A Systems Engineering Approach to Green Home Design:

The Need to Incorporate Residential Fire Sprinklers

An Interactive Qualifying Project submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science

SUBMITTED BY:

Kyle Padelford: _____
Christopher Whipple: _____

SUBMITTED TO:

Project Advisor
Prof. Kathy Notarianni: _____

Abstract

A rapidly developing trend in home building is undeniably green home design. The continual steep climb in gas and oil prices has made energy efficiency in homes not only highly desirable but also financially beneficial. To meet this growing demand, companies are continually creating new products to make homes more energy efficient. These products and are being installed in homes across America as part of energy efficient retrofit projects as well as new green construction. This study addresses the questions: How fire safe are common green products? Is there an unstated and/or poorly understood correlation between green design and fire safety? If so, is there an integrated approach that will provide for both green design and fire safety?

The market for green products is so strong that product design is focused narrowly on the product's energy saving potential. Although many "green products" provide an increase in energy efficiency, the very same material properties that provide for energy savings may also increase both the total building fire load and the rate of spread of fire. The fire protection community has repeatedly pushed for the installation of automatic fire sprinklers in new construction. Automatic fire sprinklers have been shown to be highly successful in controlling and extinguishing a fire early in its development. However, the residential building community has not embraced this technology. Automatic fire sprinklers are seen as costly and surprisingly, not environmentally friendly. The U.S. International Code Council (ICC) has developed a green building code, ISBN: 978-1-60983-097-7, yet this code also focuses solely on building for energy efficiency and is not integrated in a systems approach with the fire safety codes. Currently, residential fire sprinklers are not mandated by the international green building codes. This project focuses on the intersection of these three important components of green home design: the building and fire codes, green materials and their fire properties and the research on the environmental impact of residential sprinklers. The study takes a systems engineering approach and demonstrates the need to incorporate residential fire sprinklers as a part of green building design.

Introduction

In the current technological era, every passing day brings new ideas and technologies that were mere dreams in years past. That coupled with our consumerist society, leads too many new, innovative and exciting products and technologies being brought into our homes. These new technologies are not just limited to new consumer products, but also include new building materials and processes used in the construction and manufacturing of homes, furniture and appliances.

Society plays a large role in this rapid expansion of new technology, as supply and demand for certain types of products are determined by public views. Marketers are quick to capitalize on the collective feelings of the audience they are selling to. Due to an increase in gas, heating oil prices and the much publicized worldwide increase in carbon emissions and greenhouse gases; people have become more conscious about their carbon footprint, and are moving towards a more sustainable future. This can be defined as the green movement, which has been rapidly evolving over the past decade. With the advent of the green movement, many new products and technologies are being marketed solely based on their environmental benefits. The fact that a product is being advertised as "green" is usually enough for the average green consumer to make a purchase without even considering factors such as the fire properties of these materials and their overall product safety.

As a result, consumers are inadvertently making their homes more flammable which in turn shortens the amount of time occupants have to escape in the event of a fire. One of the main causes of this is the change in materials used in the construction and furnishing of homes, as mentioned above. As evidence of this, a recent NIST study, completed in 2004 revealed that the amount of time available to escape a burning home had dropped from 17 minutes in 1974 to about 3 minutes today. **(Bukowski)**

The rising price of oil and greater awareness of carbon emissions has made many Americans re-examine their carbon footprint and make an effort to become more environmentally friendly. Some have chosen to trade in their large, inefficient sport utility vehicle for a smaller and more fuel efficient hybrid. Other people started taking public transportation. Others are retrofitting their homes to maximize their homes heating system. Such a retrofit could include new windows, new insulation, and a new roof, new siding, etc, all of which comes at great expense to the homeowner. New technologies and materials have allowed for much more effective ways to insulate buildings and are becoming popular, both in new home construction and in retrofits of older homes. These new products offer higher insulation values over their older counterparts. However, in the rapid change to "go green", have these products been thoroughly researched and tested for potential safety hazards, namely in the area of fire safety? With all of this emphasis on going green, has anyone put the thought into whether these products are safe?

The question stands, are green products as safe as their predecessors, specifically with concerns to fire safety? Currently there are a number of private and public organizations whose main goal is to keep the average consumer well informed and safe. The Consumer Product Safety Commission or CPSC is the predominant agency in consumer safety. The CPSC is responsible for keeping products within various safety guidelines. Their mission statement: "The U.S. Consumer Product Safety Commission is charged with protecting the public from unreasonable risks of injury or death from thousands of types of consumer products under the agency's jurisdiction." **(CPSC).** Issues arise when cultural movements, like the green movement, create a sudden demand for a new type of product. Marketers are quick to take advantage of this, and start creating products to fulfill the need as they see fit. Unfortunately, the CPSC often cannot keep up with the marketers and the markets they are creating, and are left a few steps behind the ever changing marketplace. Another resourced used by consumers and builders to ensure the safety of the occupants of a home are the state and local building codes. These codes however, are not being updated fast enough to keep up with the demand of the market. Additionally, the codes do not analyze or take into consideration how these new materials impact the house as a fully integrated system, not just the material on its own. Are the materials being used more

flammable and therefore making the home more dangerous? If so what can be done to correct this problem? There is data about the materials, appliances and the furniture and their flammability statistics, but are they being analyzed in real world scenarios? If so, are they being used in the decision making process? As important as all of these questions are, the real question is what can be done to help make these homes safer from fire danger.

