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An Investigation into the Feasibility of using the Red List of Materials

Almuthanna Abusbeaa

Matthew Fong

Herman Lee

Laam Lee

Mark Otterman

University of British Columbia

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ABSTRACT

This research paper will focus on the “Red Listed” materials, as defined by the Cascadia Green Building Council’s Living Building Challenge rating system. The benefits and challenges of using and not-using listed materials are discussed, as are the potential impacts of these materials on the environment, economy, and society. Through extensive research, possible substitute materials were found for Polyvinyl Chloride (PVC), Halogenated Flame Retardants (HFRs) and Chloroflourocarbons (CFCs). These materials could potentially be replaced with HDPE, Non-Halogenated Flame Retardants, and Hydroflouro-olefin, among others.

A major problem with using alternative materials is the capability for them to be successfully integrated into new building designs. The existing dogma of currently used, and often harmful, materials needs to be eliminated before more sustainable practices should be accepted. It is recommended that the three alternative materials analyzed here be strongly considered for use in the new Student Union Building at UBC, which is aiming to become one of the foremost examples of sustainability in North America.

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1.0 INTRODUCTION

The purpose of this report is to analyze the materials in the "Red List of materials" put out by the Living Building Challenge sponsored by the Cascadia Region Green Building Council. The challenge defines the upper limit of sustainable living and attempts to minimize the gap between what is possible and the ideal.

This challenge is sent out to all building owners, architects, design professionals, engineers, and contractors. The challenge itself has several requirements, some of which are net-zero water usage, net-zero energy usage, clean air, using ethical sources for material. This report focuses on a list of materials that should not be used. This requirement is to reduce, or completely avoid using the materials on this list, which have been deemed to have adverse effects on the environment and the health of human beings. Among the Red List of materials included are: asbestos, which is proven to be carcinogenic; CFCs, which is a partial cause to ozone depletion; and formaldehyde, which affects the air quality in buildings.

Library and internet research has uncovered the importance in ensuring the reduced usage of these materials, as well as some alternatives to a few specific materials. In addition, the report will go into some other materials that should be considered on the list, and also the benefits and problems with using the Red List. Finally, an in-depth discussion and triple bottom line assessment of three materials: hydrogenated flame retardants, polyvinyl chloride, and chlorofluorocarbons will be conducted to provide recommendation for the use of the Red List within the new Student Union Building project at the University of British Columbia.

2.0 BENEFITS AND PROBLEMS

2.1 PROTECTING PEOPLE AND THE ENVIRONMENT

The biggest benefit of banning the use of materials in the Red List in construction is the reduction of hazards to the environment and the harming of the population. All of the materials in the Red List can adversely affect people and animals either through exposure or from the by-products emitted during the manufacturing process. For example, regular exposure to asbestos involves health risks such as the contraction of mesothelioma, which is the cancer of the protective lining of organs. However, asbestos is safe to handle as long as it is not inhaled. The danger of asbestos lies in the fact that people are sometimes not aware of its presence and associated health risk. In the past asbestos was the favoured insulation due to its fire retardant properties. During the remodeling of older houses, people will tear up the insulation and would consequently be exposed to mass amounts of this material. However since 1989, North America has banned, and started to phase out the use of asbestos in homes. Although on the decline, asbestos is still being used in shingles or floor tiles. Because asbestos is still valued due to its fire resistant property, stricter laws and handling procedures were created to keep people safe.

Since most of which we consume originates from natural sources, our health quality is directly related to the condition of the environment. All the materials on the Red List have the ability to deteriorate the environment. Heavy metals like mercury and lead often are found in elevated levels in aquatic life. If the demand for these metals are decreased, then the chances of them seeping into the our surroundings are lowered. Lead was very popular in paint and piping. When paints start to crack and chip away, the lead content often ends up entering our body, which can then cause neurological problems, nerve problems and blood issues.

Cadmium is most commonly found in solder, PVC, and batteries. Its corrosion resistant property makes it ideal in electroplating. When embedded in products, the risks of cadmium are low. This is because the metal cannot float freely. The problems occur in the manufacturing stage. Cadmium is usually a byproduct of zinc ore. Once extracted, the metal is sent to different industries. There are some health threats to the people working in these industries. Cadmium poisoning is associated with processes such as metal plating and the manufacturing of NiCd batteries, paints and plastics. The main method of exposure is inhalation. Homes near these manufacturing plants are often exposed to a higher level of cadmium because some forms of cadmium can dissolve into drinking water. Cadmium can cause weakened lungs, bones and some types of cancer. The problem is not with the product but with the manufacturing emissions. Use of the Red List would hopefully decrease the demand for products containing the banned substances and oblige manufacturers to continue to think about their impact.

