermal conductivity	0.0191	-	0.0231	BTU.ft/hr.ft^2.°F
Specific heat capacity	0.287	-	0.291	BTU/lb.°F
Thermal expansion coefficient	33.3	-	44.4	µstrain/°F

Electrical properties

Electrical resistivity	* 1e20	-	1e21	µohm.cm
Dielectric constant (relative permittivity)	* 1.05	-	1.1	
Dissipation factor (dielectric loss tangent)	3e-4	-	5e-4	
Dielectric strength (dielectric breakdown)	48.3	-	53.3	V/mil

Optical properties

Transparency	Opaque

Absorption, permeability

Water absorption @ 24 hrs	1	-	3	%

Durability: flammability

Flammability	Highly flammable			

Durability: fluids and sunlight

Water (fresh)	Excellent			
Water (salt)	Excellent			
Weak acids	Excellent			
Strong acids	Limited use			
Weak alkalis	Excellent			
Strong alkalis	Acceptable			
Organic solvents	Unacceptable			
UV radiation (sunlight)	Fair			
Oxidation at 500C	Unacceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 4.56e4	-	5.03e4	BTU/lb
CO2 footprint, primary production	* 4.04	-	4.46	lb/lb
Water usage	* 1.2e4	-	1.33e4	in^3/lb

Material processing: energy

Polymer extrusion energy	* 3.32e3	-	3.66e3	BTU/lb
Polymer molding energy	* 8.57e3	-	9.44e3	BTU/lb
Coarse machining energy (per unit wt removed)	* 277	-	307	BTU/lb
Fine machining energy (per unit wt removed)	* 936	-	1.03e3	BTU/lb
Grinding energy (per unit wt removed)	* 1.67e3	-	1.84e3	BTU/lb

Material processing: CO2 footprint

Polymer extrusion CO2	* 0.618	-	0.681	lb/lb
Polymer molding CO2	* 1.59	-	1.76	lb/lb
Coarse machining CO2 (per unit wt removed)	* 0.0484	-	0.0535	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.163	-	0.181	lb/lb
Grinding CO2 (per unit wt removed)	* 0.291	-	0.322	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Embodied energy, recycling	1.19e4			BTU/lb
CO2 footprint, recycling	* 1.05	-	1.17	lb/lb
Recycle fraction in current supply	0.95	-	1.05	%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	* 1.72e4	-	1.8e4	BTU/lb
Combustion CO2	* 3.3	-	3.47	lb/lb
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Packaging: electronics, household goods, food, tools. Structural reinforcement: sandwich structures. Cushioning, Thermal Insulation, Acoustic Insulation, floatation and buoyancy, Energy Absorption.

Other notes

Closed cell, expanded, polystyrene molded foam blocks

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.

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5.

PE foam (cross-linked, closed cell, 0.030)

Identification

Designation

Cross-linked polyethylene (XLPE, PE-X) closed cell foam (EPE), 0.030 specific gravity (based on Neopolen E 1710)

Tradenames

Neopolen E

General Properties

Density		9.75e-4	-	0.00119	lb/in^3
Price	*	4.51	-	5.36	USD/lb

Composition overview

Composition (summary)

(CH2)n

Base	Polymer
Polymer class	Thermoplastic : semi-crystalline
Polymer type	PE-LD
Polymer type full name	Polyethylene, low density
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer		100			%

Foam & honeycomb properties

Anisotropy ratio	*	1	-	1.5	
Cells/volume	*	1.64e3	-	1.64e4	/in^3
Relative density		0.028	-	0.034	

Mechanical properties

Young's modulus	*	7.25e-4	-	0.00116	10^6 psi
Compressive modulus	*	0.00154	-	0.00167	10^6 psi
Flexural modulus		7.25e-4	-	0.00116	10^6 psi
Shear modulus	*	4.35e-5	-	5.8e-5	10^6 psi
Bulk modulus	*	7.25e-4	-	0.00116	10^6 psi
Poisson's ratio	*	0.2	-	0.25	
Shape factor		2.9			
Yield strength (elastic limit)		0.0029	-	0.00363	ksi
Tensile strength		0.0203	-	0.0261	ksi
Compressive strength	*	0.0029	-	0.00363	ksi
Compressive stress @ 25% strain		0.00624	-	0.00682	ksi
Compressive stress @ 50% strain		0.0145	-	0.0174	ksi
Flexural strength (modulus of rupture)	*	0.0029	-	0.00363	ksi
Shear strength		0.00145	-	0.00181	ksi
Elongation		53	-	57	% strain
Hardness - Vickers	*	0.002	-	0.0025	HV
Fatigue strength at 10^7 cycles	*	0.0145	-	0.0203	ksi
Fracture toughness	*	0.0137	-	0.0182	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	0.1	-	0.2	
Densification strain	*	0.87	-	0.93	

Thermal properties

Melting point	234	-	243	°F
Glass temperature	-193	-	-130	°F
Maximum service temperature	181	-	189	°F
Minimum service temperature	-99.4	-	-81.4	°F
Thermal conductivity	0.022	-	0.0243	BTU.ft/hr.ft^2.°F
Specific heat capacity	0.466	-	0.502	BTU/lb.°F
Thermal expansion coefficient	* 106	-	122	µstrain/°F
Electrical properties				
Electrical resistivity	* 1e21	-	1e23	µohm.cm
Dielectric constant (relative permittivity)	* 1.03	-	1.06	
Dissipation factor (dielectric loss tangent)	* 1e-4	-	2e-4	
Dielectric strength (dielectric breakdown)	* 102	-	152	V/mil
Optical properties				
Transparency	Opaque			
Absorption, permeability				
Water absorption @ 24 hrs	1	-	1.5	%
Durability: flammability				
Flammability	Highly flammable			
Durability: fluids and sunlight				
Water (fresh)	Acceptable			
Water (salt)	Acceptable			
Weak acids	Acceptable			
Strong acids	Acceptable			
Weak alkalis	Acceptable			
Strong alkalis	Acceptable			
Organic solvents	Limited use			
UV radiation (sunlight)	Poor			
Oxidation at 500C	Unacceptable			
Primary material production: energy, CO2 and water				
Embodied energy, primary production	* 4.43e4	-	4.9e4	BTU/lb
CO2 footprint, primary production	* 4.28	-	4.73	lb/lb
Water usage	* 5.98e3	-	6.62e3	in^3/lb
Material processing: energy				
Polymer extrusion energy	* 2.32e3	-	2.56e3	BTU/lb
Polymer molding energy	* 5.87e3	-	6.48e3	BTU/lb
Coarse machining energy (per unit wt removed)	* 207	-	229	BTU/lb
Fine machining energy (per unit wt removed)	* 235	-	260	BTU/lb
Grinding energy (per unit wt removed)	* 265	-	293	BTU/lb
Material processing: CO2 footprint				
Polymer extrusion CO2	* 0.431	-	0.476	lb/lb
Polymer molding CO2	* 1.09	-	1.21	lb/lb
Coarse machining CO2 (per unit wt removed)	* 0.0362	-	0.04	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.041	-	0.0453	lb/lb
Grinding CO2 (per unit wt removed)	* 0.0463	-	0.0512	lb/lb
Material recycling: energy, CO2 and recycle fraction				
Recycle	False			
Embodied energy, recycling	1.16e4			BTU/lb
CO2 footprint, recycling	* 1.12	-	1.24	lb/lb
Recycle fraction in current supply	0.1			%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	* 1.89e4	-	1.98e4	BTU/lb
Combustion CO2	* 3.06	-	3.22	lb/lb
Landfill	True			

Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Packaging, Cushioning, Shock Absorption, Vibration Damping, Thermal Insulation

Other notes

Closed cell, cross-linked, polyethylene, available as beads or sheet, which can be molded to complex shapes.

Links

ProcessUniverse
Producers
Reference
Shape
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Granta Design provides no warranty for the accuracy of this data

6.

PE foam (cross-linked, closed cell, 0.050)

Identification

Designation

Cross-linked polyethylene (XLPE, PE-X) closed cell foam (EPE), 0.050 specific gravity (based on Neopolen E 1720)

Tradenames

Neopolen E

General Properties

Density	0.0017	-	0.00191	lb/in^3
Price	* 4.51	-	5.36	USD/lb

Composition overview

Composition (summary)

(CH2)n

Base	Polymer
Polymer class	Thermoplastic : semi-crystalline
Polymer type	PE-LD
Polymer type full name	Polyethylene, low density
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer	100			%

Foam & honeycomb properties

Anisotropy ratio	* 1	-	1.5	
Cells/volume	* 1.64e3	-	1.64e4	/in^3
Relative density	0.048	-	0.054	

Mechanical properties

Young's modulus	* 1.45e-4	-	2.18e-4	10^6 psi
Compressive modulus	* 0.00258	-	0.00291	10^6 psi
Flexural modulus	1.45e-4	-	2.18e-4	10^6 psi
Shear modulus	* 5.8e-5	-	1.02e-4	10^6 psi
Bulk modulus	* 1.45e-4	-	2.18e-4	10^6 psi
Poisson's ratio	* 0.24	-	0.28	
Shape factor	2.2			
Yield strength (elastic limit)	0.00508	-	0.0058	ksi

Tensile strength	0.0348	-	0.0406	ksi
Compressive strength	* 0.00508	-	0.0058	ksi
Compressive stress @ 25% strain	0.00972	-	0.0106	ksi
Compressive stress @ 50% strain	0.0189	-	0.0218	ksi
Flexural strength (modulus of rupture)	* 0.00508	-	0.0058	ksi
Shear strength	0.00254	-	0.0029	ksi
Elongation	49	-	53	% strain
Hardness - Vickers	* 0.0035	-	0.004	HV
Fatigue strength at 10^7 cycles	* 0.029	-	0.0363	ksi
Fracture toughness	* 0.02	-	0.0246	ksi.in^0.5
Mechanical loss coefficient (tan delta)	* 0.1	-	0.2	
Densification strain	* 0.85	-	0.89	
Thermal properties				
Melting point	234	-	243	°F
Glass temperature	-193	-	-130	°F
Maximum service temperature	181	-	189	°F
Minimum service temperature	-99.4	-	-81.4	°F
Thermal conductivity	0.0248	-	0.0272	BTU.ft/hr.ft^2.°F
Specific heat capacity	0.466	-	0.502	BTU/lb.°F
Thermal expansion coefficient	* 106	-	122	µstrain/°F
Electrical properties				
Electrical resistivity	* 1e21	-	1e23	µohm.cm
Dielectric constant (relative permittivity)	* 1.05	-	1.08	
Dissipation factor (dielectric loss tangent)	* 1e-4	-	2e-4	
Dielectric strength (dielectric breakdown)	* 102	-	152	V/mil
Optical properties				
Transparency	Opaque			
Absorption, permeability				
Water absorption @ 24 hrs	1	-	1.5	%
Durability: flammability				
Flammability	Highly flammable			
Durability: fluids and sunlight				
Water (fresh)	Acceptable			
Water (salt)	Acceptable			
Weak acids	Acceptable			
Strong acids	Acceptable			
Weak alkalis	Acceptable			
Strong alkalis	Acceptable			
Organic solvents	Limited use			
UV radiation (sunlight)	Poor			
Oxidation at 500C	Unacceptable			
Primary material production: energy, CO2 and water				
Embodied energy, primary production	* 4.43e4	-	4.9e4	BTU/lb
CO2 footprint, primary production	* 4.28	-	4.73	lb/lb
Water usage	* 5.98e3	-	6.62e3	in^3/lb
Material processing: energy				
Polymer extrusion energy	* 2.32e3	-	2.56e3	BTU/lb
Polymer molding energy	* 5.87e3	-	6.48e3	BTU/lb
Coarse machining energy (per unit wt removed)	* 207	-	229	BTU/lb
Fine machining energy (per unit wt removed)	* 235	-	260	BTU/lb
Grinding energy (per unit wt removed)	* 265	-	293	BTU/lb
Material processing: CO2 footprint				
Polymer extrusion CO2	* 0.431	-	0.476	lb/lb
Polymer molding CO2	* 1.09	-	1.21	lb/lb

Coarse machining CO2 (per unit wt removed)	* 0.0362	-	0.04	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.041	-	0.0453	lb/lb
Grinding CO2 (per unit wt removed)	* 0.0463	-	0.0512	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Embodied energy, recycling	1.16e4			BTU/lb
CO2 footprint, recycling	* 1.12	-	1.24	lb/lb
Recycle fraction in current supply	0.1			%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	* 1.89e4	-	1.98e4	BTU/lb
Combustion CO2	* 3.06	-	3.22	lb/lb
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Packaging, Cushioning, Shock Absorption, Vibration Damping, Thermal Insulation

Other notes

Closed cell, cross-linked, polyethylene, available as beads or sheet, which can be molded to complex shapes.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

7.

PE foam (cross-linked, closed cell, 0.080)

Identification

Designation

Cross-linked polyethylene (XLPE, PE-X) closed cell foam (EPE), 0.080 specific gravity (based on Neopolen E 1730)

Tradenames

Neopolen E

General Properties

Density	0.00278	-	0.003	lb/in^3
Price	* 4.51	-	5.36	USD/lb

Composition overview

Composition (summary)

(CH2)n

Base	Polymer
Polymer class	Thermoplastic : semi-crystalline
Polymer type	PE-LD
Polymer type full name	Polyethylene, low density
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer	100	%

Foam & honeycomb properties

Anisotropy ratio	* 1	-	1.5	
Cells/volume	* 1.64e3	-	1.64e4	/in^3
Relative density	0.078	-	0.084	

Mechanical properties

Young's modulus	* 5.8e-4	-	8.7e-4	10^6 psi
Compressive modulus	* 0.00433	-	0.00485	10^6 psi
Flexural modulus	5.8e-4	-	8.7e-4	10^6 psi
Shear modulus	* 2.9e-4	-	4.35e-4	10^6 psi
Bulk modulus	* 5.8e-4	-	8.7e-4	10^6 psi
Poisson's ratio	* 0.26	-	0.3	
Shape factor	2.6			
Yield strength (elastic limit)	0.00696	-	0.00798	ksi
Tensile strength	0.0624	-	0.0682	ksi
Compressive strength	* 0.00696	-	0.00798	ksi
Compressive stress @ 25% strain	0.0131	-	0.0141	ksi
Compressive stress @ 50% strain	0.0261	-	0.029	ksi
Flexural strength (modulus of rupture)	* 0.00696	-	0.00798	ksi
Shear strength	0.00348	-	0.00399	ksi
Elongation	51	-	55	% strain
Hardness - Vickers	* 0.0048	-	0.0055	HV
Fatigue strength at 10^7 cycles	* 0.0493	-	0.058	ksi
Fracture toughness	* 0.0546	-	0.0819	ksi.in^0.5
Mechanical loss coefficient (tan delta)	* 0.1	-	0.2	
Densification strain	* 0.8	-	0.83	

Thermal properties

Melting point	234	-	243	°F
Glass temperature	-193	-	-130	°F
Maximum service temperature	181	-	189	°F
Minimum service temperature	-99.4	-	-81.4	°F
Thermal conductivity	0.0277	-	0.03	BTU.ft/hr.ft^2.°F
Specific heat capacity	0.466	-	0.502	BTU/lb.°F
Thermal expansion coefficient	* 106	-	122	µstrain/°F

Electrical properties

Electrical resistivity	* 1e21	-	1e23	µohm.cm
Dielectric constant (relative permittivity)	* 1.07	-	1.1	
Dissipation factor (dielectric loss tangent)	* 1e-4	-	2e-4	
Dielectric strength (dielectric breakdown)	* 102	-	152	V/mil

Optical properties

Transparency	Opaque

Absorption, permeability

Water absorption @ 24 hrs	1	-	1.5	%

Durability: flammability

Flammability	Highly flammable

Durability: fluids and sunlight

Water (fresh)	Acceptable
Water (salt)	Acceptable
Weak acids	Acceptable
Strong acids	Acceptable
Weak alkalis	Acceptable
Strong alkalis	Acceptable
Organic solvents	Limited use
UV radiation (sunlight)	Poor
Oxidation at 500C	Unacceptable

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 4.43e4	-	4.9e4	BTU/lb
CO2 footprint, primary production	* 4.28	-	4.73	lb/lb
Water usage	* 5.98e3	-	6.62e3	in^3/lb

Material processing: energy

Polymer extrusion energy	* 2.32e3	-	2.56e3	BTU/lb
Polymer molding energy	* 5.87e3	-	6.48e3	BTU/lb
Coarse machining energy (per unit wt removed)	* 207	-	229	BTU/lb
Fine machining energy (per unit wt removed)	* 230	-	255	BTU/lb
Grinding energy (per unit wt removed)	* 257	-	284	BTU/lb

Material processing: CO2 footprint

Polymer extrusion CO2	* 0.431	-	0.476	lb/lb
Polymer molding CO2	* 1.09	-	1.21	lb/lb
Coarse machining CO2 (per unit wt removed)	* 0.0361	-	0.0399	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.0402	-	0.0444	lb/lb
Grinding CO2 (per unit wt removed)	* 0.0448	-	0.0495	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Embodied energy, recycling	1.16e4			BTU/lb
CO2 footprint, recycling	* 1.12	-	1.24	lb/lb
Recycle fraction in current supply	0.1			%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	* 1.89e4	-	1.98e4	BTU/lb
Combustion CO2	* 3.06	-	3.22	lb/lb
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Packaging, Cushioning, Shock Absorption, Vibration Damping, Thermal Insulation

Other notes

Closed cell, cross-linked, polyethylene, available as beads or sheet, which can be molded to complex shapes.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

8.

PE-HD foam (cross linked, closed cell, 0.080)

Identification

Designation

High density, cross-linked polyethylene (HDPE, XLPE, PE-X) closed cell foam, expanded with nitrogen, 0.080 specific gravity (based on Plastazote HD80)

Tradenames

PLASTAZOTE (EVAZOTE, SUPAZOTE are similar EVA and EMA based materials)

General Properties

Density		0.0026	-	0.00289	lb/in^3
Price	*	1.41	-	1.51	USD/lb

Composition overview

Composition (summary)

(CH2)n

Base	Polymer
Polymer class	Thermoplastic : semi-crystalline
Polymer type	PE-HD
Polymer type full name	Polyethylene, high density
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer		100			%

Foam & honeycomb properties

Anisotropy ratio	*	1	-	1.5	
Cells/volume	*	1.64e3	-	1.64e4	/in^3
Relative density		0.073	-	0.081	

Mechanical properties

Young's modulus	*	7.98e-4	-	9.43e-4	10^6 psi
Compressive modulus	*	0.00415	-	0.00452	10^6 psi
Flexural modulus		7.98e-4	-	9.43e-4	10^6 psi
Shear modulus	*	2.9e-4	-	3.63e-4	10^6 psi
Bulk modulus	*	7.98e-4	-	9.43e-4	10^6 psi
Poisson's ratio	*	0.27	-	0.32	
Shape factor		2			
Yield strength (elastic limit)	*	0.0435	-	0.0522	ksi
Tensile strength		0.319	-	0.355	ksi
Compressive strength	*	0.0435	-	0.0522	ksi
Compressive stress @ 25% strain		0.0189	-	0.0232	ksi
Compressive stress @ 50% strain		0.0508	-	0.0522	ksi
Flexural strength (modulus of rupture)	*	0.0435	-	0.0522	ksi
Shear strength		0.0218	-	0.0261	ksi
Elongation		105	-	115	% strain
Hardness - Vickers	*	0.03	-	0.036	HV
Fatigue strength at 10^7 cycles	*	0.247	-	0.305	ksi
Fracture toughness	*	0.0455	-	0.0637	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	0.1	-	0.18	
Densification strain	*	0.8	-	0.86	

Thermal properties

Melting point		266	-	284	°F
Glass temperature		-193	-	-130	°F
Maximum service temperature		207	-	230	°F
Minimum service temperature		-99.4	-	-81.4	°F
Thermal conductivity		0.0352	-	0.0376	BTU.ft/hr.ft^2.°F
Specific heat capacity		0.535	-	0.54	BTU/lb.°F
Thermal expansion coefficient		106	-	117	µstrain/°F

Electrical properties

Electrical resistivity	*	1e21	-	1e23	µohm.cm
Dielectric constant (relative permittivity)	*	1.2	-	1.35	
Dissipation factor (dielectric loss tangent)	*	1e-4	-	2e-4	
Dielectric strength (dielectric breakdown)	*	102	-	152	V/mil

Optical properties

Transparency	Opaque

Absorption, permeability

Water absorption @ 24 hrs	0.5	-	0.7	%

Durability: flammability

Flammability	Highly flammable			

Durability: fluids and sunlight

Water (fresh)	Acceptable			
Water (salt)	Acceptable			
Weak acids	Acceptable			
Strong acids	Acceptable			
Weak alkalis	Acceptable			
Strong alkalis	Acceptable			
Organic solvents	Limited use			
UV radiation (sunlight)	Fair			
Oxidation at 500C	Unacceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 4.3e4	-	4.77e4	BTU/lb
CO2 footprint, primary production	* 3.43	-	3.79	lb/lb
Water usage	* 4.59e3	-	5.07e3	in^3/lb

Material processing: energy

Polymer extrusion energy	* 2.35e3	-	2.59e3	BTU/lb
Polymer molding energy	* 5.98e3	-	6.59e3	BTU/lb
Coarse machining energy (per unit wt removed)	* 222	-	245	BTU/lb
Fine machining energy (per unit wt removed)	* 381	-	421	BTU/lb
Grinding energy (per unit wt removed)	* 558	-	617	BTU/lb

Material processing: CO2 footprint

Polymer extrusion CO2	* 0.438	-	0.483	lb/lb
Polymer molding CO2	* 1.11	-	1.23	lb/lb
Coarse machining CO2 (per unit wt removed)	* 0.0387	-	0.0428	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.0665	-	0.0735	lb/lb
Grinding CO2 (per unit wt removed)	* 0.0973	-	0.108	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Embodied energy, recycling	1.13e4			BTU/lb
CO2 footprint, recycling	* 0.896	-	0.99	lb/lb
Recycle fraction in current supply	8.02	-	8.86	%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	* 1.89e4	-	1.98e4	BTU/lb
Combustion CO2	* 3.06	-	3.22	lb/lb
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Packaging, Buoyancy, Insulation, Cushioning, Sleeping Mats, Automotive, Furnishing

Other notes

Closed cell, cross-linked, high-density polyethylene, generally available in sheet form.Can be thermomolded to simple and complex shapes.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

9.