The answer to this question lies in research. Before an answer can be determined, the risk must first be evaluated. There have been many studies published on home fire safety, including those done through National Institute Standards and Technology, the CPSC, and other such safety institutions, with particular emphasis on green construction. Once the risk is evaluated and quantified, a thorough understanding of how residential sprinklers have an impact on reducing the fire danger to people and their homes as a solution to the increased risk. The ultimate goal is to illustrate the need for residential sprinklers in new green construction homes, and also green retrofits due to the increase in flammability and subsequent increase in fire risk, and show weaknesses in the building codes in Massachusetts. It is also important to illustrate the need for the different sections of the building codes to reference each other and require builders to use a systematic approach to home design and renovation.

Study Methodology

Today, there exists a need to incorporate residential automatic fire sprinklers as an integral part of green home design. The technical and societal argument for the incorporation of automatic fire sprinklers is presented below in three sections. Each section represents one of the three key components of this study. These are: 1. A review of building and fire codes including the green building code; 2. A look at green home design and the fire properties of the materials used; and 3. An evaluation of the environmental impacts of residential fire sprinklers.

The goal of Part 1 of this study is to evaluate the degree of correlation between the building and fire code and the green building code. The goal of Part 2 is to identify products used in green home design and to determine their key fire properties. This is accomplished though a case study of a large-scale green retrofit project already completed. Part 3 consists of a review of a seminal research project conducted at FM Global. This study confirmed long-held beliefs of the fire protection community that automatic fire sprinklers are environmentally friendly. However, the degree to which this is true shocked even the FPE community. The study authors conclude with a suggested systems engineering approach to home design that is both green and fire safe.

To accomplish this, we conducted numerous interviews and a case study to validate our arguments. Interviews are going to play a key role in this research. In particular, members of the Massachusetts state fire marshal's office and members of organizations fighting for residential sprinklers will provide helpful insight into our research.

Timothee Rodrique from the Massachusetts state fire marshal's office will be the first interview, before much other research has been conducted. It is important to understand where Massachusetts is at the present time with residential sprinklers, and fire in general. Rodrique will also have access to fire data about local fires that may not be easily accessible to the public. He can also give insight as to where the current building codes are specific to Massachusetts and residential sprinklers. This interview will form a baseline off of which the rest of the research to be built.

Jeff Shapiro is a member of the IRC Fire Sprinkler Coalition. The IRC Fire Sprinkler Coalition is a group promoting the benefits of residential sprinklers and pushing law makers to pass legislation in favor of installing fire sprinklers in homes. Shapiro will be a great contact for understanding how difficult the fight has been to date, and also what arguments have been used by both sides of the issue. He also provided useful insight and creative input on how the problem should be addressed in order for it to be more universally accepted outside of academia, and therefore more useful.

Our research found that there was an increased fire risk in green homes. These risks include, but are not limited to, the flammability and flame spread rate of the materials, the heat release rate, and the gases that are emitted when the material undergoes combustion. The flammability and flame spread are important because if these constants are too high, then a fire in a home would spread faster, meaning the occupants have less time to escape safely and more damage will occur to the house before fire fighters can contain the flames. There is also the added risk to fire fighters because the more flammable materials will increase the overall heat produced by the fire and spread the fire faster. The heat release rate is also important because even if the material does not reach combustion, the heat from a nearby fire may cause some foam board insulation to heat up, and this in turn adds more heat back into the room with the fire, creating a positive feedback loop increasing the strength of a fire. What the material off gases is also very important to the safety of the materials. If the material off gases a toxic gas, then that is an increased risk to both the occupants in the home attempting to escape, as well as fire fighters attempting to extinguish the blaze.

The first aspect of research was to understand the current building codes, specifically with regards to what the codes required for sprinkler systems. The next objective was to examine the green building codes and their requirements.

Part I. Building Code Review

In the state of Massachusetts, fire sprinklers fall under the jurisdiction of both the building codes and Chapter 148 of Massachusetts General Law (M.G.L.) which covers fire prevention. Fire sprinklers in buildings are regulated by the following sections of Chapter 148 of M.G.L.: 26, 26A, 26A½, 26G, 26G½, 26H, and 26I. Section 26 states that any building that stores, manufactures or works on most flammable products is required to have sprinklers. For a full list of these Products, see Appendix A.1. This law can potentially encompass a large majority of multi-story commercial buildings. Although the installation of sprinklers is not mandatory, they can only be installed at the discretion of the fire marshal and only if four or more people live or work on or above the second floor of the building.