2.2 PROMOTE MORE INNOVATIVE PRODUCTS AND IDEAS

Since the Red List imposes bans on many different and common building materials, it often pushes the limits of a builder's creativity to come up with better alternatives. Mercury is often found inside the common household products such as analog thermostats, fluorescent lamps and neon lighting. Thermostats technologies have greatly advanced and currently there are many other different ways to regulate temperature without using mercury. Better substitutes include bimetallic strips or wax pellets that expand with temperature or electric switches.

Since the Red List is banning many products that are popular in the building industry, this can promote newer and more innovative products to be used. Builders who are enthusiastic about following the Red List will spend significant resources researching on green alternatives. The same builders will also come to critique the available choices and hopefully be able to influence the market for better products. Lighting is an essential part of a every family home. Fluorescent lamps are more energy saving and longer lasting than traditional halogen bulbs. However, mercury is a vital ingredient for most energy-efficient lamps. Without the mercury, fluorescent lighting is not possible. If a suitable replacement for fluorescent fixtures can be found, it can definitely affect the future of all preceding fluorescent fixtures to be more envionrmentally friendly. The main point of the list is not to control how a house is built, but to strive for new ideas that might one day have significant benefits for people and the planet.

2.3 PRODUCTS WITHOUT SUITABLE ALTERNATIVES

The main problem with the Red List is that also bans products that have no better alternatives. The use of Polyvinyl Chloride can be found in almost 75% of the entire building industry. [1] It is used mainly for irrigation piping and as a sheath for electrical wiring. Copper and steel piping, which are not on the Red List, were almost phased out by PVC. Today, metal piping is the only viable alternative to PVC. However the possibility of bringing back metal piping can be associated with an incredible increase in environmental and production costs; buildings will then be even more unsustainable and expensive. PVC is also used as the outer sheath of NM wiring (non-metallic). This new type of wire is more flexible and lighter. The old standard for insulated electrical wiring was copper wire wrapped around in a crimped metal sheath which is called BX cable. This wire is hard to work with because the unsmooth surface makes it hard to pull through holes. NM wiring is just coated in plastic which can be cut with side cutters or wire stripers but the covering armored cable is hard to cut safely without specially designed tools. The extra metal is also much heavier which wouldn't matter once installed but it creates more work for people using it during installation. If price is a major concern then metallic sheathed wire is also more expensive. 14/2 x 25' of BX cable costs $16.49 [2]. The same type of NX cables costs $11.99 [3]. In higher quanities, the price gap is even bigger. 12/2 x 250' of NM cable is $64.99 [4] while the BX version is 149.99 [5].

If a house uses just one type of wire, it would cost almost 200% more.

Figure 1 Metallic and Non Metallic Sheathed Electrical Wiring

The choice of insulation can greatly affect the energy usage of a home. The better the insulation, the lower the energy bill due to reduced heating and cooling cost. Currently, fiberglass is the number one choice for household insulation. It is easy to work with and does not require special equipment to install. Fiberglass is a completely man made material. Glass is heated up and drawn into long strands which become fiberglass. Formaldehyde is used as a binder for the strands since it is necessary to help the product stick together to keep its shape. The binder is capable of outgassing formaldehyde which when inhaled can irritate the soft tissue of the lungs [6]. However, since most houses are well constructed, the insulation stays where it is suppose to be and cannot leak into the air. Ducts that need to be insulated should be wrapped up to keep particles from entering. An alternative to fiberglass insulation is foam insulation. This type of insulation requires professional installers to spray the foam on to the walls. When improperly installed, it could trap moisture between the foal and the wall and promote the growth of mold. As this type of insulation is more expensive, the builders would have to calculate the potential savings first.

3.0 INVESTIGATED MATERIALS

3.1 HALOGENATED FLAME RETARDANTS

One possible replacement for a ‘Red Listed Material’ is the substitution of Non-Halogenated Flame Retardants (NHFRs) for the traditional Halogenated Flame Retardants (HFRs). Flame-retardants are a key element used in buildings to inhibit the spread of fires. Currently, flame-retardants are a major component of building design; they are integrated into electronics, furniture, and the building structure itself. Their relative abundance and high use make them highly pertinent if they are emitting toxic chemicals and this makes them an important aspect in sustainable building design. The consideration of eliminating HFRs in the new Student Union Building design should be taken seriously. Reducing the dependence on this outdated material is critical if the SUB wants to be considered among the most sustainable buildings in North America.