PE-HD foam (cross-linked, closed cell, 0.030)

Identification

Designation

High density, cross-linked polyethylene (HDPE, XLPE, PE-X) closed cell foam, expanded with nitrogen, 0.030 specific gravity (based on Plastazote HD30)

Tradenames

PLASTAZOTE (EVAZOTE, SUPAZOTE are similar EVA and EMA based materials)

General Properties

Density		9.75e-4	-	0.00108	lb/in^3
Price	*	1.41	-	1.51	USD/lb

Composition overview

Composition (summary)

(CH2)n

Base	Polymer
Polymer class	Thermoplastic : semi-crystalline
Polymer type	PE-HD
Polymer type full name	Polyethylene, high density
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer		100			%

Foam & honeycomb properties

Anisotropy ratio	*	1	-	1.5	
Cells/volume	*	1.64e3	-	1.64e4	/in^3
Relative density		0.028	-	0.031	

Mechanical properties

Young's modulus	*	1.16e-4	-	1.45e-4	10^6 psi
Compressive modulus	*	0.00139	-	0.00167	10^6 psi
Flexural modulus		1.16e-4	-	1.45e-4	10^6 psi
Shear modulus	*	5.08e-5	-	5.8e-5	10^6 psi
Bulk modulus	*	1.16e-4	-	1.45e-4	10^6 psi
Poisson's ratio	*	0.25	-	0.3	
Shape factor		1.8			
Yield strength (elastic limit)	*	0.0145	-	0.0174	ksi
Tensile strength		0.116	-	0.123	ksi
Compressive strength	*	0.0145	-	0.0174	ksi
Compressive stress @ 25% strain		0.00798	-	0.00943	ksi
Compressive stress @ 50% strain		0.0232	-	0.0247	ksi
Flexural strength (modulus of rupture)	*	0.0145	-	0.0174	ksi
Shear strength		0.00725	-	0.0087	ksi
Elongation		52	-	57	% strain
Hardness - Vickers	*	0.01	-	0.012	HV
Fatigue strength at 10^7 cycles	*	0.087	-	0.102	ksi
Fracture toughness	*	0.0109	-	0.0146	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	0.1	-	0.18	
Densification strain	*	0.9	-	0.94	

Thermal properties

Melting point		266	-	284	°F
Glass temperature		-193	-	-130	°F
Maximum service temperature		207	-	230	°F
Minimum service temperature		-99.4	-	-81.4	°F
Thermal conductivity		0.0266	-	0.0277	BTU.ft/hr.ft^2.°F

Specific heat capacity	0.535	-	0.54	BTU/lb.°F
Thermal expansion coefficient	106	-	122	µstrain/°F

Electrical properties

Electrical resistivity	* 1e21	-	1e23	µohm.cm
Dielectric constant (relative permittivity)	* 1.1	-	1.2	
Dissipation factor (dielectric loss tangent)	* 1e-4	-	2e-4	
Dielectric strength (dielectric breakdown)	* 102	-	152	V/mil

Optical properties

Transparency	Opaque

Absorption, permeability

Water absorption @ 24 hrs	0.5	-	0.7	%

Durability: flammability

Flammability	Highly flammable

Durability: fluids and sunlight

Water (fresh)	Acceptable
Water (salt)	Acceptable
Weak acids	Acceptable
Strong acids	Acceptable
Weak alkalis	Acceptable
Strong alkalis	Acceptable
Organic solvents	Limited use
UV radiation (sunlight)	Fair
Oxidation at 500C	Unacceptable

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 4.3e4	-	4.77e4	BTU/lb
CO2 footprint, primary production	* 3.43	-	3.79	lb/lb
Water usage	* 4.59e3	-	5.07e3	in^3/lb

Material processing: energy

Polymer extrusion energy	* 2.35e3	-	2.59e3	BTU/lb
Polymer molding energy	* 5.98e3	-	6.59e3	BTU/lb
Coarse machining energy (per unit wt removed)	* 220	-	243	BTU/lb
Fine machining energy (per unit wt removed)	* 361	-	399	BTU/lb
Grinding energy (per unit wt removed)	* 519	-	573	BTU/lb

Material processing: CO2 footprint

Polymer extrusion CO2	* 0.438	-	0.483	lb/lb
Polymer molding CO2	* 1.11	-	1.23	lb/lb
Coarse machining CO2 (per unit wt removed)	* 0.0384	-	0.0424	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.063	-	0.0697	lb/lb
Grinding CO2 (per unit wt removed)	* 0.0905	-	0.1	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Embodied energy, recycling	1.13e4			BTU/lb
CO2 footprint, recycling	* 0.896	-	0.99	lb/lb
Recycle fraction in current supply	8.02	-	8.86	%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	* 1.89e4	-	1.98e4	BTU/lb
Combustion CO2	* 3.06	-	3.22	lb/lb
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Packaging, Buoyancy, Insulation, Cushioning, Sleeping Mats, Automotive, Furnishing

Other notes
Closed cell, cross-linked, high-density polyethylene, generally available in sheet form.Can be thermomolded to simple and complex shapes.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

10.

PE-HD foam (cross-linked, closed cell, 0.060)

Identification

Designation
High density, cross-linked polyethylene (HDPE, XLPE, PE-X) closed cell foam, expanded with nitrogen, 0.060 specific gravity (based on Plastazote HD60)

Tradenames
PLASTAZOTE (EVAZOTE, SUPAZOTE are similar EVA and EMA based materials)

General Properties

Density		0.00206	-	0.00217	lb/in^3
Price	*	1.41	-	1.51	USD/lb

Composition overview

Composition (summary)
(CH2)n

Base	Polymer
Polymer class	Thermoplastic : semi-crystalline
Polymer type	PE-HD
Polymer type full name	Polyethylene, high density
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer		100			%

Foam & honeycomb properties

Anisotropy ratio	*	1	-	1.5	
Cells/volume	*	1.64e3	-	1.64e4	/in^3
Relative density		0.058	-	0.061	

Mechanical properties

Young's modulus	*	4.35e-4	-	5.8e-4	10^6 psi
Compressive modulus	*	0.00297	-	0.00355	10^6 psi
Flexural modulus		4.35e-4	-	5.8e-4	10^6 psi
Shear modulus	*	1.45e-4	-	2.18e-4	10^6 psi
Bulk modulus	*	4.35e-4	-	5.8e-4	10^6 psi
Poisson's ratio	*	0.26	-	0.31	
Shape factor		1.9			
Yield strength (elastic limit)	*	0.0363	-	0.0435	ksi
Tensile strength		0.305	-	0.341	ksi
Compressive strength	*	0.0363	-	0.0435	ksi
Compressive stress @ 25% strain		0.0145	-	0.0174	ksi
Compressive stress @ 50% strain		0.0435	-	0.045	ksi
Flexural strength (modulus of rupture)	*	0.0363	-	0.0435	ksi
Shear strength		0.0181	-	0.0218	ksi

Elongation		105	-	115	% strain
Hardness - Vickers	*	0.025	-	0.03	HV
Fatigue strength at 10^7 cycles	*	0.218	-	0.29	ksi
Fracture toughness	*	0.0364	-	0.0455	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	0.1	-	0.18	
Densification strain	*	0.85	-	0.9	
Thermal properties					
Melting point		266	-	284	°F
Glass temperature		-193	-	-130	°F
Maximum service temperature		207	-	230	°F
Minimum service temperature		-99.4	-	-81.4	°F
Thermal conductivity		0.0318	-	0.0341	BTU.ft/hr.ft^2.°F
Specific heat capacity		0.535	-	0.54	BTU/lb.°F
Thermal expansion coefficient		106	-	122	µstrain/°F
Electrical properties					
Electrical resistivity	*	1e21	-	1e23	µohm.cm
Dielectric constant (relative permittivity)	*	1.15	-	1.3	
Dissipation factor (dielectric loss tangent)	*	1e-4	-	2e-4	
Dielectric strength (dielectric breakdown)	*	102	-	152	V/mil
Optical properties					
Transparency		Opaque			
Absorption, permeability					
Water absorption @ 24 hrs		0.5	-	0.7	%
Durability: flammability					
Flammability		Highly flammable			
Durability: fluids and sunlight					
Water (fresh)		Acceptable			
Water (salt)		Acceptable			
Weak acids		Acceptable			
Strong acids		Acceptable			
Weak alkalis		Acceptable			
Strong alkalis		Acceptable			
Organic solvents		Limited use			
UV radiation (sunlight)		Fair			
Oxidation at 500C		Unacceptable			
Primary material production: energy, CO2 and water					
Embodied energy, primary production	*	4.3e4	-	4.77e4	BTU/lb
CO2 footprint, primary production	*	3.43	-	3.79	lb/lb
Water usage	*	4.59e3	-	5.07e3	in^3/lb
Material processing: energy					
Polymer extrusion energy	*	2.35e3	-	2.59e3	BTU/lb
Polymer molding energy	*	5.98e3	-	6.59e3	BTU/lb
Coarse machining energy (per unit wt removed)	*	223	-	247	BTU/lb
Fine machining energy (per unit wt removed)	*	395	-	437	BTU/lb
Grinding energy (per unit wt removed)	*	587	-	648	BTU/lb
Material processing: CO2 footprint					
Polymer extrusion CO2	*	0.438	-	0.483	lb/lb
Polymer molding CO2	*	1.11	-	1.23	lb/lb
Coarse machining CO2 (per unit wt removed)	*	0.039	-	0.0431	lb/lb
Fine machining CO2 (per unit wt removed)	*	0.069	-	0.0763	lb/lb
Grinding CO2 (per unit wt removed)	*	0.102	-	0.113	lb/lb
Material recycling: energy, CO2 and recycle fraction					
Recycle		False			
Embodied energy, recycling		1.13e4			BTU/lb

CO2 footprint, recycling	* 0.896	-	0.99	lb/lb
Recycle fraction in current supply	8.02	-	8.86	%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	* 1.89e4	-	1.98e4	BTU/lb
Combustion CO2	* 3.06	-	3.22	lb/lb
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Packaging, Buoyancy, Insulation, Cushioning, Sleeping Mats, Automotive, Furnishing

Other notes

Closed cell, cross-linked, high-density polyethylene, generally available in sheet form.Can be thermomolded to simple and complex shapes.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

11.

PE-HD foam (cross-linked, closed cell, 0.115)

Identification

Designation

High density, cross-linked polyethylene (HDPE, XLPE, PE-X) closed cell foam, expanded with nitrogen, 0.115 specific gravity (based on Plastazote HD115)

Tradenames

PLASTAZOTE (EVAZOTE, SUPAZOTE are similar EVA and EMA based materials)

General Properties

Density	0.00361	-	0.00415	lb/in^3
Price	* 1.41	-	1.51	USD/lb

Composition overview

Composition (summary)

(CH2)n

Base	Polymer
Polymer class	Thermoplastic : semi-crystalline
Polymer type	PE-HD
Polymer type full name	Polyethylene, high density
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer	100			%

Foam & honeycomb properties

Anisotropy ratio	* 1	-	1.5	
Cells/volume	* 1.64e3	-	1.64e4	/in^3
Relative density	0.102	-	0.117	

Mechanical properties

Young's modulus	* 0.00102	-	0.00174	10^6 psi

Compressive modulus	0.00647	-	0.00654	10^6 psi
Flexural modulus	0.00102	-	0.00174	10^6 psi
Shear modulus	* 4.35e-4	-	7.25e-4	10^6 psi
Bulk modulus	* 0.00102	-	0.00174	10^6 psi
Poisson's ratio	* 0.28	-	0.33	
Shape factor	1.9			
Yield strength (elastic limit)	* 0.087	-	0.102	ksi
Tensile strength	0.399	-	0.428	ksi
Compressive strength	* 0.087	-	0.102	ksi
Compressive stress @ 25% strain	0.0261	-	0.029	ksi
Compressive stress @ 50% strain	0.0653	-	0.0667	ksi
Flexural strength (modulus of rupture)	* 0.087	-	0.102	ksi
Shear strength	0.0435	-	0.0508	ksi
Elongation	105	-	115	% strain
Hardness - Vickers	* 0.06	-	0.07	HV
Fatigue strength at 10^7 cycles	* 0.319	-	0.363	ksi
Fracture toughness	* 0.0637	-	0.0819	ksi.in^0.5
Mechanical loss coefficient (tan delta)	* 0.1	-	0.18	
Densification strain	* 0.8	-	0.85	

Thermal properties

Melting point	266	-	284	°F
Glass temperature	-193	-	-130	°F
Maximum service temperature	207	-	230	°F
Minimum service temperature	-99.4	-	-81.4	°F
Thermal conductivity	0.0416	-	0.0451	BTU.ft/hr.ft^2.°F
Specific heat capacity	0.535	-	0.54	BTU/lb.°F
Thermal expansion coefficient	106	-	117	µstrain/°F

Electrical properties

Electrical resistivity	* 1e21	-	1e23	µohm.cm
Dielectric constant (relative permittivity)	* 1.25	-	1.35	
Dissipation factor (dielectric loss tangent)	* 1e-4	-	2e-4	
Dielectric strength (dielectric breakdown)	* 102	-	152	V/mil

Optical properties

Transparency	Opaque			

Absorption, permeability

Water absorption @ 24 hrs	0.5	-	0.7	%

Durability: flammability

Flammability	Highly flammable

Durability: fluids and sunlight

Water (fresh)	Acceptable
Water (salt)	Acceptable
Weak acids	Acceptable
Strong acids	Acceptable
Weak alkalis	Acceptable
Strong alkalis	Acceptable
Organic solvents	Limited use
UV radiation (sunlight)	Fair
Oxidation at 500C	Unacceptable

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 4.3e4	-	4.77e4	BTU/lb
CO2 footprint, primary production	* 3.43	-	3.79	lb/lb
Water usage	* 4.59e3	-	5.07e3	in^3/lb

Material processing: energy

Polymer extrusion energy	* 2.35e3	-	2.59e3	BTU/lb

Polymer molding energy	* 5.98e3	-	6.59e3	BTU/lb
Coarse machining energy (per unit wt removed)	* 229	-	253	BTU/lb
Fine machining energy (per unit wt removed)	* 451	-	499	BTU/lb
Grinding energy (per unit wt removed)	* 698	-	771	BTU/lb

Material processing: CO2 footprint

Polymer extrusion CO2	* 0.438	-	0.483	lb/lb
Polymer molding CO2	* 1.11	-	1.23	lb/lb
Coarse machining CO2 (per unit wt removed)	* 0.0399	-	0.0441	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.0787	-	0.087	lb/lb
Grinding CO2 (per unit wt removed)	* 0.122	-	0.135	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Embodied energy, recycling	1.13e4			BTU/lb
CO2 footprint, recycling	* 0.896	-	0.99	lb/lb
Recycle fraction in current supply	8.02	-	8.86	%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	* 1.89e4	-	1.98e4	BTU/lb
Combustion CO2	* 3.06	-	3.22	lb/lb
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Packaging, Buoyancy, Insulation, Cushioning, Sleeping Mats, Automotive, Furnishing

Other notes

Closed cell, cross-linked, high-density polyethylene, generally available in sheet form.Can be thermomolded to simple and complex shapes.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

12.

PE-LD foam (cross-linked, closed cell, 0.018)

Identification

Designation

Low density, cross-linked polyethylene (LDPE, XLPE, PE-X) closed cell foam, expanded with nitrogen, 0.018 specific gravity (based on Plastazote LD18)

Tradenames

PLASTAZOTE (EVAZOTE, SUPAZOTE are similar EVA and EMA based materials)

General Properties

Density	5.78e-4	-	7.23e-4	lb/in^3
Price	* 1.32	-	1.41	USD/lb

Composition overview

Composition (summary)

(CH2)n

Base	Polymer

Polymer class		Thermoplastic : semi-crystalline			
Polymer type		PE-LD			
Polymer type full name		Polyethylene, low density			
Filler type		Unfilled			

Composition detail (polymers and natural materials)

Polymer		100			%

Foam & honeycomb properties

Anisotropy ratio	*	1	-	1.5	
Cells/volume	*	1.64e3	-	1.64e4	/in^3
Relative density		0.017	-	0.022	

Mechanical properties

Young's modulus	*	3.63e-5	-	4.35e-5	10^6 psi
Compressive modulus	*	9.61e-4	-	0.00101	10^6 psi
Flexural modulus		3.63e-5	-	4.35e-5	10^6 psi
Shear modulus	*	1.45e-5	-	2.9e-5	10^6 psi
Bulk modulus	*	3.63e-5	-	4.35e-5	10^6 psi
Poisson's ratio	*	0.07	-	0.1	
Shape factor		2			
Yield strength (elastic limit)	*	0.00145	-	0.00218	ksi
Tensile strength		0.0377	-	0.0435	ksi
Compressive strength	*	0.00145	-	0.00218	ksi
Compressive stress @ 25% strain		0.0045	-	0.00508	ksi
Compressive stress @ 50% strain		0.0131	-	0.0145	ksi
Flexural strength (modulus of rupture)	*	0.00145	-	0.00218	ksi
Shear strength		7.25e-4	-	0.00109	ksi
Elongation		90	-	100	% strain
Hardness - Vickers	*	0.001	-	0.0015	HV
Fatigue strength at 10^7 cycles	*	0.0218	-	0.029	ksi
Fracture toughness	*	0.00455	-	0.0091	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	0.1	-	0.2	
Densification strain	*	0.94	-	0.96	

Thermal properties

Melting point		234	-	243	°F
Glass temperature		-193	-	-130	°F
Maximum service temperature		189	-	207	°F
Minimum service temperature		-99.4	-	-81.4	°F
Thermal conductivity		0.0208	-	0.022	BTU.ft/hr.ft^2.°F
Specific heat capacity		0.466	-	0.502	BTU/lb.°F
Thermal expansion coefficient		106	-	122	µstrain/°F

Electrical properties

Electrical resistivity	*	1e21	-	1e23	µohm.cm
Dielectric constant (relative permittivity)	*	1.05	-	1.1	
Dissipation factor (dielectric loss tangent)	*	1e-4	-	2e-4	
Dielectric strength (dielectric breakdown)	*	102	-	152	V/mil

Optical properties

Transparency		Opaque			

Absorption, permeability

Water absorption @ 24 hrs		0.4	-	0.5	%

Durability: flammability

Flammability		Highly flammable			

Durability: fluids and sunlight

Water (fresh)		Acceptable			
Water (salt)		Acceptable			
Weak acids		Acceptable			

Strong acids	Acceptable			
Weak alkalis	Acceptable			
Strong alkalis	Acceptable			
Organic solvents	Limited use			
UV radiation (sunlight)	Poor			
Oxidation at 500C	Unacceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 4.43e4	-	4.9e4	BTU/lb
CO2 footprint, primary production	* 4.28	-	4.73	lb/lb
Water usage	* 5.98e3	-	6.62e3	in^3/lb

Material processing: energy

Polymer extrusion energy	* 2.32e3	-	2.56e3	BTU/lb
Polymer molding energy	* 5.87e3	-	6.48e3	BTU/lb
Coarse machining energy (per unit wt removed)	* 207	-	229	BTU/lb
Fine machining energy (per unit wt removed)	* 232	-	257	BTU/lb
Grinding energy (per unit wt removed)	* 260	-	288	BTU/lb

Material processing: CO2 footprint

Polymer extrusion CO2	* 0.431	-	0.476	lb/lb
Polymer molding CO2	* 1.09	-	1.21	lb/lb
Coarse machining CO2 (per unit wt removed)	* 0.0361	-	0.0399	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.0405	-	0.0448	lb/lb
Grinding CO2 (per unit wt removed)	* 0.0454	-	0.0502	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Embodied energy, recycling	1.16e4			BTU/lb
CO2 footprint, recycling	1.12			lb/lb
Recycle fraction in current supply	8.02	-	8.86	%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	* 1.89e4	-	1.99e4	BTU/lb
Combustion CO2	* 3.06	-	3.22	lb/lb
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Packaging, Buoyancy, Insulation, Cushioning, Sleeping Mats, Automotive, Furnishing

Other notes

Closed cell, cross-linked, low-density polyethylene, generally available in sheet form.Can be thermomolded to simple and complex shapes.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

13.