Section 26A, unlike Section 26, is mandatory for all buildings that meet its criteria. Simply stated, this section requires automatic fire sprinklers in all buildings greater than 70 feet in height, with the exception of hospital rooms. This section is supplemented by section 26A½ which lays out a timeline for installing sprinklers in older buildings, see Appendix A.2. This section provides a timeline for installing sprinklers in all buildings that fall under the jurisdiction of this section and section 26A, but were built before these sections came into effect, which was January 1, 1975. The end result is that all buildings that meet the requirements of these sections had sprinkler systems fully installed by March 30, 1998.

Section 26G encompasses even more buildings, by approaching sprinkler installation from the direction of building floor area rather than height. This section requires sprinklers for any building that has more than 7,500 square feet of floor area, whether the building is new or undergoing renovation, providing the means to protect a large number of buildings. However, this section stops short of including and even explicitly excludes residential properties from this law. Section 26G½ takes aim at buildings used primarily as bars and nightclubs. See Appendix A.3. Again this requires that sprinklers be installed in a large number of buildings, including residential buildings containing bars and nightclubs, but does not include standalone residential properties. This is somewhat addressed by Section 26H which requires sprinklers to be installed in

boarding houses. This is a step in putting sprinklers in residences; however this law is not mandatory statewide, but can only be implemented by individual municipalities. Additionally, it does not require sprinklers in state-owned properties among others. See Appendix A.4. Some of these gaps left by Section 26H are addressed in Section 26I. This section of law encompasses virtually all residential properties except for individual residences such as single family homes. See Appendix A.5. Also, much like Section 26H, Section 26I is not a statewide mandate, but can only be implemented by individual municipalities.

The end result of all these laws is that almost all high rise and commercial structures in Massachusetts need to be equipped with sprinklers. Additionally, if all municipalities adopted Sections 26H and 26I, then virtually all new buildings except single family residences would be protected with fire sprinklers. The final step would then be to require sprinklers in the only building type left unprotected, which would be single family homes.

The International Green Construction Code or IGCC is the international standard for green building design. This code has multiple guidelines for every aspect of building design and can be adopted by any governmental authority that chooses to do so. However, this code does not view fire sprinklers as an element of green design. The only mention of fire sprinklers in the 2010 code is as a "project elective" which is an optional feature a builder may add to the building to make it more environmentally sustainable but will only satisfy these requirements if the system used non-potable rainwater as its water supply.

The International Building Code, or IBC, is similar to the IGCC but has its focus on general building safety. The code has a section for fire safety, section 703, which makes recommendations for basic fire safety including the flammability of the materials used in the building. All materials used in the structure must meet flame and smoke spread standards determined by tests ASTME 119 or UL 263. Although the ICC does not reference green products and materials specifically, since these would be included in building construction, they need to pass these flame tests. However, there is some concern that while these materials pass the small scale lab tests that they may react differently in a real world scenario where they are mixed with other materials and used in large quantities.

The ICC international Fire Code or IFC for 2009 does not require sprinklers in residential dwellings unless the building falls under another code stipulation, for example,

if the building is over 70 feet fall, the ICC International Building Code requires automatic fire sprinklers. So any apartment high-rise buildings are required to install residential sprinklers. The IFC does not make any special mention of green materials or green design, regardless of residential or commercial applications. This leads to the next point, which is that there is a gap left by these codes.

These three expansive sets of codes cover most all aspects of their intended jurisdiction. However, they do not mesh together well, and therefore leave a gap. Both the green codes and the fire codes follow the overarching building codes, but they do not reference each other. The green codes should make references not only to the building codes, but also should address fire safety in green buildings, and the fire code should address special materials used in green construction. By making these changes, contractors would be forced to use a more systematic approach to green home design. The next section covers the why green materials should be considered a special subset of the fire code, and why the green codes should include fire safety.

Part II: Green Building Materials and their Fire Properties

a. What is Green Design? How is it measured?

Environmental efficiency is a major consideration of modern building design. There are many different ways to measure the environmental impact of a building, such as carbon emissions, water usage, electricity consumption and many others. The Leadership in Engineering and Environmental Design Organization (LEED), founded by the U.S. Green Building Council, is the main authority on environmentally friendly design of buildings. LEED also highlights specific areas that determine how "green" the building is. Although there are numerous measures of a building's environmental impact, the two areas that most relate to the use of fire sprinklers are water efficiency and materials and resources, which are described below.

Buildings are major users of our potable water supply. The goal of the water efficiency credit category is to encourage smarter use of water, inside and out. Water reduction is typically achieved through more efficient appliances, fixtures and fittings inside and water-wise landscaping outside.