Traditional halogens are mixed into composite materials to produce flame-retardants. They are effective in inhibiting the spread of fires because they act in the vapor phase by using a radical mechanism to interrupt the exothermic processes and to suppress combustion (Small et al. 2007). Some problems with this are that during combustion, toxic hydrogen halides form – which can be lethal in confined spaces. Also, it has been discovered that exposure to the chemicals found in HFRs has been linked to liver, thyroid, and reproductive organ cancer; as well as neurological disorders (Illinois EPA, 2007). Some of the toxic chemicals found in HFRs include: organochlorines such as polychlorinated biphenyls (PCBs), chlorendic acid derivates (most often dibutyl chlorendate and dimethyl chlorendate) and chlorinated parafins; organobromines such as polybrominated diphenyl ether (PBDEs), which can be further broken down into pentabromodiphenyl ether (pentaBDE), octabromodiphenyl ether (octaBDE), decabromodiphenyl ether (decaBDE) and hexabromocyclodecane (HBCD); organophosphates in the form of halogenated phosphorus compounds such as tri-o-cresyl phosphate, tris(2,3-dibromopropyl) phosphate (TRIS), bis(2,3-dibromopropyl) phosphate, tris(1-aziridinyl)-phosphine oxide (TEPA), and others. Of these, only decaBDE remains on the North American Market (all have been banned in the United Kingdom) (Betts, 2008).

The use of NHFRs is geared towards replacing the widely practiced installation of HFRs. Ideally the initial design of products installed in buildings would be flame-resistant. However, as this is not currently the case, an alternative material is necessary. One such possibility is the use of superabsorbent polymers as a non-halogenated flame retardant additive for composite resins. Superabsorbent polymers (SAP) are capable of absorbing 2-10 times their weight in water (Small et al. 2007). It has been proposed that these SAPs can be loaded with inorganic phosphates as the flame retardant component in composite systems. In tests completed by Small et al it was revealed that these SAP based flame retardants had improved fire resistance when blended with common matrix resins at relatively low levels and showed minimal off-gassing of toxic compounds during combustion. This means harmful effects could be minimized while still maintaining fire protection standards. The ability for an alternative product to not experience toxicity problems of its own and adhere to fire protection standards has remained the largest challenge in finding a suitable replacement for HFRs. These new SAP based retardants are still in need of more testing before they can be deemed a suitable replacement, but this data looks promising.

Current consumption of flame-retardants is currently over 1.5 million tones – with the equivalent sales volume of approximately $2.4 billion US (Ceresana Research, 2009). The market for NHFRs is growing; there are now suitable replacements for products such as: circuit boards, electronics housing, cables, insulation, and numerous others (Danish EPA, 1999). Clearly, there is large market for an alternative HFR products; it is merely a matter of the successful integration of such a product into new building designs, such as the SUB, that becomes the issue. The toxics from HFRs are emitted during their production, use, and in case of fire, when disposed or recycled. Environmentally, the degradation products of these chemicals tend to bio-accumulate in the food chain; increasing in concentration the higher up it goes. This, coupled with the fact that in terms of installation the use of NHFRs over NFRs makes virtually no difference, the replacement of this material with something like superabsorbent polymer based fire retardants becomes a viable approach for improving the SUB's sustainability. We sincerely hope that the new SUB does not burn down. But in the unfortunate event that a fire does break out, it would be drastically more sustainable if the flame-retardants being utilized were non-halogenated in nature.

3.2 POLYVINYL CHLORIDE

3.2.1 BACKGROUND

Polyvinyl chloride, more known as PVC, is a vinyl polymer that is heavily used in many applications of the industry [1]. PVC is the third most produced plastic and is heavily used in the construction sector. In fact, 75% of the total produced PVC is used in construction sector due to its cheap, light, durable, and easy to assemble properties. Its main construction applications range from electric wires, plumbing, windows, and house siding. Since the focus of this report is looking into the Student Union Building's options for using the Red List, only the relevant applications will be looked into detail. Cascadia Green Building Council's Living Building Challenge identifies PVC as one of the red materials which is harmful to the environment and should not be used in a project.

3.2.2 MAIN APPLICATIONS

Windows

The use of wood-frame, single panel windows do not trap building heat very efficiently, hence leading to additional cost in energy losses. Due to economic costs, a common alternative material to use is PVC based frames combined with metal additives to keep the PVC from breaking down [2]. However, PVC based windows are vulnerable to expansion and shrinkage causing leaks between frame and wall [2]. Better and more sustainable alternatives are outlined in Figure 2.