PE-LD foam (cross-linked, closed cell, 0.024)

Identification

Designation
Low density, cross-linked polyethylene (LDPE, XLPE, PE-X) closed cell foam, expanded with nitrogen, 0.024 specific gravity (based on Plastazote LD24)
Tradenames
PLASTAZOTE (EVAZOTE, SUPAZOTE are similar EVA and EMA based materials)

General Properties

Density		7.95e-4	-	9.39e-4	lb/in^3
Price	*	1.32	-	1.41	USD/lb

Composition overview

Composition (summary)
(CH2)n

Base	Polymer
Polymer class	Thermoplastic : semi-crystalline
Polymer type	PE-LD
Polymer type full name	Polyethylene, low density
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer		100			%

Foam & honeycomb properties

Anisotropy ratio	*	1	-	1.5	
Cells/volume	*	1.64e3	-	1.64e4	/in^3
Relative density		0.024	-	0.028	

Mechanical properties

Young's modulus	*	5.8e-5	-	8.7e-5	10^6 psi
Compressive modulus	*	0.00124	-	0.00143	10^6 psi
Flexural modulus		5.8e-5	-	8.7e-5	10^6 psi
Shear modulus	*	2.9e-5	-	4.35e-5	10^6 psi
Bulk modulus	*	5.8e-5	-	8.7e-5	10^6 psi
Poisson's ratio	*	0.09	-	0.12	
Shape factor		2.2			
Yield strength (elastic limit)	*	0.00174	-	0.00247	ksi
Tensile strength		0.0363	-	0.0493	ksi
Compressive strength	*	0.00174	-	0.00247	ksi
Compressive stress @ 25% strain		0.00479	-	0.00537	ksi
Compressive stress @ 50% strain		0.0138	-	0.0152	ksi
Flexural strength (modulus of rupture)	*	0.00174	-	0.00247	ksi
Shear strength		8.7e-4	-	0.00123	ksi
Elongation		95	-	105	% strain
Hardness - Vickers	*	0.0012	-	0.0017	HV
Fatigue strength at 10^7 cycles	*	0.0261	-	0.0334	ksi
Fracture toughness	*	0.0091	-	0.0137	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	0.1	-	0.2	
Densification strain	*	0.9	-	0.94	

Thermal properties

Melting point		234	-	243	°F
Glass temperature		-193	-	-130	°F
Maximum service temperature		189	-	207	°F
Minimum service temperature		-99.4	-	-81.4	°F
Thermal conductivity		0.0208	-	0.022	BTU.ft/hr.ft^2.°F
Specific heat capacity		0.466	-	0.502	BTU/lb.°F
Thermal expansion coefficient		106	-	122	µstrain/°F

Electrical properties

Electrical resistivity	*	1e21	-	1e23	µohm.cm
Dielectric constant (relative permittivity)	*	1.05	-	1.1	

Dissipation factor (dielectric loss tangent)	* 1e-4	-	2e-4	
Dielectric strength (dielectric breakdown)	* 102	-	152	V/mil

Optical properties

Transparency	Opaque			

Absorption, permeability

Water absorption @ 24 hrs	0.4	-	0.5	%

Durability: flammability

Flammability	Highly flammable

Durability: fluids and sunlight

Water (fresh)	Acceptable
Water (salt)	Acceptable
Weak acids	Acceptable
Strong acids	Acceptable
Weak alkalis	Acceptable
Strong alkalis	Acceptable
Organic solvents	Limited use
UV radiation (sunlight)	Poor
Oxidation at 500C	Unacceptable

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 4.43e4	-	4.9e4	BTU/lb
CO2 footprint, primary production	* 4.28	-	4.73	lb/lb
Water usage	* 5.98e3	-	6.62e3	in^3/lb

Material processing: energy

Polymer extrusion energy	* 2.32e3	-	2.56e3	BTU/lb
Polymer molding energy	* 5.87e3	-	6.48e3	BTU/lb
Coarse machining energy (per unit wt removed)	* 207	-	228	BTU/lb
Fine machining energy (per unit wt removed)	* 229	-	253	BTU/lb
Grinding energy (per unit wt removed)	* 253	-	280	BTU/lb

Material processing: CO2 footprint

Polymer extrusion CO2	* 0.431	-	0.476	lb/lb
Polymer molding CO2	* 1.09	-	1.21	lb/lb
Coarse machining CO2 (per unit wt removed)	* 0.0361	-	0.0398	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.0399	-	0.0441	lb/lb
Grinding CO2 (per unit wt removed)	* 0.0441	-	0.0488	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Embodied energy, recycling	1.16e4			BTU/lb
CO2 footprint, recycling	* 1.12	-	1.24	lb/lb
Recycle fraction in current supply	8.02	-	8.86	%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	* 1.89e4	-	1.99e4	BTU/lb
Combustion CO2	* 3.06	-	3.22	lb/lb
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Packaging, Buoyancy, Insulation, Cushioning, Sleeping Mats, Automotive, Furnishing

Other notes

Closed cell, cross-linked, low-density polyethylene, generally available in sheet form.Can be thermomolded to simple and complex shapes.

Links

ProcessUniverse

Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

14.

PE-LD foam (cross-linked, closed cell, 0.033)

Identification

Designation

Low density, cross-linked polyethylene (LDPE, XLPE, PE-X) closed cell foam, expanded with nitrogen, 0.033 specific gravity (based on Plastazote LD33)

Tradenames

PLASTAZOTE (EVAZOTE, SUPAZOTE are similar EVA and EMA based materials)

General Properties

Density		0.00112	-	0.00126	lb/in^3
Price	*	1.32	-	1.41	USD/lb

Composition overview

Composition (summary)

(CH2)n

Base	Polymer
Polymer class	Thermoplastic : semi-crystalline
Polymer type	PE-LD
Polymer type full name	Polyethylene, low density
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer		100			%

Foam & honeycomb properties

Anisotropy ratio	*	1	-	1.5	
Cells/volume	*	1.64e3	-	1.64e4	/in^3
Relative density		0.033	-	0.038	

Mechanical properties

Young's modulus	*	1.16e-4	-	1.31e-4	10^6 psi
Compressive modulus	*	0.00174	-	0.00198	10^6 psi
Flexural modulus		1.16e-4	-	1.31e-4	10^6 psi
Shear modulus	*	5.8e-5	-	7.25e-5	10^6 psi
Bulk modulus	*	1.16e-4	-	1.31e-4	10^6 psi
Poisson's ratio	*	0.18	-	0.22	
Shape factor		2.3			
Yield strength (elastic limit)	*	0.00261	-	0.00319	ksi
Tensile strength		0.0544	-	0.066	ksi
Compressive strength	*	0.00261	-	0.00319	ksi
Compressive stress @ 25% strain		0.00551	-	0.00609	ksi
Compressive stress @ 50% strain		0.016	-	0.0174	ksi
Flexural strength (modulus of rupture)	*	0.00261	-	0.00319	ksi
Shear strength		0.00131	-	0.0016	ksi
Elongation		120	-	135	% strain
Hardness - Vickers	*	0.0018	-	0.0022	HV
Fatigue strength at 10^7 cycles	*	0.0377	-	0.0435	ksi
Fracture toughness	*	0.0137	-	0.0182	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	0.14	-	0.24	

Densification strain	*	0.88	-	0.92	

Thermal properties

Melting point		234	-	243	°F
Glass temperature		-193	-	-130	°F
Maximum service temperature		207	-	230	°F
Minimum service temperature		-99.4	-	-81.4	°F
Thermal conductivity		0.0225	-	0.0237	BTU.ft/hr.ft^2.°F
Specific heat capacity		0.466	-	0.502	BTU/lb.°F
Thermal expansion coefficient		106	-	122	µstrain/°F

Electrical properties

Electrical resistivity	*	1e21	-	1e23	µohm.cm
Dielectric constant (relative permittivity)	*	1.08	-	1.12	
Dissipation factor (dielectric loss tangent)	*	1e-4	-	2e-4	
Dielectric strength (dielectric breakdown)	*	102	-	152	V/mil

Optical properties

Transparency	Opaque

Absorption, permeability

Water absorption @ 24 hrs	0.4	-	0.5	%

Durability: flammability

Flammability	Highly flammable

Durability: fluids and sunlight

Water (fresh)	Acceptable
Water (salt)	Acceptable
Weak acids	Acceptable
Strong acids	Acceptable
Weak alkalis	Acceptable
Strong alkalis	Acceptable
Organic solvents	Limited use
UV radiation (sunlight)	Poor
Oxidation at 500C	Unacceptable

Primary material production: energy, CO2 and water

Embodied energy, primary production	*	4.43e4	-	4.9e4	BTU/lb
CO2 footprint, primary production	*	4.28	-	4.73	lb/lb
Water usage	*	5.98e3	-	6.62e3	in^3/lb

Material processing: energy

Polymer extrusion energy	*	2.32e3	-	2.56e3	BTU/lb
Polymer molding energy	*	5.87e3	-	6.48e3	BTU/lb
Coarse machining energy (per unit wt removed)	*	207	-	228	BTU/lb
Fine machining energy (per unit wt removed)	*	229	-	253	BTU/lb
Grinding energy (per unit wt removed)	*	254	-	280	BTU/lb

Material processing: CO2 footprint

Polymer extrusion CO2	*	0.431	-	0.476	lb/lb
Polymer molding CO2	*	1.09	-	1.21	lb/lb
Coarse machining CO2 (per unit wt removed)	*	0.0361	-	0.0399	lb/lb
Fine machining CO2 (per unit wt removed)	*	0.0399	-	0.0441	lb/lb
Grinding CO2 (per unit wt removed)	*	0.0442	-	0.0489	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle		False			
Embodied energy, recycling		1.16e4			BTU/lb
CO2 footprint, recycling	*	1.12	-	1.24	lb/lb
Recycle fraction in current supply		8.02	-	8.86	%
Downcycle		True			
Combust for energy recovery		True			
Heat of combustion (net)	*	1.89e4	-	1.99e4	BTU/lb

Combustion CO2	* 3.06	-	3.22	lb/lb
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Packaging, Buoyancy, Insulation, Cushioning, Sleeping Mats, Automotive, Furnishing

Other notes

Closed cell, cross-linked, low-density polyethylene, generally available in sheet form.Can be thermomolded to simple and complex shapes.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

15.PE-LD foam (cross-linked, closed cell, 0.045)

Identification

Designation

Low density, cross-linked polyethylene (LDPE, XLPE, PE-X) closed cell foam, expanded with nitrogen, 0.045 specific gravity (based on Plastazote LD45)

Tradenames

PLASTAZOTE (EVAZOTE, SUPAZOTE are similar EVA and EMA based materials)

General Properties

Density	0.00155	-	0.0017	lb/in^3
Price	* 1.32	-	1.41	USD/lb

Composition overview

Composition (summary)

(CH2)n

Base	Polymer
Polymer class	Thermoplastic : semi-crystalline
Polymer type	PE-LD
Polymer type full name	Polyethylene, low density
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer	100			%

Foam & honeycomb properties

Anisotropy ratio	* 1	-	1.5	
Cells/volume	* 1.64e3	-	1.64e4	/in^3
Relative density	0.046	-	0.051	

Mechanical properties

Young's modulus	* 2.18e-4	-	2.61e-4	10^6 psi
Compressive modulus	* 0.00241	-	0.00278	10^6 psi
Flexural modulus	2.18e-4	-	2.61e-4	10^6 psi
Shear modulus	* 2.18e-4	-	2.61e-4	10^6 psi
Bulk modulus	* 2.18e-4	-	2.61e-4	10^6 psi
Poisson's ratio	* 0.23	-	0.27	
Shape factor	2.5			
Yield strength (elastic limit)	* 0.0029	-	0.00363	ksi
Tensile strength	0.0841	-	0.0885	ksi

Compressive strength	*	0.0029	-	0.00363	ksi
Compressive stress @ 25% strain		0.00696	-	0.00754	ksi
Compressive stress @ 50% strain		0.0189	-	0.0203	ksi
Flexural strength (modulus of rupture)	*	0.0029	-	0.00363	ksi
Shear strength		0.00145	-	0.00181	ksi
Elongation		145	-	155	% strain
Hardness - Vickers	*	0.002	-	0.0025	HV
Fatigue strength at 10^7 cycles	*	0.0479	-	0.058	ksi
Fracture toughness	*	0.02	-	0.0246	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	0.16	-	0.26	
Densification strain	*	0.86	-	0.9	

Thermal properties

Melting point		234	-	243	°F
Glass temperature		-193	-	-130	°F
Maximum service temperature		216	-	234	°F
Minimum service temperature		-99.4	-	-81.4	°F
Thermal conductivity		0.0243	-	0.0254	BTU.ft/hr.ft^2.°F
Specific heat capacity		0.466	-	0.502	BTU/lb.°F
Thermal expansion coefficient		106	-	122	µstrain/°F

Electrical properties

Electrical resistivity	*	1e21	-	1e23	µohm.cm
Dielectric constant (relative permittivity)	*	1.1	-	1.15	
Dissipation factor (dielectric loss tangent)	*	1e-4	-	2e-4	
Dielectric strength (dielectric breakdown)	*	102	-	152	V/mil

Optical properties

Transparency	Opaque

Absorption, permeability

Water absorption @ 24 hrs		0.4	-	0.5	%

Durability: flammability

Flammability	Highly flammable

Durability: fluids and sunlight

Water (fresh)	Acceptable
Water (salt)	Acceptable
Weak acids	Acceptable
Strong acids	Acceptable
Weak alkalis	Acceptable
Strong alkalis	Acceptable
Organic solvents	Limited use
UV radiation (sunlight)	Poor
Oxidation at 500C	Unacceptable

Primary material production: energy, CO2 and water

Embodied energy, primary production	*	4.43e4	-	4.9e4	BTU/lb
CO2 footprint, primary production	*	4.28	-	4.73	lb/lb
Water usage	*	5.98e3	-	6.62e3	in^3/lb

Material processing: energy

Polymer extrusion energy	*	2.32e3	-	2.56e3	BTU/lb
Polymer molding energy	*	5.87e3	-	6.48e3	BTU/lb
Coarse machining energy (per unit wt removed)	*	206	-	228	BTU/lb
Fine machining energy (per unit wt removed)	*	225	-	248	BTU/lb
Grinding energy (per unit wt removed)	*	245	-	271	BTU/lb

Material processing: CO2 footprint

Polymer extrusion CO2	*	0.431	-	0.476	lb/lb
Polymer molding CO2	*	1.09	-	1.21	lb/lb
Coarse machining CO2 (per unit wt removed)	*	0.036	-	0.0398	lb/lb

Fine machining CO2 (per unit wt removed)	* 0.0392	-	0.0433	lb/lb
Grinding CO2 (per unit wt removed)	* 0.0427	-	0.0472	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Embodied energy, recycling	1.16e4			BTU/lb
CO2 footprint, recycling	* 1.12	-	1.24	lb/lb
Recycle fraction in current supply	8.02	-	8.86	%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	* 1.89e4	-	1.99e4	BTU/lb
Combustion CO2	* 3.06	-	3.22	lb/lb
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Packaging, Buoyancy, Insulation, Cushioning, Sleeping Mats, Automotive, Furnishing

Other notes

Closed cell, cross-linked, low-density polyethylene, generally available in sheet form.Can be thermomolded to simple and complex shapes.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

16. PE-LD foam (cross-linked, closed cell, 0.060)

Identification

Designation

Low density, cross-linked polyethylene (LDPE, XLPE, PE-X) closed cell foam, expanded with nitrogen, 0.060 specific gravity (based on Plastazote LD60)

Tradenames

PLASTAZOTE (EVAZOTE, SUPAZOTE are similar EVA and EMA based materials)

General Properties

Density	0.0021	-	0.00224	lb/in^3
Price	* 1.32	-	1.41	USD/lb

Composition overview

Composition (summary)

(CH2)n

Base	Polymer
Polymer class	Thermoplastic : semi-crystalline
Polymer type	PE-LD
Polymer type full name	Polyethylene, low density
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer	100	%

Foam & honeycomb properties

Anisotropy ratio	* 1	-	1.5	
Cells/volume	* 1.64e3	-	1.64e4	/in^3
Relative density	0.062	-	0.067	

Mechanical properties

Young's modulus	*	3.63e-4	-	4.35e-4	10^6 psi
Compressive modulus	*	0.00331	-	0.0038	10^6 psi
Flexural modulus		2.18e-4	-	4.35e-4	10^6 psi
Shear modulus	*	1.45e-4	-	2.18e-4	10^6 psi
Bulk modulus	*	3.63e-4	-	4.35e-4	10^6 psi
Poisson's ratio	*	0.26	-	0.3	
Shape factor		2.6			
Yield strength (elastic limit)	*	0.00363	-	0.00435	ksi
Tensile strength		0.112	-	0.116	ksi
Compressive strength	*	0.00363	-	0.00435	ksi
Compressive stress @ 25% strain		0.00986	-	0.0104	ksi
Compressive stress @ 50% strain		0.0239	-	0.0254	ksi
Flexural strength (modulus of rupture)	*	0.00363	-	0.00435	ksi
Shear strength		0.00181	-	0.00218	ksi
Elongation		155	-	165	% strain
Hardness - Vickers	*	0.0025	-	0.003	HV
Fatigue strength at 10^7 cycles	*	0.0682	-	0.0769	ksi
Fracture toughness	*	0.0319	-	0.0364	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	0.18	-	0.28	
Densification strain	*	0.84	-	0.88	

Thermal properties

Melting point		234	-	243	°F
Glass temperature		-193	-	-130	°F
Maximum service temperature		216	-	234	°F
Minimum service temperature		-99.4	-	-81.4	°F
Thermal conductivity		0.0272	-	0.0283	BTU.ft/hr.ft^2.°F
Specific heat capacity		0.466	-	0.502	BTU/lb.°F
Thermal expansion coefficient		106	-	122	µstrain/°F

Electrical properties

Electrical resistivity	*	1e21	-	1e23	µohm.cm
Dielectric constant (relative permittivity)	*	1.14	-	1.18	
Dissipation factor (dielectric loss tangent)	*	1e-4	-	2e-4	
Dielectric strength (dielectric breakdown)	*	102	-	152	V/mil

Optical properties

Transparency	Opaque

Absorption, permeability

Water absorption @ 24 hrs		0.4	-	0.5	%

Durability: flammability

Flammability	Highly flammable

Durability: fluids and sunlight

Water (fresh)	Acceptable
Water (salt)	Acceptable
Weak acids	Acceptable
Strong acids	Acceptable
Weak alkalis	Acceptable
Strong alkalis	Acceptable
Organic solvents	Limited use
UV radiation (sunlight)	Poor
Oxidation at 500C	Unacceptable

Primary material production: energy, CO2 and water

Embodied energy, primary production	*	4.43e4	-	4.9e4	BTU/lb
CO2 footprint, primary production	*	4.28	-	4.73	lb/lb
Water usage	*	5.98e3	-	6.62e3	in^3/lb

Material processing: energy

Polymer extrusion energy	* 2.32e3	-	2.56e3	BTU/lb
Polymer molding energy	* 5.87e3	-	6.48e3	BTU/lb
Coarse machining energy (per unit wt removed)	* 206	-	228	BTU/lb
Fine machining energy (per unit wt removed)	* 223	-	246	BTU/lb
Grinding energy (per unit wt removed)	* 242	-	267	BTU/lb

Material processing: CO2 footprint

Polymer extrusion CO2	* 0.431	-	0.476	lb/lb
Polymer molding CO2	* 1.09	-	1.21	lb/lb
Coarse machining CO2 (per unit wt removed)	* 0.036	-	0.0397	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.0389	-	0.043	lb/lb
Grinding CO2 (per unit wt removed)	* 0.0421	-	0.0466	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Embodied energy, recycling	1.16e4			BTU/lb
CO2 footprint, recycling	* 1.12	-	1.24	lb/lb
Recycle fraction in current supply	8.02	-	8.86	%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	* 1.89e4	-	1.99e4	BTU/lb
Combustion CO2	* 3.06	-	3.22	lb/lb
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Packaging, Buoyancy, Insulation, Cushioning, Sleeping Mats, Automotive, Furnishing

Other notes

Closed cell, cross-linked, low-density polyethylene, generally available in sheet form.Can be thermomolded to simple and complex shapes.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

17.