During both the construction and operation phases, buildings generate a lot of waste and use a lot of materials and resources. This credit category encourages the selection of sustainably grown, harvested, produced and transported products and materials. It promotes the reduction of waste as well as reuse and recycling, and it takes into account the reduction of waste at a product's source **(LEED).**

LEED's certification system is described in a 2009 report on risk factors for buildings as "established metrics and certification levels for construction and renovation."

and that "LEED certification checklists provide guidance for options and measures to reduce the environmental impact of facility construction and operations on carbon emissions" **(Wieczorek).** LEED does not spell out specific efficiency targets much like laws or codes do, but instead provides general guidelines that can be applied to various situations and allow flexibility for each specific project.

b. Why might green building products be more dangerous?

Green products can be considered dangerous for a few reasons, specifically with regards to green building products designed to tighten a building's envelope. The basic premise of these products, in terms of fire safety, is very dangerous. The idea that a home should be air tight as to keep the warm in and the cold out, though is great for lowering energy bills, creates an even more hazardous environment during a fire. If a room is completely insulated, with no pockets where the heat can escape, the room will contain all of the heat produced by the fire, which in turn intensifies the fire by directing the heat back at the source, rather than letting it escape. This intensifying property is further exaggerated when the now larger fire creates even more heat. This cycle continues until either the heat has somewhere to go or the room heats up enough where everything in the room starts combusting, sometimes explosively. This is called a flashover. Similarly, the well insulated house creates a situation where the fire may be deprived of oxygen because the building is so well insulated. This could be considered a positive effect of having a well insulated house, until a firefighter has to open the door to fight the fire, and suddenly introduces a new oxygen source to the fire, causing an explosive back draft.

The green products are themselves also more dangerous. In order to be more energy efficient, companies need to use more exotic materials and chemicals in these new products. These materials may either burn faster, hotter, or release toxic fumes when burned, all of which increase the overall fire danger in a structure. Even so, the larger problem is that people typically become narrow minded when doing green projects and do not use a systems approach, so the facts about the product safety are never considered. Project leaders become too focused on accomplishing the one goal of better energy

efficiency and disregard how their decisions impact the other systems in the building. This may be the most dangerous aspect of green products - their label and how the public at large views them for that label and that label alone. To illustrate these points, we did a case study involving a house in Arlington, MA, which recently underwent a large scale green retrofit.

c. The Case Study

Many people are currently looking for ways to make their homes more energy efficient, both to save money and to lower their carbon footprint. One man, Alex Cheimets of Arlington, MA, took this a step further. He, along with the Massachusetts Department of Energy Resources and NSTAR, the local gas utility company, completely overhauled the 80 year old duplex to make it a model of energy efficiency. The retrofit cost over $90,000 and took over two years to complete. The project was made public, and the details of the materials used and the techniques pioneered in this project are widely distributed by NSTAR and the Massachusetts Department of Energy Resources, but no mention is ever made of the anything other than the qualities of the materials that revolve around making it more energy efficient. Unsure as to whether or not these materials were in fact making the house more flammable; our case study revolves around the materials used in this specific retrofit, and their fire properties. We used the available lists of materials used to gather manufacturer data and NIST and CPSC data when available, to analyze the added risk of having these materials in this building.

The Arlington house project used a number of new green technologies in order to improve its energy efficiency, mostly with regards to insulation. They used both foam board and spray foam insulation in the home to maximize the envelope of the home. The first insulation they used was Icynene open-cell spray on foam. This foam was added to the attic ceiling, and the basement rim joints. Icynene foam is installed by spraying the walls with the mixture, which then expands to 100 times its original size, to fill every open space. (Healthy Homes) It is well known for its ability to act as both a moisture barrier as well as an insulator for heat, which, from a green, energy efficient prospective, makes icynene very attractive as an insulation material. From a fire safety standpoint, this material does not

pose a threat to the spread of fire, as it does not add fuel to the fire. According to the Insulation Handbook, when exposed to fire conditions, icynene will burn completely without increasing the intensity of the fire, but offer no resistance to the fire. The big risk that icynene poses is from the release of many toxic gases which are bad for both the occupants attempting to escape a burning home and the fire fighters attempting to extinguish the blaze. **(Gilani)** The codes call for a fire barrier to be installed with the spray foam insulation to improve fire resistance.