Type of Material	Manufacturer/ Brand	Pro/Con	Availability	Cost
Wood	Jeld-wen **www.jeld-wen.com**	PRO: Doesn't expand and contract as much as PVC, energy efficient, natural material. CON: Requires painting every 5-7 years to avoid rotting. Note that many wood windows have PVC jamb liners.	Available at Home Depot, 84 Lumber, and other retailers. Log onto **www.jeld-wen.com** for retailer closest to you.	Double hung 30 1/8" x 41" – $116
Wood clad in Aluminum on outside	Pella Windows and Doors **www.pella.com** 800-374-4758	PRO: 63% of Pella's wood is certified – though not all by FSC. 95% of aluminum is recycled. Pella has a strong recycling and reuse policy. Much lower thermal expansion coefficient, maintenance free and generally more durable than PVC. Energy Star rated. CON: Aluminum processing emits significant air pollution. May contain some PVC parts.	Lowe's, Pella stores and outlets (find one at **www.pella.com**)	Double hung 29" x 41" - $140 Pella 29" x 35" - $124
Wood Clad in Fiberglass on outside	Integrity Windows **www.integritywindows.com** 888-537-7828	PRO: Fiberglass (known as Ultrex) exterior protects wood, energy efficient (Energy Star rated), minimal expansion and contraction, does not corrode. CON: Fiberglass processing emits significant air pollution.	Dealers throughout NYS (find one at **www.integritywindows.com**)	Double hung 30.5" x 40 1/4" - $215
Aluminum	Crystal Windows **www.crystalwindows.com**	PRO: Three times as strong as vinyl and forty three times stronger than wood. Resists deterioration and does not shrink, swell, split, crack, or rust. Can be painted. CON: Aluminum processing emits significant air pollution. Windows let heat escape, may produce condensation. Must add insulation between inside and outside of frame and sash to make even moderately energy efficient.	Distributors throughout NYS (call 800-472-9988)	Double hung 29" x 41" - $120
Fiberglass	Inline Fiberglass **www.inlinefiberglass.com** 416-679-1171	PRO: Fiberglass is made of a widely available material – sand, and a resin. Durable, high energy efficiency, and quite strong. CON: Fiberglass processing emits significant air pollution. Difficult to recyle, no recycled content.	Log onto **www.inlinefiberglass.com** for local retailer.	Double hung 29" x 41" - $300

Products, manufacturers and suppliers listed are for informational purposes only. List is not comprehensive, nor does listing imply recommendation by CEC.

Figure 2: Other alternatives for Windows

Electric Wires & Cable

Commercial cable wirings are all coated with PVC [2]. The Canadian Electric standards(CSA) mandates the use of PVC coated in wiring due to the cable flame retardant property. However, the PVC cable releases toxic hydrochloric acid and heavy metals once they start burning.

Pipes and Plumbing

Pipes are used for plumbing and drainage. The advantages of PVC pipe are that it is cost effective, lightweight, and easy to install. However, the impact of sunlight and heat damages leads to contraction and shrinkage, which in turn leads to the need for repairs or replacement.

There is a range of new material which offers the same quality with comparable cost. For example, choosing polyethylene pipes to meet specific project needs such as weight. Figure 3, outlines other alternatives for specific project requirements.

HEALTHY OPTIONS FOR WIRING AND PLUMBING

Type of Material	Manufacturer/Brand	Pro/Con	Availability	Cost
Foundation Drainage (Around Outside of House)				
High Density Polyethylene (HDPE)	Hancor Pipe **www.hancor.com** 800-FOR PIPE	PRO: Durable, made from at least 50% recycled materials.	Call 800-FOR PIPE for nearest dealer, many throughout NY	$0.45/ft. for 4" pipe (comes in 250 ft. rolls) or $0.95/ft. for 6" pipe (comes in 100 ft. rolls)
Drainage, Waste, Venting (Inside the House)				
Cast Iron Pipe	Tyler Pipe **www.tylerpipe.com** 800-527-8478	PRO: Made from recycled iron. Durable. Recyclable. Quieter than any plastic. Can be attached without soldering. CON: Very heavy.	Go to **www.tylerpipe.com/ny.htm** for regional sales reps or call main number	$4.58/ft. for 3" pipe $5.95/ft. for 4" pipe (comes in 10 ft. sections)

Products, manufacturers and suppliers listed are for informational purposes only. List is not comprehensive, nor does listing imply recommendation by CEC.