PE-LD foam (cross-linked, closed cell, 0.070)

Identification

Designation

Low density, cross-linked polyethylene (LDPE, XLPE, PE-X) closed cell foam, expanded with nitrogen, 0.070 specific gravity (based on Plastazote LD70)

Tradenames

PLASTAZOTE (EVAZOTE, SUPAZOTE are similar EVA and EMA based materials)

General Properties

Density	0.00246	-	0.0026	lb/in^3
Price	* 1.32	-	1.41	USD/lb

Composition overview

Composition (summary)
(CH2)n

Base	Polymer			
Polymer class	Thermoplastic : semi-crystalline			
Polymer type	PE-LD			
Polymer type full name	Polyethylene, low density			
Filler type	Unfilled			

Composition detail (polymers and natural materials)

Polymer	100			%

Foam & honeycomb properties

Anisotropy ratio	* 1	-	1.5	
Cells/volume	* 1.64e3	-	1.64e4	/in^3
Relative density	0.073	-	0.077	

Mechanical properties

Young's modulus	* 5.08e-4	-	5.8e-4	10^6 psi
Compressive modulus	* 0.0039	-	0.00452	10^6 psi
Flexural modulus	5.08e-4	-	5.8e-4	10^6 psi
Shear modulus	* 2.47e-4	-	2.9e-4	10^6 psi
Bulk modulus	* 5.08e-4	-	5.8e-4	10^6 psi
Poisson's ratio	* 0.3	-	0.33	
Shape factor	2.7			
Yield strength (elastic limit)	* 0.00406	-	0.00508	ksi
Tensile strength	0.133	-	0.138	ksi
Compressive strength	* 0.00406	-	0.00508	ksi
Compressive stress @ 25% strain	0.012	-	0.0126	ksi
Compressive stress @ 50% strain	0.0276	-	0.0305	ksi
Flexural strength (modulus of rupture)	* 0.00406	-	0.00508	ksi
Shear strength	0.00203	-	0.00254	ksi
Elongation	165	-	175	% strain
Hardness - Vickers	* 0.0028	-	0.0035	HV
Fatigue strength at 10^7 cycles	* 0.0725	-	0.087	ksi
Fracture toughness	* 0.0391	-	0.0455	ksi.in^0.5
Mechanical loss coefficient (tan delta)	* 0.2	-	0.3	
Densification strain	* 0.82	-	0.85	

Thermal properties

Melting point	234	-	243	°F
Glass temperature	-193	-	-130	°F
Maximum service temperature	216	-	234	°F
Minimum service temperature	-99.4	-	-81.4	°F
Thermal conductivity	0.0289	-	0.03	BTU.ft/hr.ft^2.°F
Specific heat capacity	0.466	-	0.502	BTU/lb.°F
Thermal expansion coefficient	106	-	122	µstrain/°F

Electrical properties

Electrical resistivity	* 1e21	-	1e23	µohm.cm
Dielectric constant (relative permittivity)	* 1.15	-	1.2	
Dissipation factor (dielectric loss tangent)	* 1e-4	-	2e-4	
Dielectric strength (dielectric breakdown)	* 102	-	152	V/mil

Optical properties

Transparency	Opaque			

Absorption, permeability

Water absorption @ 24 hrs	0.4	-	0.5	%

Durability: flammability

Flammability	Highly flammable			

Durability: fluids and sunlight

Water (fresh)	Acceptable			
Water (salt)	Acceptable			
Weak acids	Acceptable			
Strong acids	Acceptable			
Weak alkalis	Acceptable			
Strong alkalis	Acceptable			
Organic solvents	Limited use			
UV radiation (sunlight)	Poor			
Oxidation at 500C	Unacceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 4.43e4	-	4.9e4	BTU/lb
CO2 footprint, primary production	* 4.28	-	4.73	lb/lb
Water usage	* 5.98e3	-	6.62e3	in^3/lb

Material processing: energy

Polymer extrusion energy	* 2.32e3	-	2.56e3	BTU/lb
Polymer molding energy	* 5.87e3	-	6.48e3	BTU/lb
Coarse machining energy (per unit wt removed)	* 206	-	228	BTU/lb
Fine machining energy (per unit wt removed)	* 222	-	246	BTU/lb
Grinding energy (per unit wt removed)	* 241	-	266	BTU/lb

Material processing: CO2 footprint

Polymer extrusion CO2	* 0.431	-	0.476	lb/lb
Polymer molding CO2	* 1.09	-	1.21	lb/lb
Coarse machining CO2 (per unit wt removed)	* 0.0359	-	0.0397	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.0388	-	0.0429	lb/lb
Grinding CO2 (per unit wt removed)	* 0.042	-	0.0464	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Embodied energy, recycling	1.16e4			BTU/lb
CO2 footprint, recycling	* 1.12	-	1.24	lb/lb
Recycle fraction in current supply	8.02	-	8.86	%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	* 1.89e4	-	1.99e4	BTU/lb
Combustion CO2	* 3.06	-	3.22	lb/lb
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Packaging, Buoyancy, Insulation, Cushioning, Sleeping Mats, Automotive, Furnishing

Other notes

Closed cell, cross-linked, low-density polyethylene, generally available in sheet form.Can be thermomolded to simple and complex shapes.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

18.

PE-LD foam (crosslinked, closed cell, 0.029)

Identification

Designation

Low density, cross-linked polyethylene (LDPE, XLPE, PE-X) closed cell foam, expanded with nitrogen, 0.029 specific gravity (based on Plastazote LD29)

Tradenames

PLASTAZOTE (EVAZOTE, SUPAZOTE are similar EVA and EMA based materials)

General Properties

Density		9.75e-4	-	0.00112	lb/in^3
Price	*	1.32	-	1.41	USD/lb

Composition overview

Composition (summary)

(CH2)n

Base	Polymer
Polymer class	Thermoplastic : semi-crystalline
Polymer type	PE-LD
Polymer type full name	Polyethylene, low density
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer		100			%

Foam & honeycomb properties

Anisotropy ratio	*	1	-	1.5	
Cells/volume	*	1.64e3	-	1.64e4	/in^3
Relative density		0.029	-	0.033	

Mechanical properties

Young's modulus	*	7.25e-5	-	1.02e-4	10^6 psi
Compressive modulus	*	0.00149	-	0.00173	10^6 psi
Flexural modulus		7.25e-5	-	1.02e-4	10^6 psi
Shear modulus	*	4.35e-5	-	5.8e-5	10^6 psi
Bulk modulus	*	7.25e-5	-	1.02e-4	10^6 psi
Poisson's ratio	*	0.15	-	0.18	
Shape factor		2.2			
Yield strength (elastic limit)	*	0.00218	-	0.00261	ksi
Tensile strength		0.0551	-	0.0595	ksi
Compressive strength	*	0.00218	-	0.00261	ksi
Compressive stress @ 25% strain		0.00522	-	0.0058	ksi
Compressive stress @ 50% strain		0.0152	-	0.0167	ksi
Flexural strength (modulus of rupture)	*	0.00218	-	0.00261	ksi
Shear strength		0.00109	-	0.00131	ksi
Elongation		120	-	130	% strain
Hardness - Vickers	*	0.0015	-	0.0018	HV
Fatigue strength at 10^7 cycles	*	0.0334	-	0.0392	ksi
Fracture toughness	*	0.0109	-	0.0164	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	0.12	-	0.22	
Densification strain	*	0.89	-	0.93	

Thermal properties

Melting point		234	-	243	°F
Glass temperature		-193	-	-130	°F
Maximum service temperature		207	-	230	°F
Minimum service temperature		-99.4	-	-81.4	°F
Thermal conductivity		0.022	-	0.0231	BTU.ft/hr.ft^2.°F

Specific heat capacity	0.466	-	0.502	BTU/lb.°F
Thermal expansion coefficient	106	-	122	µstrain/°F

Electrical properties

Electrical resistivity	* 1e21	-	1e23	µohm.cm
Dielectric constant (relative permittivity)	* 1.06	-	1.11	
Dissipation factor (dielectric loss tangent)	* 1e-4	-	2e-4	
Dielectric strength (dielectric breakdown)	* 102	-	152	V/mil

Optical properties

Transparency	Opaque

Absorption, permeability

Water absorption @ 24 hrs	0.4	-	0.5	%

Durability: flammability

Flammability	Highly flammable

Durability: fluids and sunlight

Water (fresh)	Acceptable
Water (salt)	Acceptable
Weak acids	Acceptable
Strong acids	Acceptable
Weak alkalis	Acceptable
Strong alkalis	Acceptable
Organic solvents	Limited use
UV radiation (sunlight)	Poor
Oxidation at 500C	Unacceptable

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 4.43e4	-	4.9e4	BTU/lb
CO2 footprint, primary production	* 4.28	-	4.73	lb/lb
Water usage	* 5.98e3	-	6.62e3	in^3/lb

Material processing: energy

Polymer extrusion energy	* 2.32e3	-	2.56e3	BTU/lb
Polymer molding energy	* 5.87e3	-	6.48e3	BTU/lb
Coarse machining energy (per unit wt removed)	* 207	-	228	BTU/lb
Fine machining energy (per unit wt removed)	* 227	-	251	BTU/lb
Grinding energy (per unit wt removed)	* 251	-	277	BTU/lb

Material processing: CO2 footprint

Polymer extrusion CO2	* 0.431	-	0.476	lb/lb
Polymer molding CO2	* 1.09	-	1.21	lb/lb
Coarse machining CO2 (per unit wt removed)	* 0.036	-	0.0398	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.0397	-	0.0438	lb/lb
Grinding CO2 (per unit wt removed)	* 0.0437	-	0.0483	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Embodied energy, recycling	1.16e4			BTU/lb
CO2 footprint, recycling	* 1.12	-	1.24	lb/lb
Recycle fraction in current supply	8.02	-	8.86	%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	* 1.89e4	-	1.99e4	BTU/lb
Combustion CO2	* 3.06	-	3.22	lb/lb
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Packaging, Buoyancy, Insulation, Cushioning, Sleeping Mats, Automotive, Furnishing

Other notes
Closed cell, cross-linked, low-density polyethylene, generally available in sheet form.Can be thermomolded to simple and complex shapes.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

19.

Polyethylene terephthalate foam (closed cell, 0.108)

Identification

Designation
Polyethylene terephthalate closed-cell foam, 0.108 specific gravity
Tradenames
Airex, G-PET, NidaFoam

General Properties

Density		0.00364	-	0.00416	lb/in^3
Price	*	5.15	-	8.59	USD/lb

Composition overview

Composition (summary)
(CO-(C6H4)-CO-O-(CH2)2-O)n

Base	Polymer
Polymer class	Thermoplastic : amorphous
Polymer type	PET
Polymer type full name	Polyethylene terephthalate
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer		100			%

Foam & honeycomb properties

Anisotropy ratio	*	1	-	1.5	
Relative density		0.0725	-	0.0893	

Mechanical properties

Young's modulus	*	0.00752	-	0.0103	10^6 psi
Compressive modulus		0.00972	-	0.016	10^6 psi
Flexural modulus	*	0.00752	-	0.0103	10^6 psi
Shear modulus		0.0029	-	0.00406	10^6 psi
Poisson's ratio		0.333			
Shape factor		2.35			
Yield strength (elastic limit)	*	0.0754	-	0.101	ksi
Tensile strength	*	0.353	-	0.484	ksi
Compressive strength		0.2	-	0.27	ksi
Flexural strength (modulus of rupture)	*	0.0754	-	0.101	ksi
Shear strength		0.116	-	0.173	ksi

Thermal properties

Glass temperature		140	-	183	°F
Maximum service temperature		203	-	221	°F
Minimum service temperature		-58.7	-	-50.1	°F

Thermal conductivity	* 0.016	-	0.0177	BTU.ft/hr.ft^2.°F
Specific heat capacity	0.272	-	0.301	BTU/lb.°F
Thermal expansion coefficient	61.8	-	68.3	µstrain/°F

Electrical properties

Electrical resistivity	8.87e21	-	6.31e22	µohm.cm
Dielectric constant (relative permittivity)	* 1.15	-	1.27	
Dissipation factor (dielectric loss tangent)	0.003	-	0.01	

Optical properties

Transparency	Opaque

Absorption, permeability

Water absorption @ 24 hrs	0.14	-	0.18	%

Durability: flammability

Flammability	Highly flammable

Durability: fluids and sunlight

Water (fresh)	Excellent
Water (salt)	Excellent
Weak acids	Acceptable
Strong acids	Unacceptable
Weak alkalis	Acceptable
Strong alkalis	Limited use
Organic solvents	Limited use
UV radiation (sunlight)	Good
Oxidation at 500C	Unacceptable

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 4.51e4	-	4.99e4	BTU/lb
CO2 footprint, primary production	* 4.89	-	5.4	lb/lb
Water usage	* 1.05e4	-	1.16e4	in^3/lb

Material processing: energy

Coarse machining energy (per unit wt removed)	* 265	-	293	BTU/lb
Fine machining energy (per unit wt removed)	* 811	-	897	BTU/lb
Grinding energy (per unit wt removed)	* 1.42e3	-	1.57e3	BTU/lb

Material processing: CO2 footprint

Coarse machining CO2 (per unit wt removed)	* 0.0462	-	0.0511	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.142	-	0.156	lb/lb
Grinding CO2 (per unit wt removed)	* 0.247	-	0.274	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Recycle fraction in current supply	20	-	22.1	%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	9.64e3	-	1.07e4	BTU/lb
Combustion CO2	2.18	-	2.41	lb/lb
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Core material for lightweight sandwich panels and structures. Wind turbine blades and nacelles, boat hulls, decks, superstructures, interiors, industrial containers, shelters and panels, X-ray tables

Other notes

Thermoformable, easy to machine, compatible with most resins and lamination processes

Links

ProcessUniverse
Producers

Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

20.

Polyethylene terephthalate foam (closed cell, 0.15)

Identification

Designation

Polyethylene terephthalate closed-cell foam, 0.15 specific gravity

Tradenames

Airex, G-PET, NidaFoam

General Properties

Density		0.00486	-	0.00578	lb/in^3
Price	*	5.15	-	8.59	USD/lb

Composition overview

Composition (summary)

(CO-(C6H4)-CO-O-(CH2)2-O)n

Base	Polymer
Polymer class	Thermoplastic : amorphous
Polymer type	PET
Polymer type full name	Polyethylene terephthalate
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer		100			%

Foam & honeycomb properties

Anisotropy ratio	*	1	-	1.5	
Relative density	*	0.0967	-	0.124	

Mechanical properties

Young's modulus	*	0.0106	-	0.0155	10^6 psi
Compressive modulus		0.0131	-	0.0203	10^6 psi
Flexural modulus	*	0.0106	-	0.0155	10^6 psi
Shear modulus		0.00435	-	0.00553	10^6 psi
Poisson's ratio		0.333			
Shape factor		2.36			
Yield strength (elastic limit)	*	0.107	-	0.15	ksi
Tensile strength	*	0.48	-	0.689	ksi
Compressive strength		0.29	-	0.389	ksi
Flexural strength (modulus of rupture)	*	0.107	-	0.15	ksi
Shear strength		0.145	-	0.197	ksi

Thermal properties

Glass temperature		140	-	183	°F
Maximum service temperature		203	-	221	°F
Minimum service temperature		-58.7	-	-50.1	°F
Thermal conductivity	*	0.0171	-	0.0189	BTU.ft/hr.ft^2.°F
Specific heat capacity		0.272	-	0.301	BTU/lb.°F
Thermal expansion coefficient		61.8	-	68.3	µstrain/°F

Electrical properties

Electrical resistivity		6.31e21	-	4.26e22	µohm.cm
Dielectric constant (relative permittivity)	*	1.22	-	1.35	

Dissipation factor (dielectric loss tangent)	0.003	-	0.01	

Optical properties

Transparency	Opaque			

Absorption, permeability

Water absorption @ 24 hrs	0.14	-	0.18	%

Durability: flammability

Flammability	Highly flammable			

Durability: fluids and sunlight

Water (fresh)	Excellent			
Water (salt)	Excellent			
Weak acids	Acceptable			
Strong acids	Unacceptable			
Weak alkalis	Acceptable			
Strong alkalis	Limited use			
Organic solvents	Limited use			
UV radiation (sunlight)	Good			
Oxidation at 500C	Unacceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 4.51e4	-	4.99e4	BTU/lb
CO2 footprint, primary production	* 4.89	-	5.4	lb/lb
Water usage	* 1.05e4	-	1.16e4	in^3/lb

Material processing: energy

Coarse machining energy (per unit wt removed)	* 269	-	297	BTU/lb
Fine machining energy (per unit wt removed)	* 850	-	939	BTU/lb
Grinding energy (per unit wt removed)	* 1.5e3	-	1.65e3	BTU/lb

Material processing: CO2 footprint

Coarse machining CO2 (per unit wt removed)	* 0.0469	-	0.0518	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.148	-	0.164	lb/lb
Grinding CO2 (per unit wt removed)	* 0.261	-	0.288	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Recycle fraction in current supply	20	-	22.1	%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	9.64e3	-	1.07e4	BTU/lb
Combustion CO2	2.18	-	2.41	lb/lb
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Core material for lightweight sandwich panels and structures. Wind turbine blades and nacelles, boat hulls, decks, superstructures, interiors, industrial containers, shelters and panels, X-ray tables

Other notes

Thermoformable, easy to machine, compatible with most resins and lamination processes

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

21.

Polyethylene terephthalate foam (closed cell, 0.24)

Identification

Designation

Polyethylene terephthalate closed-cell foam, 0.24 specific gravity

Tradenames

Airex, G-PET, NidaFoam

General Properties

Density		0.0085	-	0.00884	lb/in^3
Price	*	5.15	-	8.59	USD/lb

Composition overview

Composition (summary)

(CO-(C6H4)-CO-O-(CH2)2-O)n

Base	Polymer
Polymer class	Thermoplastic : amorphous
Polymer type	PET
Polymer type full name	Polyethylene terephthalate
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer		100			%

Foam & honeycomb properties

Anisotropy ratio	*	1	-	1.5	
Relative density	*	0.17	-	0.188	

Mechanical properties

Young's modulus	*	0.0223	-	0.0264	10^6 psi
Compressive modulus		0.0207	-	0.0228	10^6 psi
Flexural modulus	*	0.0223	-	0.0264	10^6 psi
Shear modulus		0.00689	-	0.00761	10^6 psi
Poisson's ratio		0.333			
Shape factor		2.39			
Yield strength (elastic limit)	*	0.213	-	0.257	ksi
Tensile strength	*	0.897	-	1.07	ksi
Compressive strength		0.482	-	0.532	ksi
Flexural strength (modulus of rupture)	*	0.213	-	0.257	ksi
Shear strength		0.186	-	0.206	ksi

Thermal properties

Glass temperature		140	-	183	°F
Maximum service temperature		203	-	221	°F
Minimum service temperature		-58.7	-	-50.1	°F
Thermal conductivity	*	0.02	-	0.0221	BTU.ft/hr.ft^2.°F
Specific heat capacity		0.272	-	0.301	BTU/lb.°F
Thermal expansion coefficient		61.8	-	68.3	µstrain/°F

Electrical properties

Electrical resistivity		3.13e21	-	2.6e22	µohm.cm
Dielectric constant (relative permittivity)	*	1.39	-	1.54	
Dissipation factor (dielectric loss tangent)		0.003	-	0.01	

Optical properties

Transparency	Opaque

Absorption, permeability

Water absorption @ 24 hrs		0.14	-	0.18	%

Durability: flammability

Flammability	Highly flammable			

Durability: fluids and sunlight

Water (fresh)	Excellent			
Water (salt)	Excellent			
Weak acids	Acceptable			
Strong acids	Unacceptable			
Weak alkalis	Acceptable			
Strong alkalis	Limited use			
Organic solvents	Limited use			
UV radiation (sunlight)	Good			
Oxidation at 500C	Unacceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 4.51e4	-	4.99e4	BTU/lb
CO2 footprint, primary production	* 4.89	-	5.4	lb/lb
Water usage	* 1.05e4	-	1.16e4	in^3/lb

Material processing: energy

Coarse machining energy (per unit wt removed)	* 264	-	291	BTU/lb
Fine machining energy (per unit wt removed)	* 798	-	882	BTU/lb
Grinding energy (per unit wt removed)	* 1.39e3	-	1.54e3	BTU/lb

Material processing: CO2 footprint

Coarse machining CO2 (per unit wt removed)	* 0.046	-	0.0508	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.139	-	0.154	lb/lb
Grinding CO2 (per unit wt removed)	* 0.243	-	0.268	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Recycle fraction in current supply	20	-	22.1	%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	9.64e3	-	1.07e4	BTU/lb
Combustion CO2	2.18	-	2.41	lb/lb
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Core material for lightweight sandwich panels and structures. Wind turbine blades and nacelles, boat hulls, decks, superstructures, interiors, industrial containers, shelters and panels, X-ray tables

Other notes

Thermoformable, easy to machine, compatible with most resins and lamination processes

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

22. Polyethylene terephthalate foam (closed cell, 0.32)

Identification

Designation

Polyethylene terephthalate closed-cell foam, 0.32 specific gravity

Tradenames

Airex, G-PET, NidaFoam

General Properties

Density		0.0113	-	0.0118	lb/in^3
Price	*	5.15	-	8.59	USD/lb

Composition overview

Composition (summary)

(CO-(C6H4)-CO-O-(CH2)2-O)n

Base	Polymer
Polymer class	Thermoplastic : amorphous
Polymer type	PET
Polymer type full name	Polyethylene terephthalate
Filler type	Unfilled

Composition detail (polymers and natural materials)

Polymer		100			%

Foam & honeycomb properties

Anisotropy ratio	*	1	-	1.5	
Relative density	*	0.227	-	0.251	

Mechanical properties

Young's modulus	*	0.0331	-	0.0394	10^6 psi
Compressive modulus		0.0372	-	0.0411	10^6 psi
Flexural modulus	*	0.0331	-	0.0394	10^6 psi
Shear modulus		0.0103	-	0.0114	10^6 psi
Poisson's ratio		0.333			
Shape factor		2.42			
Yield strength (elastic limit)	*	0.307	-	0.372	ksi
Tensile strength	*	1.23	-	1.47	ksi
Compressive strength		0.827	-	0.914	ksi
Flexural strength (modulus of rupture)	*	0.307	-	0.372	ksi
Shear strength		0.304	-	0.336	ksi

Thermal properties

Glass temperature		140	-	183	°F
Maximum service temperature		203	-	221	°F
Minimum service temperature		-58.7	-	-50.1	°F
Thermal conductivity	*	0.0229	-	0.0253	BTU.ft/hr.ft^2.°F
Specific heat capacity		0.272	-	0.301	BTU/lb.°F
Thermal expansion coefficient		61.8	-	68.3	µstrain/°F

Electrical properties

Electrical resistivity		2.19e21	-	1.82e22	µohm.cm
Dielectric constant (relative permittivity)	*	1.54	-	1.7	
Dissipation factor (dielectric loss tangent)		0.003	-	0.01	

Optical properties

Transparency	Opaque

Absorption, permeability

Water absorption @ 24 hrs		0.14	-	0.18	%

Durability: flammability

Flammability	Highly flammable

Durability: fluids and sunlight

Water (fresh)	Excellent

Water (salt)	Excellent			
Weak acids	Acceptable			
Strong acids	Unacceptable			
Weak alkalis	Acceptable			
Strong alkalis	Limited use			
Organic solvents	Limited use			
UV radiation (sunlight)	Good			
Oxidation at 500C	Unacceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 4.51e4	-	4.99e4	BTU/lb
CO2 footprint, primary production	* 4.89	-	5.4	lb/lb
Water usage	* 1.05e4	-	1.16e4	in^3/lb

Material processing: energy

Coarse machining energy (per unit wt removed)	* 281	-	310	BTU/lb
Fine machining energy (per unit wt removed)	* 969	-	1.07e3	BTU/lb
Grinding energy (per unit wt removed)	* 1.73e3	-	1.92e3	BTU/lb

Material processing: CO2 footprint

Coarse machining CO2 (per unit wt removed)	* 0.049	-	0.0541	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.169	-	0.187	lb/lb
Grinding CO2 (per unit wt removed)	* 0.303	-	0.334	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Recycle fraction in current supply	20	-	22.1	%
Downcycle	True			
Combust for energy recovery	True			
Heat of combustion (net)	9.64e3	-	1.07e4	BTU/lb
Combustion CO2	2.18	-	2.41	lb/lb
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Core material for lightweight sandwich panels and structures. Wind turbine blades and nacelles, boat hulls, decks, superstructures, interiors, industrial containers, shelters and panels, X-ray tables

Other notes

Thermoformable, easy to machine, compatible with most resins and lamination processes

Links

ProcessUniverse
Producers
Reference
Shape
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23.