This particular retrofit project also utilized Dow extruded polystyrene foam board insulation to further increase the energy efficiency of the home. The project used this 3 inch thick extruded polystyrene board on the roof deck and 2 inch thick extruded polystyrene board on the exterior walls of the house. This foam board may have a high r insulation value of 5 per inch of thickness, but according to the product safety sheet from Dow; this foam board is not safe from fire. If these boards are exposed to an "intense fire, [extruded polystyrene board] may burn rapidly" **(Dow plastics)** and the U.S. department of energy takes this one step further, stating that

> "Foam insulation is relatively hard to ignite, but when it is ignited, it burns readily and emits a dense smoke containing many toxic gases." **(U.S. Department of Energy)**

Both the Icynene spray foam and the Dow extruded polystyrene foam board are examples of green products specific to this project in Arlington, MA but there are other types of foam insulation not covered in depth in this study. These other types of foam insulation are also considered to be dangerous. An organization called the Alliance for the Polyurethanes Industry, or API, released a safety pamphlet about how rigid polyurethane or polyisocyanurate foams, in general, are flammable and should be treated as such. The main objective of this pamphlet was to define safety guidelines to help safeguard buildings that used rigid foam insulation from fire threats. The first safety feature they list in the pamphlet is sprinkler systems.

> ”How polyurethane or polyisocyanurate foams are used in a building ultimately determines their fire safety. In many cases, type of occupancy and type of construction also may require the addition of sprinkler protection and/or smoke detectors” **(Alliance for the Polyurethanes Industry, 1)**.

Again, this statement comes from an organization that is promoting the use of these new foam insulation technologies. They understand the risk these products incur, but feel the benefits of these products outweigh these risks, and advocate these safety measures to ensure occupant safety.

The last material used in the re-construction of this home that could pose a threat to safety is Tyvek Stuccowrap. This is what was used to wrap the home after the blue extruded polystyrene foam was installed, before the NuCedar siding was added. It too serves as a thermal barrier for the home, further increasing the homes energy efficiency, however, in the product data sheet from Dupont, there is a warning about fire safety. It reads

> “WARNING: DuPont™ Tyvek is combustible and should be protected from a flame and other high heat sources. If the temperature of DuPont™ Tyvek reaches 750 °F (400 °C), it will burn and the fire may spread and fall away from the point of ignition.” **(Dupont, 1)**

So, according to the manufacturer, under the right conditions, this house wrap could help spread the fire faster and to different parts of the home.

These types of insulation pose two problems. One is that they are, in fact, making our homes more dangerous with regards to fire. The other is that the insulation is located out of sight from the occupants in the home, typically on the exterior of the home. This means that in the event of a fire, the foam board on the exterior walls of the home will be rapidly spreading the flames around the outside of the home from the outside, making escape that much more difficult. This fact may need to be taken into account for fire

sprinklers as well, because even if residential sprinklers are installed, traditional sprinkler heads will not be able to help a fire on the exterior walls.

As it stands, green design in homes does not take a systems approach, as illustrated by this case study. The current green materials on the market being used are more flammable or release toxic gases when burned. Now the question stands, could some or all of the increased risk be mitigated by installing residential sprinklers in green homes? Can residential fire sprinklers themselves be considered a green technology?

Part III. Residential Fire Sprinklers

Residential fire sprinklers have the potential to dramatically reduce both property damage and injuries due to fire. The ability to control and contain a fire in its initial stages greatly reduces the damage caused to the structure as well as providing more time for occupants to escape safely. Even if a fire were to spread beyond the control of the sprinkler system, for instance, the fire spreading from the interior walls to the exterior of the home or spreading into the attic, the sprinklers would significantly slow the spread of the fire to allow occupants of the home to evacuate safely, while also giving emergency responders enough time to arrive on the scene and control the fire. Technology such as this is even more important today since modern homes are more flammable, making fires more dangerous. This makes residential sprinklers more valuable, since their primary function is to contain fires in their incipient stages. The technology has been used in numerous nonresidential applications for decades with proven results. It is only logical that these same benefits should be extended to residential properties where the greatest danger to life safety exists.

Residential fire sprinklers are very similar to sprinklers used in commercial applications. However, residential systems are designed differently to take into account the different needs of a home versus a commercial structure. One difference is the use of lower cost materials such as CPVC piping in place of copper pipe, this is still adequate in terms of performance (burst rating of 650 psi) but much cheaper. These systems are tested to a maximum pressure of 150 psi for up to 24 hours, although normal operation pressure from the municipal water supply is around 60-100 psi, therefore a residential sprinkler system is unlikely to develop any leaks. Residential sprinkler heads are designed to flow up to "18 gallons per minute for a single head and 26 gpm for two heads." **(Automatic Sprinkler 21)**. It has been established from test data and actual applications that most activation of sprinklers involves only 1 head, with a second head sometimes activated **(Automatic Sprinkler 21)**. In certain cases, a reserve tank may be installed to provide 10 minutes of water flow to a single sprinkler head, which is usually about 300 gallons. These are most commonly used with well water, which also requires a pump and when the

municipal water supply is insufficient. Another unique feature of residential sprinklers is the use of the municipal potable water supply. This makes sprinklers easy to integrate into the home and provides them with a reliable source of water, by simply tying them into the existing water connections. Sprinklers systems have multiple heads distributed throughout the house, providing complete coverage in all rooms and garages. Though garages, bathrooms and closets are not covered by NFPA 13D, the city of Scottsdale in its fire sprinkler ordinance required that all these areas be protected by sprinklers **(Automatic Sprinkler A-15)**. In the event of a fire, only heads that reach a high enough temperature will activate, once a fire is under control, these can then be manually shut off. This will only discharge water through the sprinkler heads that are fighting the fire. The rest remain closed until they reach their activation temperature. This limits water usage as well as potential water damage. These residential sprinkler systems are designed and built to robust standards and capable of controlling fires in their incipient stages until fire crews arrive.