Figure 2 Other alternatives for plumbing and pipes

Case Study: Pipes and Plumbing

In order to fully understand why PVC is commonly used in the construction and at the same time understand why it should not be used, one must conduct a Triple Bottom Line assessment to compare the pros and cons of using PVC in the SUB project as opposed to other substitutes. Since there are wide applications of PVC, the Triple Bottom Line assessment will focus on one particular application (pipes and plumbing). Pipes are an integral part of an infrastructure and account for significant cost to the project. The applications will be discussed briefly.

Economic Analysis: The cost of building a 10-mile pipeline and operating it for a 50 year life time period.

Findings: The cost of building, transporting, manufacturing and operating the project is $4,224,000 for the PVC pipeline and $5,808,000 for the DI pipeline. Materials required were 5,031,840 pounds of DI and 3,305,808 pounds of PVC material [3]. While PVC has a relatively cheaper initial capital cost, PVC tends to cost more over the life time of a project. This is because PVC expands and contracts, which over time, damages the pipes and leads to the need for early repair or replacement [3]. Figure 4 summarizes the results.

Figure 5-Capital and 50 Year Operating Cost

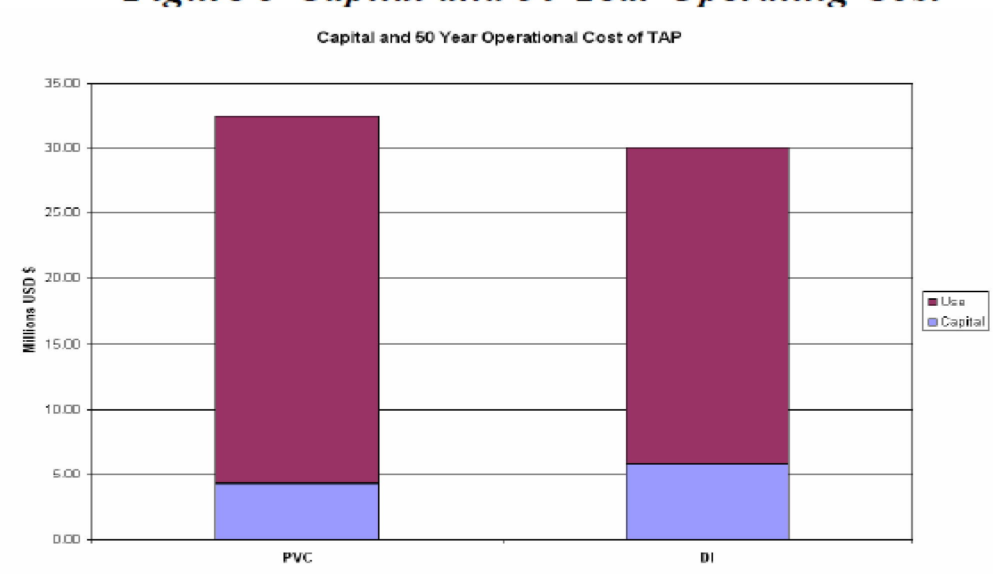

Figure 3 Economic cost of PVC vs. DI over a lifetime project of 50 years

Environmental Analysis: In the 50 year analysis of the project, comparison of the CO_2 emissions between the PVC pipeline and the DI pipeline is determined. The analysis will determine the CO2 emitted from manufactiring, processing, and transporting of the material from the plant to the project site as well as operating the project for 50 years.

Findings: The CO2 emission of building a 10-mile pipeline and operating it for a 50 year life time was found to be 131.5 million pounds of CO2 for DI while the operation of the PVC pipeline was found 153.2 million pounds of CO2. Figure 5 summarizes the CO2 emissions of the PVC vs. DI.