Alumina foam (92%)(0.61)

Identification

Designation

92% Alumina Foam

Tradenames

POR-AL, DUOCEL, SELEE, RETICEL

General Properties

Density		0.0199	- 0.0242	lb/in^3
Porosity (closed)		0		%
Porosity (open)		0.831	- 0.862	%
Price	*	14.1	- 15.1	USD/lb

Composition overview

Composition (summary)

.92 Al2O3

Base		Oxide		

Composition detail (metals, ceramics and glasses)

Al2O3 (alumina)		100		%

Foam & honeycomb properties

Anisotropy ratio	*	1	- 1.3	
Cells/volume		4.59e3	- 1.8e6	/in^3
Relative density		0.13	- 0.18	

Mechanical properties

Young's modulus	*	0.305	- 0.377	10^6 psi
Flexural modulus		0.305	- 0.377	10^6 psi
Shear modulus	*	0.087	- 0.145	10^6 psi
Bulk modulus	*	0.305	- 0.377	10^6 psi
Poisson's ratio		0.26	- 0.27	
Shape factor		3		
Yield strength (elastic limit)	*	0.087	- 0.305	ksi
Tensile strength	*	0.087	- 0.305	ksi
Compressive strength		0.116	- 0.406	ksi
Flexural strength (modulus of rupture)		0.189	- 0.406	ksi
Elongation	*	0.02	- 0.1	% strain
Hardness - Vickers	*	0.08	- 0.28	HV
Fatigue strength at 10^7 cycles	*	0.123	- 0.136	ksi
Fracture toughness	*	0.0728	- 0.091	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	0.001	- 0.003	

Thermal properties

Melting point	*	3.6e3	- 3.69e3	°F
Heat deflection temperature 0.45MPa	*	2.7e3	- 2.79e3	°F
Maximum service temperature	*	2.7e3	- 2.79e3	°F
Minimum service temperature		-459		°F
Thermal conductivity	*	0.289	- 0.385	BTU.ft/hr.ft^2.°F
Specific heat capacity		0.186	- 0.203	BTU/lb.°F
Thermal expansion coefficient	*	4.78	- 4.94	µstrain/°F
Latent heat of fusion	*	447	- 507	BTU/lb

Electrical properties

Electrical resistivity	*	1e19	- 1e20	µohm.cm
Dielectric constant (relative permittivity)	*	2.3	- 2.4	
Dissipation factor (dielectric loss tangent)	*	0.001	- 0.003	
Dielectric strength (dielectric breakdown)	*	254	- 330	V/mil

Optical properties

Color		White		
Refractive index	*	1.75	- 1.77	
Transparency		Opaque		

Absorption, permeability

Water absorption @ 24 hrs	*	0.5	- 1	%

Durability: flammability

Flammability		Non-flammable		

Durability: fluids and sunlight

Water (fresh)	Excellent			
Water (salt)	Excellent			
Weak acids	Excellent			
Strong acids	Excellent			
Weak alkalis	Excellent			
Strong alkalis	Excellent			
Organic solvents	Excellent			
UV radiation (sunlight)	Excellent			
Oxidation at 500C	Excellent			
Halogens	Acceptable			
Metals	Acceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 4.43e4	-	4.9e4	BTU/lb
CO2 footprint, primary production	* 5.56	-	6.14	lb/lb
Water usage	* 4.62e3	-	5.12e3	in^3/lb

Material processing: energy

Grinding energy (per unit wt removed)	* 406	-	448	BTU/lb

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	* 0.0708	-	0.0782	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Recycle fraction in current supply	0.1			%
Downcycle	True			
Combust for energy recovery	False			
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Catalyst Supports, Catalyst Bed Systems, Radiation Shields, Kiln Furniture, Refractories, Thermal Insulation, High Temperature Filtration, Heat Transfer.

Reference sources

Data compiled from multiple sources. See links to the References table.

Links

ProcessUniverse
Producers
Reference
Shape
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24.

Alumina foam (99%)(0.825)

Identification

Designation

99% Alumina Foam

Tradenames

POR-AL, DUOCEL, SELEE, RETICEL

General Properties

Density	0.0289	-	0.0307	lb/in^3

Porosity (closed)		0			%
Porosity (open)		0.786	-	0.799	%
Price	*	15.1	-	22.6	USD/lb

Composition overview

Composition (summary)

.99 Al2O3

Base		Oxide			

Composition detail (metals, ceramics and glasses)

Al2O3 (alumina)		100			%

Foam & honeycomb properties

Anisotropy ratio	*	1	-	1.3	
Cells/volume		1.64e3	-	2.46e5	/in^3
Relative density		0.205	-	0.215	

Mechanical properties

Young's modulus	*	0.435	-	0.58	10^6 psi
Flexural modulus		0.435	-	0.58	10^6 psi
Shear modulus	*	0.145	-	0.203	10^6 psi
Bulk modulus	*	0.435	-	0.58	10^6 psi
Poisson's ratio	*	0.26	-	0.27	
Shape factor		3			
Yield strength (elastic limit)	*	0.522	-	0.566	ksi
Tensile strength	*	0.522	-	0.566	ksi
Compressive strength		0.696	-	0.754	ksi
Flexural strength (modulus of rupture)		0.334	-	0.348	ksi
Elongation	*	0.09	-	0.13	% strain
Hardness - Vickers	*	0.48	-	0.52	HV
Fatigue strength at 10^7 cycles	*	0.413	-	0.457	ksi
Fracture toughness		0.164	-	0.182	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	0.001	-	0.003	

Thermal properties

Melting point		3.7e3	-	3.74e3	°F
Heat deflection temperature 0.45MPa		2.8e3	-	2.84e3	°F
Maximum service temperature		2.8e3	-	2.84e3	°F
Minimum service temperature		-459			°F
Thermal conductivity		0.328	-	0.414	BTU.ft/hr.ft^2.°F
Specific heat capacity		0.186	-	0.203	BTU/lb.°F
Thermal expansion coefficient		4.83	-	4.94	µstrain/°F
Latent heat of fusion	*	460	-	516	BTU/lb

Electrical properties

Electrical resistivity	*	3.16e19	-	3.16e20	µohm.cm
Dielectric constant (relative permittivity)	*	2.8	-	2.9	
Dissipation factor (dielectric loss tangent)	*	0.001	-	0.003	
Dielectric strength (dielectric breakdown)	*	254	-	330	V/mil

Optical properties

Color		White			
Refractive index	*	1.75	-	1.77	
Transparency		Opaque			

Absorption, permeability

Water absorption @ 24 hrs	*	0.5	-	1	%

Durability: flammability

Flammability		Non-flammable			

Durability: fluids and sunlight

Water (fresh)		Excellent			
Water (salt)		Excellent			

Weak acids	Excellent			
Strong acids	Excellent			
Weak alkalis	Excellent			
Strong alkalis	Excellent			
Organic solvents	Excellent			
UV radiation (sunlight)	Excellent			
Oxidation at 500C	Excellent			
Halogens	Acceptable			
Metals	Acceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 5.03e4	-	5.59e4	BTU/lb
CO2 footprint, primary production	* 6.33	-	6.99	lb/lb
Water usage	* 4.62e3	-	5.12e3	in^3/lb

Material processing: energy

Grinding energy (per unit wt removed)	* 699	-	773	BTU/lb

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	* 0.122	-	0.135	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Recycle fraction in current supply	0.1			%
Downcycle	True			
Combust for energy recovery	False			
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Catalyst Supports, Catalyst Bed Systems, Radiation Shields, Kiln Furniture, Refractories, Thermal Insulation, High Temperature Filtration, Heat Transfer. Mid temperature, gentle cycles

Reference sources

Data compiled from multiple sources. See links to the References table.

Links

ProcessUniverse
Producers
Reference
Shape
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25.

Alumina foam (99.5%)(0.745)

Identification

Designation

99.5% Alumina Foam

Tradenames

POR-AL, DUOCEL, SELEE, RETICEL

General Properties

Density	0.0235	-	0.0303	lb/in^3
Porosity (closed)	0			%
Porosity (open)	0.789	-	0.836	%

Price	* 15.1	-	22.6	USD/lb

Composition overview

Composition (summary)

.995 Al2O3

Base	Oxide			

Composition detail (metals, ceramics and glasses)

Al2O3 (alumina)	100			%

Foam & honeycomb properties

Anisotropy ratio	* 1	-	1.3	
Cells/volume	3.28e3	-	1.44e6	/in^3
Relative density	0.17	-	0.22	

Mechanical properties

Young's modulus	* 0.334	-	0.392	10^6 psi
Flexural modulus	0.334	-	0.392	10^6 psi
Shear modulus	0.16	-	0.247	10^6 psi
Bulk modulus	* 0.334	-	0.392	10^6 psi
Poisson's ratio	0.26	-	0.27	
Shape factor	3			
Yield strength (elastic limit)	* 0.131	-	0.319	ksi
Tensile strength	* 0.131	-	0.319	ksi
Compressive strength	0.174	-	0.421	ksi
Flexural strength (modulus of rupture)	0.145	-	0.421	ksi
Elongation	* 0.03	-	0.1	% strain
Hardness - Vickers	* 0.12	-	0.29	HV
Fatigue strength at 10^7 cycles	* 0.155	-	0.171	ksi
Fracture toughness	* 0.0819	-	0.109	ksi.in^0.5
Mechanical loss coefficient (tan delta)	* 0.001	-	0.003	

Thermal properties

Melting point	3.7e3	-	3.74e3	°F
Heat deflection temperature 0.45MPa	* 2.79e3	-	2.82e3	°F
Maximum service temperature	* 2.79e3	-	2.82e3	°F
Minimum service temperature	-459			°F
Thermal conductivity	* 0.289	-	0.385	BTU.ft/hr.ft^2.°F
Specific heat capacity	0.186	-	0.203	BTU/lb.°F
Thermal expansion coefficient	4.83	-	4.94	µstrain/°F
Latent heat of fusion	* 460	-	516	BTU/lb

Electrical properties

Electrical resistivity	* 3.16e19	-	3.16e20	µohm.cm
Dielectric constant (relative permittivity)	* 2.5	-	2.7	
Dissipation factor (dielectric loss tangent)	* 0.001	-	0.003	
Dielectric strength (dielectric breakdown)	* 254	-	330	V/mil

Optical properties

Color	White			
Refractive index	* 1.75	-	1.77	
Transparency	Opaque			

Absorption, permeability

Water absorption @ 24 hrs	* 0.5	-	1	%

Durability: flammability

Flammability	Non-flammable			

Durability: fluids and sunlight

Water (fresh)	Excellent			
Water (salt)	Excellent			
Weak acids	Excellent			
Strong acids	Excellent			

Weak alkalis	Excellent			
Strong alkalis	Excellent			
Organic solvents	Excellent			
UV radiation (sunlight)	Excellent			
Oxidation at 500C	Excellent			
Halogens	Acceptable			
Metals	Acceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 5.03e4	-	5.59e4	BTU/lb
CO2 footprint, primary production	* 6.33	-	6.99	lb/lb
Water usage	* 4.62e3	-	5.12e3	in^3/lb

Material processing: energy

Grinding energy (per unit wt removed)	* 410	-	454	BTU/lb

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	* 0.0716	-	0.0791	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Recycle fraction in current supply	0.1			%
Downcycle	True			
Combust for energy recovery	False			
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Catalyst Supports, Catalyst Bed Systems, Radiation Shields, Kiln Furniture, Refractories, Thermal Insulation, High Temperature Filtration, Heat Transfer.

Reference sources

Data compiled from multiple sources. See links to the References table.

Links

- ProcessUniverse
- Producers
- Reference
- Shape
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26.

Alumina foam (99.8%)(0.4)

Identification

Designation

POR-AL 10

Tradenames

POR-AL, DUOCEL, SELEE, RETICEL

General Properties

Density	0.0142	-	0.0147	lb/in^3
Porosity (closed)	0			%
Porosity (open)	0.85	-	0.95	%
Price	* 15.9	-	24	USD/lb

Composition overview

Composition (summary)

Al2O3

Base		Oxide		

Composition detail (metals, ceramics and glasses)

Al2O3 (alumina)		100		%

Foam & honeycomb properties

Anisotropy ratio	*	1 -	1.3	
Cells/volume		4.92e6 -	1.05e9	/in^3
Relative density		0.099 -	0.109	

Mechanical properties

Young's modulus	*	0.276 -	0.551	10^6 psi
Flexural modulus		0.276 -	0.551	10^6 psi
Shear modulus	*	0.102 -	0.203	10^6 psi
Bulk modulus	*	0.276 -	0.551	10^6 psi
Poisson's ratio	*	0.26 -	0.27	
Shape factor		3		
Yield strength (elastic limit)	*	0.276 -	0.29	ksi
Tensile strength	*	0.276 -	0.29	ksi
Compressive strength		0.358 -	0.396	ksi
Flexural strength (modulus of rupture)		0.331 -	0.365	ksi
Elongation	*	0.05 -	0.11	% strain
Hardness - Vickers	*	0.296 -	0.328	HV
Fatigue strength at 10^7 cycles		0.232 -	0.261	ksi
Fracture toughness	*	0.0309 -	0.0346	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	0.001 -	0.003	

Thermal properties

Melting point		3.64e3 -	3.8e3	°F
Heat deflection temperature 0.45MPa		3.27e3 -	3.36e3	°F
Heat deflection temperature 1.8MPa	*	3.27e3 -	3.36e3	°F
Maximum service temperature		3.27e3 -	3.45e3	°F
Minimum service temperature		-459		°F
Thermal conductivity	*	0.295 -	0.416	BTU.ft/hr.ft^2.°F
Specific heat capacity	*	0.196 -	0.229	BTU/lb.°F
Thermal expansion coefficient		3.86 -	4.01	µstrain/°F
Latent heat of fusion	*	499 -	563	BTU/lb

Electrical properties

Electrical resistivity	*	1e22 -	1e24	µohm.cm
Dielectric constant (relative permittivity)	*	1.7 -	1.9	
Dissipation factor (dielectric loss tangent)	*	0.005 -	0.025	
Dielectric strength (dielectric breakdown)	*	305 -	432	V/mil

Optical properties

Color		White		
Refractive index		1.75 -	1.77	
Transparency		Opaque		

Absorption, permeability

Water absorption @ 24 hrs	*	0.5 -	1	%

Durability: flammability

Flammability		Non-flammable		

Durability: fluids and sunlight

Water (fresh)		Excellent		
Water (salt)		Excellent		
Weak acids		Excellent		
Strong acids		Excellent		
Weak alkalis		Excellent		

Strong alkalis	Excellent			
Organic solvents	Excellent			
UV radiation (sunlight)	Excellent			
Oxidation at 500C	Excellent			
Halogens	Acceptable			
Metals	Acceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 5.2e4	-	5.76e4	BTU/lb
CO2 footprint, primary production	* 6.53	-	7.22	lb/lb
Water usage	* 4.62e3	-	5.12e3	in^3/lb

Material processing: energy

Grinding energy (per unit wt removed)	* 735	-	812	BTU/lb

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	* 0.128	-	0.142	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Recycle fraction in current supply	0.1			%
Downcycle	True			
Combust for energy recovery	False			
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Thermal insulation; Radiation shields; Specialist kiln furniture; Catalyst supports; Liquid and gas filtration.

Other notes

Surface can be coating, to render the material impervious.

Reference sources

Data compiled from multiple sources. See links to the References table.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
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27.

Alumina foam (99.8%)(0.8)

Identification

Designation

POR-AL 20

Tradenames

POR-AL, DUOCEL, SELEE, RETICEL

General Properties

Density	0.0283	-	0.0295	lb/in^3
Porosity (closed)	0			%
Porosity (open)	0.76	-	0.84	%
Price	* 15.9	-	24	USD/lb

Composition overview

Composition (summary)

Al2O3

Base	Oxide			

Composition detail (metals, ceramics and glasses)

Al2O3 (alumina)	100			%

Foam & honeycomb properties

Anisotropy ratio	* 1	-	1.3	
Cells/volume	4.92e6	-	1.05e9	/in^3
Relative density	0.198	-	0.219	

Mechanical properties

Young's modulus	* 1.1	-	2.2	10^6 psi
Flexural modulus	1.1	-	2.2	10^6 psi
Shear modulus	* 0.421	-	0.827	10^6 psi
Bulk modulus	* 1.1	-	2.2	10^6 psi
Poisson's ratio	* 0.26	-	0.27	
Shape factor	3			
Yield strength (elastic limit)	* 2.28	-	2.51	ksi
Tensile strength	* 2.28	-	2.51	ksi
Compressive strength	3.03	-	3.35	ksi
Flexural strength (modulus of rupture)	1.44	-	1.58	ksi
Elongation	* 0.1	-	0.23	% strain
Hardness - Vickers	* 2.93	-	3.23	HV
Fatigue strength at 10^7 cycles	* 1.82	-	2.01	ksi
Fracture toughness	* 0.0874	-	0.0974	ksi.in^0.5
Mechanical loss coefficient (tan delta)	* 0.001	-	0.003	

Thermal properties

Melting point	3.64e3	-	3.8e3	°F
Heat deflection temperature 0.45MPa	3.27e3	-	3.36e3	°F
Heat deflection temperature 1.8MPa	* 3.27e3	-	3.36e3	°F
Maximum service temperature	3.27e3	-	3.45e3	°F
Minimum service temperature	-459			°F
Thermal conductivity	1.04	-	1.27	BTU.ft/hr.ft^2.°F
Specific heat capacity	* 0.196	-	0.229	BTU/lb.°F
Thermal expansion coefficient	3.86	-	4.01	µstrain/°F
Latent heat of fusion	* 499	-	563	BTU/lb

Electrical properties

Electrical resistivity	* 1e22	-	1e24	µohm.cm
Dielectric constant (relative permittivity)	* 2.4	-	2.8	
Dissipation factor (dielectric loss tangent)	* 0.005	-	0.025	
Dielectric strength (dielectric breakdown)	* 305	-	432	V/mil

Optical properties

Color	White			
Refractive index	1.75	-	1.77	
Transparency	Opaque			

Absorption, permeability

Water absorption @ 24 hrs	* 0.5	-	1	%

Durability: flammability

Flammability	Non-flammable			

Durability: fluids and sunlight

Water (fresh)	Excellent			
Water (salt)	Excellent			
Weak acids	Excellent			
Strong acids	Excellent			
Weak alkalis	Excellent			

Strong alkalis	Excellent			
Organic solvents	Excellent			
UV radiation (sunlight)	Excellent			
Oxidation at 500C	Excellent			
Halogens	Acceptable			
Metals	Acceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 5.2e4	-	5.76e4	BTU/lb
CO2 footprint, primary production	* 6.53	-	7.22	lb/lb
Water usage	* 4.62e3	-	5.12e3	in^3/lb

Material processing: energy

Grinding energy (per unit wt removed)	* 2.45e3	-	2.71e3	BTU/lb

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	* 0.427	-	0.472	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Recycle fraction in current supply	0.1			%
Downcycle	True			
Combust for energy recovery	False			
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Thermal insulation; Radiation shields; Specialist kiln furniture; Catalyst supports; Liquid and gas filtration.

Other notes

Surface can be coating, to render the material impervious.

Reference sources

Data compiled from multiple sources. See links to the References table.

Links

ProcessUniverse
Producers
Reference
Shape
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28.