As with any other debate, the residential fire sprinkler question has two sides, those who are in favor of implementing residential sprinklers and those you are not. In order to fully understand what needs to be accomplished for residential sprinklers to be considered a part of green home design, it is important to know the facts presented by both sides of the argument.

The arguments made in favor of sprinklers include effectiveness in controlling and sometimes extinguishing fires before fire fighters arrive, allowing occupants time to escape, and doing so with impressive reliability.

There are already many places where residential properties are protected by fire sprinklers. One of the first cities to mandate residential fire sprinklers is the city of Scottsdale in Arizona. A city ordinance passed in 1985 required that all new buildings, including single and multi-family homes, were to have built-in fire sprinklers. This followed extensive studies conducted over several years that tested the effectiveness of the sprinklers as well as conducting a complete cost analysis for sprinklers and their resulting

impact on the city's water infrastructure. A 10 year study released in 1997, concluded that mandating fire sprinklers in residential homes was beneficial to the community in terms of life safety, property damage and cost. Data gathered from the study showed a remarkable decrease in the loss of life and property due to fire in sprinklered residences. Other communities have seen the benefits and followed Scottsdale's lead, nationwide, over 133 municipalities and counties in 17 states have adopted ordinances mandating sprinklers in residential homes **(NFSA).** This list includes communities in a wide range across the country, showing the ability of sprinklers to perform in multiple climates.

Residential sprinklers have also found their way into the modular home industry. Excel Homes, out of Pennsylvania, was one of the first to offer residential sprinklers as part of their optional features to their homes. Excel teamed up with fire protection Firm F.E. Moran out of Chicago to ensure that their installed systems would give the necessary amount of protection, while still making each system efficient and low cost. This important partnership extends beyond the drawing board as well. Not only does F.E. Moran design the system, they also send a team to do the finishing touches to the system after the sections of a modular home have been installed on the foundation at the work site, ensuring that the system is water tight and will work as expected in the event of a fire. They then inspect the system once the rest of the house is complete.

This decision to include sprinklers as an option in their homes was primarily to ensure their ability to still be sold in all markets. For example, Pennsylvania just passed a state mandate for all new construction homes to have residential sprinklers. This law was passed, effective January of 2011, but was repealed in the same month. Had this mandate stood, and Excel had decided not to include sprinklers in their homes, this law would have then restricted Excel from selling any homes in Pennsylvania without significant alterations on site to install the sprinklers. As if that did not sound bad enough for the home builder, the factory used by Excel to build the sections of their modular homes is located in Pennsylvania, which makes Pennsylvania their primary market. Not being able to sell and install homes there would be a devastating blow to their market share.

The overall advantages of modular home construction would also carry through to the installation of residential sprinklers in modular homes as well. They can do it at a reduced cost over a traditional stick built home for the reason that the homes are built on an assembly line, and therefore there is less wasted material, and therefore less wasted money for the excess material. This also requires less skilled laborers to complete the same jobs, which means Excel Home can pay them less than their skilled counterparts, which also decreases the overall cost of the home. Also, each section of a modular home has the same layout, and therefore the same wiring scheme and pipe layout, so all of the pieces can be pre-cut and just assembled into the walls, saving time and money with very little waste. That means that the same level of protection can be accomplished for less money, making this the best way to install sprinklers.

Excel homes has even taken the addition of sprinklers to their homes a step further. They not only offer sprinklers as an option in their homes, they also promote residential sprinklers to both builders and consumers. They have generated marketing tools to help educate consumers about the benefits of residential sprinklers **(Caulfield)**.

There are also arguments against fire sprinklers, and in order to be able to analyze the effectiveness of sprinklers as an element of green design, it is imperative to understand the negative points about fire sprinklers. The main concern about fire sprinklers from the homeowner's perspective is accidental discharge, where the sprinkler malfunctions and reacts to a non-existent fire, causing unnecessary damage to the property. This also includes the possibility of a leak developing in the closed loop system, which could also produce a significant amount of water damage to property.