Figure 6-CO_2 Emissions

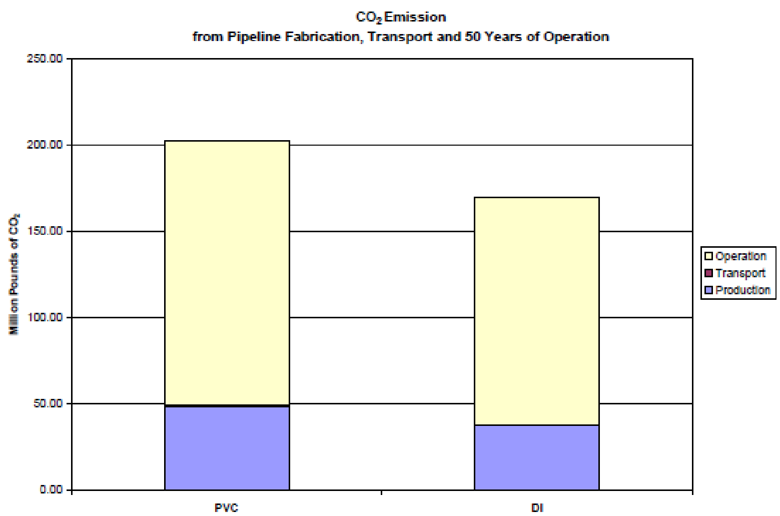

Figure 4 Ecological Footprint of PVC vs. DI

Furthermore, toxics are released during PVC production which also contributes to global pollution. One of the primary toxics of concern is dioxins, which also contributes to global pollution and in turn has negative health impacts on people.

Social Analysis: Health and Safety

Toxic Manufacturing Byproducts: Dioxin (the most potent carcinogen known) produced in the production of PVC can cause severe health problems, including [4]:

- Cancer
- Endocrine disruption:

- Endometriosis
- Neurological damage
- Birth defects & impaired child development
- Reproductive and immune system damage

Alternatives: An analysis of PVC pipe alternatives by Environment Canada found that PVC pipes alternatives are cost comparable[4]. Table 6 outlines the primary alternatives to PVC for pipes and plumbing.

Table 1. Primary Alternatives to PVC by sector

Water	Ductile iron, HDPE, Concrete, Copper, PEX
Sewer	Concrete, HDPE
Conduit and Ducting	HDPE, Steel, Aluminum
Drain, Waste and Vent (DWV)	Cast Iron, Copper, ABS, PEX
Agriculture and Drainage	HDPE, Concrete

Adapted from Environment Canada report

Figure 5 Primary Alternative to PVC

3.3 CHLOROFLUOROCARBONS

Chlorofluorocarbon (CFC) was one of the many materials listed within the Red List of materials provided by the Cascadia Green Building Council's Living Building Challenge rating system. The main reason why CFC was listed is due to its possible harmful effects upon ozone depletion. CFC was once the main refrigerant compound used in refrigerators and air conditioning systems, but it was soon phased out in the 1980's by alternative refrigerant compounds with less ozone depletion effects. Outline and explained in this section of the report, will be an analysis of the background of CFC, how and why CFC was phased out by alternative compounds, the evolution of these alternatives and also a Triple Bottom Line Assessment of CFC compared with all proceeding alternative to determine which material is best to be used in the UBC SUB project.

CFC is a haloalkane compound which contains a mixture of carbon, fluorine, and chlorine atoms. Haloalkanes in short are chemical compounds which are derived from carbon and hydrogen based compounds, and contains additional halogen elements such as chlorine or fluorine. CFC has a very ideal set of thermodynamic properties which led to its popular use as refrigerants, aerosol spray propellants, and solvents before the late 1900's. Some thermodynamic properties of CFC are:

- Chemically un-reactive
- Boiling point below target temperature
  - Boiling point: When liquid becomes gas
- High heat of vaporization
  - Heat of vaporization: Energy required transforming a substance to gas
- Moderate density in liquid form
- High density in gaseous form
- High critical temperature
  - Critical temperature: Where phase boundary cease to exist

It is also due to these properties however, which created CFC's harmful ozone depleting potential. The main chemical reaction which CFC undergoes to cause ozone depletion is the "photo-induced scission" of the carbon to chlorine bond. After a CFC compound reacts with light or ultraviolet rays, a lone chlorine atom will be broken off from the CFC compound. It is due to chlorine atom's low chemical reactivity property which prolongs its lifespan in the upper atmosphere once it is separated from the CFC compound. Residing in the upper atmosphere, the chlorine atom acts as a catalyst in converting ozone into oxygen molecules. Since oxygen molecules do not have the equivalent ultraviolet radiation absorption ability as the ozone layer, the reaction of changing ozone into oxygen molecules will increase the amount of high energy radiation reaching the Earth's surface. Ultraviolet ray are harmful to the body under intense or long term exposure. After the mid 1900's, scientists began investigating the harms which CFC compounds can bring, and began undertaking the challenge of looking for new alternative to replace the CFC compound.

Through time, many alternative compounds have been developed to replace CFC as cooling systems' medium. The main objective of each new alternative is to minimize harmful effects upon the environment by reducing the ozone depletion potential and global warming potential.