Alumina foam (99.8%)(1.2)

Identification

Designation

POR-AL 30

Tradenames

POR-AL, DUOCEL, SELEE, RETICEL

General Properties

Density	0.0425	-	0.0442	lb/in^3
Porosity (closed)	0			%
Porosity (open)	0.67	-	0.73	%
Price	* 15.9	-	24	USD/lb

Composition overview

Composition (summary)

Al2O3

Base		Oxide			

Composition detail (metals, ceramics and glasses)

Al2O3 (alumina)		100			%

Foam & honeycomb properties

Anisotropy ratio	*	1	-	1.3	
Cells/volume		4.92e6	-	1.05e9	/in^3
Relative density		0.297	-	0.328	

Mechanical properties

Young's modulus	*	2.48	-	4.96	10^6 psi
Flexural modulus		2.48	-	4.96	10^6 psi
Shear modulus	*	0.928	-	1.86	10^6 psi
Bulk modulus	*	2.48	-	4.96	10^6 psi
Poisson's ratio	*	0.26	-	0.27	
Shape factor		3			
Yield strength (elastic limit)	*	8.38	-	9.25	ksi
Tensile strength	*	8.38	-	9.25	ksi
Compressive strength		11.2	-	12.3	ksi
Flexural strength (modulus of rupture)		3.5	-	3.87	ksi
Elongation	*	0.17	-	0.37	% strain
Hardness - Vickers	*	12.3	-	13.6	HV
Fatigue strength at 10^7 cycles	*	6.69	-	7.4	ksi
Fracture toughness	*	0.161	-	0.179	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	0.001	-	0.003	

Thermal properties

Melting point		3.64e3	-	3.8e3	°F
Heat deflection temperature 0.45MPa		3.27e3	-	3.36e3	°F
Heat deflection temperature 1.8MPa	*	3.27e3	-	3.36e3	°F
Maximum service temperature		3.27e3	-	3.45e3	°F
Minimum service temperature		-459			°F
Thermal conductivity		1.79	-	2.25	BTU.ft/hr.ft^2.°F
Specific heat capacity	*	0.196	-	0.229	BTU/lb.°F
Thermal expansion coefficient		3.86	-	4.01	µstrain/°F
Latent heat of fusion	*	499	-	563	BTU/lb

Electrical properties

Electrical resistivity	*	1e22	-	1e24	µohm.cm
Dielectric constant (relative permittivity)	*	3.1	-	3.7	
Dissipation factor (dielectric loss tangent)	*	0.005	-	0.025	
Dielectric strength (dielectric breakdown)	*	305	-	432	V/mil

Optical properties

Color		White			
Refractive index		1.75	-	1.77	
Transparency		Opaque			

Absorption, permeability

Water absorption @ 24 hrs	*	0.5	-	1	%

Durability: flammability

Flammability		Non-flammable			

Durability: fluids and sunlight

Water (fresh)		Excellent			
Water (salt)		Excellent			
Weak acids		Excellent			
Strong acids		Excellent			
Weak alkalis		Excellent			

Strong alkalis	Excellent			
Organic solvents	Excellent			
UV radiation (sunlight)	Excellent			
Oxidation at 500C	Excellent			
Halogens	Acceptable			
Metals	Acceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 5.2e4	-	5.76e4	BTU/lb
CO2 footprint, primary production	* 6.53	-	7.22	lb/lb
Water usage	* 4.62e3	-	5.12e3	in^3/lb

Material processing: energy

Grinding energy (per unit wt removed)	* 5.71e3	-	6.31e3	BTU/lb

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	* 0.996	-	1.1	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Recycle fraction in current supply	0.1			%
Downcycle	True			
Combust for energy recovery	False			
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Thermal insulation; Radiation shields; Specialist kiln furniture; Catalyst supports; Liquid and gas filtration.

Other notes

Surface can be coating, to render the material impervious.

Reference sources

Data compiled from multiple sources. See links to the References table.

Grain size — Grain size: 40-150um

Links

- ProcessUniverse
- Producers
- Reference
- Shape
- Values marked * are estimates.
- Granta Design provides no warranty for the accuracy of this data

29.

Cordierite foam (0.5)

Identification

Designation

Cordierite Foam (0.5)

Tradenames

DUOCEL, SELEE, RETICEL

General Properties

Density	0.0173	-	0.0188	lb/in^3
Porosity (closed)	0			%
Porosity (open)	0.783	-	0.8	%
Price	* 4.7	-	6.59	USD/lb

Composition overview

Composition (summary)

MgO.Al2O3.SiO2

Base		Oxide			

Composition detail (metals, ceramics and glasses)

Al2O3 (alumina)		40			%
MgO (magnesia)		16			%
SiO2 (silica)		44			%

Foam & honeycomb properties

Anisotropy ratio	*	1	-	1.3	
Cells/volume		1.64e3	-	2.46e5	/in^3
Relative density		0.16	-	0.18	

Mechanical properties

Young's modulus	*	0.0725	-	0.102	10^6 psi
Flexural modulus		0.0725	-	0.102	10^6 psi
Shear modulus	*	0.0377	-	0.0421	10^6 psi
Bulk modulus	*	0.0725	-	0.102	10^6 psi
Poisson's ratio	*	0.22	-	0.25	
Shape factor		3			
Yield strength (elastic limit)	*	0.145	-	0.174	ksi
Tensile strength	*	0.145	-	0.174	ksi
Compressive strength		0.174	-	0.203	ksi
Flexural strength (modulus of rupture)		0.174	-	0.183	ksi
Elongation	*	0.14	-	0.24	% strain
Hardness - Vickers	*	0.12	-	0.14	HV
Fatigue strength at 10^7 cycles	*	0.12	-	0.133	ksi
Fracture toughness	*	0.0728	-	0.091	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	0.001	-	0.003	

Thermal properties

Melting point	*	2.73e3	-	3.09e3	°F
Heat deflection temperature 0.45MPa		2.17e3	-	2.21e3	°F
Maximum service temperature		2.17e3	-	2.21e3	°F
Minimum service temperature		-459			°F
Thermal conductivity	*	0.144	-	0.241	BTU.ft/hr.ft^2.°F
Specific heat capacity	*	0.179	-	0.203	BTU/lb.°F
Thermal expansion coefficient		1.33	-	1.44	µstrain/°F
Latent heat of fusion	*	365	-	413	BTU/lb

Electrical properties

Electrical resistivity		1e18	-	1e20	µohm.cm
Dielectric constant (relative permittivity)	*	2.4	-	3	
Dissipation factor (dielectric loss tangent)	*	0.001	-	0.002	
Dielectric strength (dielectric breakdown)	*	279	-	330	V/mil

Optical properties

Color		Cream			
Transparency		Opaque			

Absorption, permeability

Water absorption @ 24 hrs	*	0.5	-	1	%

Durability: flammability

Flammability		Non-flammable			

Durability: fluids and sunlight

Water (fresh)		Excellent			
Water (salt)		Excellent			
Weak acids		Excellent			
Strong acids		Excellent			

Weak alkalis	Excellent			
Strong alkalis	Acceptable			
Organic solvents	Excellent			
UV radiation (sunlight)	Excellent			
Oxidation at 500C	Excellent			
Halogens	Unacceptable			
Metals	Acceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 2.64e4	-	2.92e4	BTU/lb
CO2 footprint, primary production	* 3.31	-	3.66	lb/lb
Water usage	* 2.52e3	-	2.77e3	in^3/lb

Material processing: energy

Grinding energy (per unit wt removed)	* 416	-	460	BTU/lb

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	* 0.0726	-	0.0802	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Recycle fraction in current supply	0.1			%
Downcycle	True			
Combust for energy recovery	False			
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Catalyst Supports, Catalyst Bed Systems, Radiation Shields, Kiln Furniture, Refractories, Thermal Insulation, High Temperature Filtration, Heat Transfer. Low temperature, fast cycles, thermal shock resistance

Reference sources

Data compiled from multiple sources. See links to the References table.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

30.

Glass foam (0.13)

Identification

Designation

Glass Foam, Closed Cell (0.13)

Tradenames

FOAMGLAS

General Properties

Density	0.0047	-	0.00506	lb/in^3
Porosity (closed)	0.944	-	0.948	%
Porosity (open)	0			%
Price	* 5.64	-	7.53	USD/lb

Composition overview

Composition (summary)

SiO2 + Na2O + CaO + MgO + Al2O3 + Other

Base		Oxide			

Composition detail (metals, ceramics and glasses)

Al2O3 (alumina)		1			%
CaO (calcia)		5			%
MgO (magnesia)		4			%
Na2O (sodium oxide)		16			%
SiO2 (silica)		72			%
Other		2			%

Foam & honeycomb properties

Anisotropy ratio	*	1	-	1.4	
Cells/volume	*	3.28e7	-	6.55e7	/in^3
Relative density		0.05	-	0.06	

Mechanical properties

Young's modulus		0.128	-	0.136	10^6 psi
Flexural modulus		0.128	-	0.138	10^6 psi
Shear modulus	*	0.0479	-	0.0551	10^6 psi
Bulk modulus	*	0.126	-	0.138	10^6 psi
Poisson's ratio	*	0.3	-	0.33	
Shape factor		3			
Yield strength (elastic limit)	*	0.0725	-	0.0783	ksi
Tensile strength		0.0725	-	0.0783	ksi
Compressive strength		0.0972	-	0.103	ksi
Flexural strength (modulus of rupture)		0.0754	-	0.0841	ksi
Elongation	*	0.05	-	0.06	% strain
Hardness - Vickers		0.06	-	0.08	HV
Fatigue strength at 10^7 cycles	*	0.0566	-	0.0638	ksi
Fracture toughness	*	0.00546	-	0.0091	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	0.001	-	0.002	

Thermal properties

Glass temperature	*	896	-	986	°F
Heat deflection temperature 0.45MPa	*	914	-	932	°F
Heat deflection temperature 1.8MPa	*	896	-	914	°F
Maximum service temperature		770	-	1.04e3	°F
Minimum service temperature		-459			°F
Thermal conductivity		0.0248	-	0.0266	BTU.ft/hr.ft^2.°F
Specific heat capacity		0.182	-	0.191	BTU/lb.°F
Thermal expansion coefficient		4.72	-	4.83	µstrain/°F

Electrical properties

Electrical resistivity	*	1e18	-	1e20	µohm.cm
Dielectric constant (relative permittivity)		1.3	-	1.4	
Dissipation factor (dielectric loss tangent)	*	0.005	-	0.01	
Dielectric strength (dielectric breakdown)	*	254	-	305	V/mil

Optical properties

Color		Clear			
Refractive index	*	1.5	-	1.55	
Transparency		Translucent			

Absorption, permeability

Water absorption @ 24 hrs		0.18	-	0.22	%

Durability: flammability

Flammability		Non-flammable			

Durability: fluids and sunlight

Water (fresh)	Excellent			
Water (salt)	Excellent			
Weak acids	Excellent			
Strong acids	Excellent			
Weak alkalis	Excellent			
Strong alkalis	Unacceptable			
Organic solvents	Excellent			
UV radiation (sunlight)	Excellent			
Oxidation at 500C	Excellent			
Halogens	Limited use			
Metals	Limited use			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 2.87e4	-	3.17e4	BTU/lb
CO2 footprint, primary production	* 3.6	-	3.98	lb/lb
Water usage	* 76.1	-	84.1	in^3/lb

Material processing: energy

Glass molding energy	* 3.25e3	-	3.6e3	BTU/lb
Grinding energy (per unit wt removed)	* 622	-	687	BTU/lb

Material processing: CO2 footprint

Glass molding CO2	* 0.606	-	0.67	lb/lb
Grinding CO2 (per unit wt removed)	* 0.108	-	0.12	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False	
Recycle fraction in current supply	0.1	%
Downcycle	True	
Combust for energy recovery	False	
Landfill	True	
Biodegrade	False	
A renewable resource?	False	

Notes

Typical uses

Thermal insulation for pipework, walls, floors, tanks, hot oil, steam

Reference sources

Data compiled from multiple sources. See links to the References table.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

31.

Mullite foam (0.65)

Identification

Designation

Mullite Foam (0.65)

Tradenames

DUOCEL, SELEE, RETICEL

General Properties

Density	0.0224	-	0.0242	lb/in^3
Porosity (closed)	0			%
Porosity (open)	0.773	-	0.79	%
Price	* 4.7	-	5.64	USD/lb

Composition overview

Composition (summary)

3Al2O3.2SiO2

Base	Oxide			

Composition detail (metals, ceramics and glasses)

Al2O3 (alumina)	78			%
SiO2 (silica)	22			%

Foam & honeycomb properties

Anisotropy ratio	* 1	-	1.3	
Cells/volume	1.64e3	-	2.46e5	/in^3
Relative density	0.215	-	0.225	

Mechanical properties

Young's modulus	* 0.203	-	0.232	10^6 psi
Flexural modulus	0.203	-	0.232	10^6 psi
Shear modulus	* 0.0856	-	0.0914	10^6 psi
Bulk modulus	* 0.203	-	0.232	10^6 psi
Poisson's ratio	* 0.22	-	0.25	
Shape factor	3			
Yield strength (elastic limit)	* 0.087	-	0.261	ksi
Tensile strength	* 0.087	-	0.261	ksi
Compressive strength	0.58	-	0.609	ksi
Flexural strength (modulus of rupture)	* 0.218	-	0.29	ksi
Elongation	* 0.04	-	0.13	% strain
Hardness - Vickers	* 0.4	-	0.42	HV
Fatigue strength at 10^7 cycles	* 0.115	-	0.126	ksi
Fracture toughness	* 0.091	-	0.118	ksi.in^0.5
Mechanical loss coefficient (tan delta)	* 0.001	-	0.003	

Thermal properties

Melting point	3.35e3	-	3.36e3	°F
Heat deflection temperature 0.45MPa	2.53e3	-	2.57e3	°F
Maximum service temperature	2.53e3	-	2.57e3	°F
Minimum service temperature	-459			°F
Thermal conductivity	* 0.0965	-	0.192	BTU.ft/hr.ft^2.°F
Specific heat capacity	0.179	-	0.191	BTU/lb.°F
Thermal expansion coefficient	3.56	-	3.67	µstrain/°F
Latent heat of fusion	* 400	-	447	BTU/lb

Electrical properties

Electrical resistivity	* 1e19	-	1e20	µohm.cm
Dielectric constant (relative permittivity)	* 2.4	-	3	
Dissipation factor (dielectric loss tangent)	* 0.001	-	0.002	
Dielectric strength (dielectric breakdown)	* 254	-	305	V/mil

Optical properties

Color	White			
Refractive index	* 1.62	-	1.66	
Transparency	Opaque			

Absorption, permeability

Water absorption @ 24 hrs	* 0.5	-	1	%

Durability: flammability

Flammability	Non-flammable			

Durability: fluids and sunlight

Water (fresh)	Excellent			
Water (salt)	Excellent			
Weak acids	Excellent			
Strong acids	Excellent			
Weak alkalis	Excellent			
Strong alkalis	Acceptable			
Organic solvents	Excellent			
UV radiation (sunlight)	Excellent			
Oxidation at 500C	Excellent			
Halogens	Unacceptable			
Metals	Acceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 4.94e5	-	5.46e5	BTU/lb
CO2 footprint, primary production	* 70.8	-	78.3	lb/lb
Water usage	* 3.63e3	-	4.01e3	in^3/lb

Material processing: energy

Grinding energy (per unit wt removed)	* 724	-	800	BTU/lb

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	* 0.126	-	0.14	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Recycle fraction in current supply	0.1			%
Downcycle	True			
Combust for energy recovery	False			
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Catalyst Supports, Catalyst Bed Systems, Radiation Shields, Kiln Furniture, Refractories, Thermal Insulation, High Temperature Filtration, Heat Transfer. Mid temperature, thermal shock resistance

Reference sources

Data compiled from multiple sources. See links to the References table.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

32.

Mullite foam (0.70)

Identification

Designation

Mullite Foam (0.70)

Tradenames

DUOCEL, SELEE, RETICEL

General Properties

Density	0.0242	-	0.026	lb/in^3

Porosity (closed)	0			%
Porosity (open)	0.756	-	0.773	%
Price	* 4.7	-	5.64	USD/lb

Composition overview

Composition (summary)

3Al2O3.2SiO2

Base	Oxide			

Composition detail (metals, ceramics and glasses)

Al2O3 (alumina)	78			%
SiO2 (silica)	22			%

Foam & honeycomb properties

Anisotropy ratio	* 1	-	1.3	
Cells/volume	1.64e3	-	2.46e5	/in^3
Relative density	0.23	-	0.24	

Mechanical properties

Young's modulus	* 0.247	-	0.276	10^6 psi
Flexural modulus	0.247	-	0.276	10^6 psi
Shear modulus	* 0.102	-	0.109	10^6 psi
Bulk modulus	* 0.247	-	0.276	10^6 psi
Poisson's ratio	* 0.22	-	0.25	
Shape factor	3			
Yield strength (elastic limit)	* 0.087	-	0.232	ksi
Tensile strength	* 0.087	-	0.232	ksi
Compressive strength	0.551	-	0.58	ksi
Flexural strength (modulus of rupture)	* 0.189	-	0.261	ksi
Elongation	* 0.03	-	0.09	% strain
Hardness - Vickers	* 0.38	-	0.4	HV
Fatigue strength at 10^7 cycles	* 0.107	-	0.119	ksi
Fracture toughness	* 0.091	-	0.118	ksi.in^0.5
Mechanical loss coefficient (tan delta)	* 0.001	-	0.003	

Thermal properties

Melting point	3.35e3	-	3.36e3	°F
Heat deflection temperature 0.45MPa	2.8e3	-	2.84e3	°F
Maximum service temperature	2.8e3	-	2.84e3	°F
Minimum service temperature	-459			°F
Thermal conductivity	* 0.0965	-	0.192	BTU.ft/hr.ft^2.°F
Specific heat capacity	0.179	-	0.191	BTU/lb.°F
Thermal expansion coefficient	3.56	-	3.67	µstrain/°F
Latent heat of fusion	* 400	-	447	BTU/lb

Electrical properties

Electrical resistivity	* 1e19	-	1e20	µohm.cm
Dielectric constant (relative permittivity)	* 2.4	-	3	
Dissipation factor (dielectric loss tangent)	* 0.001	-	0.002	
Dielectric strength (dielectric breakdown)	* 254	-	305	V/mil

Optical properties

Color	White			
Refractive index	* 1.62	-	1.66	
Transparency	Opaque			

Absorption, permeability

Water absorption @ 24 hrs	* 0.5	-	1	%

Durability: flammability

Flammability	Non-flammable			

Durability: fluids and sunlight

Water (fresh)	Excellent			

Water (salt)	Excellent			
Weak acids	Excellent			
Strong acids	Excellent			
Weak alkalis	Excellent			
Strong alkalis	Acceptable			
Organic solvents	Excellent			
UV radiation (sunlight)	Excellent			
Oxidation at 500C	Excellent			
Halogens	Unacceptable			
Metals	Acceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 2.53e4	-	2.79e4	BTU/lb
CO2 footprint, primary production	* 3.17	-	3.51	lb/lb
Water usage	* 3.63e3	-	4.01e3	in^3/lb

Material processing: energy

Grinding energy (per unit wt removed)	* 663	-	732	BTU/lb

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	* 0.116	-	0.128	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Recycle fraction in current supply	0.1			%
Downcycle	True			
Combust for energy recovery	False			
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Catalyst Supports, Catalyst Bed Systems, Radiation Shields, Kiln Furniture, Refractories, Thermal Insulation, High Temperature Filtration, Heat Transfer. High temperature, thermal shock resistance

Reference sources

Data compiled from multiple sources. See links to the References table.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

33.

Mullite foam (NCL)(0.46)

Identification

Designation

Mullite NCL Foam (0.46)

Tradenames

DUOCEL, SELEE, RETICEL

General Properties

Density	0.0163	-	0.017	lb/in^3
Porosity (closed)	0			%

Porosity (open)	0.841	-	0.847	%
Price	* 4.7	-	5.64	USD/lb

Composition overview

Composition (summary)

3Al2O3.2SiO2

Base	Oxide			

Composition detail (metals, ceramics and glasses)

Al2O3 (alumina)	78			%
SiO2 (silica)	22			%

Foam & honeycomb properties

Anisotropy ratio	* 1	-	1.3	
Cells/volume	3.28e3	-	6.88e5	/in^3
Relative density	0.15	-	0.16	

Mechanical properties

Young's modulus	* 0.087	-	0.145	10^6 psi
Flexural modulus	0.087	-	0.145	10^6 psi
Shear modulus	* 0.0363	-	0.058	10^6 psi
Bulk modulus	* 0.087	-	0.145	10^6 psi
Poisson's ratio	* 0.22	-	0.25	
Shape factor	3			
Yield strength (elastic limit)	* 0.087	-	0.189	ksi
Tensile strength	* 0.087	-	0.189	ksi
Compressive strength	0.116	-	0.334	ksi
Flexural strength (modulus of rupture)	0.102	-	0.218	ksi
Elongation	* 0.06	-	0.22	% strain
Hardness - Vickers	* 0.08	-	0.23	HV
Fatigue strength at 10^7 cycles	* 0.0972	-	0.107	ksi
Fracture toughness	* 0.0546	-	0.091	ksi.in^0.5
Mechanical loss coefficient (tan delta)	* 0.001	-	0.003	

Thermal properties

Melting point	3.35e3	-	3.36e3	°F
Heat deflection temperature 0.45MPa	* 2.77e3	-	2.8e3	°F
Maximum service temperature	* 2.77e3	-	2.8e3	°F
Minimum service temperature	-459			°F
Thermal conductivity	* 0.0867	-	0.183	BTU.ft/hr.ft^2.°F
Specific heat capacity	0.179	-	0.186	BTU/lb.°F
Thermal expansion coefficient	3.56	-	3.67	µstrain/°F
Latent heat of fusion	* 391	-	443	BTU/lb

Electrical properties

Electrical resistivity	* 1e19	-	1e20	µohm.cm
Dielectric constant (relative permittivity)	* 2	-	2.5	
Dissipation factor (dielectric loss tangent)	* 0.001	-	0.002	
Dielectric strength (dielectric breakdown)	* 254	-	305	V/mil

Optical properties

Color	White			
Refractive index	* 1.62	-	1.66	
Transparency	Opaque			

Absorption, permeability

Water absorption @ 24 hrs	* 0.5	-	1	%

Durability: flammability

Flammability	Non-flammable			

Durability: fluids and sunlight

Water (fresh)	Excellent			
Water (salt)	Excellent			

Weak acids	Excellent			
Strong acids	Excellent			
Weak alkalis	Excellent			
Strong alkalis	Acceptable			
Organic solvents	Excellent			
UV radiation (sunlight)	Excellent			
Oxidation at 500C	Excellent			
Halogens	Unacceptable			
Metals	Acceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 4.94e5	-	5.46e5	BTU/lb
CO2 footprint, primary production	* 70.8	-	78.3	lb/lb
Water usage	* 3.63e3	-	4.01e3	in^3/lb

Material processing: energy

Grinding energy (per unit wt removed)	* 445	-	492	BTU/lb

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	* 0.0777	-	0.0858	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Recycle fraction in current supply	0.1			%
Downcycle	True			
Combust for energy recovery	False			
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Catalyst Supports, Catalyst Bed Systems, Radiation Shields, Kiln Furniture, Refractories, Thermal Insulation, High Temperature Filtration, Heat Transfer.