For the builders building new homes their biggest fear about fire sprinklers is the cost. The price of new homes is primarily driven by the housing market, not the features the house offers. In other words, a house with residential sprinklers will be put on the market for the same price as it did not have sprinklers, because that is what the market demands. Therefore, in new construction, installing extra features like residential sprinklers directly impacts the contractor's bottom line on the home, and they think sprinklers can be very expensive, requiring much on site installation by specially trained

sub contractors. This need for extra contractors on site is not only expensive, but delays other sub contractors from finishing their work, which increases the overall construction time per house, further impacting the contractor's bottom line. The home builders' statement is that they will fight any new codes that add to the bottom line cost of a home.

Green or environmentally friendly construction is the popular wave right now. When most people think of green, they might think of green roofs, better insulation or efficient appliances. However, these conversations routinely bypass sprinklers as a 'green' product. Sprinklers are usually thought of in the context of fire protection and prevention and are kept entirely separate from the green conversation. If anything, some might consider sprinklers to be less green due to the emissions associated with producing and installing them. However, this is not the case. In a recent study, conducted by FM Global, residential fire sprinklers were found to be green. The benefit comes from limiting losses incurred by fire damage by attacking it in its incipient stages and limiting its growth until fire department personnel can arrive and extinguish the fire. By stopping the spread and intensity of the fire, sprinklers achieve multiple things related to environmental protection.

First, the use of sprinklers reduces the amount of water used in combating the fire. Residential sprinklers typically use up to 18gpm (gallons per minute) of water per sprinkler head. By comparison, a standard firefighting 1 ¾ inch attack line flows 150 gpm, additionally, multiple attack lines are often used resulting in larger flow rates. In most documented cases of sprinkler use, the sprinkler heads were rarely activated for more than 10 minutes, resulting in water usage of around 200 gallons. This can be compared to an attack on the fire by firefighters, which would quickly require hundreds if not thousands of gallons of water to bring the fire under control. This is a result of a more advanced fire, thus requiring more water and the nature of firefighting which uses a lot of water.

The second green benefit of sprinklers is reduced emissions from the fire. With most structure fires, especially in newer buildings with more synthetic materials, many different harmful gases are given off as a result of the fire. According to the FM Global study conducted in 2010, these emissions included several greenhouse gases such as

carbon dioxide, carbon monoxide, methane and nitrous oxides. These are in addition to several other gases measured in the test. The use of sprinklers in the test produced reductions in several of these gases by as much as 97.8% **(FM Global)**. Testing of the air quality inside the test room showed an even more dramatic difference with the carbon monoxide levels reaching a maximum of about 7 ppm, compared to the unsprinklered test, in which CO levels reached almost 500 ppm. Additionally, emissions of other various chemicals and compounds were greatly reduced.

The third major benefit to sprinkler use is the quality of fire runoff water. Due to the increasing use of synthetics in homes, runoff water from firefighting efforts can become highly toxic, to the point where it can be classified as a hazardous material and cannot be safely discharged to the environment. This can become a concern, since the pH levels in the non-sprinklered tests showed pH values of 11.6 and 12.1. The allowable pH range for runoff water is 5.5-9 pH and freely discharging the water can lead to environmental damage. By comparison, the pH value of water from the sprinklered test had a pH value of only 7.9, which can be safely discharged to the environment.

It should come as no surprise that residential sprinklers are such effective fire safety devices capable of preventing fatalities and loss of property. This technology has been in use for decades and has a proven track record. However, the real surprise lies in the numerous additional benefits that sprinklers can provide. These can extend to benefits such as less restrictive fire codes and lower infrastructure costs, but also include a wide range of environmental benefits. Sprinklers have the potential to dramatically curb the severity of fires and therefore their impact on the environment. This extends to direct impact of the fire from smoke and emissions given off by the burning structure, potential damage caused by toxic runoff water and the extra carbon emissions needed to clean up, repair or replace the structure. The need for this additional fire protection is becoming more relevant every day as homes take more steps to become more energy efficient and use more synthetic materials in their construction and furnishing.

Conclusions and Recommendations

Residential fire sprinklers are green, as shown in the FM study. They reduce the amount of green houses gases emitted into the atmosphere due to house fires by containing them quicker. They also prevent chemicals from the products in homes from contaminating the soil and ground water after a fire due to the water runoff from the fire fighters efforts to extinguish the blaze. On the other hand, green products are often more dangerous than non green products, as in the case study, making the threat of fire in green homes much higher than in traditional construction. In particular, the use of spray foam and foam board insulation increases the fire risk in a home. Even the manufacturers of these products observe the risk posed by these new materials and have attempted to promote the use of fire sprinklers to guard against this new threat.