Hydrochlorofluorocarbon (HCFC) is one of the first alternatives used to replace CFC. HCFC, similar to CFC is also a haloalkane compound. With the lowest number of chlorine atoms in its composition, HCFC is ranked as the most environmentally friendly out of all haloalkane compounds. The extent to which HCFC depletes the ozone layer is much less than CFC due to the presence of hydrogen and the reduced chlorine composition. CFC is capable of remaining un-reactive at any altitude below the stratosphere, while HCFC, with the presence of hydrogen, will only become more easily reactive lower in the troposphere. Not being able to reside in the stratosphere in a stable state, HCFC will not be as much of an effective catalyst compared to CFC in converting the ozone into oxygen molecules. Even so, the Montreal Protocol still calls for the elimination of HCFC due to HCFC still having some degree of ozone depletion potential.

Hydrofluorocarbon (HFC) is the next type of compound which was incorporated into the evolution of CFC alternatives. The benefit of HFC is its non-ozone destructive nature. Without the presence of chlorine in its compound, there are no elements which can serve as catalysts for the depletion of the ozone. In addition to such, HFC has an even shorter lifetime in the atmosphere than HCFC, therefore making it less plausible for it to stay in the upper atmosphere to create any potential harm. Even thought HFC is "ozone friendly", it does have a large effect upon global warming. Due to this global warming concern, HFC is regulated in the Kyoto Protocol and its use is limited, as an attempt to reduce global warming potentials. HFC is the dominate refrigerant currently used today, but there is a shift now to a new generation of refrigerants. These new generation refrigerants are hydrofluoro-olefin and carbon dioxide.

Hydrofluoro-olefin (HFO) is very similar to HFC in which they can basically serve as substitutions of each other in the same mechanical components without any modifications. HFO is now being brought to the attention in the car industry because of its low global warming potential compared to HFC. Even thought HFO seems to be the hype of the new generation of refrigerant, there are still obstacles and tests which HFO must pass in order to become the refrigerant of choice in this decade or century.

Carbon dioxide (CO_2), another replacement to HFC is a natural refrigerant compound that has an even lower global warming potential than HFO. CO_2 has been proven to be non-toxic, and non-flammable, making it one of the best natural refrigerant compounds out of the group. After numerous tests, CO_2 has proven to decrease car emissions by 10%, consequently lowering a total of 1% Green House Gas worldwide. CO_2 can be implemented into components other than automobile air conditioning, such as heat pumps, refrigerators and water heating systems. One major drawback of CO_2 however, is that its use requires mechanical components that are not currently implemented in today's systems. Unlike CFC, HCFC and HFC, which serve as the medium within vapor compression cycle, CO_2 serves as the medium within a new system called the transcritical CO_2 system. The transcritical CO_2 system replaces the condenser and expansion valve within regular vapor compression system and use a method of gas cooling and the application of high pressure expansion valves to achieve the same cooling effect.

A Triple Bottom Line Assessment is a comparison between materials' environmental, economical and social impacts. Impacts include both cost and benefits to fully determine which material is the best choice for any particular project.

The environmental impacts of each material can be categorized mainly into its ozone depletion potential (ODP), its global warming potential (GWP), and the general hazards associated with the use of the material. For ODP and GDP, each material's impacts are classified by number values, with higher values meaning a more negative impact upon the environment. Shown below is a summary of each material's ODP, GWP, and associated hazards.

	GDP	ODP	Hazards
CFC	1800	1	• Do not breathe gas/ vapour/ fumes/ spray • Avoid contact with skin or eye • Can cause dizziness and loss of concentration
HCFC	1810	0.055	• Do not breathe gas/ vapour/ fumes/ spray • Avoid contact with skin or eye • Can cause dizziness and loss of concentration
HFC	1300	0	• Do not breathe gas/ vapour/ fumes/ spray • Avoid contact with skin or eye • Use only in well-ventilated areas
HFO	4	0	• Flammability safety risk
CO2	1	0	• Increase concentration of CO2 will increase toxicity.

Figure 6 Analysis of possible CFC alternatives

As shown, CO_2 has the least environmental effects out of almost every category; however this does not mean CO_2 is the best choice of material to be used in the UBC SUB project. One problem with the usage of CO_2 refrigerant is the lack of energy efficiency in the transcritical system. With a low efficiency, the system must input more power to achieve desirable cooling results; therefore this increase in power consumption can lead to increase in emission from power generating machines.

In term of analyzing materials' economic impact, we look at the cost of each material and also any cost related to modifications to system to adjust for the different materials.