Reference sources

Data compiled from multiple sources. See links to the References table.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

34.

Yttria zirconia alumina foam (1.20)

Identification

Designation

Yttria Zirconia Alumina Foam (1.20)

Tradenames

DUOCEL, SELEE, RETICEL

General Properties

Density	0.0423	-	0.0441	lb/in^3
Porosity (closed)	0			%
Porosity (open)	0.776	-	0.785	%

Price	* 28.2	-	32.9	USD/lb

Composition overview

Composition (summary)

ZrO2 + Al2O3 + Y2O3 + CaO

Base	Oxide			

Composition detail (metals, ceramics and glasses)

Al2O3 (alumina)	34			%
CaO (calcia)	2.5			%
Y2O3 (yttria)	2.5			%
ZrO2 (zirconia)	61			%

Foam & honeycomb properties

Anisotropy ratio	* 1	-	1.3	
Cells/volume	1.64e3	-	2.46e5	/in^3
Relative density	0.195	-	0.205	

Mechanical properties

Young's modulus	* 0.247	-	0.276	10^6 psi
Flexural modulus	0.247	-	0.276	10^6 psi
Shear modulus	* 0.0798	-	0.0928	10^6 psi
Bulk modulus	* 0.247	-	0.276	10^6 psi
Poisson's ratio	* 0.24	-	0.28	
Shape factor	3			
Yield strength (elastic limit)	* 0.087	-	0.276	ksi
Tensile strength	* 0.087	-	0.276	ksi
Compressive strength	0.827	-	0.856	ksi
Flexural strength (modulus of rupture)	* 0.232	-	0.29	ksi
Elongation	* 0.03	-	0.11	% strain
Hardness - Vickers	* 0.56	-	0.58	HV
Fatigue strength at 10^7 cycles	* 0.117	-	0.131	ksi
Fracture toughness	* 0.182	-	0.218	ksi.in^0.5
Mechanical loss coefficient (tan delta)	* 0.001	-	0.003	

Thermal properties

Melting point	4.8e3	-	4.89e3	°F
Heat deflection temperature 0.45MPa	3.07e3	-	3.11e3	°F
Maximum service temperature	3.07e3	-	3.11e3	°F
Minimum service temperature	-459			°F
Thermal conductivity	* 0.144	-	0.159	BTU.ft/hr.ft^2.°F
Specific heat capacity	0.107	-	0.122	BTU/lb.°F
Thermal expansion coefficient	4.39	-	4.5	µstrain/°F
Latent heat of fusion	* 344	-	387	BTU/lb

Electrical properties

Electrical resistivity	1e17	-	1e18	µohm.cm
Dielectric constant (relative permittivity)	* 2.4	-	2.7	
Dissipation factor (dielectric loss tangent)	* 0.001	-	0.002	
Dielectric strength (dielectric breakdown)	* 254	-	305	V/mil

Optical properties

Color	Black			
Refractive index	* 2.13	-	2.2	
Transparency	Opaque			

Absorption, permeability

Water absorption @ 24 hrs	* 0.5	-	1	%

Durability: flammability

Flammability	Non-flammable			

Durability: fluids and sunlight

Water (fresh)	Excellent			

Water (salt)	Excellent			
Weak acids	Excellent			
Strong acids	Excellent			
Weak alkalis	Excellent			
Strong alkalis	Acceptable			
Organic solvents	Excellent			
UV radiation (sunlight)	Excellent			
Oxidation at 500C	Excellent			
Halogens	Acceptable			
Metals	Acceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 6.62e4	-	7.31e4	BTU/lb
CO2 footprint, primary production	* 8.3	-	9.17	lb/lb
Water usage	* 4.12e3	-	4.57e3	in^3/lb

Material processing: energy

Grinding energy (per unit wt removed)	* 601	-	664	BTU/lb

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	* 0.105	-	0.116	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Recycle fraction in current supply	0.1			%
Downcycle	True			
Combust for energy recovery	False			
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Catalyst Supports, Catalyst Bed Systems, Radiation Shields, Kiln Furniture, Refractories, Thermal Insulation, High Temperature Filtration, Heat Transfer. Mid temperature, fast cycles

Reference sources

Data compiled from multiple sources. See links to the References table.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
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35.

Zirconia foam (partly stabilized)(1.23)

Identification

Designation

Partly Stabilized Zirconia Foam (1.23)

Tradenames

DUOCEL, SELEE, RETICEL

General Properties

Density	0.0434	-	0.0452	lb/in^3
Porosity (closed)	0			%

Porosity (open)	0.77	-	0.779	%
Price	* 28.2	-	32.9	USD/lb

Composition overview

Composition (summary)

ZrO2 + MgO + Other oxide

Base	Oxide			

Composition detail (metals, ceramics and glasses)

MgO (magnesia)	3.5			%
ZrO2 (zirconia)	95			%
Other oxide	1.5			%

Foam & honeycomb properties

Anisotropy ratio	* 1	-	1.3	
Cells/volume	1.64e3	-	2.46e5	/in^3
Relative density	0.195	-	0.205	

Mechanical properties

Young's modulus	* 0.305	-	0.334	10^6 psi
Flexural modulus	0.305	-	0.334	10^6 psi
Shear modulus	* 0.106	-	0.11	10^6 psi
Bulk modulus	* 0.305	-	0.334	10^6 psi
Poisson's ratio	* 0.24	-	0.28	
Shape factor	3			
Yield strength (elastic limit)	* 0.087	-	0.305	ksi
Tensile strength	* 0.087	-	0.305	ksi
Compressive strength	0.326	-	0.957	ksi
Flexural strength (modulus of rupture)	* 0.29	-	0.305	ksi
Elongation	* 0.03	-	0.1	% strain
Hardness - Vickers	* 0.18	-	0.22	HV
Fatigue strength at 10^7 cycles	* 0.123	-	0.136	ksi
Fracture toughness	* 0.237	-	0.282	ksi.in^0.5
Mechanical loss coefficient (tan delta)	* 0.001	-	0.003	

Thermal properties

Melting point	4.85e3	-	4.91e3	°F
Heat deflection temperature 0.45MPa	3.43e3	-	3.47e3	°F
Maximum service temperature	3.43e3	-	3.47e3	°F
Minimum service temperature	-459			°F
Thermal conductivity	* 0.149	-	0.169	BTU.ft/hr.ft^2.°F
Specific heat capacity	0.107	-	0.122	BTU/lb.°F
Thermal expansion coefficient	4.28	-	4.39	µstrain/°F
Latent heat of fusion	* 344	-	387	BTU/lb

Electrical properties

Electrical resistivity	* 1e17	-	1e18	µohm.cm
Dielectric constant (relative permittivity)	* 3.6	-	3.9	
Dissipation factor (dielectric loss tangent)	* 0.001	-	0.0025	
Dielectric strength (dielectric breakdown)	* 152	-	203	V/mil

Optical properties

Color	Black			
Refractive index	* 2.13	-	2.2	
Transparency	Opaque			

Absorption, permeability

Water absorption @ 24 hrs	* 0.5	-	1	%

Durability: flammability

Flammability	Non-flammable			

Durability: fluids and sunlight

Water (fresh)	Excellent			

Water (salt)	Excellent			
Weak acids	Excellent			
Strong acids	Excellent			
Weak alkalis	Excellent			
Strong alkalis	Acceptable			
Organic solvents	Excellent			
UV radiation (sunlight)	Excellent			
Oxidation at 500C	Excellent			
Halogens	Acceptable			
Metals	Acceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 6.62e4	-	7.31e4	BTU/lb
CO2 footprint, primary production	* 8.3	-	9.17	lb/lb
Water usage	* 3.88e3	-	4.26e3	in^3/lb

Material processing: energy

Grinding energy (per unit wt removed)	* 461	-	510	BTU/lb

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	* 0.0805	-	0.0889	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Recycle fraction in current supply	0.1			%
Downcycle	True			
Combust for energy recovery	False			
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Catalyst Supports, Catalyst Bed Systems, Radiation Shields, Kiln Furniture, Refractories, Thermal Insulation, High Temperature Filtration, Heat Transfer. Extreme temperature

Reference sources

Data compiled from multiple sources. See links to the References table.

Links

- ProcessUniverse
- Producers
- Reference
- Shape
- Values marked * are estimates.
- Granta Design provides no warranty for the accuracy of this data

36.

Zirconia foam (partly stabilized)(1.27)

Identification

Designation

Partly Stabilized Zirconia Foam (1.27)

Tradenames

DUOCEL, SELEE, RETICEL

General Properties

Density	0.0459	-	0.047	lb/in^3
Porosity (closed)	0			%

Porosity (open)	0.761	-	0.767	%
Price	* 28.2	-	32.9	USD/lb

Composition overview

Composition (summary)

ZrO2 + Y2O3 + Other oxide

Base	Oxide			

Composition detail (metals, ceramics and glasses)

Y2O3 (yttria)	10			%
ZrO2 (zirconia)	89			%
Other oxide	1			%

Foam & honeycomb properties

Anisotropy ratio	* 1	-	1.3	
Cells/volume	1.64e3	-	2.46e5	/in^3
Relative density	0.21	-	0.22	

Mechanical properties

Young's modulus	* 0.319	-	0.348	10^6 psi
Flexural modulus	0.319	-	0.348	10^6 psi
Shear modulus	* 0.087	-	0.116	10^6 psi
Bulk modulus	* 0.319	-	0.348	10^6 psi
Poisson's ratio	* 0.24	-	0.28	
Shape factor	3			
Yield strength (elastic limit)	* 0.29	-	0.334	ksi
Tensile strength	* 0.29	-	0.334	ksi
Compressive strength	1.2	-	1.26	ksi
Flexural strength (modulus of rupture)	* 0.29	-	0.363	ksi
Elongation	* 0.08	-	0.1	% strain
Hardness - Vickers	* 0.81	-	0.89	HV
Fatigue strength at 10^7 cycles	* 0.232	-	0.247	ksi
Fracture toughness	* 0.228	-	0.255	ksi.in^0.5
Mechanical loss coefficient (tan delta)	* 0.001	-	0.003	

Thermal properties

Melting point	4.8e3	-	4.89e3	°F
Heat deflection temperature 0.45MPa	3.07e3	-	3.11e3	°F
Maximum service temperature	3.07e3	-	3.11e3	°F
Minimum service temperature	-459			°F
Thermal conductivity	* 0.154	-	0.173	BTU.ft/hr.ft^2.°F
Specific heat capacity	0.107	-	0.122	BTU/lb.°F
Thermal expansion coefficient	4.28	-	4.39	µstrain/°F
Latent heat of fusion	* 344	-	387	BTU/lb

Electrical properties

Electrical resistivity	1e17	-	1e18	µohm.cm
Dielectric constant (relative permittivity)	* 2.4	-	2.7	
Dissipation factor (dielectric loss tangent)	* 0.001	-	0.002	
Dielectric strength (dielectric breakdown)	* 254	-	305	V/mil

Optical properties

Color	Black			
Refractive index	* 2.13	-	2.2	
Transparency	Opaque			

Absorption, permeability

Water absorption @ 24 hrs	* 0.5	-	1	%

Durability: flammability

Flammability	Non-flammable			

Durability: fluids and sunlight

Water (fresh)	Excellent			

Water (salt)	Excellent			
Weak acids	Excellent			
Strong acids	Excellent			
Weak alkalis	Excellent			
Strong alkalis	Acceptable			
Organic solvents	Excellent			
UV radiation (sunlight)	Excellent			
Oxidation at 500C	Excellent			
Halogens	Acceptable			
Metals	Acceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 6.62e4	-	7.31e4	BTU/lb
CO2 footprint, primary production	* 8.3	-	9.17	lb/lb
Water usage	* 3.88e3	-	4.26e3	in^3/lb

Material processing: energy

Grinding energy (per unit wt removed)	* 744	-	823	BTU/lb

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	* 0.13	-	0.144	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Recycle fraction in current supply	0.1			%
Downcycle	True			
Combust for energy recovery	False			
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Catalyst Supports, Catalyst Bed Systems, Radiation Shields, Kiln Furniture, Refractories, Thermal Insulation, High Temperature Filtration, Heat Transfer. Mid temperature, fast cycles

Reference sources

Data compiled from multiple sources. See links to the References table.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

37.

Zirconia foam (partly stabilized)(1.28)

Identification

Designation

Partly Stabilized Zirconia Foam (1.28)

Tradenames

DUOCEL, SELEE, RETICEL

General Properties

Density	0.0452	-	0.0488	lb/in^3
Porosity (closed)	0			%

Porosity (open)	0.752	-	0.77	%
Price	* 28.2	-	32.9	USD/lb

Composition overview

Composition (summary)

ZrO2 + CaO + MgO + Other oxide

Base	Oxide			

Composition detail (metals, ceramics and glasses)

CaO (calcia)	5			%
MgO (magnesia)	5			%
ZrO2 (zirconia)	89			%
Other oxide	1			%

Foam & honeycomb properties

Anisotropy ratio	* 1	-	1.3	
Cells/volume	1.64e3	-	2.46e5	/in^3
Relative density	0.205	-	0.215	

Mechanical properties

Young's modulus	* 0.29	-	0.319	10^6 psi
Flexural modulus	0.29	-	0.319	10^6 psi
Shear modulus	* 0.102	-	0.107	10^6 psi
Bulk modulus	* 0.29	-	0.319	10^6 psi
Poisson's ratio	* 0.24	-	0.28	
Shape factor	3			
Yield strength (elastic limit)	* 0.087	-	0.232	ksi
Tensile strength	* 0.087	-	0.232	ksi
Compressive strength	0.812	-	0.87	ksi
Flexural strength (modulus of rupture)	0.229	-	0.247	ksi
Elongation	* 0.03	-	0.08	% strain
Hardness - Vickers	* 0.56	-	0.6	HV
Fatigue strength at 10^7 cycles	* 0.107	-	0.119	ksi
Fracture toughness	* 0.228	-	0.273	ksi.in^0.5
Mechanical loss coefficient (tan delta)	* 0.001	-	0.003	

Thermal properties

Melting point	4.85e3	-	4.91e3	°F
Heat deflection temperature 0.45MPa	3.07e3	-	3.11e3	°F
Maximum service temperature	3.07e3	-	3.11e3	°F
Minimum service temperature	-459			°F
Thermal conductivity	0.149	-	0.169	BTU.ft/hr.ft^2.°F
Specific heat capacity	0.107	-	0.122	BTU/lb.°F
Thermal expansion coefficient	4.28	-	4.39	µstrain/°F
Latent heat of fusion	* 344	-	387	BTU/lb

Electrical properties

Electrical resistivity	* 1e17	-	1e18	µohm.cm
Dielectric constant (relative permittivity)	* 3.6	-	3.9	
Dissipation factor (dielectric loss tangent)	* 0.001	-	0.0025	
Dielectric strength (dielectric breakdown)	* 152	-	203	V/mil

Optical properties

Color	Black			
Refractive index	* 2.13	-	2.2	
Transparency	Opaque			

Absorption, permeability

Water absorption @ 24 hrs	* 0.5	-	1	%

Durability: flammability

Flammability	Non-flammable			

Durability: fluids and sunlight

Water (fresh)	Excellent			
Water (salt)	Excellent			
Weak acids	Excellent			
Strong acids	Excellent			
Weak alkalis	Excellent			
Strong alkalis	Acceptable			
Organic solvents	Excellent			
UV radiation (sunlight)	Excellent			
Oxidation at 500C	Excellent			
Halogens	Acceptable			
Metals	Acceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 6.62e4	-	7.31e4	BTU/lb
CO2 footprint, primary production	* 8.3	-	9.17	lb/lb
Water usage	* 3.88e3	-	4.26e3	in^3/lb

Material processing: energy

Grinding energy (per unit wt removed)	* 569	-	629	BTU/lb

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	* 0.0992	-	0.11	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Recycle fraction in current supply	0.1			%
Downcycle	True			
Combust for energy recovery	False			
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Catalyst Supports, Catalyst Bed Systems, Radiation Shields, Kiln Furniture, Refractories, Thermal Insulation, High Temperature Filtration, Heat Transfer. Mid temperature, fast cycles

Reference sources

Data compiled from multiple sources. See links to the References table.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

38.

Zirconia mullite alumina foam (0.63)

Identification

Designation

Zirconia Mullite Alumina Foam (0.63)

Tradenames

DUOCEL, SELEE, RETICEL

General Properties

Density	0.0206	-	0.0246	lb/in^3

Porosity (closed)		0		%
Porosity (open)		0.829 -	0.857	%
Price	*	9.41 -	11.3	USD/lb

Composition overview

Composition (summary)

Al2O3 + ZrO2 + SiO2 + Na2O + Other oxide

Base		Oxide		

Composition detail (metals, ceramics and glasses)

Al2O3 (alumina)		48.5		%
Na2O (sodium oxide)		0.2		%
SiO2 (silica)		16.5		%
ZrO2 (zirconia)		34.5		%
Other oxide		0.3		%

Foam & honeycomb properties

Anisotropy ratio	*	1 -	1.3	
Cells/volume		5.41e3 -	9.34e5	/in^3
Relative density		0.15 -	0.19	

Mechanical properties

Young's modulus	*	0.145 -	0.232	10^6 psi
Flexural modulus		0.145 -	0.232	10^6 psi
Shear modulus	*	0.087 -	0.116	10^6 psi
Bulk modulus	*	0.145 -	0.232	10^6 psi
Poisson's ratio	*	0.23 -	0.27	
Shape factor		3		
Yield strength (elastic limit)	*	0.116 -	0.261	ksi
Tensile strength	*	0.116 -	0.261	ksi
Compressive strength		0.145 -	0.355	ksi
Flexural strength (modulus of rupture)		0.167 -	0.261	ksi
Elongation	*	0.05 -	0.18	% strain
Hardness - Vickers	*	0.1 -	0.245	HV
Fatigue strength at 10^7 cycles	*	0.132 -	0.146	ksi
Fracture toughness	*	0.091 -	0.127	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	0.001 -	0.003	

Thermal properties

Melting point	*	3.6e3 -	3.69e3	°F
Heat deflection temperature 0.45MPa	*	2.7e3 -	2.79e3	°F
Maximum service temperature	*	2.7e3 -	2.79e3	°F
Minimum service temperature		-459		°F
Thermal conductivity	*	0.192 -	0.289	BTU.ft/hr.ft^2.°F
Specific heat capacity	*	0.155 -	0.186	BTU/lb.°F
Thermal expansion coefficient	*	4.39 -	4.78	µstrain/°F
Latent heat of fusion	*	391 -	443	BTU/lb

Electrical properties

Electrical resistivity	*	1e17 -	1e18	µohm.cm
Dielectric constant (relative permittivity)	*	2.4 -	2.6	
Dissipation factor (dielectric loss tangent)	*	0.001 -	0.0025	
Dielectric strength (dielectric breakdown)	*	152 -	203	V/mil

Optical properties

Color		Gray		
Refractive index	*	1.75 -	1.77	
Transparency		Opaque		

Absorption, permeability

Water absorption @ 24 hrs	*	0.5 -	1	%

Durability: flammability

Flammability	Non-flammable			

Durability: fluids and sunlight

Water (fresh)	Excellent			
Water (salt)	Excellent			
Weak acids	Excellent			
Strong acids	Excellent			
Weak alkalis	Excellent			
Strong alkalis	Acceptable			
Organic solvents	Excellent			
UV radiation (sunlight)	Excellent			
Oxidation at 500C	Excellent			
Halogens	Acceptable			
Metals	Acceptable			

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 3.68e4	-	4.07e4	BTU/lb
CO2 footprint, primary production	* 4.62	-	5.1	lb/lb
Water usage	* 3.65e3	-	4.01e3	in^3/lb

Material processing: energy

Grinding energy (per unit wt removed)	* 410	-	453	BTU/lb

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	* 0.0715	-	0.079	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Recycle fraction in current supply	0.1			%
Downcycle	True			
Combust for energy recovery	False			
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Catalyst Supports, Catalyst Bed Systems, Radiation Shields, Kiln Furniture, Refractories, Thermal Insulation, High Temperature Filtration, Heat Transfer.

Reference sources

Data compiled from multiple sources. See links to the References table.

Links

ProcessUniverse
Producers
Reference
Shape
Values marked * are estimates.
Granta Design provides no warranty for the accuracy of this data

39.