Ultimately, the root problem is that green design does not currently have a systems approach. Green projects and the people behind them typically have one goal - energy efficiency - and all other aspects of the project get sidelined, including fire safety. There is a need for a systematic approach to green home design, that looks at every aspect of the design and makes conscious decisions regarding what materials are being used and how that may affect both energy efficiency and fire safety. There is also the need to get residential sprinklers more universally accepted as a green product. Also, because the general public is willing to spend more money in order to make their homes green, such as the $90,000 spent on the home in Arlington, sprinklers would only increase the total for the project by a small fraction. According to the Massachusetts state fire marshal's office, the cost to a homeowner to install sprinklers in a 2,500 square foot home is approximately $4,000 without a tank, and $6,000 with a tank. This is a mere 5% of the total cost of the Arlington renovation, and only 1.66% of the cost of a new $300,000 home. Moreover, if done as a part of a green retrofit, the walls and ceiling would already be torn apart, so installation would be easy and would not leave the homeowner any additional inconveniences. The benefits of installing a fire sprinkler system far outweigh the cost, especially in a new green home. The ease of installation also comes with a good, systematic

approach to the project. If the project is planned properly, then the installation of each component will run smoothly. Once the project is complete, the home will also be safer, having had a systematic approach to design and construction, to ensure both energy efficiency and fire safety.

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Appendix A

A.1

"…wooden, basket, rattan or cane goods or articles, or tow, shavings, excelsior, oakum, rope, twine, string, thread, bagging, paper, paper stock, cardboard, rags, cotton or linen, or cotton or linen garments or goods, or rubber, feathers, paint, grease, soap, oil, varnish, petroleum, gasoline, kerosene, benzine, naphtha or other inflammable fluids or compounds…"

"shall, upon the order of the marshal, be equipped with automatic sprinklers; provided, that no such order shall apply to any building unless four or more persons live or are usually employed therein above the second floor." **(Sec. 26 Ch. 148 M.G.L.)**

A.2

"Every building or structure of more than seventy feet in height above the mean grade shall be protected with an adequate system of automatic sprinklers in accordance with the provisions of the state building code, except that sprinklers shall not be required to be installed in patient rooms in hospitals." **(Sec. 26A Ch. 148 M.G.L.)**

"Every building or structure of more than seventy feet in height above the mean grade and constructed prior to January first, nineteen hundred and seventy-five, shall be protected with an adequate system of automatic sprinklers in accordance with the provisions of the state building code;…"

"Any building or structure subject to the provisions of this section shall comply with the following schedule for the installation of automatic sprinklers:— one-third of the gross square footage of the building or structure shall be equipped with automatic sprinklers by March thirtieth, nineteen hundred and ninety-one; two-thirds of the gross square footage of the building or structure shall be equipped with automatic sprinklers by March thirtieth, nineteen hundred and ninety-four; and the entire gross square footage of the building or structure shall be equipped with automatic sprinklers by March thirtieth, nineteen hundred and ninety-eight;" **(Sec. 26A½ Ch. 148 M.G.L.)**

A.3

"Every building or structure, including any additions or major alterations thereto, which totals, in the aggregate, more than 7,500 gross square feet in floor area shall be protected throughout with an adequate system of automatic sprinklers in accordance with the provisions of the state building code."

"Sprinkler systems shall not be required in open-air parking structures, defined as: buildings, structures, or portions thereof, used for parking motor vehicles and having not less than twenty-five per cent of the total wall area open to atmosphere at each level, utilizing at least two sides of the structure. This section shall not apply to buildings or additions used for residential purposes." **(Sec. 26G Ch. 148 M.G.L.)**

"Every building or structure, or portions thereof, of public assembly, with a capacity of 100 persons or more, that is designed or used for occupancy as a nightclub, dance hall, discotheque, bar, or for similar entertainment purposes, including all rooms, lobbies, and other spaces connected thereto and all means of egress and entrances, including any such public assembly located within a mixed use building or structure, including a building or structure owned or controlled by the commonwealth or a political subdivision thereof, (a) which is existing, or (b) for which an approved building permit was issued before December 1, 2004, shall be protected throughout with an adequate system of automatic sprinklers, in accordance with the state building code. **(Sec. 26G½ Ch. 148 M.G.L.)**

A.4

"In any city or town which accepts the provisions of this section, every lodging house or boarding house shall be protected throughout with an adequate system of automatic sprinklers in accordance with the provisions of the state building code."

"For the purposes of this section "lodging house" or "boarding house" shall mean a house where lodgings are let to six or more persons not within the second degree of kindred to the person conducting it, but shall not include fraternity houses or dormitories, rest homes or group residences licensed or regulated by agencies of the commonwealth." **(Sec. 26H Ch. 148 M.G.L.)**

A.5

"In a city, town or district which accepts the provisions of this section, any building hereafter constructed or hereafter substantially rehabilitated so as to constitute the equivalent of new construction and occupied in whole or in part for residential purposes and containing not less than four dwelling units including, but not limited to, lodging houses, boarding houses, fraternity houses, dormitories, apartments, townhouses, condominiums, hotels, motels and group residences, shall be equipped with an approved system of automatic sprinklers in accordance with the provisions of the state building code." **(Sec. 26I Ch. 148 M.G.L.)**