CFC:	$700 for 30lb cylinder
HCFC:	$195 for 30lb cylinder
HFC:	$175 for 30lb cylinder
HFO:	Promoted to be more cost efficient than HFC
CO_2:	Promoted to be cheapest out of all refrigerant materials

Even though, CO_2 is the cheapest out of all refrigerant materials, there are extra modification costs to the system in order to use CO_2 refrigerant materials. These modifications are expensive and unavoidable. HFO on the other hand are very compatible with existing systems and would not need any modifications, making it in all cheaper than CO_2.

Finally, we look at the social impacts of each material and analyzing their effects on workers and work habits. If CO_2 is used, new training routines and skills must to taught to workers in order to construct and maintain the new transcritical system. Older workers who are accustomed to working with regular vapor compression systems may find it hard to learn the new techniques of the trade and consequently be driven out of a job. If HFO is used in the future, no new training is required because the usage of HFO does not require any modifications to existing systems.

In summary, we would recommend the UBC SUB project to use HFO as the refrigerant of choice in air conditioning and refrigerator applications due to the low environmental effects, low economical cost, and also minimal social impacts associated with its use.

4.0 MATERIALS TO BE CONSIDERED

While the Red List is thorough on well known materials, it is not quite complete. The Red List is ongoing challenge, and is thus lenient towards some additional items that are listed below:

- antimony trioxide
- chromium
- copper
- zinc
- bisphenol a
- solvent-based coatings

Antimony is a heavy metal and many of its compounds are toxic. Antimony poisoning can cause headache, dizziness, depression, and in worse cases, frequent vomiting and death. The compound of interest is antimony trioxide, or Sb_2O_3, which is generally used as an opacifying agent for glasses, ceramics and enamels, a catalyst in production of polyethlene terephthalate (PET plastic) and vulcanization of rubber, and as a flame retardant for textiles, leather, polymers and coatings. Specific to Sb_2O_3 is that it is classified as a carcinogen by California Proposition 65.

Following up on heavy metals is chromium, and specifically, the chromium VI ion, found in chromic acid or chromium trioxide(CrO_3). Extended periods of exposure can cause symptoms such as nosebleeds, ulcers, and holes in the nasal septum. Ingesting it can cause convulsions, kidney damage, liver damage, and death. Chromium has been used in dyes and paints and tanning of leather and has caused significant environmental damage as it is often found in soil and groundwater near abandoned industrial sites.

Copper is a material that is favoured for its non-corrosive properties and its malleability, making it perfect for transporting water. However, if the water supply is even slightly acidic, copper poisoning may occur. While this is easily sorted out by regulating the pH of the incoming water supply, it is still a consideration as to the type of material to use.

Zinc is essential to the human body. However, free floating zinc ions are particularly toxic when ingested. Zinc readily dissolves into hydrochloric acid in the stomach to give zinc chloride. This will cause damage to the stomach lining, death due to gastrointestinal bacterial and fungal sepsis, as well as lethargy and ataxia. The most common forms of zinc used are zinc chloride, which is a fire retardant in lumber and wood preservative, as well as zinc sulphide, which is used for luminescent pigments and luminous paints.

Bisphenol A is key to the production of epoxy resins and is most commonly used to form polycarbonate plastic which is clear and nearly shatter-proof. Bisphenol A is known to be harmful to humans from plastic bottles, but it is also has environmental effects, especially on ocean life. The continued use of bisphenol A in epoxy resins may be a contributor.

Solvent based coatings typically contain more than 60% organic solvents that are classified as volatile organic compounds (VOCs). VOCs have low vapour pressures, and will readily emit gases, that are generally harmful to the environment and cause health problems. Such sources of VOCs generally include paints, paint strippers and wood preservatives.

The materials Red List specified by the Living Green Building Challenge is quite thorough and defined to be a guideline that can be followed quite easily. It is possible to tighten these restrictions if we add additional concerns. However, while the materials listed above have real health and environmental effects, their use in practise is very limited and does not pose too significant a risk.

5.0 CONCLUSION

The Red List of Materials tries to eliminate any construction material which can possibly cause harm to the environment or to humans. By establishing this list, engineers can have a simple guideline to follow to assist their projects in becoming more sustainable in terms of material selection. Even though this list does limit the amount of negative impacts which can be produce by using certain materials, there are a few disadvantages to implementing this list which engineers must be aware of. Even so, this list does inspire a lot of creative approaches to construction material selection and also motives to search for more environmentally friendly alternatives such as those to replace halogenated flame retardant, PVC or CFC. To sum up, it may be hard to ban every material which is listed, but it surely will be a good start to any project to try to minimize or eliminate materials from the Red List to help protect ourselves and the environment. This list is definitely a feasible guideline to follow during any construction projects and will definitely get more attention and use as more engineering projects focus upon sustainability.

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