Zirconia with calcia foam (fully stabilized)(0.74)

Identification

Designation

Fully Stabilized Zirconia with Calcia Foam (0.74)

Tradenames

DUOCEL, SELEE, RETICEL

General Properties

Density	0.026	-	0.0275	lb/in^3
Porosity (closed)	0			%
Porosity (open)	0.86	-	0.868	%
Price	* 28.2	-	32.9	USD/lb

Composition overview

Composition (summary)

ZrO2 + CaO

Base	Oxide			

Composition detail (metals, ceramics and glasses)

CaO (calcia)	3.5			%
ZrO2 (zirconia)	96.5			%

Foam & honeycomb properties

Anisotropy ratio	* 1	-	1.3	
Cells/volume	3.77e4	-	6.23e5	/in^3
Relative density	0.11	-	0.14	

Mechanical properties

Young's modulus	* 0.087	-	0.174	10^6 psi
Flexural modulus	0.087	-	0.174	10^6 psi
Shear modulus	* 0.0435	-	0.0725	10^6 psi
Bulk modulus	* 0.087	-	0.174	10^6 psi
Poisson's ratio	* 0.24	-	0.28	
Shape factor	3			
Yield strength (elastic limit)	* 0.087	-	0.247	ksi
Tensile strength	* 0.087	-	0.247	ksi
Compressive strength	0.131	-	0.218	ksi
Flexural strength (modulus of rupture)	0.11	-	0.258	ksi
Elongation	* 0.05	-	0.28	% strain
Hardness - Vickers	* 0.09	-	0.15	HV
Fatigue strength at 10^7 cycles	* 0.112	-	0.123	ksi
Fracture toughness	* 0.0728	-	0.1	ksi.in^0.5
Mechanical loss coefficient (tan delta)	* 0.001	-	0.003	

Thermal properties

Melting point	4.85e3	-	4.91e3	°F
Heat deflection temperature 0.45MPa	* 3.06e3	-	3.11e3	°F
Maximum service temperature	* 3.06e3	-	3.11e3	°F
Minimum service temperature	-459			°F
Thermal conductivity	* 0.14	-	0.164	BTU.ft/hr.ft^2.°F
Specific heat capacity	0.107	-	0.122	BTU/lb.°F
Thermal expansion coefficient	4.28	-	4.39	µstrain/°F
Latent heat of fusion	* 344	-	387	BTU/lb

Electrical properties

Electrical resistivity	1e18	-	1e19	µohm.cm
Dielectric constant (relative permittivity)	* 2.5	-	2.7	
Dissipation factor (dielectric loss tangent)	* 0.001	-	0.0025	
Dielectric strength (dielectric breakdown)	* 152	-	203	V/mil

Optical properties

Color	Black			
Refractive index	* 2.13	-	2.2	
Transparency	Opaque			

Absorption, permeability

Water absorption @ 24 hrs	* 0.5	-	1	%

Durability: flammability

Flammability	Non-flammable			

Durability: fluids and sunlight

Water (fresh)	Excellent
Water (salt)	Excellent
Weak acids	Excellent
Strong acids	Excellent
Weak alkalis	Excellent
Strong alkalis	Acceptable
Organic solvents	Excellent
UV radiation (sunlight)	Excellent
Oxidation at 500C	Excellent
Halogens	Acceptable
Metals	Acceptable

Primary material production: energy, CO2 and water

Embodied energy, primary production	*	6.62e4	-	7.31e4	BTU/lb
CO2 footprint, primary production	*	8.3	-	9.17	lb/lb
Water usage	*	3.88e3	-	4.26e3	in^3/lb

Material processing: energy

Grinding energy (per unit wt removed)	*	333	-	368	BTU/lb

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	*	0.058	-	0.0641	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False	
Recycle fraction in current supply	0.1	%
Downcycle	True	
Combust for energy recovery	False	
Landfill	True	
Biodegrade	False	
A renewable resource?	False	

Notes

Typical uses

Catalyst Supports, Catalyst Bed Systems, Radiation Shields, Kiln Furniture, Refractories, Thermal Insulation, High Temperature Filtration, Heat Transfer.

Reference sources

Data compiled from multiple sources. See links to the References table.

Links

- ProcessUniverse
- Producers
- Reference
- Shape
- Values marked * are estimates.
- Granta Design provides no warranty for the accuracy of this data

40.

Zirconia with magnesia foam (partly stabilized)(0.81)

Identification

Designation

Partly Stabilized Zirconia with Magnesia Foam (0.81)

Tradenames

DUOCEL, SELEE, RETICEL

General Properties

Density		0.0267	- 0.0318	lb/in^3
Porosity (closed)		0		%
Porosity (open)		0.838	- 0.864	%
Price	*	28.2	- 32.9	USD/lb

Composition overview

Composition (summary)

ZrO2 + MgO + Other oxide

Base		Oxide		

Composition detail (metals, ceramics and glasses)

MgO (magnesia)		3.5		%
ZrO2 (zirconia)		95		%
Other oxide		1.5		%

Foam & honeycomb properties

Anisotropy ratio	*	1	- 1.3	
Cells/volume		8.19e3	- 9.83e5	/in^3
Relative density		0.123	- 0.147	

Mechanical properties

Young's modulus	*	0.145	- 0.218	10^6 psi
Flexural modulus		0.145	- 0.218	10^6 psi
Shear modulus	*	0.0725	- 0.102	10^6 psi
Bulk modulus	*	0.145	- 0.218	10^6 psi
Poisson's ratio	*	0.24	- 0.28	
Shape factor		3		
Yield strength (elastic limit)	*	0.087	- 0.276	ksi
Tensile strength	*	0.087	- 0.276	ksi
Compressive strength		0.189	- 0.363	ksi
Flexural strength (modulus of rupture)		0.16	- 0.29	ksi
Elongation	*	0.04	- 0.19	% strain
Hardness - Vickers	*	0.13	- 0.25	HV
Fatigue strength at 10^7 cycles	*	0.117	- 0.131	ksi
Fracture toughness	*	0.091	- 0.127	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	0.001	- 0.003	

Thermal properties

Melting point	*	4.82e3	- 4.86e3	°F
Heat deflection temperature 0.45MPa	*	2.97e3	- 3e3	°F
Maximum service temperature	*	2.97e3	- 3e3	°F
Minimum service temperature		-459		°F
Thermal conductivity	*	0.14	- 0.154	BTU.ft/hr.ft^2.°F
Specific heat capacity		0.107	- 0.122	BTU/lb.°F
Thermal expansion coefficient		4.28	- 4.39	µstrain/°F
Latent heat of fusion	*	340	- 387	BTU/lb

Electrical properties

Electrical resistivity		1e18	- 1e19	µohm.cm
Dielectric constant (relative permittivity)	*	2.6	- 3	
Dissipation factor (dielectric loss tangent)	*	0.001	- 0.0025	
Dielectric strength (dielectric breakdown)	*	152	- 203	V/mil

Optical properties

Color		Black		
Refractive index	*	2.13	- 2.2	
Transparency		Opaque		

Absorption, permeability

Water absorption @ 24 hrs	*	0.5	- 1	%

Durability: flammability

Flammability		Non-flammable		

Durability: fluids and sunlight

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Weak acids	Excellent			
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CO2 footprint, primary production	* 8.3	-	9.17	lb/lb
Water usage	* 3.88e3	-	4.26e3	in^3/lb

Material processing: energy

Grinding energy (per unit wt removed)	* 387	-	427	BTU/lb

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	* 0.0675	-	0.0746	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	False			
Recycle fraction in current supply	0.1			%
Downcycle	True			
Combust for energy recovery	False			
Landfill	True			
Biodegrade	False			
A renewable resource?	False			

Notes

Typical uses

Catalyst Supports, Catalyst Bed Systems, Radiation Shields, Kiln Furniture, Refractories, Thermal Insulation, High Temperature Filtration, Heat Transfer.

Reference sources

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APPENDIXB Specific Interview Notes

We would like to preface this section with the note that the names and affiliations of the interviewed have been provided with the prior knowledge of the interviewee.

The first person we interviewed about anything regarding this project was Stephen Hayes, the head of the Worcester Ambulance Fleet. While this interview was rather unofficial, his concerns regarding the ambulance features were very relevant to our research. This interview was conducted the last Tuesday of August of 2012 at the fleet yard while all of the teams working on IQPs under Professor Mustafa Fofana met for the first time to find information related to their respective IQPs.

At the time of this interview, the ambulances in the Worcester fleet were just beginning to make the transition from the fluorescent banks and halogen dome lights to the newer LED lighting. Out of the four ambulances we were able to get a look into, only one of them even had any LED lighting- and these lights were only dome lights – giving us only a limited idea as to the true potential pure LED lighting has.

The reason this detail is mentioned is because the questions that follow are under the assumption that LED lighting had not yet received wide-spread implementation in modern ambulances.

The first lighting related question we asked Hayes was how comfortable the lighting in the ambulance compartment was. We asked Hayes this question more to see if the lighting in the compartment was considered too brutal for the EMTs or patients, or generally provided the proper amount of light necessary for the EMTs to do their jobs effectively without causing a delay due to light irritation.

His response, paraphrased, was as follows: ‘the lighting system’s brightness does not interfere with the work the EMTs do while transporting the patients to the hospital. The only reason soft lighting can be necessary in an ambulance is for patients who are very sensitive to light, but the EMTs themselves are trained to work under any circumstance.’ The general idea we got from this answer is that lighting serves mostly as an ambiance effect in ambulance care. The EMTs are trained to the point, that as he later put, they could do their jobs effectively under any circumstance. This makes a lot of sense due to the sheer importance of their position; such things as inadequate lighting cannot be the end-all-be-all.

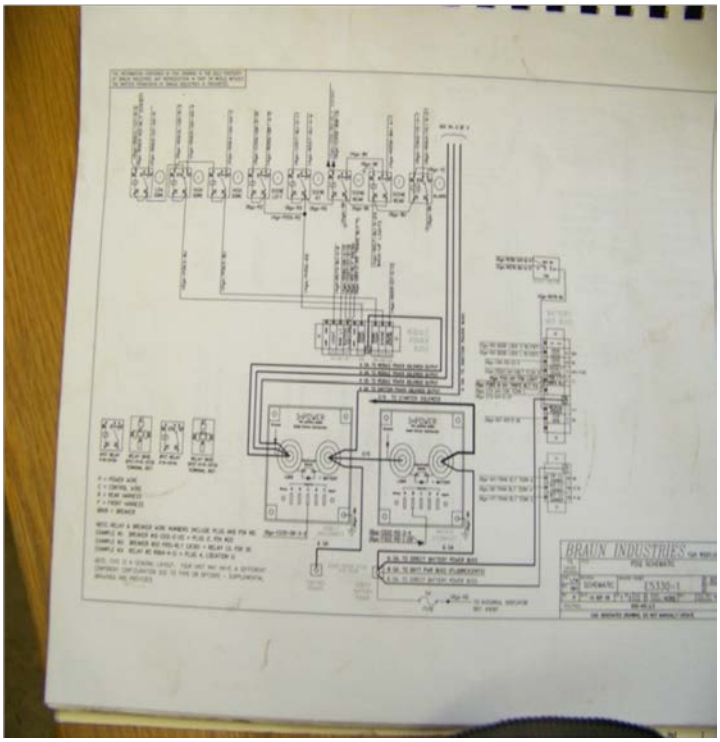
The next question about lighting that we asked Hayes was why he thought that LED lighting was not used in more of the ambulances already. The answer we had originally anticipated was that money was the real problem. While this detail is rather indisputable presently, we were surprised to find that this was not the only reason LED lighting is not incorporated in all of the ambulances in the fleet. Maintenance of ambulances is a difficult thing to do when you have only a limited number of ambulances at your disposal. The fleet that we visited in Worcester, MA only contained enough housing for 3 or 4 ambulances at any given time; therefore, taking one out to receive upgrades can put a lot of pressure on the other stationed ambulance crews to pick up the slack of a machine not in use. Since ambulances are constantly in use, the abuse they take combined with the strict regulations ambulance mechanics are forced to follow by governmental law can make things like repairs, upgrades and modifications a lengthy process. For this reason, combined with the high budget necessary to transition between maintaining low cost fluorescent banks and halogen bulbs to brand new LED lit units, the time taken to move towards the new technology has been forcibly extended.

It should be mentioned that as the Head of the Ambulance Fleet, it is not Hayes' duty to know all of the internals of the ambulances like a mechanic would have to know; however, this did not stop us from asking him while we had him how much power the interior lighting systems consumed. To which, he did not have a numerical answer ready for us. He did, however, inform us that the systems the ambulance ran on consumed a large amount of power, and while the standards dictate the lighting control circuits be designed to consume a minimal amount of power, the vehicles still require anywhere from 2 to 4 car batteries to maintain proper operation. In the vehicle using LED lit dome lights, the ambulance had a total of 4 car batteries powering all of the electronic equipment in the ambulance. As was later discovered through other research endeavors, each of those batteries has to deliver about 800CCA (cold crank amps). This number is specific to each battery used by each ambulance manufacturer [22].

The next question brought up involved the material storage containers that are visible in the top-right and mid-left hand sides of the image above. We asked him what he thought of the idea of putting strip lighting in the back of the cabinets to better illuminate the containers, and maybe reorganize the containers to make everything better accessible. With tinted glass on the outside of the cabinets, it was difficult to see where things are immediately for quick access. On top of this, the cabinets on the left are deep enough for two rows worth of material storage, and, being a vehicle with less than perfect shock absorption, the materials from the first row can fall back into the second row, making the search for specific items a potentially time consuming process for an EMT than it should be. This is better illustrated in the image below.

Hayes did not think that the strip lighting in the back of the cabinets to illuminate the containers was entirely necessary due to the extensive training and experience the EMTs have who make up the crew of the ambulance have received. However, he did not think it was a particularly *bad* idea, and seemed interested in the prospect of reorganizing the blue containers to better access important items. Sadly, that wasn't the part of the question we were hoping he would be interested in. We also later learned that ambulance manufacturers such as Horton Ambulance already use strip lighting in the back of their cabinets inside their ambulance.

The last thing we asked Hayes was if he had a book of the schematics for the ambulances in his fleet. He was able to show us one of the schematics. This schematic booklet, if you could call it that, was probably 200 some-odd pages worth of schematic diagrams. With an Electrical Engineering student on our team, it was a difficult task to get him to leave. However, we were able to snag a picture of one of the schematics that would be useful to analyze the systems that have electric draw from the ambulance to maintain the peace.



This schematic drawing also indicates the manufacturer of the models of ambulance that are typically used by the Worcester Fleet to be none other than Braun Industries, the same manufacturer who has kept much the same design as you can see in Figure 6.

With this addition to the project, the researching began shifting toward the standards and regulations put onto the lighting, and less on the interviews with the EMTs. That is, until we went to a conference roughly 7 weeks after we had interviewed Hayes. It was here that we conducted something less of an interview, and more like a presentation/ multi-personnel think tank all simultaneously sparked by the questions that we had come up with to ask the manufacturers and engineers showing up to this meeting after the main presentation was over. Due to the sudden nature of our presentation - for which we were not prepared at all beforehand – we slimmed down the questions we wanted to ask and put them out to the entire audience. The people of note from this audience who contributed the most relevant information are Neil Blackington, the Head of the Boston Fleet, Chad Brown, Vice President of Sales and Marketing from Braun Industries, and David White, General Manager with Professional Vehicle Corporation.

We had four questions about lighting in total, including one which we decided not to ask, but we will mention it on the grounds that we did plan on asking it.

The first question was what shortcomings there were in the lighting in an ambulance.

Neil Blackington was probably the most insightful in this regard, as his experience with riding in the ambulance and listening to the other EMTs concerns with the lighting allowed us to get more field information. Some of the shortcomings that were mentioned in response to this question were the different hues of light the fluorescent lights made has contributed to some cases of misdiagnosis; the side lighting has been replaced by cabinets; thus, there is a lack of lighting where the EMTs may benefit from seeing the patient at different angles. Chad Brown also added in saying that the lighting presently draws a lot more power than its LED counterpart, and while power draw is not necessarily a shortcoming, it can be potentially harmful if there is heat sensitive or light sensitive medicine in a lit cabinet. The shortcoming of the lighting type is that they produce more heat and a different spectral signature than LED lighting, in some cases, having the potential to damage medication that has strict instructions for proper handling and storage. In conjunction with heat emission having the potential to damage medication, the heat emission of the lighting- while less noticeable than the outside temperature – contributes to the total amount of time it takes to regulate the temperature in the compartment which in turn makes the ventilation system draw more power. The issues raised in this question became more flushed out the longer we talked about these troubles.

The next question was the question that we decided not to ask. We wanted to know why there was not a more flexible system in place for adjusting the lighting intensity in the compartment. For example, in the image below the reader can see that there is only two settings for the dimming feature on this control board; one for the low lights, and one for the high lights.

The reason we decided against this question was because in some additional research, after we had come up with the questions but before we presented, we found that there were many ambulance manufacturers who installed a dimmer for the lights in a heat control dial and controlled the lighting that way. This method would obviously not show up on the control panels, since it is an entirely different mechanism for lighting control. However, in some systems like the Horton Emergency Vehicle control panel, there is an air control feature that adjust like a true variable-setting device, yet the lighting on this system is either high or low using the same feature. Anyhow, knowledge of this utility led us not to ask this particular question.

The last truly lighting related question was what challenges lighting designers have faced in the past, and present, and what lighting design challenges can we expect in the future.

The answers we got for this one always seemed to revolve around the need of the patient above all else. Lighting will always be an important aspect of ambulance design for the sole reason of keeping the patient comfortable and as relaxed as possible on their ride to the hospital. It is difficult to meet the requirements of modern consumers while technology cannot advance fast enough to match the demand. This subject will make itself more apparent in the next interview, but we will get to that in a little bit.

The last question we asked that was not exactly related to lighting directly, but more related to the method standards were implemented. We wanted to know what they would change about the standards if they could change anything.

We expected something a little bit more pertaining to the standards themselves than what we got. However, the general consensus was the one thing they would change about the standards is how they were made in the first place. The suggestion was to move the authority to a third party policing agency that would have nothing to gain from poor performing systems or unnecessary gimmicks in the standards.

With these questions answered, Chad Brown gave us a contact for acquiring more information about the lighting system, Tony Angellela. We sent him the list of questions we had asked at the presentation, and he responded shortly after giving us a couple other contacts to talk to that would be better resources; Paul Gergets, General Manager and Director of Engineering of Federal Signals, and Robert Hartke, Head of the Engineering Team of Federal Signals. Kevin was privileged to speak with Paul Gergets and get an interview about the lighting systems in an ambulance, where he asked and got answers to the following questions.

In similar fashion to the interview at the conference, Paul Gergets was asked what he thought the biggest limitation to lighting design was. Gergets responded with more detail than Kevin was able to jot down on the go, but we managed to get the general idea that technology was the biggest limitation to lighting design. There are a lot of brilliant minds out there trying to come up with the next big thing in lighting design, but in order to get those ideas into action, we need to wait until the technology catches up to it. This ‘technology’ is both in the form of tools and mechanics, as well as the public’s readiness to behave as proper consumers when the next advance makes itself present.

The next question asked to Gergets was how ambulance lighting was tested in the industry. It turns out that there is a special instrument used to test the luminosity of a given light anywhere from 3 feet to 10 feet away from the source of the light (never both for the purpose of accurate test results with a controlled variable). The results are then categorized in units such as ‘foot candles’. The standards for ambulance design are measured in foot candles, and this bit of information was very helpful in analyzing the meaning of those measurements. That is just for the ambulance testing however and the lights themselves are actually first tested in a pitch black 60 foot room. Due to the room's total absence of light, this room actually simulates a 120 foot distance the light would cover with no reflections. There is a light sensor on a particular wall measuring the luminosity of the light in testing. The light is on a stand that is rotated 360 degrees in the theta and phi spherical coordinates by ¼ of a degree each time, which is about 2.0736 million times. The resulting accuracy of the light propagation pattern of any tested light is unparalleled by any other test.

After that, Gergets answered what is the difference between the different measurements light is measured in; specifically the difference between lumens, foot candles, and watts. The answer to this question was one that was not expected: preference. They all mean the same thing. The difference between them is where the source of the light is measured from. The example given was a standard halogen bulb, whose wattage is generally around 60 for in home use. A lighting engineer who is older would be more inclined to refer to the luminosity in watts – a measurement taken from the electrical characteristics of the light, not the visual - as opposed to a newer lighting engineer who would likely measure light intensity from a distance and classify it as foot candles - or lumens in the case of LEDs.

The following question was more out of curiosity. Due to his position, Gergets is a part of an engineering team. That said, he's not a manufacturer, and purchases his lighting outside of his company. We wanted to know where the lighting his team uses to implement in ambulances. The two companies that he mentioned were Cree, and Philips Lumens. Cree and Philips Lumens both specialize in LED lighting design, and their products are top of the line in quality. The lighting in the vehicles these teams are designing at Federal Lighting is crisp, clear, and most importantly, driven by quality.

The final question Gergets was asked was what reason there may be to want to have a third party agency develop the standards for ambulance design. The explanation we got is as follows, paraphrased: The standards made for manufacturers to follow are made by the companies that can benefit off of the standards in place. This means that for any given part of an ambulance, say the lighting in this case, they could, if they so desired, change the luminosity requirement to something much higher at any given area of the ambulance in order to make more money from the lighting, or at the same time, could change the voltage requirements for any given system to force a revision to the control circuits that are required for those systems. This seemingly whimsy-based standard revision process can make any area of the actual ambulance’s features performance lackluster.

With that last tidbit of information, the interview was over, and we did not conduct another official one until we met up with Steven Hayes again in December. By this time, however, more of the ambulances in his fleet had started to convert from the typical halogen/ fluorescent lighting to LED lighting, and his general interest with advancement in the lighting area became less than it had been originally. Which, to be honest, was not really there in the first place. With that said, the interview regarding lighting questions was over before it really began, and we spent that entire interview talking about ventilation; the results of which will be shared in the ventilation section.